



Environmental Flow Determination
for the Barwon River:
Final Report - Flow
Recommendations

**Corangamite Catchment Management
Authority**

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1.1 The Barwon River Environmental Flows Project

Introduction

The Barwon River Environmental Flows Project will recommend the flows required to achieve a 'healthy river ecosystem', as defined by the Victorian River Health Strategy. The project applies the FLOWS methodology for determining environmental water requirements (DNRE 2002). This project follows the recent Victorian Government White Paper, *Our Water Our Future*, which recognised that water in the Barwon River is fully allocated.

The FLOWS methodology involves the collation and review of the information through literature review, field assessments, consultations with agency and community members, topographic surveys of each site, hydraulic modelling, and a scientific panel workshop to make environmental flow recommendations. This document, the Issues Paper presents a preliminary assessment of the physical and ecological assets that are to be protected and promoted in the river, and makes preliminary recommendations for the flows on which they depend. It should be read in conjunction with the Site Paper that was completed earlier in the project and summarised the general characteristics of the study area and identified the river reaches on which the methodology will be based.

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

Background

The Barwon River is identified as a fully-allocated catchment where the water reserve will be established initially by recognising existing entitlements, capping consumption, and applying a moratorium to new diversions. In a state-wide assessment, the Barwon has been identified as one of 21 streams which require the development of a stream flow management plan. The Victorian Government White Paper 'Securing Our Water Future Together' provides the policy underpinning for the water needs of the environment by establishing an Environmental Water Reserve.

The Corangamite CMA is responsible for the overall river health of the Barwon River and the assessment of the environmental flow needs of this river, including its internationally significant lakes and wetlands in its estuary zone. The CMA is responsible for determining ecological objectives for flow-dependent ecosystems, which will be used by DSE to set priorities and develop options for water recovery.

The Barwon is a major water supply for Geelong, the smaller urban centres, and farm water supply for the region. The system is significantly altered via extensive farm dam storages, on-stream reservoirs and many diversion licences. Inter-basin transfers occur from Lake Colac (via the Lough Calvert drainage scheme) and Lake Corangamite (via the Woody Yaloak drainage scheme) into the Barwon River.

Recent assessment of the ecological condition of the river, as part of the Corangamite River Health Strategy, has indicated that most reaches are in marginal to very poor condition, whereas a few streams in

good or excellent condition are high in the catchment, above water supply storages. Wetland condition assessment (2004) has shown that most wetlands (60%) are either degraded or severely degraded, with only 15% being intact or pristine.

The estuary of the Barwon River, which includes Lake Connemarre, Reedy Lake and the lower Barwon, are internationally significant wetlands and regional, Victorian and Australian government agencies have a responsibility to protect and enhance these values.

The Corangamite CMA has commissioned Lloyd Environmental Pty Ltd, Ecological Associates Pty Ltd, and Fluvial Systems Pty Ltd to undertake this FLOWs study to gain an understanding of the role of water in the health and functioning of the freshwater and estuarine reaches of the Barwon River system. The study will classify the flows in each hydrological component, or reach, of the system, and predict the frequency, duration and seasonality of each flow band required to sustain the ecosystem. Quantification of these requirements, through a hydrological model, will allow the deficiencies between the required and current water regime to be prioritised and targeted by appropriate use of available environmental flows.

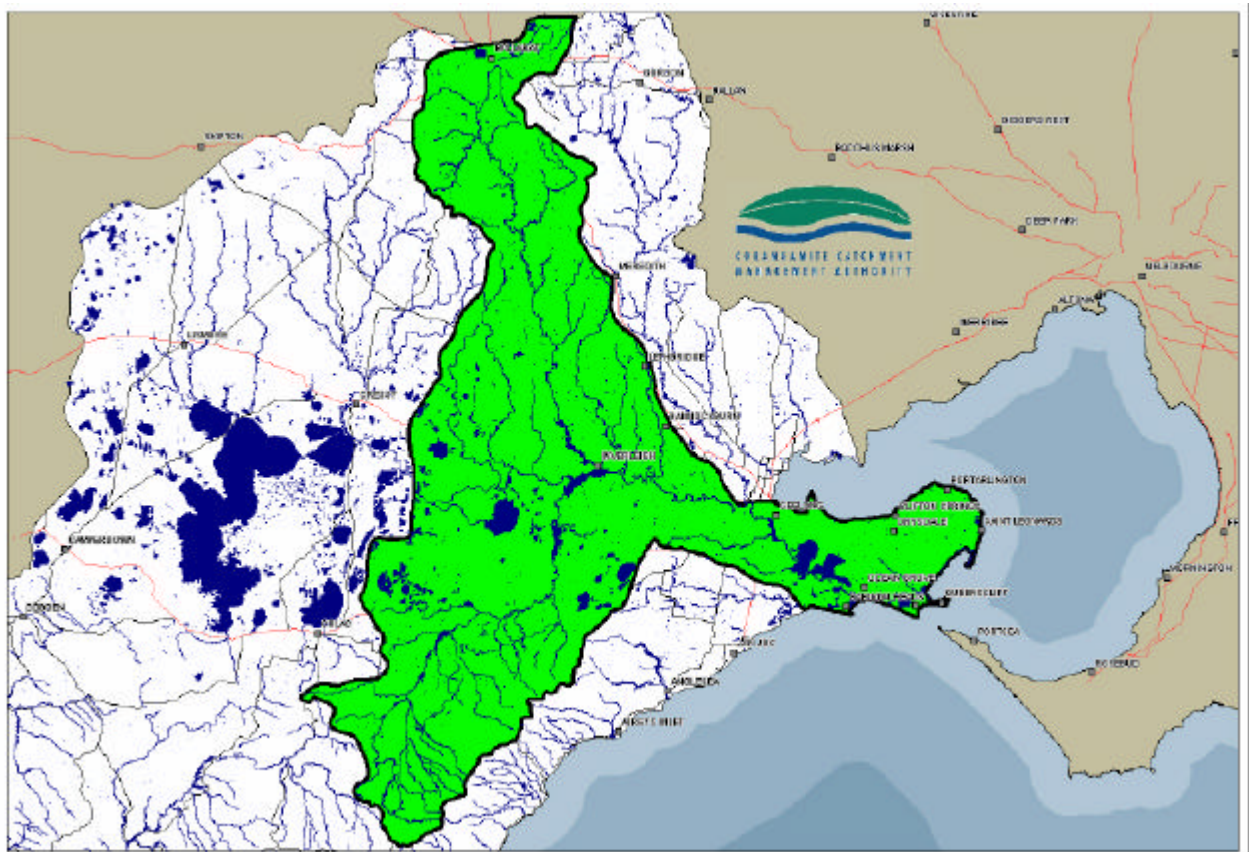


Figure 1. The Study Area

Objectives

The overall objective of this project is to determine the environmental water requirements of the Barwon River, including Lake Connewarre and the Barwon Estuary, and to develop options to meet the environmental needs.

More specifically, this investigation:

- identifies water dependent environmental and social values within each reach;
- gauges the current health of environmental values;
- identifies the flow regimes that will maintain or enhance the environmental values;
- develops Environmental Flow Objectives that take into account current social, economic and environmental values of the river; and
- recommends an environmental flow regime to meet the objectives.

The Study Area

The Barwon River rises in the Otway Ranges and flows close to the townships of Forrest, Birregurra, Winchelsea, and Inverleigh before flowing through Geelong and joining the coast at Barwon Heads. The Leigh River, a major tributary, rises near Ballarat and joins the Barwon River at Inverleigh. Two other tributaries, Birregurra and Boundary Creeks, flow into the Barwon from the western part of the catchment. The environmental flow requirements of the Moorabool River, also a major tributary of the Barwon River, have been determined in previous studies and will not be revisited in this study. The Upper Leigh River is not considered in this study (apart from the downstream effects in the mid and lower Leigh River).

The project study area comprises of nine reaches which are shown in Table 1 and Figure 2.

Table 1. Reach names and descriptions for the Barwon River Environmental Flow Study

Reach Name	Description
Upper Barwon	Barwon River from West Barwon Reservoir to Birregurra Creek confluence
Winchelsea	Barwon River from Birregurra Creek confluence to Leigh River confluence
Murgheboluc Valley	Barwon River from Leigh River confluence to Moorabool River confluence
Geelong	Barwon River from Moorabool River confluence to the Lower Breakwater
Estuary	Lower Breakwater, Lake Connewarre and Reedy Lake, lower estuary to Barwon Mouth
Birregurra Creek	Birregurra Creek
Boundary Creek	Boundary Creek
Mid Leigh River	Leigh River from Napoleons Rd to Quinney Hill
Lower Leigh River	Leigh River from Quinney Hill to Barwon confluence

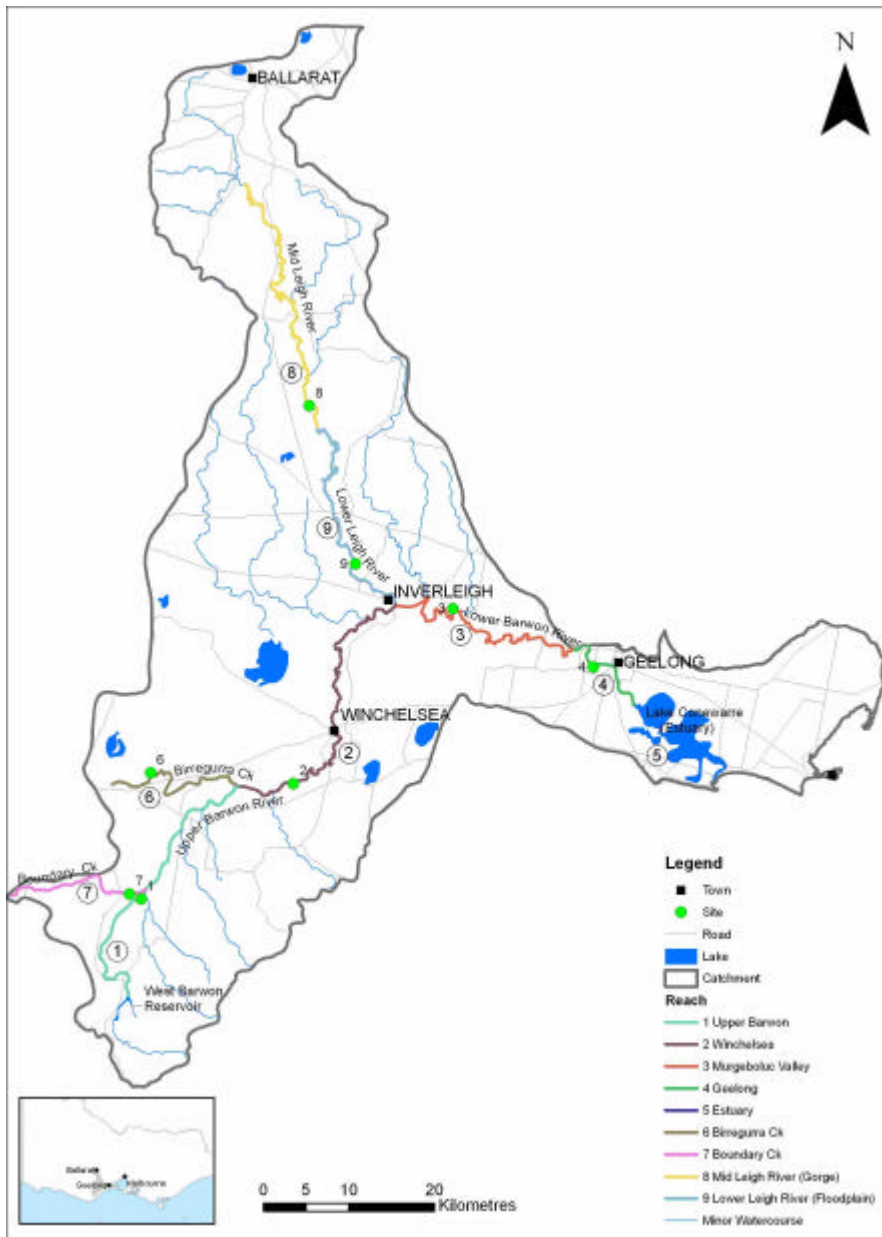


Figure 2. Map indicating delineated reaches of the Barwon River

1.2 The Adopted Methodology

This project applies the FLOWS method to determine environmental flows in rivers and streams in Victoria (DNRE 2002). The steps involved in the application of the method are presented in Figure 3.

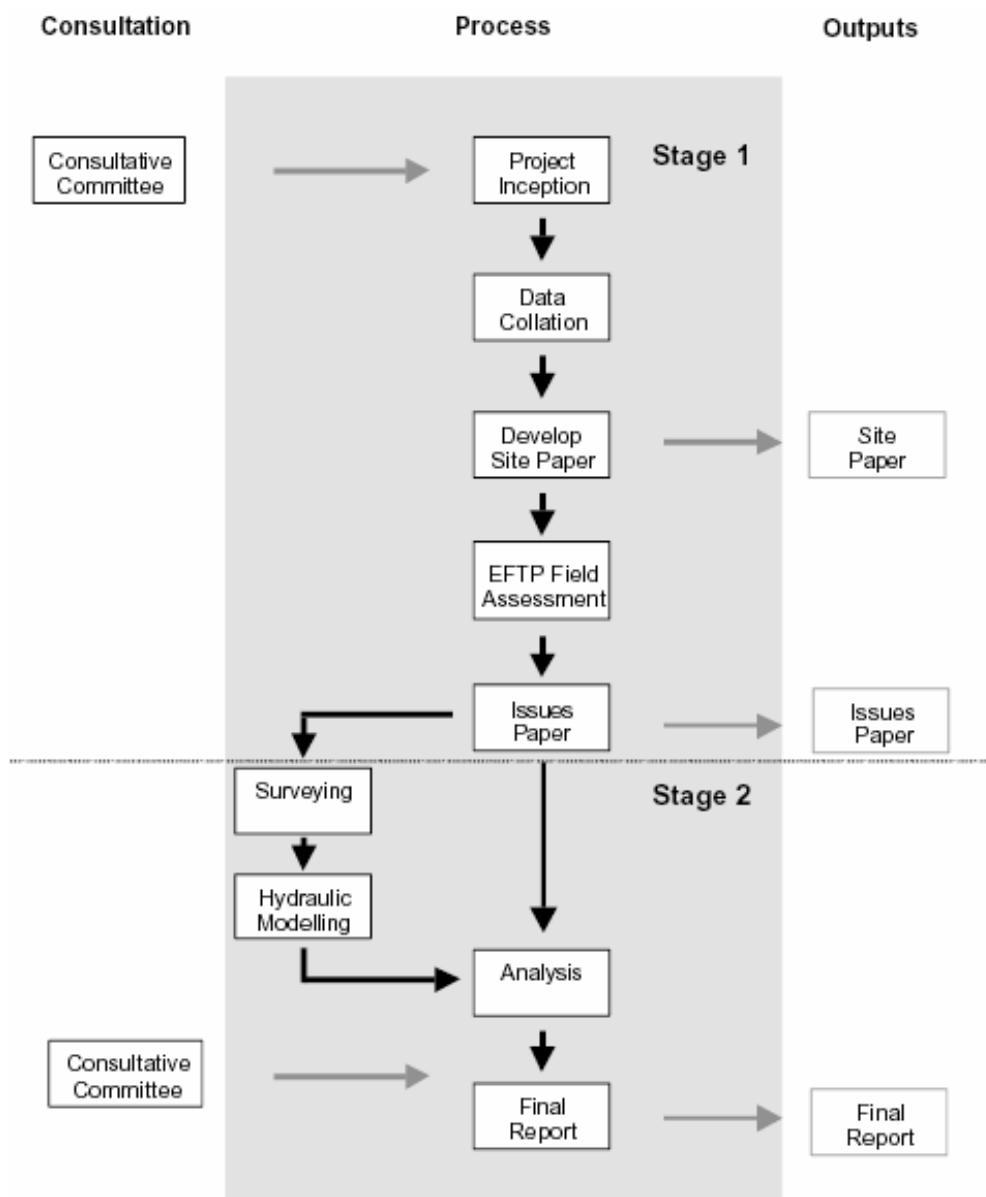


Figure 3. Flow chart illustrating the implementation of the FLOWS methodology. Note EFTP refers to the Environmental Flows Technical Panel (DNRE 2002a).

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. For example, the flow component of "low flow in summer" might be attributed to the persistence of aquatic habitat in a stream bed.

Stage 1 of the project was completed with the preparation of the Issues Paper (Lloyd Environmental 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 Barwon 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.

1.3 The Environmental Flows Technical Panel

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

- Lance Lloyd Fish and Macro-invertebrate Ecology
- Dr Marcus Cooling Plant Ecology
- Dr Chris Gippel Hydrology and Fluvial Geomorphology
- Dr Brett Anderson Hydraulics & Modelling
- Associate Professor John Sherwood Estuarine Ecology

Dr Allen McIlwee (Ecological Associates) undertook a review of water bird ecology in relation to the water regime recommendation for the estuary reach within this report. The project was reviewed by Dr Mike Stewardson of The University of Melbourne, who is a hydrologist and environmental flows expert.

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

- Simone Gunn, Corangamite Catchment Management Authority
- Cameron Welsh, Southern Rural Water
- Steve Nicol, Department of Sustainability and Environment
- Cameron Howie and Mee Teng, Barwon Region Water Authority.

In addition, a Community Advisory Committee and an Expert Panel – Estuaries (consisting of the estuary and freshwater scientists and managers) have also been established to assist the Environmental Flows Technical Panel and the Steering Committee for this project. Advisory Committee members included Bob Carrail, Pat Russell, Cameron Steele, Steven McDougal, Trevor Pescott, Nellie Shalley, Stuart Mathieson, Gary Battye, Graham Perkins, Neil Pearce, Gary Wishart, and David Cotsell. The Expert Panel – Estuaries included Matt Ward, Lochie Jackson, Peter Kemp, Ian McLaughlan, Graham Perkins, Trevor Pescott as well as members of the Steering Committee and the Project team.

This is an overview of the Hydraulic Analysis Report (HAR) that was undertaken for the Barwon River FLOWS assessment. The HAR is included as an Appendix to the final report. The HAR explains the analysis in detail, and presents a summary of the results of the hydraulic simulations. The hydraulic analysis is also based in part on material presented in the Issues Paper.

2.1 Hydraulic Analysis

Numerical hydraulic models were developed for eight of the nine focus reaches on the Barwon River (the estuarine reach - site 5 - was not suitable for analysis using the FLOWS method (DNRE 2002)). Hydraulic analysis provides an efficient means to estimate the relationship between flow depth and discharge for each reach. Flow data was supplied by SKM (2005). For this project models were constructed using the HEC-RAS software (U.S. Army Corps of Engineers, Version 3.1.3, May 2005: www.hec.usace.army.mil), which is designed to perform one-dimensional steady state calculations for natural and constructed 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.

2.1.1 Reach geometry defined by survey

Cross-sectional surveys were undertaken by Reed& Reed Surveying of the eight selected reaches of the Barwon Rivers and tributaries in July and August of 2005. At each reach between 6 and 10 cross-sections were surveyed at locations identified by pegs placed during field reconnaissance in Stage 1. Transects were located 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.

Cross-section data was supplied in both text file format (comma separated values) and as ESRI format shape files (included on the data CD). The principal parameters provided were:

- Co-ordinates in Zone 54 AMG.66 (Easting and Northing to ± 0.01 metres);
- Reduced levels to Australian Height Datum (AHD, ± 0.02 metres);
- Lateral position (in East-North plane) measured from zero at the most extreme point on the left hand bank (left side facing downstream) and increasing toward the right bank.

The surveyors also surveyed the location of uniquely numbered pegs placed during the field survey conducted by scientific team to mark important physical features or vegetation assemblages. Water surface levels on the day of the survey were also noted, as were other features such as the elevation of gauging station boards.

The raw survey data was manipulated and translated into HEC-RAS geometry file format using custom written routines using the scripting language of **Matlab** (Release 14, The Math Works: <http://www.mathworks.com/>). The manipulations included:

- Identify longitudinal features including the thalweg and the left and right bank positions (for the main channel).
- Project points in the survey of the main channel (between the left and right banks) to a common plane so as to avoid exaggeration of the cross-section dimensions.
- Un-cross section lines (on floodplains) where the surveyed sections are overlapping¹ or need realignment with floodplain flow direction.
- Extrapolate most downstream cross-section.

Once this pre-processing is complete the cross-section data is written to a text file that can be read by HEC-RAS. Matlab routines were also written to:

- Compute the dimensional properties of each cross-section, including the variation with flow depth of wet perimeter, hydraulic radius, water surface top width and flow area.
- Estimate Manning's n roughness values using the empirical equations of Riggs (1976) and Dingman and Sharma (1997).
- Post-process flow results exported from HEC-RAS by evaluating quantitative discharge thresholds (see following section) with output written to a text file.

2.1.2 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 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

¹ Section lines were un-crossed in two stages. First, a three dimensional surface was interpolated using the surveyed data point. Second, cross-section lines were moved so as to be parallel to the floodplain flow direction and to realign overlapping sections.

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.

The impact of uncertainty in the specification of hydraulic roughness was explicitly considered in reporting results from the one-dimensional simulations.

2.1.3 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 eight reaches assessed for in the Barwon 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 ($n^1, n^2 \dots n^6$). 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. A more detailed description of these methods can be found in the Hydraulic Analysis Report (Appendix).

2.2 Results of hydraulic analysis

A series of standard outputs were compiled for each reach. A sample of the output is presented here for Reach 1, Upper Barwon River, with each individual product listed with a brief description in Table 2.1.

Table 2.1 List of hydraulic analysis outputs produced for each of the surveyed reaches

Hydraulic Analysis Output	Reference
Plan view of the site with each of the surveyed cross-section labelled.	Figure 2.1
List of geometric properties associated with bankfull channel stage at each cross-section, including: flow area, A; top width, B; and hydraulic radius, R.	Table 2.2
Summary of reach hydrology listing the range of flows under the natural and current flow regimes.	"Hydrology"
Commentary describing how floodplain roughness vales were assigned (and possibly other reach-specific hydraulic considerations).	"Floodplain Roughness"
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).	"Roughness Coefficient Estimation"
List of thresholds associated with sediment entrainment and vegetation removal, with the discharge estimated to breach each threshold listed in the final column.	Table 2.3
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).	Figure 2.2

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

2.2.1 Sample results: Site 1: Barwon River @ Upper Barwon.

Plan View of Reach

Eight cross-sections were surveyed over a reach length of 585 metres at the Upper Barwon site. The HEC-RAS model of these cross-sections is shown in plan view in Figure 2.1, and indicative channel dimensions are listed in Table 2.2.

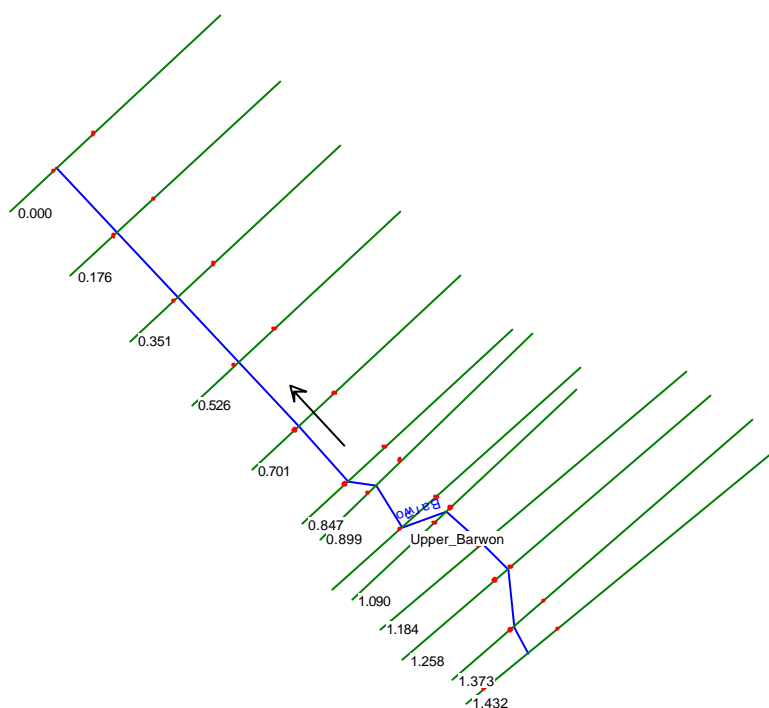


Figure 2.1 Plan view of Site 1 (labels give distance (km) upstream of reach outlet). The five lower cross-sections (0.000 - 0.701) are extrapolated from cross-section 0.847.

Table 2.2 Summary of Channel Dimensions

XS	Distance	Elevation	Dimensions		
	(km)	(m)	A (m ²)	B (m)	R (m)
1	1.431	121.2	14.8	15.7	0.9
2	1.373	121.3	14.2	14.3	0.9
3	1.257	120.9	8.2	10	0.8
4	1.184	120.7	14.9	17.2	0.8
5	1.089	120.3	8.4	10.7	0.7
6	0.997	120.1	8.4	12.8	0.6
7	0.899	120.1	5.3	8.6	0.6
8	0.846	119.7	3.5	5.3	0.6
<i>Reach average:</i>			9.7	11.8	0.8
<i>Std. deviation:</i>			4.1	3.7	0.1

Hydrology

The following hydrologic properties were extracted from the issues paper. Thirty flows were simulated in the HEC-RAS model. The minimum flow simulated was set at 50 times lower than the smallest flow listed. The maximum flow simulated was set equal to the highest discharge.

ARI (yr)	0.5	1	2	5	11	31
Discharge (ML/day)						
Natural	1 020	1725	2 865	8 250	13 215	22 230
Current	405	735	1 140	2 325	2 325	6 735

Floodplain roughness

The floodplain zones at Site 1 are dissected by a number of small channels. These surfaces are in places covered with scattered brush (including macrophytes and some low trees (Chow's Table: D-2.c.1) and in the remainder it is pasture with high grass (Chow's Table: D-2.a.2). An intermediate roughness was assigned: $n = 0.042$.

Levees

This reach is dissected by a number of channels. The main functional channel is flanked by high levees, which hydraulic modelling suggests are capable of containing a large flood (5 - 15 year ARI; 6000 - 18000 ML/day). However, the field inspection revealed that some of the secondary channels were active, presumably supplied by breaches in the levee, under Winter baseflow conditions. Consequently, the levee was considered ineffective in the numerical model.

Site 1: Roughness coefficient estimation

Method	Manning's n	Selected values		Description
Cowan's Method	0.040	$n_b = 0.020$	$n_3 = 0.000$	Silt-clay (earth) substrate with negligible irregularity (very flat profiles) with occasional cross-section shape change. Obstructions are negligible with vegetation (medium) important at lower flow stages. Meandering is considered minor in this context.
		$n_1 = 0.000$	$n_4 = 0.015$	
		$n_2 = 0.005$	$m = 1.00$	
Chow's Table	0.040	Table Ref: D-1.a.5 (minimum)		Minor stream with some weeds (#4) but also at low stage (#5) - select low end of #5 (Table 5-6 in Chow, 1959, p.113)
Bathurst's Table	0.030 +veg = 0.015	Slope: 0.18%	D_{50} : 0.008mm	Slope greater than threshold but finer bed material (than sand). Select intermediate roughness and add vegetation increment (n_4)
Hicks and Mason	0.054 – 0.073 0.051 – 0.061	id: 25902 (p.214) id: 45311 (p.234)	$Q = 0.48$ m^3/sec $S = 0.0018$ silt/clay	Principal matched parameters: bed material (silt), slope and especially vegetation. Mean annual discharge is too high in both cases so have selected roughness range from bottom half of discharge measurements.
Empirical Equations	0.042 – 0.047 0.050 – 0.056	Rigg's (1976) Dingman and Sharma (1997)		
FINAL ESTIMATE:	0.050 ± 0.010	(mean \pm 2 SD)		SD = standard deviation

Sediment entrainment and vegetation scour thresholds

Table 2.3 lists the thresholds for sediment entrainment and vegetation scour at Site 1.

Table 2.3 Site 1 thresholds for sediment entrainment and vegetation removal expressed in terms of either a critical shear stress (N/m^2) or a threshold discharge (ML/d).

Substrate	Conditions	Equation	Threshold	Discharge*
SEDIMENTS				(ML/d)
finer ($d = 0.1$ mm)	flushing from gravel	$t_c = 0.34 d$	0.034 N/m^2	0.1
sand ($d = 1$ mm)	spherical shape	$t_c = 0.97 d$	0.97 N/m^2	2.8
	normal, settled bed			
gravel ($d = 10$ mm)	spherical shape	$t_c = 0.97 d$	9.7 N/m^2	22 000
	normal, settled bed			
Riffle $d_{50} = 0.008$ mm	flat shape normal, settled bed	$t_c = 0.49 d$	0.004 N/m^2	< 0.1
VEGETATION				(ML/d)
bunch grass	Bunch grass (minimum)	erosion study	80 N/m^2	> 22 230
macrophytes	$d_m = 0.0119$ m	$uD/d_m = 12.8$	(flow dependent)	97.7
	$u =$ velocity (m/s)	$uD/d_m = 128$		> 22 230
	$D =$ flow depth (m)			

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

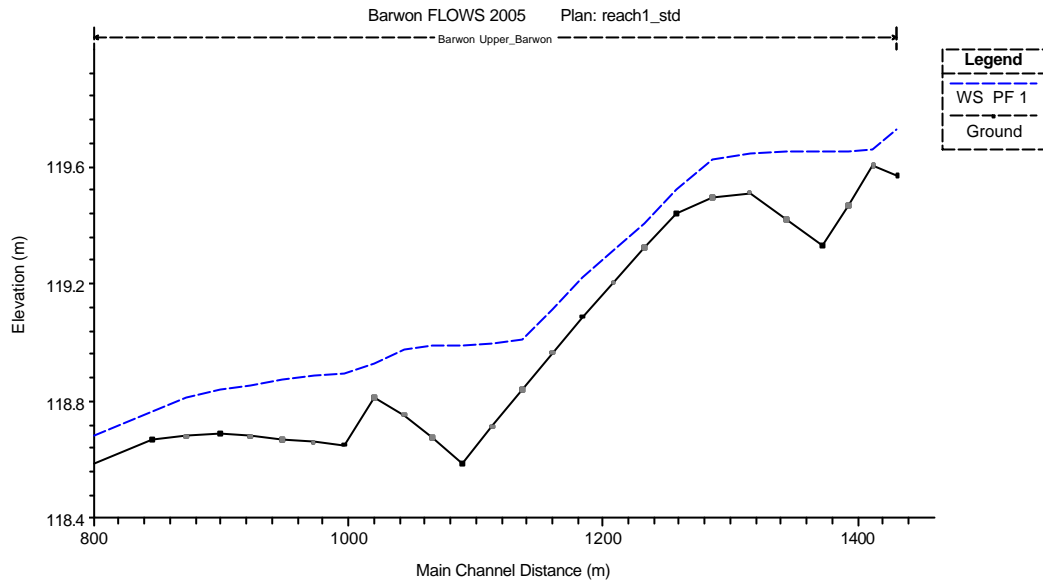


Figure 2.2 Longitudinal profile of Site 1 for very low flow (0.8 ML/d) with normal roughness specified (i.e. best estimate Manning’s n). Water surface elevation (m) is the broken line (WS), and the ground represents the thalweg profile (deepest point at each section). Channel distance is measured increasing upstream from zero at the outlet.

Site 1: Roughness coefficient estimation

Method	Manning's n	Selected values		Description
Cowan's Method	0.040	$n_b = 0.020$	$n_3 = 0.000$	Silt-clay (earth) substrate with negligible irregularity (very flat profiles) with occasional cross-section shape change. Obstructions are negligible with vegetation (medium) important at lower flow stages. Meandering is considered minor in this context.
		$n_1 = 0.000$	$n_4 = 0.015$	
		$n_2 = 0.005$	$m = 1.00$	
Chow's Table	0.040	Table Ref: D-1.a.5 (minimum)		Minor stream with some weeds (#4) but also at low stage (#5) - select low end of #5 (Table 5-6 in Chow, 1959, p.113)
Bathurst's Table	0.030 +veg = 0.015	Slope: 0.18%	D_{50} : 0.008mm	Slope greater than threshold but finer bed material (than sand). Select intermediate roughness and add vegetation increment (n_4)
Hicks and Mason	0.054 – 0.073 0.051 – 0.061	id: 25902 (p.214) id: 45311 (p.234)	$Q = 0.48$ m ³ /sec $S = 0.0018$ silt/clay	Principal matched parameters: bed material (silt), slope and especially vegetation. Mean annual discharge is too high in both cases so have selected roughness range from bottom half of discharge measurements.
Empirical Equations	0.042 – 0.047 0.050 – 0.056	Rigg's (1976) Dingman and Sharma (1997)		
FINAL ESTIMATE:	0.050 ± 0.010	(mean ± 2 SD)		SD = standard deviation

Sediment entrainment and vegetation scour thresholds

Table 4 lists the thresholds for sediment entrainment and vegetation removal. A longitudinal section through the site illustrates how the channel capacity and bed level relate to the water surface at a discharge of 0.8 ML/d (Figure 3).

Table 4. Site 1 thresholds for sediment entrainment and vegetation removal expressed in terms of either a critical shear stress (N/m²) or a threshold discharge (ML/d).

Substrate	Conditions	Equation	Threshold	Discharge*
SEDIMENTS				(ML/d)
finer ($d = 0.1$ mm)	flushing from gravel	$t_c = 0.34 d$	0.034 N/m ²	0.1
sand ($d = 1$ mm)	spherical shape	$t_c = 0.97 d$	0.97 N/m ²	2.8
	normal, settled bed			
gravel ($d = 10$ mm)	spherical shape	$t_c = 0.97 d$	9.7 N/m ²	22 000
	normal, settled bed			
Riffle $d_{50} = 0.008$ m	flat shape normal, settled bed	$t_c = 0.49 d$	0.004 N/m ²	< 0.1
VEGETATION				(ML/d)
bunch grass	Bunch grass (minimum)	erosion study	80 N/m ²	> 22 230
macrophytes	$d_m = 0.0119$ m	$uD/d_m = 12.8$	(flow dependent)	97.7
	$u =$ velocity (m/s)	$uD/d_m = 128$		> 22 230
	$D =$ flow depth (m)			

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

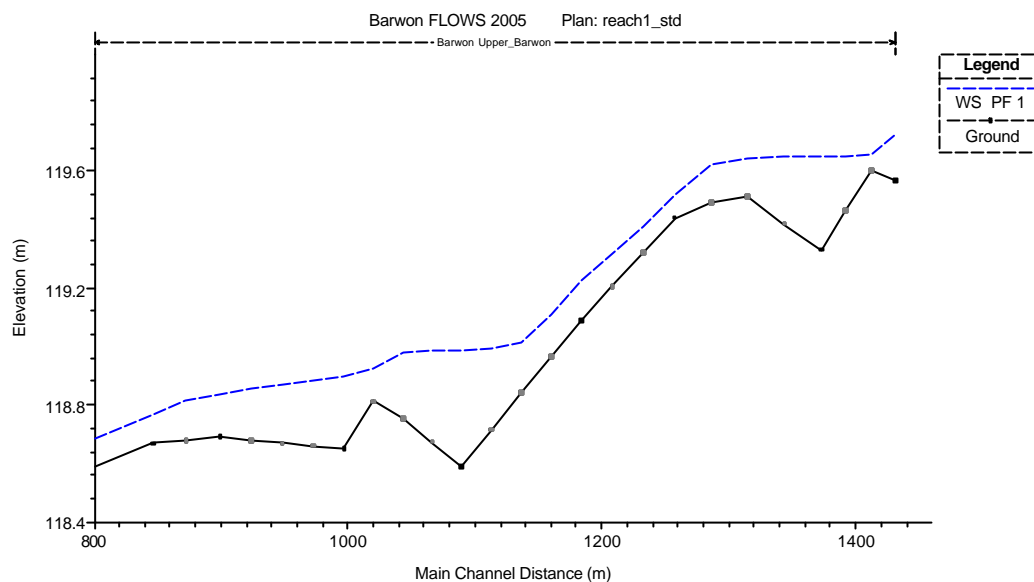


Figure 3. Longitudinal profile of Site 1 for very low flow (0.8 ML/d) with normal roughness specified (i.e. best estimate Manning's n).

Water surface elevation (m) is the broken line (WS), and the ground represents the thalweg profile (deepest point at each section). Channel distance is measured increasing upstream from zero at the outlet.

2.3 Analysis

Environmental flow recommendations were developed at a workshop held at the Corangamite CMA Geelong Offices on September 29 and 30, 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 (Lloyd Environmental 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.

3.1 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 5). The rationalised objectives were numbered for reference in the reach analysis presented in Section 4.

Table 5. Specific Flow Objectives.

Category	Sub-category	Specific Objective
Vegetation	Floodplain shrubland community	1a Perennial riparian shrub growth
		1b Riparian shrub community recruitment
	Submerged aquatic macrophytes	1c Perennial submerged aquatic macrophyte growth in pools (either in channel or low floodplain)
		1d Seasonal submerged aquatic macrophyte growth in floodplain pools or wetland areas
		1h Opportunistic growth in flooded billabongs
	Emergent macrophytes	1e Seasonal emergent macrophyte growth
		1i Summer macrophyte and grass colonisation of stream bed
	Drought-tolerant emergent macrophytes	1j Temporary inundation of saline floodplain
Floodplain woodland community	1f Growth and recruitment of Red Gum, Blackwood and other floodplain woodland species	
Halophytes	1g Presence of salt indicator plants (e.g. Sea Club Rush, <i>Selliera radicans</i>)	
2. Fish	Dwarf Galaxids	2a Maintain permanent populations in reach
		2b Provide breeding trigger and recruitment in reach by prolonged seasonal inundation of vegetation beds and Instream benches.
	Climbing Galaxiids	2c Longitudinal connection in channel for Galaxias olidus dispersal and G. brevipinnis juvenile upstream migration (late hydrological winter)
		2d Downstream migration of G. brevipinnis (early hydrological winter)
	Blackfish	2f Permanent pool habitat
		2g Submerged woody debris for breeding and / or hard and clean substrate
		2h Longitudinal connection in channel
	Mountain Galaxiids	2i Provide flow over sandy islands and benches
	Australian Grayling	2j Maintain permanent deep pool of minimum depth 3 m
		2k Provide breeding trigger and recruitment in reach, flush reach between February to May and inundation of vegetation beds and Instream benches is required
		2l Longitudinal connection in channel for adult grayling movement
		2m Juveniles migrate upstream from sea between October and December
2n Downstream migration of larvae between May and July (early hydrological winter)		
3. Geomorphology	Maintain capacity to mobilise sediment and shape channel and habitat features	3a Prevent excessive macrophyte colonisation of the bed leading to channel capacity reduction and potential erosion
		3b Disturb riparian vegetation to provide new habitats and regeneration and to control riparian vegetation encroachment into stream channel
		3c Maintain channel form and key habitats, including undercuts, in-

Category	Sub-category	Specific Objective
		channel benches, and flood runners where present
		3d Maintain channels and inlets for connectivity of main channel with important floodplain and wetland zones (where present)
		3e Maintain downstream sediment transport processes to prevent incision and aggradation of the bed, and consequent accelerated bank erosion and changed flood frequency
		3f Movement of sand bed material to maintain bed morphological and hydraulic diversity
		3g Scour sediments from base of pools to maintain quantity and quality of pool habitat.
		3h Scour surficial and interstitial fine sediment from riffles and overturn bed substrate (gravels and cobbles where present)
		3i Form large woody debris accumulations and scour pools around large woody debris.
		3j Disturb shrub layer vegetation on floodplain to create a mosaic of habitats
4. Macro-invertebrates		4a Sustain macroinvertebrate communities during Summer and Autumn
		4b Create and extend aquatic habitat for macroinvertebrate growth (flourish of life)
		4c Create and extend aquatic habitat for macroinvertebrate growth
		4d Support main growth and reproductive season for macroinvertebrates in Spring
5. Water Quality		5a Avoid prolonged stratified conditions in pools

3.2 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 6 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 small tributaries Boundary Creek and Birregurra Creek. They provide a dormant period for some emergent macrophytes such as *Bolboschoenus caldwellii* and allow grasses, sedges and herbs to colonise the stream bed, contributing to habitat diversity for fish and macroinvertebrates (Objective 1i). 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.

Groundwater Discharge

Groundwater discharge was not quantitatively assessed in this study, but it was recognised as an important process in some reaches. Groundwater discharge is interpreted to contribute to flow in the Barwon River below the Upper Barwon Reservoir and in Boundary Creek. Additionally, groundwater discharge contributes to seasonal variation in soil salinity in the watercourse in Birregurra Creek and in the Barwon River at Murghebuloc (Objective 1g). Evaluation of groundwater discharge and salt fluxes are beyond the scope of this study.

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 (Objective 1e). This was related to the discharge at which water reaches the toe of the channel bank. Inundating riffle cross sections is also an important indicator of the availability of habitat for benthic macroinvertebrates. The flows required to fully wet the perimeter of riffles (Objective 4a) were interpreted from the surveyed cross sections and referral to field notes and photographs. These were related to discharge using the hydraulic model.

Table 6. Flow Indices and Objectives

Index Type	Index	Objectives
Cease to Flow	Cease to flow duration	1c Perennial submerged aquatic macrophyte growth
Groundwater Discharge	Saline groundwater discharge to watercourse	1g Presence of salt indicator plants
Lateral Flow Extent	Water extends to toe of bank	1e Seasonal emergent macrophyte growth
	Perimeter of riffles fully wetted	4a Habitat for macroinvertebrate communities during summer and autumn
Velocity	Pool volume replacement	5a Avoid prolonged stratified conditions in pools
Flow Depth	Hydraulic depth at riffles (flow required to cover d50 particles + 50 mm)	2c Longitudinal connection in channel for <i>Galaxias olidus</i> dispersal 2d Downstream migration of <i>G. brevipinnis</i>
	Hydraulic depth over shallowest riffle thalweg d50+100 mm	2h Flow to connect Blackfish pool habitats 2i Longitudinal connection in channel for adult Grayling movement
	Inundate some macrophyte beds to at least 200 mm	4d Main growth and reproductive season for macroinvertebrates in spring
	Pool depth	2a Maintain permanent Dwarf Galaxiid populations in reach 2f Permanent pool habitat for Blackfish >500mm 2j Permanent deep pool of minimum depth 3 m for Australian Grayling (Reach 4 only)
	Flow passes lower breakwater	2m Juvenile Grayling migrate upstream from sea
	Inundation of woody debris	2g Submerged woody debris for Blackfish breeding
	Inundation of benches	1b Growth and recruitment of riparian shrubby vegetation 2i Flow over sandy islands and benches for Mountain Galaxids breeding 4c Create and extend habitat for aquatic macroinvertebrates
	Inundation of low floodplain wetlands	1d Seasonal submerged aquatic macrophyte growth in floodplain pools or wetlands areas 1i Summer macrophyte and grass colonisation of stream bed
	Inundation of floodplain	1f Growth and recruitment of floodplain woodland vegetation 1h Opportunistic aquatic plant growth in flooded billabongs 1j Temporary inundation of saline floodplain 2b Inundation of floodplain vegetation for Dwarf Galaxias breeding 4b Create and extend habitat for aquatic macroinvertebrates
	Water table within 500 mm of surface of floodplain shrub habitat	1a Perennial riparian shrub growth
Sediment Mobilisation	Flush fines (0.0034 N/m ²)	2g Hard clean surface at the edge of pools for Blackfish breeding
	Entrain sands (0.97 N/m ²)	
	Mobilise fine gravel (97 9.7 N/m ²)	
	Mobilise fine gravel (97 N/m ²)	
	Mobilise riffle material – d16	
	Mobilise riffle material – d50	
	Mobilise riffle material – d84	
Vegetation Removal	Velocity x Depth in channel exceeds 0.15	3a Prevent excessive macrophyte colonisation of

	(Q95)	the bed of leading to channel capacity reduction and potential erosion
	Q99.9	3b Disturb riparian vegetation to provide new habitats and regeneration and to control riparian vegetation encroachment into stream channel
Channel Dimensions and Form	Q99.9	3c Maintain channel form and key habitats including undercuts, in-channel benches and flood runners where present 3d Maintain channels and inlets for connectivity of main channel with important floodplain and wetland zones where present
	Mobilise riffle material – d50 Mobilise riffle material – d84	3e Maintain downstream sediment transport processes to prevent incision and aggradation of the bed and consequent accelerated bank erosion and changed flood frequency
	Grass removal (80 N/m ² shear stress)	

Flow Depth

The depth of water in riffles connecting pools during baseflow can limit the movement of fish between pools. For movement of *Galaxias olidus* and *G. brevipinnis* between pool habitats, there needs to be a minimum depth of around 50 mm at the thalweg (deepest point) of the shallowest riffle (Objectives 2c, 2d). A deeper threshold of d50 +100 mm over the shallowest riffle thalweg was applied for the movement of the larger species River Blackfish and Australian Grayling (Objectives 2h, 2i) where d50 is the diameter of the fiftieth percentile of substrate particles. 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. River Blackfish spawn from November to January and the fry are ready to disperse and feed after a few weeks.

Flow depth was also used to define the discharge required to support emergent macrophyte growth over spring (Objective 4d). The adopted threshold provides inundation of some of the emergent macrophytes in the reach to a depth of 200 mm.

The discharge required to maintain pools was used to evaluate the availability of permanent habitat for Dwarf Galaxiid, River Blackfish and Australian Grayling (Objectives 2a, 2f and 2j, respectively).

The population of Australian Grayling in the lower Barwon River depend on opportunities to migrate between the weir pool in Geelong and the estuary. This means that flows must be sufficient to flow over and drown out the upper breakwater and flows sufficient to allow the fishway on the lower breakwater to operate effectively or that this weir is drowned out.

Woody debris or hard, rocky surfaces are used by River Blackfish to lay eggs (Objective 2g). Once laid, the eggs must remain flooded for a period of 21 days until the larvae are released. During the field

assessment the distribution and level of woody debris and rocky surfaces, where present, where noted, and minimum discharges determined from the hydraulic model accordingly.

The inundation of benches in winter and spring supports the seasonal growth of aquatic macrophytes and other riparian plant species (Objectives 1b, 4c). Flow over sandy islands provides sites for Mountain Galaxias to breed (Objective 2i). The flows required to inundate benches (where present) were interpreted from cross sections that showed benches, using the hydraulic model.

The discharges required to inundate floodplain wetlands and the greater floodplain was determined from the hydraulic model and used to establish the achievement of objectives relating to aquatic macroinvertebrate habitat, Dwarf Galaxias breeding habitat and vegetation growth and reproduction.

In general, the baseflow or low flow level is expected to closely reflect the water table under the adjacent floodplain. Periods of shallow water below the floodplain are believed to support the seasonal growth of plant communities dominated by *Callistemon sieberi*, *Leptospermum lanigerum* and *Lomandra longifolia*. The flow depth which corresponded to a depth to groundwater of 500 mm was applied in reaches where these communities were significant.

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 ($d = 0.01\text{m}$) 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 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 Groeneveld 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. 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.

3.3 Flow Threshold Interpretation

Flow Magnitude

In the flow recommendation tables flow magnitude is the daily average of the flow including the peak of the event. We need to specify the rate of rise and recession. The duration represents the entire event, including the rise, peak and fall.

This is the daily average of the flow including the peak of event. The instantaneous peak would be higher.

– need to specify rate of rise and recession use triangle – peak, duration rate of rise and fall - t

Low Flow and Baseflow

The timing or duration of Low flow and Baseflow events is not specified in each reach. These are generally specified to occur throughout the hydrological summer and winter respectively. They are the minimum to which flows may be reduced by water managers, but should fall lower if natural was lower. Therefore, intervention is not required to increase flow if the low flow or baseflow recommendation is higher than natural at any time.

Flow Duration

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 state 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.

4.1 Reach 1 – Barwon River at Upper Barwon

Environmental Flow Objectives

Flow recommendations for Reach 1 are provided in Table 7. This reach extends from the Barwon River from West Barwon River Reservoir to upstream of the Birregurra Creek junction.

The representative site selected in this reach resembles a modified wetland habitat. Under natural conditions flow would have been dispersed over a broad floodplain in which multiple, poorly defined flow paths may have existed. This has since been modified to a narrow constructed channel which drains the broad floodplain. The EFTP determined that a healthy stream in this reach would retain the natural vegetation communities, including a Tea Tree shrubland on the floodplain and wetland habitats associated with the main flow path. These environments could not be restored without changes to current drainage practices and land uses, particularly works to promote floodplain inundation and the exclusion of stock from the watercourse.

Cease to flow is not recommended in this reach. While it occurs for a period of two weeks approximately once every three years, this is not sufficient to dry out wetlands or channel pools. No ecological role for cease to flow was identified.

Persistent, low flow during summer and autumn is important in this reach for the continued growth of aquatic plants and animals throughout the year. Low flows of 5 ML/d will maintain a depth of 30 to 50 cm in pools in the stream channel, which will provide a permanent habitat for the small fish and macroinvertebrates expected in this reach. This discharge will also fully wet the stream perimeter, providing habitat for aquatic macroinvertebrates. Perennial flow will also maintain a shallow watertable under the floodplain which will support the growth of shrubby floodplain vegetation, such as *Leptospermum lanigerum*.

Low flow freshes are required to periodically inundate floodplain pools and wetlands and to sustain perennial growth of aquatic macrophytes such as Milfoil. This objective could be achieved at a lower discharge than the recommended 215 ML/d if the drain were less effective.

Baseflow is required to support the seasonal growth of submerged and emergent macrophytes and for the seasonal growth and reproduction of aquatic fauna. The recommended discharge of 50 ML/d will maintain flow in the channel sufficient to inundate adjacent wetlands and floodplain pools. It also provides sufficient hydraulic depth in the channel for small fish to disperse.

Macro-invertebrate production increases during periodic increases in flow as additional habitat becomes available. These events supply additional prey for larger aquatic fauna and waterbirds. Discharges of 153 ML/d inundate low-lying floodplain areas and activate all floodplain channels and is recommended as the threshold for high flow freshes. This threshold exceeds the discharge required to transport sediment and remove sand in all cross sections (76 ML/d).

The inundation of the floodplain with a recurrence interval of one year is recommended. A discharge of 1600 ML/d will inundate the entire floodplain and will achieve bank full level in all floodplain channels.

This will support a seasonal flush in growth and will support the recruitment of floodplain plant species and would provide habitat for small fish to breed. Dwarf Galaxias require events lasting 5 to 7 days to recruit while other Galaxiids and Pygmy Perch require 5 to 7 days to recruit.

It is assumed that the low levee alongside the excavated channel is ineffective. Therefore all geomorphological objectives are achieved by high flow freshes and no recommendation is made for bankfull or overbank flows.

The pools in this reach are shallow and frequently flushed by low flows. No flow recommendation is made to address pool water quality (5a).

Table 7. Flow objectives for Reach 1 – Barwon River at Upper Barwon.

Flow				Rationale
Season	Magnitude	Frequency	Total Event Duration	
summer	Low Flow 5 ML/d	continuous		1a Perennial riparian shrub growth 1c Perennial submerged aquatic macrophyte growth 2a Permanent Dwarf Galaxid population 4a Habitat for macroinvertebrate communities in summer and autumn
summer	Low flow freshes 215 ML/d	2-3 per year	2 days	1d Seasonal submerged aquatic macrophyte growth in floodplain pools or wetlands
winter	Baseflow 50 ML/day	continuous		1d Submerged aquatic macrophyte growth in floodplain pools and wetlands 1e Seasonal emergent macrophyte growth 2c Longitudinal connection in channel for <i>Galaxias olidus</i> dispersal 2d Downstream migration of <i>G. brevipinnis</i> 4d Support main growth and reproductive season for macroinvertebrates
winter	Small High Flow Fresh 153 ML/d	2-3 per season	5 days	4b Create and extend habitat for aquatic macroinvertebrates 3c 3d 3e Geomorphological features
winter	Large High Flow Freshes 1600ML/d	annual	7-10 days	1b Riparian shrub community growth 2b Inundation of floodplain vegetation for Dwarf Galaxid breeding 3c 3d 3e Geomorphological features 4b Create and extend habitat for aquatic macroinvertebrates

Achievement of Recommendations

The recommendations for this reach are only partially achieved under currently flow conditions due largely to the influence of the West Barwon Dam upstream of this reach. The influence of the dam is stronger in the upper sections of this reach. Given, we have only flow records at the beginning and end of the reach we cannot say how much of the reach achieves these recommendations. The low flows in the summer and high flow freshes in winter are met meaning that fish and aquatic vegetation populations may be maintained but growth and expansion of macro-invertebrates and aquatic macrophytes will not occur nor will regular longitudinal connections will not be available for fish migration (Galaxiid species). Some of the geomorphological functions will also not occur.

Table 8. Analysis of the current frequency and duration of the recommended flows for Reach 1.

Season	Recommendation	Current	Achievement
Summer	Low continuous flows of 5 ML/d	Currently exceeded 85% of the time which is close to natural flow series	Flow recommendation largely met
Summer	Low flow freshes of 215 ML/d 2-3 times per year for 2 days	Currently occurs 1-2 times per year (always over 2 days)	Flow recommendation not currently met
Winter	Baseflow of 50 ML/d	Currently exceeded 50% of the time when naturally it would have occurred about 80% of the time	Flow recommendation not currently met
Winter	Small high flow freshes of 153 ML/d 2-3 times per season for 5 days	Currently occurs 7-8 times per season with over 3 events of over 5 days	Flow recommendation met
Winter	Large high flow freshes of 1600 ML/d	Current occurs 3-4 times per year for with at least one event of over 7 days	Flow recommendation met

4.2 Reach 2 - Winchelsea

Environmental Flow Objectives

The flow objectives for Winchelsea are presented in Table 9.

Cease to flow is not a natural phenomenon in this reach and no recommendation was made for cease to flow.

During summer and autumn, low flows are required to maintain permanent pools in this reach. Low flows are also required to sustain some riffle habitat between the main growing period of winter and spring. This flow is determined by the lowest flow that provides a pool depth of more than 50 cm at two out of three cross sections and wets the stream bed perimeter at all cross sections.

Low flow freshes are recommended on the basis of the habitat requirements of River Blackfish. Freshes inundate hard surfaces, such as woody debris on which eggs are laid. They also allow fish to meet and breed and for larval fish to disperse to pools throughout the reach. This threshold was set by the flow required to cover woody debris at the island cross section (section number 5). Only one event of this duration is required to trigger breeding, but two are specified to ensure that breeding occurs.

The baseflow recommendation is based on the flows to promote seasonal growth of emergent macrophytes and to provide sustained aquatic habitat for aquatic macroinvertebrates. The recommended flow wets the toe of the bank, and will either waterlog or inundating emergent vegetation on sandy benches or fringing the stream.

Periods of elevated baseflow are recommended to provide additional temporary habitat for macroinvertebrates. This discharge will inundate the majority of the island at cross section 5 and will completely inundate all other benches in the reach. Periods of two weeks are required to provide significant breeding and growth opportunities.

High flow freshes are required 3 to 5 times per year over a period of seven days each. The channel in this reach is steeply incised into the floodplain. This discharge will inundate shrubby vegetation growing on the steep banks of the channel, such as *Leptospermum lanigerum* and *Callistemon sieberi* and will reach the upper extent of *Phragmites australis*. This discharge connects pool and riffle habitats throughout the reach and provides migration opportunities for *Galaxias olidus* and *G. brevipinnis*. Sandy bench habitats are also inundated, which provides breeding habitat for *G. olidus*. Large high flow freshes will have sufficient energy to disturb vegetation from the stream channel, thereby maintaining habitat diversity and areas with an open stream environment. Woody debris will also be moved, to create snaggy accumulations.

At bankfull levels, morphological features will be maintained by scouring pools, creating sandy benches and maintaining the downstream movement of sediment.

Overbank flows are recommended primarily to provide periodic, temporary inundation of the scattered remnant Red Gum and Blackwood vegetation on the floodplain. Overbank flows will also have sufficient

energy to remove any accumulated macrophyte beds in the stream channel, and are therefore recommended every 5 years.

Table 9. Flow objectives for Reach 2 - Winchelsea

Flow				Rationale
Season	Peak Magnitude (Mean Daily)	Frequency	Total Event Duration	
summer	Low Flow 12 ML/d	continuous		2f River Blackfish require sustained low flows to maintain permanent pools in this reach 4a Low flows sustain the macroinvertebrate community in summer
summer	Low flow freshes 175 ML/d	2 per year	4 days	2g Submerge woody debris or hard, clean surfaces for River Blackfish breeding 2h Flows to connect pools for River Blackfish movement
winter	Baseflow 120 ML/d	continuous		1e Seasonal growth of emergent macrophytes 4d Aquatic macroinvertebrates activity
winter	Elevated Base Flow 240 ML/d	1-2 per year	14 days	4c Macroinvertebrate growth and reproduction
winter	Large High Flow Freshes 2,400 ML/d	3-5 times per year	7 days	1b Riparian shrub community growth 2c Upstream migration of Galaxias olildus 2d Downstream migration of Galaxias brevipinnis 2i Inundate sandy benches for Mountain Galaxias habitat 3b 3d 3f 3g 3i Geomorphological features
winter	Bankfull Flows 12,000 ML/d	1 per year	12 days	3c 3e Geomorphological features
winter	Overbank flows >12,000 ML/d	One 30,000 ML/d event every 5 years	16 days	3a Disturb emergent macrophyte beds 1f Support growth and recruitment of floodplain woody vegetation

Achievement of Recommendations

The recommendations for this reach are largely achieved with current flows. This indicates however any further reduction in frequency or duration of these flow events will lead to a decline of the values of the reach.

Table 10. Analysis of the current frequency and duration of the recommended flows – Reach 2.

Season	Recommendation	Current	Achievement
Summer	Low flows of 12 ML/d	Currently and natural occurs 70% of the time or more	Flow recommendation largely met
Summer	Low flow freshes of 175 ML/d 2 times per year for 4 days	Currently occurs 2-3 times per year with several events over 4 days in duration	Flow recommendation met
Winter	Baseflows of 50 ML/d	Currently occurs 50% of the time which exceeds the natural occurrence	Flow recommendation met
Winter	Elevated base flows of 240 ML/d 1-2 times per year for 14 days	Currently occurs for approx. 18% of the time whereas naturally occurred about 25% of time	Flow recommendation largely met
Winter	Large high flow freshes of 2,400 ML/d 3-5 times per year for 7 days	Currently these occur 2-3 times per year for mostly over 7 days which is similar to natural which occurred 3 times per year	Flow recommendation largely met
Winter	Bankfull flows of 12,000 ML/d once per year for 12 days	This flow occurs once every 1.5 years with at least 1 or 2 events over 12 days in length	Flow recommendation largely met
Winter	Overbank flows of 30,000 ML/d for 16 days every 5 years	This currently occurs over 5 years with some events of about 15 days 16 days	Flow recommendation largely met

4.3 Reach 3 – Murgheboluc Valley

Environmental Flow Objectives

Flow objectives for the Murgheboluc Valley reach are presented in Table 11. This reach represents the Barwon River from Leigh River confluence to Buckley's Falls.

Cease to flow does not occur either naturally or currently in this reach. No related ecological objectives were identified and no recommendation is made for cease to flow.

The presence of resident population of River Blackfish requires low flow to be sustained throughout the hydrological summer period. At a discharge of 22 ML/d, the channel width is completely wetted, all pools are maintained. This flow is currently exceeded 80% of the time, which creates a low likelihood of stratified anoxic or saline conditions in pools. This discharge will sustain aquatic macroinvertebrate fauna. A low flow period is important to allow groundwater to recharge the stream. The water table is interpreted to be saline, and the presence of salt tolerant plants in the riparian zone, such as *Selliera radicans*, requires periodic saline conditions.

Low flow freshes support breeding by River Blackfish which occurs over the period from November to January. The woody debris on which fish lay eggs is inundated at several locations at 498 ML/d, and this is the flow recommended for the freshes. This discharge exceeds the level required for fish to move between pools during the breeding period, which occurs at 20.4 ML/d.

The recommended baseflow discharge represents the flow required to create waterlogged conditions in the lowest benches adjacent to the channel bed. This will support the seasonal growth of emergent macrophytes growing on the channel fringe will provide habitat in riffles, pools and vegetation for aquatic macroinvertebrates.

One to two periods of elevated baseflow are recommended to occur each year to provide additional habitat for aquatic macroinvertebrates. This discharge will inundate benches at the upstream end of the main pool in the modelled stream section and will inundate most riffles.

Two sustained high flow freshes are required in most years to support the seasonal growth of shrubby vegetation on the floodplain, including *Callistemon sieberi* and *Lomandra longifolia*. The flow threshold of 11,000 ML/d was determined as the level required to provide a shallow water table for floodplain vegetation and to activate flood runners. Freshes will also allow the migration of Galaxias and Grayling. High flow freshes will maintain geomorphological features in the reach such as bench formation, sediment transport, woody debris movement and the formation of pools.

Bankfull flows are required primarily to maintain geomorphological features such as pools, benches, undercuts and floodplain channels. The current frequency and duration is recommended to maintain the existing stream geomorphology. This exceeds the requirement to disturb reedy vegetation from the stream channel every 5 years to maintain an open cobble habitat for fish and macro-invertebrates.

The objective to periodically remove shrubby vegetation from floodplain benches is achieved by the overbank flow discharge of 40,000 ML/d. This achieves a flow depth of 1.4 m over the floodplain delivering a velocity of 1.1 m/sec. It is required every ten years, with the duration of such events naturally spanning 17 days.

Table 11. Flow objectives for Reach 3 – Murgheboluc Valley

Flow				Rationale
Season	Peak Magnitude (Mean Daily)	Frequency	Total Event Duration	
summer	Low Flow 22 ML/d	continuous		1g Presence of salt indicator plants 2f River Blackfish require sustained low flows to maintain permanent pools in this reach 4a Low flows sustain the macroinvertebrate community in summer 5a Avoid prolonged stratified conditions in pools
summer	Low flow freshes 498 ML/d	2 per year	5 days	2g Submerge woody debris or hard, clean surfaces for River Blackfish breeding 2h (20.4 ML/d) Flows to connect pools for River Blackfish movement
winter	Baseflow 56 ML/d	continuous		1e Seasonal emergent macrophyte growth 4d Support main growth and reproductive season for macroinvertebrates in spring
winter	Elevated Base Flow 196 ML/day	1-2 times per year	2 weeks	4c Create and extend habitat for aquatic macroinvertebrates
winter	High Flow Freshes 11,000 ML/day	2 per year	10 days	4c Create and extend habitat for aquatic macroinvertebrates 1b Perennial riparian shrub growth 2c Longitudinal connection in channel for Galaxias olidus dispersal 2d Downstream migration of G. brevipinnis 2g Submerged woody debris for Blackfish breeding 2i Longitudinal connection in channel for adult Grayling movement 2i Flow over sandy islands and benches for Mountain Galaxias breeding 3b 3d 3f 3g 3h 3i Geomorphological features
winter	Bankfull Flows 28,000 ML/d	Every 1.5 years	15 days	3a 3c 3e 3h Geomorphological features
winter	Overbank flows 40,000 ML/d	Every 10 years	17 days	3j Disturb shrub layer vegetation on floodplain to create a mosaic of habitats

Achievement of Recommendations

The recommended flow are mostly met in the lower flow ranges but bankfull and overbank flows do not occur with the required frequency or duration under current conditions. This means that many geomorphological functions are not catered for including vegetation disturbance required for a diverse floodplain habitats. Some of the high flow functions may not be met each year under current conditions therefore limiting the growth and population size and diversity of riparian vegetation, macroinvertebrates, and fish.

Table 12. Analysis of the current frequency and duration of the recommended flows at Reach 3.

Season	Recommendation	Current	Achievement
Summer	Lows flows of 22 ML/d	This flow is currently exceeded 95% of the time	Flow recommendation met
Sumer	Low flow freshes of 498 ML/d twice per year for 5 days	This flow currently occurs about twice per year for approx. with durations of event for at least 5 days	Flow recommendation met
Winter	A baseflow of 56 ML/d	This flow is currently exceeded 95% of the time	Flow recommendation met
Winter	An elevated baseflow of 196 ML/d once or twice per years for 2 weeks	This flow is currently exceeded 55% of the time slightly exceeding natural flow events	Flow recommendation met
Winter	High flow freshes 11,000 ML/d twice per year for 10 days	These flows currently occur only once per year with several events are over 10 days	Flow recommendation only partially met
Winter	Bankfull flows of 28,000 ML/d every 1.5 years for about 15 days	This flow currently only occurs every 3 years but no event occur more than 12 days	Flow recommendation not met
Winter	Overbank flows of 40,000 ML/d over 10 years for 17 days	This currently happen every 5 years but no event currently exceeds 7 days	Flow recommendation not met

4.4 Reach 4 - Geelong

Environmental Flow Objectives

Flow objectives are presented in Table 13. This reach represents the Barwon River from Buckley's Falls to the Lower Breakwater.

Limited habitat is available for aquatic macroinvertebrates in the emergent vegetation fringing the weir pool in this reach. The water level is largely controlled by the lower breakwater (the weir) so a flow as low as 8 ML/d is sufficient partially inundate this fringing vegetation during summer. Similarly, a baseflow of 8 ML/d is recommended in winter. This value is provisional, and should be refined through additional investigations into the discharge required to maintain the pool water level after stormwater, groundwater and evaporative fluxes are taken into account.

Further work is required to determine an appropriate discharge for low flow freshes. These events must regularly mix the pool to prevent stratification and associated risks of anoxia and algal blooms. The flow to achieve destratification can only be determined through a specialist study of the hydraulics of the pool. The requirement for such a flow should also be considered in the light of alternative mixing strategies by aeration or mechanical means.

Sustained low flow freshes are required in the reach to enable Australian Grayling to breed between February and May in most years. These flows will allow for a well mixed and oxygenated water column and that aquatic vegetation beds and Instream benches to be inundated providing required habitat and food items for larvae and juveniles.

High flow freshes are recommended to partially inundate low floodplain areas and billabongs near the river. This occurs at a discharge of 4153 ML/d and supports the seasonal growth of floodplain and wetland vegetation and provides habitat for floodplain fauna including macroinvertebrates, small fish and waterbirds. Four events per year are recommended to maintain wetland habitat throughout the season. This flow is also sufficient to maintain the physical form of floodplain channels and inlets.

The bankfull discharge is based on the geomorphological bankfull level and will maintain the downstream movement of sediment and will maintain physical habitat features such as pools, undercuts and benches.

These flows are noted as these recommendations are only provisional at this stage pending assessment of downstream flow requirements and adaptive management results. This reach is subject to specific impacts and changes which need to be considered in these assessments, including:

- storm water management and impacts
- risks of algal blooms
- continued modification of the Reach e.g. through further revegetation
- flows to support recreation and tourism (as already foreshadowed by the CCMA)

Table 13. Flow Objectives for Reach 4 - Geelong

Flow				Rationale
Season	Peak Magnitude (Mean Daily)	Frequency	Total Event Duration	
summer	Low Flow 8 ML/d			4a Low flows sustain the macroinvertebrate community in summer
summer	Low flow freshes 250 ML/d	2 events per year	14 days	5a Avoid prolonged stratified conditions in pools 2k Grayling breeding trigger
winter	Baseflow 80 ML/d			1e Seasonal emergent macrophyte growth 2j Permanent deep pool (min depth 3 m) for Grayling 2l Connecting flow between pools for Grayling 2m Connecting flow to estuary 4d Support main growth and reproductive season for macroinvertebrates in spring
winter	High Flow Freshes 4,153 ML/day	4 per season	6 days	1b Growth and recruitment of riparian shrubby vegetation 1f Growth and recruitment of floodplain woodland vegetation 1h Opportunistic aquatic plant growth in flooded billabongs 3g (ML/d ²) Scour sediments from base of pools 3d Maintain floodplain channels and inlets 2b Inundate floodplain vegetation for Dwarf Galaxias breeding 4b Extend habitat for aquatic macroinvertebrates
winter	Bankfull Flows 40,000 ML/d	Every 1.2 year	16 days	3c Maintain channel form and key physical habitat features 3e Downstream sediment transport

Note: These recommendations are only provisional at this stage pending assessment of downstream flow requirements

² Sufficient for scour holes etc check flow measure flow concentration

Achievement of Recommendations

The recommendations for this reach are largely achieved with current flows. Bankfull flows are not currently met. However this assessment indicates that further reductions in frequency or duration of these flow events will lead to a decline of the values of the reach.

Table 14. Analysis of the current frequency and duration of the recommended flows at Reach 4.

Season	Recommendation	Current	Achievement
Summer	Low flow of 8 ML/d	Currently this occurs nearly 100% of the time which is slightly more frequent than naturally	Flow recommendation met
Summer	Low flow freshes of 250 ML/d twice per year for at least 14 days	This flow is currently occurs 3-4 times each year with at least two events over 15 days in length	Flow recommendation met
Winter	Baseflow of 80 ML/d	This flow currently occurs 85% of the time which is similar to the natural frequency	Flow recommendation met
Winter	High flow freshes of 4153 ML/d which occur 4 times each season for about 6 days	This flow currently just 4 times per season (previously was 7-8 times per season) for durations mainly above 6 days	Flow recommendation met
Winter	Bankfull flows of 40,000 ML/d 6 times every 5 years for 16 days	Currently this flow occurs only once every 3 years with no events longer than 15 days	Flow recommendation not met

4.5 Reach 6 – Birregurra Creek

Environmental Flow Objectives

Flow objectives for Reach 6 (Birregurra Creek) are presented in Table 15.

Birregurra Creek is a significantly modified stream environment. The hydrology and salinity regime has been altered by releases made to the watercourse and the clearance of native vegetation from the catchment. The vegetation the stream supports are affected by the altered hydrology and salinity regime, as well as land clearance, weed invasion and continued stock access. Under these circumstances, where the stream is a managed and highly modified ecosystem, it was not reasonable for the EFTP to recommend a flow that would sustain the components of the original stream ecosystem. Instead, objectives were set to maintain the current community of salt-tolerant emergent macrophytes and associated fauna.

The salt-tolerant species *Bolboschoenus caldwellii* occurs in watercourses subject to seasonal drying and temporary salinisation. A cease to flow period of 22 days, occurring twice per year (which is the current

regime), was recommended to provide a dormant period for *Bolboschoenus* and *Eleocharis acuta* and to allow the salinity of the soil and shallow groundwater to increase.

No baseflow recommendation was made. Instead frequent high flow freshes are recommended to maintain the waterlogged soils and temporary inundation that supports the seasonal growth of emergent macrophytes. The recommended discharge of 24 ML/d will provide a depth of 200 mm throughout the reach will support fish movement. Between 5 and 6 events per year was recommended as sufficient to provide a minimum growing period for the existing plant assemblage.

Bankfull flows will temporarily increase the habitat for aquatic macroinvertebrates, increasing the food available for fish and waterbirds. By maintaining the current frequency and total event duration, they will also continue to maintain geomorphic features and maintain the movement of sediment downstream.

Overbank flows will spread on to the flats in the upstream section of this reach, inundating the low shrubland community of *Halosarcia* spp., *Juncus* spp. and *Distichlis disticophylla*. Events occurring every second year will help maintain the current soil moisture and salinity regime and will help exclude terrestrial vegetation from the watercourse. They will provide temporary additional habitat for macroinvertebrates, waterbirds and fish.

Table 15. Flow objectives for Reach 6 – Birregurra Creek

Flow				Rationale
Season	Magnitude	Frequency	Total Event Duration	
summer	Cease to flow	2 per year	22 days	1g Presence of salt indicator plants
winter	High Flow Freshes 24 ML/d	5-6 events per year (current is 8)	15 days	1e Seasonal emergent macrophyte growth 4d Main growth and reproductive season for aquatic macroinvertebrates 2c <i>Galaxias olidus</i> dispersal 2d Downstream migration of <i>G. brevipinnis</i>
winter	Bankfull Flows 136 ML/d	1 every 0.8 of a year	9 days	3c Channel form and key physical habitats 3e Downstream sediment transport 4b Extend aquatic macroinvertebrate habitat
winter	Overbank flows 321 ML/d	1 in 2 years	7 days minimum	1j Temporary inundation of saline floodplain vegetation

Achievement of Recommendations

As outlined in the Issues Paper, the flow regime of this reach has been significantly impacted with increased flows meaning that most of these flows being exceeded under current conditions and more frequently than under natural conditions. Biodiversity, growth and reproduction are likely to be limited by increased frequency of flow events and the salinity range of discharged water.

Table 16. Analysis of the current frequency and duration of the recommended flows for Reach 6.

Season	Recommendation	Current	Achievement
Summer	2 Cease to flow events per year for 22 days each	This currently occurs 70% of the time	Flow recommendation met
Winter	High flow freshes of 24 ML/d 5-6 per year	Currently occur 8 times per year	Flow recommendation met
Winter	Bankfull flows of 136 ML/d 4 times very 5 years	This now occurs very frequently, well above this threshold and more frequently under natural conditions	Flow recommendation met
Winter	Overbank flows of 321 ML/d every 2 years for a minimum of 7 days	This now occurs very frequently, well above this threshold and more frequently under natural conditions	Flow recommendation met

4.6 Reach 7 – Boundary Creek

Environmental Flow Objectives

Flow objectives for Reach 7 (Boundary Creek) are presented in Table 17.

The channel in this reach has been artificially deepened and straightened drain cut into the floodplain. The channel has steep sides with little bench development. It is desirable to promote bench development to provide additional habitat complexity, the geomorphological objective 3g, to scour sediments from the base of pools was not included. Objective 3a, to create open water habitat by disturbing emergent vegetation, was also considered irrelevant as open water is not a natural characteristic of this stream.

A healthy stream in this reach would support dense, reedy vegetation, although this has largely been replaced by exotic grasses and forbs. A cease to flow period of 2 weeks, twice per year, is recommended to support the growth of grasses and reeds on the stream bed.

A baseflow of 1 ML/d is recommended to maintain semi-permanent aquatic habitat for small fish and macroinvertebrates. This discharge will fully wet the channel perimeter. Groundwater discharge is likely to contribute significantly to this flow requirement. Similarly in summer, a baseflow of 1 ML/d is

recommended to promote the growth of emergent macrophytes growing at the channel edge. Inundation of this vegetation will provide habitat for aquatic macroinvertebrates.

A discharge of 64 ML/d provides 200 mm inundation over vegetation on the bench in the channel. Freshes of this discharge will provide temporary additional habitat for macroinvertebrates.

The channel is artificially and deeply incised. Therefore no bankfull level can be defined. Overbank flows are intended to contribute to (or reflect) the presence of a shallow water table under the floodplain, which is required to support the growth of waterlogging-dependent vegetation. Although it has been cleared from the floodplain, Tea Tea would formerly have been the dominant vegetation type. A discharge of 137 ML/d corresponds to a water table lying 0.5 m below depressions on the floodplain, and would allow Tea Tree communities to be restored.

Table 17. Flow recommendations for Reach 7 – Boundary Creek

Season	Flow			Rationale
	Magnitud	Frequency	Total Event Duration	
summer	Cease to flow	2 per year	2 weeks	1i Summer macrophyte and grass colonisation of stream bed
summer	Low Flow 1 ML/d			2a Semi-permanent aquatic habitat for Dwarf Galaxid 4a Macroinvertebrate habitat in summer and autumn
winter	Baseflow 1 ML/day			1e Seasonal emergent macrophyte growth 2b Inundation of vegetation for Dwarf Galaxias breeding 4d Main growth and reproduction season for aquatic macroinvertebrates
winter	High Flow Fishes 64 ML/d	4 per season	6 days	4b Extend aquatic macroinvertebrate habitat
winter	Overbank flows 137 ML/d ³	1 in 2 years	9 days	1a Perennial riparian shrub growth 3b Disturb riparian vegetation 3c Maintain channel form and key habitats 3e Main downstream sediment transport

Achievement of Recommendations

Flow recommendations in this reach are mostly achieved however these flow recommendations could be easily curtailed with increasing catchment dam development.

Table 18. Analysis of the current frequency and duration of the recommended flows for Reach 7.

Season	Recommendation	Current	Achievement
Summer	2 Cease to flow events per year for 2 weeks	This currently occurs 30% of the time which is slightly more frequent than natural	Flow recommendation met
Summer	A summer low flow of 1 ML/d	This occurs about 40% of the time during summer which is about the same as the natural frequency	Flow recommendation met
Winter	A baseflow 1 ML/d	This occurs about 80% of the time during summer which is about the same as the natural frequency	Flow recommendation met
Winter	High flow freshes of 64 ML/d 4 times each season for 6 days	This occurs about 3-4 times per year with many events longer than 6 days	Flow recommendation largely met
Winter	Overbank flows of 137 ML/d once every two years for 9 days	This flow occurs every 1.5 years with several events over 9 days	Flow recommendation met

³ Half a metre of groundwater under the depressions on the floodplain required – which is met by this flow

4.7 Reach 8 – Mid-Leigh River

Environmental Flow Objectives

Flow objectives for Reach 8 are presented in Table 19. This reach represents the Leigh River from Cambrian Hill to Quiney Hill.

Under natural conditions cease to flow events occurred only rarely, approximately once every year for five days. Cease to flow no longer occurs due to discharges to the stream higher in the catchment. There is no ecological basis for recommending that cease to flow is restored.

Low flows are required to maintain the extensive pool habitats that occur in this reach. The pools will support River Blackfish and macroinvertebrates over summer and autumn. A flow of 12 ML/d will entirely wet the channel width and will provide up to 300 mm inundation in the active parts of the riffles and most riffle beds. This will provide perennial habitat for aquatic macroinvertebrates and will maintain. The requirement for permanent pools for River Blackfish is met at a discharge of 6 ML/d and will also be achieved. Currently this flow is exceeded 90% of the season, and will also protect pool water quality from risks associated with salinity and anoxia.

Low flow freshes are required to support River Blackfish breeding. Sediment is removed from the substrate on which eggs are laid, snags and other hard surfaces, at key locations in the reach at 5.6 ML/d. However, the threshold for this flowband is based on the requirement for connectivity between pools for Blackfish adults and juveniles to move during and after breeding, which occurs at flows of 44.5 ML/d. Two freshes are required each year to provide a reasonable certainty of breeding occurring.

Baseflows support the main growth and reproductive period for aquatic macrophytes. A discharge of 49 ML/d provides waterlogged conditions for the lowest benches adjacent to the channel bed on which *Phragmites australis* and *Eleocharis acuta* occur. These conditions will also support the seasonal activity of aquatic macroinvertebrates. This discharge will allow the migration of small fish up and downstream.

Two periods of elevated baseflow, each lasting two weeks are recommended to support the growth of riparian shrubs growing in a broader zone than the channel perimeter. At a discharge of 248 ML/d, the stream level corresponds to a water table less than half a metre below the floodplain surface at several sites. This would support the seasonal growth of *Callistemon sieberi* and *Leptospermum lanigerum* and other deep-rooted floodplain plants such as *Lomandra longifolia* and *Phragmites australis*. This discharge will also inundate benches on which emergent macrophytes grow, providing additional temporary habitat for aquatic macroinvertebrates.

The lowest flood runners crossing the floodplain are activated at a discharge of 1658 ML/d. This has been set as the threshold for high flow freshes which will provide breeding habitat for Mountain Galaxias by inundating sandy islands and benches and will maintain the physical environment of the stream channel and floodplain.

The threshold for bankfull events of 3744 ML/d was set to inundate and promote recruitment in floodplain shrub communities and to maintain the channel and floodplain form. This threshold reflects the

geomorphological bankfull level and will have sufficient energy to remove emergent macrophytes from the stream channel, which occurs at a discharge of 2025 ML/d. The recommended discharge will disrupt and open up patches of vegetation on the floodplain by achieving the Q95 threshold at at least one cross section, thereby maintaining a mosaic of environments. It will also maintain downstream sediment movement and maintain undercuts, pools and benches.

Table 19. Flow objectives for Reach 8 – Mid-Leigh River

Flow				Rationale
Season	Peak Magnitude (Mean Daily)	Frequency	Total Event Duration	
Summer	Low Flow 12 ML/d			2f (6 ML/d) Permanent pool habitat for Blackfish 4a (12 ML/d) Sustain macroinvertebrates during summer and autumn
Summer	Low flow freshe 44.5 ML/d	2 per year	2-3 days	2g (5.6 ML/d) Inundate woody debris or hard surfaces as a Blackfish 2h (44.5 ML/d) Longitudinal connection in channel
winter	Baseflow 49 ML/d			4d Main growth and reproductive season for macroinvertebrates 2c (44.5 ML/d) Connect pools for small fish migration 2d Downstream migration of <i>G. brevipinnis</i> 1e Seasonal emergent macrophyte growth
winter	Elevated Base Flow 248 ML/day	2 times per year	2 weeks	1a Perennial riparian shrub growth 4c Extend aquatic macrophyte habitat
winter	High Flow Freshe 1,658 ML/day	2 per season	7 days	2i Flow over sandy islands and benches 3b 3d 3f 3g 3h ⁴ (93 ML/day) Geomorphological objectives
winter	Bankfull Flows 3,744 ML/d	Every 1.2 years	10 days	1b Riparian shrub community recruitment 3a (2,025 ML/day) 3c (depth) 3e 3j Geomorphological objectives

⁴ provisional

Achievement of Recommendations

The recommended flows for this reach are largely met under the current regime although high flow freshes are only marginally achieved indicating further flow extraction is unsustainable.

Table 20. Analysis of the current frequency and duration of the recommended flows for Reach 8.

Season	Recommendation	Current	Achievement
Summer	No cease to flow	No cease to flow	Flow recommendation met
Summer	Low flow of 12 ML/d	This flow is currently exceeded 90% of time which is slightly more frequent than natural	Flow recommendation met
Summer	Low flow freshes of 44.5 ML/d twice per year for 2-3 days	Currently occurs more than 8 times per year for up to 15 days	Flow recommendation met
Winter	Elevated baseflow of 49 ML/d	Currently occurs 65% of the time	Flow recommendation met
Winter	Elevated baseflow of 248 ML/d twice per year for 14 days	Currently occurs between August and December 5% of the time	Flow recommendation met
Winter	High flow freshes of 1,658 ML/d twice per season for 7 days	This occurs 1-2 times per year with durations for some events over 7 days	Flow recommendation largely met
Winter	Bankfull flows of 3,744 ML/d every 1.2 years for 10 days	This flow occurs every 1.2 years with several events exceeding 10 days	Flow recommendation met

4.8 Reach 9 – Lower-Leigh River

Environmental Flow Objectives

Flow objectives for Reach 9 are presented in Table 19. This reach represents the Leigh River from Quiney Hill to the Barwon River confluence.

Under natural conditions cease to flow events occurred only rarely, approximately once every two years for three days. Cease to flow no longer occurs due to discharges to the stream higher in the catchment. There is no ecological basis for recommending that cease to flow is restored.

The requirement to maintain pools for aquatic fauna and macroinvertebrate habitat during the hydrological summer is met by a low flow of 8 ML/d. This discharge provides a trickle flow between pools and completely wets the channel width in all channel pools.

Emergent macrophyte growth in this reach is limited to a narrow zone near the baseflow level and sparse patches on low sandy benches. Baseflow is required to support the growth of this vegetation and to provide habitat for aquatic macroinvertebrates. The recommended discharge of 52 ML/d provides waterlogged conditions for the lowest benches adjacent to the channel bed at cross sections 2 and 4 and provides sufficient flow for small fish to migrate through the reach.

High flow freshes that support breeding events for Dwarf Galaxias are recommended to occur twice per year to provide a reasonable certainty of successful breeding. Shrubby vegetation (*Leptoserium lanigerum* and *Callistemon sieberi*) grow half-way up the bank on this reach. The recommended discharge of 2217 ML/d will inundate this level and is interpreted to support growth and reproduction of vegetation in this zone. This discharge will also achieve geomorphological objectives to maintain physical habitat features in the watercourse.

Bankfull flows is geomorphologically defined, i.e. it is the flow required to reach the top of the bank. The current discharge of 11000 ML/d currently occurs once every five years with a total event duration of 22 days, and should be continued to maintain the current stream geomorphology.

The billabongs and woodland vegetation on the floodplain are dependent on overbank flows. A discharge of 11000 ML/d will fill billabongs, providing temporary habitat for submerged aquatic macrophytes such as Milfoil, habitat for macroinvertebrates and small fish. When flooded, the billabongs are likely to support waterfowl and possibly piscivorous waterbirds. Overbank flows will also increase floodplain soil moisture, promoting the growth of Red Gum and Blackwood and promoting tree recruitment. These events only occur intermittently in this reach and it is recommended that the current event frequency of one in five years, with total event duration of 22 days is maintained.

Table 21. Flow objectives for Reach 9 – Lower Leigh River

Flow				Rationale
Season	Peak Magnitude (Mean Daily)	Frequency	Total Event Duration	
summer	Low Flow 8 ML/d			2a (ML/d) Semi-permanent aquatic habitat for Dwarf Galaxid 4a Macroinvertebrate habitat in summer and autumn
winter	Baseflow 52 ML/d			1e Seasonal emergent macrophyte growth 2c Flow connects pools to allow <i>Galaxias olidus</i> dispersal and <i>G. brevipinnis</i> migration upstream 2d Downstream migration of <i>G. olidus</i> 4d Main growth and reproduction season for aquatic macroinvertebrates
winter	High Flow Fishes 2217 ML/day	2 per year	8 days	1b Riparian shrub community recruitment 2b Inundation of vegetation for Dwarf Galaxias breeding 3a (48.8 ML/d) Disturb stream-bed macrophytes 3b (48.8 ML/d) Disturb riparian vegetation 3g (90.2 ML/d) Scour sediments from pools 3i (1.9 ML/d ⁵) Form woody debris accumulations
winter	Bankfull Flows 8476 ML/d ⁶	Every 5 years	17 days	3c Maintain channel form and physical habitat features 3e Downstream sediment transport
winter	Overbank flows >11000 ML/d ⁷	Once every 5 years	22 days	1f Growth and recruitment of floodplain woodland species 1h Submerged aquatic macrophyte growth in billabongs

⁵ Sufficient for scour holes etc check flow measure flow concentration

⁶ This level is the geomorphological bankfull 7 Nov 1995 flood was 7884 ML/d mean daily

⁷ Flood billabongs and floodplain redgums for opportunistic growth & recruitment

Achievement of Recommendations

The flow recommendations for this reach are mostly met but large flows are slightly reduced in frequency and duration.

Table 22. Analysis of the current frequency and duration of the recommended flows for Reach 9.

Season	Recommendation	Current	Achievement
Summer	Low flow of 8 ML/d	Currently this flow occurs 95% of time	Flow recommendation met
Winter	Baseflow of 52 ML/d	Currently this flow occurs 50% of the time	Flow recommendation met
Winter	High flow freshes of 2217 twice per years for 8 days	This flow occurs twice per year with events up to 15 days	Flow recommendation met
Winter	Bankfull flows of 8476 ML/d every 5 years for 17 days	This flow currently occurs once every five years for up to 17 days	Flow recommendation met
Winter	Overbank flows of over 11,000 ML/d once every 5 years for 22 days	This flow currently occurs every 30 years or so which is about the same frequency as the natural frequency	Flow recommendation met but flow series indicates some doubt about this flow recommendation

4.9 Reach 5 – Estuary

The Estuary is a complex of habitats, such as:

- Salt Swamp
- Hospital Swamp
- Reedy Lake
- Lake Connewarre including the estuarine sections of the lower River Channel

Each has a range of values for waterbirds, vegetation, fish and aquatic fauna, despite modification of the water regime of three of these, with only Lake Connewarre fully connected to the estuary.

Reedy Lake is approximately 550 ha in area and is reported to be the largest freshwater wetland in central Victoria (Yugovic 1985). Prior to European settlement, Reedy Lake was an ephemeral wetland that received minor flow from a small local catchment and major flows from peaks in the Barwon River. The Barwon River was originally estuarine upstream beyond the lake and the lake would have received a combination of saline and freshwater inflows, depending on the contribution of high tides and high river flows.

A regulated channel was cut between the Barwon River and Reedy Lake in 1953, upstream of the lower breakwater. The channel provided a regular input of freshwater to the lake. Initially, water entering the lake rapidly drained to the estuary. In order to maintain water levels in the lake during the 1967-1968 drought, the bank at the outlet was raised.

These works have important implications for the groundwater environment of the lake. Like the other lakes fringing the estuary, the lake is a natural discharge site for shallow groundwater. Under natural conditions, the salinity of the lake would have increased when water was absent, as groundwater discharge to the surface, or when sea water entered the lake. The salinity of the lake would have declined when the lake was inundated by fresh water from the Barwon River. The greater the depth of flooding, the greater was the potential for fresh surface water to have freshened the soil profile.

This water regime is likely to have created a similar plant habitat to conditions currently found in Hospital Swamp. Shallow saline groundwater would have supported a zone of salt tolerant macrophytes at the fringe, such as *Muehlenbeckia florulenta*, *Gahnia sieberi*, *Poa labillardieri* and *Distichlis distichophylla*. Shallow, seasonal inundation by freshwater would have occurred at the fringes of the wetland, at the limit of normal flooding from the Barwon River. This would have created waterlogged, flooded soils with some degree of freshening in winter and spring, but more saline in summer and autumn. These conditions are tolerated by the emergent macrophytes *Typha* sp., *Phragmites australis*, *Schoenoplectus validus*, *Eleocharis sphacelata* and *Bolboschoenus medianus*. *Schoenoplectus validus* and *Eleocharis sphacelata* tend to occur in deeper water (a normal seasonal range of 0.2 to 0.8 m) that does not normally dry out. *Phragmites australis* and *Typha* sp. tend to occur in soils that dry out seasonally, but are flooded seasonally by 0.2 to 1.5 m of water, ideally for 9 months. *Bolboschoenus caldwellii* is highly salt tolerant and will grow in areas that are seasonally inundated by up to 0.8 m for as little as 2 months per year. Sandy soils at the wetland fringe would provide favourable habitat for *Baumea juncea*. It is possible that well-flushed soils with low salinity may have supported sedgelands of other *Baumea* species.

Emergent macrophytes are likely to have been excluded from the lower bed of the lake by deep flooding in winter and spring. Regular seasonal flooding to more than 1 m will exclude most emergent macrophytes, particularly when flooding depth represents an additional stress to saline soils. When flooded, the lake is likely to have supported a variety of salt tolerant semi-emergent and submerged macrophytes such as *Ruppia* sp., *Lepilaena* sp., *Myriophyllum* sp., *Vallisneria gigantea*, and *Triglochin procerum*. Falling lake levels in late spring / early summer would have provided a saline marsh habitat for herbs such as *Triglochin striata*, *Mimulus repens*, *Pratia concolor*, *Apium annuum* and *Cotula* spp.

If the lake dried out, the deepest lake bed may only have provided bare soil, but would have been colonised by opportunistic terrestrial grasses, particularly *Agrostis avenacea*. These broad concentric zones of vegetation were observed by Yugovic (1985) in the 1980s.

The balance between these plant habitats has been altered by a gradual freshening of the lake and the introduction of a more stable and permanent freshwater regime. Since 2000, a new water regime has been introduced with the objectives of controlling carp and maintaining the quality of habitat for waterbirds. The flow thresholds relevant to the current water management regime are:

- 0 m AHD - inlet sill at the channel between the Barwon River and Reedy Lake upstream of the lower breakwater;
- 0 m AHD – lake bed level;
- 0 m AHD – sill of outlet channel between Reedy Lake and Lake Connewarre;
- 1.7 m AHD - overtop level of bank between Barwon River and Reedy Lake; and
- 0.9 m AHD – overtop level of bank between Reedy Lake and Lake Connewarre.

The water regime as recommended by PPK (2000) is presented in Table N.

Table 14. Recommended Water Regime for Reedy Lake (PPK 2000).

Month	Water Level (m AHD)
May	0.5
June	0.6
July	0.6
August	0.7
September	0.75
October	0.8
November	0.8
December	0.6
January	0.4
February	0.2
March	0.2
April	0.4
May	0.5

The key expected outcomes of this regime were:

- to provide deep water feeding and breeding habitat for waterfowl and habitat for eels and other fish between May and December;
- to exclude emergent macrophytes from most of the seasonally inundated area;
- to expose the lake margins between November and February to provide mudflat habitat for wading birds;
- to attract ducks and provide access by shooters to a range of locations with flooding of 0.4 m AHD in April and May.

In addition to this annual cycle was recommended that the lake is completely dried from time to time to eliminate carp. The recommended regime was to completely dry the lake for three months from February.

It was also recommended that in years when large numbers of Ibis breed that higher lake levels are maintained until fledging occurs.

This water regime has not had the intended result. The extent of open water habitat has been extensively replaced by reeds (particularly *Typha orientalis* and *Phragmites australis*) such that only a small area of open water remains. Furthermore, the reed habitat has a low floristic diversity and many of the plant communities described by Yugovic (1985) have declined or been lost.

The main causes of the change in vegetation are likely to relate to the relatively stable water levels under the current water regime (particularly during the growing season of plants between September and January) and the relatively deep water levels.

While the current water regime floods and exposes a significant proportion of the lake bed June and December, this corresponds to a change in water level of only 0.2 m. It is likely that the area that is exposed by falling water levels will remain damp and will therefore provide similar plant habitat to areas flooded by up to 0.4 m. This is particularly true for summer-growing generalist species such as *Typha orientalis* and *Phragmites australis* which will readily grow in a range of water depths ranging from waterlogged soils to depths of 0.5 m. The current water regime provides these conditions over a large proportion of the lake between October and January, which is the main growing period for these species.

The current water regime also maintains a water depth of 0.5 m or more for 8 months of the year in Reedy Lake. This will exert a downward pressure on the naturally saline groundwater that lies beneath the lake. Saline groundwater is a significant controlling factor on the structure of plant communities in the Barwon River estuary. This water regime will create fresh soil conditions over a large proportion of the lake, which will favour species that grow in low salinity soils, such as *Typha orientalis* and *Phragmites* sp.

Lake Connewarre State Wildlife Reserve consists of an extensive estuarine and saltmarsh system drained by the Barwon River. It includes a large permanent freshwater lake, a deep freshwater marsh, several semi-permanent saline wetlands and an estuary. Water is supplied from the Barwon River, local catchments and estuarine flows.

This wide variety of wetland habitats supports large and diverse waterbird populations. A total of 135 bird species (72 waterbird species) have been recorded in the reserve (Pescott 1983). This includes 29 species listed by JAMBA and CAMBA, two species listed only by CAMBA and two species listed only by JAMBA (NRE 1995).

Reedy and Middle Lakes have supported large populations of Sharp-tailed Sandpipers and Marsh Sandpipers (Watkins 1993). Up to 2830 Straw-necked Ibis, 1230 Australian Shelduck, 2500 Pacific Black Duck, 2805 Grey Teal, 609 Purple Swamphens and 5508 Eurasian Coots have also occurred here (NRE 1995). The lakes have also supported threatened waterbirds such as Freckled Duck and Blue-billed Duck (listed under the Flora and Fauna Guarantee Act) (NRE 1995). Reedy Lake also supports the largest breeding population of Swamp Harrier in Victoria (DCNR 1993).

A number of rare and threatened waterbird species have been recorded at Lake Connewarre. These include Great Egret, Fairy Tern, Blue-billed Duck and Australasian Bittern (NRE 1995a). The lake has support large numbers of Curlew Sandpipers and Sharp-tailed Sandpipers (Watkins 1993). Up to 5000 Black

Swans and 2500 Eurasian Coot also have been observed (NRE 1995). Up to 2000 Black Swans, 980 Sharp-tailed Sandpipers, 1550 Red-necked Stints and 2800 Curlew Sandpipers have been counted at the Barwon Estuary (NRE 1995).

4.9.1 Waterbird Breeding

Waterbirds require successful nesting sites for successful breeding. Colonial nesting waterbirds such as Little Egret, White-necked Heron, White-faced Heron, Great Cormorant, Little Black Cormorant, Pied Cormorant, Little Pied Cormorant and Yellow-billed Spoonbill build stick-nests in trees next to lakes or wetlands (page 55). These nests are often built in branches overhanging open water. This group of waterbirds feed in wetlands within the reserve but are not likely to breed, due to a lack of large trees.

Some duck species nest in tree hollows near water. While the Australian Wood Duck is only waterbird dependent on tree hollows, other species such as Pink-eared Duck, Blue-billed Duck, Chestnut Teal, Grey Teal, Australian Shelduck, Pacific Black Duck may nest in tree hollows or on the ground amongst dense vegetation. These species may breed at Lake Connemarre State Wildlife Reserve during periods of high food availability.

Three groups of waterbirds are likely to breed in Lake Connemarre State Wildlife Reserve. Colonial nesting species such as the Straw-necked Ibis and Glossy Ibis build their nests in bushes of lignum. Large breeding populations of Straw-necked Ibis, Australian White Ibis, Glossy Ibis and Royal Spoonbills have been recorded from Reedy and Middle Lakes (NRE 1995). The lakes have supported more than 10% of the regional breeding population of Straw-necked Ibis and Australian White Ibis and more than 5% of the State's breeding population of Royal Spoonbill (ANCA 1996). A colony of 10 000 plus Straw-necked Ibis nested in 1977, 1978 and 1979 and a colony of 500 Australian White Ibis was observed in 1983 (Marchant & Higgins 1991).

Most colonial nesting waterbirds only breed successfully when their nests are surrounded by water. If water levels drop before the young birds fledge, adult birds often abandon their nests (Scott 2001). Flood magnitude and duration is may be important determinant of the size and success of breeding events for colonial nesting waterbirds in Lake Connemarre State Wildlife Reserve.

Another group of waterbirds likely to breed in reserve are those that create platform nests on or near water by trampling down rushes, reeds or cumbungi. Freckled Duck, Black Swan and Musk Duck. Australasian Grebe and Great Crested Grebe form a platform nest at water level in dense stands of reeds and rushes by collecting together a mass of submerged and floating water plants. Buff-banded, Rail Dusky Moorhen and Purple Swamphen build platform nests under the cover of dense emergent water plants.

A third group of waterbirds likely to breed in Lake Connemarre State Wildlife Reserve are those that build shallow ground scapes amongst various dense vegetation or debris near the edge of waterbodies. This includes a range of small waders such as Red-necked Avocet, Black-fronted Dotterel, Red-capped Plover and Black-winged Stilt.

Use of Water Regime Classes by breeding waterbirds

Common Name	Breeding Stimulus	Nest Type	Principal Breeding Site
Red-necked Avocet	Flooding, Seasonal	Ground scrape in flooded reeds	Temporary Wetland
Black-fronted Dotterel	Flooding	Ground scrape in flooded reeds	Temporary Wetland
Masked Lapwing	Flooding	Ground scrape in flooded reeds	Temporary Wetland
Red-capped Plover	Flooding	Ground scrape in flooded reeds	Temporary Wetland
Black-winted Stilt	Flooding	Ground scrape in flooded reeds	Temporary Wetland
Freckled Duck	Flooding, Seasonal	Platform in reeds or shrubs 1 m above water	Temporary Wetland
Black Swan	Flooding	Mattress of vegetation near reeds	Temporary Wetland
Musk Duck	Seasonal	Mattress of vegetation near reeds	Temporary Wetland
Australasian Grebe	Flooding	Raft of reedy vegetation over deep water	Temporary Wetland
Great Crested Grebe	Flooding	Raft of reedy vegetation over deep water	Temporary Wetland
Buff-banded Rail	Flooding, Seasonal	Platform in or on flooded reeds	Temporary Wetland
Dusky Moorhen	Flooding	Platform in or on flooded reeds	Temporary Wetland
Purple Swamphen	Flooding	Platform in or flooded reeds	Temporary Wetland
Darter	Flooding	Stick nest in flooded trees	Red Gum Forest
Little Egret	Flooding, Seasonal	Stick nest in flooded trees	Red Gum Forest
White-necked Heron	Flooding, Seasonal	Stick nest in flooded trees	Red Gum Forest
White-faced Heron	Flooding	Stick nest in flooded trees	Red Gum Forest
Great Cormorant	Flooding	Stick nest in flooded trees	Red Gum Forest
Little Black Cormorant	Flooding	Stick nest in flooded trees	Red Gum Forest
Pied Cormorant	Flooding	Stick nest in flooded trees	Red Gum Forest
Little Pied Cormorant	Flooding	Stick nest in flooded trees	Red Gum Forest
Yellow-billed Spoonbill	Flooding, Seasonal	Stick nest in flooded trees	Red Gum Forest
Australian Wood Duck	Flooding	Tree hollows near water	Red Gum Forest
Pink-eared Duck	Flooding	Tree hollows or reedy platform	Red Gum Forest
Blue-billed Duck	Flooding	Tree hollow or reedy platform	Red Gum Forest, Temporary Wetland
Chestnut Teal	Flooding	Tree hollow or reedy platform	Red Gum Forest, Temporary Wetland
Grey Teal	Flooding	Tree hollow or reedy platform	Red Gum Forest, Temporary Wetland
Australian Shelduck	Flooding, Seasonal	Tree hollow or reedy platform	Red Gum Forest, Temporary Wetland
Pacific Black Duck	Flooding	Tree hollow or reedy platform	Red Gum Forest Temporary Wetland

Floods are likely to play a major role in waterbird breeding in Lake Connemare State Wildlife Reserve. Flooding initiates a productive succession of potential food resources, which attracts waterbird species and stimulates breeding (Maher and Carpenter 1984; Crome 1986). Wetland productivity is tied to wetting and drying cycles associated with the growth and decay of aquatic plants (Maher and Carpenter 1984). On reflooding, the vegetation is drowned, and the rich organic substrate and decaying vegetation supports the development of complex wetland flora and large invertebrate populations (Crome, 1986). In contrast, permanent water bodies with little fluctuation in water level do not promote large scale breeding of waterbirds (Frith, 1982).

There is no hydrological hydraulic or systematic, long-term water level records for the three main wetlands of the estuary to reliably relate water levels to ecological outcomes. The following recommendations are based on discussions with Field and Game representatives and the land and water resource managers responsible for managing the estuary.

4.9.2 Reedy Lake

Discussions with local stakeholders have identified the following objectives for Reedy Lake:

- the lake should support a diverse range of waterfowl, reed-dependent birds, fish eating birds and large and small waders;
- the lake should support a range of aquatic plant communities including open water, semi-emergent macrophytes and emergent macrophytes;
- carp populations should be minimised;
- water should have sufficient clarity to support the growth of submerged macrophytes;
- the lake should support waterfowl hunting in late autumn and early winter.

The lake does not currently achieve these objectives, particularly due to the increasing dominance of emergent reeds, particularly *Typha* sp. and *Phragmites australis*. Consequently there has been an increase in the abundance of reed-dependent waterbirds and decline in species dependent on open water. The habitat available for waterfowl and opportunities to hunt them have declined. Carp have become increasingly dominant and are thought to limit the growth of submerged aquatic macrophytes. Reedy Lake also supports beneficial uses such as water extraction, a commercial eel fishery and game hunting as it is a game reserve and all of these beneficial uses are also not supported by the current regime as access to the Lake is gradually excluded by reed growth.

The current water regime provides conditions that promotes emergent reeds at the expense of other species. The current regime also provides limited opportunities for carp to be controlled (a drawdown every 6-7 years only). It is recommended that the following principles are used to alter the water regime and to achieve the management objectives. A proposed water regime is presented to apply the principles (Table 23).

The majority of the lake bed should dry out completely over summer and autumn. *Typha* and *Phragmites* are summer-growing plants that grow best in flooding up to 500 mm deep between October and February. Dry conditions from November to March will check the growth of these plants and lead to an eventual decline. There may be short term conflicts with the beneficial uses of the Lake at these times but the proposed regime will lead to a longer term improvement for each of the beneficial uses.

Dry conditions over summer and early autumn will also restore a more saline water table beneath the lake. The vegetation and water regime of the lakes fringing the estuary indicate that a saline water table lies close to the surface (but groundwater monitoring would be required to confirm this). At Reedy Lake, permanent flooding will have exerted downward pressure on the aquifer, reducing groundwater salinity. Higher soil salinities occur where groundwater evaporates from a dry lake bed, such as at Salt Swamp, and these conditions are too saline for *Typha* and *Phragmites* to grow. Higher soil salinities would further limit the growth of *Typha* and *Phragmites*. They would promote salt-tolerant shrubs and herbs (such as Samphire) when the lake is dry and would promote semi-emergent macrophytes and open water when the lake is flooded. Dry conditions will also reduce the population of resident carp.

A large proportion of the lake should be to a depth of more than 1 m during winter and early autumn. Seasonal flooding will provide habitat for waterbirds, fish and submerged aquatic macrophytes. If the water level is maintained at a fairly stable level for most of this time, emergent macrophytes will be limited to a narrow zone at the perimeter of the flooded area. Active control of these water levels would be required and it is believed that the current infrastructure is not able to provide this level of control to create the desired water regime.

Central to this conceptual model of lake water requirements is an understanding of the response of the aquifer to flooding and drying. Monitoring bores are required in the lake bed and the lake perimeter to assess the potential for these principles to be applied and to modify the conceptual model if required. Deep and shallow bores located in the lake bed and the lake perimeter would provide information on the vertical salinity gradient in salinity, water table responses to flooding and drying, response times and local groundwater gradients and flows. Monthly records of surface water levels should also be kept.

It may not be possible to apply the proposed water regime without modifications to existing structures and flow paths. In particular, the current density of reeds significantly slows water movement. Upgrade to the water distribution infrastructure is required to achieve the necessary level of control over water regime to ensure water regime objectives to be met and to enable timely response to unforeseen or undesirable ecological or environmental changes.

Due to the resilience of reeds to seasonal flooding conditions, an amended flow regime would have to be applied for at least five years for significant changes in their distributions to appear. If this time frame was unacceptable, it would be possible to accelerate change by introducing a complete drought (permanent drying) for an initial period of three years to initiate the restoration of the desired ecosystem structure. This suggestion however would impact upon the beneficial uses of duck hunting and the commercial eel fishery for this period, so it is likely that the first or second option in Table 23 is more likely allow these uses to continue (even if it is with some impacts initially),

Table 23. Recommended Water Regime for Reedy Lake

Month	1 st Option Water Level (m AHD)	2 nd Option Water Level (m AHD)	3 rd Option Water Level (m AHD)
May	0.4	0.4	0.4
June	0.4	0.4	0.4
July	0.6	0.6	0.6
August	0.9	0.9	0.9
September	0.9	0.9	0.9
October	0.5	0.9	0.9
November	0.3	0.5	0.9
December	0.1	0.3	0.5
January	0	0.1	0.3
February	0	0	0.1
March	0	0	0
April	0	0	0

Three options are proposed for the management of Reedy Lake:

- The first option is most conservative and has a strong chance of resulting in a change in the vegetation structure to the desired system of open water with submergent macrophytes and diverse fringing vegetation.
- The second option could be applied every year with the likelihood that the preferred vegetation objectives occur but the change may take a longer time to re-adjust. There is an increased, but still low, risk of summer growing macrophytes (such as *Typha* & *Phragmites*) becoming more prevalent. This might better support waterbird breeding and an ideal water regime might see this option applied four out of five years and option one in the remaining year (with a low rainfall).
- The third option could be applied but would have a low likelihood of change to the preferred ecological condition. It is perhaps an option that could be applied in high rainfall years only – based on a rainfall trigger of something like the 75th percentile rainfall, which might co-occur with large waterbird breeding events once in a decade or similar frequency.

Broadly the water regime will result in:

- Flooding in early winter and drying out in mid-spring before the main growing season of reeds;
- Reeds would be excluded from the central area by saline groundwater, by flooding that is too deep for them in spring and by the absence of flooding in their main summer growth period;
- A drying phase to control exotic fish species and allow nutrient processing in the wetland bed;

-
- The central lake area would be flooded to a depth of more than 1 m for 3 to 6 months, in which would grow emergent and semi-emergent water plants like milfoil, *Potamogeton*, *Triglochin* and *Lepilaena*. This will allow for aquatic invertebrates and fish populations to breed and expand with Reedy Lake;
 - Reeds would persist, but in a zone near the seasonal upper limit of water levels in winter and spring;
 - High level intermittent flooding in winter and spring by rainfall and river flows every 2-3 years to allow extensive flooding, aquatic habitat creation and fish breeding events.

This would probably provide the greatest diversity in waterbird, fish and plant habitats, but has the limitation of not having water present during the duck shooting season. Note however, the infrastructure currently is not able to provide this option and would need upgrading to enable it to proceed. Without such changes the values and beneficial uses of Reedy Lake may be lost or diminished.

4.9.3 Hospital Swamp

The water regime of Hospital Swamp has been regulated for approximately 20 years. The wetland features a range plant assemblages that correspond to soil the various soil moisture, salinity and flooding environments present. According to local wetland managers, the existing water regime supports the desired ecological community. The following articulates the existing relationship between water regime and ecology so that management may be formalised.

Hospital Swamp comprises 5 basins which receive water both from the Barwon River estuary and from local runoff. The wetland is isolated from the estuary by a bund. Water is diverted from the Barwon River via a regulated channel through Sparrowvale Farm, which has an invert of 0.3 m AHD. Other unregulated channels become active at Barwon River levels greater than 1.4 m AHD.

The wetland overflows to Lake Connewarre at a level of 0.5 m AHD. The wetland can be drained using a regulated pipe with an invert of 0.2 m AHD.

The regulator is opened when the Barwon River exceeds 0.7 m AHD. Barwon levels greater than 0.9 m AHD allow Hospital Swamp levels to reach 0.5 m AHD, the normal full level.

The limit of wetland vegetation is defined by *Muehlenbeckia florulenta* shrubland which occurs in association with *Distichlis distochophylla* and *Juncus kraussii*. This association lies at an elevation of more than 1 m AHD is rarely flooded. It is likely to occur in soils that are seasonally waterlogged. Flooding would be tolerated, but is not a requirement to sustain this vegetation.

Elevations between the Lignum and the normal full level of the wetland (0.5 m AHD) support salt tolerant sedges and herbs. *Bolboschoenus caldwellii* was observed growing over *Sarcocornia quinqueflora* and *Selliera radicans*. Other species likely to be present include *Mimulus repens*, *Schoenoplectus pungens*, *Triglochin striata* and *Distichlis distichophylla*. *Bolboschoenus caldwellii* grows in saline areas subject to inundation with fresh or brackish water for a period of 1 month to 4 months in most years. The vegetation in this area most likely reflects a zone of permanent waterlogging where saline groundwater discharges to the surface, but soil salinities are reduced seasonally by flooding.

The normal full level of the wetland is marked by emergent macrophytes, particularly *Phragmites australis* and *Bolboschoenus caldwellii*. *Schoenoplectus validus* is also likely to be present. This association occurs at the fringe at the wetland at islands within the wetland that emerge above 0.5 m AHD.

Between elevations of 0.5 and 0.1 m AHD (the base of the wetland) the vegetation comprises a marshland assemblage. This area is regularly inundated to a largely stable maximum depth of 0.5 m AHD and supports a range of submerged and semi-emergent herbs and shrubs. Common species observed during the site inspection include *Sarcocornia quinqueflora*, *Ruppia maritima*, *Distichlis distichophylla*, *Mimulus repens* and *Cotula coronopifolia*. Other species likely to be present include *Potamogeton* sp., *Crassula helmsii*, *Rumex bidens*, *Triglochin procerum*, *Triglochin striata*, *Schoenoplectus pungens* and *Lilaeopsis polyantha*. This assemblage reflects the brackish conditions of the wetland, which are likely to be least saline when freshwater enters from the Barwon River, but becomes progressively more saline as water levels fall and groundwater discharge increases. Species such as *Triglochin procerum*, *Ruppia* and *Lilaeopsis* will tolerate permanent inundation or seasonal flooding. Species such as *Sarcocornia*, *Distichlis*, *Mimulus*, *Rumex* and *Triglochin striata* are favoured by seasonal inundation but will tolerate permanent waterlogging. The presence of the latter species suggests that drawdown of the wetland in late spring is important to this vegetation structure. Low water levels in November and December will provide an opportunity for these low-growing species to flower and set seed before excessive temperatures, high salinities or insufficient moisture in January and February inhibit further growth.

Water management specifically involves:

- maintenance of a saline water table at or near the surface of the wetland bed. This will allow some areas of permanent low level pools providing fish habitat in which to over summer;
- fresh water inundation between June and November for a period of at least 3 months in most years to a depth of more than 0.4 m to support the growth of submerged aquatic plants such as *Lilaeopsis*, *Potamogeton* and *Ruppia*;
- fresh water inundation for 2 to 4 months to an elevation of 0.5 m AHD in winter and spring in most years to support the growth of emergent aquatic macrophytes such as *Phragmites australis* and the creation of extensive aquatic habitat, stimulate fish breeding and enable recruitment of fish larvae;
- intermittent inundation (events of 1 to 2 weeks, 2 to 4 times per year) of the *Bolboschoenus* sedgeland and to enable extensive breeding events of fish such as galaxiids within the sedgelands;
- drawdown in November or December in most years to provide a growing opportunity for lake bed herbland species; and
- drawdown of the wetland in late summer and all of autumn to maintain the salinity of soil water and to restrict emergent macrophytes to the wetland fringe.

Flooding is not required by *Muehlenbeckia* shrubland growing at the fringes of the wetland. However this plant association tolerates temporary inundation and probably reflects a water regime involving soils that

are seasonally waterlogged by saline groundwater and inundated by surface water for 2 months 1 year in 10.

4.9.4 Salt Swamp

Salt Swamp is a shallow basin located to the south of Lake Connewarre, extending south-west from the Lower Barwon Channel. The Barwon Heads Road intersects the southern corner of the swamp. The site has previously been impacted by grazing and shell-grit extraction, but it retains diverse and largely intact native vegetation.

Estuarine water is excluded from the lake at normal levels by a low bund. The lake receives runoff from a local catchment which accumulates in the lake bed and is lost to seepage and evaporation. High levels in the estuary can spill into the swamp with a reported recurrence interval of 2 years (Yugovic 1985). The site appears to be a groundwater discharge zone and supports a waterlogging-tolerant halophytic plant community.

The central, lowest lying part of the lake supports an extensive (approximately 40 ha) *Wilsonia* herbfield. The dominant species in this assemblage is *Wilsonia humilis*, but the species *W. backhousei* and *W. rotundifolia* are also present. The herbfield is subject to annual inundation, approximately from June to December. The extent of the herbfield corresponds to the extent of regular inundation. When flooded the swamp supports *Ruppia maritima*, *Lepilaena preissii* and *Chara* sp.

A *Sarcocornia quinqueflora* herbfield occurs in seasonally waterlogged, saline soils at the perimeter of the area subject to regular inundation. Component species of this association are *Triglochin striata* and *Samolus repens*.

A samphire shrubland, dominated *Sclerostegia arbuscula* and *Halosarcia pergranulata* occurs on well-drained saline soils at the perimeter of the *Sarcocornia* herbfield. Rainfall in winter and spring promotes seasonal growth and flowering of *Disphyma clavellatum*, *Frankenia pauciflora* and *Cotula coronopifolia*.

Gahnia filum sedgeland occurs at the perimeter of the wetland in association with *Distichlis distichophylla*, *Enchylaena tomentosa*, *Dysphyma clavellatum*, *Wilsonia humilis* and *Poa poiformis*. It appears to be associated with seasonally waterlogged soils that lying over a saline water table.

Water management at Salt Swamp specifically involves:

- a saline water table that lies at or near the surface of the wetland bed;
- drying of the wetland bed in summer and autumn to maintain the dominance of *Wilsonia* spp. by curtailing the growth of aquatic plants and providing a recovery period for *Wilsonia* spp.; and
- flooding the wetland to the limit of the *Wilsonia* herbfield on an annual or biannual basis for 4 to 6 months to provide surface water and soil water and salinity requirements for *Wilsonia* spp. and to provide growing conditions for aquatic plants (e.g. *Ruppia maritima*). This will also create habitat, trigger breeding and allow for recruitment of macroinvertebrate and fish species.

Flooding of areas higher in the wetland are probably not essential to maintaining the vegetation communities of the wetland. However, they are tolerant of flooding and would tolerate the following water regime:

- flooding in the Sapphire shrubland for up to 2 months 1 year in 5; and
- flooding in the *Gahnia* sedgeland for up to 2 months 1 year in 10.

The flooding in the fringing shrubland and sedgelands for 1- 2 months every 3 years will enable extensive breeding events for fish species such as Common Jollytail, Blue-Spot Goby, Congolli, and Silverside.

4.9.5 Lake Connewarre including the estuarine sections of the lower River Channel

Lake Connewarre, the current active estuary of the Barwon, is characterised by dynamic changes in water levels and salinity – this variability is required to maintain the diverse fish and macroinvertebrate fauna.

The principles of the water regime to support the aquatic ecosystem and its habitat for Lake Connewarre are:

- Complete flushing during winter to maintain salinities at or below seawater;
- Spring flushes of freshwater from upstream to lower salinity and flood marginal zones of the lake to trigger fish breeding and recruitment;
- Low discharge in autumn to minimise flushing; and,
- Flows over the fishway at Lower Breakwater to enable fish movement along the lower Barwon.

Specifically, the following flow recommendations are made for the current active estuary:

- Late winter to early spring flushing flows

A flow of at least 600 ± 200 ML/day measured at McIntyres Bridge (Geelong) should be maintained for at least 3 months in late winter/early spring (between July and October) as a flushing flow to maintain freshwater conditions. This flow should occur at least once annually.

This estimate is based on a logarithmic relationship found between discharge and salinity in Lake Connewarre and on a hydrodynamic model developed for the lake (Sherwood *et al.* 1987)

- Summer/Autumn Low Flows

Salinity in Lake Connewarre should not exceed 35ppt during summer and autumn low flow conditions and this maximum level should not be maintained for more than 2 months. The minimum environmental flow needed to achieve this is 30 ± 10 ML/day at McIntyres Bridge

- Flow variability

Temporal variability in the input of freshwater flow is an inherent component of a functioning estuarine environment. Such variability, for example, results in variations in salinity that advantage euryhaline species adapted to highly variable salinity regimes. Loss of this variability has the potential to drastically alter community structure, with euryhaline estuary species replaced by stenohaline species adapted to either truly marine or freshwater environments. A minimum flow (Recommendation 2) will provide flows to ensure that a salinity gradient is maintained in the upper estuary. However, a minimum flow will not provide the variability required to maintain the estuarine ecological community. It is recommended, therefore, that the managed flow regime include periods of low flow (or cease to flow conditions) and freshes to mimic natural levels of flow variability. The frequency and timing of the recommended flows, and any independence rules related to meeting the recommendations, have not been specified here and will need to be formulated via further analysis of modelled flow data.

Flows less than the minimum flow established in Recommendation 2 (including cease to flow conditions) should be allowed to occur at their natural frequency and timing. The frequency and timing of these flows, and any independence rules relating to this recommendation, will need to be formulated via further analysis of modelled flow data.

Periods of higher flow should occur during summer and autumn at their natural frequency and timing to mimic natural freshes. The frequency and timing of these flows, and any independence rules relating to this recommendation, will need to be formulated via further analysis of modelled flow data.

- 4.5 Maintenance of Connectivity

The Upper and Lower Breakwaters (or Barrages) present barriers to fish migration in the Barwon River. Such barriers break the connectivity between the sea, estuary and river essential for the lifecycles of diadromous fish including galaxids, tupong, eels and, potentially, the threatened Australian grayling.

Fish passage should be provided to allow migration of diadromous species between freshwater and the estuary/sea.

5.1 Conclusions

Recommended and Current flows

The flow recommendations for the main stem of the Barwon River are largely met under current flow conditions. The effects of the West Barwon Dam upstream of this reach in the upper section of the first reach and may be evident in other reaches in terms of the high flows (bankfull and overbank flows) not being met in reaches 3 and 4. However, it is also clear that further reductions in frequency or duration of these flow events will lead to a decline of the values of the mainstem of the Barwon. The values at risk are geomorphological functions of flows (i.e. creation and maintenance of the form of the river channel and its habitats) and large breeding events the lack of which will limit the growth and population size and diversity of riparian vegetation, macroinvertebrates, and fish.

The flow recommendations for the tributaries of the Barwon are largely met by the current flow but Birregurra Creek and the Leigh River are subject to additional flows due to interbasin transfers or STP discharges. These additional discharges, in themselves, do not seem to have large adverse impacts but do create risks from additional saline or eutrophic conditions. These means that increases in the duration or frequency of cease to flows may provide additional threats to the values of these systems. High flows in these tributaries are generally only marginally met under the current flow regime. These flows and the ecological or geomorphological objectives they support are under risk with increasing catchment dam development or flow diversions.

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 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
- adherence 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.

5.2 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 environmental 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 (and reduce the risks) 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.

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