

# ENVIRONMENTAL FLOW DETERMINATION OF THE LODDON RIVER CATCHMENT

## Part A - Final Report

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**Acronyms/Abbreviations Used in this report:**

BE	Bulk water Entitlements
CMA	Catchment Management Authority
CRC	Co-operative Research Centre
EFSP	Environmental Flows Scientific Panel
FEM	The Flow Events Method
FLOWS	The “Statewide Method for Determining Environmental Water Requirements”
GMW	Goulburn Murray Water
NRE	Department of Natural Resources and Environment
SKM	Sinclair Knight Merz Pty Ltd.
Scientific Panel	The Loddon River Environmental Flows Scientific Panel
VHRS	Victorian River Health Strategy

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# 1. Introduction

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This report details the final deliberations of the Loddon River Environmental Flows Scientific Panel (the “Scientific Panel”) and presents environmental flow recommendations for reaches of the Loddon River. The recommendations are to be used in the development of Bulk water Entitlement (BE) conversions in the Loddon River.

The study area in this report covered the Loddon River between Cairn Curran and Laanecoorie Reservoirs, Tullaroop Creek between Tullaroop and Laanecoorie Reservoirs, and the Loddon River from Laanecoorie Reservoir to the confluence with the River Murray. This study does not consider environmental flow requirements for wetlands in the lower portion of the catchment that have a hydrology largely controlled by operation of the River Murray, nor wetlands in the upper catchment largely influenced by the Loddon River.

The study used the general framework of the standardised Statewide method for determining environmental water requirements in Victoria, referred to as the FLOWS method (SKM *et al*, 2002), with the addition of elements of the Flow Events Method (FEM) developed by the CRC for Catchment Hydrology (Stewardson and Cottingham, 2002), to derive environmental flow recommendations for six reaches in the Loddon River.

The recommendations for environmental flows were made under the general framework of the Draft Victorian River Health Strategy (NRE, 2002). The overall objective of the Strategy is to achieve:

*“healthy rivers, streams and floodplains which meet the environmental, economic, recreational and cultural needs of current and future generations”* (Draft Victorian River Health Strategy – VRHS - NRE 2002, p. 8).

An ecologically healthy river has flow regimes, water quality and channel characteristics such that:

- *“in the river and riparian zone, the majority of plant and animal species are native and no exotic species dominates the system;*
- *natural ecosystem processes are maintained;*
- *major natural habitat features are represented and maintained over time;*
- *native riparian vegetation exist sustainably for the majority of its length;*
- *native fish and other fauna can move and migrate up and down the river;*
- *linkages between river and floodplain and associated wetlands are able to maintain ecological processes;*
- *natural linkages with the sea or terminal lakes are maintained; and*
- *associated estuaries and terminal lake systems are productive ecosystems.”* (VRHS, p. 29).

This definition has significant implications for the development of environmental flow recommendations. Specifically, it allows systems to be managed in a modified state, compared to natural or pristine. While full restoration of degraded or modified ecosystems should always be seen as the most desirable outcome, this may not be possible due to factors which cannot be substantially altered (e.g. releases downstream of irrigation reservoirs). The VRHS provides for the possibility to manage the system in a modified state, providing that state has the characteristics of a healthy ecosystem and is sustainable.

## Outline of this Report

Section 2 of this report presents an outline of the methods used in this study – the FLOWS and FEM methods.

A summary of the Environmental Flow Objectives for the entire study area is presented in Section 3. The derivation of these are described in more detail in the Issues Paper (LREFSP, 2002). The Issues Paper is included as an adjunct to this report as Part B.

The flow recommendations for each reach are then presented in Section 4 in a standard format with five individual sections: a summary of the reach condition (the major environmental issues in the reach), the Biodiversity Objectives (the ecological objectives of environmental flows), flow recommendations (the flows that should achieve the ecological objectives) with justifications, supporting information (cross-section plots and results of hydrologic/hydraulic analysis), and supporting recommendations (non-flow related issues that require attention in order that the flow recommendations will achieve their intended objectives).

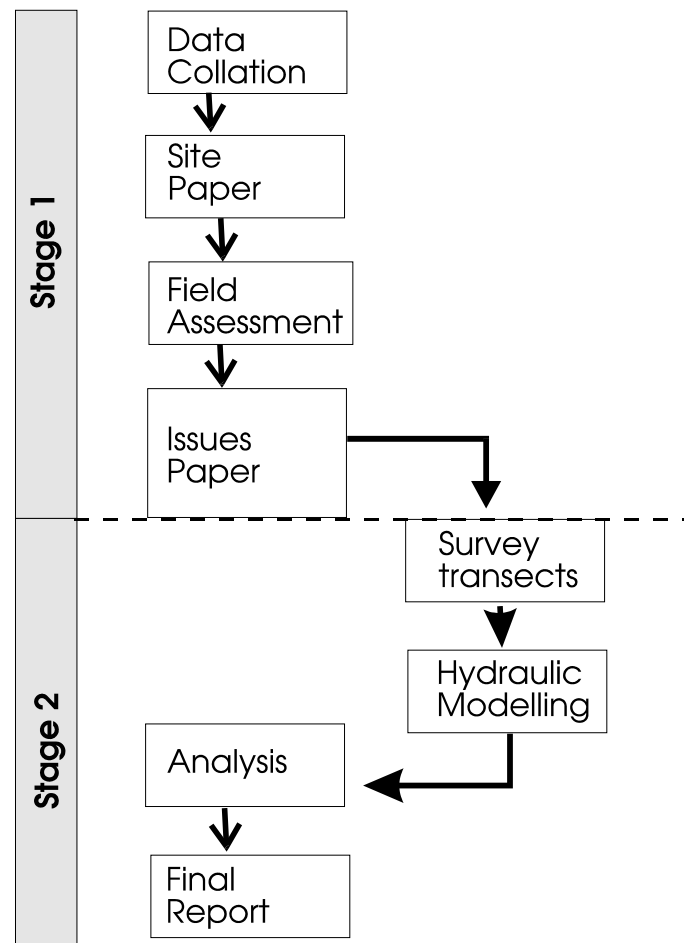
The report also includes a discussion of the methods used in this study, including the value of the FEM as an additional component of the FLOWS method (Appendix 1).

Please note that the Final Environmental Flow Recommendations report should be read in conjunction with the Issues Paper, included as an adjunct to this report as Part B.

## 2. Methods

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The study used the general framework of the standardised Statewide method for determining environmental water requirements in Victoria, referred to as the FLOWS method (SKM *et al.* 2002). The FLOWS method is targeted at developing environmental flow objectives for the study area and developing flow recommendations to meet those objectives. The major components of FLOWS is shown in Figure 1 and are described in the following sections.



**Figure 1. Outline of the steps in the FLOWS method.**

### 2.1 Data Collation

Initially, available information on the ecology and hydrology of the study area that was deemed necessary to formulate environmental flow recommendations was collected. This information was derived from both published and unpublished sources (including unpublished reports and unwritten advice from selected individuals).

### 2.2 Site Paper

The available information was used to identify key reaches and sites within the study area. Natural zones with similar biodiversity values (fish, macroinvertebrates and vegetation), hydrology (reflecting

the influence of tributary inflows or distributory outflows), geology and geomorphology were identified. The reaches selected therefore represent regions with similar natural attributes (and hence, different reaches will have different biodiversity objectives, which may require different environmental flow recommendations).

Six reaches were identified in the Loddon River study area. Fortuitously, the reaches based on natural zones fitted well with reaches delineated by major water resource development structures, which should simplify the incorporation of the recommendations into the BE conversion process:

- Reach 1 - Cairn Curran Reservoir to Laanecoorie Reservoir;
- Reach 2 - Tullaroop Reservoir to Laanecoorie Reservoir;
- Reach 3a - Laanecoorie Reservoir to Serpentine Weir;
- Reach 3b - Serpentine Weir to Loddon Weir;
- Reach 4 - Loddon Weir to Kerang Weir; and
- Reach 5 - Kerang Weir to River Murray.

Within each reach, a site was selected which was representative of the key features within the reach (Figure 2). These representative sites were used in the detailed analyses to assist in quantifying environmental flow recommendations.

The Site Paper, and further information on reach selection is presented in the Issues Paper, included as an adjunct to this report as Part B.

## **2.3 Field Assessment**

A rapid field assessment of the selected sites was conducted by the Scientific Panel. The field inspection allowed the Scientific Panel to gain an overall impression of the landscape, assess the suitability of representative sites selected for each reach, identify simple environmental indicators appropriate for each reach, and discuss cross-discipline issues. Major river features at representative sites were documented during the field assessment at a general descriptive scale (for example, substrate is described as sand or clay, without actually measuring particle size). During the field assessment, the Scientific Panel was able to make a judgement of the likely important flow components at a site by noting any physical features likely to be inundated by different flows (such as in-stream benches).

## **2.4 Establishment of Environmental Flow Objectives and preparation of the Issues Paper**

In this study, the Scientific Panel adopted a hydrological year classification into an irrigation season from November to April, and a non-irrigation season from May to October. This recognises the limitations of providing recommended flows due to operational constraints of the system.

Based on all the information gathered, reach-based Environmental Flow Objectives were established for each reach.

Environmental Flow Objectives were considered in two categories: Biodiversity Objectives and Flow Objectives. Biodiversity Objectives detailed a desired future state of key listed or threatened fauna within the reach, flora and fauna of value, or those with a strong relationship with flow. Biodiversity Objectives also included objectives for the physical nature of the channel or ecological processes (such as connectivity) that have an indirect influence on biodiversity through some physical response. Flow Objectives identified the important flow components that would need to be present in order to achieve the Biodiversity Objectives.

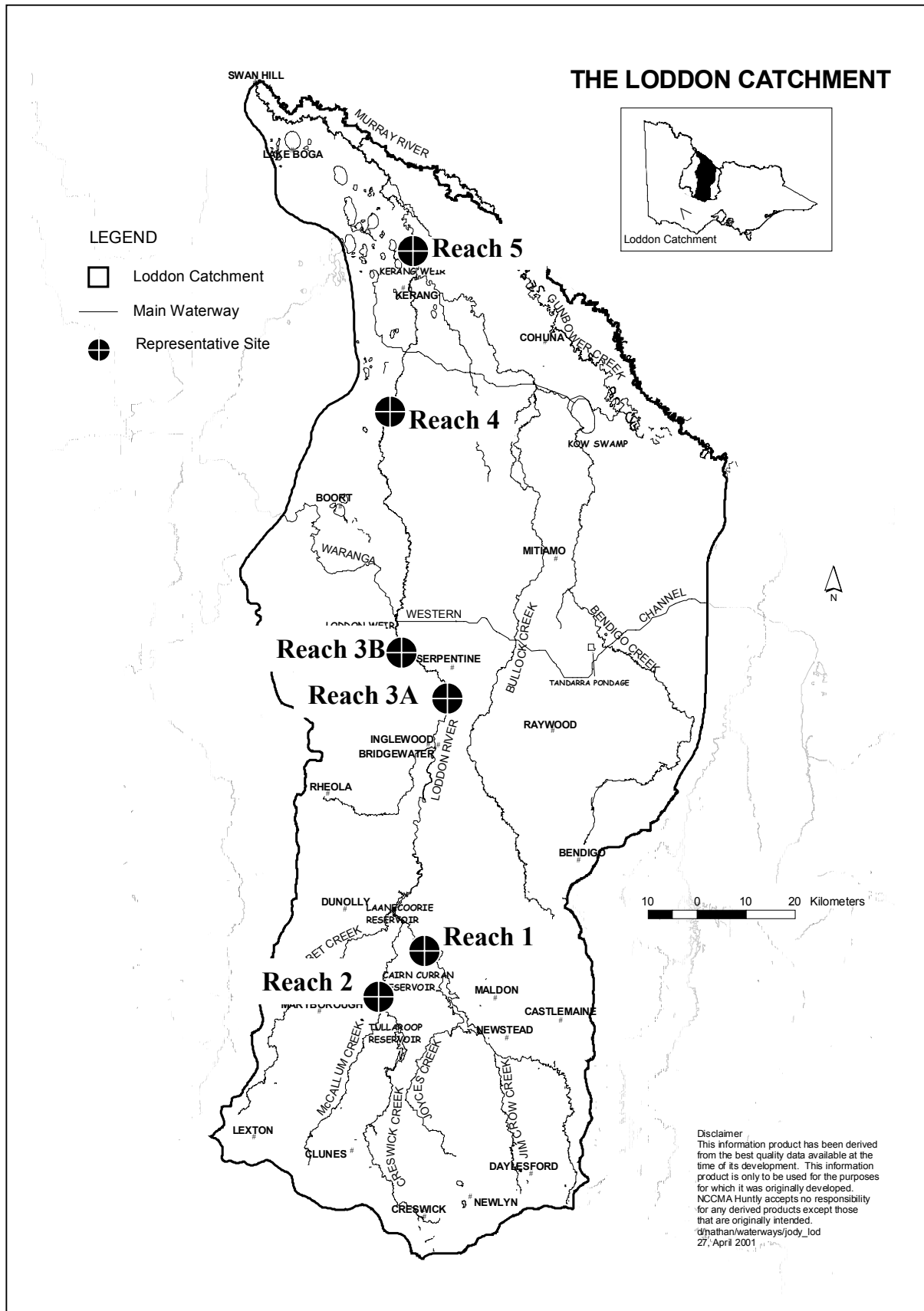


Figure 2. Map of the study area showing the location of representative sites.

The derivation of the Biodiversity and Flow Objectives is included in the issues Paper (LREFSP, 2002).

Biodiversity Objectives needed to be consistent with pre-determined regional objectives, catchment plans and legislation (such as State strategies and legislation, or Catchment Management Plans). The regional and catchment Biodiversity objectives for the Loddon River were provided in the Issues Paper (LREFSP, 2002), and are not repeated in this Final Report, which deals specifically with reach-scale flow recommendations. A summary of the Environmental Flow Objectives is presented in Section 3.

## **2.5 Survey of selected reaches**

Survey at six sites along the Loddon River and Tullaroop Creek was undertaken by Earth Tech Engineering Pty Ltd Shepparton Survey Group. The survey was undertaken to allow development of a hydraulic model and for description of ecological habitat.

The location of at least one cross-section at each of the six sites was pegged by the Scientific Panel and identified by GPS coordinates during the field inspection. The pegged cross-sections were either hydraulic control points (e.g. logs, riffles, controls) or cross sections selected by the Scientific Panel as important for ecological interpretation. In addition to the pegged cross-sections, Earth Tech Engineering Pty Ltd also surveyed a series of cross-sections beginning at the lower end of the reach and spaced at intervals of approximately 50 m, or where major changes in channel morphology occurred. At each site, a minimum of six cross-sections (below Kerang Weir) to a maximum of 12 cross-sections (on Tullaroop Creek) were surveyed. More cross-sections were undertaken at sites where there was greater variability in the morphology of the reach. Cross-section survey points focused on the channel detail, with fewer points on the floodplain. Water surface levels on the day were identified in the survey. Photographs were taken at each cross-section location. Where possible, levels were adjusted to the Australian Height Datum.

## **2.6 Hydraulic Modelling**

Hydraulic modelling of the sites was undertaken using the one-dimensional steady state backwater analysis model HEC RAS. The survey data for each site were input into the Digital Terrain Model 12D. This package allows direct transfer of data from the survey total station, into 12D, and a HEC RAS hydraulic model created through the 12D package.

### Channel Roughness

One of the most important interpretive components of the hydraulic modelling is channel roughness. Manning's  $n$  is used in the model to derive channel roughness. The roughness value is variable along a reach, and is used in conjunction with other flow obstructions within the channel. In particular, where large woody debris makes a significant contribution to the form roughness of the channel cross-section, a span (e.g. a bridge) was included to represent this obstruction. Large vertical tree trunks were represented in the same way.

Manning's  $n$  was identified through awareness of the reach gained through the field inspection and identification of reach variability from photographs. Interpretation of the effects of large woody debris on roughness was based on Gippel (1999), and French (1994).

Normal depth was used as the downstream boundary condition, with a slope determined by a combination of the water surface level and the channel invert level, particularly in the lower reaches. The use of this boundary condition allows for adjustment of flows without a corresponding adjustment of boundary condition.

Calibration

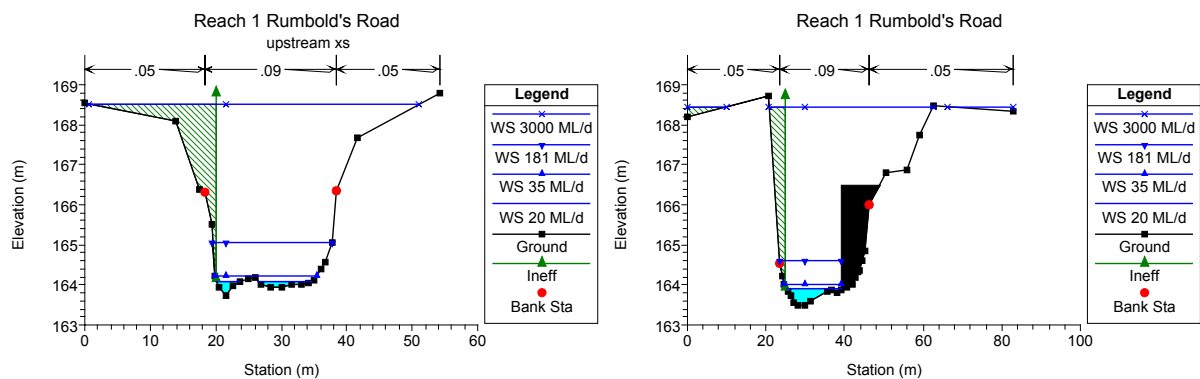
The hydraulic model was calibrated through the use of known water surface levels for the river flows identified on the day of the survey (flow on the day at a nearby gauge was supplied by GMW). Calibration greatly increases reliability of the model. The accuracy of the hydraulic model output varied with the flow being assessed. In general, low flows were prone to the highest percentage error, with flows in the vicinity of the observed flows being the most accurate. Flows on the day of the survey tended to be typical (or slightly higher) of regulated flow for the period of March.

Outputs

Outputs used in this project from the model included the flows (ultimately expressed in ML/d) required to inundate identified channel units such as benches or for fish passage flows (as specified by the Issues Paper, and later analysis). Model outputs also included the area of habitat of a certain minimum depth produced by particular flows. These outputs are required by the FEM (see description below). Stream power and velocity values were also identified for the purposes of assessing the geomorphic thresholds (e.g. flows required for scour) and to identify the channel forming capacity of flows.

The key output from the modelling is a graphical presentation of the cross sections (see Figure 3). In these, the black line (“Ground” in the legend) represents the ground surface, reflecting the channel shape at the cross-section. Small black squares on the ground line show the exact points where survey measurements were taken (note that these are more frequent within the channel than further out). Values across the top of each graph are Manning’s n values selected for different sections of the channel.

Horizontal blue lines within the cross-section represent the water surface at the various flows (which are detailed in the legend). Green hatching represents vegetation (labeled “Ineff” in the legend) that would have the effect of altering the flow characteristics in certain parts of the cross-sections. Solid black areas (Figure 3, right hand graph) are impervious obstructions, such as logs or trees.



**Figure 3. Example cross-section outputs from the hydraulic model.**

## 2.7 Analysis

Final environmental flow recommendations for the Loddon River reaches were prepared at a workshop. The Scientific Panel worked through the process of determining flow recommendations on a reach by reach basis.

Initially, the basic ecological conditions of the reach (including regulation impacts) and the previously determined ecological objectives (from the Issues Paper) were summarised and reviewed.

For each reach, each flow component were considered in turn. If a particular flow component could be associated with an Environmental Flow Objective for the reach, a suitable flow recommendation was derived by the Scientific Panel using a number of analysis tools. These included:

- The daily hydrology records for natural and current conditions;
- criteria or definitions for each of the flow components (Table 1) developed by the Scientific Panel;
- The hydraulic model developed for each reach;
- Drawings and notes taken during the field inspection; and
- Photos taken during the field inspection, and those taken of each transect during the survey.

**Table 1. FLOWS method flow components and definitions for use in environmental flow determinations**

<b>Flow component</b>	<b>Physical description</b>	<b>Hydrological definition</b>
Cease-to-flow	When there is no flow recorded at the gauge	A flow of 0.1 ML/d was selected by the Scientific Panel as effectively not flowing from an ecological perspective.
Low flow	Minimum flow that provides a continuous flow through the channel	The Scientific Panel used 0.2 m depth at the shallowest cross-section.
Freshes	Small and short duration peak flow events that exceed the baseflow. Usually summer or spring in Victoria	A flow that exceeds the median flow for a set period. Freshes are defined for the irrigation season (median flow between November and April) and the non-irrigation season (median flow between May and October). Also defined as the flow that provided temporary fish passage where appropriate.
High flows	Persistent increases in the seasonal baseflow that remain within the channel	The Scientific Panel used either fish passage requirements, or inundation of in-channel benches as morphological indicators.
Bankfull flow	Completely fill the channel, with little flow spilling onto the floodplain	Morphologically defined, with some interpretation required as cross-sections may differ in capacity. Also thought to have major geomorphological functions, but the Scientific Panel additionally used stream power (for sediment transport) and morphological characteristics for guidance.
Overbank flows	These flows are greater than bankfull and result in surface flow on the floodplain habitats	Morphologically defined and self-explanatory – flows higher than those defined as bankfull flows.

Primarily, the hydraulic model was used interactively to identify, represent and visually interpret these flow criteria. For example, to determine low flow recommendations, a variety of flows were entered into the hydraulic model and adjusted until a flow gave a depth of 0.2 m over the shallowest point of all transects. Where fish passage was required, flows were entered into the model until an appropriate water depth at critical fish passage areas were obtained.

The recommendations for frequency and duration of events (e.g. freshes) were based on the natural frequency and duration. The hydrologic program GetSpells 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 (usually based on the median or modal natural annual frequency, and duration).

In addition, the Flow Events Method (described in the next section) was used to derive recommendations, where the objective required an analysis of available habitat for fish, plants and macroinvertebrates, or for inundation of important benches.

### 2.7.1 Flow Events Method

The Flow Events Method (FEM) was developed by the CRC for Catchment Hydrology as a method to support environmental flow assessments. It is intended to be a flexible method that can be adapted to individual project needs, such as an adjunct to the FLOWS method. FEM encourages the use of available ecological knowledge and opinion and, where necessary, provides a systematic approach for proceeding where knowledge is lacking. The method is also useful for documenting the logic of an environmental flow recommendation, examining assumptions held by experts or other stakeholders, and for developing hypothesis regarding the impact of changes in flow regime on the stream ecosystem. FEM is not a step-by-step procedure for calculating environmental flow requirements; rather it is a tool to assist experienced practitioners in developing an environmental flow recommendation.

After first obtaining or modelling the hydrological data (as described above, and in common with the FLOWS method), the next step in the FEM process is to identify the key aspects of the flow regime that influence the stream ecosystem. These aspects are referred to as “flow events” and each flow event is associated with a particular ecological response. The flow events selected for the Loddon River were identified as availability of habitat satisfying a certain depth criteria (corresponding to known needs of certain important biota - Table 2). These were selected from the list of Biodiversity Objectives developed under the FLOWS method.

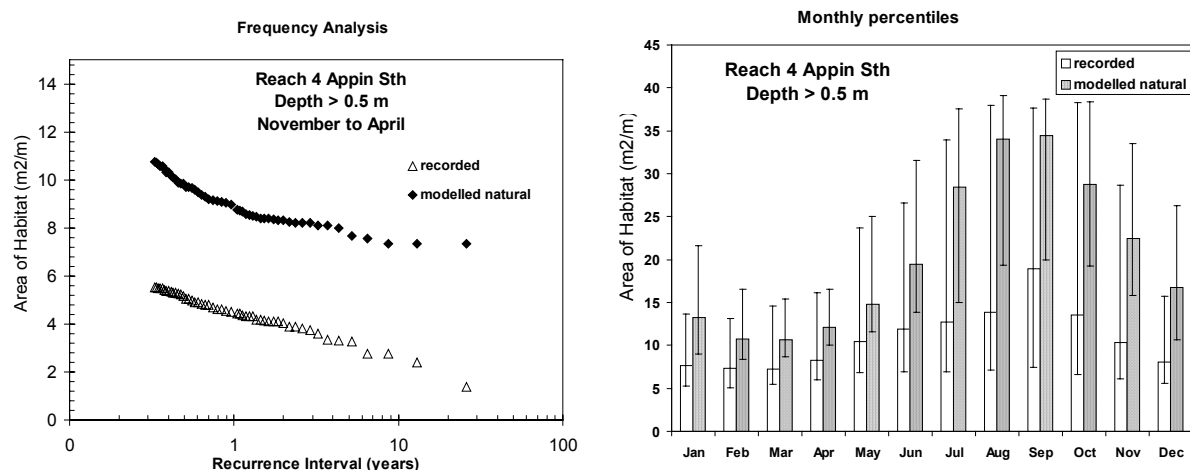
**Table 2. Flow Events used in the Loddon River and associated objectives**

<b>Flow Event identified</b>	<b>Associated Objective</b>
Area of water depth >0.1 m	Provision of habitat for macroinvertebrate communities.
Area of water depth >0.4 m	Provision of habitat for River blackfish populations.
Area of water depth >0.5 m	Provision of habitat for Murray cod, Golden perch and Silver perch populations.
Area of channel bed with water depth <0.3 m	Provision of habitat for low flow macrophyte populations and recruitment opportunity.
Area of in-channel bench inundation	Identification of the amount of benches inundated by various flows.

FEM is specifically intended to make use of available ecological knowledge, and to facilitate the use of expert judgement where this knowledge is lacking. To do this successfully, it is necessary to establish an effective dialogue between the ecologists and modeller. The modeller must provide useful information to the ecologists and the ecologists must in turn focus the modeller's analysis to detect the important aspects of the flow regime. An effective method of analysis is unlikely to be obvious at the start of the project, but must be sought iteratively by the project team. In the Loddon River, two modellers were available (Mike Stewardson and Geoff Vietz). The former was a member of the Scientific Panel and the latter was an integral adjunct to the Scientific Panel and attended the field assessment and objective setting workshop.

Meetings and workshops are important for the successful application of FEM. Time is required to develop an understanding of the method and digest preliminary results presented at initial meetings, and follow-up discussions are usually required. The ideal arrangement is probably to hold three or four meetings in a relatively short period of time. However, this luxury was not available for the Loddon River study, with the FEM analysis being done in parallel with the FLOWS method at the same single workshop.

The FEM requires derivation of relationships between the events of interest (areas with certain depth characteristics in this case) and discharge. The main form of presentation of results of FEM analysis is the recurrence interval plot (Figure 4 - left). This is a graph that plots the frequency of occurrence of a particular event, and is identical to a partial series plot for floods, except that the events are not floods above a given threshold, but other hydrological events that have a defined ecological significance (e.g. occurrence of area of habitat >0.5m depth). Normally, the plots show relationships for natural and current flow conditions, with the objective being to determine where the curves deviate. The second form of presentation of FEM analysis results is the monthly percentile plot (Figure 4 – right). This plots the median, 20<sup>th</sup> and 80<sup>th</sup> percentile values of the event index (e.g. occurrence of area of habitat >0.5 m depth) by months, and is presented for natural and current conditions. In this way, specific flow recommendations that relate to the natural occurrence of the flow event can be determined, and the comparison shows how the seasonal occurrence of the events has been disrupted by regulation.



**Figure 4. Example outputs from the Flow Events Method. Left - recurrence interval plot; Right - monthly percentile plot.**

Such graphs are complicated and difficult to explain simply. Basically, they show the frequency that various amounts of in-stream habitat occur under natural and current conditions. It is then possible to tell whether the current flow conditions result in more or less of the habitat area. In the frequency analysis (Figure 4 – left). The lowest natural habitat area on record for November to April (seen at the highest recurrence interval) is 7.3 m<sup>2</sup>/m (meaning that for every metre of stream length, there is 7.3 m<sup>2</sup>

of habitat with water deeper than 0.5 m). This is the area of habitat generated by the lowest flow on record. Points further to the left on the graph represent the habitat areas for more common flows (i.e. shorter recurrence intervals). In the example, for the current record, areas are lower than the equivalent natural recurrence interval over the whole range of the graph, and lower than the lowest recorded natural value, meaning that the area of habitat is frequently lower than the lowest value recorded.

In the monthly percentiles (Figure 4 - right), summaries for each month are presented. For each month, the habitat area is calculated at each flow. The median habitat area (not necessarily at the median flow) is shown, as is a measure of the variability of habitat availability (the whiskers). Again, it can be seen that the values for the current flows are always lower than for natural flows (e.g. compare individual months for November to April).

The FEM outputs allow the identification of where the flow events occur under the current flows differ from the natural situation. In the example, habitat area with depths greater than 0.5 are less common under current flows in November to April (Figure 4 – left) and in each month over the whole year (Figure 4 – right). The outputs also provide the opportunity to set a desirable amount of habitat that can then be turned into a specific flow. The desirable amount of habitat may be the minimum on record (that with the longest recurrence interval), the area associated with a particular recurrence interval, the median of a particular month, or some other target based on the environmental objective..

### 2.7.2 Rates of Rise and Fall

While specific flow recommendations (flow, frequency and duration) are the most critical component of the recommendations, the rates of rise and fall leading up to the particular flow are also important.

Subsequent to the workshop, an analysis of rates of rise and fall was conducted. The differences between 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 maximum desirable rate of rise was selected as the 90<sup>th</sup> percentile value of all recorded rates of rise (representing a fairly high rate that was recorded naturally) and the maximum desirable rate of fall was selected as the 10<sup>th</sup> percentile value of all recorded rates of fall (Table 3). Recommendations could not be made for downstream of Kerang Weir due to the lack of natural flow data.

**Table 3. Recommended maximum rates of rise and fall (expressed as a percentage of the previous days flow) at various sites on the Loddon River .**

Site	Rate of rise	Rate of fall
Cairn Curran Reservoir	204%	71%
Tullaroop Reservoir	185%	75%
Laanecoorie Reservoir	180%	74%
Serpentine Weir	164%	76%
Loddon Weir	186%	72%
Appin South	129%	86%

## 2.8 Important considerations arising from the study

Water quality was recognised as an important issue in the Loddon River, but the Scientific Panel concluded that water quality problems should be dealt with at the source, not managed artificially through flow manipulation. The rationale for this was that water is too valuable a resource to be used in this way. Hence, no environmental flow objectives or recommendations are made dealing with water quality issues, although water quality may improve as a valuable by-product of recommendations made for other reasons.

Also, the geomorphological issues in the Loddon River were mainly to do with the form of the channel, and how this gives rise to habitat availability (when flows interact with the habitat features), which is ultimately an ecological issue. Environmental flows can rarely be used to correct gross changes in channel form, especially when the changes to the channel are usually a response to multiple impacts. Some geomorphological changes cannot be reversed, so the emphasis here was on making the most of the current channel form with available flows, or encouraging some modest changes in form. This is in line with the principle espoused in the VRHS that ecosystems can be managed to a modified condition, providing that state produces the characteristics of a healthy ecosystem.

### 3. Biodiversity Objectives for the Loddon River

The list of study area Biodiversity Objectives collated from the objectives derived for each of the six reaches is presented in Table 4. It is important to note that all objectives may not be appropriate for all reaches (e.g. River blackfish objectives are only applicable to Reaches 1 and 2), nor may they be appropriate for reaches outside the study area - upstream of Cairn Curran or Tullaroop Reservoir, or in tributaries of the main river. The Objectives are presented in further detail in the Issues Paper (Part B to this report).

**Table 4. Summary of Environmental Flow Objectives for the Loddon River study area**

Biodiversity Objective	No.	Process	Draft Flow Objective	
			Flow Component	Timing
Restore or maintain River blackfish population	1a	Habitat availability	Low (depth >0.4 m)	All year
	1b	Breeding/Recruitment	Low	Spring
	1c	Movement	Low	All year
Restore or maintain native fish community (Murray cod, Golden perch and Silver perch)	2a	Available habitat and movement for all fish	All (depth > 0.5 m)	All year
	2b	Breeding cues for Murray cod	Freshes	Winter/Spring
	2c	Breeding cues for Golden perch	Freshes	Winter/Spring
	2d	Breeding cues for Silver perch	Freshes	Winter/Spring
Restore or maintain natural invertebrate community	3a	Disturbance	Cease-to-flow	Summer
	3b	Habitat maintenance	Freshes	Winter/Spring
	3c	Habitat availability	Low (depth >0.1 m)	Spring/Summer
Reinstate or maintain a mosaic of aquatic macrophytes	4a	Colonisation	Low	Spring
	4b	Disturbance	Low/Cease-to-flow	Summer
	4c	Habitat maintenance	Freshes	All year
Improve in-stream macrophyte habitat	4d	Colonisation/growth	Low	Spring/Summer
Improve submerged macrophyte habitat	4e	Colonisation/growth	Low (depth <0.3m)	Spring/Summer
Reinstate a mosaic of bank vegetation	5a	Colonisation/growth	All	Spring/Summer
	5b	Disturbance	Low/Cease-to-flow	Summer
	5c	Wetting	Freshes	Winter/Spring
Reverse terrestrialisation of bank/bench grasses	6	Disturbance	Freshes/High	Winter/Spring
Maintain red gum regeneration	7a	Wetting	Overbank	Spring
Restore or maintain floodplain/wetland processes	7b	Inundation	Overbank	Spring
Clean bed surface	8a	Disturbance	Freshes	Any time
Restore or maintain pools	8b	Scour	High	Any time
Restore or maintain runs	8c	Disturbance	Freshes/High	Any time
Re-shape in-channel forms to maintain physical habitat diversity and complexity	8d	Scour/deposition	Freshes/High	Any time
Scour silt on bed	8e	Scour	High/Overbank	Any time
Restore or maintain snag habitat	9	Submergence	Low	Any time
Entrain organic litter – carbon cycling	10	Disturbance	High	Winter

## 4. Recommendations for each reach

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The flow recommendations for each reach are presented below in a standard format with six 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 (LREFSP, 2002);
- The Biodiversity Objectives. For each reach, only those objectives from the list of study area objectives (Table 4) that apply to that reach are presented;
- The flow recommendations. These represent the flows that should achieve the ecological objectives, and were derived at the recommendation workshop. The recommendations are presented in two formats – the standard table format as used in the FLOWS method, and a seasonal table format developed by the Scientific Panel that, we feel, presents the recommendations in a more easily visualised manner;
- Supporting information. A number of cross-section plots are presented for each reach with the flows recommended shown. These demonstrate where each flow would be expected to occur in the channel cross-section. Where FEM results were used in the determination of a recommendation, the appropriate hydrologic/hydraulic analysis output is provided; and
- Achievement of recommendations. An analysis of the current frequency and duration of the recommended flows was conducted to indicate where the recommendations are being achieved by current operational practices.
- Supporting recommendations. These indicate non-flow related issues that require attention in order that the flow recommendations will achieve their intended objectives.

## 4.1 Reach 1 – Cairn Curran Reservoir to Laanecoorie Reservoir

### 4.1.1 Current condition

The current condition of Reach 1 was detailed in the Issues Paper (LREFSP, 2002). A summary of the current condition is provided in Table 5.

**Table 5. Current condition of Reach 1 – Cairn Curran Reservoir to Laanecoorie Reservoir.**

Aspect	Current condition
Hydrology	<ul style="list-style-type: none"> <li>• Strong reversal of seasonal flows</li> <li>• Floods less than 2 year ARI reduced</li> </ul>
Water Quality	<ul style="list-style-type: none"> <li>• Variable, but generally good water quality</li> </ul>
Geomorphology	<ul style="list-style-type: none"> <li>• Channel in-filled, lack of pools, some bank notching</li> </ul>
Habitat	<ul style="list-style-type: none"> <li>• Little woody debris</li> </ul>
Fish	<ul style="list-style-type: none"> <li>• 5 native fish expected, Murray cod and Golden perch stocked, past distribution of River blackfish</li> </ul>
Macroinvertebrates	<ul style="list-style-type: none"> <li>• No macroinvertebrate data, expect moderate flow fauna</li> </ul>
Vegetation	<ul style="list-style-type: none"> <li>• Aquatic macrophytes favouring summer growing species</li> <li>• Bank species may be terrestrialised</li> </ul>

### 4.1.2 Biodiversity Objectives

The flow related biodiversity objectives for Reach 1 were detailed in the Issues Paper (LREFSP, 2002). A summary of the objectives is provided in Table 6.

**Table 6. Flow related biodiversity objectives for Reach 1 – Cairn Curran Reservoir to Laanecoorie Reservoir.**

Category of objective	Detailed objective number (Table 4)
Restore flow conditions suitable for River blackfish	1a, 1b, 1c
Maintain or restore native fish community, potential breeding cues for Murray cod and Golden perch	2a, 2b, 2c
Maintain and/or restore natural invertebrate community	3a, 3b, 3c
Maintain a mosaic of aquatic macrophytes	4a, 4b, 4c
Reinstate a mosaic of bank vegetation	5a, 5b, 5c
Restore pools, maintain riffles and clean bed surfaces	8a, 8b, 8c, 8d
Entrain litter for carbon cycling	10

### 4.1.3 Flow Recommendations

A key observation in this reach is that the channel form appears to be altered, with pools in-filled with sediment. Before any of the other biodiversity objectives can be attained, it is important that flow conditions that restore the pool structure in the reach are reinstated. A bankfull flow of 3,000 ML/d is required to generate sufficient stream power for scouring. Flows at this level would occur naturally at some time in most years for a period of 3-5 days.

This high flow would also be important for Murray cod and Golden perch breeding. This would not have to occur every year, as breeding once every four years is adequate for Murray cod and Golden perch survival. However, the flow event must be between August and November.

There are few in-stream benches in the reach, meaning that organic material such as red gum leaves and twigs need to be entrained from the floodplain. Flows over 3,000 ML/d will break out of the channel and sweep leaves into the river. Ideally this should occur in June to August, as at this time of year riparian zone river red gum litter is aged and primed for entrainment to the stream. Overbank flows at this level would occur naturally at this time in most years for a period of 3-5 days.

Low flow recommendations during the irrigation season in the reach are mainly designed for the preservation of fish species. Using habitat for Murray cod and Golden perch as an FEM criteria, the flow that gives the equivalent “habitat area” of the highest monthly median area of habitat ( $d > 0.5$  m) over January to April (about  $4 \text{ m}^2 \text{m}^{-1}$ ) is 16 ML/d (Figure 6). However, 16 ML/d flow gives a maximum depth less than 0.3 m over the shallowest cross-section which means the critical point is probably too shallow to allow adequate fish passage between sections of the stream. A small increase in flow to 20 ML/d maintains River blackfish movement between habitat elements (minimum depth of 0.4 m over the shallowest point). Low flow connectivity is required to re-establish River blackfish throughout the reach. This flow may also increase heterogeneity of macrophytes in terms of cover and species richness.

The addition of the “or natural” proviso to the low flow recommendation means that cease-to-flows (important for invertebrate and aquatic macrophyte communities) will occur at the natural frequency and duration. Cease-to-flows occurred about every 4 years for periods up to 2 months. However, if higher flows needed to reinstate the pool structure cannot be provided, cease-to-flows would not be advisable. The proviso “or natural” is a common feature of environmental flow recommendations. Referring to minimum flow recommendations, it means that if the natural flow (in this case, the inflow to Cairn Curran reservoir) is lower than the recommended flow, then the natural inflow should be released, rather than the minimum flow value. In this way, low flow variability, including cease-to-flows, is maintained in the natural state (water does not have to be released to top up the flows to the minimum value).

Freshes over the irrigation season are important for temporary local movement of bigger fish (Murray cod and Golden perch), and for scouring deposited sediment off the stream bed. The flow that gives a minimum depth  $> 0.5$  m over the shallowest point for local movement is about 35 ML/d. Naturally, such freshes occur about 3 times per year for about 7 days.

Higher baseflows are required over the non-irrigation season, compared to the irrigation season, to allow for permanent movement of large bodied fish throughout the reach in the lead up to the breeding season. The flow that would provide such conditions is 35 ML/d, based on providing continuous depth over the shallowest point  $> 0.5$  m (see irrigation season freshes).

High flow winter freshes are usually an important flow component in unregulated streams to assist in stream bed maintenance and bank vegetation following lower flows in summer, based on the expectation that first flushes after summer are important for these features. However, it may be that the high irrigation flows may make the first winter flush benefit less important. An early winter fresh (May to August) is included here as a conservative measure (primarily as the bank vegetation shows signs of terrestrialisation), based on the natural median flow of that period. Naturally, this would occur about 3 times a year, usually for about 25 days.

The flow recommendations for Reach 1 are tabulated in the FLOWS format in Table 7. The recommendations are summarised in a seasonal format in Table 8.

**Table 7. Flow recommendations for Reach 1 - Cairn Curran Reservoir to Laanecoorie Reservoir**

River		Loddon River		Reach	Cairn Curran Reservoir to Laanecoorie Reservoir
Compliance Point		d/s Cairn Curran Res.		Gauge No.	407210
Flow				Rationale	
Season	Magnitude	Frequency	Duration	Objective	Evaluation
Nov–Apr	Minimum 20 ML/d (or natural)	Annually	Nov-Apr (between irrigation releases)	1a, 1b, 1c, 2a, 3a, 3c, 4a, 4b, 5a, 5b	Maintain area of flowing water at 0.5 m depth or more
Nov-Apr	Fresh >35 ML/d	3 times per year	7 days	2a, 3b, 4c, 5a, 8a	Allows temporary movement of large fish (0.5 m depth), clean biofilms and entrains litter
May –Oct	Minimum 35 ML/d (or natural)	Annually	May-Oct	1a, 2a, 3b	Allows permanent movement of large fish (0.5 m depth),
May-Aug	Early winter fresh >181 ML/d	3 times per year	25 days	4c, 5c, 8a	Benefit uncertain under management for irrigation
Aug-Nov	3,000 ML/d	1 in 4 years	4 days	2b, 2c	Native fish breeding
Any time	3,000 ML/d	Every year	4 days	4c, 8b, 8c, 8d	Pool scouring
Jun-Aug	>3,000 ML/d	Once per year	4 days	10	Entrain river red gum litter

**Table 8. Flow recommendations for Reach 1 - Cairn Curran Reservoir to Laanecoorie Reservoir in seasonal format**

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Low flow: Minimum 20 ML/d (or natural)						Low flow: Minimum 35 ML/d (or natural)					
Fresh: >35 ML/d, 3 per year, minimum 5 days						Fresh: >181 ML/d, 3 per year, minimum 25 days					
									High flow: 3000 ML/d, 1 in 4 years, minimum 4 days		
High flow: 3000 ML/d, 1 per year, minimum 4 days											
							Overbank Flow: >3000 ML/d, 1 per year, minimum 4 days				

#### 4.1.4 Supporting information

HEC RAS generated plots of cross-sections with water surface at the various recommended flow levels are given in Figure 5. FEM generated monthly 20<sup>th</sup>, 50<sup>th</sup> and 80<sup>th</sup> percentiles for area of habitat with depth >0.5 m are given in Figure 6.

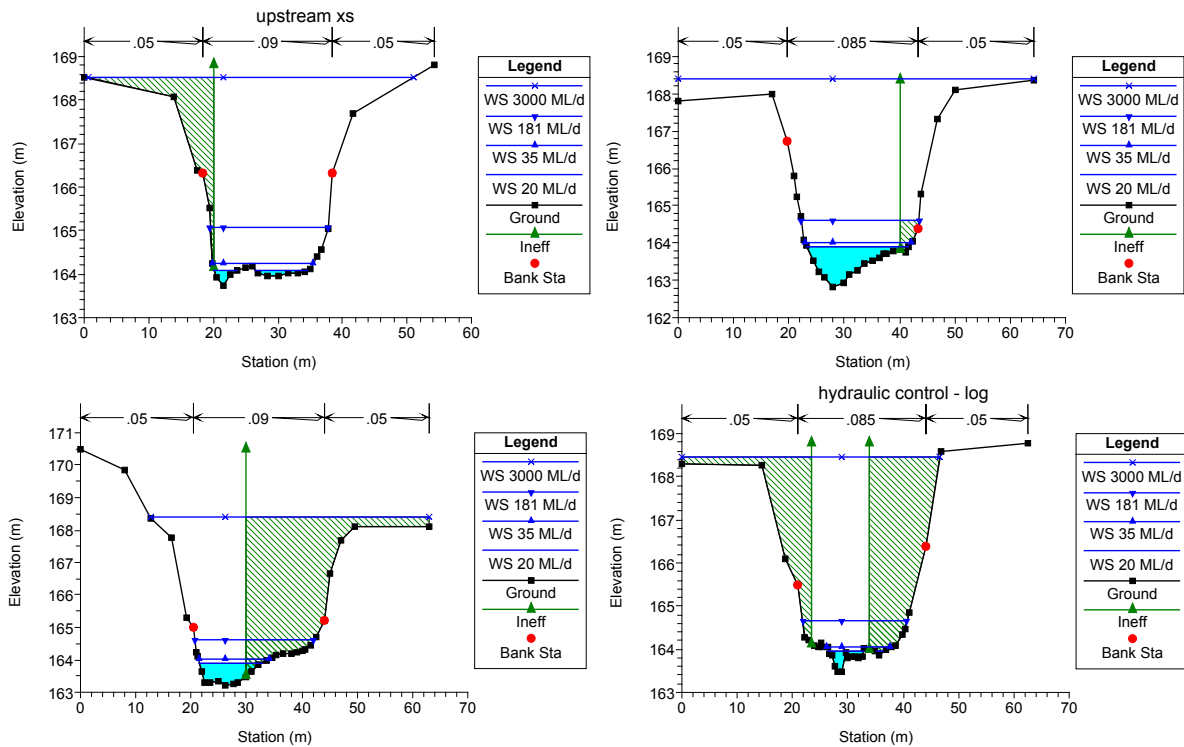


Figure 5. Reach 1 – Loddon River Cairn Curran to Laanecoorie cross-sections with water levels at selected flows.

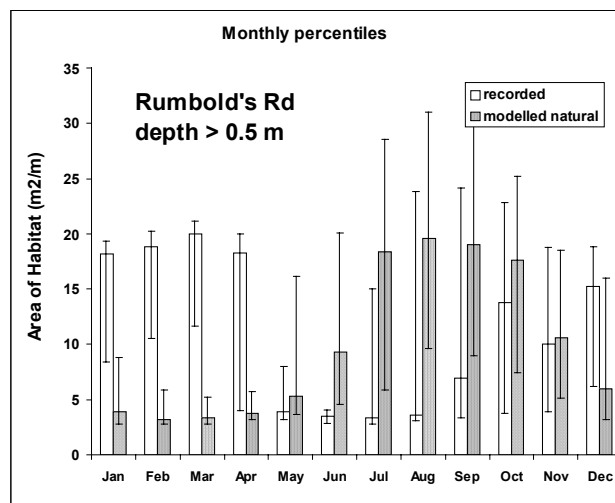


Figure 6. Reach 1 – Loddon River Cairn Curran to Laanecoorie monthly 20<sup>th</sup>, 50<sup>th</sup> and 80<sup>th</sup> percentiles for area of habitat with depth >0.5 m.

#### 4.1.5 Achievement of recommendations

The following table (Table 9) analyses the current frequency and duration of the flows recommended and assesses whether the recommendation is currently being achieved by current operational management. The current frequency range is based on the 20-80<sup>th</sup> percentile exceedence range (i.e. the more common annual occurrence) and the duration is the median values over the period of record.

**Table 9. Analysis of current frequency and duration of the recommended flows**

Season	Recommendation	Current	Achievement
Summer	Cease to flow, 1 in 4 years, 2 month duration	Does not occur	Not achieved, but should be with “or natural” proviso
Nov–Apr	Minimum 20 ML/d (or natural)	Naturally less than 20 ML/d, 1-3 times per year, 23 days; Currently 0-2 times per year, 8 days	Current minimum flow release from Cairn Curran 15-20 ML/d largely achieves aim of recommendation. “Or natural” proviso should restore lower values.
Nov-Apr	>35 ML/d, 3 per year, minimum 7 days	Currently 1-3 per year, 80 days.	Recommendation largely achieved by irrigation releases (reduction in frequency compensated by increase in duration).
May –Oct	Minimum 35 ML/d (or natural)	Naturally less than 35 ML/d, 1-2 times per year, 14 days; Currently 2-4 times per year, 13 days.	Not achieved, lower flows more frequent than natural.
May-Aug	>181 ML/d, 3 per year, minimum 25 days.	Currently 0-2 times per year, 7 days.	Frequency and duration not achieved
Aug-Nov	3000 ML/d, 1 in 4 years, minimum 4 days.	Currently 13 years in 27 years, 4 days.	Achieved
Any time	3000 ML/d, 1/year, minimum 4 days.	Currently 14 years in 27 years, 3 days.	Frequency not achieved
Jun-Aug	>3000 ML/d, 1/year, minimum 4 day.	Currently 6 years in 27 years, 4 days.	Frequency not achieved

#### 4.1.6 Supporting Recommendations

Reach 1 has relatively low large woody debris loadings. This could be marginally increased by addition of debris in selected areas. In the longer-term it will be prudent to manage the riparian vegetation to provide a source of large woody debris to the stream, and to develop a large woody debris management strategy that aims to achieve close-to-natural loadings, but without creating intolerable hydraulic or erosion problems.

The high turbidity of Laanecoorie Reservoir is due to the resuspension of fine material from the bed. This is a shallow reservoir, not well vegetated, possibly due to high turbidity restricting plant growth. The turbidity has been increasing with time. A management plan for Laanecoorie Reservoir is required.

Cairn Curran Reservoir has been identified as a site of potential cold water pollution (Ryan *et al.*, 2001), although adequate data are not available to confirm this. This issue needs to be investigated with further detailed temperature monitoring of releases from Cairn Curran, Tullaroop and Laanecoorie Reservoirs, as cold water releases have the potential to interfere with achievement of the objectives (particularly fish breeding).

Land-use changes are likely to be an important component of the health of the macroinvertebrate community in the reach, and need to be addressed. In particular, the degradation of the riparian zone, and stock access to the stream bank may both have an impact on the achievement of the flow objectives.

## 4.2 Reach 2 - Tullaroop Creek, Tullaroop Reservoir to Laanecoorie Reservoir

### 4.2.1 Current condition

The current condition of Reach 2 was detailed in the Issues Paper (LREFSP, 2002). A summary of the current condition is provided in Table 10.

**Table 10. Current condition of Reach 2 – Tullaroop Creek, Tullaroop Reservoir to Laanecoorie Reservoir.**

Aspect	Current condition
Hydrology	<ul style="list-style-type: none"> <li>• Strong reversal of seasonal flows</li> <li>• Floods less than 5 year ARI reduced</li> </ul>
Water Quality	<ul style="list-style-type: none"> <li>• Data poor, but available data suggest generally good water quality just below the reservoir. Downstream, nutrient concentrations can be high, and high turbidity in the lower reaches has been reported anecdotally</li> </ul>
Geomorphology	<ul style="list-style-type: none"> <li>• No active problems noted, complex morphology present</li> </ul>
Habitat	<ul style="list-style-type: none"> <li>• High loading of woody debris</li> </ul>
Fish	<ul style="list-style-type: none"> <li>• 4 native fish expected – River blackfish high value, Golden perch stocked outside range</li> </ul>
Macroinvertebrates	<ul style="list-style-type: none"> <li>• No macroinvertebrate data, expect moderate flow fauna</li> </ul>
Vegetation	<ul style="list-style-type: none"> <li>• Rich and diverse macrophyte community</li> <li>• Terrestrialised bank vegetation</li> </ul>

### 4.2.2 Biodiversity Objectives

The flow related biodiversity objectives for Reach 2 were detailed in the Issues Paper (LREFSP, 2002). A summary of the objectives is provided in Table 11.

**Table 11. Flow related biodiversity objectives for Reach 2 – Tullaroop Creek, Tullaroop Reservoir to Laanecoorie Reservoir.**

Category of objective	Detailed objective number (Table 4)
Maintain sustainable population of River blackfish	1a, 1b, 1c
Maintain and/or restore natural invertebrate community	3b, 3c
Maintain a mosaic of aquatic macrophytes	4a, 4b, 4c
Reverse terrestrialisation of river bank flora	6
Maintain pools, riffles and clean bed surfaces	8a, 8b, 8c, 8d
Maintain current snag habitat	9
Entrain litter for carbon cycling	10

### 4.2.3 Flow Recommendations

Although the site examined was downstream of the McCallum Creek junction, the compliance point for this reach is upstream of the junction. This is to ensure that the recommended flows are delivered throughout the entire reach (from Tullaroop Reservoir to Laanecoorie Reservoir) and conditions in the

section upstream of McCallum Creek is not compromised by flows from McCallum Creek. No gauge exists at this point, but a gauge exists at the Outlet Measuring Weir downstream of Tullaroop Reservoir (407248).

A key objective in this reach is the maintenance of River blackfish populations (a regionally significant species). Low flow recommendations throughout the whole year were therefore based on maintaining adequate habitat for the species (defined as the area of stream with water depth over 0.4 m). The FEM results for area of depth over 0.4 m indicate the monthly medians between January and April are between  $4.04 \text{ m}^2\text{m}^{-1}$  (provided at 9.0 ML/d) and  $4.17 \text{ m}^2\text{m}^{-1}$  (provided at 12.7 ML/d - Figure 8). A value of 10 ML/d was selected as a reasonable minimum flow.

The recommended low flow is for the entire year as there are no additional objectives that require higher minimum flows in the non-irrigation season (as for Reach 1 where permanent large bodied fish movement was deemed important in the lead up to the breeding season). While Golden perch have been stocked in the reach, this is outside its natural range and no flows have been recommended to maintain the species (stocking should be discontinued).

Low flows of 10 ML/d should also provide adequate habitat for aquatic macroinvertebrate populations and aquatic plant communities.

Irrigation season freshes are required to scour excess silt from the bed surface. Without a physical or hydraulic parameter with which to evaluate a flow volume, the FLOWS method definition of a fresh as the median flow of the season was used. The median November to April natural flow was 13.5 ML/d. Naturally, this would have occurred about 4 times each year with each fresh lasting about 7 days.

Neither the low flow recommendation or the irrigation season freshes provide much connectivity through the reach (these flows provide only about 0.1 m depth over the shallowest point in the reach). This is different to Reach 1, where the aim is to allow River blackfish to re-establish through the reach. In the lead up to the breeding season, some River blackfish movement between habitats is desirable. Also, recolonisation of any depleted habitats require connectivity along the reach. A flow of 132 ML/d provides 0.4 m depth over the shallowest point, suitable for temporary movement.

The disturbance of early winter freshes may have an added benefit of assisting to maintain and potentially increase the heterogeneity of macrophytes in terms of cover, forms and species richness.

The reach is characterised by a number of high level benches, where bank vegetation has been terrestrialised. Higher in-channel flows are required to both inundate these benches (returning a more natural vegetation mosaic) and to sweep organic material into the stream. From transect analysis, the flows appropriate for this are about 500 ML/d. Fortuitously, such flows would also produce sufficient stream power to maintain the condition of the pool/run sequence within the channel.

Flows of 500 ML/d would occur naturally in 4 out of 5 years, but when it occurs, it happens about 3 times each year. Preferably, it is recommended that at least 2 of these 3 flows should occur in early winter (May to August), as at this time of year riparian zone river red gum litter is aged and primed for entrainment to the stream.

Higher flow again are required to maintain the geomorphic processes of re-shaping channel elements (scouring pools etc). As the channel is incised, a current bankfull flow would be inappropriate (as it would have excess stream power to that required). An estimate of historic bankfull flows is 3,000 ML/d. This would have occurred once every two years, with the peak flow lasting only for 1 day.

Overbank flows have not been recommended for this reach as floodplain functions are performed by extensive high level benches and there are no significant wetlands identified in the area (DCE 1992).

The flow recommendations with rationales and justifications for Reach 2 are tabulated in the FLOWS format in Table 12. The recommendations are summarised in a seasonal format in Table 13.

**Table 12. Flow recommendations for Reach 2 – Tullaroop Creek, Tullaroop Reservoir to Laanecoorie Reservoir with rationales and justifications.**

River		Tullaroop Creek		Reach	Tullaroop Reservoir to Laanecoorie Reservoir	
Compliance Point		u/s McCallum Creek		Gauge No.	none available	
Flow				Rationale		
Season	Magnitude	Frequency	Duration	Objective	Evaluation	
Any time	Minimum 10 ML/d (or natural)	Annually	All year	1a, 1c, 3c, 4a, 4b, 9	Maintain area of flowing water at 0.4 m depth or more	
Nov-Apr	Fresh >13.5 ML/d	4 times per year	7 days	3b, 4c, 8a	Clean biofilms and stream bed	
May-Aug	Early winter fresh >132 ML/d	2 times per year	7 days	1b, 1c, 4c, 8a	Maintain minimum flowing water depth at 0.4 m depth	
Any time	500 ML/d	3 times per year (2 in early winter) for 4 years in 5	4 days	4c, 6, 8b, 8c, 10	Maintains disturbance related processes	
Any time	3,000 ML/d	1 in 2 years	Peak of 1 day (natural rates of rise and fall)	4c, 8d, 8e	Maintain channel	

**Table 13. Flow recommendations for Reach 2 – Tullaroop Creek, Tullaroop Reservoir to Laanecoorie Reservoir in seasonal format.**

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Low flow: Minimum 10 ML/d (or natural)											
Fresh: >13.5ML/d, 4 per year, minimum 7 days						Fresh: >132 ML/d, 2 per year, minimum 7 days					
						High flow: 500 ML/d, 2 per year (4 years in 5), minimum 4 days					
High flow: 500 ML/d, 1 per year (4 years in 5), minimum 4 days											
High flow: 3000 ML/d, 1 year in 2, peak flow for 1 day with natural rise and fall rates											

#### 4.2.4 Supporting information

HEC RAS generated plots of cross-sections with water surface at various flow levels are given in Figure 7. FEM generated monthly 20<sup>th</sup>, 50<sup>th</sup> and 80<sup>th</sup> percentiles for area of habitat with depth >0.4 m are given in Figure 8.

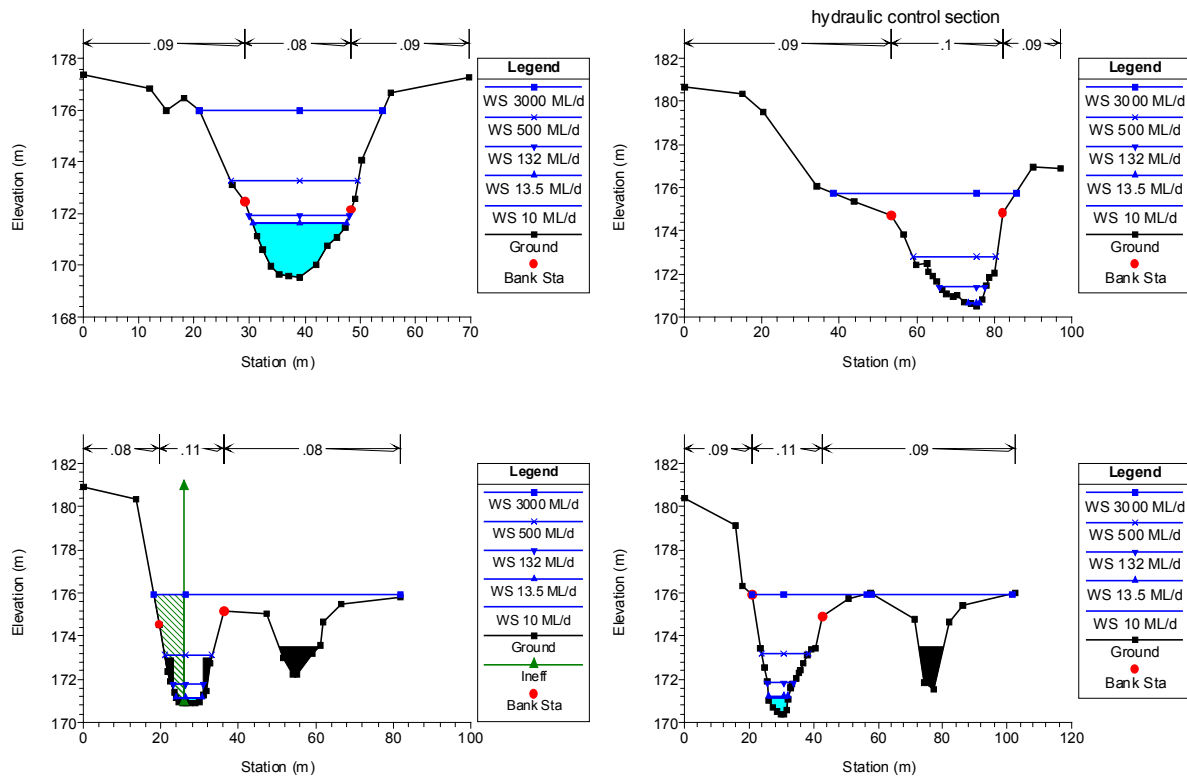


Figure 7. Reach 2 – Tullaroop Creek, Tullaroop Reservoir to Laanecoorie Reservoir cross-sections with water levels at selected flows.

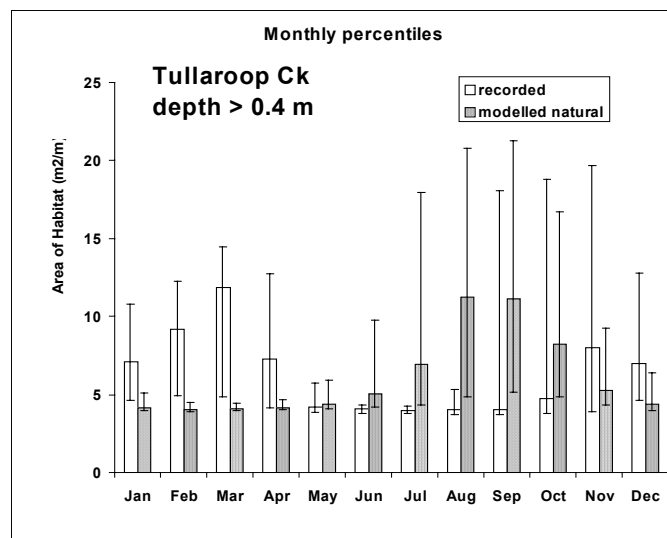


Figure 8. Reach 2 – Tullaroop Creek, Tullaroop Reservoir to Laanecoorie Reservoir monthly 20<sup>th</sup>, 50<sup>th</sup> and 80<sup>th</sup> percentiles for area of habitat with depth >0.4 m.

#### 4.2.5 Achievement of recommendations

The following table (Table 14) analyses the current frequency and duration of the flows recommended and assesses whether each recommendation is being achieved by current operational management. The current frequency range is based on the 20-80<sup>th</sup> percentile exceedence range (i.e. the more common annual occurrence) and the duration is the median values over the period of record.

**Table 14. Analysis of current frequency and duration of the recommended flows.**

Season	Recommendation	Current	Achieved
Any time	Minimum 10 ML/d (or natural)	Naturally less than 10 ML/d, 2-4 times per year, 9 days; Currently 1-3 times per year, 19 days	Not achieved. Low flows longer than natural and seasonally reversed (most current low flows in May-Oct). Minimum flow release of 15 ML/d at Tullaroop not apparent.
Nov-Apr	>13.5 ML/d, 4 per year, 7 days	Currently 1-2 per year, 154 days	Recommendation largely achieved by irrigation releases (reduction in frequency compensated by increase in duration).
May-Aug	>132 ML/d, 2 per year, 7 days	Currently 0-1 per year, 7 days	Frequency not achieved
May - Aug	500 ML/d, 2 per year (4 years in 5), 4 days	Currently 2 year in 27, 4 days.	Frequency not achieved
Any time	500 ML/d, 1 per year (4 years in 5), 4 days	Currently 18 years in 27, 7 days	Frequency not achieved
Any time	3,000 ML/d, 1 in 2 years, 1 day	Currently 6 years in 27 years, 3 days	Frequency not achieved

#### 4.2.6 Supporting Recommendations

There is no gauge associated with the compliance point upstream of McCallum Creek. A gauge needs to be installed, or the relationship between flows at gauge 407248 and the compliance point needs to be established.

Anecdotal reports suggest that turbidity of Tullaroop Creek entering Laanecoorie Reservoir is higher than that of the upper Loddon River (LREFSP, 2002). However, Tullaroop Creek downstream of the Reservoir has a similar water quality profile to that of the Loddon River downstream of Cairn Curran, except that turbidity is slightly lower. This may suggest that the sediment may be entering via tributaries downstream of Tullaroop Reservoir. This should be investigated.

It needs to be established whether Freshwater blackfish are present upstream of McCallum Creek. If they are absent from that section, a translocation program should be considered (as natural recolonisation after the implementation of environmental flows may be very slow).

Tullaroop Reservoir has been identified as a site of potential cold water pollution (Ryan *et al.*, 2001), although adequate data are not available to confirm this. This issue needs to be investigated with further detailed temperature monitoring of releases from Cairn Curran, Tullaroop and Laanecoorie Reservoirs, as cold water releases have the potential to interfere with achievement of the objectives (particularly fish breeding).

Land-use changes are likely to be an important determinant of the health of the macroinvertebrate community in the reach. In particular, the degradation of the riparian zone, and stock access to the stream bank may both have an impact on the achievement of the flow objectives. The quantity of riparian vegetation (although most of it is native) is relatively poor and may not be the original vegetation community, and there is common stock access along the reach. These issues will need to be addressed to assist achieving the flow objectives.

## 4.3 Reach 3a – Laanecoorie Reservoir to Serpentine Weir

### 4.3.1 Current condition

The current condition of Reach 3a was detailed in the Issues Paper (LREFSP, 2002). A summary of the current condition is provided in Table 15.

**Table 15. Current condition of Reach 3a – Laanecoorie Reservoir to Serpentine Weir**

Aspect	Current condition
Hydrology	<ul style="list-style-type: none"> <li>Moderate reversal of seasonal flows</li> <li>Floods less than 2 year ARI reduced</li> </ul>
Water Quality	<ul style="list-style-type: none"> <li>TN and EC can be high, and high turbidity water is sourced from Laanecoorie. TP exceeds guidelines.</li> </ul>
Geomorphology	<ul style="list-style-type: none"> <li>History of channel instability. The channel is active within the trench creating a diverse morphology.</li> </ul>
Habitat	<ul style="list-style-type: none"> <li>High loading of woody debris</li> </ul>
Fish	<ul style="list-style-type: none"> <li>4 native fish expected – Murray cod and Golden perch stocked, past distribution of Silver perch.</li> </ul>
Macroinvertebrates	<ul style="list-style-type: none"> <li>Slow water macroinvertebrate fauna (high diversity community)</li> </ul>
Vegetation	<ul style="list-style-type: none"> <li>Emergent macrophyte habitat limited to islands and protected edge habitats</li> <li>Limited submerged macrophyte habitat (unknown reason)</li> </ul>

### 4.3.2 Biodiversity Objectives

The flow related biodiversity objectives for Reach 3a were detailed in the Issues Paper (LREFSP, 2002). A summary of the objectives is provided in Table 16.

**Table 16. Flow related biodiversity objectives for Reach 3a – Laanecoorie Reservoir to Serpentine Weir**

Category of objective	Detailed objective number (Table 4)
Maintain or restore native fish community, potential breeding cues for Murray cod, Golden perch and Silver perch	2a, 2b, 2c, 2d
Maintain and/or restore natural invertebrate community	3a, 3b, 3c
Improve in-stream macrophyte habitat	4d
Improve submerged macrophyte habitat	4e
Maintain pools, riffles and clean bed surfaces	8a, 8b, 8c, 8d
Maintain current snag habitat	9
Entrain litter for carbon cycling	10

### 4.3.3 Flow Recommendations

This reach is characterised by large pools separated by areas of shallow water with a high structural diversity (Figure 9). The pools are large enough to secure fish populations, even at very low flows. The complex areas of shallow water provide an opportunity in this reach to rehabilitate in-stream plant communities back towards a more natural state (which has been lost at upstream reaches). Using

FEM, the area of habitat <0.3 m (corresponding to the depth areas where submerged summer growing plants can potentially re-establish), has been greatly reduced over the November to April period under current flow conditions (Figure 10 – left graph) due to higher than natural flows. Under natural flows, the maximum amount of habitat area with depth <0.3 m is between 4-5 m<sup>2</sup>/m (Figure 10 – right graph), but with a rapid decline with flow at about 4.4 m<sup>2</sup>/m (the inflection point on the natural graph). The low flow recommendation is therefore designed to maintain an area of 4.4 m<sup>2</sup>/m, corresponding to a flow of 15 ML/d (a higher flow would greatly decrease suitable habitat area). Therefore, adopting a low flow recommendation of 15 ML/d should provide conditions suitable for the re-establishment of in-stream summer-growing vegetation between irrigation releases. Extending this minimum flow into the non-irrigation season (to include May-July) will allow further establishment of plants free from any potential disturbance of irrigation releases.

Even at this low flow, adequate fish and macroinvertebrate habitat will exist in the reach, including inundation of woody debris (although a lower minimum would increase the risk to fish and macroinvertebrates).

This flow (15 ML/d) provides a depth of 0.1 over the shallowest point in the reach. For Golden perch movement over the irrigation season, freshes are required that give occasional periods of depths over 0.5 m. The median natural flow of the season is 52 ML/d, which provides suitable depth for temporary large fish movement (i.e. >0.5 m). Naturally, this flow would occur about 3 times per season for 13 days each time.

For the remainder of the year (August to October), permanent large-bodied fish movement requirements require that the minimum flow should be 52 ML/d.

Freshes during this period are required to maintain habitat quality in pools and runs, and to inundate low level benches in the river. The median flow of the August to October period (900 ML/d) adequately performs this function. Freshes are not recommended over the entire non-irrigation season (to assist in in-stream vegetation establishment in the May to July period). Flows over 900 ML/d would occur naturally about 2 times a year for 9 days each in August to October.

Higher flows are required to inundate high level benches to entrain organic material and maintain the channel form and complexity. Flows of 7,300 ML/d are sufficient to inundate high level benches. An analysis of stream power suggests that stream power does not increase at flows higher than this. Flows of 7,300 ML/d or more occurred once every two years over June to October (the period when such flows are naturally more likely), peaking for a single day.

The flow recommendations with rationales and justifications for Reach 3a are tabulated in the FLOWS format in Table 17. The recommendations are summarised in a seasonal format in Table 18.

**Table 17. Flow recommendations for Reach 3a – Laanecoorie Reservoir to Serpentine Weir**

River		Loddon River		Reach	Laanecoorie Reservoir to Serpentine Weir
Compliance Point		u/s Serpentine Weir		Gauge No.	none available
Flow				Rationale	
Season	Magnitude	Frequency	Duration	Objective	Evaluation
Nov-Jul	Minimum 15 ML/d (or natural)	Annually	Nov-Apr (between irrigation releases), May-Jul	3a, 3c, 4d, 4e, 9	Maximise submerged macrophyte habitat and regeneration opportunity
Nov-Apr	Fresh >52 ML/d	Min. 3 times per season	Min. 13 days	2c, 2d, 3b, 8a, 9	Golden perch upstream movement to spawn
Aug-Oct	Minimum 52 ML/d	Annually	Aug-Oct	2a, 2b	Permanent large bodied fish movement through reach
Aug-Oct	900 ML/d	2 times per year	9 days	8b, 8c	Maintain disturbance processes
Jun-Oct	7,300 ML/d	Once every two years	Peak for 1 day (natural rates of rise and fall)	8b, 8c, 8d, 10	Inundates high level benches, performs geomorphic work

**Table 18. Flow recommendations for Reach 3a – Laanecoorie Reservoir to Serpentine Weir in seasonal format.**

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Low flow: Minimum 15 ML/d (or natural)									Low flow: minimum 52 ML/d		
Fresh: >52 ML/d, 3 per year, minimum 13 days									Fresh: >900 ML/d, 2 per year, minimum 9 days		
							High flow: 7,300 ML/d, 1 year in 2, peak flow for 1 day with natural rise and fall rates				

### 4.3.4 Supporting information

HEC RAS generated plots of cross-sections with water surface at various flow levels are given in Figure 9. FEM generated monthly 20<sup>th</sup>, 50<sup>th</sup> and 80<sup>th</sup> percentiles for area of bed with depth <0.3 m are given in Figure 10.

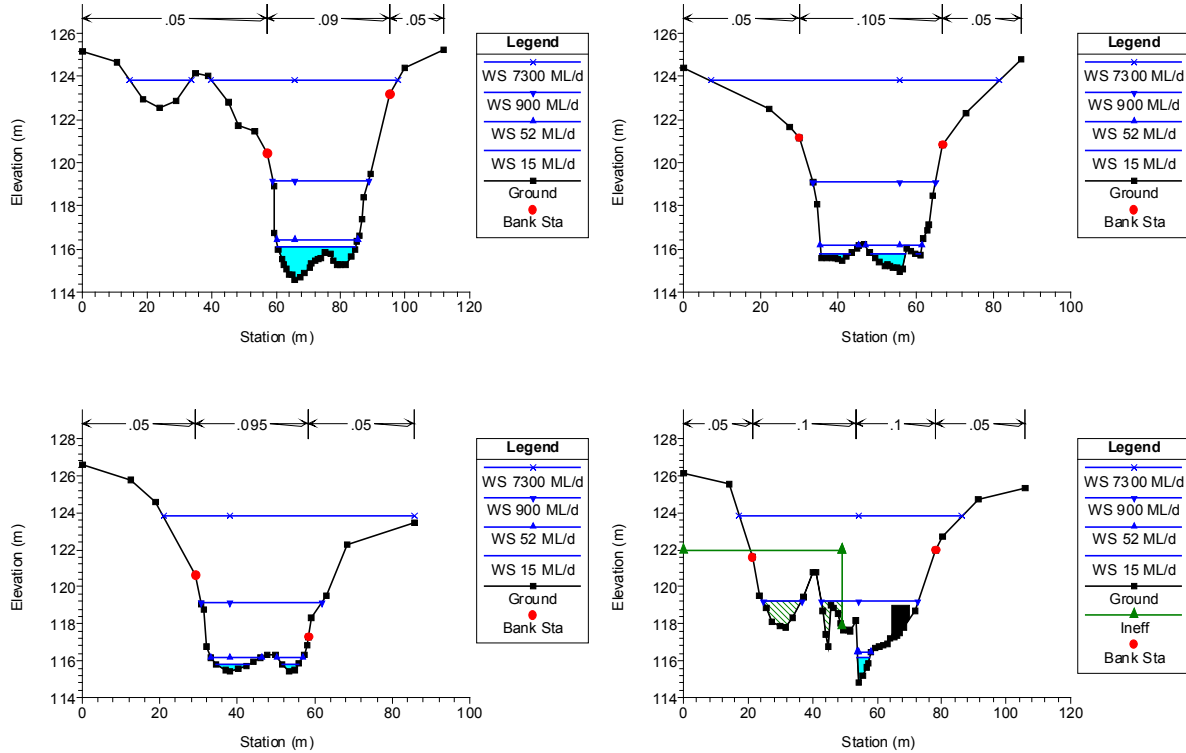


Figure 9. Reach 3a – Laanecoorie Reservoir to Serpentine Weir cross-sections with water levels at selected flows.

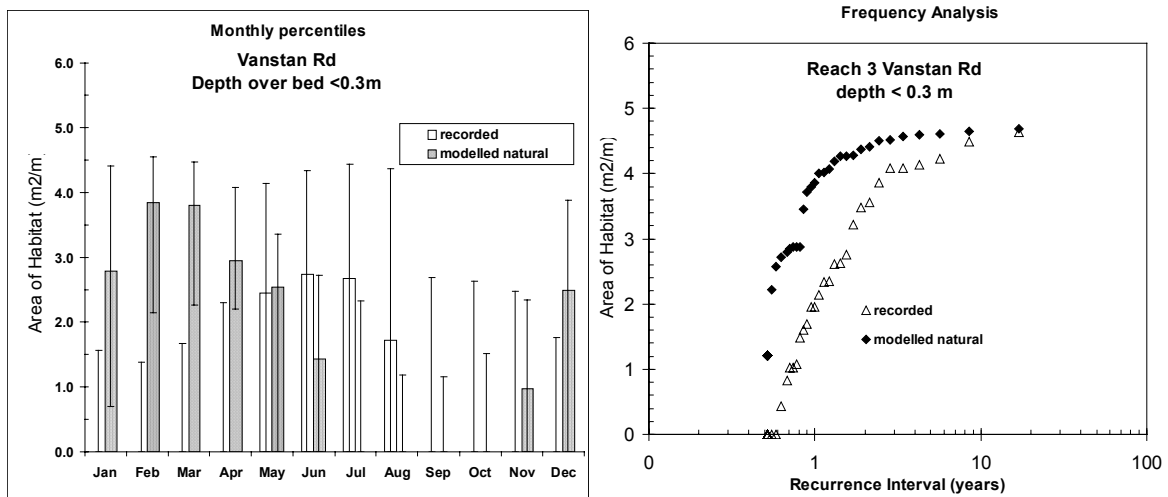


Figure 10. Reach 3a – Laanecoorie Reservoir to Serpentine Weir monthly 20<sup>th</sup>, 50<sup>th</sup> and 80<sup>th</sup> percentiles, and frequency analysis (November to April) for area of bed with depth <0.3 m .

### 4.3.5 Achievement of recommendations

The following table (Table 19) analyses the current frequency and duration of the flows recommended and assesses whether each recommendation is being achieved by current operational management. The current frequency range is based on the 20-80<sup>th</sup> percentile exceedence range (i.e. the more common annual occurrence) and the duration is the median values over the period of record.

**Table 19. Analysis of current frequency and duration of the recommended flows.**

Season	Recommendation	Current	Achieved
Nov-Jul	Minimum 15 ML/d	Naturally less than 15 ML/d, 0-2 times per year, 17 days; Currently less than 15 ML/d, 0-2 times per year, 4 days	Not achieved. Low flows shorter than natural (an issue given the objectives of the low flows).
Nov-Apr	>52 ML/d, 3 per year, 13 days	Currently 1 per year, 179 days	Flows almost always over recommendation
Aug-Oct	Minimum 52 ML/d	Naturally flows always 52 ML/d or more; Currently less than 52 ML/d, 0-3 times per year, 8 days	Not achieved
Aug-Oct	900 ML/d, 2 per year, 9 days	Currently 0-3 per year, 6 days	Minimum frequency and duration not achieved
Jun-Oct	7,300 ML/d, 1 in 2 years, 1 day	Currently 8 years in 18 years, 2 days	Achieved

### 4.3.6 Supporting Recommendations

TN, TP and EC can be high in this reach, and high turbidity water is sourced from Laanecoorie Reservoir. The elevated salinity is partly due to degradation of the surrounding upper catchment, but to a large degree the salinity of the upper catchment streams is naturally high. Further salinity inputs are saline groundwater on the Loddon Plain. Water quality management needs to be investigated.

Laanecoorie Reservoir appears to slightly lower summer water temperatures (LREFSP, 2002). Laanecoorie Reservoir has been identified as a site of potential cold water pollution (Ryan *et al.*, 2001), although adequate data are not available to confirm this. This issue needs to be investigated with further detailed temperature monitoring of releases from Cairn Curran, Tullaroop and Laanecoorie Reservoirs, as cold water releases have the potential to interfere with achievement of the objectives (particularly fish breeding).

There is no gauge associated with the compliance point upstream of Serpentine Weir. A gauge needs to be installed, or alternative methods of determining the flow upstream of Serpentine Weir needs to be devised.

The history of bank and bed stabilization works in this reach suggests some history of channel instability. Bank stability, and the integrity of the existing works, requires monitoring.

Without DNRE stockings of Golden perch and Murray cod, these species may have disappeared (as Silver perch have), as spawning opportunities are currently limited by inadequate streamflows and potential cool water releases. The stocking program will require re-evaluation when environmental flows are implemented.

Land-use changes are likely to be an important component of the health of the macroinvertebrate community in the reach. Riparian vegetation is relatively healthy (and most of it is native), but uncontrolled stock access in many places along the reach and represents a threat to the vegetation and bank integrity. These issues will need to be addressed to assist achieving the flow objectives.

## 4.4 Reach 3b – Serpentine Weir to Loddon Weir

### 4.4.1 Current condition

The current condition of Reach 3b was detailed in the Issues Paper (LREFSP, 2002). A summary of the current condition is provided in Table 20.

**Table 20. Current condition of Reach 3b –Serpentine Weir to Loddon Weir**

Aspect	Current condition
Hydrology	<ul style="list-style-type: none"> <li>Moderate reversal of seasonal flows</li> <li>Floods less than 2 year ARI reduced</li> <li>Greater than natural percentage of flows pass down Serpentine</li> <li>Cease-to-flow occurs under current conditions (unnatural)</li> </ul>
Water Quality	<ul style="list-style-type: none"> <li>TN and EC can be high, and high turbidity water is sourced from Laanecoorie. TP exceeds guidelines.</li> </ul>
Geomorphology	<ul style="list-style-type: none"> <li>The river passes through a depositional zone, and is not incised. In fact, aggradation of the channel appears to be occurring</li> </ul>
Habitat	<ul style="list-style-type: none"> <li>Moderate loading of woody debris</li> </ul>
Fish	<ul style="list-style-type: none"> <li>4 native fish expected – Murray cod and Golden perch stocked, past distribution of Silver perch.</li> </ul>
Macroinvertebrates	<ul style="list-style-type: none"> <li>Slow water macroinvertebrate fauna (possibly reduced diversity)</li> </ul>
Vegetation	<ul style="list-style-type: none"> <li>Emergent macrophyte habitat limited to islands and protected edge habitats</li> <li>Limited submerged macrophytes (unknown reason)</li> <li>Regeneration of red gums occurring on some banks</li> </ul>

### 4.4.2 Biodiversity Objectives

The flow related biodiversity objectives for Reach 3b were detailed in the Issues Paper (LREFSP, 2002). A summary of the objectives is provided in Table 21.

**Table 21. Flow related biodiversity objectives for Reach 3b –Serpentine Weir to Loddon Weir**

Category of objective	Detailed objective number (Table 4)
Maintain or restore native fish community, potential breeding cues for Murray cod, Golden perch and Silver perch	2a, 2b, 2c, 2d
Maintain and/or restore natural invertebrate community (either community # or O/E Score)	3b, 3c
Re-instate a mosaic of aquatic macrophytes	4a, 4b, 4c
Maintain red gum regeneration	7a
Maintain pools, riffles and clean bed surfaces	8a, 8b, 8c, 8d
Maintain current snag habitat	9
Entrain litter for carbon cycling	10

#### 4.4.3 Flow Recommendations

As in Reach 3a immediately upstream, this reach is characterised by large pools separated by areas of shallow water. The pools are large enough to secure fish populations, even at very low flows. However, the structural complexity of shallow water areas seen upstream is not present, so returning summer-growing in-stream vegetation may not be as successful at this site. Changes at low flows create large depth changes, affecting shallow sections between pools. Using FEM criteria for depth >0.1 m (the surrogate for invertebrate habitat), current flows produce less area of suitable shallow water than under the natural flows (Figure 12). The crossover point in the natural and current recurrence graphs allows the identification of a flow that would preserve natural low flow shallow water conditions. This occurs at  $10.6 \text{ m}^2\text{m}^{-1}$ , which corresponds to 19 ML/d. A low flow recommendation of 19 ML/d therefore gives natural levels of water over 0.1 m depth over shallow areas. This also maintains at least 0.5 m depth in pools for large-bodied fish.

As for the upstream reach, freshes in the irrigation season are required for temporary Golden perch movement and habitat maintenance. The level of fresh that provides occasional periods of depths over the shallowest point of 0.5 m is 61 ML/d. Naturally, this flow would occur about 3 times per season for 11 days each time.

Again similar to upstream, permanent large-bodied fish movement requirements suggest that the minimum flow (May to October) should be 61 ML/d.

In-stream benches in this reach can be divided into low level (near the bottom of the channel) and high level (nearer the top of the channel). Low level benches are fully inundated at 400 ML/d (the median natural flow of the May to October period). These flows occurred naturally about 2 times a year for 7 days each. It is possible that these freshes would also provide breeding cues for Murray cod, so the recommendations are restricted to the August to October period.

Higher level benches are inundated at around 2,000 ML/d. These higher benches would provide a major source of terrestrial carbon for the river. Flows of this nature would also serve geomorphic functions of maintaining the pool conditions through scour. Again, these flows may provide breeding cues for Murray cod, so the recommendations are restricted to the August to October period.

Higher overbank flows – higher than 13,000 ML/d – would occur in June to October (the period when such flows are naturally more likely) about once every three years, peaking for a period of 1-2 days. Such flows are important for red-gum regeneration and geomorphic functions.

The flow recommendations with rationales and justifications for Reach 3b are tabulated in the FLOWS format in Table 22. The recommendations are summarised in a seasonal format in Table 23.

**Table 22. Flow recommendations for Reach 3b –Serpentine Weir to Loddon Weir**

River		Loddon River		Reach	Serpentine Weir to Loddon Weir
Compliance Point		d/s Serpentine Weir		Gauge No.	407229
Flow				Rationale	
Season	Magnitude	Frequency	Duration	Objective	Evaluation
Nov-Apr	19 ML/d (or natural)	Annually	Nov-Apr (between irrigation releases)	4a, 4b, 4d, 3c, 9	Maintains area of flowing water at 0.1 m depth
Nov-Apr	Fresh >61 ML/d	Min. 3 times per season	Min. 11 days	2c, 2d, 3b, 4c, 8a, 9	Golden perch upstream movement to spawn
May-Oct	Baseflow 61 ML/d <sup>3</sup>	Annually	May-Oct	2a	Maintain passage for large fish
Aug-Oct	>400 ML/d	2 times per year	7 days	2b, 5c, 8a	Inundate low-lying benches, and help stimulate fish breeding
Aug-Oct	>2,000 ML/d	2 times per year	Min. 6 days	2b, 5c, 8b, 10	Maintain disturbance processes, and inundate high-level benches
Jun-Oct	>13,000 ML/d	Once every three years	Peak for 2 day (natural rates of rise and fall)	7a, 8b, 8c, 8d, 10	Entrain leaf litter, perform geomorphic work and maintain red gum regeneration

**Table 23. Flow recommendations for Reach 3b – Serpentine Weir to Loddon Weir in seasonal format**

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Low flow: Minimum 19 ML/d (or natural)						Low flow: Minimum 61 ML/d (or natural)					
Fresh: >61ML/d, 3 per year, minimum 11 days									Fresh: >400 ML/d, 2 per year, minimum 7 days		
									High flow: >2000 ML/d, 2 per year, minimum 6 days		
							Overbank Flow: >13000 ML/d, 1 year in 3, peak flow for 2 day with natural rise and fall rates				

**4.4.4 Supporting information**

HEC RAS generated plots of cross-sections with water surface at various flow levels are given in Figure 11. FEM generated frequency analysis for depth >0.1 m for natural and current conditions is given in Figure 12.

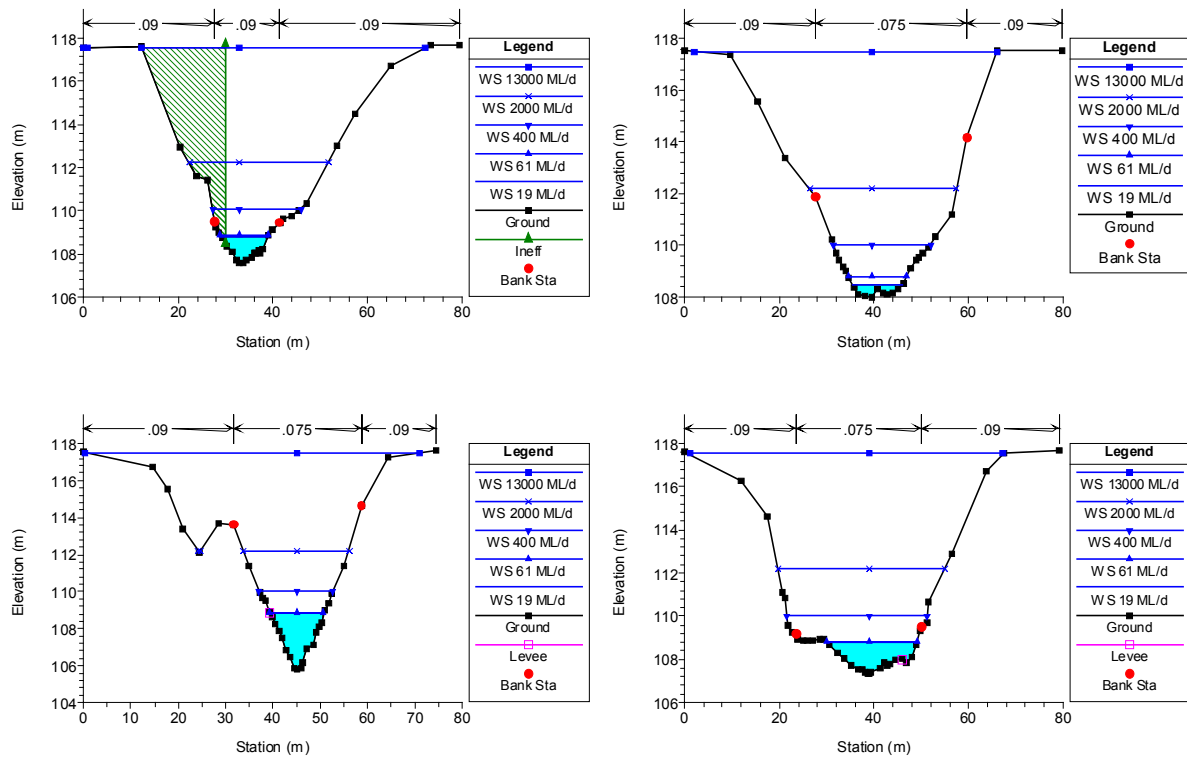


Figure 11. Reach 3b –Serpentine Weir to Loddon Weir cross-sections with water levels at selected flows.

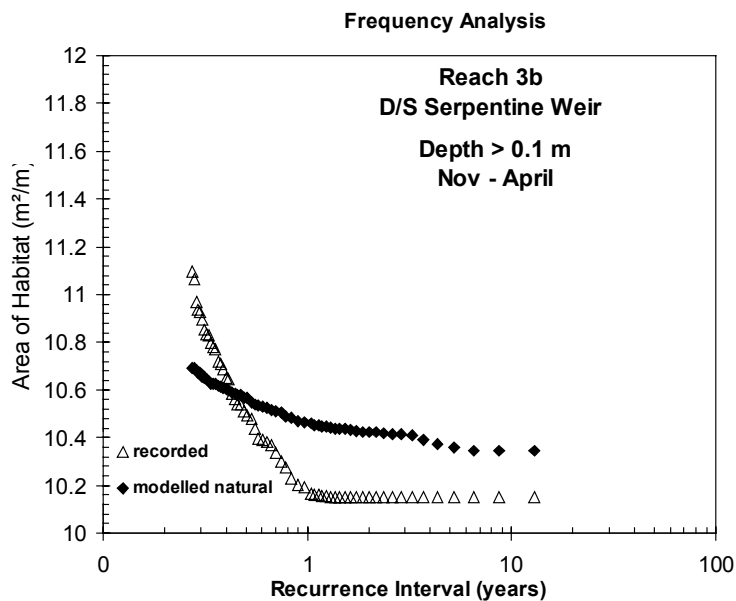


Figure 12. Reach 3b –Serpentine Weir to Loddon Weir frequency analysis for depth >0.1 m for natural and current conditions.

#### 4.4.5 Achievement of recommendations

The following table (Table 24) analyses the current frequency and duration of the flows recommended and assesses whether each recommendation is being achieved by current operational management. The

current frequency range is based on the 20-80<sup>th</sup> percentile exceedence range (i.e. the more common annual occurrence) and the duration is the median values over the period of record.

**Table 24. Analysis of current frequency and duration of the recommended flows**

<b>Season</b>	<b>Recommendation</b>	<b>Current</b>	<b>Achieved</b>
Nov-Apr	Minimum 19 ML/d	Naturally less than 19 ML/d, 0-2 times per year, 20 days; Currently 0-3 times per year, 3 days	Achieved.
Nov-Apr	>61 ML/d, 3 per year, 11 days	Currently 1-5 per year, 8 days	Achieved.
May-Oct	Minimum 61 ML/d	Naturally flows lower than 61 ML/d 0-1 per year, 7 days; Currently 1-4 times per year, 11 days	Not achieved, flows lower than recommendation too frequent
Aug-Oct	>400 ML/d, 2 per year, 7 days	Currently 1-3 per year, 12 days.	Achieved
Aug-Oct	>2000 ML/d, 2 per year, 6 days	Currently 0-2 per year, 26 days	Frequency not achieved
Jun-Oct	>13,000 ML/d, 1 in 3 years, 2 days	Currently 9 years in 27 years, 2 days	Achieved

#### **4.4.6 Supporting Recommendations**

TN,TP and EC can be high in this reach, and high turbidity water sourced from Laanecoerie Reservoir becomes even more turbid from local sources. Further salinity inputs are received from saline groundwater on the Loddon Plain. Water quality management needs to be investigated.

The Loddon weir is an instream barrier that is responsible for preventing the potential upstream movement of warm water River Murray fish species into Reach 3b. With the provision of a fishway downstream at Kerang, natural fish communities may establish. Consideration needs to be given to a fishway at Loddon Weir to increase the amount of available river length for these species, which may mean that stocking will not be required.

Land-use changes are likely to be an important component of the health of the macroinvertebrate community in the reach. Riparian vegetation is relatively healthy (and most of it is native), but uncontrolled stock access in many places along the reach and represents a threat to the vegetation and bank integrity. These issues will need to be addressed to assist achieving the flow objectives.

## 4.5 Reach 4 – Loddon Weir to Kerang Weir

### 4.5.1 Current condition

The current condition of Reach 4 was detailed in the Issues Paper (LREFSP, 2002). A summary of the current condition is provided in Table 25.

**Table 25. Current condition of Reach 4 – Loddon Weir to Kerang Weir**

Aspect	Current condition
Hydrology	<ul style="list-style-type: none"> <li>• Flows reduced for each month</li> <li>• Duration of low flows lengthened</li> <li>• Floods less than 2 year ARI reduced</li> </ul>
Water Quality	<ul style="list-style-type: none"> <li>• High turbidity, TN, TP and EC</li> </ul>
Geomorphology	<ul style="list-style-type: none"> <li>• Channel much smaller than upstream</li> <li>• Channel appears to have suffered excessive siltation</li> </ul>
Habitat	<ul style="list-style-type: none"> <li>• Moderate loading of woody debris</li> </ul>
Fish	<ul style="list-style-type: none"> <li>• Potential high fish diversity (few data available)</li> </ul>
Macroinvertebrates	<ul style="list-style-type: none"> <li>• Slow water macroinvertebrate fauna (possibly reduced diversity)</li> </ul>
Vegetation	<ul style="list-style-type: none"> <li>• Submerged macrophytes absent</li> <li>• Grassland bank understorey present</li> </ul>

### 4.5.2 Biodiversity Objectives

The flow related biodiversity objectives for Reach 4 were detailed in the Issues Paper (LREFSP, 2002). A summary of the objectives is provided in Table 26.

**Table 26. Flow related biodiversity objectives for Reach 4 – Loddon Weir to Kerang Weir**

Category of objective	Detailed objective number (Table 4)
Maintain or restore native fish community	2a, 2b, 2c
Maintain and/or restore natural invertebrate community	3b, 3c
Reinstate a mosaic of aquatic macrophytes	4a, 4b, 4c, 4d, 4e
Reverse bank terrestrialisation	6
Maintain red gum regeneration	7a
Maintain floodplain/wetland processes	7b
Scour silt on bed	8e
Maintain/improve current snag habitat	9
Entrain litter for carbon cycling	10

### 4.5.3 Flow Recommendations

Due to an inability to accurately estimate natural losses in the Loddon River downstream of Laanecoorie Reservoir at low flows, there is some doubt about the veracity of the natural low flow estimates at this site. Flows have been modelled with no losses, so the real natural flows could be lower than those provided. However, until these questions are resolved, the available data is used as the best that is currently available.

One of the major objectives in this reach is to support native fish populations that will recolonise the reach once the fishway is installed at Kerang Weir. The low flow recommendation between November and April is therefore based on maintaining natural levels of large-bodied fish habitat (area of water with depth greater than 0.5 m) and providing connectivity between habitats on a permanent basis. A flow of 10 ML/d provides a depth of 0.5 m at the shallowest point in the transect. This flow also provides an area of habitat with depth greater than 0.5 m of 7.9 m<sup>2</sup>/m, equivalent to a natural habitat area that would occur once every 3-4 years (Figure 14 – left graph).

Long periods of constant low flows should be avoided due to the possibility of bank notching, so it is recommended that the low flows be varied on a two weekly basis, rising from 7-12 ML/d over 1 week, then falling from 12-7 ML/d over 1 weeks. The variable flow should still provide adequate fish habitat (much better than currently - Figure 14 - although the low flow doubts need to be remembered).

It is unclear whether cease-to-flows occurred naturally in this reach. This cannot be overcome by adding the proviso “or natural” to the low flow recommendations as natural inflows upstream have been so altered and there appears to be no way to estimate what natural inflows would be. Should natural cease-to-flows turn out to be common, a recommendation on their frequency and duration will need to be made. Until then, the recommendations are for permanent provisions of the low flow recommendation.

Freshes over the November to April period have an added objective to provide an attracting flow for Golden perch from the Kerang Weir. These flows should therefore be provided in January or February. A flow of 50 ML/d (the natural median flow of January and February) is recommended for those two months, on an annual basis. Naturally, this flow would occur for about 14 days in those months.

Over the May to October period, levels of fish habitat are also currently much less than natural (Figure 14 – right graph). Due to the requirement to provide very secure fish habitat in the reach over the breeding period, a more conservative approach was adopted. From Figure 14 (right graph), the amount of habitat declines with flow until an area of about 13.5 m<sup>2</sup>/m (the inflection point), below which habitat remains fairly constant. This, therefore, is proposed as the minimum desirable habitat availability that should be currently provided (all current flows provide much less habitat than this). A habitat area of 13.5 m<sup>2</sup>/m corresponds to a flow of about 55 ML/d. As this is similar to the upstream May to October low flow recommendation, it is recommended that the upstream flows be passed with 100% transparency (i.e. the minimum is 61 ML/d).

Due to the smaller nature of the channel in the reach, bankfull flows correspond to around 400 ML/d. In this case, overbank flows can also provide the function of freshes in this season (inundating in-channel benches and maintaining in-stream conditions), as well as the normal functions of overbank flows. Flows over 400 ML/d occur naturally about 2 times per year for 7 days each.

It should be noted that the compliance point is the gauge at Appin South. Higher flows may need to be passed at Loddon Weir to achieve these recommendations.

The flow recommendations with rationales and justifications for Reach 4 are tabulated in the FLOWS format in Table 27. The recommendations are summarised in a seasonal format in Table 28.

**Table 27. Flow recommendations for Reach 4 – Loddon Weir to Kerang Weir**

River		Loddon River		Reach	Loddon Weir to Kerang Weir	
Compliance Point		Appin South		Gauge No.	407205	
Flow				Rationale		
Season	Magnitude	Frequency	Duration	Objective	Evaluation	
Summer	Cease-to-flow				Data unavailable – to be determined later	
Nov–Apr	Variable minimum 7-12 ML/d	Annually	Nov-Apr	2a, 3c, 4a, 4b, 4e, 9	Maintain connectivity for fish	
Jan-Feb	Fresh >50 ML/d	Once in summer	14 days	2c, 3b, 4c, 9	Attractant flow for Golden perch	
May –Oct	Minimum is 61 ML/d	Annually	May-Oct	2a	Maintain habitat for fish	
July-Oct	Over bank >400 ML/d	2 times per year	Min. 7 days	2b, 4c, 6, 7a, 7b, 8e, 10	Maintain bank and floodplain ecology, and perform geomorphic work	

**Table 28. Flow recommendations for Reach 4 – Loddon Weir to Kerang Weir in seasonal format.**

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Vary flows from 7-12 ML/d over a two week cycle						Minimum 61 ML/d					
		Fresh: >50 ML/d, 1 per year, minimum 14 days									
								Overbank flow: >400 ML/d, 2 per year, minimum 7 days			

**4.5.4 Supporting information**

HEC RAS generated plots of cross-sections with water surface at various flow levels are given in Figure 13. FEM generated frequency analysis for depth >0.5 m for natural and current conditions is given in Figure 14.

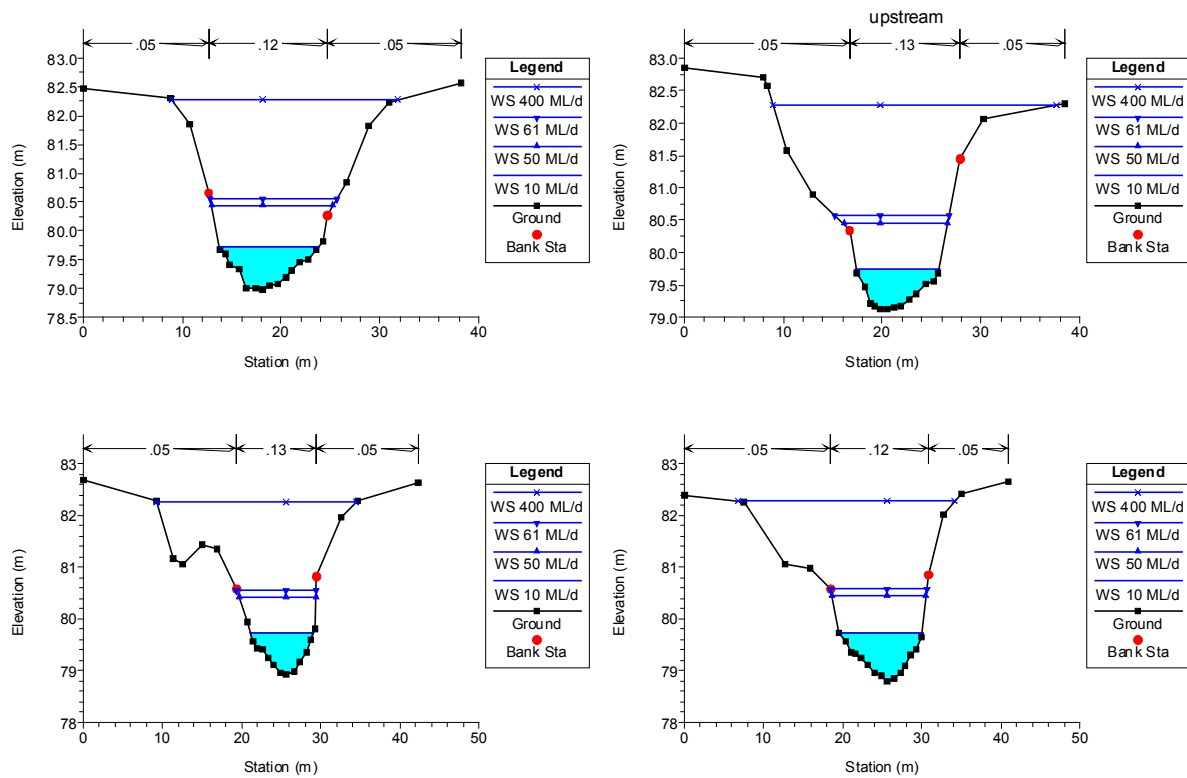


Figure 13. Reach 4 – Loddon Weir to Kerang Weir cross-sections with water levels at selected flows.

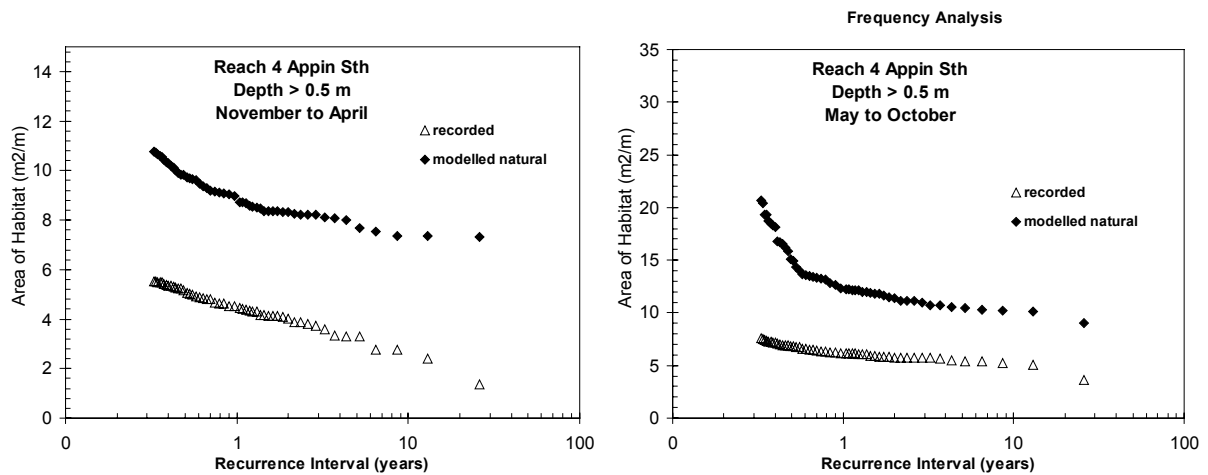


Figure 14. Reach 4 – Loddon Weir to Kerang Weir frequency analysis for depth >0.5 m for natural and current conditions.

#### 4.5.5 Achievement of recommendations

The following table (Table 29) analyses the current frequency and duration of the flows recommended and assesses whether each recommendation is being achieved by current operational management. The current frequency range is based on the 20-80<sup>th</sup> percentile exceedence range (i.e. the more common annual occurrence) and the duration is the median values over the period of record.

**Table 29. Analysis of current frequency and duration of the recommended flows**

Season	Recommendation	Current	Achieved
Nov-Apr	Minimum 7-12 ML/d	Never naturally less than 7 ML/d, naturally less than 12 ML/d 5 times in 27 years, 15 days Currently less than 7 ML/d 1-5 times per year, 8 days Currently less than 12 ML/d 1-4 times per year, 11 days	Not achieved. (Note These data should be treated with caution due to doubts about the accuracy of the low flows)
Jan-Feb	>50 ML/d, 1 per year, 14 days	Currently 0-2 per year, 5 days	Not achieved.
May-Oct	Minimum 61 ML/d	Naturally flows lower than 61 ML/d 0-1 per year, 12 days; Currently 2-4 times per year, 18 days	Not achieved. Lower than recommended flows too frequent.
Jul-Oct	>400 ML/d, 2 per year, 7 days	Currently 0-3 per year, 13 days	Not achieved. Frequency not achieved in most years.

#### 4.5.6 Supporting Recommendations

Natural losses at low flows need to be evaluated to obtain better natural flow data from which to make recommendations on cease-to-flows and to confirm the low flow recommendations over November to April.

In terms of turbidity and EC, this reach has degraded water quality, with EC of the Loddon River peaking at Appin South. The turbidity is very high by Victorian standards. TN and TP are well above the guidelines for protection of aquatic ecosystems. Further salinity inputs are received from saline groundwater on the Loddon Plain. Water quality is likely to be limiting to aquatic ecological diversity in this reach, so additional water quality improvement works may be needed.

Stream clearing works have been conducted just upstream from Kerang, so there may be a need to re-introduce large woody debris, or at least plan its long-term natural recruitment from the riparian zone.

Large stands of *Phragmites* have established downstream of Loddon Weir. These have probably been encouraged by the low constant flows that have been present in the past. Such stands would be difficult to manipulate by the provision of an environmental flow, as the species is particularly persistent once established. Specific local actions may be required to manage these stands if they are deemed to be a problem.

The one instream barrier known to this section of the Loddon River is located at Appin South and is a small low level weir that is frequently drowned out. Another piped section known as 'the Chute' may also be a barrier to fish passage under low flow conditions. If the installation of a fishway at Kerang Weir proceeds, minor modification to these structures may be necessary to improve fish passage.

Unregulated diverters have extraction licences downstream of Loddon Weir. The potential impact of licenced diversions from the river on the achievement of the recommendations needs to be evaluated.

Land-use changes are likely to be an important component of the health of the macroinvertebrate community in the reach. The riparian zone is in reasonable condition in that the vegetation is mostly native, but uncontrolled stock access in many places along the reach represents a threat to the vegetation and bank integrity. These issues will need to be addressed to assist achieving the flow objectives.

## 4.6 Reach 5 – Kerang Weir to the River Murray

### 4.6.1 Current condition

The current condition of Reach 5 was detailed in the Issues Paper (LREFSP, 2002). A summary of the current condition is provided in Table 30.

**Table 30. Current condition of Reach 5 –Kerang Weir to the River Murray**

Aspect	Current condition
Hydrology (natural flow data unavailable)	<ul style="list-style-type: none"> <li>• Summer flows increased</li> </ul>
Water Quality	<ul style="list-style-type: none"> <li>• High turbidity, TN, TP and EC (although TN and EC improved through dilution by water from Torrumbarry Irrigation Supply System). Turbidity and TP particularly high. High salinity below Barr Creek.</li> </ul>
Geomorphology	<ul style="list-style-type: none"> <li>• Siltation of bed, and physical disturbance from channelisation</li> </ul>
Habitat	<ul style="list-style-type: none"> <li>• Channelised and de-snagged</li> </ul>
Fish	<ul style="list-style-type: none"> <li>• Potential high fish diversity (few data available)</li> </ul>
Macroinvertebrates	<ul style="list-style-type: none"> <li>• Slow water macroinvertebrate fauna (possibly reduced diversity)</li> </ul>
Vegetation	<ul style="list-style-type: none"> <li>• Riparian vegetation is dominated by native species (predominantly a lignum shrubland), and regeneration is widespread and common. However non-native species are also regenerating.</li> <li>• Redgum sparse</li> <li>• In-stream vegetation is generally absent, and not all banks are vegetated</li> </ul>

### 4.6.2 Biodiversity Objectives

The flow related biodiversity objectives for Reach 5 were detailed in the Issues Paper (LREFSP, 2002). A summary of the objectives is provided in Table 31.

**Table 31. Flow related biodiversity objectives for Reach 5 –Kerang Weir to the River Murray**

Category of objective	Detailed objective number (Table 4)
Maintain or restore native fish community	2a, 2b, 2c
Maintain and/or restore natural invertebrate community	3b, 3c
Reinstate a mosaic of aquatic macrophytes	4a, 4b, 4c
Maintain/restore red gum regeneration	7a
Maintain floodplain ecology	7b
Entrain litter for carbon cycling	10

### 4.6.3 Flow Recommendations

Without natural flow data from this reach, recommendations for most flow components are based on preserving the environmental flows from upstream of Kerang Weir. Examination of transect hydraulics suggest that these flows are appropriate for objectives in this reach (Figure 15).

While the flow of 400 ML/d produces overbank flows upstream, this is not the case in this reach. In this reach, overbank flows occur at 1,200 ML/d. The recommendation here is made with an arbitrary duration and frequency, set the same as for overbank at Appin South (based on the assumption that floodplain vegetation has similar requirements).

The flow recommendations with rationales and justifications for Reach 5 are tabulated in the FLOWS format in Table 32. The recommendations are summarised in a seasonal format in Table 33.

**Table 32. Flow recommendations for Reach 5 –Kerang Weir to the River Murray**

River		Loddon River			Reach	Kerang Weir to River Murray
Compliance Point		d/s Kerang Weir			Gauge No.	407202
Flow				Rationale		
Season	Magnitude	Frequency	Duration	Objective	Evaluation	
Summer	Cease-to-flow				Data unavailable – to be determined later	
Nov–Apr	Variable minimum 7-12 ML/d	Annually	Nov-Apr	2a, 3c, 4a, 4b	Maintain connectivity for fish	
Summer (Jan-Feb)	Summer fresh >50 ML/d	Once in summer	14 days	2c, 3b, 4c	Attractant flow for Golden perch	
May –Oct	Minimum of 61 ML/d	Annually	May-Oct	2a	Maintain habitat for fish	
July-Oct	>400 ML/d	2 times per year	Min. 7 days	2a, 2b, 4c		
July - Oct	>1200 ML/d	2 times per year	Min. 7 days	7a, 7b, 10	Maintain bank and floodplain ecology, and perform geomorphic work	

**Table 33. Flow recommendations for Reach 5 –Kerang Weir to the River Murray in seasonal format**

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Vary flows from 7-12 ML/d over a two week cycle.						Minimum 61 ML/d (or natural)					
		Fresh: >50 ML/d, 1 per year, minimum 14 days									
								High flow: >400 ML/d, 2 per year, minimum 7 days			
								Overbank flow: >1200 ML/d, 2 per year, minimum 7 days			

#### 4.6.4 Supporting information

HEC RAS generated plots of cross-sections with water surface at various flow levels are given in Figure 15.

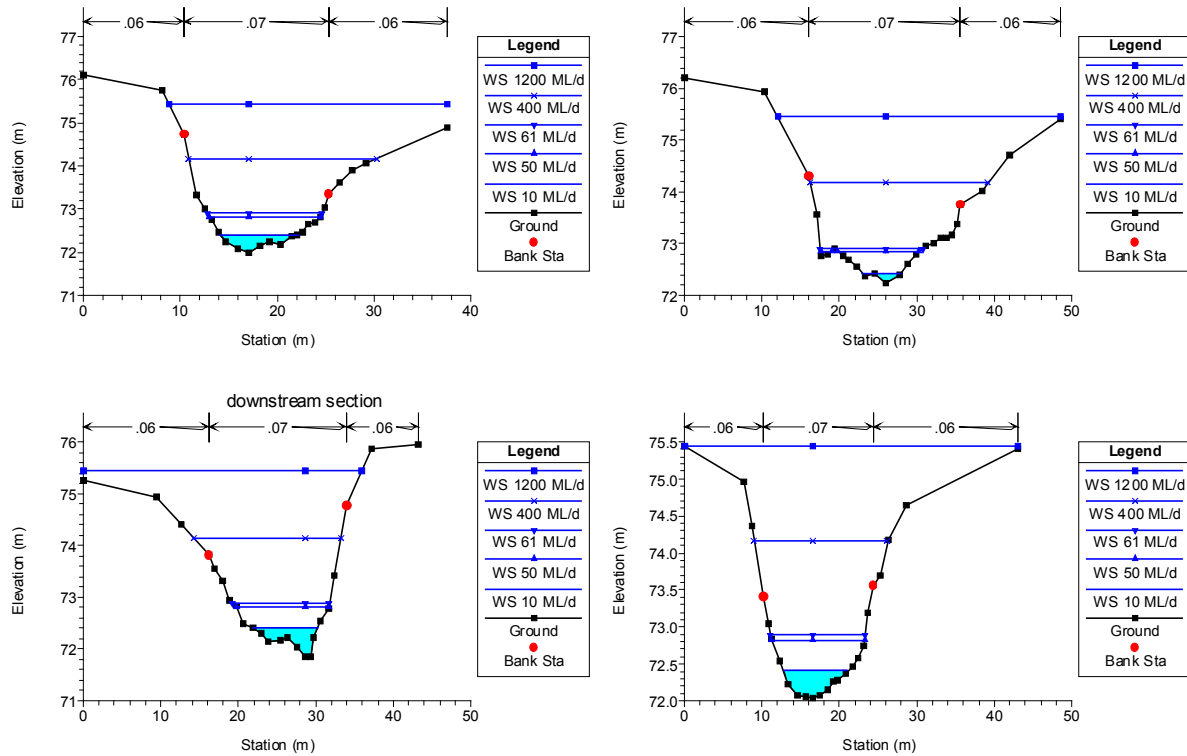


Figure 15. Reach 5 –Kerang Weir to the River Murray cross-sections with water levels at selected flows

#### 4.6.5 Achievement of recommendations

The following table (Table 34) analyses the current frequency and duration of the flows recommended and assesses whether each recommendation is being achieved by current operational management. The current frequency range is based on the 20-80<sup>th</sup> percentile exceedence range (i.e. the more common annual occurrence) and the duration is the median values over the period of record.

**Table 34. Analysis of current frequency and duration of the recommended flows in Reach 5**

Season	Recommendation	Current	Achieved
Nov-Apr	Vary flows from 7-12 ML/d over a two week cycle	Natural frequency and duration of flows less than 7 or 12 ML/d unknown. Currently always higher than 12 ML/d	Achieved.
Jan-Feb	>50 ML/d, 1 per year, 14 days	Currently almost always over 50 ML/d	Achieved.
May-Oct	Minimum 61 ML/d	Natural frequency and duration of flows less than 61 ML/d unknown. Currently 4 times in 27 years, 1 day.	Achieved (current frequency and duration deemed insignificant).
Jul-Oct	>400 ML/d, 2 per year, 7 days	Currently 1-2 per year, 16 days	Not achieved. Frequency not achieved in most years.
Jul-Oct	>1200 ML/d, 2 per year, minimum 7 days	Currently 0-2 per year, 22 days	Not achieved. Frequency not achieved in most years.

#### 4.6.6 Supporting Recommendations

Inputs of water from the Torrumbarry Irrigation Supply System ameliorate Loddon River water quality at Kerang, but downstream of Barr Creek the water quality is likely to be very poor. Water quality is likely to be limiting to aquatic ecological diversity in this reach and needs to be addressed through other activities.

The effects of channelisation and clearing should be reversed, through re-introduction of large woody debris, or at least plan for its long-term natural recruitment from the riparian zone.

Installation of a fishway at Kerang Weir will provide improved fish passage to upstream reaches.

The Kerang Lakes, as a group, are much modified from their original condition, but their ecological and conservation significance lies more in their function as a habitat and refuge for specific flora and fauna than in their representativeness or 'reference' condition. Maintenance of the environmental values of Kerang Lakes is high priority.

## 5. Conclusions

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Environmental flow recommendations were made for each of six reaches of the Loddon River. The recommendations are to be used in the development of Bulk water Entitlement (BE) conversions in the Loddon River.

The recommendations were developed using the process outlined in the Statewide method for determining environmental water requirements in Victoria, referred to as the FLOWS method. The Flow Events Method was also used to refine some recommendations. The Flow Events Method is considered a valuable adjunct to the FLOWS process.

Importantly, the recommendations were developed to meet specified Biodiversity Objectives for fish, macroinvertebrates, and in-stream, bank and floodplain vegetation. Each recommendation can be related to a specific Biodiversity Objective.

Only a few of the recommendations are being met by the current management of the system. The main flow recommendations not being achieved are:

- Non-irrigation season recommendations for baseflow not being met in some reaches (lower than recommended flows generally occur for longer periods than recommended);
- Non-irrigation season recommendations for higher in-channel flows not being met in some reaches (mainly frequency);
- Irrigation season low flows not being met in some reaches (lower than recommended flows occur for longer periods than recommended)

The Scientific Panel believes that it has provided recommendations which, if applied appropriately, should improve the ecological condition of the Loddon river. The challenge for the BE process is to come up with management alternatives to re-instate the recommended flows that provide a healthy river which meets the environmental, economic, recreational and cultural needs of current and future generations.

## 6. References

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## Appendix 1. Discussion of Methods

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The environmental flow recommendations in this report were developed for each reach using the basic process outlined in the standardised Statewide method for determining environmental water requirements in Victoria, referred to as the FLOWS method (SKM *et al*, 2002). FLOWS was primarily developed for use in Stream Flow Management Plans and small to mid sized BE conversions projects. The FLOWS method incorporates components of a number of existing environmental flow methods, with specific variations based on the requirements of the Streamflow Management Plan process in Victoria. The method was developed and tested in the Wimmera, Avoca and Glenelg River Catchments.

However, the Loddon BE will be a relatively large and complex process, beyond the intended scope of the FLOWS method. Despite this, the North Central CMA, and NRE believe that the FLOWS process and guidelines can be used and adapted for the Loddon River.

At the core of the FLOWS method is an Environmental Flows Technical Panel (EFTP), assembled to provide environmental expertise for the project, with all key decisions and recommendations made by the EFTP. For the Loddon River, a larger panel was used and has been termed a Scientific Panel to reflect the larger membership and perceived higher level of skills that would be expected from a Technical Panel.

The Scientific Panel found that the framework for the FLOWS method was generally applicable for the Loddon River project. However, a number of issues arose during the project that may require consideration in the further development of the FLOWS method.

- *The Issues Paper.* Some of the work done in the preparation of the Issues Paper was not relevant to production of reach-scale flow recommendations. One example of this is water quality, which the Scientific Panel subsequently decided should not be considered for amelioration through the provision of environmental flows. Another was the desire of the Steering Committee to include wetland considerations. These were not part of the project and could not be accommodated within the FLOWS method. Decisions on the agreed scope of the project need to be made early in the process to avoid unnecessary work.
- *The field visit.* FLOWS is essentially a rapid expert panel approach that relies heavily on existing information. The field visit is brief, limited and cursory, and for determining environmental condition, more reliance should be placed on previous, more comprehensive and representative surveys (if available). The field visit bears no resemblance to a proper scientific geomorphic or ecological survey, and the Steering Committee should not be under the illusion that it does. The value of the field visit is that it can clarify points of interest from the earlier data review, to get local and regional direct input, to potentially identify points and features that may have been overlooked, as well as providing the opportunity for the members of the EFTP to discuss and resolve cross-disciplinary questions on site.
- *The FLOWS field sheets.* The field sheets used for this exercise may be of some assistance to inexperienced operators, but the Scientific Panel found them somewhat tedious, time consuming and repetitive, and the data they produced was of limited direct practical use. The Scientific Panel preferred instead to make individualised records of important points for each reach. Obtaining a good photographic record of the field visit was deemed to be more important and valuable as a point of common reference. The photographs of the Loddon River were used extensively during the later analysis, workshop and write-up stages to check notes on channel morphology and vegetation type and cover, and to compare with cross-section survey plots.

This is not to say that another Scientific Panel with a different composition would not find the field sheets of value. Rather, it indicates that the Scientific Panel should determine their own method of recording data on the field trip and that the field sheets may be used as a potential tool, rather than an obligatory part of the method.

- *Flows flow component definitions.* Some of the FLOWS component definitions resulted in inconsistent recommendations. For example, the recommendation for freshes based on the median flow of a particular season sometimes produced a value lower than low flow recommendation, and the low flow definition based on simply providing connecting flow through the reach occasionally produced recommendations that were lower than natural low flows. The Scientific Panel realised these inconsistencies, and overruled the FLOWS definitions by seeking alternative rationales (using expert opinion) or by using the FEM as an adjunct method.

The potential limitations of the FLOWS definitions need to be recognised prior to the instigation of any project. Alternative approaches to defining flow components must be made part of the FLOWS framework for it to have general usefulness.

- *Recommendation workshop.* The FLOWS method does not provide guidance as to how such a workshop should be structured, nor does it strictly specify the processes to be followed in determination of environmental flow recommendations. For the Loddon River, the Scientific Panel derived an agreed process at the beginning of the workshop.

The Scientific Panel allowed two days for a workshop to derive the recommendations. This did not allow enough time to complete the task, primarily due to the need to develop a process through which the recommendations could be made. Future Scientific Panels particularly need to ensure that time is made available to develop their own process to determine recommendations, which may take some time.

- *Recommendation format.* The specified format for presentation of flow recommendations under the FLOWS method was found to be appropriate, but the Scientific Panel also developed a reformatted and simplified table that arranged the recommendations by seasons. It was felt this better visualised the flow recommendations.
- The main addition to the standard FLOWS process was the incorporation of the Flow Events Method (FEM) developed by the CRC for Catchment Hydrology (Stewardson and Cottingham, 2002).

The FEM was more difficult to apply interactively in the workshop situation owing to the time required to run the models and the statistical analysis. The forms of data output are unconventional, which meant that members of Scientific Panels initially struggled with interpretation. This will be the case in future assessments until familiarity with this method grows. However, there were several instances in this Loddon River study where the FEM was relied upon heavily to produce the flow recommendation.

In the opinion of the Scientific Panel, the additional time required to understand the FEM procedure and outputs added significantly to the production of the recommendations. In the future, if FEM is to be incorporated into an environmental flow study, it would be advisable to train Technical Panel participants in FEM prior to the workshop and distribute FEM results well in advance of the workshop.