

Assessment of Environmental Flow Requirements for the Gellibrand River

RECOMMENDATIONS

Revision E

July 2006

Assessment of Environmental Flow Requirements for the Gellibrand River

RECOMMENDATIONS

L:\work\NRG\PROJECTS\2005\042 Gellibrand\02\03 Recommendations Paper\Recommendations_RevE.doc

Document History:

ISSUE DATE	REVISION NUMBER	AUTHOR	CHECKED	APPROVED	DESCRIPTION
Dec 2005	A	C.Stephenson	L.Roach	C.Arnott	Preliminary Draft
Jan 2006	B	C.Stephenson	L.Roach	C.Arnott	Draft Recommendations
Feb 2006	C	C.Stephenson	L.Roach	C.Arnott	Draft Recommendations
May 2006	D	C.Stephenson	L.Roach	C.Arnott	Revised Recommendations – Reach 3
July 2006	E	C.Stephenson	L.Roach	L.Roach	CCMA Comments

EarthTech

Natural Resources Group

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

Contents

Tables

Please cite this document as:

Earth Tech (2005). *Assessment of Environmental Flow Requirements for the Gellibrand River – Recommendations*. Unpublished report to the Corangamite Catchment Management Authority.

The Gellibrand River Environmental Water Requirements Technical Panel (the Technical Panel) consists of (in alphabetical order, with fields of expertise):

Chris Arnott	Chair of the Technical Panel & Project Manager
Tim Doeg	Macroinvertebrate ecology and fish
Ross Hardie	Geomorphology
James Kaye	Riparian vegetation
Lisa Roach	Hydraulic modelling
John Sherwood	Estuarine processes

The Steering Committee for the project consisted of:

Mee Teng	Barwon Water
Greg Williams	Corangamite Catchment Management Authority
Steve Nicol	Department of Sustainability and the Environment
John Whitewood	Wannon Water
Cameron Welsh	Southern Rural Water

The Advisory Group consisted of:

Ivan Sharp	Irrigator
Ian Vesey	Irrigator
Kevin Ferrari	Irrigator
Robert Maxwell	Irrigator
Terry Harris	Irrigator
Gavin Bone	Irrigator
Steve Theodore	Recreational angler
Chris Tipler	Environment Victoria
Peter Gstrein	Southern Rural Water
Jill Fleming on behalf of Ian Voigt	Department of Sustainability and Environment
Gary Summers on behalf of Darren Shiell	Parks Victoria
Troy Duthrie on behalf of Graeme Hannel	Fisheries Victoria
Denis Lovric	Corangamite Catchment Management Authority
Anne-Marie McCarthy on behalf of Alexander Jovcic	Environment Protection Authority

Acronyms/Abbreviations Used in this report:

BE	Bulk water Entitlements
CMA	Catchment Management Authority
CCMA	Corangamite Catchment Management Authority
DSE	Department of Sustainability and Environment
E	Endangered species/community
EVC	Ecological Vegetation Class
EWR	Environmental Water Requirements
FLOWS	The "Statewide Method for Determining Environmental Water Requirements"
ISC	Index of Stream Condition
LWD	Large Woody Debris
SKM	Sinclair Knight Merz Pty Ltd.
SRW	Southern Rural Water
Technical Panel	The Gellibrand River Environmental Flows Technical Panel
VRHS	Victorian River Health Strategy

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

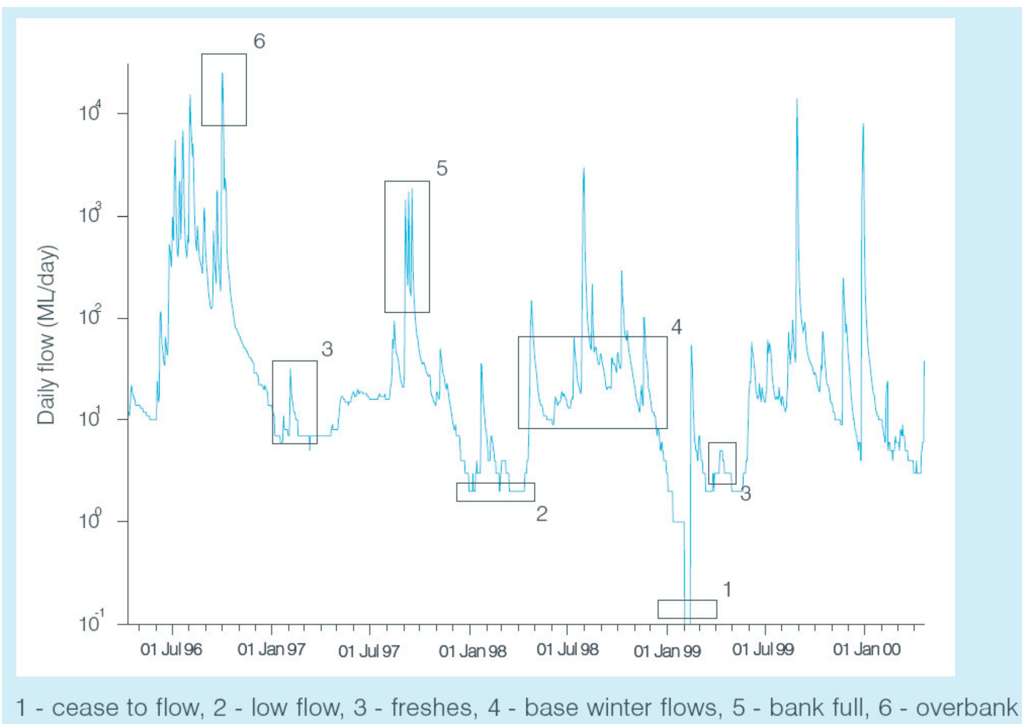


Figure 1. Graphical example of flow components (DNRE, 2002)

Introduction

The Corangamite Catchment Management Authority (CCMA) has engaged Earth Tech Engineering Pty Ltd (Earth Tech) to undertake an assessment of environmental flow requirements for the Gellibrand River and selected tributaries (the Gellibrand River system).

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) (DNRE, 2002).

This paper is an interim report that collates information from an abridged workshop process which was required to produce preliminary flows recommendations for the Department of sustainability and Environment in a shortened timeframe. The workshop involved a limited technical panel representing the fields of geomorphology, hydraulics and macroinvertebrate and fish ecology. The technical panel vegetation specialist was not present for this abridged workshop process.

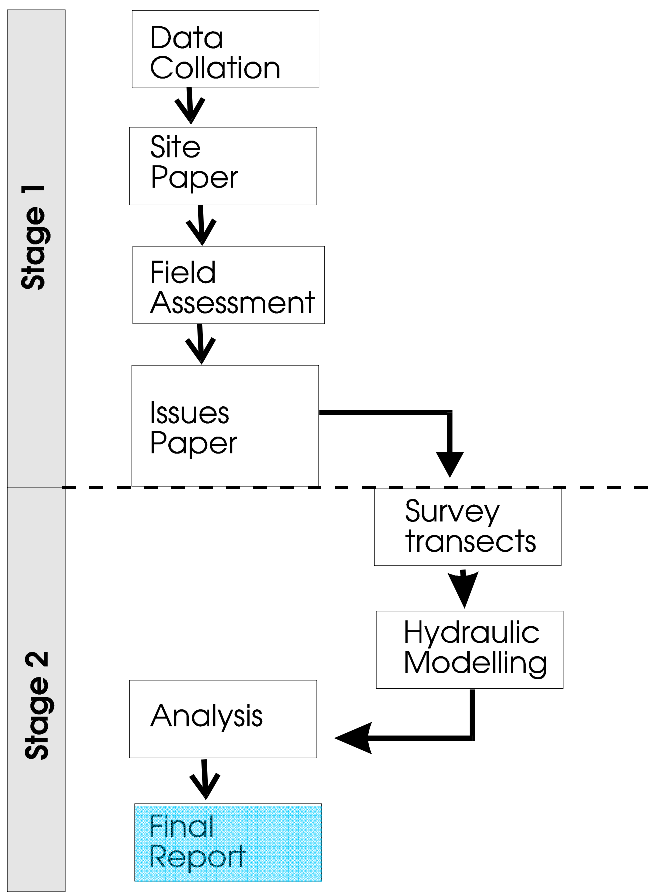


Figure 2. Outline of the steps in the FLOWS method

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 does not directly address non-flow related issues impacting on river health and management. These issues are addressed in part by existing CCMA documents (i.e. River Health Strategy). The preparation of a Waterway Action Plan (WAP) 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 2005a) provides background information on the Gellibrand River including catchment descriptions, historic land use, water use, broad condition descriptions and recommended reaches for the investigations. Objectives for ecological river health, and the background information for the project are defined in the Issues Paper (Earth Tech 2005b). 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 Gellibrand River and selected tributaries. 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 on the Gellibrand River system.

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.

Approach to EWR Analysis

1.2 Flow Analysis

Three hydraulic and hydrologic tools were utilised by the Technical Panel for the analysis:

- Digital terrain model – 12D
- Hydraulic model – HEC RAS
- Hydrologic/hydraulic analysis tool – RAP

The digital terrain modelling software (12D) was used to interpret the survey of the representative sites and generate topographic data into a format suitable for input to and creation of a hydraulic model.

The hydraulic modelling software package HEC RAS was used to generate the hydraulic data required for analysis.

The RAP software package was used to interpret and visualise the hydraulic results and to analyse the hydrologic data. The hydraulic analysis component of RAP was used interactively to identify, represent and visually interpret the flow criteria. For example, to determine flow recommendations for fish passage a critical depth and location was defined and the flow corresponding to this depth determined subsequently through the hydraulic model. Similarly, for bench inundation, flows were entered and adjusted until a particular selected bench was inundated.

The recommendations for frequency and duration of events (e.g. freshes, bankfull) are based on the frequency and duration of the natural flow series. The time series component of RAP was used to examine the frequency and duration of particular flows under natural conditions. The recommended frequency and duration was chosen from within the range of natural conditions (often based on the average natural annual seasonal frequency and duration).

Independence criteria of 7 days between events was adopted for the hydrologic analysis.

1.3 Philosophy of Flow Determination

The FLOWS method is based on the adoption of a minimum justifiable flow necessary to maintain identified assets and processes and was originally developed for the recovery of flows in a degraded system. 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 intact system than for 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. For intact systems failure to identify a key asset or process, or failure to correctly identify a flow relationship, has potential to result in lower the required environmental flow recommendations and the potential for the loss of some unidentified or poorly described values.

While the Gellibrand River has some level of extraction for consumptive purposes, for the most part much of the flow regime remains intact. To provide consistency with other environmental flow investigations, and in accordance with the project brief, this assessment has been undertaken using the FLOWS method. However, having regard to the level of confidence applicable to the FLOWs method and the environmental risks associated with extraction of water for consumptive uses, it is recommended that additional and more comprehensive analysis of the system be undertaken prior to finalisation of the environmental water requirements for the Gellibrand River.

1.4 Rates of Rise and Fall

While specific flow recommendations (flow, frequency and duration) are the most critical component of the recommendations, the maximum allowable rates of rise and fall leading up to the particular flow have been identified. These ensure rapid fluctuations greater than normal do not occur.

In order to recommend maximum rates of rise and fall, the differences between natural flows on individual days were divided into days when flows rose and days when flows fell. The ratio of the change in flow was calculated for each rise or fall. The average desirable rate of rise and of fall were selected as the average value of all recorded rates of change for each reach. The maximum desirable rate of rise and fall were selected as the average greatest value of all recorded rates of change.

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 and non-flow dependent issues 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 6 – Gellibrand River Estuary* were not developed as the current flows process is not suitable for estuary behaviour. Estuary flow recommendations will form part of a separate project scheduled for completion in 2006.

Reach One – Love Creek Catchment

Reach 1 encompasses the Love Creek catchment, which includes tributaries such as Yahoo Creek, Ten Mile Creek and Porcupine Creek. Love Creek is a major tributary to the upper reaches of the Gellibrand River, and is unregulated although there are some irrigation extractions and farm dams located within the catchment. The creek is surrounded by predominantly rural land uses, with some remnant and wet sclerophyll forest.

The representative site of Love Creek is in moderate to good condition. Two sites on Love Creek have been included in the recent Index of Stream Condition (ISC) assessments. Physical form at the site is generally good. Hydrology is modified from natural catchment conditions with most of the change occurring during the autumn period. Seasonality of flows remain the same as natural conditions.

Key Values

- Intact, partly confined, sand bed stream system
- Floodplain pockets
- Macroinvertebrates
- River Blackfish and small-bodied fish
- Remnant patch of EVC 18 Riparian Forest (Otway Plain Bioregion)
- Manna Gum canopy with Blackwoods abundant in the sub-canopy, herbs, grasses and ferns abundant on banks

Reach Vision

To maintain existing physical form and processes and the diversity of aquatic and riparian species.

Environmental Objectives

Macroinvertebrates

Maintain self sustaining populations of macroinvertebrates

Fish

Maintain self-sustaining populations of River Blackfish and small-bodied fish

Water Quality

Maintain water quality to meet environmental objectives

Physical Form

Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes

Vegetation

Maintain/restore distinctive riparian vegetation community and structure, including zonation up the bank and verge

Table 0-1 Flow Processes and Components – Reach One

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Macroinvertebrates	Maintain self sustaining populations of macroinvertebrates	1-M1	Habitat availability (inundation of leaf packs and shallow runs from edge to edge)	Low flow	All year	Provision of habitat to wide diversity of macroinvertebrate types
		1-M2	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		1-M3	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Scour and regeneration of macroinvertebrate community
		1-M4	Flush habitat	High flow fresh	High flow season	Scour and regeneration of macroinvertebrate community
		1-M5	Entrain terrestrial carbon	Overbank	High flow season	Provision of food source to macroinvertebrate community
Fish	Maintain self sustaining populations of River Blackfish and small-bodied fish	1-F1	Habitat availability for River Blackfish (inundation of pool to median depth of 50cm)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		1-F2	Habitat availability for small-bodied fish (inundation of pool to median depth of 20cm)	Low flow	All year	Provision of pool with adequate depth to support fish species
		1-F3	Localised movement of small-bodied fish (minimum depth of runs between pools 12cm)	Low flow fresh	Early low flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		1-F4	Localised movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Late high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		1-F5	Migration movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Early high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover including cover vegetation

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		1-F6	Migration stimulation of small-bodied migratory fish	High flow fresh	Early high flow season	Provision of unconfined fish passage over riffles and runs
		1-F7	Spawning stimulation of small-bodied resident fish	High flow fresh	Late high flow season	Successful reproduction of species
		1-F8	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		1-F9	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Provides advantages to native species over introduced species
		1-F10	Flush habitat	High flow fresh	High flow season	Provides advantages to native species over introduced species
Water Quality	Maintain water quality to meet environmental objectives	1-W1	Flushing of pools	Low flow fresh	Summer	Reoxygenation of water, introduction of carbon and nutrients
Physical Form	Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes	1-P1	Maintain frequency and duration of mid bank to overbank flows to within 20% of natural	High flow freshes & overbank	Any time	Prevent channel encroachment or enlargements
		1-P2	No change in the occurrence and timing of events that maintain scour holes of dimension sort by ecologists Bed disturbance minimum average flow of 0.3m/s through pool in sand bed	Low flow freshes	Any time	Establishment and maintenance of scour holes
		1-P3	Provide natural frequency of overbank flows to maintain sediment accession onto the floodplain	Overbank	Any time	Maintain floodplain evolution
		1-P4	Refer vegetation criteria	Freshes	Any time	Prevent instream vegetation colonisation to maintain flow capacity
		1-P5	Bench formation/ provision of flow over benches	High flow fresh	Any time	Ongoing bench formation

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		1-P6	Bank and bed scour process. Minimum average flow of 1.0m/s through pools in sand bed and silty sand bank stream	High flow fresh	Any time	Ongoing meander development formation of undercut banks and establishment of scour holes
Vegetation	Maintain/restore distinctive riparian vegetation community and structure including zonation up the bank and verge	1-V1	Habitat inundation – provision of moisture to benches	High flow fresh	Winter/Spring	Watering of bench vegetation
		1-V2	Habitat inundation – provision of moisture to floodplain	Overbank	Winter/Spring	Watering of floodplain vegetation
		1-V3	Habitat inundation – variability to provide zonation	High flow variability (high flow freshes, bankfull)	Any time (with natural rate of rise and fall)	Watering of bank vegetation
		1-V4	Habitat regeneration – deposition of sediments on benches	High flow fresh	Any time	Sediment deposition for vegetation regeneration
		1-V5	Bank/bench inundation to provide regeneration niches and prevent vegetation encroachment	High flow	Spring/Summer	Watering of bank and bench vegetation
		1-V6	Delivery of seeds from upper catchment	High flow	Any time	Distribution of riparian and floodplain seed
		1-V7	Inundation of bank and benches to disadvantage terrestrial species	Bankfull	Winter/Spring	Prevention of terrestrial vegetation encroachment
		1-V8	Prevent over colonisation of instream vegetation	High flow fresh	Any time	Encouragement of native species diversity
		1-V9	Inundation of bars to disadvantage terrestrial species	High flow	Continuous over Winter	Prevent vegetation encroachment onto bars
		1-V10	Maintain frequency and duration of mid bank to overbank flows to within 20% of natural	High flow freshes & overbank	Any time	Prevent sedimentation and entrain debris
		1-V11	Ensure near natural rates of overbank and high flows to within 20% of natural	High flows to overbank	Any time	Maintain health of above bank vegetation
		1-V12	Riparian disturbance	Overbank	Any time	Encourage species diversity, health and regeneration on floodplain

Reach 1 Summary Recommendations

Table 0-2. Flow recommendations for Reach 1 – Love Creek Catchment

Flow				Rationale	
Compliance Point – Love Creek at Gellibrand				Gauge Number - 235234	
Period	Magnitude	Frequency	Duration	Objectives	Controlling Criteria and discussion
Dec – May	*Low Flow* ≥ 6 ML/d (or natural)	Natural flow regime below 6ML/d		**1-M1**, 1-M2, **1-F1**,1-F2, 1-F8	Habitat availability (River Blackfish), minimum depth over riffles, wetting of entire bed for macroinvertebrates
Dec – May	*Low Flow Freshes* ≥8.6 ML/d	5 per year	4 days	1-M3, 1-F3, **1-F9**, 1-W1	Inundation of bars within channel, habitat availability, wetting of bed, prevention of vegetation colonisation, entrainment of litter
Dec - May	*Low Flow Freshes* ≥26 ML/d	2 per year	2 days	1-M3, 1-F3, 1-F9, 1-W1, **1-P2**	Maintain scour holes
June – Nov	*High Flow* ≥ 26 ML/d (or natural)	Natural flow regime below 26ML/d		1-F4, 1-F5, 1-V5, 1-V6, **1-V9**, 1-V11	Prevent vegetation encroachment onto benches (weed suppression)
June – Nov	*High Flow Freshes* ≥86.4 ML/d	5 per year	5 days	1-M4, **1-F6**, **1-F7**, 1-F10, 1-P1, 1-V1, 1-V3, 1-V4, 1-V8, 1-V10	Spawning stimulation of small-bodied resident fish Migration stimulation of small-bodied migratory fish
Anytime	*Annual Flood* ≥518.4 ML/d	1 per year	3 days	**1-P1**, **1-P2**	Prevent channel encroachment or enlargements (maintain channel form) Prevent infilling of scour holes
Anytime	*Overbank* ≥1000 ML/d	1 per 2 yrs	1 day	1-M5, 1-F11, **1-P1**, 1-P3, 1-V2, 1-V10, 1-V11, **1-V12**	Channel forming flow Riparian disturbance, encourage species and structural diversity
Anytime	*Overbank* ≥1,728 ML/d	1 per 10 yrs	1 day	1-M5, 1-F11, 1-P3, 1-V2, 1-V10, 1-V11, **1-V12**	Riparian disturbance, encourage species and structural diversity, health and regeneration

Notes:

- 7 day independence is recommended between events.
- In addition to the above flow component criteria there should be no more than a 20% variation to the natural duration of events that exceed the threshold of motion of the weakest component of the bed and bank material. The low flow fresh is adopted as this threshold.

Table 0-3 Recommended average and maximum rates of rise and fall (expressed as the change in discharge of the event divided by the length of the event, ML/day/day)

Reach/Site	Flow Component	Rate of Rise (ML/day/day)		Rate of Fall (ML/day/day)	
		AVE rate of rise	MAX rate of rise	AVE rate of fall	MAX rate of fall
1 Love Creek Catchment	Low Flow Fresh	13	74	4	21
	High Flow Fresh	61	466	32	270

Reach Two A – Gellibrand River at James Access Bridge

Reach Two covers the headwaters of the Gellibrand River, rising on the northern face of the Otway Ranges, through the mid-reaches of the Gellibrand, to the confluence with Carlisle River. This reach is divided into two, namely Reach 2A (discussed below), which extends from the Upper Gellibrand Reservoir through to the township of Gellibrand, and Reach 2B, which covers the remainder of the downstream reach.

Reach 2A includes the upper Gellibrand tributaries of Barramunga Creek, Olangolah Creek, Asplin Creek, Lardner Creek and Charleys Creek. Surrounding land use varies from undisturbed wet sclerophyll forest and cool temperate rainforest in the upper reaches, with some cleared grazing land and floodplain pockets downstream of the representative site at James Access Bridge. There are also conifer plantations in parts of the catchment.

The representative site of the Gellibrand River is in good condition. Three sites on the upper part of the Gellibrand River have been included in the recent Index of Stream Condition (ISC) assessments and in Reach 2A aquatic life and water quality rate high in the ISC condition assessment. Hydrology is highly modified from natural catchment conditions with most of the change primarily due to the impact of the main dam in the upper catchment. Seasonality of flows remains the same as natural conditions.

Key Values

- Undisturbed wet sclerophyll forest and cool temperate forest in the upper reaches
- River Blackfish, Australian Grayling and small-bodied fish
- Offstream billabongs present on adjacent floodplain

Reach Vision

To maintain existing physical form and processes and the diversity of aquatic species. To restore and maintain the reach as an ecological corridor between the estuary and the upland streams of the Otway Forests.

Environmental Objectives

Macroinvertebrates

Maintain self sustaining populations of macroinvertebrates

Fish

Maintain self-sustaining populations of River Blackfish, Australian Grayling and small-bodied fish

Water Quality

Maintain water quality to meet environmental objectives

Physical Form

Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes

Vegetation

Maintain/restore distinctive riparian vegetation community and structure, including zonation up the bank, and discourage exotic species

Table 0-4 Flow Processes and Components – Reach Two A

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Macroinvertebrates	Maintain self sustaining populations of macroinvertebrates	2A-M1	Habitat availability (inundation of leaf packs and shallow runs from edge to edge)	Low flow	All year	Provision of habitat to wide diversity of macroinvertebrate types
		2A-M2	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		2A-M3	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Scour and regeneration of macroinvertebrate community
		2A-M4	Flush habitat	High flow fresh	High flow season	Scour and regeneration of macroinvertebrate community
		2A-M5	Entrain terrestrial carbon (defined by bankfull in transect)	Overbank	High flow season	Provision of food source to macroinvertebrate community
Fish	Maintain self sustaining populations of River Blackfish, Australian Grayling and small-bodied fish	2A-F1	Habitat availability for River Blackfish (median depth of 50cm in deeper pools)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		2A-F2	Habitat availability for Australian Grayling (median depth of 40cm in deeper pools)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		2A-F3	Habitat availability for small-bodied fish (median depth of 20cm in deeper pools)	Low flow	All year	Provision of pool with adequate depth to support fish species
		2A-F4	Localised movement of Australian Grayling and River Blackfish (minimum depth of runs between pools of 20 cm for Blackfish)	Low flow fresh	Low flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		2A-F5	Spawning trigger / larval transport of Australian Grayling	Low flow fresh	April – May	Successful reproduction of species

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		2A-F6	Localised movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Late high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		2A-F7	Migration movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Early high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover including cover vegetation
		2A-F8	Migration stimulation of small-bodied migratory fish	High flow fresh	Early high flow season	Provision of unconfined fish passage over riffles and runs
		2A-F9	Spawning stimulation of small resident fish	High flow fresh	Late high flow season	Successful reproduction of species
		2A-F10	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		2A-F11	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Provides advantages to native species over introduced species
		2A-F12	Flush habitat	High flow fresh	High flow season	Provides advantages to native species over introduced species
Water Quality	Maintain water quality to meet environmental objectives	2A-W1	Flushing of pools	Low flow fresh	Summer	Reoxygenation of water, introduction of carbon and nutrients
Physical Form	Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes	2A-P1	Maintain frequency and duration of mid bank to overbank flows to within 20% of natural	High flow freshes & overbank	Anytime	Prevent channel encroachment or enlargements
		2A-P2	No change in the occurrence and timing of events that maintain scour holes of dimension sort by ecologists Bed disturbance minimum average flow of 0.3m/s through pool in sand bed	Low flow fresh	Anytime	Establishment and maintenance of scour holes
		2A-P3	Provide natural frequency of overbank flows to maintain sediment accession onto the floodplain	Overbank	Anytime	Maintain floodplain evolution

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		2A-P4	Refer vegetation criteria	Freshes	Anytime	Prevent instream vegetation colonisation to maintain flow capacity
		2A-P5	Bench formation/ provision of flow over benches	High flow fresh	Any time	Ongoing bench formation
		2A-P6	Bank and bed scour process. Minimum average flow of 1.0m/s through pool in sand bed and silty sand bank stream	High flow fresh	Any time	Ongoing meander development formation of undercut banks and establishment of scour holes
Vegetation	Maintain/restore distinctive riparian vegetation community and structure including zonation up the bank, and discouraging exotic species	2A-V1	Habitat inundation – provision of moisture to benches	High flow fresh	Winter/Spring	Watering of bench vegetation
		2A-V2	Habitat inundation – provision of moisture to floodplain	Overbank	Winter/Spring	Watering of floodplain vegetation
		2A-V3	Habitat inundation – variability to provide zonation	High flow variability (high flow freshes, bankfull)	Any time (with natural rate of rise and fall)	Watering of bank vegetation
		2A-V4	Habitat regeneration – deposition of sediments on benches	High flow fresh	Any time	Sediment deposition for vegetation regeneration
		2A-V5	Bank/bench inundation to provide regeneration niches and prevent vegetation encroachment	High flow	Spring/Summer	Watering of bank and bench vegetation
		2A-V6	Delivery of seeds from upper catchment	High flow	Any time	Distribution of riparian and floodplain seed
		2A-V7	Inundation of bank and benches to disadvantage terrestrial species	Bankfull	Winter/Spring	Prevention of vegetation encroachment
		2A-V8	Prevent over colonisation of instream vegetation	High flow fresh	Anytime	Encouragement of native species diversity at natural densities
		2A-V9	Inundation of bars to disadvantage terrestrial species	High flow	Continuous over Winter	Prevent vegetation encroachment onto bars

Reach 2A Summary Recommendations

Table 0-5. Flow recommendations for Reach 2A – Gellibrand River at James Access Bridge

Flow				Rationale	
Compliance Point – Gellibrand River at D/S of Dam Site				Gauge Number - 235236	
Period	**Magnitude**	**Frequency**	**Duration**	**Objectives**	**Controlling criteria and discussion**
Dec – May	*Low Flow* ≥8.6 ML/d (or natural)	Natural flow regime below 8.6ML/d		**2A-M1**, 2A-M2, 2A-F1, 2A-F2, 2A-F3, 2A-F10	Inundate sand bed, inundate macroinvertebrate habitat
Dec – May	*Low Flow Freshes* ≥22 ML/d	4 per year	4 days	2A-M3, **2A-F4,** 2A-F5, 2A-F11, 2A-W1	Migration trigger at end of summer Disturbance of sand bed
Dec – May	*Low Flow Freshes* ≥173 ML/d	2 per year	2 days	2A-M3, 2A-F4, 2A-F5, 2A-F11, **2A-W1**	Migration trigger at end of summer Disturbance of sand bed
June – Nov	*High Flow* ≥130 ML/d (or natural)	Natural flow regime below 130ML/d		2A-F6, 2A-F7, **2A-V5**, 2A-V6, 2A-V9	Sustained disturbance and habitat continuity
June – Nov	*High Flow Freshes* ≥260 ML/d	5 per year	5 days	2A-M4, **2A-F8**, **2A-F9**, 2A-F12, 2A-P1, 2A-V1, 2A-V3, 2A-V4, 2A-V8	Migration stimulation of small-bodied migratory fish Spawning stimulation of small resident fish
Anytime	*Bankfull* ≥2,000 ML/d	2 per 3 years	1 day	**2A-V3**, **2A-V7**	Habitat inundation Prolonged inundation of bank and benches
Anytime	*Overbank Flow* ≥3,500 ML/d	1 per 5 year	1 day	2A-M5, **2A-P1**, 2A-P3, 2A-V2	Inundated floodplain pockets/billabongs

Notes:

- 7 day independence is recommended between events.
- In addition to the above flow component criteria there should be no more than a 20% variation to the natural duration of events that exceed the threshold of motion of the weakest component of the bed and bank material. The low flow fresh is adopted as this threshold.

Table 0-6 Recommended average and maximum rates of rise and fall (expressed as the change in discharge of the event divided by the length of the event, ML/day/day)

Reach/Site	Flow Component	Rate of Rise (ML/day/day)		Rate of Fall (ML/day/day)	
		AVG rate of rise	MAX rate of rise	AVG rate of fall	MAX rate of fall
2A Gellibrand River (James Access Bridge)	Low Flow Fresh	26	511	20	292
	High Flow Fresh	102	946	61	669

Reach Two B – Upper Gellibrand River (downstream of 2A)

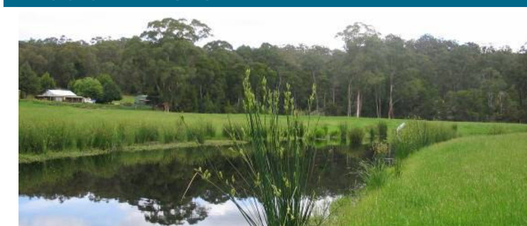
Reach 2B includes the mid-reach Gellibrand tributaries of Gum Gully Creek and Boggy Creek. Surrounding land use varies from modified wet sclerophyll forest in the upper reach, to cleared grazing land downstream of Bunkers Hill.

The representative site of the Gellibrand River is in moderate condition. Three sites on the upper part of the Gellibrand River have been included in the recent Index of Stream Condition (ISC) assessments and in Reach 2B aquatic life rates high in the ISC condition assessment. The creek displays a variety of features including a billabong present on the left bank and aquatic life rates high in the ISC condition assessment. Hydrology is modified from natural catchment conditions with most of the change occurring during the autumn period. Seasonality of flows remain the same as natural conditions.

Key Values

- Undisturbed wet sclerophyll forest and cool temperate forest in the upper reaches
- River Blackfish, Australian Grayling and small-bodied fish
- Offstream billabongs present on adjacent floodplain

Reach Vision



To maintain existing physical form and processes and the diversity of aquatic species. To restore and maintain the reach as an ecological corridor between the estuary and the upland streams of the Otway Forests.

Environmental Objectives

Macroinvertebrates

Maintain self sustaining populations of macroinvertebrates

Fish

Maintain self-sustaining populations of River Blackfish, Australian Grayling and small-bodied fish

Water Quality

Maintain water quality to meet environmental objectives

Physical Form

Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes

Vegetation

Maintain/restore distinctive riparian vegetation community and structure, including zonation up the bank, and discourage exotic species

Table 0-7 Flow Processes and Components – Reach Two B

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Macroinvertebrates	Maintain self sustaining populations of macroinvertebrates	2B-M1	Habitat availability (inundation of leaf packs and shallow runs from edge to edge)	Low flow	All year	Provision of habitat to wide diversity of macroinvertebrate types
		2B-M2	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		2B-M3	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Scour and regeneration of macroinvertebrate community
		2B-M4	Flush habitat	High flow fresh	High flow season	Scour and regeneration of macroinvertebrate community
		2B-M5	Entrain terrestrial carbon (defined by bankfull in transect)	Overbank	High flow season	Provision of food source to macroinvertebrate community
Fish	Maintain self sustaining populations of River Blackfish, Australian Grayling and small-bodied fish	2B-F1	Habitat availability for River Blackfish (median depth of 50cm in deeper pools)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		2B-F2	Habitat availability for Australian Grayling (median depth of 40cm in deeper pools)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		2B-F3	Habitat availability for small-bodied fish (median depth of 20cm in deeper pools)	Low flow	All year	Provision of pool with adequate depth to support fish species
		2B-F4	Localised movement of Australian Grayling and River Blackfish (minimum depth of runs between pools of 20 cm for Blackfish)	Low flow fresh	Low flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		2B-F5	Spawning trigger / larval transport of Australian Grayling	Low flow fresh	April – May	Successful reproduction of species

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		2B-F6	Localised movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Late high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		2B-F7	Migration movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Early high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover including cover vegetation
		2B-F8	Migration stimulation of small-bodied migratory fish	High flow fresh	Early high flow season	Provision of unconfined fish passage over riffles and runs
		2B-F9	Spawning stimulation of small resident fish	High flow fresh	Late high flow season	Successful reproduction of species
		2B-F10	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		2B-F11	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Provides advantages to native species over introduced species
		2B-F12	Flush habitat	High flow fresh	High flow season	Provides advantages to native species over introduced species
Water Quality	Maintain water quality to meet environmental objectives	2B-W1	Flushing of pools	Low flow fresh	Summer	Reoxygenation of water, introduction of carbon and nutrients
Physical Form	Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes	2B-P1	Maintain frequency and duration of mid bank to overbank flows to within 20% of natural	High flow freshes & overbank	Anytime	Prevent channel encroachment or enlargements
		2B-P2	No change in the occurrence and timing of events that maintain scour holes of dimension sort by ecologists Bed disturbance minimum average flow of 0.3m/s through pool in sand bed	Low flow fresh	Anytime	Establishment and maintenance of scour holes
		2B-P3	Provide natural frequency of overbank flows to maintain sediment accession onto the floodplain	Overbank	Anytime	Maintain floodplain evolution

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		2B-P4	Refer vegetation criteria	Freshes	Anytime	Prevent instream vegetation colonisation to maintain flow capacity
		2B-P5	Bench formation/ provision of flow over benches	High flow fresh	Any time	Ongoing bench formation
		2B-P6	Bank and bed scour process. Minimum average flow of 1.0m/s through pool in sand bed and silty sand bank stream	High flow fresh	Any time	Ongoing meander development formation of undercut banks and establishment of scour holes
Vegetation	Maintain/restore distinctive riparian vegetation community and structure including zonation up the bank, and discouraging exotic species	2B-V1	Habitat inundation – provision of moisture to benches	High flow fresh	Winter/Spring	Watering of bench vegetation
		2B-V2	Habitat inundation – provision of moisture to floodplain	Overbank	Winter/Spring	Watering of floodplain vegetation
		2B-V3	Habitat inundation – variability to provide zonation	High flow variability (high flow freshes, bankfull)	Any time (with natural rate of rise and fall)	Watering of bank vegetation
		2B-V4	Habitat regeneration – deposition of sediments on benches	High flow fresh	Any time	Sediment deposition for vegetation regeneration
		2B-V5	Bank/bench inundation to provide regeneration niches and prevent vegetation encroachment	High flow	Spring/Summer	Watering of bank and bench vegetation
		2B-V6	Delivery of seeds from upper catchment	High flow	Any time	Distribution of riparian and floodplain seed
		2B-V7	Inundation of bank and benches to disadvantage terrestrial species	Bankfull	Winter/Spring	Prevention of vegetation encroachment
		2B-V8	Prevent over colonisation of instream vegetation	High flow fresh	Anytime	Encouragement of native species diversity at natural densities
		2B-V9	Inundation of bars to disadvantage terrestrial species	High flow	Continuous over Winter	Prevent vegetation encroachment onto bars

Reach 2B Summary Recommendations

Table 0-8. Flow recommendations for Reach 2B – Upper Gellibrand River (downstream of 2A)

Flow				Rationale	
Compliance Point – Gellibrand River at Bunkers Hill				Gauge Number - 235227	
Period	Magnitude	Frequency	Duration	Objectives	Controlling criteria and discussion
Dec – May	Low Flow ≥13 ML/d (or natural)	Natural flow regime below 13ML/d		**2B-M1**, 2B-M2, 2B-F1, 2B-F2, 2B-F3, 2B-F10	Inundate sand bed, inundate macroinvertebrate habitat
Dec – May	Low Flow Freshes ≥86.4 ML/d	5 per year	4 days	2B-M3, **2B-F4**, 2B-F5, 2B-F11, 2B-W1	Migration trigger at end of summer Disturbance of sand bed
Dec – May	Low Flow Freshes ≥260 ML/d	2 per year	2 days	2B-M3, 2B-F4, 2B-F5, 2B-F11, **2B-W1**	Migration trigger at end of summer Disturbance of sand bed
June – Nov	High Flow ≥173 ML/d (or natural)	Natural flow regime below 173ML/d		2B-F6, 2B-F7, **2B-V5**, 2B-V6, 2B-V9	Sustained disturbance and habitat continuity
June – Nov	High Flow Freshes ≥1,901 ML/d	2 per year (1 in June and 1 in October)	2 days	2B-M4, **2B-F8**, **2B-F9**, 2B-F12, 2B-P1, 2B-V1, 2B-V3, 2B-V4, 2B-V8	Migration stimulation of small-bodied migratory fish Spawning stimulation of small resident fish
Anytime	Overbank Flow ≥5,184 ML/d	1 per 2 years	1 day	2B-M5, **2B-P1**, 2B-P3, 2B-V2, 2B-V3, 2B-V7	Inundated floodplain pockets/billabongs

Notes:

- 7 day independence is recommended between events.
- In addition to the above flow component criteria there should be no more than a 20% variation to the natural duration of events that exceed the threshold of motion of the weakest component of the bed and bank material. The low flow fresh is adopted as this threshold.

Table 0-9 Recommended average and maximum rates of rise and fall (expressed as the change in discharge of the event divided by the length of the event, ML/day/day)

Reach/Site	Flow Component	Rate of Rise (ML/day/day)		Rate of Fall (ML/day/day)	
		AVG rate of rise	MAX rate of rise	AVG rate of fall	MAX rate of fall
2B Upper Gellibrand River	Low Flow Fresh	74	766	32	375
	High Flow Fresh	265	1816	144	1147

Reach Three – Carlisle River Catchment

Reach 3 encompasses the Carlisle River and its tributaries Cole Creek, Camp Creek and Arkins Creek. Carlisle River is a major tributary to the Gellibrand River and enters the Gellibrand River at the township of Carlisle River. The upper tributaries flow through wet sclerophyll forest and cool temperate rainforest. Approaching the confluence with the Gellibrand River, the land has been cleared for agriculture and plantations. The reach is unregulated although is subject to irrigation extractions and there are farm dams located within the catchment.

The representative site of Carlisle River is currently undergoing rehabilitation works in the form of weed control (primarily Willows) and a revegetation program. Recent ISC assessments indicate the condition of Carlisle River overall is good. One site on the river has been included in the recent Index of Stream Condition assessments. Moderate habitat features such as large woody debris are evident in the reach and aquatic life was evident during site inspections however the presence of Willows has altered channel form. Hydrology is modified from natural catchment conditions with most of the change occurring during the autumn period. Seasonality of flows remain the same as natural conditions.

Key Values

- Wet sclerophyll forest and cool temperate forest in the upper reaches
- River Blackfish, Australian Grayling and small-bodied fish
- Unconfined alluvial system

Reach Vision

Provide flows that support the restoration of self-sustaining populations of aquatic and riparian species and ecosystem processes in accordance with resource condition targets in the CCMA River Health Strategy.

Environmental Objectives

Macroinvertebrates
Maintain self sustaining populations of macroinvertebrates

Fish
Maintain self-sustaining populations of River Blackfish, Australian Grayling and small-bodied fish

Water Quality
Maintain water quality to meet environmental objectives

Physical Form
Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes

Vegetation
Maintain and restore distinctive riparian vegetation community and structure, including zonation up the bank, and discourage exotic species

Table 0-10 Flow Processes and Components – Reach Three

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Macroinvertebrates	Maintain self sustaining populations of macroinvertebrates	3-M1	Habitat availability (inundation of leaf packs and shallow runs from edge to edge)	Low flow	All year	Provision of habitat to wide diversity of macroinvertebrate types
		3-M2	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		3-M3	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Scour and regeneration of macroinvertebrate community
		3-M4	Flush habitat	High flow fresh	High flow season	Scour and regeneration of macroinvertebrate community
		3-M5	Entrain terrestrial carbon (defined by bankfull in transect)	Overbank	High flow season / June-Oct	Provision of food source to macroinvertebrate community
Fish	Maintain self sustaining populations of River Blackfish, Australian Grayling and small-bodied fish	3-F1	Habitat availability for River Blackfish (median depth of 50cm in deeper pools)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		3-F2	Habitat availability for Australian Grayling (median depth of 40cm in deeper pools)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		3-F3	Habitat availability for small-bodied fish (median depth of 20cm in deeper pools)	Low flow	All year	Provision of pool with adequate depth to support fish species
		3-F4	Localised movement of Australian Grayling and River Blackfish (minimum depth of runs between pools of 20 cm for Blackfish)	Low flow fresh	Low flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		3-F5	Spawning trigger / larval transport of Australian Grayling	Low flow fresh	April – May	Successful reproduction of species

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		3-F6	Localised movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Late high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		3-F7	Migration movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Early high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover including cover vegetation
		3-F8	Migration stimulation of small-bodied migratory fish	High flow fresh	Early high flow season	Provision of unconfined fish passage over riffles and runs
		3-F9	Spawning stimulation of small resident fish	High flow fresh	Late high flow season	Successful reproduction of species
		3-F10	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		3-F11	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Provides advantages to native species over introduced species
		3-F12	Flush habitat	High flow fresh	High flow season	Provides advantages to native species over introduced species
Water Quality	Maintain water quality to meet environmental objectives	3-W1	Flushing of pools	Low flow fresh	Summer	Reoxygenation of water, introduction of carbon and nutrients
Physical Form	Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes	3-P1	Maintain frequency and duration of mid bank to overbank flows to within 20% of natural	High flow freshes & overbank	Any time	Prevent channel encroachment or enlargements
		3-P2	No change in the occurrence and timing of events that maintain scour holes of dimension sort by ecologists Bed disturbance minimum average flow of 0.3m/s through pool in sand bed	Freshes	Any time	Establishment and maintenance of scour holes
		3-P3	Provide natural frequency of overbank flows to maintain sediment accession onto the floodplain	Overbank	Any time	Maintain floodplain evolution

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		3-P4	Refer vegetation criteria	Freshes	Any time	Prevent instream vegetation colonisation to maintain flow capacity
		3-P5	Bench formation/ provision of flow over benches	High flow fresh	Any time	Ongoing bench formation
		3-P6	Bank and scour process. Minimum average flow of 1.0m/s through pool in sand bed and silty sand bank stream	High flow fresh	Any time	Ongoing meander development formation of undercut banks and establishment of scour holes
Vegetation	Maintain/restore distinctive riparian vegetation community and structure including zonation up the bank, and discouraging exotic species	3-V1	Habitat inundation – provision of moisture to benches	High flow fresh	Winter/Spring	Watering of bench vegetation
		3-V2	Habitat inundation – provision of moisture to floodplain	Overbank	Winter/Spring	Watering of floodplain vegetation
		3-V3	Habitat inundation – variability to provide zonation	High flow variability (high flow freshes, bankfull)	Any time (with natural rate of rise and fall)	Watering of bank vegetation
		3-V4	Habitat regeneration – deposition of sediments on benches	High flow fresh	Any time	Sediment deposition for vegetation regeneration
		3-V5	Bank/bench inundation to provide regeneration niches and prevent vegetation encroachment	High flow	Spring/Summer	Watering of bank and bench vegetation
		3-V6	Delivery of seeds from upper catchment	High flow	Any time	Distribution of riparian and floodplain seed
		3-V7	Inundation of bank and benches to disadvantage native terrestrial species	Bankfull	Winter/Spring	Prevention of vegetation encroachment
		3-V8	Prevent over colonisation of instream vegetation	High flow fresh	Anytime	Encouragement of native species diversity
		3-V9	Inundation of bars, banks and benches to disadvantage terrestrial exotic species	Low flow fresh and bankfull	Winter /Spring	Prevent vegetation encroachment onto bars

Reach 3 Summary Recommendations

Table 0-11. Flow recommendations for Reach 3 – Carlisle River

Flow				Rationale	
Compliance Point – Carlisle River at Carlisle River				Gauge Number - 235200	
Period	Magnitude	Frequency	Duration	Objectives	Controlling criteria and discussion
Dec – May	*Low Flow* ≥5.2 ML/d (or natural)	Natural flow regime below 5.2ML/d		**3-M1**, 3-M2, 3-F1, 3-F2, 3-F3, 3-F10	Habitat availability (inundation of leaf packs and shallow runs)
Dec – May	*Low Flow Freshes* ≥61 ML/d >121ML/d	2 per year (1 of the 2 at ≥ 121 ML/d)	2 days	3-M3, **3-F4**, 3-F5, 3-F11, 3-W1, **3-V9**	Inundation of bars, and localised fish movement
June – Nov	*High Flow* ≥61 ML/d (or natural)	Natural flow regime below 61ML/d		3-F6, 3-F7, **3-V5**, 3-V6	Habitat disturbance (bank. Bench inundation)
June – Nov	*High Flow Freshes* ≥372 ML/d	2 per year	2 days	3-M4, 3-M5, 3-F8, 3-F9, 3-F12, 3-P1, **3-P5**,3-V1, 3-V3, 3-V4, 3-V8	Bench formation/provision of flow over benches.
Anytime	*Overbank Flow* ≥1106 ML/d	1 per 10 yrs	1 day	3-M5, 3-P3, **3-V2**, 2-V3, 3-V7, 3-V9	Inundation of the floodplain

Notes:

- 7 day independence is recommended between events.
- In addition to the above flow component criteria there should be no more than a 20% variation to the natural duration of events that exceed the threshold of motion of the weakest component of the bed and bank material. The low flow fresh is adopted as this threshold.

Table 0-12. Recommended average and maximum rates of rise and fall (expressed as the change in discharge of the event divided by the length of the event, ML/day/day)

Reach/Site	Flow Component	Rate of Rise (ML/day/day)		Rate of Fall (ML/day/day)	
		AVG rate of rise	MAX rate of rise	AVG rate of fall	MAX rate of fall
3 **Carlisle River**	Low Flow Fresh	11	91	5	48
	High Flow Fresh	37	238	20	148

Reach Four – Gellibrand River Mid Reach

The mid reach of the Gellibrand River encompasses the area from the confluence with Carlisle River (upstream of the Otway Main Pipeline pumping station) past the township of Burrupa and through to the Great Ocean Road (the commencement of the estuarine reach). This reach flows through areas dominated by rural land uses and is impacted by agricultural runoff and uncontrolled stock access. Tributaries through this reach include Leahy Creek, Sandy Creek, Chapple Creek, Jones Creek and Atkinson Creek. The reach is unregulated, although is subject to urban extractions for the North and South Otway Supply Systems.

The representative site of the lower reach of the Gellibrand River is in moderate condition. Hydrology is modified with increased periods of low flow however seasonality of flows remain the same as natural conditions. Physical form is generally good however fish migration barriers are present beyond the site on the Gellibrand River Road. Water quality is defined through the ISC results as being good with some elevated levels of total phosphorous.

Key Values

- Physical form is generally good
- River Blackfish, Australian Grayling and small-bodied fish are present
- Water quality is defined through the ISC results as being good
- River banks are dominated by blackwoods with the occasional gum

Reach Vision

To maintain existing physical form and processes and the diversity of aquatic species. To restore and maintain the reach as an ecological corridor between the estuary and the upland streams of the Otway Forests.

Environmental Objectives

Macroinvertebrates

Maintain self sustaining populations of macroinvertebrates

Fish

Maintain self-sustaining populations of River Blackfish, Australian Grayling and small-bodied fish

Water Quality

Maintain water quality to meet environmental objectives

Physical Form

Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes

Vegetation

Maintain/restore distinctive riparian vegetation community and structure, including zonation up the bank, and discouraging exotic species

Table 0-13 Flow Processes and Components – Reach Four

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Macroinvertebrates	Maintain self sustaining populations of macroinvertebrates	4-M1	Habitat availability (inundation of leaf packs and shallow runs from edge to edge)	Low flow	All year	Provision of habitat to wide diversity of macroinvertebrate types
		4-M2	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		4-M3	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Scour and regeneration of macroinvertebrate community
		4-M4	Flush habitat	High flow fresh	High flow season	Scour and regeneration of macroinvertebrate community
		4-M5	Entrain terrestrial carbon (defined by bankfull in transect)	High flow fresh and overbank	High flow season / June-Oct	Provision of food source to macroinvertebrate community
Fish	Maintain self sustaining populations of River Blackfish, Australian Grayling and small-bodied fish	4-F1	Habitat availability for River Blackfish (median depth of 50cm in deeper pools)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		4-F2	Habitat availability for Australian Grayling (median depth of 40cm in deeper pools)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		4-F3	Habitat availability for small-bodied fish (median depth of 20cm in deeper pools)	Low flow	All year	Provision of pool with adequate depth to support fish species
		4-F4	Localised movement of Australian Grayling and River Blackfish (minimum depth of runs between pools of 20 cm for Blackfish)	Low flow fresh	Low flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		4-F5	Spawning trigger / larval transport of Australian Grayling	Low flow fresh	April – May	Successful reproduction of species

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		4-F6	Localised movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Late high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		4-F7	Migration movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Early high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover including cover vegetation
		4-F8	Migration stimulation of small-bodied migratory fish	High flow fresh	Early high flow season	Provision of unconfined fish passage over riffles and runs
		4-F9	Spawning stimulation of small resident fish	High flow fresh	Late high flow season	Successful reproduction of species
		4-F10	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		4-F11	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Provides advantages to native species over introduced species
		4-F12	Flush habitat	High flow fresh	High flow season	Provides advantages to native species over introduced species
Water Quality	Maintain water quality to meet environmental objectives	4-W1	Flushing of pools	Low flow fresh	Summer	Reoxygenation of water, introduction of carbon and nutrients
Physical Form	Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes	4-P1	Maintain frequency and duration of mid bank to overbank flows to within 20% of natural	High flow freshes & overbank	Anytime	Prevent channel encroachment or enlargements
		4-P2	No change in the occurrence and timing of events that maintain scour holes of dimension sort by ecologists Bed disturbance minimum average flow of 0.3m/s through pool in sand bed	Freshes	Anytime	Establishment and maintenance of scour holes
		4-P3	Provide natural frequency of overbank flows to maintain sediment accession onto the floodplain	Overbank	Anytime	Maintain floodplain evolution

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		4-P4	Refer vegetation criteria	Freshes	Anytime	Prevent instream vegetation colonisation to maintain flow capacity
		4-P5	Bench formation/ provision of flow over benches	High flow fresh	Any time	Ongoing bench formation
		4-P6	Bank scour process. Minimum average flow of 1.0m/s through pool in sand bed and silty sand bank stream	High flow fresh	Any time	Ongoing meander development formation of undercut banks and establishment of scour holes
Vegetation	Maintain/restore distinctive riparian vegetation community and structure including zonation up the bank	4-V1	Habitat inundation – provision of moisture to benches	High flow fresh	Winter/Spring	Watering of bench vegetation
		4-V2	Habitat inundation – provision of moisture to floodplain	Overbank	Winter/Spring	Watering of floodplain vegetation and encouragement of floodplain regeneration
		4-V3	Habitat inundation – variability to provide zonation	High flow variability (high flow freshes, bankfull)	Any time (with natural rate of rise and fall)	Watering of bank vegetation
		4-V4	Habitat regeneration – deposition of sediments on benches	High flow fresh	Any time	Sediment deposition for vegetation regeneration
		4-V5	Bank/bench inundation to provide regeneration niches and prevent vegetation encroachment	High flow	Spring/Summer	Watering of bank and bench vegetation
		4-V6	Delivery of seeds from upper catchment	High flow	Any time	Distribution of riparian and floodplain seed
		4-V7	Inundation of bank and benches to disadvantage native terrestrial species	Bankfull	Winter/Spring	Prevention of vegetation encroachment
		4-V8	Prevent over colonisation of instream vegetation	High flow fresh	Anytime	Encouragement of native species diversity
	Maintain health of above bank vegetation	4-V9	Ensure near natural rates of overbank and high flows	High flows to bankfull	Anytime	Prevent vegetation encroachment onto bars

Reach 4 Summary Recommendations

Table 0-14. Flow recommendations for Reach 4 – Gellibrand River Mid Reach

Flow				Rationale	
Compliance Point – Gellibrand River at Burrupa				Gauge Number - 235224	
Period	Magnitude	Frequency	Duration	Objectives	Controlling criteria and discussion
Dec – May	*Low Flow* ≥86.4 ML/d (or natural)	Natural flow regime below 86.4ML/d		**4-M1**, 4-M2, 4-F1, 4-F2, 4-F3, 4-F10	Habitat availability (inundation of shallow runs from edge to edge)
Dec – May	*Low Flow Freshes* ≥260 ML/d	4 per year	4 days	4-M3, 4-F4, 4-F5, **4-F11**, 4-W1	Disturbance flow
June – Nov	*High Flow* ≥260 ML/d (or natural)	Natural flow regime below 260ML/d		**4-F6**, **4-F7**, 4-V5, 4-V6, 4-V9	Fish passage and migration triggers
June – Nov	*High Flow Freshes* ≥3,284 ML/d	3 per year	3 days	4-M4, 4,M5, **4-F8**, **4-F9**, 4-F12, **4-P1**, 4-V1, 4-V3, 4-V4, 4-V8	Migration and spawning stimulation of small-bodied fish Floodplain wetland inundation
Anytime	*Annual Flood* ≥6048 ML/d	1 per year	3 days	4-P1, **4-P2**	Prevent channel encroachment or enlargements (maintain channel form) Prevent infilling of scour holes
Anytime	*Overbank Flow* ≥12,960 ML/d	1 per 3 years	1 day	4-M5, **4-P1**, 4-P3, 4-V2, 4-V3, 4-V7, 4-V9, 4-P3	Wetland connection, LWD entrainment

Notes:

- 7 day independence is recommended between events.
- In addition to the above flow component criteria there should be no more than a 20% variation to the natural duration of events that exceed the threshold of motion of the weakest component of the bed and bank material. The low flow fresh is adopted as this threshold.

Table 0-15. Recommended average and maximum rates of rise and fall (expressed as the change in discharge of the event divided by the length of the event, ML/day/day)

Reach/Site	Flow Component	Rate of Rise (ML/day/day)		Rate of Fall (ML/day/day)	
		AVG rate of rise	MAX rate of rise	AVG rate of fall	MAX rate of fall
4 **Gellibrand River Mid Reach**	Low Flow Fresh	123	1,220	50	536
	High Flow Fresh	562	3,606	274	1,810

Reach Five – Kennedys Creek Catchment

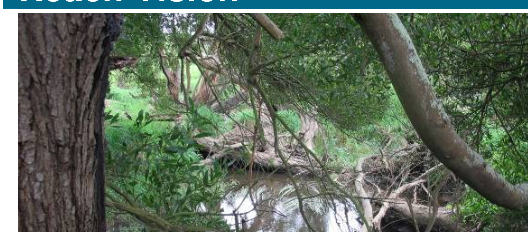
Kennedys Creek is the major western tributary to the Gellibrand River. The western side of the catchment has been largely cleared for agriculture and there is a high proportion of exotic vegetation. Kennedys Creek flows into the Gellibrand River at the South Otway Pipeline pumping station. Tributaries include Muree Creek, Tomahawk Creek and Danger Creek. The reach is unregulated, although is subject to irrigation extractions and has farm dams located within the catchment.

The current flow regime of Kennedys Creek is characterised by a general decrease in flows particularly during the summer and autumn periods. Recent ISC assessments indicate the condition of Kennedys Creek overall is moderate. Two sites on the river have been included in the recent Index of Stream Condition assessments. No physical fish barriers were present and moderate habitat features such as large woody debris are evident in the reach. Quality of instream vegetation is good with much of the representative site dominated by reeds.

Key Values

- River Blackfish and small-bodied fish
- Modified EVC 18 Riparian Forest (edge of the Otway Plain and Warrnambool Plain Bioregions)
- No physical fish barriers
- Habitat features (large woody debris)

Reach Vision



To maintain the current aquatic diversity, physical form and ecosystem processes in Kennedys Creek, and provide a flow regime that supports the restoration of the riparian condition and ecologically healthy corridor.

Environmental Objectives

Macroinvertebrates

Maintain self sustaining populations of macroinvertebrates

Fish

Maintain self-sustaining populations of River Blackfish and small-bodied fish

Water Quality

Maintain water quality to meet environmental objectives

Physical Form

Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes

Vegetation

Maintain/restore distinctive riparian vegetation community and structure, including zonation up the bank, and discouraging exotic species

Table 0-16 Flow Processes and Components - Reach Five

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
Macroinvertebrates	Maintain self sustaining populations of macroinvertebrates	5-M1	Habitat availability (inundation of leaf packs and shallow runs from edge to edge)	Low flow	All year	Provision of habitat to wide diversity of macroinvertebrate types
		5-M2	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		5-M3	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Scour and regeneration of macroinvertebrate community
		5-M4	Flush habitat	High flow fresh	High flow season	Scour and regeneration of macroinvertebrate community
		5-M5	Entrain terrestrial carbon (defined by bankfull in transect)	High flow fresh and overbank	High flow season / June-Oct	Provision of food source to macroinvertebrate community
Fish	Maintain self sustaining populations of River Blackfish and small-bodied fish	5-F1	Habitat availability for River Blackfish (inundation of pool to median depth of 50cm)	Low flow	All year	Provision of deep pool suitable for cover protection from birds of prey and overheating of pools in summer
		5-F2	Habitat availability for small-bodied fish (inundation of pool to median depth of 20cm)	Low flow	All year	Provision of pool with adequate depth to support fish species
		5-F3	Localised movement of small-bodied fish (minimum depth of runs between pools 12cm)	Low flow fresh	Low flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		5-F4	Localised movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Late high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover
		5-F5	Migration movement of small-bodied fish (minimum depth of runs between pools 12cm)	High flow	Early high flow season	Provision of suitable fish passage over riffles and runs with suitable depth of cover including cover vegetation

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		5-F6	Migration stimulation of small-bodied migratory fish	High flow fresh	Early high flow season	Provision of unconfined fish passage over riffles and runs
		5-F7	Spawning stimulation of small resident fish	High flow fresh	Late high flow season	Successful reproduction of species
		5-F8	Water quality maintenance	Low flow	Low flow season	Reoxygenation of water, introduction of carbon and nutrients
		5-F9	Refresh water quality and flush habitat	Low flow fresh	Low flow season	Reoxygenation of water, introduction of carbon and nutrients Provides advantages to native species over introduced species
		5-F10	Flush habitat	High flow fresh	High flow season	Provides advantages to native species over introduced species
Water Quality	Maintain water quality to meet environmental objectives	5-W1	Flushing of pools	Low flow fresh	Summer	Reoxygenation of water, introduction of carbon and nutrients
Physical Form	Provide suitable conditions to maintain and protect channel morphology and dependant assets and processes	5-P1	Maintain frequency and duration of mid bank to overbank flows to within 20% of natural	High flow freshes & overbank	Any time	Prevent channel encroachment or enlargements
		5-P2	No change in the occurrence and timing of events that maintain scour holes of dimension sort by ecologists Bed disturbance minimum average flow of 0.3m/s through pool in sand bed	Freshes	Any time	Establishment and maintenance of scour holes
		5-P3	Provide natural frequency of overbank flows to maintain sediment accession onto the floodplain	Overbank	Any time	Maintain floodplain evolution
		5-P4	Refer vegetation criteria	Freshes	Any time	Prevent instream vegetation colonisation to maintain flow capacity
		5-P5	Bench formation/ provision of flow over benches	High flow fresh	Any time	Ongoing bench formation

Asset	Environmental Objective	No.	Flow Process/Function	Flow Component	Timing	Expected Response
		5-P6	Bank scour process. Minimum average flow of 1.0m/s through pool in sand bed and silty sand bank stream	High flow fresh	Any time	Ongoing meander development formation of undercut banks and establishment of scour holes
Vegetation	Maintain/restore distinctive riparian vegetation community and structure including zonation up the bank, and discouraging exotic species	5-V1	Habitat inundation – provision of moisture to benches	High flow fresh	Winter/Spring	Watering of bench vegetation
		5-V2	Habitat inundation – provision of moisture to floodplain	Overbank	Winter/Spring	Watering of floodplain vegetation
		5-V3	Habitat inundation – variability to provide zonation	High flow variability (high flow freshes, bankfull)	Any time (with natural rate of rise and fall)	Watering of bank vegetation
		5-V4	Habitat regeneration – deposition of sediments on benches	High flow fresh	Any time	Sediment deposition for vegetation regeneration
		5-V5	Bank/bench inundation to provide regeneration niches and prevent vegetation encroachment	High flow	Spring/Summer	Watering of bank and bench vegetation
		5-V6	Delivery of seeds from upper catchment	High flow	Any time	Distribution of riparian and floodplain seed
		5-V7	Inundation of bank and benches to disadvantage native terrestrial species	Bankfull	Winter/Spring	Prevention of vegetation encroachment particularly exotic pasture grasses
		5-V8	Prevent over colonisation of instream vegetation	High flow fresh	Anytime	Encouragement of native species diversity
		5-V9	Inundation of bars to disadvantage terrestrial species	High flow	Continuous over Winter	Prevent vegetation encroachment onto bars

Reach 5 Summary Recommendations

Table 0-17. Flow recommendations for Reach 5 – Kennedys Creek Catchment

Flow				Rationale	
Compliance Point – Kennedys Creek at Kennedys Creek				Gauge Number - 235211	
Period	Magnitude	Frequency	Duration	Objectives	Controlling criteria and discussion
Dec – May	*Low Flow* ≥2 ML/d (or natural)	Natural flow regime below 2ML/d		**5-M1**, 5-M2, 5-F1, 5-F2, 5-F8	Habitat availability (macroinvertebrates), wetting of full bed width
Dec – May	*Low Flow Freshes* ≥35 ML/d	3 per year	5 days	5-M3, **5-F3**, 5-F9, 5-W1	Localised movement (between pools) of small-bodied fish, refresh water quality
June – Nov	*High Flow* ≥35 ML/d (or natural)	Natural flow regime below 35ML/d		**5-F4**, 5-F5, 5-V5, 5-V6, 5-V9	Fish passage
June – Nov	*High Flow Freshes* ≥259 ML/d	4 per year	3 days	5-M4, 5-M5, 5-F6, 5-F7, 5-F10, F-P1, F-V1, 5-V3, **5-V4**, 5-V8	Habitat inundation (provision of moisture to benches), regional fish movement, flush habitat, channel maintenance/ vegetation restriction, habitat regeneration (deposition of sediments on benches)
Anytime	*Overbank Flow* ≥1,728 ML/d	1 per year	2 days	5-M5, 5-P1, **5-P3**, 5-V2, 5-V3, 5-V7	Inundation of floodplain, sediment accession onto floodplain and LWD entrainment

Notes:

- 7 day independence is recommended between events.
- In addition to the above flow component criteria there should be no more than a 20% variation to the natural duration of events that exceed the threshold of motion of the weakest component of the bed and bank material. The low flow fresh is adopted as this threshold.

Table 0-18. Recommended average and maximum rates of rise and fall (expressed as the change in discharge of the event divided by the length of the event, ML/day/day)

Reach/Site	Flow Component	Rate of Rise (ML/day/day)		Rate of Fall (ML/day/day)	
		AVG rate of rise	MAX rate of rise	AVG rate of fall	MAX rate of fall
5 Kennedys Creek Catchment	Low Flow Fresh	14	105	6	50
	High Flow Fresh	120	795	65	408

Reach Six – Estuary

The Gellibrand River Estuary and wetlands are a key environmental asset. Flows in these systems are dependent on inflows from contributing catchments (including the Gellibrand River catchment).

The FLOWS method used for the five other reaches of the Gellibrand catchment is not suitable for use on the estuary. Flow recommendations for Reach 4 (inflow to the estuary) have considered the health and water quality of the estuary are will ensure that these objectives are maintained.

The environmental flow needs of the Gellibrand Estuary have been assessed in a report prepared by John Sherwood (2006). A copy of this report has been included in Appendix A, and a summary of the key recommendations included below.

A risk matrix, shown in Table 0-19 below, has been developed to identify flow-related environmental risks as either a low, medium or high threats to the ecological health of the Gellibrand Estuary.

Table 0-19. Risk Matrix for Flow-related Environmental Risks

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

Table 0-20 provides a list of major ecological processes by which reduced estuary flow can impact on estuarine ecosystems. The likelihood of each of the flow related processes being significant for the Gellibrand estuary has also been included, as is an assessment of the severity of consequence should the adverse effects manifest themselves (Sherwood, 2005). The right hand column identifies the risk that each process presents, based on the matrix in Table 0-19 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 0-20. Major ecological processes by which reduced estuary flows can impact estuarine ecosystems (based on Pierson *et al*, 2002 and cited in Sherwood, 2005)

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

Recommendation 1 – Late Winter to Early Spring Flushing Flows

Flow sufficient to remove all salt water from the estuary should occur for 4 to 6 days at least monthly during the period July to October. For each episode initial flushing will require flows of 1500 – 2000 ML/day for 2 – 3 days. Thereafter, flows of 500 – 750 ML/day for 2 – 3 days will prevent re-entry of salt water into the estuary.

Recommendation 2 – Summer/ Autumn Low Flows

Diversion of water should cease when flows fall to 100 ML/day. A key consideration during the summer/autumn low flow period is to reduce the incidence of mouth closure.

Recommendation 3 – Flow Variability

Temporal variability in freshwater inflow is an inherent component of a functioning estuarine environment. Such variability, for example, results in variations in salinity that advantage euryhaline species (capable of tolerating a wide range of salinity) adapted to highly variable salinity regimes. Loss of this variability has the potential to drastically alter community structure, with euryhaline estuary species replaced by stenohaline species (unable to tolerate a wide range of salinity) adapted to either truly marine or freshwater environments.

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

Recommendation 4 – Flow Variability

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

Recommendation 5 – Maintenance of Connectivity

Weirs and other cross-stream barriers can prevent fish migration along rivers. Such barriers break the connectivity between the sea, estuary and river essential for the lifecycles of diadromous fish including galaxids, tupong , eels and the threatened pouched lamprey. They can have a much greater impact on fish populations than reductions in discharge.

Fish passage must be provided for in any proposed works on the Gellibrand River to allow migration of diadromous species between freshwater and the estuary/sea.

Comparison with Upstream Flow Recommendations

The table below compares the flow recommendations for the Estuary with the recommendations established for Reach 4, immediately upstream. The recommendations for comparable for low flows, and the recommendations for high flow freshes in Reach 4 more than satisfy the flow requirement for maintaining estuarine processes downstream.

Table 0-21. Comparison of Flow Recommendations for the Estuary and Reach 4 (immediately upstream of the Estuary)

	Reach 4 Recommendations				Estuary Recommendations			
	Period	Magnitude	Frequency	Duration	Period	Magnitude	Frequency	Duration
Low Flows	Dec-May	≥ 86.4 ML/day (or natural)	Natural flow regime below 86.4ML/d		Summer/ Autumn	≥ 100 ML/day	Always	Continuous
High Flow Freshes	Jun-Nov	≥ 3,284 ML/day	3 per year	3 days	Jul-Oct	1500-2000 ML/day and then 500-750 ML/day	Monthly	4-6 days (2-3 days each)

Flow Recommendation Comparison

A comparison of the recommended flows with the natural, current and full development flow regime is tabulated below. Flows presented are the median seasonal flows and have been derived for the summer (Low Flow) and winter (High Flow) periods. The mean 10th and 90th percentiles have also been included, as indicative of typical seasonal flow variation.

Table 0-1 Flow Comparison

Reach No.	Flow	Low Flow (ML/day)			High Flow (ML/day)		
		Median	***10th Percentile***	***90th Percentile***	***Median***	***10th Percentile***	***90th Percentile***
1 Love Creek	Recommendation	6 (or natural)			26 (or natural)		
	Natural	4	21	3	22	118	7
	Current	3	19	2	22	117	7
	Full	3	18	2	21	116	6
2a Upper Gellibrand	Recommendation	8.6 (or natural)			130 (or natural)		
	Natural	27	94	18	137	354	59
	Current	13	83	8	130	344	50
	Full	13	76	7	127	341	47
2b Upper Gellibrand	Recommendation	13 (or natural)			173 (or natural)		
	Natural	62	212	38	325	916	144
	Current	45	198	26	317	907	134
	Full	42	191	23	313	903	130
3 Carlisle River	Recommendation	5.2 (or natural)			61 (or natural)		
	Natural	17	50	11	96	213	43
	Current	10	40	5	79	199	32
	Full	10	39	5	81	198	32
4 Mid Gellibrand	Recommendation	86.4 (or natural)			259 (or natural)		
	Natural	166	493	104	781	2280	344
	Current	115	444	57	738	2231	306
	Full	109	435	49	732	2222	299
5 Kennedys Creek	Recommendation	2 (or natural)			35 (or natural)		
	Natural	7	40	3	92	480	27
	Current	5	32	2	90	472	24
	Full	5	32	2	90	472	24

The environmental flow recommendations presented in this report are based on the application of the FLOWS method using identified assets and available, justifiable, dependant flow relationships. In Table 0-1 above, it is shown that some of the recommendations, particularly those on the Gellibrand River are lower than the naturally occurring 90th percentile flow. As previously discussed in this report environmental flow investigations and recommendations can be of higher risk for intact systems, than investigations aimed at water recovery for the environment.

In the case of the Gellibrand River it is not possible to say whether all flow dependant assets and processes have been identified and whether all flow dependant relationships have been accurately specified. While this is not dissimilar to other FLOWs investigation, the absence of complete knowledge places a higher risk on the results for the Gellibrand River than investigations for flow stressed systems aimed at water recovery. In other words, the level of confidence in the results may not be commensurate with the level of risk to the Gellibrand River environment.

We recommend that additional and more comprehensive investigations be undertaken for the system prior to finalisation of environmental water requirements for the Gellibrand River.

Supporting Recommendations

There are a number of key supporting recommendations for the implementation of EWR in the Gellibrand River catchment, which include:

a. Develop a Waterway Activity Plan (WAP) for the Gellibrand River catchment

The WAP 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 (gauging station weirs)

The environmental flow recommendations contained within this report have been based on the return of fish passage through the Gellibrand River system. Fish passage provision over the gauging station weirs throughout the reaches of the Gellibrand River system is a factor of the success of the environmental flow recommendations of this study. It is recommended that investigations be undertaken into the feasibility of the provision of fish ladders, fish locks and other means of fish passage over existing instream barriers.

c. Manage water quality inputs to the system

Water quality in the Gellibrand River is impacted to some extent by industrial discharges (agricultural runoff). These inputs are addressed through EPA licensed discharges and best management practice. Ongoing programs will be required to address water quality issues in the Gellibrand River system and catchment.

d. Community engagement regarding meander cut-off management and floodplain billabong connectivity

Removal of barriers and the sustainable management of the Gellibrand River floodplain are required to rehabilitate the condition of floodplain billabongs. This requires community engagement to encourage and facilitate such land management practices.

e. 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 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.

Conclusion

Recommendations presented in this report identify the flow regime required to sustain ecological and geomorphic assets and processes of the Gellibrand River . 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, wetlands, 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 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 Gellibrand River. The impacts of the recommendations are to be analysed through hydrologic modelling by DSE to determine the allocation of water for environmental recommendations and consumptive users. The results of this process, and additional information, will be utilised in the decision making process of determining water allocation along the Gellibrand River for the various environmental and consumptive uses.

References

DNRE (2002) *FLOWS – a method for determining environmental water requirements in Victoria*.

DSE (2005) *Index of Stream Condition: The Second Benchmark of Victorian River Condition*. August 2005

Earth Tech (2004) *NSW Urban Stream Integrity*. Unpublished report to NSW Environment Protection Authority.

Earth Tech (2005a) *Environmental Flow Determination for the Gellibrand River – Site Paper*. Unpublished Report to Corangamite Catchment Management Authority by the Gellibrand River Environmental Water Requirements Technical Panel.

Earth Tech (2005b) *Environmental Flow Determination for the Gellibrand River – Issues Paper*. Unpublished Report to Corangamite Catchment Management Authority by the Gellibrand River Environmental Water Requirements Technical Panel.

GHD (2005) *Gellibrand REALM Development: Model Setup and Calibration Report*. Prepared for Corangamite CMA, August 2005

Koehn, J. D. and O'Connor, W. G. (1990) *Biological Information for Management of Native Freshwater Fish in Victoria.* Government Printer, Melbourne.

LYDEFTP (2004) *Environmental flow determination for the Little Yarra and Don Rivers: Final Recommendations*. Unpublished Report by Little Yarra and Don Rivers Environmental Flow Technical Panel, to Melbourne Water Corporation, Melbourne.

Sherwood, J. (2006) *Environmental Flows Needs of the Gellibrand Estuary*, Unpublished Report, January 2006

Tilleard J.W. (2001) *River channel adjustment to hydrologic change*. PhD Thesis. University of Melbourne.

Appendix A

Environmental Flow Needs of the Gellibrand Estuary

Environmental Flow Determination for the Gellibrand River

Report: Environmental Flow Needs of the Gellibrand Estuary

Associate Professor John Sherwood

Deakin University

Warrnambool Campus

January 2006

1. Nature of the Estuary

(Adapted from Barton and Sherwood 2004)

1.1 General Physical Description

The Gellibrand River headwaters are in the Otway Ranges, draining from the western side of Lavers Hill. The Gellibrand River joins the coast below the township of Princetown. The estuary has only one major tributary, Latrobe (or Serpentine) Creek, which joins the Gellibrand from the west 1.25 km above the mouth (Figures 1 and 2). The wetlands surrounding Princetown have total area of 320 ha and include areas listed as having national importance (Environment Australia, 2001)

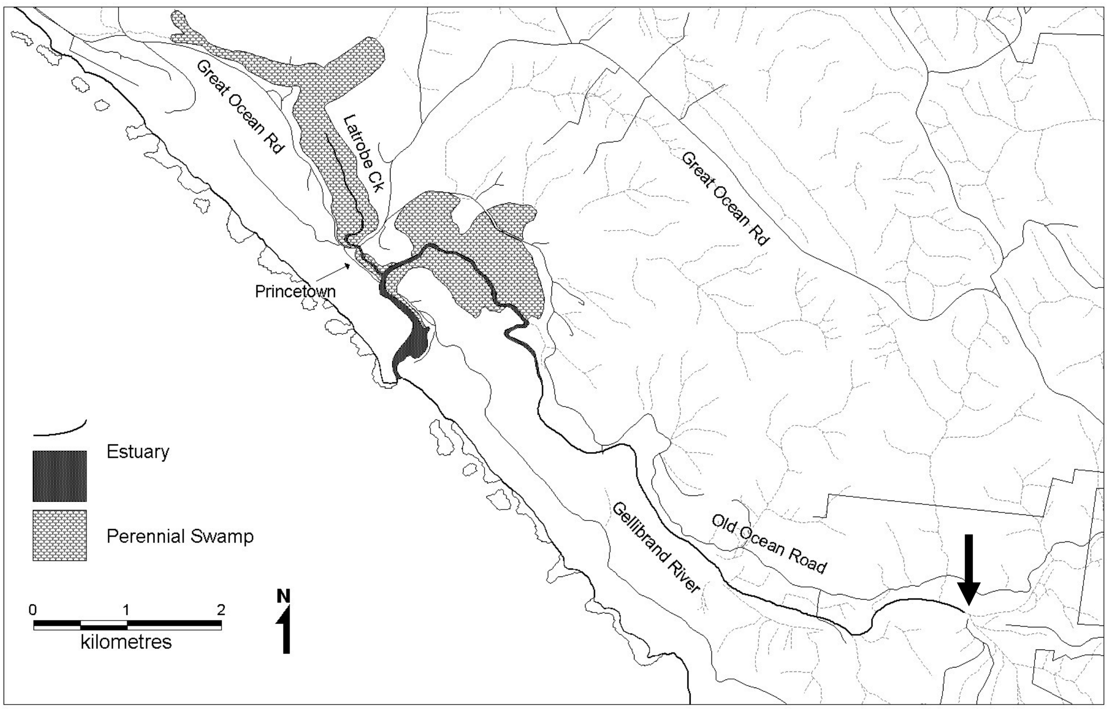


Figure 1: Map of the Gellibrand estuary, and estuary catchment, showing the extent of tidal influence upstream (arrowed) and the area of estuarine waters and wetlands (Map generated from OSRA, 2001).

The estuary, with its tidal and seawater influence has a maximum extent of 10.7 km upstream (Sherwood, 1983). The estuary opens to the east of the high (50 m) cliffs of Pt Ronald, cutting across a sand bar that is approximately 150 m wide, with a typical channel width of 25 - 30 m, and a channel depth of 1 to 1.5 m (Figure 3). Upstream, the channel broadens to up to 50 m wide and 3 m deep, with occasional deeper (6-8m) scour holes at bends, and with wide floodplains. The upper part of the estuary narrows at approximately 3.5 km from the mouth becoming 6 to 20 m wide and 5 to 7 m deep, and with narrow floodplains, and levee banks beside the channel (Figure 2). It is a mature barrier estuary in the final stages of infilling (Roy, 1982).

Figure 2: Aerial photo of the Gellibrand River estuary at Princetown, 23/2/00. (Photo provided by Western Coastal Board; © QASCO; scale approximately 1:25000.)

The upper estuary floodplain is approximately 1 km wide, considerably narrower than that of the lower estuary, and is mostly cleared and drained for dairy pasture. This land is often inundated by floods, which deposit silt. Most of the banks were cleared of vegetation in the early 1900's, to allow horse drawn barges to transport milk and cream to a factory upstream (O'May and Wallace, 2001). There has been some regrowth of *Leptospermun* and *Acacia*, but the majority of the floodplain and estuary banks are without major trees (McKay, 2000).

Figure 3: Aerial photo of the mouth of Gellibrand River estuary near Princetown, 23/2/00. (Photo provided by Western Coastal Board, © QASCO)

Rosengren (1984) has identified a number of sites of State and regional geomorphological importance along the Gellibrand estuary:

(i) La Trobe Creek and its crescent shaped escarpment of Port Campbell limestone. The limestone is a small down faulted outlier overlying Gellibrand marl on the NW side of the Creek valley. Low bluffs on the east of the alluvial valley indicate a previous open water or lagoonal environment in the Creek.

(ii) Point Ronald – a large rocky outcrop forming the western headland at the entrance to the Gellibrand estuary (Figure 3). It consists of aeolian calcarenite but also has the type section for the Clifton Formation – a late Oligicene marine deposit.

(iii) East of Point Ronald a large transgressive sand dune has invaded the river valley (Figures 2 and 3). The present estuary entrance occupies the boundary between this dune and Point Ronald.

(iv) A large gently ridged sand body occurs north of the access road to Princetown recreation reserve and on the eastern side of the estuary. Rosengren has identified this as a relict flood tide shoal with a series of recurring spits developed at a time of greater tidal inflow into the estuary – possibly due to higher sea-level.

In the upper estuary nearly continuous levee banks line the estuary channel. The levee banks are approximately 1 m higher than the surrounding flood plains and are 5 – 10 m wide. They are a significant geomorphic feature of the estuary and are some of the best examples in the State (Rosengren, 1984).

(v) The well-defined levees have resulted in long back swamps where the flood plain meets the valley sides.

(vi) Small hills in the upper valley flood plain are partially buried spurs formed at a time of greater riverine erosion when sea level was lower.

Latrobe Creek enters the Gellibrand 1.25 km above the mouth, where the Gellibrand is 15 m wide. It is a small system, being approximately 2 m deep and navigatable for 2.5 km before it becomes too narrow for a boat. It has a considerable area of wetlands, making up approximately half of the total lower Gellibrand wetland area (Sherwood, 1983). The extent of tidal influence up the Latrobe Creek has not been established. The salinity of Latrobe Creek is generally higher than that of the freshwaters of Gellibrand River. Leaching of salts from the adjoining wetlands may be a cause of this (Sherwood, 1984).

The Gellibrand estuary is shallower than the Hopkins or Glenelg estuaries, which are set in deep canyons with minimal floodplains. The large area of floodplain in the Gellibrand estuary dissipates freshwater flood energy and limits the amount of flood scour.

A large body of work exists on the Gellibrand River and estuary from the early 1980's (Sherwood, 1983 and 1984; Breen, 1982; Earl and Bennett, 1986; Koehn, 1984; Tunbridge and Glenane, 1988). This is because of a major investigation by the State Rivers and Water Supply Commission into the environmental consequences of increased water diversion of the Gellibrand to supply southwestern district towns and Geelong (NREC, 1989). There has also been recent research (Kelly, 2000; McKay, 2000) which formed a basis for the development of an estuary and wetland management plan (O'May and Wallace, 2001) and a review for Parks Victoria (Barton and Sherwood 2004).

1.2 Hydrology

The hydrological study by Sherwood (1983 and 1984) showed the estuary to be a highly stratified "salt wedge" type (Figure 4). The halocline marking the interface between fresher surface water and deeper more saline water can vary from less than 0.2 m to 1m. The upstream end (or "toe") of the wedge is quite truncated and its position in the estuary can be quite sharply defined (± 0.5 km; Sherwood, 1983).

The wedge moves up and down the length of the estuary depending on freshwater flow, tidal flow and storm surges (Figure 5). The maximum measured length of the wedge is 9.5 km (29 Jan 1982; Sherwood, 1983). The likely upper extent of the estuary is at a section of shallow rapids 10.7km upstream that prevents the salt wedge migrating further (Sherwood, 1983). From cross sections along the length of the estuary Sherwood estimated the total estuary water area to be 20.8 ha and the total estuary volume to be 490 ML (Sherwood, 1983). This means that under most flow conditions the residence time of freshwater in the estuary is unlikely to be more than a few days.

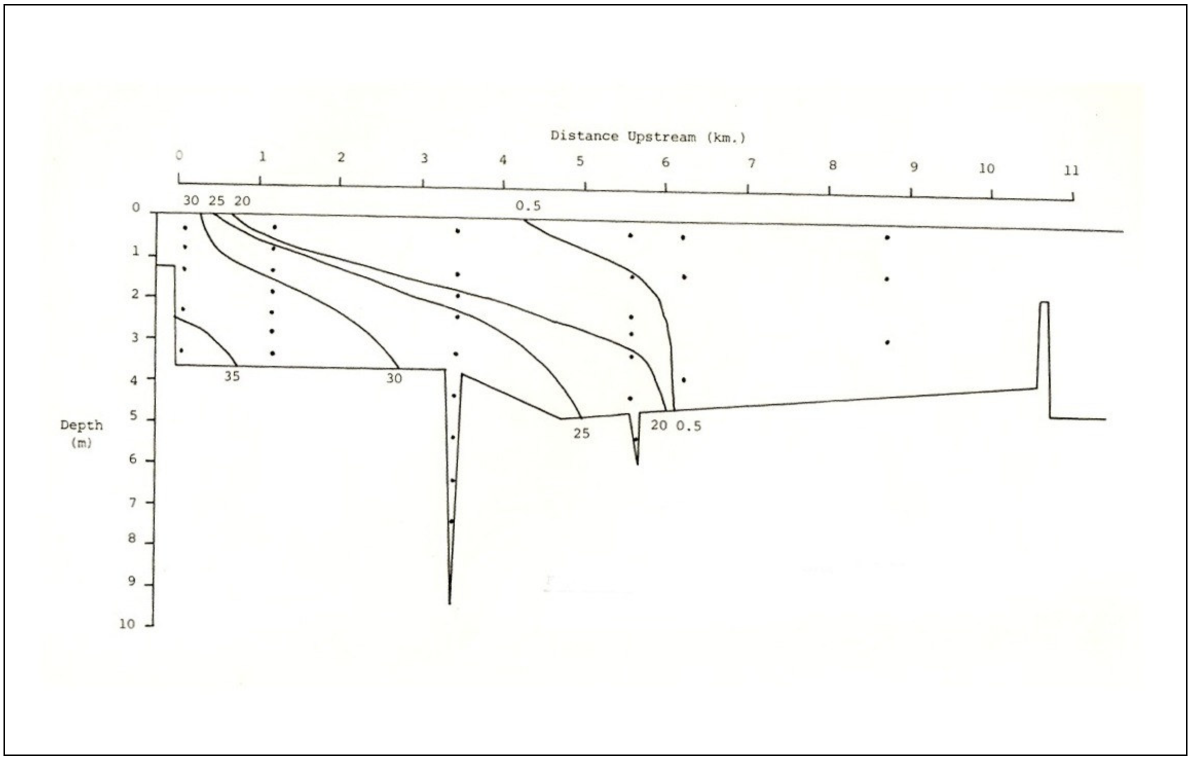


Figure 4: Longitudinal salinity profile of the Gellibrand estuary on 29 July 1982 (Sherwood 1983).

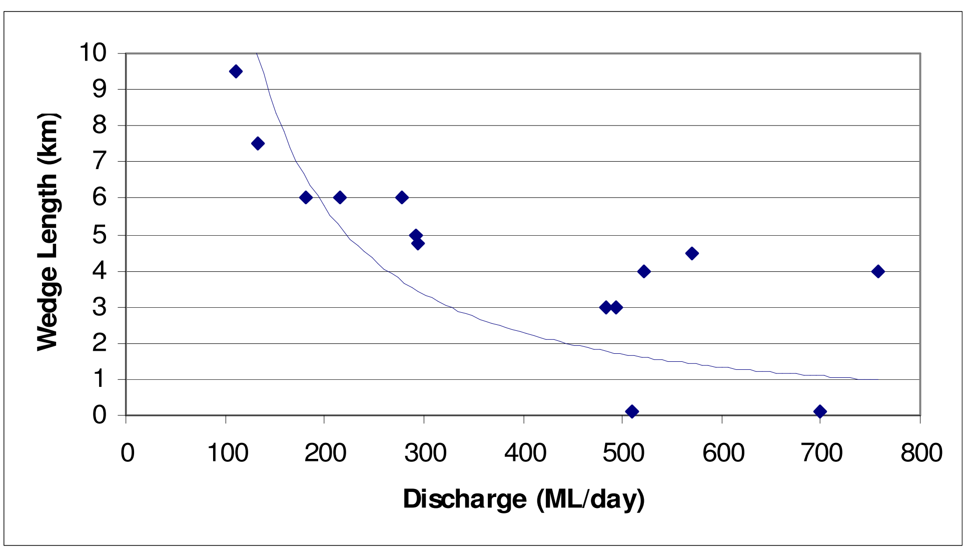


Figure 5: Variation of the salt wedge length with discharge (Sherwood 1983,1984)

Increased freshwater flow in the estuary happens 1 to 4 days after rainfall in the upper catchment (Sherwood, 1984). Peak flows of over 500 ML/day lasted 3 to 5 days during a 1983 study period and flushed the estuary of saline water (Sherwood, 1984). Five days after these peak flows, the salt wedge had returned to the estuary, so complete flushing lasted a short time. Long term hydrological records show daily flows of 500 ML/day are exceeded 75% of the time during winter and 65% of the time during spring (Earth Tech 2005). The estuary in normal rainfall years is likely to be fully freshwater for months. Tides in the Gellibrand estuary have been studied on two occasions and are asymmetrical, the flood tide being shorter than the ebb tide (Sherwood, 1983). High tide can occur within 30 minutes of the predicted high tide for Portland, but may differ by two hours for low tide.

1.3 Environmental Values

The Gellibrand River is highly valued for its still largely natural state, especially in its upper catchment. In its lower reaches the Princetown Wetlands (VIC093) have national recognition in the directory of important Australian wetlands (http://www.ea.gov.au/water/wetlands/database/, 2002). They were included in the directory because of three characteristics:

- It is a good example of a wetland type occurring within a biogeographic region in Australia
- It is a wetland that plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex
- It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge in adverse conditions such as droughts.

The Princetown Wetlands include both the lower Gellibrand wetlands and Latrobe Creek wetlands. Their major ecological features are their extensive beds of Common Reed, and meadows dominated by Beaded Glasswort which can support large numbers of waterbirds. Significant numbers of the Swamp Greenhood occur in this wetland, growing under dense Woolly Tea-tree groves.

Three conservation listed plants have been recorded in the Gellibrand estuary catchment - the Swamp Greenhood, Ruddy Bent and Coast Stackhousia. An additional nine species of listed plants, Leafy Greenhood, Green Leek-orchid, Broad-lip orchid, Short Water Starwort, Long Rope-rush, Velvet Correa, Hairy Shepard's Purse, Bog Gum and Coast Pomaderris, have the potential to occur in the estuarine catchment (Barton and Sherwood 2004).

Only one conservation listed fish has been recorded from Gellibrand estuary, the Pouched Lamprey. In total twenty species of fish have been recorded in the estuary. The high number of native fish species that occur in the Gellibrand places it among Victoria's more important rivers for the conservation of native fish (Smith, 1989). Yellow-eye mullet and black bream numbers dominate estuarine recreational fish populations, and blackfish dominate freshwater populations (Koehn, 1984). The abundance of other estuarine recreational fish species are thought to be low compared with other estuaries in western Victoria (Tunbridge and Glenane, 1988). The Gellibrand River also carries the largest population of blackfish, in both number and size of fish, of any river in Victoria and possibly southeast Australia (Tunbridge and Glenane, 1988) and attracts large numbers of people for fishing, camping and other recreation (Koehn, 1984).

Nine species of conservation listed birds have been recorded in the Gellibrand estuary catchment. These species are the Great Egret, Little Egret, Australian Bittern, Cape Barren Goose, Blue-billed Duck, Grey Goshawk, Letter-winged Kite, Black Falcon, Powerful Owl and Rufous Bristlebird. The Great Egret is protected under JAMBA and CAMBA.

One conservation listed invertebrate (the Otway Black snail), a mammal (Swamp Antechinus) and a reptile (Swamp Skink) have been recorded in the Gellibrand estuary catchment.

1.4 Management Plans

A management plan involving extensive stakeholder consultation has been finalised (O'May and Wallace, 2001). The plan proposes that ongoing management directions be supported by the formation of the Gellibrand River Estuary and Wetlands Advisory Committee (GREWAC) to manage mouth openings and associated procedures.

Strategic directions identified in the plan that directly relate to mouth opening are:

- A flooding cycle for the river which is as close as practicable to natural, with occasional mouth openings managed by the relevant government authorities (CCMA and PV) and the community.
- Wetland ecosystems that are healthy and diverse, and management practices on both public and private land that contribute to its continuing health.

Management directions identified to help achieve these directions are:

- Establishment of an interim river mouth opening protocol which attempts to maintain a flooding regime that is close to natural and protects both the health of the ecosystem and community.
- Establishment of an ongoing research, monitoring and review program that provides a basis to improve management of the flood regime.
- Ensuring that members of the local community that has the most direct interest in flooding are closely involved in management and review of the river mouth opening process.

A Parliamentary enquiry into southwest region water management, decided that no further diversions should occur on the Gellibrand River, and that additional water for Geelong be sourced from groundwater (NREC, 1989). The Gellibrand River is considered a priority environmental flow stream by DSE and it was one of the first in Victoria to have a draft stream flow management plan developed (SRW, 1998).

1.5 Estuary Entrance Opening Regimes and Protocols

The mouth predominantly closes during times of low freshwater flow. During 1982, the mouth was recorded as closed at least seven times, for periods of up to several weeks (Sherwood, 1983). Drought conditions influenced the number and duration of mouth closures. During mouth closures, farm land, formerly natural wetlands, may be inundated as far as 10 km upstream, and the Old Ocean Road is subject to flooding (O'May and Wallace, 2001). In June 2000 the Great Ocean Road had to be closed because of flood waters from mouth closure, with water levels 1.5 to 2 m higher than normal (Kelly, 2000).

The trigger level for considering artificial opening of the mouth is at 1.136 AHD on the Latrobe Creek Bridge (O'May and Wallace, 2001).
The flooding associated with mouth closure has long been considered a problem, and engineering solutions were tried in the early 1900's to prevent mouth closure, and decrease flooding (O'May and Wallace, 2001). Most spectacularly, a tunnel was dug through Pt Ronald, and fitted with a gate so that flood waters could be released. The tunnel silted up soon after construction and the scheme was abandoned. Subsequently a wooden wall was built on the beach at approximately 45^0 to the entrance channel to stop sand from filling it. This apparently worked quite well until large floods washed away the wall, the remaining pylons can still be seen at the mouth.

From measurements of the surface areas of the estuary and wetlands, and river flow rate, the time it would take for the water levels to rise 1 m after mouth closure has been estimated for different flow rates (Table 1; Sherwood, 1983).

River discharge (ML/day)	Flooding time (days)
50	36
100	18
200	9
500	3.6

Table 1: Estimated time, once the mouth is closed, for the water level to rise 1 m under different river flows.

Gellibrand, of all the southwest estuaries, probably has the most detailed licence conditions for artificial opening (O'May and Wallace, 2001). Factors to be taken into account include:

- the amount of rainfall in the upper catchment in the previous 7 days must be more than 60 mm, or
- the streamflows below the North Otway Pipeline must be 100 ML/day, or
- there is no less than 1 m depth of water of more than 5 mg/L DO in the Gellibrand and Latrobe rivers and specified wetland monitoring points

As well as specifying a trigger height, the estuary may be opened if the river mouth has been closed for more than 60 days. The opening protocol also specifies avoiding spring tides (new or full moon) and the three weeks before the opening of duck hunting season. Monitoring, both pre- and post- opening, at specified sites must be carried out, and public safety warning signs erected.

The implications of artificial mouth opening to the Gellibrand have been the focus of recent research (Kelly, 2000; McKay, 2000; Walker, 2001). Fish kills have been observed to accompany mouth openings. In April 2000 large numbers of spawning Common Galaxias, adult smelt and gudgeon were killed when deoxygenated waters filled the main channel from fringing wetlands (Kelly, 2000).

Another study was based around an opening event on 29 March 2001. It included pre- and post- opening sampling of water quality in the estuary and diurnal surveys of DO (Walker, 2001). DO levels in surface waters pre- and post- opening were within the requirements of the management plan (DO > 5 mg/L; O'May and Wallace, 2001). This study concluded that the Princetown Wetlands, particularly the Latrobe Creek Wetlands, may be the most important factor in the health, as measured by DO, of the lower estuary during a mouth opening event. The highest risk area for adverse effects from low DO water was identified as the reach from the mouth to 1 km past Campground Bridge. This work supported the findings of previous studies (Kelly, 2000; McKay, 2000).

A diurnal DO survey measured a decrease in dissolved oxygen amongst wetland vegetation at night (Walker, 2001). It was suggested that this had implications for mouth opening, as most openings occur in the morning, when DO levels would still be low. The lowest concentrations recorded during the decrease in DO over-night however were still above those recommended for safe opening (O'May and Wallace, 2001). More understanding of the factors controlling DO concentrations in the wetlands is necessary to evaluate potential risks of mouth opening.

Corangamite CMA has raised concerns about the risk associated with artificial opening, in particular the affect of the manipulation of wetland water levels by artificial opening and altering the natural flooding regimes of the wetlands (CCMA, 2001).

2. The Estuarine Hydrodynamic Cycle

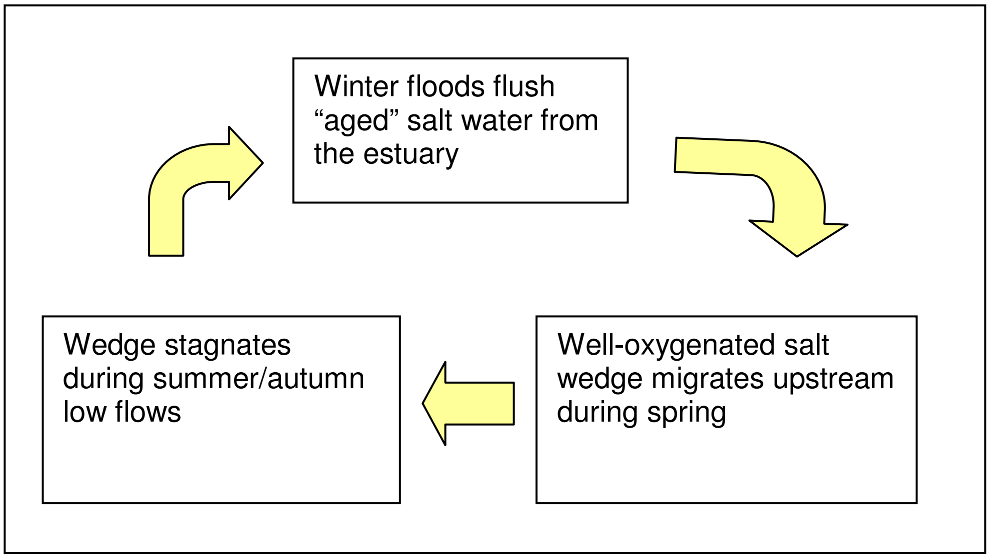


Figure 6: Annual hydrodynamic cycle of west Victorian estuaries (Sherwood, 1985).

A marked seasonal inequality in discharge results in an annual hydrodynamic cycle for western Victoria's estuaries. During winter and spring, high flows may flush all salt water from the estuary, which becomes an extension of the freshwater section of the river for periods up to several weeks (Figure 6). As flows recede through spring and summer, salt water reinvades the estuary. As flow decreases the length of the salt water intrusion increases. Re-entry of well-oxygenated saline water into the estuary appears to be a trigger for breeding in many estuarine organisms, from zooplankton to fish (Newton 1996; Nicholson *et al*, 2004). During summer and autumn, salt water penetrates to its maximum extent and estuarine circulation is reduced. This can lead to extended periods of anoxia or hypoxia in deeper water of the estuary. The aerobic community is then confined to the surface water layer under these conditions – a layer found to be less than 1m thick in some estuaries (Sherwood and Rouse, 1997, Rouse, 1998). Spawning success in some species with floating eggs and/or larval life stages may be compromised by the presence of anoxic saline waters containing high concentrations of toxic substances such as hydrogen sulphide (H_2S) and ammonia (NH_3). The black bream (*Acanthopagrus butcherii*) for example has eggs which float in the halocline as they are neutrally buoyant in water of salinity 16-20 (Nicholson *et al* 2004, Sherwood and Backhouse 1982).

Two important features of the annual hydrodynamic cycle are relevant to the consideration of environmental flows:

(a) Winter flows sufficient to flush salt water from the estuary.
The biological communities of the Gellibrand estuary have adapted to seasonal pulses in river discharge and salt water incursion.These pulses alter salinity spatially and temporally within the estuary. Any alteration to normal patterns of river discharge will affect seasonal salinity cycles within the estuary and may subject estuarine communities to salinity extremes beyond their tolerances or provide suitable conditions for competing organisms. Also, bottom water may be anoxic or

hypoxic and this reduces the availability of water having both adequate dissolved oxygen for respiration and optimal salinity for breeding of estuarine organisms.

(b) Summer/autumn low flows sufficient to maintain estuarine circulation.
Turbulent entertainment of bottom salt water (either generated by wind, river flow or tidal forcing) into surface waters, and the subsequent transport of this from the estuary, allows replacement of bottom water. This reduces the incidence and longitudinal extent of hypoxic/anoxic conditions. Sanding at the estuary entrance can result in its complete closure during summer and autumn. Under these conditions bottom water is not replaced and stagnates. River discharge is a significant factor in maintaining an open estuary entrance.

3. Summary of Flow-related Environmental Risks

Pierson *et al* (2002) have identified 16 major flow-related processes which impact on estuarine environments (Table 2). The impacts have been categorised according to the relative flow magnitude for which their effects are most noticeable. Not all of these will be significant for all estuaries. The likelihood of each of the flow-related processes being significant for the Gellibrand estuary is summarised below, as is an assessment of the severity of consequences should the adverse effects manifest themselves.

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

Table 2: Major ecological processes by which reduced estuary flows can impact on estuarine ecosystems (Pierson *et al.*, 2002)

3.1 Low Flow Conditions.

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

Likelihood – High

Anoxic bottom waters have been detected in the deeper holes of the estuary during times of mouth closure (Sherwood, 1983). Low oxygen concentrations (<5 mg/L) have also been recorded throughout bottom waters under low flow conditions in summer and autumn (Sherwood, 1983; Tunbridge and Glenane, 1988; McKay, 2000; Kelly, 2000). A reduction in freshwater flows will reduce the thickness of the surface oxygenated water in this reach – reducing available habitat for fish and other aerobic organisms.

Reduction in freshwater flow will also increase the frequency of mouth closure. Raised water levels lead to greater inundations of wetlands in La Trobe Creek and the Lower Gellibrand River. Water quality in the wetlands can be poor - high organic loadings result in low DO concentrations or anoxic conditions (Kelly, 2000).

Consequence – Severe

The level of dissolved oxygen in a water body is a critical factor in determining what species can survive in it. Oxygen tolerance of organisms varies and for many common Australian estuarine species is not known. As a general rule oxygen levels less than 50% of saturation pose a threat to fish (Royce, 1972; Hoss and Peters, 1976). Invertebrates can survive in lower levels (Hammen, 1976). Only a few specially adapted organisms can survive in water containing less than 1 ppm DO. The viability of eggs and larvae in contact with anoxic water will be greatly reduced (eg at the halocline).

Mouth closure occurs with greater frequency and for longer duration as river flow is decreased. Prolonged mouth closure leads to a slow rise in water level which may affect the utility of structures such as jetties and boat ramps, loss of access to farmland and flooding of roads and buildings. Mouth closure may also interfere with the migration of fish species into or through the estuary. In some estuaries however, this rise in water level may flood adjoining wetlands and sand flats creating important water bird habitat – particularly during drought periods.

Subsequent opening of the blocked mouth can have a number of harmful effects on estuarine ecosystems. These have been documented in the Gellibrand and also the Surrey estuaries – under certain conditions they include mass mortality of fish and loss of water bird habitat. In one case in the Gellibrand estuary an opening on 15 April 2000 coincided with an aggregation of galaxids which had entered the estuary to spawn. When the mouth of the estuary was opened anoxic water in the fringing wetlands flooded into the main estuary channel preventing oxygenated river or seawater entering for over 2 days – very large numbers of adult galaxids, yellow eye mullet, bream, flounder, shrimp (*Paratya* sp)and other estuarine organisms were killed (Kelly, 2000).

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

Likelihood – Low

Freshwater flows in the Gellibrand River are sufficient to maintain quite fresh (salinity < 5 ppt) surface waters throughout the estuary – even under low flow (< 1000ML/day) conditions (Sherwood, 1983; Tunbridge and Glenane, 1988). This is a result of the relatively small volume of the estuary channel (~ 490 ML; Sherwood, 1983) which ensures efficient dilution of salt water entrained into the surface layer by freshwater discharge. A surface fresh layer of 1 – 2 m depth is common in the estuary throughout the year.

Consequence – Minor

Estuarine organisms may benefit if surface salinities were higher in the upper estuary. Tunbridge and Glenane (1988) have suggested for example, that spawning success and survival of immature bream may be enhanced if freshwater volumes were reduced over the spawning period (spring to early summer). Estuary perch spawning at this time may also be delayed if salinities are too low. They argue that high inflows of freshwater from May to November impose a predominantly freshwater regime on the estuary. Fish such as yellow-eye mullet and brown trout which can tolerate these conditions are more prevalent than species such as bream and estuary perch as a result.

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

Likelihood –Low

Even under the lowest flows the freshwater influence in the lower estuary is sufficient to maintain low surface salinities. Bottom salinities are already strongly marine (>25 ppt) when the salt wedge is present

Consequence – Minor

Marine conditions already exist in bottom waters of the estuary and expansion of these should have little impact on the species present.

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

Likelihood – Medium to Low

A reduction in freshwater flows during summer and autumn could result in increased mouth closure. This will reduce the ability of both tidal currents and freshwater discharge to resuspend eggs and larvae. During high flow conditions it is unlikely that currents would be sufficiently reduced for this factor to be substantially impacted.

Adequate freshwater inflow is required during summer and autumn to establish a well-defined halocline. Density changes of the halocline provide important buoyancy control for eggs and larvae of estuarine species.

Consequence – Severe

The absence of transporting mechanisms could compromise breeding success of susceptible species – altering species composition in the estuary as well as the river – particularly where freshwater species enter the estuary to breed or eggs and larvae must be transported out of the estuary to the sea.

Process 7. Aggravation of pollution problems.

Likelihood – Medium to Low

The major water quality threat to the estuary would be expected to come from eutrophication. Nutrient (ie N and P) concentrations in inflowing water are predominantly "poor" or "degraded" (Kelly, 2000) according to an OCE Index (OCE, 1988). Estuarine concentrations were generally high but within ranges for other SW Victorian estuaries (Kelly, 2000; McKay, 2000). Concentrations of both nutrients in inflowing waters were strongly correlated with discharge (for N, $r = 0.74$; for P, $r = 0.85$; Kelly, 2000).

Algal blooms have not been recorded in the Gellibrand River (O'May and Wallace, 2001). Reduction in river flow may create more favourable conditions for algal growth and increase their residence time in the estuary, particularly during summer and autumn.

Consequence – Severe

Any increase in the incidence of algal blooms threatens other species and reduces the recreational amenity of the estuary.

Corangamite CMA has ranked the Gellibrand as "high priority" for its algal bloom potential (CCMA, 2000) based on 5 criteria including biodiversity value, risk of bloom and scale of potential impact.

Process 8. Reduced longitudinal connectivity with upstream river systems.

Likelihood –Medium to Low

There are no barriers to fish migration along most of the Gellibrand River. Alterations to river flow are unlikely to impact on connectivity with upstream reaches.

The Gellibrand estuary supports at least 18 native fish and a single introduced species (brown trout – *Salmo trutta*). The estuary contains the same species of fish sought by anglers as other west Victorian estuaries. Populations of most species however, are significantly lower than in these estuaries (Tunbridge and Glenane, 1988).

The pouched lamprey (Geotria australis) has a restricted distribution which includes the Gellibrand River and is classified as threatened in Victoria (McKay, 2000). It moves upstream to spawn and then ammocoetes pass through the estuary to the sea. Not much is known of its life history but it is thought to be similar to the short-headed lamprey (Cadwallader and Backhouse, 1983).

Period	Fish Activity
Dec-Feb	Adult short-finned eels leave the estuary to spawn at sea.
March- Nov	Juvenile common galaxias run upstream from the estuary.
May-July	Adult tupong and common galaxias run downstream into the estuary to spawn. Glass eels enter the estuary from the sea.
Oct-Nov	Brown elvers run upstream from the estuary. Adult lamprey run upstream to spawn in fresh water. Blackfish move to spawning sites in the river. Adult short-finned eels move from freshwater into the estuary.

Table 3: Seasonal movement of fish in the Barwon River and estuary (Modified from Tunbridge, 1988)

Some fish species migrate between the estuaries and the sea and/or freshwater reaches of the river. Table 3 is adapted from a report on fish migration in the Barwon River and demonstrates the importance of maintaining connectivity at the estuary entrance Reductions in flow may lead to increased frequency and/or duration of mouth closure.

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.

3.2 Middle-High Flow Conditions.

Processes 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 – Low

Generally high flows in winter are able to remove all salt water from the estuary and so expose the bottom sediments to fast flowing river water. Even deep holes in the estuary are completely fresh under current winter/spring flows. A very significant reduction in winter flows would be needed to interfere substantially with this process.

During low flow periods weaker tidal currents are unlikely to remobilise bottom sediments.

Consequence – Moderate to Severe

In the absence of scouring flows accumulation of fine organic matter on the estuary floor, combined with an increased incidence of mouth closure may lead to more extensive episodes of anoxia in bottom waters.

Process 11. Reduced channel maintenance processes.

Likelihood – Low

Present high winter/spring flows:

- scour the estuary channel
- over top banks adding sediment to levee banks and flood plains
- refill wetlands, and;
- shift sand in the entrance channel seawards.

A substantial reduction in winter flows would be needed to reduce the effectiveness of these processes.

Consequence – Severe

Loss of flood flows would result in an increased rate of sedimentation in the estuary. Under low flows reduction in estuary entrance cross-sectional area would reduce tidal exchange and increase periods of mouth closure.

Process 12. Reduced inputs of nutrients and organic material.

Likelihood – Low

The estuary already has elevated nutrient concentrations and input waters have high nutrient loads. Catchment management aims to reduce the concentrations of nutrients and suspended solids in streams in the region

Consequence – Minor

Any reduction in nutrients entering the estuary will probably be beneficial – reducing the probability of algal blooms.

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

Likelihood – Medium

Flooding frequency of the wetlands adjacent to the open waters of the lower estuary is an important determinant of the composition of their vegetation communities. Robson et al (2002) studied macroinvertebrate communities of fringing floodplain wetlands along the estuary and found them to be dominated by freshwater species. Diversity was relatively high (67 taxa from 39 families) and varied between wetlands and over time. These wetlands rely on flooding for replenishment of water. Currently upstream backwater wetlands may dry out completely during summer and autumn. Reduced flows could increase the frequency and duration of dessication.

Consequence – Severe

A reduction in freshwater floods will reduce the viability of fringing flood plain wetlands. During low-flow periods prolonged mouth closure may result in unseasonal flooding of wetlands with more saline waters for extended periods. This may lead to deterioration of vegetation communities and loss of some plant and animal species. Local landholders have reported a deterioration in wetland macrophyte in the lower estuary during prolonged autumn flooding (O'May and Wallace 2001).

3.3 All Flow Conditions.

Process 14. Altered variability in salinity structure.

Likelihood – Medium

The organisms of the estuary have adapted to the annual hydrological cycle of the Gellibrand River. This is characterised by winter/spring floods and summer/autumn low flows. Long periods of constant flow do not naturally occur. In low flow conditions small increases in flow ("freshes") change salinities in the estuary and contribute to entrance maintenance.

As previously discussed, the impacts of altered flow regimes on the hydrodynamic cycle have important implications for the distribution of organisms and the breeding success of some species

Consequence – Minor

The relative insensitivity of surface water salinity to changes in river discharge make it unlikely flow changes would alter the estuary's community structure.

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

Likelihood – Low

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, could reduce recruitment of diadromous fish in the catchment. The salinity of outflowing surface waters however, is not greatly altered by changes to river discharge.

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

Present spring flows regularly exceed the capacity of the estuary channel. Water dissipates is energy as it spreads across the wetlands and flood plains of the estuary.

Higher water velocities will be maintained in the central estuary channel unless substantial reductions in winter flows occur.

Consequence – Minor (?)

The species requiring such velocity dependent physical habitat have not been identified in the estuary.

4. Draft Management Recommendations.

4.1 Key Characteristics of Environmental Flows.

Given uncertainties over the ecological effects of changes in flow to estuaries these recommendations for environmental flows are based on the principle that:

diversion of water from river systems should not disturb the major features of the estuarine hydrodynamic cycle.

In the case of estuaries in Western Victoria, this means that the following key characteristics should be maintained.

(i) Late winter to early spring flows sufficient to flush “aged” salt water from the estuary and allow migration of a well-oxygenated salt water upstream as the flows reduce.

(ii) Flows sufficient to maintain a salinity gradient both vertically and horizontally. The gradients should ensure that water over the range of salinities from fresh to strongly marine is present in the estuary most of the time.

(iii) Avoidance of long periods of constant flow. The inherent variability of stream flow (including periods of cease-to-flow conditions if naturally occurring) should be maintained. This will require short periods when higher flows (“spates” or “freshes”) enter the estuary. These serve also to improve the flushing characteristics of the estuary.

4.2 Late winter to early spring flushing flows

Recommendation 1.

Flow sufficient to remove all salt water from the estuary should occur for 4 to 6 days at least monthly during the period July to October. For each episode initial flushing will require flows of 1500 – 2000 ML/day for 2 – 3 days. Thereafter flows of 500 – 750 ML/day for 2 – 3 days will prevent re-entry of salt water into the estuary.

This recommendation is based on an analysis by Tunbridge and Glenane (1988) of 80 longitudinal surveys of estuarine salinity. These authors studied data collected by Sherwood (for 1982 and 1983), the Fisheries Division of the Department of Conservation, Forests and Lands (for 1986 and 1987) and their own data (for 1982 to 1984).

Assuming 1500 Ml/day would maintain freshwater in the estuary Tunbridge and Glenane (1988) compared this flow to measured flows between 1969 and 1983. They found the estuary was likely to be totally fresh for between 34 to 215 days in any year (mean value = 106 days). Only in 1982 was the estuary saline for a complete year.

Table 4 summarises a more recent analysis (Earth Tech 2005) of flow exceedence curves for the most downstream gauging station at Burrupa (Stn:235224) – approximately 20km above the estuary. This data shows that in winter and spring flows of the magnitude proposed here are relatively common. Current and modelled natural flows of the Gellibrand are virtually identical for winter and spring showing diversions have had little effect on hydrology over these seasons.

Flow	% of Time Exceeded

(ML/day)	winter	spring	summer	autumn
100	nd+	nd	80*	80
500	75	70	10	10
1500	30	20	nd	nd
2000	20	10	nd	nd

Table 4: Seasonal variation in the percentage of time river flow exceeds nominated discharges at the Burrupa gauging station (Earth Tech 2005)
+ nd = not determined for this report
* Under modelled natural flows exceed 95% of the time in summer.

4.3 Summer/Autumn Low Flows

Recommendation 2.

Diversion of water should cease when flows fall to 100 ML/day. A key consideration during the summer/autumn low flow period is to reduce the incidence of mouth closure.

The cross-sectional areas of the mouth was measured on various field surveys by Sherwood (1983, 1984), McKay (2000) and Kelly (2000). A correlation of estuary entrance cross-sectional area against discharge of the previous day gave $r^2 = 0.61$ (N = 21; Figure 7). The coefficient of determination (r^2) varied only slightly from this value if discharge on the day of measurement or 2 days prior was used. This result indicates that 60% of the variability in entrance cross-sectional area can be attributed to discharge. Part of the scatter in data for Figure 7 may be related to artificial mouth opening. During 1982 (unusually dry year) the entrance was deliberately opened 9 times, in 1999 it was opened twice and in 2000 at least 5 times (McKay, 2000; Kelly, 2000). Some measurements may have been unknowingly made just after a deliberate opening.

River discharge is an important but not the sole determinant of whether an estuary mouth remains open (Sherwood et al, 2003). Tunbridge and Glenane (1988) for example, report that the entrance closed on 29 November 1983 despite high (>420 ML/day) flows for 23 consecutive days prior to this. Sherwood (1983) reported that the mouth was nearly closed (area ~ $2m^2$) on 29 July 1982 even though flows exceeded 250 ML/day for over one month prior to this.

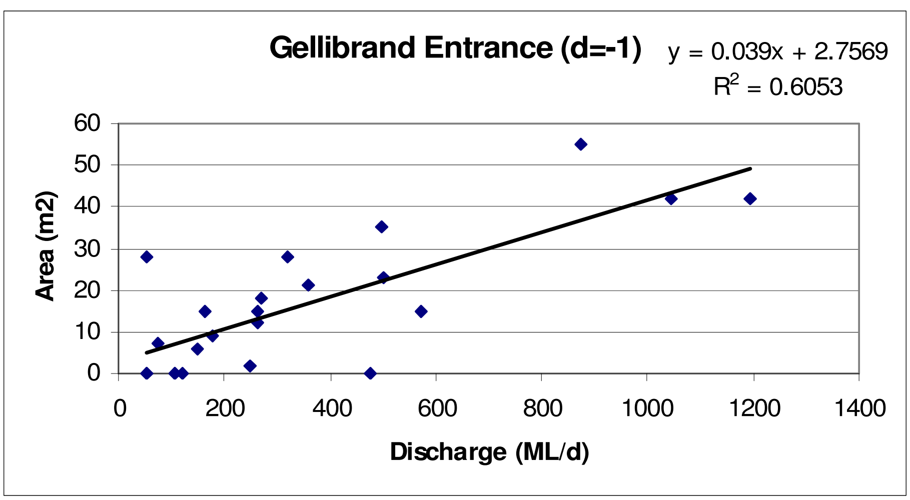


Figure 7: Variation of Gellibrand estuary entrance cross-sectional area with discharge on the day prior to measurement (ie d=-1).

Other factors that may influence mouth state include changes in astronomical tidal amplitude during the spring-neap tidal cycle and changes in sea level due to atmospheric pressure, wind speed and direction and wave height (known as the meteorological tide). These all directly affect the energy of ocean water and its ability to shift sand along the coast. Wave energy is able to resuspend sand and currents then transport it. Once the water velocity drops (as when seawater enters an estuary entrance or travels up a beach face as wave swash) its capacity to hold sand in suspension decreases and the sand is deposited. On Southwest Victoria's micro-tidal coast even small changes in sea level or wave height can cause significant changes in the location of sand deposition zones.

Astronomical tides (predominantly due to the sun and moon) vary in amplitude by up to 1m over an approximately 15 day period in southwest Victoria. During spring tides the capacity of seawater to transport water and sand into the estuary is greater than during neap tides.

Atmospheric pressure change leads to sea-level variations by what is known as the "inverse barometer effect" (Beer, 1983). Sea level rises under low pressure systems and is depressed under high pressure, theoretically by a factor of 1.01cm.mbar^{-1}. Hamon (1966) found that sea level actually changed by 1.26cm.mbar^{-1} at Port McDonnell, South Australia (28 km west of the Victorian border). Hamon concluded that the inverse barometric effect thus accounted for about 80% of non-tidal sea-level variation, with sea level lagging pressure change by less than half a day. Pressure systems move through southwest Victoria every 5-15 days with speeds of 700-800 km.day^{-1} (Morrow, 1984) resulting in pressure changes of up to 40 mbar. Sea level may therefore change by up to 50cm as a result. This is comparable to the tidal range and so has a significant effect on salt water and sand intrusion into the region's estuaries.

In western Victoria, on-shore winds from the southeast to southwest are common in all months and may reach speeds up to 30 knots. Such strong winds are often associated with low pressure and cold fronts. Wind stress associated with these winds can move water towards the coast – raising sea level near the shore. Sand and salt water are transported further inland under these conditions.
The off-shore winds (north to north-westerly) of up to 20 knots which often follow high pressure systems have the reverse effect.

A study by Nelson and Keats (1981) of meteorological tides at the entrance to the Barwon estuary between 1975 and 1977 indicated that about 60% of the meteorological tide could be attributed to a combination of atmospheric pressure and the westerly vector of wind velocity. They found that actual still water sea levels could be between 0.5m higher and 0.3m lower than predicted from astronomical tides. This analysis made no allowances for wave height or wave run-up.

Large waves generated by storms in the Southern Ocean may arrive at the coast any time. Such waves may have originated thousands of kilometres from Australia. They can overtop the sand bar at an estuary mouth and add significant volumes of sea water and sand in a short time. In April 1994 for example, the Hopkins estuary level rose 10cm in 6 hours due to this effect (Rouse, 1998).

Mouth State	Q (ML/day)	Date	Reference
Closed*	99	29 Jan 1982	Sherwood (1983)
	154	31 Mar 1982	Sherwood (1983)
	420	29 Nov 1983	Tunbridge and Glenane (1988)

	55	23 Mar 2000	Kelly (2000)
	53	4 Apr 2000	Kelly (2000)
	119	5 May 2000	Kelly (2000)
Open+	174	31 Aug 1982	Sherwood (1983)
	153	31 Mar 1982	Tunbridge and Glenane (1988)
	64	Apr 1982	Tunbridge and Glenane (1988)
	44	7 Jan 1983	Tunbridge and Glenane (1988)
	133	19 Nov 1999	Kelly (2000)

Table 5: Relationship of low flows to mouth state for the Gellibrand estuary.

* Highest discharge at which entrance was closed.
\+ Lowest discharge at which entrance was open.

Thus, the interplay of river discharge and sea state at any time will determine whether there is a nett accumulation or erosion of sand at the estuary entrance. Changes in one or the other can alter the balance between them over time scales of a day or less. This becomes most critical when the rate of sand erosion by river flows is close to the rate of sand deposition by seawater. The dynamic nature of the processes means that under these conditions the estuary entrance may be closed or may re-open in response to subtle changes in one of the sea or river conditions. At higher flows the range of sea states may never result in sand deposition rates which exceed the river erosion rates and the estuary remains open. At low flows the mouth may be closed because river water erosion is always insufficient to scour sand brought into the entrance by wave action. It is thus important to realise that at the minimum flow specified here (100ML/day) the mouth may not be open at all times. Closure under these minimum flows however, would not be expected to be of long duration. The higher the flow the less likely it is that temporary closures will occur.

Table 5 summarises data for the highest discharges observed while the entrance was closed and the lowest flows while the mouth was open. The flow in Recommendation 2 is based on these values - which are centred on 100ML/day. Flow exceedence data (Table 4) indicates that this flow is currently exceeded 70% of the time in summer and autumn. Under modelled natural flows it was exceeded 95% of the time. Current water diversions would thus be expected to have increased the likelihood of mouth closure in these seasons.

4.4 Flow variability

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

Recommendation 3.

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

Recommendation 4.

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

4.5 Maintenance of Connectivity

Weirs and other cross-stream barriers can prevent fish migration along rivers. Such barriers break the connectivity between the sea, estuary and river essential for the lifecycles of diadromous fish including galaxids, tupong , eels and the threatened pouched lamprey. They can have a much greater impact on fish populations than reductions in discharge.

Recommendation 5.

Fish passage must be provided for in any proposed works on the Gellibrand River to allow migration of diadromous species between freshwater and the estuary/sea.

References

Barton J. and Sherwood J. (2004) *Estuary Opening Management : Information Analysis*, Parks Victoria, Technical Report No. 11, Melbourne, Victoria (105pp).

Beer, T. (1983). *Environmental Oceanography : An Introduction to the Behaviour of Coastal Waters*. Pergamon Press, Oxford.

Breen, P. (1982). *Gellibrand River Riparian and Aquatic Vegetation Survey*. Arthur Rylah Institute for Environmental Research, Heidelberg.

Cadwallader P.L. and Backhouse GH.N. (1983) *A Guide to the Freshwater Fish of Victoria,* Ministry for Conservation., Melbourne, Victoria.

CCMA. (2000). *Corangamite Regional Nutrient Management Plan*. Corangamite Catchment Management Authority, Colac, Victoria.

CCMA. (2001). *Draft Waterway Health Strategy*. Corangamite Catchment Management Authority, Colac, Victoria.

Earl, G. E. and Bennett, A. F. (1986). *A survey of the flora and fauna in four catchments of the Gellibrand River Basin, Otway Ranges, Victoria*. Arthur Rylah Institute for Environmental Research, Department of Conservation, Forests and Lands, Heidelberg.

Earth Tech (2005) *Environmental Flow Determination for the Gellibrand River: Technical Panel Field Trip Notes*, October 2005.

Environment Australia (2001) *A Directory of Important Wetlands in Australia*. Environment Australia, Canberra, 3rd Edition.

Hammen C.S. (1976) Respiratory Adaptations:Invertebrates In *Estuarine Processes – Volume 1*, Wiley M. (ed) Academic Press, New York, 347 -355.

Hamon, B. V. (1966). Continental shelf waves and the effects of atmospheric pressure and wind stress on sea level. *Journal of Geophysical Research*, 71: 2883-2893.

Hoss D.E. and Peters D.S. (1976) Respiratory Adaptations –Fishes, In *Estuarine Processes – Volume 1*, Wiley M. (ed) Academic Press, New York, 335 -346.

Kelly, L. (2000) *The Management of Ecological Impacts of Nutrients, Vegetation and River Mouth Opening Processes in the Gellibrand River Estuary and Wetlands,* Honours Thesis, School of Ecology and Environment, Deakin University, Warrnambool.

Koehn, J. D. (1984*). Survey of angling and recreational use of the Gellibrand River, south-western Victoria*. Arthur Rylah Institute, Department of Conservation and Lands, Heidelberg.

McKay, S. (2000) *The Ecology and Management of the Gellibrand Estuary and Wetlands,* Honours Thesis, School of Ecology and Environment, Deakin University, Warrnambool.

Morrow, R. A. (1984). The movement of pressure systems across Bass Strait. *Bass Bulletin*, No.5, May: 6-7.

NREC. (1989). *Inquiry into water resources management in Victoria: South-Western region management strategy*. Natural Resources and Environment Committee, Melbourne.
Nelson, R. C. and Keats, A. J. (1981). Design sea levels for the Victorian Otway coast, in *Fifth Australian Conference on Coastal and Ocean Engineering, Proceedings*. Perth (pp. 252-257).

Newton G.N. (1996) *Estuarine ichthyoplankton ecology in relation to hydrology and zooplankton dynamics in a salt-wedge estuary*, Marine and Freshwater Research, 47:99-111.

Nicholson G, Sherwood J, Jenkins G and Longmore A (2004) *Effects of Environmental flows on the spawning success of resident black bream in estuarine environments.* Primary Industries Research, Queenscliff, Victoria. Report No.23, June 2004 (68pp)

OCE (1988) *State of the Environment Report 1988: Victoria's Inland Waters*, Office of the Commissioner for the Environment, Melbourne Victoria.

O'May J. and Wallace G. (2001) *Gellibrand River Estuary and Wetland Management Plan,* Centre for Environmental Management, University of Ballarat.

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).

Robson B.J., Sherwood J., McKay S.F. and Kelly L.M. (2002) *Floodplain wetlands of the Gellibrand estuary: What type of community ?*, Ecological Management and Restoration, 3(2), 139 -141.

Rosengren, N. (1984) *Sites of Geological and Geomorphological Significance in the Shire of Otway*, Dept of Conservation , Forests and Lands, Melbourne, Victoria.

Rouse, A. (1998). *Annual phytoplankton and nutrient fluctuations in the Hopkins Estuary*. PhD Thesis, Deakin University, Warrnambool.

Roy, P. S. (1982). Evolution of NSW Estuary Types, in *Symposium on Management of Estuaries*. Water Research Foundation of Australia Ltd, Sydney.

Royce W.F. (1972) *Introduction to the Fishery Sciences* Academic Press, New York, 119-120.

Sherwood, J.E. (1983). *Hydrodynamics of the Gellibrand River Estuary*. Faculty of Applied Science and Technology, WIAE. Research Report 83-1. Prepared for the Rural Water Commission, Victoria (102pp).

Sherwood, J.E. (1984) *Hydrodynamics of the Gellibrand River Estuary (Part 2)*. Faculty of Applied Science and Technology, WIAE. Research Report 84-1, April, 1984. Prepared for the Rural Water Commission, Victoria (84pp).

Sherwood, J. E., (1985). *Hydrodynamics of South West Victorian Estuaries*. Faculty of Applied Science and Technology, WIAE, Research Report 85-1.

Sherwood, J. E. and Backhouse, G. N. (1982). *Hydrodynamics of salt wedge estuaries: Implications for successful spawning in black bream (Acanthopagrus butcheri).* Warrnambool Institute of Advanced Education, Warrnambool.

Sherwood J., Fenton C. and Mondon J. (2003) *Environmental Flow Needs of the Barham River Estuary*, School of Ecology and Environment, Deakin University, Warrnambool, Victoria.

Sherwood, J. and Rouse, A. (1997). Estuarine chemistry - primordial soup Down Under! *Chemistry in Australia*, August 1997: 19-22.

Smith, I. (1989). *Management of fish resources in the Otway Forest as part of the Otway Forest Management Plan*. Department of Conservation Forests and Lands, Colac.

SRW (1998) *Draft Gellibrand River Streamflow Management Plan,* Southern Rural Water, Maffra, Victoria, May 1998.

Tunbridge B.R. (1988) *Environmental Flows and Fish Populations of Waters in the South-western Region of Victoria.* Arthur Rylah Institute for Environmental Research, Dept of Conservation, Forests and Lands, Melbourne, Victoria (140pp)

Tunbridge B.R. and Glenane T.J. (1988) *A Study of Environmental Flows Necessary to Maintain Fish Populations in the Gellibrand River and Estuary,* Arthur Rylah Institute for Environmental research, Melbourne Victoria.

Walker, M. (2001). *Implications of river mouth opening at the Gellibrand River Estuary, Victoria*. Deakin University, Warrnambool.