Melbourne Water

FLOW RECOMMENDATIONS

ENVIRONMENTAL FLOW DETERMINATION FOR THE TARAGO AND BUNYIP RIVERS



EarthTech

Environmental Flow Determination for the Tarago and Bunyip Rivers

FLOW RECOMMENDATIONS PAPER

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EarthTech

Environment Group

Earth Tech Engineering Pty Ltd
ABN 61 089 482 888
Head Office 71 Queens Road
Melbourne VIC 3004
Tel +61 3 8517 9200

The Bunyip and Tarago Rivers Environmental Water Requirements Technical Panel (the Technical Panel) consists of (in alphabetical order, with fields of expertise):

Nick Bond	Fish Ecology
Tim Doeg	Macroinvertebrate Ecology and Water Quality
James Kaye	Vegetation
Ross Hardie	Geomorphology
John Sherwood	Estuary
Geoff Vietz	Hydrology and Hydraulics

The project management team consists of:

Chris Arnott	Technical Reviewer and Advisory Group Facilitator
Lisa Roach	Project Manager
Lizzie Pope	Project Support

The Steering Committee for the project consists of:

Christine Hughes	Melbourne Water Project Manager
Phil Mitchell	Department of Sustainability and Environment
Lizzy Skinner	Melbourne Water
Roy White	Gippsland Water
Penny Winbanks	Southern Rural Water

The Community Advisory Group consists of:

Ian Anderson	Cardinia Branch – VFF
Sarah Canham	PPWCMW
Ron Chatfield	SRW Diverter
Alan Cole	Bunyip Landcare
Frank Crameri	Southern Rural Water
Syd Deam	Baw Baw Shire Council
Carolyn Ferguson	Baw Baw Shire Council
Rob Ferguson	Melbourne Water
Susanna Finger	EPA
Alister Harrison	SRW Diverter
Mike Haughton	Neerim District Landcare Group
Greg Holis	Department of Sustainability and Environment
Helen Mathieson	Tarago Water Monitoring Group
John Palmer	Jindivick Landcare
Paul Pearson	Department of Sustainability and Environment
David Rhode	Gippsland Water

Dan Robertson	CEC + Cannibal Creek Water Monitoring Group
Peter Ronalds	WCLN + Jindivick Water Monitoring Group
Frank Rouse	SRW Diverter
Tom Schreurs	SRW Diverter
Bruce Shenfield	Labertouche Landcare
Ian Stevenson	Cardinia Shire Council
Betty Tromp	Tarago Water Monitoring Group
Gerry Tymensen	SRW Diverter
Janene Vurlow	Cardinia Shire Council
Julie Weatherhead	Westernport Catchment Landcare Network
Dean White	Melbourne Water
Greg Young	Parks Victoria

Acronyms/Abbreviations:

BE	Bulk water Entitlements
CMA	Catchment Management Authority
DSE	Department of Sustainability and Environment
EVC	Ecological Vegetation Class
EWR	Environmental Water Requirements
FLOWS	The Victorian "Statewide Method for Determining Environmental Water Requirements"
ISC	Index of Stream Condition
LWD	Large Woody Debris
MW	Melbourne Water Corporation
SRW	Southern Rural Water
SWS	Port Phillip and Westernport Bay Regional Sustainable Water Strategy.
Technical Panel	The Bunyip and Tarago Rivers Environmental Water Requirements Technical Panel
VRHS	Victorian River Health Strategy

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Definitions:

Flow components used in this report and their descriptions are provided below together with a graphical representation of the components in Figure A.

Cease-to-flow	No discernible flow in the river, or no measurable flow recorded at a gauge.
Low Flow	Flow that generally provides a continuous flow through the channel.
Low Flow Freshes	Small and short duration peak flow events that exceed the baseflow (low flow) and last for at least several days. Usually in summer and autumn in Victoria.
High Flow	Persistent increases in the seasonal baseflow that remain within the channel.
High Flow Freshes	Small and short duration peak flow events that exceed the baseflow (high flow) and last for at least several days. Usually in winter and spring in Victoria.
Bankfull Flow	Completely fill the channel, with little flow spilling onto the floodplain.
Overbank flows	These flows are greater than bankfull and result in surface flow on the floodplain habitats.

Figure A: Flow components required to maintain a healthy ecosystem (DSE, 2006).

Executive Summary

Table A: Summary of Flow Recommendations

Reach	***Low Flow****	***Low Flow Fresh***	***High Flow***	***High Flow Fresh***	***Bankfull***	***Overbank***	***Channel Maintenance Flow***
1	>10ML/d – or natural (Dec-May)	35ML/d (5/yr, 4d – or natural)	35ML/d – or natural (Jun-Nov)	120ML/d (3/yr, 2d – or natural)	200ML/d (2/yr, 2d – or natural)	300ML/d (1/yr, 1d– or natural)	NS
2	>12ML/d – or natural (Dec-May)	100ML/d (5/yr, 4d– or natural) 200ML/d (1/yr, 1d– or natural)	100ML/d – or natural (Jun-Nov)	280ML/d (4/yr, 3d incl. 1 event in late Oct-Nov – or natural)	600ML/d (1/yr, 1d– or natural)	1000ML/d (1 in 2 years, 1d– or natural)	1000ML/d (1 in 2 years, 1d– or natural)
4	>10ML/d – or natural (Dec-May)	22ML/d (5/yr, 4d– or natural) 175ML/d (1/yr, 1d– or natural)	22ML/d – or natural (Jun-Nov)	70ML/d (4/yr, 3d including 1 in late Oct-Nov – or natural)	100ML/d (4/yr, 3d– or natural)	200ML/d (2/yr, 3d– or natural)	NS
6	50ML/d – or natural (Dec-May)	120ML/d (3/yr, 7d– or natural)	50ML/d – or natural (Jun-Nov) 70ML/d – or natural (Oct-Nov)	170ML/d (3/yr, 2d including 1 in Nov – or natural)	NS	NS	1500ML/d (1 in 2 years, 1d– or natural)

NS = not specified for this reach

The 'or natural' clause attached to the low flow and high flow recommendations indicate that flow is recommended to be equal to or above the value specified for that season except when flows ***naturally*** fall below that value. For the freshes and larger events, the 'or natural' clause refers to the frequency and duration of the event. That is, the event must occur for the duration and frequency specified unless the particular event would be ***naturally*** less frequent or of a shorter duration. In both cases, where the 'natural' clause is applied, the recommendation is met.

* **Note:** The development of low flow recommendations in sand bed streams using the current Victorian FLOWS methodology is currently under review by DSE. Refer discussion in section 2.5.1 of this report.

Contents

1. Introduction

Melbourne Water (MW) has engaged Earth Tech Engineering Pty Ltd (Earth Tech) to undertake an assessment of environmental flow requirements for the Bunyip and Tarago Rivers.

The environmental flow assessment is being undertaken in accordance with the FLOWS method – an established approach for the determination of environmental water requirements in Victoria (Figure 1-1) (DNRE, 2002a).

This paper is the final report that presents the flow recommendations for the Bunyip and Tarago Rivers arising from the Technical Panel Workshops held on the 23rd and 24th of October 2006. The workshops included all members of the Technical Panel and represented the fields of geomorphology, hydraulics, vegetation and macroinvertebrate and fish ecology.

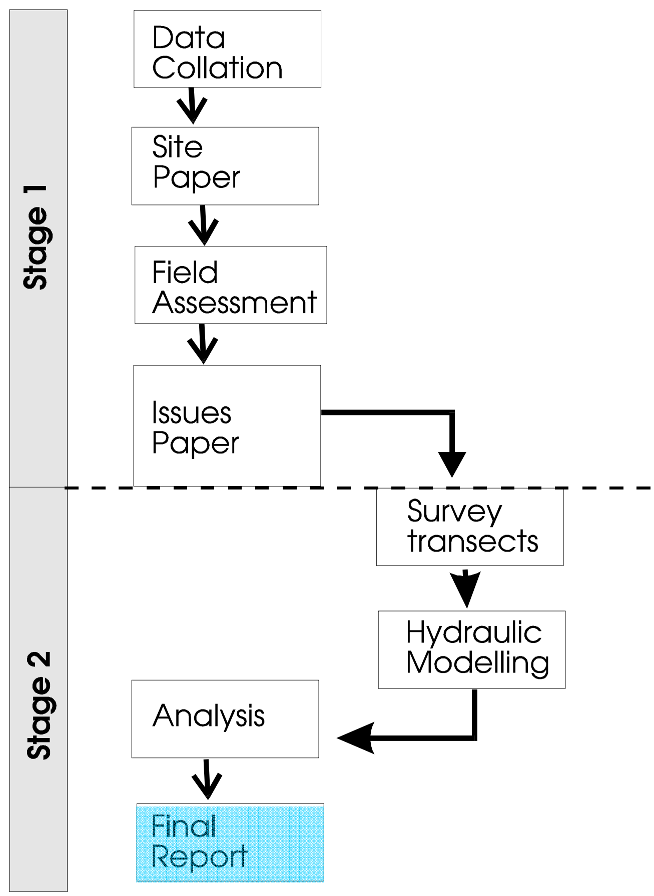


Figure 1-1: Outline of the steps in the FLOWS method (DNRE, 2002a)

The FLOWS method assists in the identification of critical flow components, as part of the total flow regime, to protect, sustain or restore specific flow dependent assets or values. The key elements of the flows process include:

- An objective setting process that links environmental objectives to flow objectives and recommendations
- The use of an environmental flows Technical Panel
- The use of hydrologic and hydraulic analysis tools in the interpretation and development of recommendations (DNRE, 2002).

The environmental flow assessment addresses the flow dependant issues within this catchment only and does not directly address non-flow related issues impacting on river health and management. These issues are addressed in part by existing Melbourne Water and Port Phillip CMA documents (i.e. River Health Strategy). The preparation of a River Health Program or modification to the existing Tarago Catchment Management Plan (Melbourne Water, 2003) is likely to be a key future activity for identification of specific management actions that may alleviate some of the river health issues peripheral to the flow stresses identified in this report.

The Recommendations Report has been developed following the production of a Site Paper and an Issues Paper and forms part of the FLOWS method. The Site Paper (Earth Tech, 2006b) provides background information on the Bunyip and Tarago Rivers including catchment descriptions, historic land use, water use, broad condition descriptions and recommended reaches for the investigations. Reach Visions, environmental objectives and the flow criteria to achieve them are set out in the Issues Paper (Earth Tech, 2006a). The environmental objectives have been developed in line with those set out in the Victorian River Health Strategy (DNRE, 2002b) and the Port Phillip and Westernport Regional River Health Strategy (Melbourne Water and Port Phillip and Westernport CMA, 2004). The Issues Paper is the culmination of literature reviews, anecdotal evidence, background knowledge and site visits by the Technical Panel and should be read in conjunction with this final report.

This Recommendations Report identifies the recommendations for environmental water requirements (EWR) for the Bunyip and Tarago Rivers. This report includes recommendations for reaches one, two, four and six only. Reach three (Labertouche Creek) and five (Cannibal Creek) have not proceeded beyond the objective setting stage. Flow gauges are not currently present within these reaches and provide no ability to validate the hydrologic data (derived from REALM modelling) for these reaches.

The scope for the report does not include analysis of impacts of the recommended flow regime or details of operational or infrastructure issues in relation to implementation of environmental water requirements. Recommendations from this report are to be analysed by the Department of Sustainability and Environment (DSE) to identify impacts of the recommendations on security of supply. The results of this analysis will be utilised to inform the negotiations for changes to the allocation of environmental water requirements in the current Bulk Entitlement (BE) process taking into account consumptive users within the system. For example, within the draft Port Phillip and Westernport Regional Sustainable Water Strategy (SWS) a 3,000ML increase to the current environmental flow allocation is proposed (DSE, 2006).

The format of this report is intended to provide clear linkages between identified river assets and processes, intended river health outcomes (vision and objectives) and flow recommendations to achieve these objectives.

1.1 OUTLINE OF THIS REPORT

Section 1 identifies the background to this project.

Section 2 of this report presents an outline of the method used in determining the EWR for this study

Section 3 defines the EWR recommendations for each reach. Each recommendation includes characteristics of the required flow events resulting from the hydrologic and hydraulic tools utilised and ecological justifications. The standard format for each reach includes four components:

- A summary of the reach condition (the major environmental issues in the reach);
- The environmental flow objectives for the reach;
- The flow processes and components linked to each environmental objective
- Summary tables of the recommendations.

Background information can be found in the Issues Paper.

Appendix A provides a more detailed discussion of the Bunyip River estuary (Reach 7) and the flow recommendations set for this reach.

This report seeks to link the vision and objective setting process with the final recommendations as presented in this report. The means in which this link is made is documented in Appendix B through a summary of all hydrologic or hydraulic measures used to develop the recommendations. Discussion notes arising through the recommendations workshops have also been included in this appendix where appropriate. Where possible, references to scientific or documented evidence has been provided. Recommendations for objectives that do not have references listed in this appendix have been developed based on the experience and knowledge of the Technical Panel.

2. Environmental Flow Analysis

2.1 SURVEYS OF SELECTED REACHES

Cross-sectional surveys for the representative reaches on the Tarago and Bunyip Rivers were undertaken by the Earth Tech surveying group using a Total Station and differential GPS. Transects were identified and pegged by the Technical Panel during the field inspection. Cross sections were chosen based upon the requirements of the hydraulic model e.g. constrictions and riffles and the ecological and geomorphologic points of interest e.g. deep pools and benches. Cross-sections were surveyed perpendicular to the flow with a greater density of points within the low flow channel where finer detail is required and fewer points on the floodplain (Figure 2-1). Between five and eleven cross sections were surveyed at the four sites, with the downstream section placed at a greater spacing and where possible, at a constriction to provide a hydraulic control to the computer model. Water levels were also surveyed for each section.

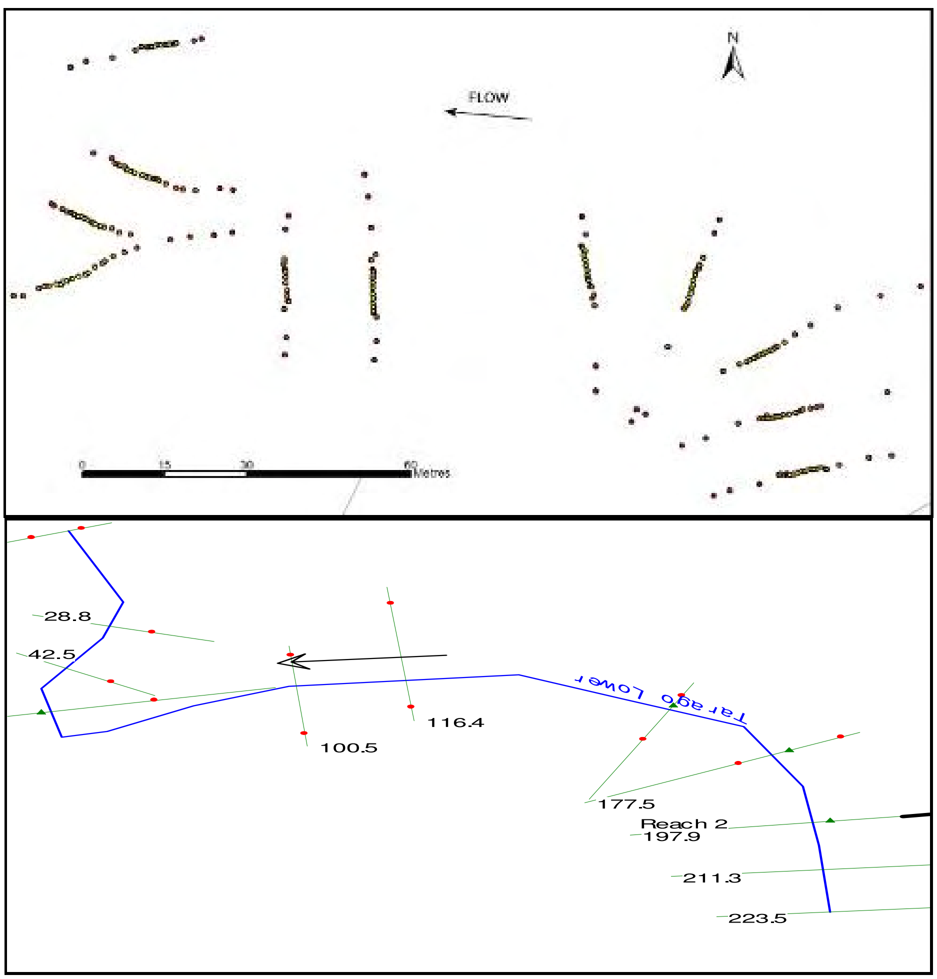


Figure 2-1: Surveyed points within a) ArcMap GIS and b) the resulting hydraulic model schematic (HEC RAS) for the site at Reach 2 Tarago River. Note: Values in figure b indicate the distance in metres of each cross section from the first.

2.2 HYDRAULIC MODELLING

Hydraulic modelling of the sites was undertaken using the one-dimensional steady state backwater analysis model HEC RAS version 3.1.3. This model was designed by the United States Army Corps of Engineers (USACE) and has been extensively used for environmental flow studies in Victoria and to a much greater extent for flood studies throughout the world. HEC RAS is well suited to the FLOWS assessment approach whereby channel morphology is related to discharge.

There are three key parametric inputs to HEC RAS: channel geometry, hydraulic roughness and a boundary condition. Channel geometry represents the topography of the channel and is provided by the survey data, the more reliable the survey data at each cross section the better the results in interpreting water levels for the site. *Channel roughness* is the most important interpretive component in the model and is provided by Manning's *n* (a measure of channel roughness). The appropriate Manning's *n* for each part of each cross-section was identified through observations of the reach by the modeller during the field inspection, and identification of variability in downstream roughness for each section from photographs taken during the inspection. The selection of appropriate Manning's values is based on the descriptive method for natural streams (Chow, 1959), and the experience of the hydraulic modeller. The boundary condition in the case of the sub-critical flows modelled for these reaches is applied to the downstream control section and provides the starting point for the backwater computations. The condition of 'normal depth' allows the modeller to identify a water slope downstream of the site. In this case the slope for the models was determined through a combination of channel slope throughout the surveyed reach (riffle to riffle thalweg level), the valley slope and the observed water levels.

Calibration of the model through known water surface elevations for a given flow assists in refining model parameters. Where a proximal stream gauge is present the known flow can be related to surveyed water levels and hydraulic roughness and the downstream boundary condition can be adjusted accordingly where appropriate. Topographic controls missed by the surveying can also be identified and adjusted with options such as ineffective flow areas and obstructions. Since surveyed water levels are generally identified during low discharges the benefit of calibration is greater for low flows in the vicinity of these discharges. Discharges for inspection and survey days were available for all sites except Reach 2 Upper Tarago River, in which the surveyed water levels were solely used to identify the water slope.

The key output from the modelling is a graphic presentation of each transect with accurate water levels related to discharge (Figure 2-2a). In these, the black line represents channel topography, with small black squares along this line identifying survey points (note that these are more frequent within the channel than further out). Horizontal blue lines within the cross-section represent the water surface at the various discharges (which are detailed in the legend). Long profiles can also be displayed (thalweg level plot), showing the maximum or minimum depths at each surveyed transect for the range of discharges (Figure 2-2b). Other than water levels the hydraulic models also allow for interpretation of important hydraulic parameters such as velocity and shear stress.

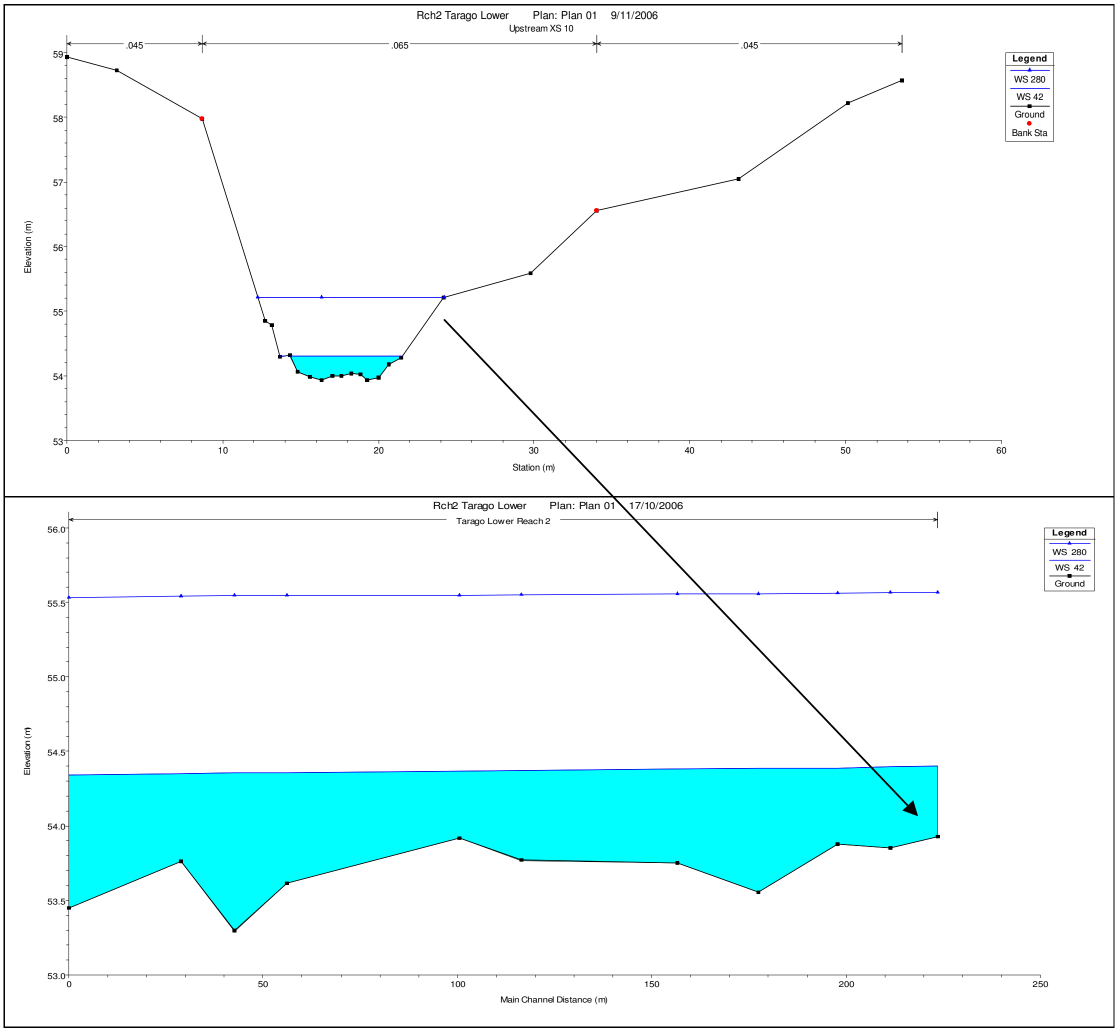


Figure 2-2: (a) Cross section and (b) longitudinal section displaying two flow levels.

2.3 HYDRAULIC MODEL SENSITIVITY ASSESSMENT

The representativeness of the sections in terms of site topography, and particularly reach topography, cannot be easily verified. However, the two types of modeling error that can be assessed are the selection of hydraulic roughness and boundary condition parameters. The sensitivity of the model (i.e. how wrong it can be?) to errors in parameter selection can be identified through a sensitivity analysis. In this analysis, the flow required to achieve the flow recommendations has been identified in scenarios where the model parameters are considerably greater and less than the calibrated value. This has been undertaken for the lowest recommended flow (low flow) and highest recommended flow (bankfull flow) for the mid-catchment site Reach 2 Lower Tarago River and the upland site Reach 4 Upper Bunyip River. The hydraulics for these sites was remodeled for a +/-25% change in the boundary conditions of roughness and downstream slope (a very significant difference). The upper limits are based on decreased roughness and increased slope (higher water levels) and the lower limits are based on a 25% change for increased roughness and decreased slope (lower water levels). The limits are the discharge required to obtain the same water level as the recommendation (Table 2-1). The water levels are identified at the most upstream cross section and as such the error in the selection of the roughness value has the most influence.

Table 2-1: Upper and lower error limits for a 25% change in boundary conditions for the recommended low flow and bankfull flow.

	Reach 2 Lower Tarago River	***Reach 4 Upper Bunyip River***
Recommended Low Flow	**12 ML/d**	**10 ML/d**
Upper Limit	16.4 ML/d (+37%)	13.0 ML/d (+30%)
Lower Limit	6.9 ML/d (-42%)	8.6 ML/d (-14%)
Recommended Bankfull Flow	**600 ML/d**	**100 ML/d**
Upper Limit	886 ML/d (+48%)	189 ML/d (+89%)
Lower Limit	453 ML/d (-25%)	68 ML/d (-22%)

The low flows in the model are most sensitive to topographic survey, not verified here, and as such often have a lower relative sensitivity to error with boundary conditions. Therefore, the lower limits of the sensitivity analysis for low flows, should only be used as a rough guide. There is however a significant change in flows for the bankfull flow in small channels where the roughness has a considerable impact. While a 25% error in boundary conditions (particularly roughness) should be outside the realm of an experienced hydraulic modeler this analysis serves to put extreme bounds on potential variability in flow recommendations extremes and identifies the importance of boundary conditions for higher flows. Conversely for low flows the level of detail and section placement is extremely important. The calibration of the model with observed water surface levels greatly improves the accuracy of parameter selection, particularly at the lower flows.

2.4 RATES OF RISE AND FALL

In addition to the standard components of each flow recommendation (magnitude, frequency, duration and timing) the rates of rise and fall of each recommendation are also important both ecologically and geomorphologically. This prevents unnaturally rapid fluctuations from occurring. The approach is to separate the rise and fall components (i.e. the proportion of flow from one day to the next) from the natural (un-impacted) flow record. For the Tarago and Bunyip Catchments the maximum rate of rise was selected as the 90th percentile of all rates of natural rise and the rate of fall was selected as the 10th percentile of all the fall rates, Table 2-2.

The rationale for the percentiles is that while a rapid rate of rise was not seen as a significant concern (the 90th percentile is a significantly high rate) the allowable rate of fall is critical to prevent ecological concerns such as stranding of fish or geomorphic concerns such as bank slumping by surcharging.

Table 2-2: Recommended maximum rates of rise and fall (expressed as a proportion of the previous days flow) for all reaches of the Tarago and Bunyip Reaches.

Reach/Site	*Maximum rate of rise (proportion of previous day)*	*Maximum rate of fall (proportion of previous day)*
Reach 1 **Tarago River at Neerim**	1.68	0.74
Reach 2 **Tarago River at Drouin West**	1.77	0.72
Reach 4 **Bunyip River at Tonimbuk**	2.00	0.71
Reach 6 **Bunyip River at Iona**	1.56	0.75

2.5 PROJECT LIMITATIONS

The FLOWS method is based on the adoption of a minimum justifiable flow necessary to maintain identified environmental assets and processes. For flow stressed systems, this approach provides a cost effective low risk outcome for the environment with any recovery of water being a positive environmental outcome.

However environmental flow recommendations have greater risk for an intact system than for a flow stressed system. For intact systems the flow regime can only be either maintained or degraded. The standard FLOWS approach may not be commensurate with the inherent risks to the environment for intact systems. Failure to identify a key asset or process, or failure to correctly identify a flow relationship in an intact system, has potential to result in lower than required environmental flow recommendations and the loss of some unidentified or poorly described values.

While the Bunyip catchment has some level of extraction for consumptive purposes, the upper sections of the Tarago (Reach 1) and Bunyip (Reach 4) rivers have essentially intact flow regimes. To provide consistency with other environmental flow investigations, and in accordance with the project brief, the environmental flow assessment has been undertaken in the upper Bunyip/Tarago catchments using the FLOWS method.

2.5.1 Sand Bed Streams

A potential issue with using the FLOWS methodology to set environmental flow recommendations in sand bed streams such as the Bunyip and Tarago Rivers is the dynamic nature of the bed forms in these systems.

The hydraulic model (HECRAS) used in the process of determining flows is not dynamic and thus presumes a static bed morphology in predicting depths, velocities and other hydraulic parameters. In contrast, the empirical experience in sand bed streams shows that this assumption is not valid even at very low flows due to the high mobility of sand.

The survey taken for a FLOWS study ultimately represents a single snap shot in time. The Bunyip-Tarago survey was undertaken during the winter period, immediately following a fresh. It is possible that survey undertaken at the same locations during the low flow period flow would produce very different low flow recommendations. For example, many of the low flow recommendations are controlled by a minimum depth in pools to sustain fish populations. These pools may be deeper in the winter period than in the summer period due to natural in-filling of the pools during low flows. As such, greater flow recommendations may be developed from modelling using summer survey than that produced from a winter survey. **Without access to information on pool structure in summer, the current low flow recommendations are developed with a low confidence and should be adopted with caution.**

Historic data shows that extreme low flows can lead to rapid loss of geomorphic complexity in sand bed streams. For this reason it is important that low flows in sand bed streams, in the low flow period, will meet ecological objectives. For the reasons discussed above, i.e. the assumption of a static bed form and sub-surface flow, the hydraulic model and survey used within this study may not adequately calculate the low flow required. In correspondence provided to the steering committee as part of this study, it is acknowledged that DSE are aware of these limitations to the FLOWS method and are currently planning to update the FLOWS framework at the state-wide level. **Therefore, we strongly suggest the development of an interim passing flow until the updated methodology can be applied to the Bunyip and Tarago Rivers.**

3. Reach Recommendations

The flow recommendations for each reach are presented below in a standard format with four individual sections:

- **A Summary of the Reach Condition.** These are a very brief summary of the hydrology, water quality, geomorphology, macroinvertebrate, fish and vegetation condition in the reach. These are taken from information presented in the Issues Paper;
- **The Environmental Flow Objectives.** For each reach, the objectives that apply to that reach are presented;
- **Flow Processes and Components.** For each reach, the objectives are linked to the flow processes and flow components required to meet the objective;
- **Summary Tables.** The recommendations are presented in a standard table format as used in the FLOWS method. In this table, a controlling criteria is identified. This criteria is the objective/s that produce the greatest flow requirement for each flow component. All other objectives related to the flow component (as listed in the column titled 'Objectives') are also met in setting the recommended flow.

Note: Flow recommendations for *Reach 7 – Bunyip River Estuary* have been developed based on the expert opinion of Associate Professor John Sherwood, School of Life and Environmental Sciences, Deakin University. Following the development of a specific 'FLOWS method for estuaries', these recommendations may need to be reviewed.

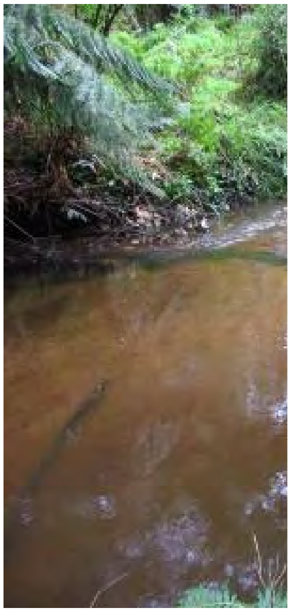
The recommended flows for each reach are to be measured at the compliance point specified for each reach. In some cases, the flow recommendation in the upper reaches is higher, than that in the lower reaches. It is not the intention of a reach recommendation to be carried over to another reach. Recommendations should therefore be read and applied in isolation to each other. For example, the high flow recommendation for Reach 2 is 100ML/day while the recommendation for Reach 6 is up to 70ML/day. This means that Reach 6 does not require flow in excess of 70ML/day to achieve all of it's environmental objectives.

3.1 REACH ONE – UPPER TARAGO RIVER

Reach 1 extends from Pederson Weir to the Tarago Reservoir. The catchment is characterised by an almost continuous cover of native vegetation with the exception of a small pocket of agricultural land use along the East Branch of the Tarago River.

Apart from the potential to over-extract water from Pederson Weir and the Tarago Diversion Weir, key degrading factors in the reach are sedimentation due to forestry activity and recreational access and possibly interactions between introduced trout and small native fish such as the mountain galaxias.

Summary of Reach Condition



In the upper section of the reach, the river is confined by forested hills. Bedrock was observed in the stream bed and banks. Further downstream the river is partly confined to unconfined, meandering within the Quaternary alluvial material. The vegetation at the site is largely intact, providing high levels of instream timber. Aquatic life scores for upper Tarago River indicate excellent or near reference condition. River Blackfish and mountain galaxias are the only two native species that occur in reasonable numbers in the upper reaches of the Tarago River. There are also several introduced species present. Seasonality in this reach has been well preserved but there is a general reduction in flow, particularly in the low flows.

The 2004 Index of Stream Condition (ISC) assessment, on the upper Tarago River found this reach to be in moderate condition with generally good to excellent scores for Aquatic Life, Water Quality and Physical Form.[*]

Key Values

- Excellent condition macroinvertebrate community
- Good instream habitat diversity
- River Blackfish and Mountain Galaxias
- High quality riparian vegetation

Reach Vision

An ecologically healthy river that supports a diverse and self-sustaining non-migratory fish community, a reference condition macroinvertebrate community and a complete range of intact native riparian vegetation species.

[*] Errors have been noted within the 2004 ISC Scores for Streamside zone in the Bunyip catchment and actual stream condition may be higher than that indicated (www.vicwaterdata.net).

Environmental Objectives

Macroinvertebrates - Maintain excellent condition macroinvertebrate community (Aquatic Life Score 9-10).

Physical Form - Maintain the high level of instream habitat diversity by maintaining the occurrence and duration of events that have the potential to mobilise the sand bed and initiate scour.

Water Quality - Maintain water quality to meet environmental objectives.

Fish - Maintain self sustaining populations of Blackfish and Mountain Galaxias.

Vegetation - Maintain high quality riparian vegetation.

Table 3-1: Flow Processes and Components – Reach One

Asset	*Environmental Objective*	*No.*	*Flow Process/Function*	*Flow Component*	*Timing*	*Expected Response*
Macroinvertebrates and water quality	Maintain excellent condition macroinvertebrate community.	1-M1	Bed habitat availability	Low Flow	Low Flow Season	Provision of habitat to wide diversity of macroinvertebrate types
		1-M2		High Flow	High Flow Season	
		1-M3	Edge habitat availability	Low Flow	All year	
		1-M4	Water quality maintenance	Low Flow	All year	Re-oxygenation of water and flushing of nutrients out of pools
		1-M5	Refresh water quality and flush habitat	Low Flow Fresh	Low Flow Season	Re-oxygenation of water, introduction of carbon and nutrients Scour and regeneration of macroinvertebrate community
		1-M6	Habitat maintenance	Low Flow Fresh	Low Flow Season	Removal of sediments and biofilm from woody debris to enhance habitat value of LWD.
		1-M7		High Flow Fresh	High Flow Season	
		1-M8	Movement of bed material to maintain bed diversity	High Flow Fresh	High Flow Season	Mobilisation of sand to maintain and create a diversity of habitats
		1-M9	Entrain terrestrial carbon to the stream	High Flow Fresh	High Flow Season	Provision of food source to macroinvertebrate community
		1-M10		Overbank Flow	High Flow Season	
Physical Form	Maintain in-stream habitat diversity	1-P1	Remove silt from timber	Low Flow	Low Flow Season	Removal of sediments and biofilm from woody debris to enhance habitat value of LWD.
		1-P2	Scour hole formation under and around large wood.	High flow fresh	High flow season	Establishment and maintenance of scour holes to create a diversity of habitats.
		1-P3	Scour hole formation in bed at location of meander bends	Bankfull	Anytime	
		1-P4	Scour hole creation	Low Flow Fresh	Low Flow Season	

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Fish	Maintain self sustaining populations of river blackfish and mountain galaxias.	1-F1	Habitat availability for River Blackfish	Low Flow	All Year	Provision of deep pools suitable for cover protection from birds of prey and overheating of pools in summer
		1-F2	Habitat availability for Mountain Galaxias	Low Flow	All Year	Provision of pool with adequate depth to support fish species
		1-F3	Habitat maintenance	Low Flow Fresh	Low Flow Season	Maintenance of pool habitat, undercut banks, riffles and debris accumulations
		1-F4	Localised movement of resident fish	Low Flow Fresh	Low flow Season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		1-F5	Localised movement of resident fish	High Flow	High Flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		1-F6	Inundate marginal habitats for juvenile fish	High Flow	Late high flow season	Creation of habitat necessary for successful recruitment of resident species
		1-F7	Habitat maintenance	High Flow Fresh	High Flow Season	Maintenance of pool habitat, undercut banks, riffles and large debris accumulations

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Vegetation	Maintain high quality riparian vegetation.	1-V1	Habitat inundation – variability to provide zonation	High Flow Fresh	Any Time (with natural rate of rise and fall)	Successful establishment and reproduction of a range of riparian species throughout the riparian zone
		1-V2		Bankfull		
		1-V3	Habitat inundation – provision of moisture to benches	High Flow	High Flow Season	
		1-V4	Habitat inundation – provision of moisture to floodplain	Overbank	High Flow Season	
		1-V5	Prolonged inundation of bank, bench and bars to disadvantage terrestrial species	High Flow	High Flow Season	Prevention of vegetation encroachment in riparian zone
		1-V6	Riparian disturbance and propagule distribution	Overbank	Any Time	Successful recruitment of riparian species
		1-V7	Habitat inundation/regeneration – provision of moisture and sediment to benches	High Flow Fresh	Anytime	Continued sediment supply to benches to maintain good habitat for riparian vegetation
		1-V8	Maintain aquatic vegetation in channel	Low Flow	Low Flow Season	Healthy populations of in-stream vegetation
		1-V9	Prevent encroachment on vegetated bar	Low Flow Fresh	Low Flow Season	Disturbance of vegetation species living on in-stream bars to prevent overcrowding

3.1.1 Reach One Summary Recommendations

Table 3-2: Flow recommendations for Reach 1 – Upper Tarago River

Compliance Point – Tarago River @ Neerim				***Gauge Number - 228206***	
Flow				***Rationale***	
Period	***Magnitude***	***Frequency***	***Duration***	***Objectives***	***Controlling Criteria & Discussion***
Dec-May	Low Flow* >10 ML/day (or natural)	Continuous	Continuous	1-M1, 1-M3, 1-M4, 1-P1, **1-F1**, 1-F2, 1-V8.	Habitat availability (River Blackfish) – Depth availability and sufficient area
Dec-May	Low Flow Fresh 35 ML/day	5/season (or natural)	4 days (or natural)	1-M5, 1-M6, 1-P4, 1-F3, 1-F4, **1-V9**	Inundation of vegetated bar – prevent vegetation encroachment into the stream
Jun-Nov	High Flow 35 ML/day (or natural)	Continuous	Continuous	1-M2, 1-F5, 1-F6, **1-V3**, **1-V5**	Inundation of banks, benches and bars to disadvantage terrestrial species
Jun-Nov	High Flow Fresh 120 ML/day	3/season (or natural)	2 days (or natural)	1-M7, 1-M8, 1-M9, 1-P2, 1-F7, **1-V1**, 1-V7	Water to reach lowest top of bank for all cross sections – prevent encroachment of terrestrial vegetation and maintain flood tolerant species
Anytime	Bankfull/ Channel-full ≥ 200 ML/day	2/yr (or natural)	2 days (or natural)	1-P3, **1-V2**	Water level to reach top of bank – encourage flood tolerant vegetation
Anytime	Overbank ≥ 300 ML/day	1/yr (or natural)	1 day (or natural)	1-V4, **1-V6**	Water to reach top of both banks (floodplain) – to inundate floodplain habitats and relocate propagules or create re-generation niches

Notes:

- 7 day independence is recommended between events.
- Flow recommendations for each flow component do not have to be discrete. For example an overbank event recommended once every two years will also satisfy the requirement for a bankfull event and one of the high flow freshes.
- The controlling criteria relates to the objective that requires the highest flow to be achieved. These are shown in bold.
- The 'or natural' clause attached to the low flow and high flow recommendations indicate that flow is recommended to be equal to or above the value specified for that season except when flows ***naturally*** fall below that value. For the freshes and larger events, the 'or natural' clause refers to the frequency and duration of the event. That is, the event must occur for the duration and frequency specified unless the particular event would be ***naturally*** less frequent or of a shorter duration. In both cases, where the 'natural' clause is applied, the recommendation is met.

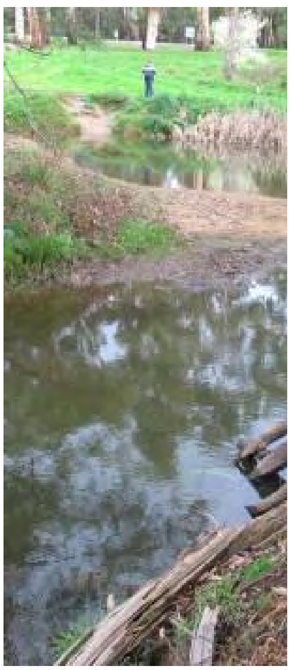
* The development of low flow recommendations in sand bed streams using the current Victorian FLOWS methodology is currently under review by DSE. Refer discussion in section 2.5.1 of this report.

3.2 REACH TWO – LOWER TARAGO RIVER

Reach 2 encompasses the Tarago River from below the reservoir down to the confluence with the Bunyip River. The riparian zone of this reach is highly modified. Land use in the reach is primarily agricultural (dairy and cattle).

Apart from the hydrological impacts from Tarago Reservoir, the key external degrading factors in the reach are the poor riparian vegetation quality, poor water quality from agricultural and urban run-off, and cattle access to the stream. These result in high rates of fine sediment deposition in and on the streambed which affects habitat, food availability and egg mortality of native fish. Introduced brown trout may also be having a negative impact on some smaller bodied native species.

Summary of Reach Condition



Under current levels of use, flow seasonality in this reach has been preserved but is significantly impacted by Tarago Reservoir releases in the upper section of the reach. Vegetation within this reach below the Reservoir has been highly disturbed and much of the riparian zone has been cleared for agriculture. The Tarago River, at the selected survey site, is a single channel, unconfined, meandering, alluvial stream located within an extensive adjoining floodplain. The cross section contains some instream bars and benches. Aquatic Life score for both the mid and lower Tarago River (to June 2004) indicate excellent or reference condition. The lower Tarago River currently supports a high diversity of native fish, including the Australian Grayling which is listed as threatened under the Flora and Fauna Guarantee Act.

The 2004 ISC assessment, on the lower Tarago River found this reach to be in very poor condition, although with an excellent score for Aquatic Life and a moderate score for physical form.

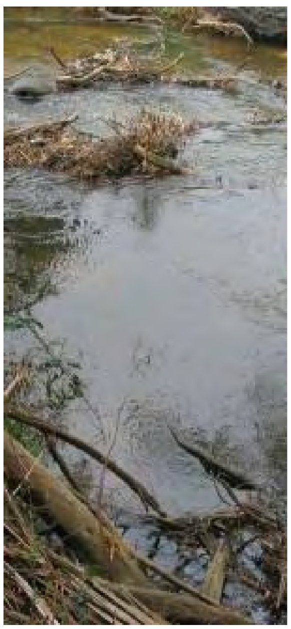
Key Values

- Excellent condition macroinvertebrate community
- Migratory fish species including Australian Grayling
- Non-migratory fish species including River Blackfish
- Patches of remnant riparian vegetation

Reach Vision

An ecologically healthy river that supports the full suite of migratory and non-migratory fish species, a diverse and reference condition macroinvertebrate community, a restored riparian strip with natural species diversity and structure, and a diverse range of geomorphic processes that increase the range of ecological habitat and prevent channel aggradation.

Environmental Objectives



Physical Form - Restore the occurrence and duration of events that have the potential to modify channel form.

No increase in the occurrence of events that have the potential to initiate instabilities in the system that trigger gross channel change.

Macroinvertebrates - Maintain excellent condition macroinvertebrate community (Aquatic Life Score 9-10).

Water Quality - Maintain water quality to meet environmental objectives.

Fish - Maintain the full suite of native migratory and non-migratory fish species, and increase the abundance of native fish within the reach.

Vegetation - Maintain the health of remnant riparian vegetation and provide flow conditions to encourage diverse riparian regeneration.

Table 3-3: Flow Processes and Components – Reach Two

Asset	*Environmental Objective*	*No.*	*Flow Process/Function*	*Flow Component*	*Timing*	*Expected Response*
Macroinvertebrates and water quality	Maintain excellent condition macroinvertebrate community.	2-M1	Bed habitat availability	Low Flow	Low Flow Season	Provision of habitat to wide diversity of macroinvertebrate types
		2-M2		High Flow	High Flow Season	
		2-M3	Edge habitat availability	Low Flow	All year	
		2-M4	Water quality maintenance	Low Flow	All year	Re-oxygenation of water and flushing of nutrients out of pools
		2-M5	Refresh water quality and flush habitat	Low Flow Fresh	Low Flow Season	Re-oxygenation of water, introduction of carbon and nutrients; Scour & regeneration of macroinvertebrate community
		2-M6	Habitat maintenance	Low Flow Fresh	Low Flow Season	Removal of sediments and biofilm from woody debris to enhance habitat value of LWD.
		2-M7		High Flow Fresh	High Flow Season	
		2-M8	Movement of bed material to maintain bed diversity	High Flow Fresh	High Flow Season	Mobilisation of sand to maintain and create a diversity of habitats
		2-M9	Entrain terrestrial carbon to the stream	High Flow Fresh	High Flow Season	Provision of food source to macroinvertebrate community
Physical Form	Restore in-stream habitat diversity.	2-P1	Remove silt from timber	Low Flow	Low Flow Season	Removal of sediments and biofilm from woody debris to enhance habitat value of LWD.
		2-P2	Scour hole formation under and around large wood.	High flow fresh	High flow season	Establishment and maintenance of scour holes to create a diversity of habitats.
		2-P3	Scour hole formation in bed at location of meander bends	Bankfull	Anytime	
	Prevent gross channel change.	2-P4	Prevent gross channel change	Channel Maintenance	Anytime	Prevention of significant erosion of the bed and banks
		2-P5	Scour hole creation	Low Flow Fresh	Low Flow Season	Establishment and maintenance of scour holes to create a diversity of habitats.

Asset	***Environmental Objective***	***No.***	***Flow Process/Function***	***Flow Component***	***Timing***	***Expected Response***
Fish	Maintain the full suite of native migratory and non-migratory fish species, and increase the abundance of native fish within the reach.	2-F1	Habitat availability for River Blackfish	Low Flow	All Year	Provision of deep pools suitable for cover protection from birds of prey and overheating of pools in summer
		2-F2	Habitat availability for Australian Grayling	Low Flow	All Year	
		2-F3	Habitat availability for small-bodied fish	Low Flow	All Year	Provision of pool with adequate depth to support fish species
		2-F4	Habitat Maintenance	Low Flow Fresh	Low Flow Season	Maintenance of fish habitat
		2-F5	Localised movement of resident fish	Low Flow Fresh	Low flow Season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		2-F6	Spawning trigger & downstream dispersal of Australian Grayling larvae	Low Flow Fresh	April-May	Successful reproduction of Australian Grayling
		2-F7	Localised movement of resident fish	High Flow	High Flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		2-F8	Inundate marginal habitats for juvenile fish	High Flow	Late high flow season	Creation of habitat necessary for successful recruitment of resident species
		2-F9	Habitat maintenance	High Flow Fresh	High Flow Season	Maintenance of fish habitat
		2-F10	Upstream migration trigger for Australian Grayling	High Flow Fresh	October-November	Successful reproduction of Australian Grayling
		2-F11	Upstream migration of Australian Grayling from estuary to the river	High Flow	October-November	Successful reproduction of Australian Grayling
		2-F12	Upstream migration of small bodied migratory fish	High Flow	October-November	Successful reproduction of small bodied migratory fish populations

Asset	***Environmental Objective***	***No.***	***Flow Process/Function***	***Flow Component***	***Timing***	***Expected Response***
Vegetation	Maintain the health of remnant riparian vegetation and provide flow conditions to encourage diverse riparian regeneration.	2-V1	Habitat inundation – variability to provide zonation	High Flow Fresh	Any Time (with natural rate of rise and fall)	Successful establishment and reproduction of a range of riparian species throughout the riparian zone
		2-V2		Bankfull		
		2-V3	Habitat inundation – provision of moisture to benches	High Flow	High Flow Season	
		2-V4	Habitat inundation – provision of moisture to floodplain	Overbank	High Flow Season	
		2-V5	Prolonged inundation of bank, bench and bars to disadvantage terrestrial species	High Flow	High Flow Season	Prevention of vegetation encroachment in riparian zone
		2-V6	Riparian disturbance and propagule distribution	High Flow	Any Time	Successful recruitment of riparian species
		2-V7		Bankfull	High flow season	
		2-V8	Habitat inundation/regeneration – provision of moisture and sediment to benches	High Flow Fresh	Anytime	Continued sediment supply to benches to maintain good habitat for riparian vegetation
		1-V9	Maintain aquatic vegetation in channel	Low Flow	Low flow season	Healthy populations of in-stream vegetation
		1-V10	Prevent encroachment of vegetation to sand bars	Low flow fresh	Low flow season	Disturbance of vegetation species living on in-stream bars to prevent overcrowding

3.2.1 Reach Two Summary Recommendations

Table 3-4: Flow recommendations for Reach 2 – Lower Tarago River

Compliance Point – Tarago River @ Drouin West				***Gauge Number - 228201***	
Flow				***Rationale***	
Period	***Magnitude***	***Frequency***	***Duration***	***Objectives***	***Controlling Criteria & Discussion***
Dec-May	Low Flow* >12 ML/day (or natural)	Continuous	Continuous	2-M1, 2-M3, 2-M4, 2-P1, **2-F1, 2-F2**, 2-F3 2-V9.	Habitat availability (River Blackfish and Grayling) – Depth availability and sufficient area
Dec-May	Low Flow Fresh 100 ML/day	5/season (or natural)	4 days (or natural)	2-M5, 2-M6, 2-P5, 2-F4, 2-F5, **2-V10**	Inundation of sand bars – prevent vegetation encroachment onto bars
April-May	Low Flow Fresh 200 ML/day	1/season (or natural)	1 day	**2-F6**	Trigger Grayling spawning and transport larvae from spawning habitat to the estuary
Jun-Nov	High Flow 100 ML/day (or natural)	Continuous	Continuous	2-M2, 2-F7, 2-F8, 2-F11, 2-F12, **2-V3, 2-V5,** 2-V6	Inundation of banks, benches and bars to disadvantage terrestrial species
Jun-Nov	High Flow Fresh 280 ML/day	4/season (or natural)	3 days (or natural)	2-M7, 2-M8, 2-M9, 2-P2, 2-F9; 2-F10, **2-V1, 2-V8**	Water to reach lowest top of bank for all cross sections – prevent encroachment of terrestrial vegetation, maintain flood tolerant species and resuspend and distribute sediments
Late Oct-Nov		1/season (or natural)	1 day (or natural)	**2-F10**	Trigger Grayling movement from the estuary to the upper reaches
Anytime	Bankfull/ Channel-full 600 ML/day	1/yr (or natural)	1 day (or natural)	2-P3, **2-V2, 2-V7**	Water to reach top of bank for most cross-sections to wet bank profile, encourage flood tolerant species, and resuspend and distribute sediments
Anytime	Overbank 1000 ML/day	1 in 2 years (or natural)	1 day (or natural)	**2-V4**	Water to reach top of both banks (floodplain) – to inundate floodplain habitats
Anytime	Channel Maintenance 1000 ML/day	1 in 2 years (or natural)	1 day (or natural)	**2-P4**	Prevent gross channel change including erosion of the bed and banks

Notes:

- 7 day independence is recommended between events.

* The development of low flow recommendations in sand bed streams using the current Victorian FLOWS methodology is currently under review by DSE. Refer discussion in section 2.5.1 of this report.

- Flow recommendations for each flow component do not have to be discrete. For example an overbank event recommended once every two years will also satisfy the requirement for a bankfull event and one of the high flow freshes.
- The controlling criteria relates to the objective that requires the highest flow to be achieved. These are shown in bold.
- The 'or natural' clause attached to the low flow and high flow recommendations indicate that flow is recommended to be equal to or above the value specified for that season except when flows ***naturally*** fall below that value. For the freshes and larger events, the 'or natural' clause refers to the frequency and duration of the event. That is, the event must occur for the duration and frequency specified unless the particular event would be ***naturally*** less frequent or of a shorter duration. In both cases, where the 'natural' clause is applied, the recommendation is met.

3.3 REACH FOUR – UPPER BUNYIP RIVER

Reach 4 encompasses the Bunyip River from the Bunyip Diversion weir to the Tarago River confluence. The upper section of the reach runs through the Bunyip State Forest and is characterised by an intact riparian zone with a diverse range of vegetation types. The lower section of the reach contains a modified riparian zone. Land use below the State Forest is primarily agricultural (dairy and cattle).

Apart from the hydrological impacts from Bunyip Weir, the key external degrading factors in the reach are the poor riparian vegetation quality in the lower catchment, poor water quality from agricultural run-off, and cattle access to the stream. In addition several of the introduced fish species in the reach (Brown Trout, Rainbow Trout and Eastern Gambusia) may be having negative impacts on some smaller bodied native species.

Summary of Reach Condition

The flow gauge at this site reveals the preservation of seasonality but some considerable impacts on flow from water diversion. There is a general reduction throughout the range of flows for all seasons. The subject site is a single channel, meandering, alluvial reach within a partly confined valley setting. The vegetation at the site is largely intact, providing high levels of instream timber. Instream channel diversity is dominated by timber and scour associated with timber and meander bends. Aquatic Life score for both the mid and lower Bunyip River indicates excellent or reference condition and the river supports a high diversity of native fish, including two species (Australian Grayling and Dwarf Galaxias) listed as threatened under the Flora and Fauna Guarantee Act.

The 2004 ISC assessments, on Back Creek and the Middle Bunyip River, found these sections to be in moderate condition, while the section on Diamond Creek was rated as good. All reaches had excellent scores for Aquatic Life.

Key Values

- Excellent condition macroinvertebrate community
- Good instream habitat diversity
- Migratory fish species
- Non-migratory fish species including River Blackfish
- High quality riparian vegetation

Reach Vision

An ecological healthy river with geomorphic diversity, that supports a healthy and diverse vegetation community providing habitat connectivity to support the helmeted honey eater, the full suite of migratory and non-migratory fish species, and a reference condition macroinvertebrate community.

Environmental Objectives

Physical Form - Maintain the high level of instream habitat diversity by maintaining the occurrence and duration of events that have the potential to mobilise the sand bed and initiate scour.

Macroinvertebrates - Maintain an excellent condition macroinvertebrate community (Aquatic Life Score 9-10).

Water Quality - Maintain water quality to meet environmental objectives.

Fish - Maintain the full suite of native migratory and non-migratory fish species, and increase the abundance of native fish within the reach.

Vegetation - Provide flows to prevent the decline in riparian condition and contraction of the riparian zone.

Table 3-5: Flow Processes and Components – Reach Four

Asset	*Environmental Objective*	*No.*	*Flow Process/Function*	*Flow Component*	*Timing*	*Expected Response*
Macroinvertebrates and water quality	Maintain excellent condition macroinvertebrate community.	4-M1	Bed habitat availability	Low Flow	Low Flow Season	Provision of habitat to wide diversity of macroinvertebrate types
		4-M2		High Flow	High Flow Season	
		4-M3	Edge habitat availability	Low Flow	All year	
		4-M4	Water quality maintenance	Low Flow	All year	Re-oxygenation of water and flushing of nutrients out of pools
		4-M5	Refresh water quality and flush habitat	Low Flow Fresh	Low Flow Season	Re-oxygenation of water, introduction of carbon and nutrients Scour and regeneration of macroinvertebrate community
		4-M6	Habitat maintenance	Low Flow Fresh	Low Flow Season	Removal of sediments and biofilm from woody debris to enhance habitat value of LWD.
		4-M7		High Flow Fresh	High Flow Season	
		4-M8	Movement of bed material to maintain bed diversity	High Flow Fresh	High Flow Season	Mobilisation of sand to maintain and create a diversity of habitats
		4-M9	Entrain terrestrial carbon to the stream	High Flow Fresh	High Flow Season	Provision of food source to macroinvertebrate community
		4-M10		Overbank Flow	High Flow Season	
Physical Form	Maintain in-stream habitat diversity.	4-P1	Remove silt from timber	Low Flow	Low Flow Season	Removal of sediments and biofilm from woody debris to enhance habitat value of LWD.
		4-P2	Scour hole formation under and around large wood.	High flow fresh	High flow season	Establishment and maintenance of scour holes to create a diversity of habitats.
		4-P3	Scour hole formation in bed at location of meander bends	Bankfull	Anytime	
		4-P4	Scour hole creation	Low Flow Fresh	Low Flow Season	

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Fish	Maintain the full suite of native migratory and non-migratory fish species, and increase the abundance of native fish within the reach.	4-F1	Habitat availability for River Blackfish	Low Flow	All Year	Provision of deep pools suitable for cover protection from birds of prey and overheating of pools in summer
		4-F2	Habitat availability for Australian Grayling	Low Flow	All Year	
		4-F3	Habitat availability for small-bodied fish	Low Flow	All Year	Provision of pool with adequate depth to support fish species
		4-F4	Habitat Maintenance	Low Flow Fresh	Low Flow Season	Maintenance of fish habitat
		4-F5	Localised movement of resident fish	Low Flow Fresh	Low flow Season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		4-F6	Spawning trigger & downstream dispersal of Australian Grayling larvae	Low Flow Fresh	April-May	Successful reproduction of Australian Grayling
		4-F7	Localised movement of resident fish	High Flow	High Flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		4-F8	Inundate marginal habitats for juvenile fish	High Flow	Late high flow season	Creation of habitat necessary for successful recruitment of resident species
		4-F9	Habitat maintenance	High Flow Fresh	High Flow Season	Maintenance of fish habitat
		4-F10	Upstream migration trigger for Australian Grayling	High Flow Fresh	October-November	Successful reproduction of Australian Grayling
		4-F11	Upstream migration of Australian Grayling from estuary to the river	High Flow	October-November	Successful reproduction of Australian Grayling
		4-F12	Upstream migration of small bodied migratory fish	High Flow	October-November	Successful reproduction of small bodied migratory fish populations

Asset	***Environmental Objective***	***No.***	***Flow Process/Function***	***Flow Component***	***Timing***	***Expected Response***
Vegetation	Provide flows to prevent the decline in riparian condition and contraction of the riparian zone.	4-V1	Habitat inundation – variability to provide zonation	High Flow Fresh	Any Time (with natural rate of rise and fall)	Successful establishment and reproduction of a range of riparian species throughout the riparian zone
		4-V2		Bankfull		
		4-V3	Habitat inundation – provision of moisture to benches	High Flow	High Flow Season	
		4-V4	Habitat inundation – provision of moisture to floodplain	Overbank	High Flow Season	
		4-V5	Prolonged inundation of bank, bench and bars to disadvantage terrestrial species	High Flow	High Flow Season	Prevention of vegetation encroachment in riparian zone
		4-V6	Riparian disturbance and propagule distribution	Overbank	Any Time	Successful recruitment of riparian species
		4-V7	Maintain aquatic vegetation in channel	Low Flow	Low Flow Season	Healthy populations of in-stream vegetation
		4-V8		Low Flow Fresh	Low Flow Season	

3.3.1 Reach Four Summary Recommendations

Table 3-6: Flow recommendations for Reach 4 – Upper Bunyip River

Compliance Point – Bunyip River @ Tonimbuk				***Gauge Number - 228212***	
Flow				***Rationale***	
Period	***Magnitude***	***Frequency***	***Duration***	***Objectives***	***Controlling Criteria & Discussion***
Dec-May	Low Flow[*] >10 ML/day (or natural)	Continuous	Continuous	4-M1, 4-M3, 4-M4, 4-P1, **4-F1, 4-F2**, 4-F3 4-V7.	Habitat availability (River Blackfish and Grayling) – Depth availability and sufficient area
Dec-May	Low Flow Fresh 22 ML/day	5/season (or natural)	4 days (or natural)	4-M5, 4-M6**, 4-P4,** 4-F4, 4-F5, 4-V8	Create scour holes – inundate to a minimum depth of 400mm in all cross sections
April-May	Low Flow Fresh 175 ML/day	1/season (or natural)	1 day (or natural)	**4-F6**	Trigger Grayling spawning and transport larvae from spawning habitat to the estuary
Jun-Nov	High Flow 22 ML/day (or natural)	Continuous	Continuous	**4-M2**, 4-F7, **4-F8**, 4-F11, 4-F12, 4-V3, 4-V5	Continuous flow across channel at a depth to inundate leaf packs and cover sand exposed during low flow season – creates marginal habitat for juvenile fish
Jun-Nov	High Flow Fresh 70 ML/day	4/season (or natural)	3 days (or natural)	4-M7, 4-M8, 4-M9, 4-P2, 4-F9; 4-F10, **4-V1**	Water to reach lowest top of bank for all cross sections – prevent encroachment of terrestrial vegetation and maintain flood tolerant species
Late Oct-Nov		1/season (or natural)	3 days (or natural)	**4-F10**	Trigger Grayling movement from the estuary to the upper reaches
Anytime	Bankfull/ Channel-full 100 ML/day	4/yr (or natural)	3 days (or natural)	4-P3, **4-V2**	Water to reach top of bank for most cross-sections to wet bank profile and encourage flood tolerant species
Anytime	Overbank 200 ML/day	2/year (or natural)	3 days (or natural)	**4-V4, 4-V6**	Water to reach top of both banks (floodplain) – to inundate floodplain habitats, relocate propagules and create regeneration niches

Notes:

- 7 day independence is recommended between events.
- Flow recommendations for each flow component do not have to be discrete. For example an overbank event recommended once every two years will also satisfy the requirement for a bankfull event and one of the high flow freshes.

[*] The development of low flow recommendations in sand bed streams using the current Victorian FLOWS methodology is currently under review by DSE. Refer discussion in section 2.5.1 of this report.

- The controlling criteria relates to the objective that requires the highest flow to be achieved. These are shown in bold.
- The 'or natural' clause attached to the low flow and high flow recommendations indicate that flow is recommended to be equal to or above the value specified for that season except when flows ***naturally*** fall below that value. For the freshes and larger events, the 'or natural' clause refers to the frequency and duration of the event. That is, the event must occur for the duration and frequency specified unless the particular event would be ***naturally*** less frequent or of a shorter duration. In both cases, where the 'natural' clause is applied, the recommendation is met.

3.4 REACH SIX – BUNYIP MAIN DRAIN

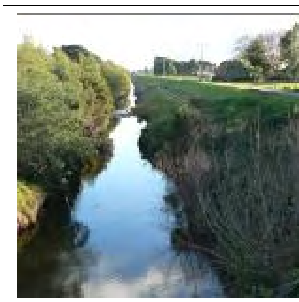
Reach 6 includes the Bunyip River below the Tarago River confluence, down to the estuary. Throughout this reach, the river consists of a uniform, constructed, trapezoidal drain. Land use is agricultural.

Given the use and management of the reach for flood control, activities that would normally be degrading factors (clearing of riparian vegetation, removal of woody debris) are not considered as such. The only external key degrading factor would be poor water quality from agricultural and urban run-off.

Summary of Reach Condition

This reach exhibits very similar hydrologic trends to the Bunyip River upstream at Tonimbuk, but with an approximately five fold increase in monthly volumes. The waterway throughout most of the reach is a constructed straight, drainage channel. Habitat and habitat diversity are provided as a consequence of the grade control rock riffles and accompanying upstream pools. Aquatic life assessments indicate an excellent or reference condition macroinvertebrate community. Platypus have been recorded in the Bunyip Main Drain and local knowledge suggests the populations are abundant and healthy. The majority of native fish species that have been recorded in the Bunyip Main Drain are migratory, and the reach is thought to provide poor habitat for resident native fish, being relatively homogeneous, fast flowing and lacking instream structure.

Key Values

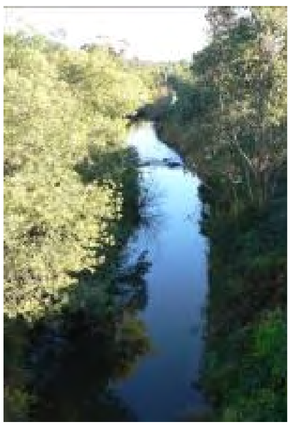


- Excellent condition macroinvertebrate community
- Self sustaining Platypus population
- Passage for migratory fish species between the estuary and upper reaches

Reach Vision

A drainage channel with stable bed and banks, that provides secure Platypus habitat, allows adequate fish passage between the estuary and the upper catchment, and ensures the conveyance of required flows for the Bunyip estuary, while acknowledging the role of flood protection.

Summary of objectives for Reach 6



Physical Form - Prevent gross channel change.

Macroinvertebrates - Maintain excellent condition macroinvertebrate community (Aquatic Life Score 9-10).

Water Quality - Maintain water quality to meet environmental objectives.

Fish - Maintain passage for migratory fish moving between the estuary and the upper reaches.

Vegetation- Maintain health and improve the diversity of lower bank riparian vegetation.

Table 3-7: Flow Processes and Components – Reach Six

Asset	*Environmental Objective*	*No.*	*Flow Process/Function*	*Flow Component*	*Timing*	*Expected Response*
Macroinvertebrates and water quality	Maintain excellent condition macroinvertebrate community	6-M1	Edge habitat availability	Low Flow	Low Flow Season	Provision of habitat to macroinvertebrates
		6-M2		High Flow	High Flow Season	
		6-M3	Habitat maintenance	Low Flow Fresh	Low Flow Season	Removal of sediments and biofilm from available habitats
		6-M4		High Flow Fresh	High Flow Season	
		6-M5	Water quality maintenance	Low Flow	Low Flow Season	Re-oxygenation of water and flushing of nutrients out of pools
Platypus	Maintain flow conditions suitable for Platypus	6-Y1	Habitat availability	Low Flow	Low Flow Season	Maintain sufficient water level to inundate habitats for Platypus
		6-Y2		High Flow	High Flow Season	
		6-Y3	Habitat maintenance	Low Flow Fresh	Low Flow Season	Removal of sediments and biofilm from available habitats
		6-Y4		High Flow Fresh	High Flow Season	
		6-Y5	Water quality maintenance	Low Flow	Low Flow Season	Re-oxygenation of water and flushing of nutrients out of pools
Physical Form	Prevent gross channel change	6-P1	Prevent bank and bed erosion	Channel Maintenance Flow	Anytime	Prevention of significant erosion of the bed and banks
		6-P2	Prevention of sedimentation to provide sufficient depth for fish passage	Low Flow Fresh	Low Flow Season	Scouring of sediments from pools behind drop structures
		6-P3		High Flow Fresh	High Flow Season	
Fish	Maintain passage for migratory fish moving between the estuary and the upper reaches	6-F1	Upstream migration of Australian Grayling from estuary to the river	High Flow	Late High Flow Season	Successful reproduction of Australian Grayling
		6-F2	Upstream migration of small bodied migratory fish	High Flow	Late High Flow Season	Successful reproduction of small bodied migratory fish populations
Vegetation	Maintain health and improve the diversity of lower bank riparian vegetation	6-V1	Habitat inundation – variability to provide zonation	Low Flow Fresh	Anytime	Successful establishment and reproduction of some riparian species in the lower riparian zone
		6-V2	Maintain aquatic vegetation in channel	Low Flow	Low Flow Season	Healthy populations of in-stream vegetation

3.4.1 Reach 6 Summary Recommendations

Table 3-8: Flow recommendations for Reach 6 – Bunyip Main Drain

Compliance Point – Bunyip River @ Iona				***Gauge Number - 228212***	
Flow				***Rationale***	
Period	***Magnitude***	***Frequency***	***Duration***	***Objectives***	***Controlling Criteria & Discussion***
Dec-May	Low Flow 50 ML/day (or natural)	Continuous	Continuous	**6-M1**, 6-M5, **6-Y1,** 6-Y5, **6-V2**	Habitat availability for macroinvertebrates and Platypus and maintenance of aquatic vegetation
Dec-May	Low Flow Fresh 120 ML/day	3/season (or natural)	7 days (or natural)	**6-M3, 6-Y3,** 6-P2, **6-V1**	Habitat maintenance – removal of silt and inundation of the bank to discourage terrestrial species and sustain flood tolerant species
Jun-Sept	High Flow 50 ML/day (or natural)	Continuous	Continuous	**6-M2**, 6-Y2	Maintain water level at edge of channel -Water level to reach edge of bed
Oct-Nov	High Flow 70 ML/day (or natural)	Continuous	Continuous	**6-F1, 6-F2**	Inundate barriers and provide access for fish between the estuary and the upper reaches
Jun-Nov	High Flow Fresh 170 ML/day	3/season incl. 1 in Nov (or natural)	2 days (or natural)	6-M4, 6-Y4, **6-P3**	Prevention of sedimentation to provide sufficient depth for fish passage
Anytime	Channel Maintenance 1,500ML/day	1 in 2 years (or natural)	1 day (or natural)	**6-P1**	2 year ARI event to be maintained above 20 and below 60N/m/s

Notes:

- 7 day independence is recommended between events.
- Flow recommendations for each flow component do not have to be discrete. For example an overbank event recommended once every two years will also satisfy the requirement for a bankfull event and one of the high flow freshes.
- The controlling criteria relates to the objective that requires the highest flow to be achieved. These are shown in bold.
- The ‘or natural’ clause attached to the low flow and high flow recommendations indicate that flow is recommended to be equal to or above the value specified for that season except when flows ***naturally*** fall below that value. For the freshes and larger events, the ‘or natural’ clause refers to the frequency and duration of the event. That is, the event must occur for the duration and frequency specified unless the particular event would be ***naturally*** less frequent or of a shorter duration. In both cases, where the ‘natural’ clause is applied, the recommendation is met.

3.5 REACH SEVEN – BUNYIP RIVER ESTUARY

Characteristics of the Bunyip River estuary have been outlined in the *Issues Paper* for this study. It is a highly dynamic system in which virtually all of the water which enters on a flood tide is removed in the subsequent ebb. For a large part of the tidal cycle the estuarine section (defined as *that section of the river below the Koo-wee-rup Weir*) is an extension of the river itself and freshwater flows through the estuary into Westernport Bay. As a result the health of the estuary is dependent on inflows from the Bunyip and Tarago River catchments.

The FLOWS method used for the four other reaches of the Bunyip and Tarago Rivers is not suitable for use on the estuary. As a result, this reach has been considered separately and recommendations are based on the expert opinion of Associate Professor John Sherwood from Deakin University. The risks to the estuary and the flow recommendations are summarised below. Appendix A provides a more detailed discussion and includes an assessment of the severity of consequences should adverse effects manifest themselves.

A risk matrix, shown in Table 3-9 below, has been developed to identify flow-related environmental risks as either a low, medium or high threats to the ecological health of the Bunyip Estuary.

Table 3-9. Risk Matrix for Flow-related Environmental Risks

	CONSEQUENCE		
LIKELIHOOD	**Minor**	**Moderate**	**Severe**
High	**MEDIUM**	**HIGH**	**HIGH**
Medium	LOW	**MEDIUM**	**HIGH**
Low	LOW	LOW	**MEDIUM**
Very Low	LOW	LOW	**MEDIUM**

In order to assess the likely effects of reduced flow regimes on the estuary a scheme developed by Pierson *et al* (2002) has been used. These authors have identified 16 major flow-related processes which impact on estuarine environments (Table 3-10) - although not all of these are important for all estuaries. The likelihood of each of the flow-related processes being significant for the Bunyip estuary is summarised in Table 3-10. The right hand column identifies the risk that each process presents, based on the matrix in Table 3-9 above.

Those processes identified as medium – high to high risk have been used as the basis of flow recommendations for the estuary, as summarised below.

Table 3-10. Major ecological processes by which reduced estuary flows can impact estuarine ecosystems (based on Pierson et al, 2002)

Relative River Inflow	***Number***	***Process***	***Likelihood***	***Consequence***	***Risk***
Low	1	Increased incidence of hostile water quality conditions at depth	VERY LOW	**SEVERE**	MEDIUM
	2	Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna	VERY LOW	MINOR	LOW
	3	Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora	VERY LOW	MINOR	LOW
	4	Extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota	**MEDIUM**	MINOR	LOW
	5	Extended periods when flow-induced currents cannot suspend eggs or larvae	**MEDIUM**	**SEVERE**	**HIGH**
	6	Extended periods when flow-induced currents cannot transport eggs or larvae	**MEDIUM**	**SEVERE**	**HIGH**
	7	Aggravation of pollution problems	LOW	**SEVERE**	MEDIUM
	8	Reduced longitudinal connectivity with upstream river systems	**HIGH**	**SEVERE**	**HIGH**
Middle-High	9	Diminished frequency of flushing of the estuary bed of fine sediments and organic matter – reducing the quality of physical habitat	**MEDIUM**	**MODERATE – SEVERE**	**MEDIUM-HIGH**
	10	Diminished frequency of flushing of organic matter from deep sections of the estuary – reducing water quality	**LOW**	**MODERATE - SEVERE**	**LOW-MEDIUM**
	11	Reduced channel maintenance processes	**HIGH**	**SEVERE**	**HIGH**
	12	Reduced inputs of nutrients and organic material	VERY LOW	MINOR	LOW
	13	Reduced lateral connectivity and reduced maintenance of ecological processes in water bodies adjacent to the estuary	LOW-**MEDIUM**	**SEVERE**	**MEDIUM-HIGH**
All	14	Altered variability in salinity structure	LOW	MINOR	LOW
	15	Dissipated salinity/chemical gradients used for animal navigation and transport	**HIGH**	**SEVERE**	**HIGH**
	16	Decreases in the availability of critical physical habitat features, particularly those components associated with higher velocities	LOW	MINOR	LOW

3.5.1 Environmental Flow Recommendations

The analysis of flow related processes (Table 3-10) has indicated two key requirements for the estuary based on the likelihood of the process being affected by reduced flow and the severity of consequences of reducing flow:

- Flow sufficient to maintain connectivity with the upper catchment (processes 5,6,8,15)
- Flow sufficient to maintain channel forming processes and to mobilise sediment (processes 9,11).

Maintaining connectivity.

Two surveys of the estuary measured water level at the highway bridge during the freshwater run-out of low tide (Table 3-11). From these data it appears that a flow of 70 ML/d will maintain a depth of water in the estuary of 0.15m. This is considered a minimum for fish passage. The uniformity of the channelised cross-section means the head of water at the weir is similar to the depth of water in the estuary at low tide. The weir top could define a benchmark for flow specification.

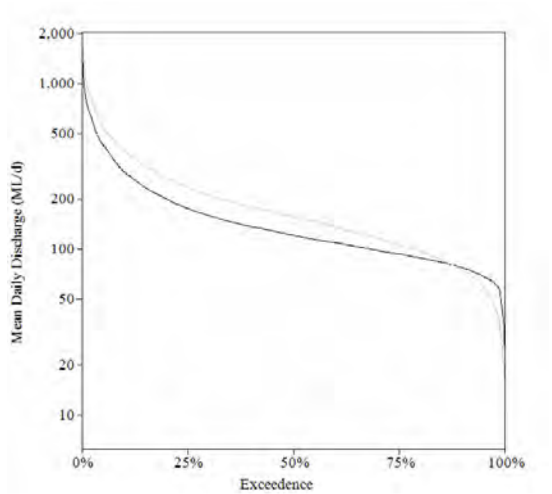
Table 3-11: Flow characteristics during low tide at the Highway Bridge

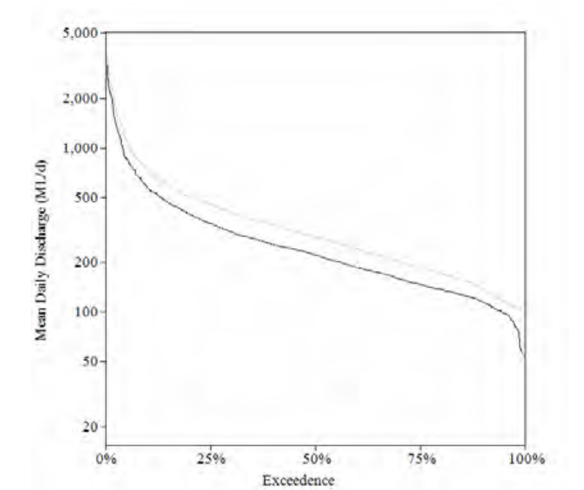
Date	Flow (ML/d)	Water Depth (m)
22 June 2006	68.4	0.14
28 Sep 2006	83.6	0.18*

* Water level 0.13m above top of the Koo-wee-rup weir.

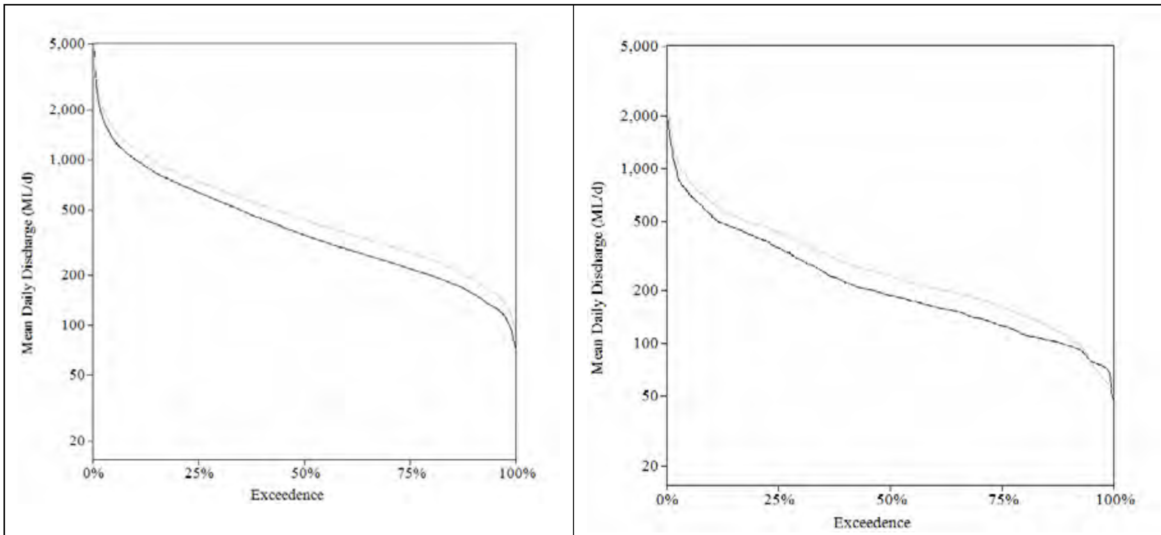
Recommendation 1: A minimum flow of 70ML/d should be maintained in the estuary in all seasons unless low flows fall naturally below this.

Flows of this magnitude will result in a water depth of approximately 15 cm in the estuary. Flow-duration curves for the Iona gauge indicate such flows are exceeded over 95% of the time under present flow conditions (Figure 3-1).





Low flow season	Transition (low to high)



High flow season	Transition (high to low)

Figure 3-1: Flow duration curves for each season for Bunyip River at Iona (Reach 6) comparing Natural (light) with Current (dark).

Channel Forming Flows

It has not been possible to assess the channel forming flows required for the estuary, however the estuary is similar in morphology to Reach 6 and in high flows will become an extension of it. Channel forming flows set for Reach 6 are considered appropriate for the estuary.

Recommendation 2: Higher flows (> 1500ML/d) should occur at the frequency specified for Reach 6 (once every 2 years).

In addition smaller flood flows (freshes) are required to aid in sediment removal from the estuary and to increase the frequency of inundation of fringing salt marsh and salt scrub communities in the lower estuary. As an interim measure, pending a detailed study of the plant community needs, the flow recommendations of Reach 6 should be adopted.

Recommendation 3: As an interim flow regime the frequency of freshes recommended for Reach 6 under both high and low flow conditions should be adopted for the estuary i.e. in low flow: 3 freshes of ≥ 120ML/d over 7 days; in high flow: 3 freshes of ≥ 170ML/d over 2 days.

3.5.2 Future Research

The Bunyip River estuary is a highly altered system and its major environmental assets are considered to be the mangrove and salt marsh /scrub communities in its lower reach (ie below the highway bridge). Unfortunately these sensitive plant communities are not adequately protected from stock access at present. Fencing of the areas affected should be discussed with landholders and land managers.

There should also be further expert assessment of the inundation regimes required to protect these plant communities.

Recommendation 4: The water requirements of the salt marsh and salt scrub communities should be subject to further investigation over the 5 year review period.

Until this study is undertaken, the flows of Recommendation 3 should be regarded as a preliminary assessment. If the salt marsh communities require more frequent flood assisted inundation a change in the number and/or size of freshes might be necessary.

Given the nature of this estuary further hydrodynamic investigations are not warranted.

3.5.3 Comparison with Upstream Flow Recommendations

The table below compares the flow recommendations for the Estuary with the recommendations established for Reach 6, immediately upstream. The recommendations for freshes and channel maintenance events in Reach 6 are identical to those recommended to maintain estuarine processes downstream. However, the low and high flow recommendations for the majority of the year are lower for Reach 6 than for the estuary (50ML/day compared with 70ML/day).

Table 3-12: Comparison of Flow Recommendations for the Estuary and Reach 6 (immediately upstream of the Estuary)

	Reach 6 Recommendations				***Estuary Recommendations***			
	Period	**Magnitude**	**Frequency**	**Duration**	**Period**	**Magnitude**	**Frequency**	**Duration**
Low Flow	Dec-May	≥50ML/day (or natural)	Continuous	Continuous	Dec-May	≥70ML/day (or natural)	Always	Continuous
Low Flow Fresh	Dec-May	≥120ML/day	3/season – or natural	7 days – or natural	Dec-May	≥120ML/day	3/year	7 days
High Flow	Jun-Sept	≥50ML/day (or natural)	Continuous	Continuous	Jun-Nov	≥70ML/day (or natural)	Always	Continuous
	Oct-Nov	≥70ML/day (or natural)	Continuous	Continuous				
High Flow Fresh	Jun-Nov	≥170ML/day	3/season – or natural	2 days – or natural	July-Nov	≥170ML/day	3/year	2 days
Other	Anytime	≥1500ML/day	1 in 2 years or natural	1 day – or natural	Anytime	≥1500ML/day	1 in 2 years	1 day

* The flow components from Reach 6 that are highlighted, DO NOT satisfy the requirements of the estuary.

4. Flow Recommendation Comparison

A reach by reach comparison of the recommended flows with the current flow regime is tabulated below. An assessment of whether the recommendation is currently being achieved is also noted in each table.

Note that the comparison to the current flow regime will alter for Reaches 2 and 6 should the Tarago Reservoir be re-connected to the Melbourne water supply network.

Table 4-1: Reach 1 Flow Comparison

Season	***Recommendation***	***Current***	***Achieved***
Dec-May	>10 ML/d[*] continuous (or natural)	Naturally less in only 1 year in 40 Currently more frequently less with 9 years in 40	Achieved*
Dec-May	35 ML/d 5/season for 4 days	Currently 3-9 per year for 4 days, frequency not achieved in all years	Achieved**
Jun-Nov	35 ML/d continuous (or natural)	Naturally and currently below 0-6 times/yr for 2 days	Achieved*
Jun-Nov	120 ML/d 3/season for 2 days	Currently 0-8 times/yr for 3 days (median), frequency achieved on average but not every year	Achieved**
Anytime	200 ML/d 2/yr for 2 days	Currently 0-7 times/yr for 1 day (median), duration not achieved	Not achieved
Anytime	300 ML/d 1/yr for 1 day	Currently 0-5 times/yr for 1 day (median)	Achieved**

* 'or natural' frequency means recommendation achieved only if inflows are less than recommendation

** recommendation frequency achieved on average but not for each year

[*] The development of low flow recommendations in sand bed streams using the current Victorian FLOWS methodology is currently under review by DSE. Refer discussion in section 2.5.1 of this report.

Table 4-2: Reach 2 Flow Comparison

Season	*Recommendation*	*Current*	*Achieved*
Dec-May	>12 ML/d[*] continuous (or natural)	Naturally less than this flow only twice in 40 years (1968). Never currently less than 12 ML/d (less than 20 ML/d twice in 40 years).	Achieved
Dec-May	100 ML/d 5/season 4 days	Currently 0-6 times/yr (median 3/yr) for 3 days, frequency and duration not achieved	Not achieved
April-May	200 ML/d 1/season 1 day	Naturally 1/yr for 2 days Currently rare with 1 every 3 or 4 years	Not achieved
Jun-Nov	100 ML/d continuous (or natural)	Currently drops below 100 ML/d 1 to 4 times per year for 22 days (median)	Achieved*
Jun-Nov	280 ML/d 4/season for 3 days	Naturally 4/yr for 28 days Currently 3/yr for 2 days, frequency and duration not achieved	Not achieved
Oct-Nov	280 ML/d 1/season for 1 day	Currently 0-3 times/yr for 3 days, frequency lower than recommended	Achieved**
Anytime	1000 ML/d 1 in 2 years for 1 day	Naturally 1/yr for 1 day Currently rarely achieved (and no events since 1993)	Not achieved
Anytime	600 ML/d 1/yr for 1 day	Naturally 3/yr for 4 days Currently 0-5/yr (median 1/yr), frequency less than recommended	Not achieved

* 'or natural' frequency means recommendation achieved only if inflows are less than recommendation

** recommendation frequency achieved on average but not for each year

[*] The development of low flow recommendations in sand bed streams using the current Victorian FLOWS methodology is currently under review by DSE. Refer discussion in section 2.5.1 of this report.

Table 4-3: Reach 4 Flow Comparison

Season	***Recommendation***	***Current***	***Achieved***
Dec-May	>10 ML/d[*] continuous (or natural)	Naturally below 10 ML/d 0-3 times per year for up to 36 days in a year (14 times in 40 years) Currently flow below 10ML/d 0-4 times per year for up to 49 days in a year	Achieved*
Dec-May	22 ML/d 5/season for 4 days	Currently exceeded for 28-151 days of the season (sometimes flow continuous for entire season). Little change from natural	Achieved*
April-May	175 ML/d 1/season for 1 day	Naturally 0-4/yr (median of 1) Currently 0-3/yr for 2 days, commonly several years without occurrence (median frequency of 0)	Not achieved
Jun-Nov	22 ML/d continuous (or natural)	Naturally below 5 times in 40 years for up to 18 days in a year Currently below 13 times in 40 years for up to 38 days in a year	Achieved*
Jun-Nov	70 ML/d 4/season for 3 days	Currently 1-6 times/yr for 7.5 days (median 4/yr)	Achieved**
Oct-Nov	70 ML/d 1/season for 3 days	Currently 0-4 times/yr for 9.5 days (median 1/yr)	Achieved**
Anytime	100 ML/d 4/yr for 3 days	Currently 3-13 times/yr for 4 days	Achieved
Anytime	200 ML/d 2/yr for 3 days	Currently 0-12 times/yr (median 5/yr) for 3 days	Achieved

* 'or natural' frequency means recommendation achieved only if inflows are less than recommendation

** Recommendation frequency achieved on average but not for each year

[*] The development of low flow recommendations in sand bed streams using the current Victorian FLOWS methodology is currently under review by DSE. Refer discussion in section 2.5.1 of this report.

Table 4-4: Reach 6 Flow Comparison

Season	***Recommendation***	***Current***	***Achieved***
Dec-May	50 ML/d continuous (or natural)	Naturally below 0-5 times for up to 96 days (1968) Currently below 0-4 times per year for up to 38 days in a year	Achieved*
Dec-May	120 ML/d 3/season for 7 days	Currently 0-6 times/yr (median 3/yr) for 6 days, median duration not achieved	Not achieved
Jun-Nov	50 ML/d Continuous (or natural)	Naturally or currently never below 50 ML/d	Achieved
Oct-Nov	70 ML/d Continuous (or natural)	Currently always > 70 ML/d	Achieved
Jun-Nov	170 ML/d 3/season 2 days	Currently > 170 ML/d exceeded most months	Achieved
Anytime	1500 ML/d 1 in 2 years for 1 day	Naturally 2/yr for 5 days median duration Currently 1/yr for 3 days	Achieved

* ‘or natural’ frequency means recommendation achieved only if inflows are less than recommendation

5. Supporting Recommendations

In order to achieve the overall visions set for each reach, a number of supporting recommendations are suggested to occur alongside the implementation of the environmental flow recommendations specified in this report.

These supporting recommendations include:

a. Develop a River Health Program for the Bunyip and Tarago River catchment

The environmental flow assessment addresses the flow dependant issues within this catchment only and does not directly address non-flow related issues impacting on river health and management. These issues are addressed in part by existing Melbourne Water and Port Phillip CMA documents (i.e. River Health Strategy). The preparation of a new River Health Program or modification to the existing Tarago Catchment Management Plan (Melbourne Water, 2003) would be a key future activity for identification of specific management actions that may alleviate some of the river health issues peripheral to the flow stresses identified in this report.

The program will identify and address the complementary non-flow related options to restore river health such as stock exclusion, riparian revegetation, willow and weed control, instream habitat restoration and floodplain and billabong connectivity. The implementation of these works are inherent in the achieving the vision and expected outcome sought within the flow recommendations for each reach.

b. Examine the removal or provision of passage over fish barriers

The environmental flow recommendations contained within this report have been based on the return of fish passage through the Bunyip and Tarago River system (With the exception of the Tarago Reservoir). Fish passage provision over the gauging station weirs and drop structures throughout the reaches of the Bunyip and Tarago River system is key to the success of the environmental flow recommendations of this study. It is Earth Tech understanding that Melbourne Water is currently undertaking investigations into the feasibility of achieving fish passage over all existing instream barriers except the Tarago Reservoir.

c. Investigate the impact of Bell Miners on riparian vegetation along Labertouche Creek

Trees along Labertouche Ck (Reach 3) appeared to be in poor health. It has been suggested that tree dieback may be attributed to the increase in Bell Birds and their subsequent driving out other insect eating birds. Borer marks were observed in many of the trees but it is unclear whether they are secondary to the problem. Further research is recommended to determine if this is the case and what can be done to improve the health of the significant riparian vegetation communities within this reach.

d. Continue eradication of *Glyceria maxima* to the Tarago and Bunyip Rivers

Glyceria maxima is an introduced weed capable of forming large infestations in a short period of time. Dense stands of Glyceria may restrict access to waterways, impede water flow, cause local flooding, reduce the holding capacity and accelerate siltation. In rivers, creeks, and irrigation and drainage channels, the stems slow the water velocity, then silt and other debris is trapped and builds up. The reduced flow rate of water may also create suitable environments for mosquito larvae and other pests (DPIWE, 2002).

Advisory Group members have indicated that Glyceria is established in some drains and tributaries within the Tarago and Bunyip catchment. Containment of this weed is important to achieving the visions and objectives specified for all reaches in the catchment.

Advice from Melbourne Water indicates that an on-going *Glyceria* spraying program is currently underway in infested areas.

e. Continue willow management

The continued eradication and management of willows in the catchment is also essential to achieving the reach visions, particularly in relation to achieving healthy riparian zones. Willows were observed to be widespread in some areas of Reach 2 including a section just below the Tarago Reservoir. Melbourne Water is currently running an ongoing program of willow removal and re-vegetation within the catchment, particularly in Reach 2.

f. Continue the fencing of riparian zones for stock exclusion

Stock exclusion from the riparian zone is key to achieving a healthy riparian zone. This is particularly important in areas where patches of high quality remnant riparian vegetation remain such as on Cannibal Creek. Fencing programs by Melbourne Water are ongoing throughout the catchment via the Stream Frontage Management Program and capital works at willow removal sites.

g. Conduct sediment transport modelling

The provision of flows for sediment transport is a complex process that is difficult to accurately specify without conducting modelling on sediment transport processes using specific criteria relevant to the study reach. The FLOWS method does not require this sort of detailed modelling to set flow recommendations however, the lack of this modelling means that current recommendations regarding sediment transport are of a low confidence. In order to increase the confidence that the recommended flows will achieve the desired objectives, it is recommended that a more detailed sediment transport analysis be carried out.

At present, it is unclear whether recommendations set for other objectives such as, provision of low flows to sustain macroinvertebrates and fish during the summer, may have an adverse effect on pool morphology in a sand bed system.

h. Investigate the fencing off of the salt marsh community near the estuary

The Bunyip River estuary is a highly altered system and its major environmental assets are considered to be the mangrove and salt marsh /scrub communities in its lower reach (i.e. below the highway bridge). Unfortunately these sensitive plant communities are not adequately protected from stock access at present. Fencing of the areas affected is recommended and should be discussed with landholders and land managers.

i. Develop and implement a monitoring and evaluation program

A robust monitoring program will be required to assess whether the improvements expected from flow regime change are in fact being achieved. If the objectives expected of the flow regime are not being achieved over time, the flow regime will require adjustment. It is important to note that time frames for expected improvements may vary and improvements may not be immediate. In the same way that processes that lead to a degraded river system may occur over time frames ranging from days to years, in cases where degrading processes are widespread and persistent, it is highly likely that the effect of rehabilitation efforts will take many years to become apparent. The ability of the monitoring and evaluation program to identify ecological changes, quantify these changes, detect time frames expected and adjust actions accordingly will be critical to the adaptive management approach that is necessary for the environmental flow regime.

6. Conclusion

Recommendations presented in this report identify the flow regime required to sustain ecological and geomorphic assets and processes of the Bunyip and Tarago Rivers. The recommendations have been developed by the Technical Panel utilising the FLOWS method. In particular the recommendations are based on satisfying ecological requirements for fish, macroinvertebrates, riparian vegetation, water quality, and geomorphologic requirements as determined by the Technical Panel.

Analysis of non-flow related options to improve river health has not been the focus of this report and will need to be addressed in a Waterway Management Activity Plan. The focus of this report has been identifying flow regime requirements for ecological health, and not the physical, social or economic impacts of implementing these recommendations.

The report forms a component of the implementation of environmental flows for the Bunyip and Tarago Rivers. The results of this process (environmental flow requirements), and additional information, such as community water demands, will be utilised in the decision making process of determining water allocation along the Bunyip and Tarago Rivers for various environmental and consumptive uses, including the re-introduction of the Tarago Reservoir to Melbourne's water supply.

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Appendix A

Environmental Flow Needs of the Bunyip River Estuary

Environmental Flow Needs of the Bunyip River Estuary

Associate Professor John Sherwood
Deakin University

1. INTRODUCTION

Characteristics of the Bunyip River estuary have been outlined in the *Issues Paper* for this study. It is a highly dynamic system in which virtually all of the water which enters on a flood tide is removed in the subsequent ebb. For a large part of the tidal cycle the estuarine section (defined as *that section of the river below the Koo-wee-rup Weir*) is an extension of the river itself and freshwater flows through the estuary into Westernport Bay. The reason for this is that the estuary has a uniform coarse sandy channel grading to approximately the Bay's mid-tide level. Seawater from Westernport Bay doesn't enter the estuary during a flood tide until water level rises to beyond the level of the estuary floor. This means truly estuarine conditions occur intermittently each day in response to tidal inflows.

The estuary is very different to many others along the Victorian coast, including those which enter into Port Philip Bay. The absence of deep basins (a consequence of current flows sufficient to mobilise coarse sands on the bed of the estuary) means that there is little permanent refuge for truly estuarine organisms. Most use of the estuary occurs when fish and birds move into the estuary on a flood tide. Permanent residents such as crabs and other invertebrates have strategies such as retreating to burrows or burying in bottom sediments to escape both exposure to the air and freshwater during low tides.

Because of rapid exchange with Westernport Bay marine water is oxygenated and of comparable quality to that of the Bay. In floods seawater may not enter the estuary and a plume of freshwater will flow directly into Bay waters at high tide or across mudflats in channels at low tide.

2. FLOW-RELATE PROCESSES IN THE ESTUARY

In order to assess the likely effects of reduced flow regimes on the estuary a scheme developed by Pierson et al (2002) has been used. These authors have identified 16 major flow-related processes which impact on estuarine environments (Table A-1) - although not all of these are important for all estuaries. The likelihood of each of the flow-related processes being significant for the Bunyip estuary is discussed below along with an assessment of the severity of consequences should adverse effects manifest themselves.

Table A-1: Major ecological processes by which reduced estuary flows can impact on estuarine ecosystems (Pierson et al., 2002)

Relative River Inflow	Process	
	No.	Nature
Low	1	Increased incidence of hostile water quality conditions at depth
	2	Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna
	3	Extended durations of elevated salinity in the upper-middle estuary adversely affecting sensitive flora
	4	Extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota
	5	Extended periods when flow-induced currents cannot suspend eggs or larvae
	6	Extended periods when flow-induced currents cannot transport eggs or larvae
	7	Aggravation of pollution problems
	8	Reduced longitudinal connectivity with upstream river systems
Middle-High	9	Diminished frequency of flushing of the estuary bed of fine sediments and organic matter – reducing the quality of physical habitat
	10	Diminished frequency of flushing of organic matter from deep sections of the estuary – reducing water quality
	11	Reduced channel maintenance processes
	12	Reduced inputs of nutrients and organic material
	13	Reduced lateral connectivity and reduced maintenance of ecological processes in water bodies adjacent to the estuary
All	14	Altered variability in salinity structure
	15	Dissipated salinity/chemical gradients used for animal navigation and transport
	16	Decreases in the availability of critical physical habitat features, particularly those components associated with higher velocities

2.1 Low Flow Conditions.

Process 1 - Increased incidence of hostile water conditions at depth.

Likelihood – Very Low

The estuary is shallow with no deep basins and virtually all water is exchanged in each tidal cycle.

Consequence – Severe

Anoxic water close to the surface could impede migration of organisms between Westernport Bay and the upstream reaches of the river. The viability of eggs and larvae in contact with anoxic water would be greatly reduced (eg at the halocline).

Process 2 and 3 - Extended durations of elevated salinity in the upper – middle estuary adversely affecting sensitive flora and fauna.

Likelihood – Very Low

The duration of all salt water intrusion is limited to approximately half of each tidal cycle (i.e. 3 - 6 hours). A reduction in flow will have little influence on this.

Consequence – Minor

Any increase in salinity in the upper to middle estuary will advantage opportunistic fish species entering from Westernport Bay but have little effect on the small number of estuarine species or freshwater species.

Process 4 - Extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota.

Likelihood – Moderate

Mangroves may increase their range upstream in the lower estuary if freshwater influence in this reach is reduced. The well-mixed nature of water in this reach (due to effective tidal exchange) means it is marine dominated under low flows.

Consequence – Minor

Extension of saline conditions in the lower estuary will have little impact on the species utilising the estuary. Extension of mangroves would be constrained by the channelised nature and hydrology of the estuary upstream of the highway bridge.

Process 5 and 6 - Extended periods when flow-induced currents cannot suspend or transport eggs and larvae.

Likelihood –Moderate

Tidal circulation is very effective. Present river flow is large enough to transport fine particles - the bed is predominantly a clean, coarse sand along most of its length because silts and clays are continually mobilised.

Consequence – Severe

Very low flows may compromise transport of eggs and larvae between the river and Westernport Bay. For this reason river flow should be sufficient to maintain connectivity.

Process 7 - Aggravation of pollution problems.

Likelihood –Low

There is no evidence of pollution problems in the estuary. Water quality is determined by that of the Bay and River rather than by processes in the estuary. Residence times of both are short (hours).

Consequence – Severe

Poor water quality in this section of the river could compromise movement of organisms between the Bay and the river. Flushing is an important mechanism to maintain good water quality – provided the river water itself is of acceptable quality.

Process 8 - Reduced longitudinal connectivity with upstream river systems.

Likelihood – High

Freshwater flow along the estuary during low tide is critical for maintaining connectivity. A sufficient water depth (10 – 20cm at least) is needed for fish passage. Some of the fish species in the river which require passage to complete their life cycle include short-headed lamprey, short-finned eels, broad-finned galaxias, common galaxias, spotted galaxias, tupong and Australian grayling (see Table 4-5 of the Site Paper for this study).

Barriers to fish migration such as the Koo-wee-rup weir could also impact on fish migration if water depth is too low.

Consequence – Severe

Migration is essential for some fish species to complete their life cycles. If this is not possible species may be lost from the river system.

2.2 Middle-High Flow Conditions.

Process 9, 10 - Diminished frequency of flushing of the estuary bed and deep sections of fine sediments and organic matter – reducing the quality of physical habitat.

Likelihood – Moderate

Present river flows are sufficient to remove fine sediments from most of the estuary. There are no deep basins in the estuary. Silt, clay and organic particulates transported into the estuary from Westernport Bay accumulate near the estuary entrance and for a short distance upstream (less than 0.8 km). Tidal currents would be expected to remove some of this material; however, higher river flows will increase the rate of sediment removal and so maintain an open entrance.

Consequence – Moderate to Severe

Without high flows to erode deposited sediment the estuary entrance will shallow, with consequent reduction in marine tidal intrusion. In an extreme situation the lower estuary could develop semi-permanent pools behind a sediment barrier, increasing the incidence of poor water quality and reducing connectivity for aquatic organisms.

Rivers provide a significant source of particulate matter to Westernport Bay and this material is important for the Bay's ecosystems. Floods from the catchment deliver organic matter which provides food for mud flat organisms.

Process 11 - Reduced channel maintenance processes.

Likelihood – High

Higher water currents associated with large floods serve an important function by eroding sediment at the entrance to the estuary. They will also transport coarser sand from upstream into Westernport Bay, maintaining the upstream channel. The larger grain size of coarse sands in the channelised section require higher velocities to shift them.

Consequence – Severe

Reduction in the cross-sectional area of the channel will restrict water flow and create habitat for invasive plant species. It will also reduce the extent of tidally driven salt water intrusion.

Process 12 - Reduced inputs of nutrients and organic material.

Likelihood – Very Low

The estuary receives most nutrients from Westernport Bay.

Consequence – Minor

Remineralisation of organic matter in the sediments of the estuary can provide necessary nutrients for the ecosystem. These organic-rich sediments are continually recycled by tides and river flow.

Process 13 - Reduced lateral connectivity and reduced maintenance of ecological processes in water bodies adjacent to the estuary.

Likelihood – Low to Moderate

Flooding frequency of the salt marsh and salt scrub adjacent to the open waters of the estuary would be expected to be an important determinant of their vegetation communities. These communities are dependent on intermittent inundation by estuarine or marine waters. Higher river flows in conjunction with flood tides raise water levels and increase the frequency of flooding. Other factors such as the spring-neap tidal cycle and storm surges also cause inundation. The relative importance of these is unknown.

Consequence – Severe

These plant communities are an important component of Westernport Bay's ecology. They are particularly vulnerable to disturbance.

2.3 All Flow Conditions.

Process 14 - Altered variability in salinity structure.

Likelihood – Low

Salinity structure, particularly the degree of stratification, is not likely to be a significant determinant of opportunistic use of the estuary.

Consequence – Minor

The diversity of truly estuarine species is low in this estuary.

Process 15 - Dissipated salinity/chemical gradients used for animal navigation and transport.

Likelihood – High(?)

The impacts of flow on factors such as this are not well understood. Freshwater outflows from the estuary are important in attracting the juvenile stages of diadromous species (eg. eels, galaxiids) into the river. Freshwater outflows are also important for transporting eggs and larvae of some diadromous species into the marine environment, and act as adult migration triggers for diadromous species that migrate from freshwater to the estuary or sea to spawn. Reductions in freshwater outflow, therefore, are likely to reduce recruitment of diadromous fish in the catchment.

Consequence – Severe

Interference with animal migration or transport threatens the viability of species populations in the river and estuary. Localised extinctions could result.

Process 16 - Decreases in the availability of critical physical habitat features, particularly those components associated with higher velocities.

Likelihood – Low

Tidal dynamics are more likely to determine utilisation of the estuary than river flow.

Consequence – Minor

Opportunistic use of the estuary is the dominant characteristic of its fauna. It is unlikely their utilisation is dependent upon particular habitat features.

3. ENVIRONMENTAL FLOW RECOMMENDATIONS

The analysis of flow related processes (Table A-2) has indicated two key requirements for the estuary based on the likelihood of the process being affected by reduced flow and the severity of consequences of reducing flow:

- Flow sufficient to maintain connectivity with the upper catchment (processes 5,6,8,15)
- Flow sufficient to maintain channel forming processes and to mobilise sediment (processes 9,11).
-

Table A-2: Summary of risk assessment of the effect of reduced flow on estuarine processes.

Process	***Likelihood***	***Consequences***	***Process***	***Likelihood***	***Consequences***
1	very low	severe	9	moderate	moderate to severe
2	very low	minor	10	low	moderate to severe
3	very low	minor	11	high	severe
4	moderate	minor	12	very low	minor
5	moderate	severe	13	low - moderate	severe
6	moderate	severe	14	low	minor
7	low	severe	15	high	severe
8	high	severe	16	low	minor

3.1 Maintaining connectivity.

Two surveys of the estuary measured water level at the highway bridge during the freshwater run-out of low tide (Table A-3). From this data it appears that a flow of 70 ML/d will maintain a depth of water in the estuary of 0.15m. This is considered a minimum for fish passage. The uniformity of the channelised cross-section means the head of water at the weir is similar to the depth of water in the estuary at low tide. The weir top could define a benchmark for flow specification.

Table A-3: Flow characteristics during low tide at the Highway Bridge

Date	Flow (ML/d)	Water Depth (m)
22 June 2006	68.4	0.14
28 Sep 2006	83.6	0.18*

* Water level 0.13m above top of the Koo-wee-rup weir.

Recommendation 1: *A minimum flow of 70ML/d should be maintained in the estuary in all seasons unless low flows fall naturally below this.*

Flows of this magnitude will result in a water depth of approximately 15 cm in the estuary. Flow-duration curves for the Iona gauge indicate such flows are exceeded over 95% of the time under present flow conditions (See Figure 3-1).

During July 2005 to September 2006 discharge was generally higher than this value (Figure A-1). Mean water level in the estuary varied by 0.5 to 1.5m over this same period – reflecting the influence of both marine and freshwater flows (Figure A-2).

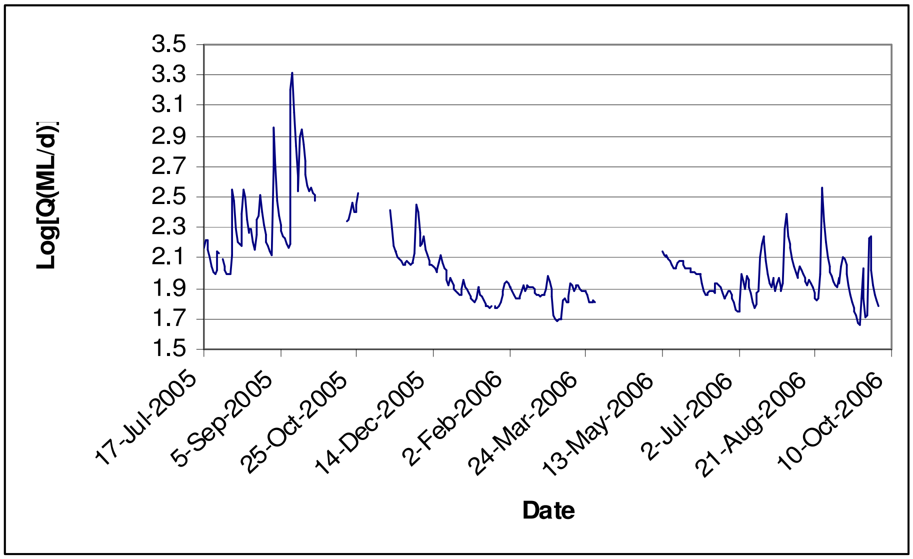

Figure A-1: Flow at the Iona gauge from July 2005 to September 2006. The recommended environmental flow of 70ML/d corresponds to LogQ = 1.85 on this scale. Gaps are periods when flow was not recorded.

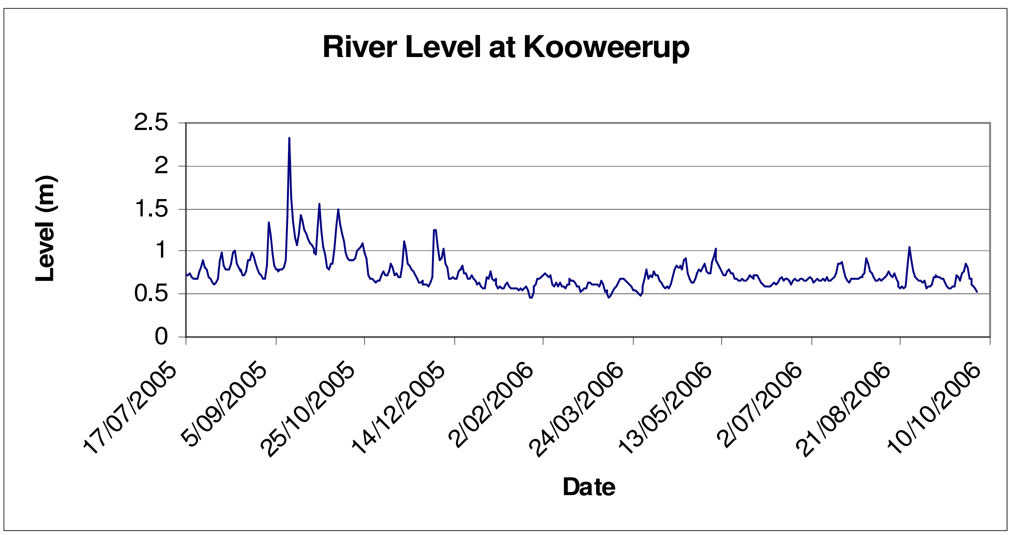

Figure A-2: The variation in mean daily water level (mAHD) downstream of the Koo-wee-rup weir from July 2005 to September 2006.

3.2 Channel Forming Flows

It has not been possible to assess the channel forming flows required for the estuary, however the estuary is similar in morphology to reach 6 and in high flows will become an extension of it. Channel forming flows set for Reach 6 are considered appropriate for the estuary.

Recommendation 2: *Higher flows (> 1500ML/d) should occur at the frequency specified for Reach 6 (once every 2 years).*

In addition smaller flood flows (freshes) are required to aid in sediment removal from the estuary and to increase the frequency of inundation of fringing salt marsh and salt scrub communities in the lower estuary. As an interim measure, pending a detailed study of the plant community needs, the flow recommendations of Reach 6 should be adopted.

Recommendation 3: *As an interim flow regime the frequency of freshes recommended for Reach 6 under both high and low flow conditions should be adopted for the estuary ie in low flow: 3 freshes of ≥ 120ML/d over 7 days; in high flow: 3 freshes of ≥ 170ML/d over 2 days.*

4. FUTURE RESEARCH

The Bunyip River estuary is a highly altered system and its major environmental assets are considered to be the mangrove and salt marsh /scrub communities in its lower reach (ie below the highway bridge). Unfortunately these sensitive plant communities are not adequately protected from stock access at present. Fencing of the areas affected should be discussed with landholders and land managers.

There should also be further expert assessment of the inundation regimes required to protect these plant communities.

Recommendation 4: *The water requirements of the salt marsh and salt scrub communities should be subject to further investigation over the 5 year review period.*

Until this study is done the flows of Recommendation 3 should be regarded as a preliminary assessment. If the salt marsh communities require more frequent flood assisted inundation a change in the number and/or size of freshes might be necessary.

Given the nature of this estuary further hydrodynamic investigations are not warranted.

REFERENCES

Pierson W.T., Bishop K., Van Senden D., Horton P.R. and Adamantidis C.A. (2002) Environmental Water Requirements to Maintain Estuarine Processes,

Environment Australia, Environmental Flows Initiative Technical report No. 3 (147pp).

Appendix B

Summary of hydrologic or hydraulic measures used to develop flow recommendations

Reach 1 – Upper Tarago River

Asset	*Environmental Objective*	*No.*	*Flow Process/ Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*References and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommen dations*
Macroinvertebrates and water quality	Maintain excellent condition macroinvertebrate community.	1-M1	Bed habitat availability	Low Flow	Low Flow Season	Continuous flow in low flow channel at a depth to inundate leaf packs and keep any exposed sand damp	Water level to cover leaf packs	Expert Panel member personal opinion.							Y
		1-M2		High Flow	High Flow Season	Continuous flow across channel at a depth to inundate leaf packs and cover sand exposed during low flow season	Minimum depth of water over leaf packs - 5 cm, or maybe just edge to edge of flow channel	Expert Panel member personal opinion.							Y
		1-M3	Edge habitat availability	Low Flow	All year	Continuous flow to maintain water at one edge of channel	Water level to reach edge of pools to inundate instream vegetation	Expert Panel member personal opinion.							Y
		1-M4	Water quality maintenance	Low Flow	All year	Low flow recommendation adequate to prevent water quality issues in pools	Velocity > 0.01m/s	Expert Panel member personal opinion. Positive velocity in all transects (but flow rate determined by other objectives)							Y
		1-M5	Refresh water quality and flush habitat	Low Flow Fresh	Low Flow Season	Flow rate, frequency and duration suitable to regularly turn over deep pools	Average Velocity in deepest transect greater than 0.01 m/s	Western, A. and Stewardson, M. (1999) Thermal stratification in the Wimmera and Glenelg Rivers. CEAH Report 4/99. Report to Wimmera Mallee Water by the Centre for Environmental Applied Hydrology, University of Melbourne							Y
		1-M6	Habitat maintenance	Low Flow Fresh	Low Flow Season	Shear stress at woody debris surface sufficient to remove silt	See 1-P1								Y
		1-M7		High Flow Fresh	High Flow Season	Shear stress at woody debris surface sufficient to remove attached algae and biofilm	See 1-P2								Y
		1-M8	Movement of bed material to maintain bed diversity	High Flow Fresh	High Flow Season	Shear stress at stream bed surface sufficient to mobilise sand	See 1-P2								Y
		1-M9	Entrain terrestrial carbon to the stream	High Flow Fresh	High Flow Season	Morphological criteria based on benches	Water level to reach lowest bench	Expert Panel member personal opinion.							Y
		1-M10		Overbank Flow	High Flow Season	Morphological criteria based on channel form	Water level to reach lowest bank	Expert Panel member personal opinion.							Y
Physical Form	Maintain in-stream habitat diversity[1]	1-P1	Remove silt from timber	Low Flow	Low Flow Season	Shear stress at woody debris surface sufficient to prevent accumulated sediment (silt)	Minimum average bed shear stress of $0.04N/m^2$	Critical shear stress for non cohesive material based on shield entrainment factor of 0.047 and sediment density of 2.65tonnes/m3							Y
		1-P2	Scour hole formation under and around large wood.	High flow fresh	High flow season	Depth of flow approx 1 X diameter of large wood assume 200mm dia	Minimum depth of water in pools and runs is 400mm	Expert Panel member personal opinion. Impediment provided by large wood significantly diminishes at flows in excess of 1X dia over timber. Assumes log is at bed level.							Y

[1] Assume: coarse sand up to 2mm and critical shear stress of 1.5N/m2 and silts of 0.05mm and critical shear stress of 0.04N/m2

Asset	*Environmental Objective*	*No.*	*Flow Process/ Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*References and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommendations*
		1-P3	Scour hole formation in bed at location of meander bends	Bankfull	Anytime	Maintain occurrence and duration of bankfull events that optimise scour hole formation	Water level to reach TOB on bends	Expert Panel member personal opinion. Empirical relationship. Events in excess of bankfull do not add significantly to shear stress and scour hole formation. Assumes maximum scour at bankfull							Y
	-	1-P4	Scour hole creation	Low Flow Fresh	Low Flow Season	Create scour holes. Assume 200mm diam timber plus 50mm depth.	Minimum depth of 250mm in all cross sections	Expert Panel member personal opinion. Based on 200 diameter timber							Y
Fish	Maintain self sustaining populations of river blackfish and mountain galaxias.	1-F1	Habitat availability for River Blackfish	Low Flow	All Year	Flow to provide habitats of sufficient depth and area to sustain local populations	Average pool depth >40 cm	Koehn et al. 1994, Bond, unpublished data Empirical data suggests minimum depths of 20-40cm are utilised by blackfish. As the hydraulic measure focuses on pools rather than runs etc I have adopted the larger number. This is also likely to depend on stream size.	3	10	0.12	depth availability and sufficient area	Continuous	Continuous	
		1-F2	Habitat availability for Mountain galaxias	Low Flow	All Year	Flow to provide habitats of sufficient depth and area to sustain local populations	Average pool depth > 20 cm	Bond & Lake, 2003; Bond, unpublished data							Y
		1-F3	Habitat maintenance	Low Flow Fresh	Low Flow Season	Shear stress sufficient to maintain small scour pools.	See 1-P4								Y
		1-F4	Localised movement of resident fish	Low Flow Fresh	Low flow Season	Maintain flow variability, including freshes, throughout the year	Minimum depth over riffles of 15cm	There are no good references on this for Australian species. Overseas studies show movements of small fish restricted at shallower depths (e.g. Schaefer, J. 2001). Frequency should be based on the natural frequency of such flows							Y
		1-F5	Localised movement of resident fish	High Flow	High Flow season	Allow movement of fish between habitat units along the channel	Average depth over riffles of 15cm	There are no good references on this for Australian species. Overseas studies show movements of small fish restricted at shallower depths (e.g. Schaefer, J. 2001). Flow frequency should be based on the natural frequency of such flows.							Y
		1-F6	Inundate marginal habitats for juvenile fish	High Flow	Late high flow season	Inundate areas of leaf litter which may be important habitat for juvenile fish	Inundate margins to a depth of at least 5cm.	Expert Panel member personal opinion. Flow should be maintained for several weeks in late spring.							Y
		1-F7	Habitat maintenance	High Flow Fresh	High Flow Season	Shear stress sufficient to maintain larger pool habitats in sand bed.	See 1-P2								Y
Vegetation	Maintain high quality riparian vegetation.	1-V1	Habitat inundation – variability to provide zonation	High Flow Fresh	Any Time (with natural rate of rise and fall)	Short duration wetting of the bank to prevent terrestrial species and maintain flood tolerant species	Water to reach lowest top of bank for all cross sections	Expert Panel member personal opinion.	1,4	120	1.39		3/season	2 days	
		1-V2		Bankfull	Any Time (with natural rate of rise and fall)	Longer duration wetting of the bank profile to encourage flood tolerant species	Water level to reach lowest top of bank of all cross sections	Expert Panel member personal opinion.	All	200	2.3		2/year	2 days	
		1-V3	Habitat inundation – provision of moisture to benches	High Flow	High Flow Season	Wet and connect most habitats within the main channel	Water level to reach lowest bench	Expert Panel member personal opinion.							
		1-V4	Habitat inundation – provision of moisture to floodplain	Overbank	High Flow Season	Overbank flow for sufficient duration to wet and fill floodplain pockets	Water to reach lowest top of bank (floodplain level) for all cross sections	Expert Panel member personal opinion.							Y

Asset	Environmental Objective	No.	Flow Process/ Function	Flow Component	Timing	Criteria	Hydraulic Measure	References and Comments	Cross - section Reference	Flow Recommendation (ML/d)	Flow Recommendation (m3/s)	Comments	Frequency	Duration	Criteria Met by other recommendations
		1-V5	Prolonged inundation of bank, bench and bars to disadvantage terrestrial species	High Flow	High Flow Season	High flows wetting entire bank	Water level to inundate bank, benches and bars.	Expert Panel member personal opinion.	1,4	35	0.41		Continuous	Continuous	
		1-V6	Riparian disturbance and propagule distribution	Overbank	Any Time	Floodplain flows to inundate floodplain habitats and relocate propagules or create regeneration niches	Water to reach top of both banks (floodplain level)	Expert Panel member personal opinion.	1 left, 5 both, 6 right	300	3.47		2/yr	2 days	
		1-V7	Habitat inundation/regeneration – provision of moisture and sediment to benches	High Flow Fresh	Anytime	Inundation sufficient to resuspend and distribute sediments	Water level to reach higher benches	Expert Panel member personal opinion.							Y
		1-V8	Maintain aquatic vegetation in channel	Low Flow	Low Flow Season	Continuous flow to maintain water at one edge of channel	Water level to reach edge of pools to inundate instream vegetation	Expert Panel member personal opinion.							Y
		1-V9	Prevent encroachment on vegetated bar	Low Flow Fresh	Low Flow Season	Inundated vegetated bar	Water level to reach bar	Expert Panel member personal opinion.	1, 6	35	0.41	Prevent veg encroaching onto bar	5/year	4 days	

Reach 2 – Lower Tarago River

Asset	Environmental Objective	No.	Flow Process/ Function	Flow Component	Timing	Criteria	Hydraulic Measure	Reference and Comments	Cross - section Reference	Flow Recommendation (ML/d)	Flow Recommendation (m3/s)	Comments	Frequency	Duration	Criteria Met by other recommendations
Macroinvertebrates and water quality	Maintain excellent condition macroinvertebrate community.	2-M1	Bed habitat availability	Low Flow	Low Flow Season	Continuous flow in low flow channel at a depth to inundate leaf packs and keep any exposed sand damp	Water level to cover leaf packs	Expert Panel member personal opinion.							Y
		2-M2		High Flow	High Flow Season	Continuous flow across channel at a depth to inundate leaf packs and cover sand exposed during low flow season	Minimum depth of water over leaf packs - 5 cm, or maybe just edge to edge of flow channel	Expert Panel member personal opinion.							Y
		2-M3	Edge habitat availability	Low Flow	All year	Continuous flow to maintain water at edge of channel	Water level to reach edge of bed	Expert Panel member personal opinion.							Y
		2-M4	Water quality maintenance	Low Flow	All year	Low flow recommendation adequate to prevent water quality issues in pools	Velocity > 0.01m/s	Expert Panel member personal opinion. Positive velocity in all transects (but flow rate determined by other objectives)							Y

Asset	*Environmental Objective*	*No.*	*Flow Process/ Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*Reference and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommendations*
		2-M5	Refresh water quality and flush habitat	Low Flow Fresh	Low Flow Season	Flow rate, frequency and duration suitable to regularly turn over deep pools	Average Velocity in deepest transect greater than 0.01 m/s	Western, A. and Stewardson, M. (1999) Thermal stratification in the Wimmera and Glenelg Rivers. CEAH Report 4/99. Report to Wimmera Mallee Water by the Centre for Environmental Applied Hydrology, University of Melbourne							Y
		2-M6	Habitat maintenance	Low Flow Fresh	Low Flow Season	Shear stress at woody debris surface sufficient to remove silt	See 2-P5								Y
		2-M7		High Flow Fresh	High Flow Season	Shear stress at woody debris surface sufficient to remove attached algae and biofilm	See 1-P2								Y
		2-M8	Movement of bed material to maintain bed diversity	High Flow Fresh	High Flow Season	Morphological criteria based on channel form	See 1-P2								Y
		2-M9	Entrain terrestrial carbon to the stream	High Flow Fresh	High Flow Season	Morphological criteria based on benches	Water level to reach lowest bench	Expert Panel member personal opinion.							Y
Physical Form	Restore in-stream habitat diversity.	2-P1	Remove silt from timber	Low Flow	Low Flow Season	Shear stress at woody debris surface sufficient to prevent accumulated sediment (silt)	Minimum average bed shear stress of $0.04 N/m^2$	Critical shear stress for non cohesive material based on shield entrainment factor of 0.047 and sediment density of 2.65tonnes/m3							Y
		2-P2	Scour hole formation under and around large wood.	High flow fresh	High flow season	Depth of flow approx 1 X diameter of large wood assume 350mm dia	Minimum depth of water in pools and runs is 700mm	Expert Panel member personal opinion. Impediment provided by large wood significantly diminishes at flows in excess of 1X dia over timber.							Y
		2-P3	Scour hole formation in bed at location of meander bends	Bankfull	Anytime	Maintain occurrence and duration of bankfull events that optimise scour hole formation	Water level to reach TOB on bends	Expert Panel member personal opinion. Empirical relationship Events in excess of bankfull do not add significantly to shear stress and scour hole formation							Y
	Prevent gross channel change.	2-P4	Prevent gross channel change	Channel Maintenance Flow	Anytime	2 year ARI flow event to be maintained above 10 and below 60N/m.s . Adjusted for sediment deprived system (downstream of reservoir).	the flow to deliver the power	Fisher Stewart (2002). *Bowen Basin River Diversions, Design and Rehabilitation Criteria.* Report for Australian Coal Association Research Program (ACARP), Queensland.	All	1000	11.57		1 in 2 years	1 day	
		2-P5	Scour hole creation	Low Flow Fresh	Low Flow Season	Create scour holes. Assume 350mm diam timber plus 50mm depth.	Minimum depth of 400mm in all cross sections	Expert Panel member personal opinion. Based on observed size timber at site (mature veg)							Y
Fish	Maintain the full suite of native migratory and non-migratory fish species, and increase the abundance of native fish within the reach.	2-F1	Habitat availability for River Blackfish	Low Flow	All Year	Flow to provide habitats of sufficient depth and area to sustain local populations	Pool depth >40 cm	Koehn et al. 1994, Bond, unpublished data Empirical data suggests minimum depths of 20-40cm are utilised by blackfish. As the hydraulic measure focuses on pools rather than runs etc I have adopted the larger number. This is also likely to depend on stream size.		12	0.14	Depth on small pool 50-53cm.	Continuous	Continuous	
		2-F2	Habitat availability for Australian Grayling	Low Flow	All Year	Flow to provide habitats of sufficient depth and area to sustain local populations	Pool depth >40 cm	Bond & Lake, 2003; Bond, unpublished data Not much quantitative data available on habitat use of grayling. I have observed them in pools 40-60cm deep so >40 cm may be an appropriate measure. Hydraulic criteria associated with riffles may be the controlling factor in these reaches							Y

Asset	Environmental Objective	No.	Flow Process/ Function	Flow Component	Timing	Criteria	Hydraulic Measure	Reference and Comments	Cross - section Reference	Flow Recommendation (ML/d)	Flow Recommendation (m3/s)	Comments	Frequency	Duration	Criteria Met by other recommend ations
		2-F3	Habitat availability for small-bodied fish	Low Flow	All Year	Flow to provide habitats of sufficient depth and area to sustain local populations	pool depth > 20 cm	Bond & Lake, 2003; Bond, unpublished data							Y
		2-F4	Habitat Maintenance	Low Flow Fresh	Low Flow Season	Shear stress sufficient to scour fine sediments from the streambed and LWD	See 2-P5								Y
		2-F5	Localised movement of resident fish	Low Flow Fresh	Low flow Season	Maintain flow variability, including freshes, throughout the year	Minimum depth over riffles of 10-15cm	There are no good references on this for Australian species. Overseas studies show movements of small fish restricted at shallower depths (e.g. Schaefer, J. 2001). Timing should be based on natural flows							Y
		2-F6	Spawning trigger & downstream dispersal of Australian Grayling larvae	Low Flow Fresh	April-May	Trigger spawning and transport larvae from spawning habitats to the estuary.	NO HYDRAULIC CRITERIA RELEVANT. Flow that occurs naturally in 4 out of 5 years.	Jackson, P. D., and J. D. Koehn. 1988 Rise in stage rather than hydraulic parameters may be more appropriate indicator. Hydraulic parameter to achieve transportation component of objective met by other objectives. Need to compare to existing hydrology to assist in developing appropriate criteria.	N/A	200	2.32	200ML/d, occurs 3 out of 4 years	1/yr	1 day	
		2-F7	Localised movement of resident fish	High Flow	High Flow season	Allow movement of fish between habitat units along the channel	Minimum depth over riffle of 10-15cm	There are no good references on this for Australian species. Overseas studies show movements of small fish restricted at shallower depths (e.g. Schaefer, J. 2001). Timing should be based on natural flows							Y
		2-F8	Inundate marginal habitats for juvenile fish	High Flow	Late high flow season	Inundate areas of leaf litter which may be important habitat for juvenile fish	Inundate margins to a depth of at least 5cm.	Expert Panel member personal opinion. Flow should be maintained for several weeks in late spring.							Y
		2-F9	Habitat maintenance	High Flow Fresh	High Flow Season	Shear stress sufficient to create/maintain larger pool habitats in sand bed	See 2-P2								Y
		2-F10	Upstream migration trigger for Australian Grayling	High Flow Fresh	October-November	Trigger movement from the Estuary to residential habitats	NO HYDRAULIC CRITERIA RELEVANT. Flow that occurs naturally in 4 out of 5 years.	Expert Panel member personal opinion.	N/A	280	3.24		1	Oct/Nov	
		2-F11	Upstream migration of Australian Grayling from estuary to the river	High Flow	October-November	Inundate barriers and provide access from estuary to upper reaches	Depth > 10-15cm	Expert Panel member personal opinion.							Y
		2-F12	Upstream migration of small bodied migratory fish	High Flow	October-November	Inundate barriers and provide access from estuary to upper reaches	Depth > 10-15cm	Expert Panel member personal opinion.							Y

Asset	*Environmental Objective*	*No.*	*Flow Process/ Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*Reference and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommendations*
Vegetation	Maintain the health of remnant riparian vegetation and provide flow conditions to encourage diverse riparian regeneration.	2-V1	Habitat inundation – variability to provide zonation	High Flow Fresh	Any Time (with natural rate of rise and fall)	Short duration wetting of the bank to prevent terrestrial species and maintain flood tolerant species	Water level to reach higher benches	Expert Panel member personal opinion. Inset floodplain	All	280	3.24		4	3 days	
		2-V2		Bankfull	Any Time (with natural rate of rise and fall)	Wetting of the bank profile to encourage flood tolerant species	Water level to reach channel full for most cross sections	Expert Panel member personal opinion.	2, 4, 6	600	6.94		1/year	1 day	
		2-V3	Habitat inundation – provision of moisture to benches	High Flow	High Flow Season	Wet and connect most habitats within the main channel	Water level to reach lowest bench	Expert Panel member personal opinion.			1				Y
		2-V4	Habitat inundation – provision of moisture to floodplain	Overbank	High Flow Season	Floodplain flows to inundate floodplain habitats	Flow extending to floodplain surface	Expert Panel member personal opinion.		1000	11.57		1 in 2 years	1 day	
		2-V5	Prolonged inundation of bank, bench and bars to disadvantage terrestrial species	High Flow	High Flow Season	High flows wetting entire bank	Water level to inundate bank, benches and bars.	Expert Panel member personal opinion.		100	1.16				
		2-V6	Riparian disturbance and propagule distribution	High Flow	Any Time	Velocity at stream bar surface sufficient to mobilise sand	Minimum average bank velocity of 1.0m/s and shear stress of 80M/m^2 on bar	Expert Panel member personal opinion.							Y
		2-V7		Bankfull	High flow season	Floodplain flows to inundate floodplain habitats and relocate propagules or create regeneration niches	Water level to reach inset floodplain for all cross sections	Expert Panel member personal opinion.	2, 4, 6	600	6.94		1/year	1 day	
		2-V8	Habitat inundation/regeneration – provision of moisture and sediment to benches	High Flow Fresh	Anytime	Inundation sufficient to resuspend and distribute sediments	Water level to reach higher benches	Expert Panel member personal opinion.	1- bench, 8&9 - meander cut-off	280	3.24		4	3 days	
		2-V9	Maintain aquatic vegetation in channel	Low Flow	Low Flow Season	Continuous flow to maintain water at one edge of channel	Water level to reach edge of pools to inundate instream vegetation	Expert Panel member personal opinion.							Y
		2-V10	Prevent encroachment of vegetation to sand bars	Low Flow Fresh	Low Flow Season	Inundate sand bars	Water level to cover all sand bars	Expert Panel member personal opinion.		100	1.16		5	4 days	

Reach 4 – Upper Bunyip River

Asset	*Environmental Objective*	*No.*	*Flow Process/ Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*Reference and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommend ations*
Macroinvertebrates and water quality	Maintain excellent condition macroinvertebrate community.	4-M1	Bed habitat availability	Low Flow	Low Flow Season	Continuous flow in low flow channel at a depth to inundate leaf packs and keep any exposed sand damp	Water level to cover leaf packs	Expert Panel member personal opinion.							Y
		4-M2		High Flow	High Flow Season	Continuous flow across channel at a depth to inundate leaf packs and cover sand exposed during low flow season	Minimum depth of water over leaf packs - 5cm, or edge to edge of flow channel	Expert Panel member personal opinion.		22	0.25		Continuous	Continuous	
		4-M3	Edge habitat availability	Low Flow	All year	Continuous flow to maintain water at edge of channel	Water level to reach edge of bed	Expert Panel member personal opinion.							Y
		4-M4	Water quality maintenance	Low Flow	All year	Low flow recommendation adequate to prevent water quality issues in pools	Velocity > 0.01m/s	Expert Panel member personal opinion. Positive velocity in all transects (but flow rate determined by other objectives)							Y
		4-M5	Refresh water quality and flush habitat	Low Flow Fresh	Low Flow Season	Flow rate, frequency and duration suitable to regularly turn over deep pools	Average Velocity in deepest transect greater than 0.01 m/s	Western, A. and Stewardson, M. (1999) Thermal stratification in the Wimmera and Glenelg Rivers. CEAH Report 4/99. Report to Wimmera Mallee Water by the Centre for Environmental Applied Hydrology, University of Melbourne							Y
		4-M6	Habitat maintenance	Low Flow Fresh	Low Flow Season	Shear stress at woody debris surface sufficient to remove silt	See 1-P1								Y
		4-M7		High Flow Fresh	High Flow Season	Shear stress at woody debris surface sufficient to remove attached algae and biofilm	See 1-P2								Y
		4-M8	Movement of bed material to maintain bed diversity	High Flow Fresh	High Flow Season	Shear stress at stream bed surface sufficient to mobilise sand	See 1-P2								Y
		4-M9	Entrain terrestrial carbon to the stream	High Flow Fresh	High Flow Season	Morphological criteria based on benches	Water level to reach lowest bench	Expert Panel member personal opinion.							Y
		4-M10		Overbank Flow	High Flow Season	Morphological criteria based on channel form	Water level to reach lowest bank	Expert Panel member personal opinion.							Y
Physical Form	Maintain in-stream habitat diversity.	4-P1	Remove silt from timber	Low Flow	Low Flow Season	Shear stress at woody debris surface sufficient to prevent accumulated sediment (silt)	Minimum average bed shear stress of $0.04N/m^2$	Critical shear stress for non cohesive material based on shield entrainment factor of 0.047 and sediment density of 2.65tonnes/m3							Y
		4-P2	Scour hole formation under and around large wood.	High flow fresh	High flow season	Depth of flow approx 1 X diameter of large wood assume 350mm dia	Minimum depth of water in pools and runs is 700mm	Expert Panel member personal opinion. Empirical relationship Impediment provided by large wood significantly diminishes at flows in excess of 1X dia over timber.							Y
		4-P3	Scour hole formation in bed at location of meander bends	Bankfull	Anytime	Maintain occurrence and duration of bankfull events that optimise scour hole formation	Water level to reach TOB on bends	Expert Panel member personal opinion. Empirical relationship Events in excess of bankfull do not add significantly to shear stress and scour hole formation							Y

Asset	*Environmental Objective*	*No.*	*Flow Process/ Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*Reference and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommend ations*
		4-P4	Scour hole creation	Low Flow Fresh	Low Flow Season	Create scour holes. Assume 350mm diam timber plus 50mm depth.	Minimum depth of 400mm in all cross sections	Expert Panel member personal opinion. Based on observed size timber at site(mature veg)	All	22	0.25	(exclude transect 6 where log sits high)	5 / year	4 days	
Fish	Maintain the full suite of native migratory and non-migratory fish species, and increase the abundance of native fish within the reach.	4-F1	Habitat availability for River Blackfish	Low Flow	All Year	Flow to provide habitats of sufficient depth and area to sustain local populations	Pool depth >40 cm	Koehn et al. 1994; Bond, unpublished data Empirical data suggests minimum depths of 20-40cm are utilised by blackfish. As the hydraulic measure focuses on pools rather than runs etc I have adopted the larger number. This is also likely to depend on stream size.	1	10	0.12		Continuous	Continuous	
		4-F2	Habitat availability for Australian Grayling	Low Flow	All Year	Flow to provide habitats of sufficient depth and area to sustain local populations	Pool depth >40 cm	Bond & Lake, 2003; Bond, unpublished data Not much quantitative data available on habitat use of grayling. I have observed them in pools 40-60cm deep so >40 cm may be an appropriate measure. Hydraulic criteria associated with riffles may be the controlling factor in these reaches	1	10	0.12		Continuous	Continuous	
		4-F3	Habitat availability for small-bodied fish	Low Flow	All Year	Flow to provide habitats of sufficient depth and area to sustain local populations	pool depth > 20 cm	Bond & Lake, 2003; Bond, unpublished data							Y
		4-F4	Habitat Maintenance	Low Flow Fresh	Low Flow Season	Shear stress sufficient to scour fine sediments from the streambed and LWD	See 4-P4								Y
		4-F5	Localised movement of resident fish	Low Flow Fresh	Low flow Season	Maintain flow variability, including freshes, throughout the year	Average depth over riffles of 15cm	There are no good references on this for Australian species. Overseas studies show movements of small fish restricted at shallower depths (e.g. Schaefer, J. 2001). Timing should be based on natural flows							Y
		4-F6	Spawning trigger & downstream dispersal of Australian Grayling larvae	Low Flow Fresh	April-May	Trigger spawning and transport larvae from spawning habitats to the estuary.	NO HYDRAULIC CRITERIA RELEVANT. Flow that occurs naturally in 4 out of 5 years.	Jackson, P. D., and J. D. Koehn. 1988		175	2.03	84% occurrence (in 40 year flow record)	1/year	1 day	
		4-F7	Localised movement of resident fish	High Flow	High Flow season	Allow movement of fish between habitat units along the channel	Average depth over riffles of 15cm	There are no good references on this for Australian species. Overseas studies show movements of small fish restricted at shallower depths (e.g. Schaefer, J. 2001). Timing should be based on natural flows							Y
		4-F8	Inundate marginal habitats for juvenile fish	High Flow	Late high flow season	Inundate areas of leaf litter which may be important habitat for juvenile fish	Inundate margins to a depth of at least 5cm.	Expert Panel member personal opinion. Flow should be maintained for several weeks in late spring.		22	0.25		Continuous	Continuous	
		4-F9	Habitat maintenance	High Flow Fresh	High Flow Season	Shear stress sufficient to create/maintain larger pool habitats in sand bed	See 4-P2								Y
		4-F10	Upstream migration trigger for Australian Grayling	High Flow Fresh	October-November	Trigger movement from the Estuary to residential habitats	NO HYDRAULIC CRITERIA RELEVANT.	Expert Panel member personal opinion.		70	0.81		4/year	3 days	
		4-F11	Upstream migration of Australian Grayling from estuary to the river	High Flow	October-November	Inundate barriers and provide access from estuary to upper reaches	Depth > 15cm	Estimate to be discussed based on hydraulic model and measurements at downstream rock ramps							Y

Asset	*Environmental Objective*	*No.*	*Flow Process/ Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*Reference and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommend ations*
		4-F12	Upstream migration of small bodied migratory fish	High Flow	October-November	Inundate barriers and provide access from estuary to upper reaches	Depth > 15cm	Estimate to be discussed based on hydraulic model and measurements at downstream rock ramps							Y
Vegetation	Provide flows to prevent the decline in riparian condition and contraction of the riparian zone.	4-V1	Habitat inundation – variability to provide zonation	High Flow Fresh	Any Time (with natural rate of rise and fall)	Short duration wetting of the bank to prevent terrestrial species and maintain flood tolerant species	Water to reach lowest top of bank for all cross sections	Expert Panel member personal opinion.	5	70	0.81	900mm depth	4/year	3 days	
		4-V2		Bankfull	Any Time (with natural rate of rise and fall)	Longer duration wetting of the bank profile to encourage flood tollerant species	Water level to reach lowest top of bank of all cross sections	Expert Panel member personal opinion.	All	100	1.16		4/year	3 days	
		4-V3	Habitat inundation – provision of moisture to benches	High Flow	High Flow Season	Wet and connect most habitats within the main channel	Water level to reach higher benches	Expert Panel member personal opinion.							Y
		4-V4	Habitat inundation – provision of moisture to floodplain	Overbank	High Flow Season	Overbank flow for sufficient duration to wet and fill floodplain pockets	Water to reach lowest top of bank (floodplain level) for all cross sections	Expert Panel member personal opinion. Assume inundating flood runner will allow inundation of floodplain.		200	2.31		2/year	3 days	
		4-V5	Prolonged inundation of bank, bench and bars to disadvantage terrestrial species	High Flow	High Flow Season	High flows wetting entire bank	Water level to inundate bank, benches and bars.	Expert Panel member personal opinion.							Y
		4-V6	Riparian disturbance and propagule distribution	Overbank	Any Time	Floodplain flows to inundate floodplain habitats and relocate propagules or create regeneration niches	Water to reach highest top of bank (floodplain level) for all cross sections	Expert Panel member personal opinion.		200	2.31		2/year	3 days	
		4-V7	Maintain aquatic vegetation in channel	Low Flow	Low Flow Season	Continuous flow to maintain water at one edge of channel	Water level to reach edge of pools to inundate instream vegetation	Expert Panel member personal opinion. Water to connect most channel habitats, less than bank full							Y
		4-V8		Low Flow Fresh	Low Flow Season	Inundate all bed and lower bank habitats	Water level to cover bed and all lower bank habitats	Expert Panel member personal opinion.							Y

Reach 6 – Bunyip Main Drain

Asset	*Environmental Objective*	*No.*	*Flow Process/Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*Reference and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommendations*
Macroinvertebrates and water quality	Maintain excellent condition macroinvertebrate community	6-M1	Edge habitat availability	Low Flow	Low Flow Season	Continuous flow to maintain water at edge of channel	Water level to reach edge of bed	Expert Panel member personal opinion.	1	50	0.58		Continuous	Continuous	
		6-M2		High Flow	High Flow Season	Continuous flow to maintain water at edge of channel	Water level to reach edge of bed	Expert Panel member personal opinion.	1	50	0.58		Continuous	Continuous	
		6-M3	Habitat maintenance	Low Flow Fresh	Low Flow Season	Shear stress at edge sufficient to remove silt	15cm above water level of low flow recommendation	Expert Panel member personal opinion.	1	120	1.39		3/season	7 days	
		6-M4		High Flow Fresh	High Flow Season	Shear stress at edge sufficient to remove silt	15cm above water level of high flow recommendation	Expert Panel member personal opinion.							Y
		6-M5	Water quality maintenance	Low Flow	Low Flow Season	Low flow recommendation adequate to prevent water quality issues in pools formed upstream of grade control structures	Average Velocity in deepest transect greater than 0.01 m/s	Expert Panel member personal opinion.							Y
Platypus	Maintain flow conditions suitable for Platypus	6-Y1	Habitat availability	Low Flow	Low Flow Season	Continuous flow to maintain water at edge of channel to maintain depth profile and macroinvertebrate food source	Water level to reach edge of bed in all cross sections (excluding rock chute)	Expert Panel member personal opinion.	1	50	0.58		Continuous	Continuous	
		6-Y2		High Flow	High Flow Season	Continuous flow to maintain water at edge of bed	Water level to reach edge of bed in all cross sections (excluding rock chute)	Expert Panel member personal opinion.	1	50	0.58		Continuous	Continuous	
		6-Y3	Habitat maintenance	Low Flow Fresh	Low Flow Season	Shear stress at edge sufficient to remove silt	15cm above water level of low flow recommendation	Expert Panel member personal opinion.	1	120	1.39		3/season	7 days	
		6-Y4		High Flow Fresh	High Flow Season	Shear stress at edge sufficient to remove silt	15cm above water level of high flow recommendation	Expert Panel member personal opinion.							Y
		6-Y5	Water quality maintenance	Low Flow	Low Flow Season	Low flow recommendation adequate to prevent water quality issues in pools formed upstream of grade control structures	Average Velocity in deepest transect greater than 0.01 m/s	Expert Panel member personal opinion. Positive velocity in all transects (but flow rate determined by other objectives)							Y
Physical Form	Prevent gross channel change	6-P1	Prevent bank and bed erosion	Channel Maintenance Flow	Anytime	2 year ARI flow event to be maintained above 20 and below 60N/m.s (refer Note1)	the flow to deliver the power	Fisher Stewart (2002). *Bowen Basin River Diversions, Design and Rehabilitation Criteria.* Report for Australian Coal Association Research Program (ACARP), Queensland.		1500	17.36		1/ 2 yrs	1 days	
		6-P2	Prevention of sedimentation to provide sufficient depth for fish passage	Low Flow Fresh	Low Flow Season	Long term maintenance of pools upstream of rock chutes	Minimum average bed shear stress of $2N/m^2$	Expert Panel member personal opinion.							Y
		6-P3		High Flow Fresh	High Flow Season	Depth of flow approx 1 X diameter of large wood assume 200mm dia	Minimum depth of water in pools and runs is 400mm	Expert Panel member personal opinion.	1	170	1.97	Depth in reeds - 400mm	3/season	2 days	

Asset	*Environmental Objective*	*No.*	*Flow Process/Function*	*Flow Component*	*Timing*	*Criteria*	*Hydraulic Measure*	*Reference and Comments*	*Cross - section Reference*	*Flow Recommendation (ML/d)*	*Flow Recommendation (m3/s)*	*Comments*	*Frequency*	*Duration*	*Criteria Met by other recommendations*
Fish	Maintain passage for migratory fish moving between the estuary and the upper reaches	6-F1	Upstream migration of Australian Grayling from estuary to the river	High Flow	Late High Flow Season	Inundate barriers and provide access from estuary to upper reaches	Depth > 10-15cm	Expert Panel member personal opinion.	3	50, 70	0.58, 0.81	Depth 24cm-34cm depending on whether it is modelled or observed.	Continuous	Continuous	
		6-F2	Upstream migration of small bodied migratory fish	High Flow	Late High Flow Season	Inundate barriers and provide access from estuary to upper reaches	Depth > 10-15cm	Expert Panel member personal opinion.	3	50, 70	0.58, 0.81	Depth 24cm-34cm depending on whether it is modelled or observed.	Continuous	Continuous	
Vegetation	Maintain, and improve the health and diversity of lower bank riparian vegetation.	6-V1	Habitat inundation – variability to provide zonation	Low Flow Fresh	Anytime	Short duration wetting of the bank to discourage terrestrial species and sustain flood tolerant species	15cm above water level of low flow recommendation	Expert Panel member personal opinion. Estimate to achieve variability	1	120	1.39		3/season	7 days	
		6-V2	Maintain aquatic vegetation in channel	Low Flow	Low Flow Season	Continuous flow to maintain water at one edge of channel	Inundate full bed width in all transects	Expert Panel member personal opinion. Water to connect most channel habitats, less than bank full							Y