Determination of the Minimum Environmental Water Requirement for the Yarra River

MINIMUM ENVIRONMENTAL WATER REQUIREMENT AND COMPLEMENTARY WORKS RECOMMENDATIONS

- Final
- 30 September 2005
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Minimum Environmental Water Requirement and Complementary Works Recommendations

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1. Introduction

1.1 Project background
There is an increasing awareness in water resource management of the need to incorporate the environmental requirements of ecosystems into the water resource planning process. Determination of environmental water requirements is a key part of the water resource planning process, as alterations to natural flow regimes can have significant impacts on riverine ecosystems.

The Department of Sustainability and Environment (DSE) developed the *Victorian River Health Strategy* (NRE 2002b), in part, to implement measures that provide water to meet environmental needs. The *Victorian River Health Strategy* sets goals to maintain and, where possible, restore the environmental values of rivers and wetlands, whilst recognising existing entitlements.

In 2004 the Victorian Government White Paper, *Securing our Water Future Together* (DSE 2004), announced a commitment to finalise the Bulk Entitlement (BE) Conversion process for the Yarra River. The aim of the process is to provide authorities with a clearly defined property right to water and protect instream values by allowing specific entitlements for the environment.

Currently, Melbourne Water harvests water from the Yarra River and tributaries for urban supply under a draft BE. A BE resulting from the conversion process for the Yarra System will be held by three retail water companies (Yarra Valley Water, City West Water and South East Water) and will include a cap on the extraction of water from the Yarra River.

Melbourne Water requires a determination of the environmental water reserve for the main stem of the Yarra River and its tributaries the Watts and Plenty Rivers. This project identifies the minimum environmental water requirements to maintain and enhance the significant ecological values in the Yarra River and tributaries and will ensure that the environmental flow needs of the Yarra River system are protected into the future. The environmental flow recommendations will also provide input to long-term water resource planning to ensure Victoria’s water security over time through the Central Region Sustainable Water Strategy.

The project study area includes the freshwater and estuarine reaches of the Yarra River catchment (from the Upper Yarra Reservoir to the West Gate Bridge) and its sub-catchments, the Plenty River (Toorourrong Reservoir to Plenty Gorge) and Watts River (Maroondah Reservoir to the Yarra River). Flow issues of the Yarra Estuary (Dights Falls to West Gate Bridge) have also been considered within the scope of the project, although at this point no specific flow recommendation is made for the estuary.
The objectives of the project are:

- to identify the water dependent social and environmental values in the Yarra River and tributaries;
- to gauge the current health of these values;
- to identify flow regimes that will maintain, sustain or improve these environmental values;
- to recommended environmental flow objectives that reflect community values for the river;
- to recommend the minimum environmental flows to meet the objectives, particularly to review the existing minimum environmental flow requirement for 245 ML/d at Yering; and
- to recommend other waterway works that could also meet the environmental flow objectives.

1.2 This report

This report presents the environmental flow and complementary waterway works recommendations for the Yarra River. The current report was preceded by a Site Paper and Issues Paper. The Site Paper described the process used to separate the Yarra River into representative reaches for the purposes of environmental flow assessments (SKM 2005a). The Issues Paper discussed the current environmental status of the study area —water system operations, ecology, hydrology, geomorphology and water quality— and canvasses those catchment and streamflow issues that affect the environmental condition of the study area and culminated in the determination of environmental objectives required to ensure the Yarra River is an ecologically healthy river (SKM 2005c). The Issue Paper summarises all the supporting information required to determine the environmental flow requirements for the Yarra River.

Using hydrological and hydraulic data and information contained in the Issues Paper, the EFTP determined a series of flow recommendations. The outputs of this task are documented in this report, which provides the minimum flow recommendations and the associated level of compliance under current flow conditions. Two workshops were held with the steering committee and advisory group on the 20th July 2005 and the 5th September 2005 to present and discuss draft and final flow recommendations. Outcomes from these discussions have been incorporated into this report.

1.2.1 Report structure

Section 2 provides a summary of the methods employed to develop flow recommendations for the Yarra, Plenty and Watts Rivers. Environmental objectives and their function are presented in Section 3. The flow recommendations themselves are provided in Section 4 along with an overview of reach conditions and a brief assessment of the current degree of compliance. Section 5 provides a discussion of the importance of each flow component/recommendation at the system level, identifies priority flow components and discusses uncertainties and risks associated with each component. Section 6 provides recommendations for complementary waterway works and further investigations required to support environmental objectives and complement the environmental flow recommendations.
2. Methods

The determination of an Environmental Water Reserve for the Yarra River relies on the FLOWS method (NRE 2002a) to produce environmental flow recommendations. The FLOWS method details the available information on the environmental and social values of the study area and uses a sound scientific method to define environmental objectives that will serve as a basis for environmental flow recommendations. The method relies on a multi-disciplinary approach with intellectual input and direction provided by the Environmental Flows Technical Panel (EFTP). The FLOWS method relies on intellectual input and direction from the EFTP. The EFTP consists of members that have expertise in an environmental discipline. Members of the EFTP for this project are (in alphabetical order, with fields of expertise):

- Dr Bruce Abernethy  Geomorphology
- Trevor Dando  Waterway management
- Tim Doeg  Macroinvertebrate ecology
- Harry Houridis  Estuarine ecology
- Dr Rory Nathan  Hydrology
- Dr Jane Roberts  Vegetation and wetland ecology
- Dr Michael Shirley  Fish ecology
- Dr Simon Treadwell  Aquatic ecology

Technical assistance was provided by Kylie Swingler and hydraulic modelling was undertaken by Lisa Lowe.

In addition to the EFTP, there are a number of Technical Advisers who have provided specific technical advice on aspects of the Yarra River. Technical advisers for this project are (in alphabetical order, with fields of expertise):

- Associate Professor Gerry Quinn  Expert review
- Scott Seymour  Waterway management
- Dr Chris Walsh  Urban ecology

A Project Steering Committee and Project Advisory Group have been established to provide a forum in which the rivers key stakeholders can provide technical input into the study. The advisory group has met on six occasions to discuss background information, site selection, environmental issues, environmental objectives and flow recommendations. Discussion and comments from the advisory have been considered in the formulation of environmental objectives and flow recommendations.

A brief description of the method applied to this project area is provided below. The full method and rationale is presented in NRE (2002a).
2.1 Fieldwork

The first stage of this project was to collect and collate all available information relating to the project area. The methods and outputs of this task are described in SKM (2005c). As part of the first stage a site visit was conducted to identify reaches and select sites that were representative of a range of hydrological, ecological and geomorphological features of each reach. A total of 11 sites were selected: nine on the main stem of the Yarra River and one each on the Plenty and Watts Rivers (Table 2.1 and see Figure 2.1).

### Table 2.1 Yarra River reaches and field assessment sites.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Location</th>
<th>Site</th>
<th>Site location</th>
<th>Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Upper Yarra Reservoir to Armstrong Creek junction</td>
<td>1</td>
<td>Downstream of Upper Yarra Reservoir, Reefton</td>
<td>Doctors Creek</td>
</tr>
<tr>
<td>2</td>
<td>Armstrong Creek to Millgrove</td>
<td>2</td>
<td>Warburton East (downstream of major tributary harvesting operations)</td>
<td>Millgrove</td>
</tr>
<tr>
<td>3</td>
<td>Millgrove to Watts River junction</td>
<td>3</td>
<td>Everard Park, upstream of Maroondah Highway</td>
<td>Yarra Grange</td>
</tr>
<tr>
<td>4</td>
<td>Watts River to top of Yering Gorge</td>
<td>4</td>
<td>Tarrawarra Abbey, Yarra Glen.</td>
<td>Yarra Glen</td>
</tr>
<tr>
<td>5</td>
<td>Top of Yering Gorge to Mullum Mullum Creek</td>
<td>5a</td>
<td>Immediately downstream of Yering Gorge pumping station.</td>
<td>Warrandyte</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5b</td>
<td>Everard Drive, Warrandyte</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mullum Mullum Creek to Dights Falls</td>
<td>6a</td>
<td>Banyule Flats, downstream of Plenty River</td>
<td>Chandler Hwy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6b</td>
<td>Dights Falls, Abbotsford (no hydraulic survey)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Yarra Estuary</td>
<td>7</td>
<td>Herring Island - South Yarra (no hydraulic survey)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Watts River from Maroondah Reservoir to Yarra River confluence</td>
<td>8</td>
<td>Coronation Park (River St) downstream of confluence with Grace Burn</td>
<td>Healesville</td>
</tr>
<tr>
<td>9</td>
<td>Plenty River from Toorourrong Reservoir to Mernda</td>
<td>9</td>
<td>Upstream of Gordon's Lane (Nioka Bush Camp)</td>
<td>Mernda</td>
</tr>
</tbody>
</table>

Detailed site assessments were undertaken by the EFTP at nine of the 11 sites. Up to six transects were identified at each site for subsequent surveying. These transects were selected as representative of the range of channel and habitat features of the site, such as pools, riffles, log jams, and channel benches. Once selected, photographs were taken of each transect and a sketch drawn to identify important geomorphic and ecological features. An evaluation of the key components of the flow regime at each of the sites was carried out to identify flows that would be geomorphically or ecologically important for the river system.

All of the transects selected were surveyed and incorporated into a hydraulic model for each site. A total station was used to measure any significant changes in channel features across each transect and all transects were linked together to provide a three-dimensional model of each site. Water level was recorded at all sites to assist in validation of the hydraulic model. Invert levels (i.e. the lowest point) of wetland inlets were also surveyed to determine levels at which water commences to enter wetlands.
- Figure 2.1 Reaches and environmental flow assessment sites in the Yarra, Watts and Plenty Rivers.
2.2 Hydraulic model

A hydraulic model was prepared to develop a relationship between stream flow, and water level and velocity for each site. The hydraulic analyses of the sites were undertaken using the HEC-RAS software, which is designed to perform one-dimensional steady state calculations for a full network of natural and constructed channels or a single river reach. Separate hydraulic models were constructed for each of the sites. Each model was then validated by undertaking a sensitivity analysis of the channel roughness represented by Manning’s ‘n’ values and by adjusting the downstream boundary condition. As there was little or no data available for calibration it was necessary to assign textbook Manning’s ‘n’ values for channel roughness.

Additionally, a sensitivity analysis was undertaken by adjusting Manning’s ‘n’. Model outputs showed the variation in total depth for the range of Manning’s values tested. The sensitivity of the model to the downstream condition was also assessed to determine the impact on calculated results. Various flows were routed through the model that represented the full range of flows, including overbank flows to assess floodplain and wetland inundation.

2.3 Hydrology

Daily flow series for natural, current and historical flows have been developed for all reaches (SKM 2004). Natural flows are those that would have occurred over the historical climate sequence without private diversions, Melbourne Water diversions, the effects of farm dams and the effects of major reservoirs. Current flows are those that would have occurred over the historical climate sequence but with the current level of development (ie. infrastructure and demand). Historical flows are those actually recorded. Hydrological assessment involved consideration of a range of hydrological parameters to describe the flow regime, including:

- flow duration curves to examine the percentage of time that a flow of a given size is exceeded;
- time series graphs to examine the sequence of flow events, particularly during very dry or very wet conditions; and
- flow spell analysis using GetSpells Software to describe the frequency, duration and start month of flow spells (flow events above or below a defined threshold).

The analysis of the outputs and development of the recommendations was carried out by the EFTP. The recommendations were aimed at meeting the environmental objectives identified in the Issues Paper and are based on the physical characteristics of the reach and a range of criteria for selecting various flow volumes, timing and duration. Criteria and rationale for each flow component are discussed in the presentation of flow recommendations for each reach in following sections. Uncertainty and risks associated with any of the flow recommendations are also discussed. The recommended flows are the minimum required for the Yarra to be considered an ecologically healthy river. Any reduction in the recommended flows will compromise objectives.

2.3.1 Ramp rates

The rate at which flows rise and fall are known as ramp rates. These rates are environmentally significant particularly for short duration spells such as freshes and bank-full flows. If rates of rise are too fast they may exceed the ability of biota to adapt, thereby causing stress. Rapid falls in
flow can increase the risk of bank failure leading to increased erosion and sediment loads and in some instances may strand biota.

Ramp rates were calculated from natural daily flow data for each reach. Summer and winter freshes, high flows and bankfull flow spells were isolated and the percentile rates of rise and fall for these spells calculated for each reach. There were no significant differences in the rates of rise or fall for individual flow components so all spells were combined to calculate rates (Figure 2.2). Based on inflection points in Figure 2.2 the 20th\%ile rate of rise and 80th\%ile rate of fall have been chosen as the recommended rates of rise and fall for each flow recommendation. These rates of rise and fall also apply to rates of level change associated with pumping at the Yering Gorge pumping station and are aimed at avoiding rapid stepped changes in flow and river level.

The ramp rate recommendations are provided as a factor of the previous day’s flow. For example a recommended rate of rise of 1.6 stipulates that flow on a given day should not exceed 1.6 times the previous day’s flow.
2.3.2 **HecRas and Getspells output**

Where possible six transects was surveyed at each site. Fewer transects were surveyed if there was little variation in channel features, or where reach length constrained the number of transects that could be surveyed. All transects were used to develop the flow recommendations, however only two from each site are provided in this report. A pool transect and a riffle transect illustrate the water levels associated with each recommended flow threshold (e.g. Figure 2.3).

![Figure 2.3: Stage height in pool (Transect 1, left) and riffle (Transect 2, right) transects at the recommended threshold (740 ML/d) for summer/autumn freshes at Site 5a, Yarra River at Yering Gorge.](image)

Getspells software is used to describe and compare the duration, frequency and start months of flow events (spells) that rise above or fall below a stipulated flow threshold under current and natural conditions. These analyses are carried out using modelled daily flow data for either the high flow (June to November) or low flow (December to May) periods. For our analyses, flow spells are considered to be separate events if they are more than five days apart. It is important to note that for low flows, spells that fall below the threshold are evaluated. For freshes, high flows and bankfull flows, spells above the threshold are evaluated.

An example of a Getspells output is provided in Figure 2.4. The percentile plots describe the duration of each flow spell. In each plot the median spell duration (50\textsuperscript{th} percentile) is indicated with variation in spell duration described by the box and whiskers plots. Sixty percent of flow spells have a duration that lies within the box (20\textsuperscript{th} and 80\textsuperscript{th} percentiles) while outliers are described by the whiskers (spells within the 10\textsuperscript{th} and 90\textsuperscript{th} percentiles). In the example provided in Figure 2.4 for spells that occurred during summer/autumn under current conditions:

- the median duration of spells above the flow threshold is 4 days;
- 60\% of spells above the flow threshold lasted between 3 and 15 days; and
- 80\% of spells above the flow threshold lasted between 3 and 33 days.
Under natural conditions the median duration of spells above the flow threshold is also 4 days, but 60% of spells above the flow threshold lasted between 3 and 38 days and 80% of spells above the flow threshold lasted between 3 and 66 days. This indicates a higher proportion of spells above the flow threshold occur for a longer duration under the natural regime compared to current.

The upper box and whisker have a greater spread than the lower box and whisker. This indicates that the data is skewed, that is to say that most spells are of short duration and long duration spells are relatively infrequent.

The frequency plot compares the average number of times that the spells will occur in any 100 year period. Flow spells that occur with a frequency of less than 100 do not occur every year while spells with a frequency greater than 100 occur more than once a year on average. Using the example in Figure 2.4 the frequency of spells above the flow threshold that occurred during summer/autumn under current conditions is 225 times in every 100 years (i.e. approximately two times a year). Under natural conditions flows above the threshold would have occurred 500 times in every 100 (i.e. five times a year).

The frequency of start month plot describes the frequency distribution of the months in which flow spells have started. In Figure 2.4 freshes during the summer/autumn period most often start during December. The width of the bars provides an indication of the number of events that start in each month and differences in the distribution of events can be compared between natural and current.
2.4 Development of flow recommendations
Flow recommendations for each reach were determined by the EFTP in a workshop conducted on 9 June 2005. The workshop was also attended by several members of the Project Steering Committee (Jamie Ewert and Christine Hughes from Melbourne Water and Steve Nicol from DSE). At the workshop, the EFTP undertook a reach by reach assessment whereby they examined flow components required to achieve objectives. Flow volume was determined based on physical features such as the flow required to inundate specific channel features or generate sufficient velocity. A number of criteria were used to determine appropriate flow volumes and these are described in more detail in Section 3 and referenced throughout Section 4, which describes in detail the flow recommendations. Frequency and duration were typically based on the median natural frequency or duration or expert opinion where a specific frequency or duration was required to achieve objectives, for example prolonged inundation of bank vegetation.

2.5 Compliance with recommendations
Percentage compliance with the flow recommendations has been determined for each component as described below for the current flow regime.

2.5.1 Volume compliance
For summer and winter low flow volumes compliance is based on the percentage of time (days) within the relevant period that the flow exceeds the volume recommendation. For all other flow components (fresh, high, bankfull and overbank) the volume compliance is based on the percentage of years when the volume recommendation is met. For example, a 70% compliance with the volume recommendation for a fresh or high flow means that in 70% of years the volume recommendation was met or exceeded in the defined season.

2.5.2 Frequency compliance
Compliance with the frequency or number of events is based on the percentage of years when the recommended number of events was met. For example, if one event is required each year but currently only occurs in eight years out of ten then compliance is 80%. If two events are recommended to occur each year but currently two events only occur every second year then compliance is 50%. Where an event is not required every year, for example the recommendation is one event every two years, the percentage compliance is adjusted. As an example, if an event is required in 50% of years (ie 1:2 years) and currently occurs in 45% of years then the percentage compliance is 90% (ie. 45/50x100).

Note, that for the purposes of testing compliance, frequency has been determined based on the percentage of years when the threshold was exceeded, rather than an average of the number of exceedences in a 100 year period.

2.5.3 Duration compliance
Compliance with duration is based on the percentage of events (ie. when the volume is met at the right time of year) where the recommended duration is met. For example, the recommended event duration may be 7 days but if only 25% of events last for 7 days or longer then compliance is 25%.
Compliance has been colour coded according to the arbitrary ranges in Table 2.2.

Table 2.2 Key to colour coding for percentage compliance.

<table>
<thead>
<tr>
<th>Component</th>
<th>Mostly complies</th>
<th>Frequently complies</th>
<th>Often complies</th>
<th>Occasionally complies</th>
<th>Rarely complies</th>
<th>Never complies</th>
</tr>
</thead>
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<tr>
<td>Volume (ML/d) as percentage of years (or time in the case of low flows) when recommended volume is met</td>
<td>&gt;95% of years</td>
<td>76-95% of years</td>
<td>51-75% of years</td>
<td>26-50% of years</td>
<td>5-25% of years</td>
<td>&lt;5% of years</td>
</tr>
<tr>
<td>No. (frequency of occurrence per year) as percentage of years when frequency is met</td>
<td>&gt;95% of years</td>
<td>76-95% of years</td>
<td>51-75% of years</td>
<td>26-50% of years</td>
<td>5-25% of years</td>
<td>&lt;5% of years</td>
</tr>
<tr>
<td>Duration (days) as percentage of events when duration is met</td>
<td>&gt;95% of events</td>
<td>76-95% of events</td>
<td>51-75% of events</td>
<td>26-50% of events</td>
<td>5-25% of events</td>
<td>&lt;5% of events</td>
</tr>
</tbody>
</table>

2.5.4 Flow comparisons

The FLOWS method is based on the determination of flow components to meet agreed environmental objectives. As such, in regulated rivers the recommended flow does not necessarily resemble the natural flow regime; rather it resembles a regime that is considered by the EFTP to be one that maximises the ability to achieve the stated environmental objectives. For the Yarra River, the PAG has requested that the flow recommendations be compared with the current and natural flow regime. This has been undertaken on the proviso that flow statistics used are surrogates only and are not meant to imply ideal or preferred flow; they are for comparative purposes only.

Volume comparison

There are no universally defined percentiles that correspond to specific flow components. However, as simple surrogates, for the current and natural flow regimes, the volume of each flow component has been estimated where the low flow equivalent has been calculated as the 80th%ile of the daily flow, freshes have been calculated as the 50th%ile of the daily flow and high flows as the 20th%ile of the daily flow in the specified period. The low flow is typically considered as the flow that occurs on more than 80-90% of days and the high flow is typically considered as the flow that occurs on less than 5-20% of days (Poff et al. 1997). We have chosen the 80th%ile to represent low flows and the 20th%ile to represent high flows simply for comparative purposes. There is no standard percentile definition for a fresh flow, however the FLOWS method described a flow that exceeds the median flow (50th%ile) for more than 5 days as a fresh (NRE 2002a).

As an example, to compare the summer low flow between the current and natural flow regimes the 80th%ile of flow in the summer period has been calculated for both regimes and can be compared to highlight the differences in the low flow volume between natural and current. This volume can then be compared with the recommended low flow volume.
Frequency and duration comparison

For frequency and duration, the comparison between current and natural is based on the median number (50th percentile) of events in the specified period and the median (50th percentile) duration of each event.

The following table is an example of how to interpret the compliance summary tables for each reach.

The summer low flow rec is 80 ML/d. For comparative purposes the current summer low flow (80th percentile) is 139 ML/d & the natural summer low flow (80th percentile) was 273 ML/d. Under both the current & natural regime

The summer high flow rec is 560 ML/d, once in April-May & for 7 days duration. For comparative purposes the current summer high flow (20th percentile) is 347 ML/d & the natural summer high flow (20th percentile) was 723 ML/d. Under the current regime the volume recommendation is met 70% of the time.

The current median frequency is 0.7 events each year & the recommended frequency is only met in 80% of years. The current median duration is 2 days & the recommended duration of 7 days is only met for 5% of events.

The winter low flow rec is 350 ML/d. The current winter low flow (80th percentile) is 263 ML/d & the natural winter low flow (80th percentile) was 724 ML/d. Under current conditions the rec is complied with 68% of the time.

The winter fresh rec is 700 ML/d on two occasions for 7 days duration. Under current conditions the winter fresh (50th percentile) is 524 ML/d & the natural fresh (50th percentile) was 1316 ML/d. Under both current conditions the volume rec is met in 100% of years. However, the frequency rec is only met in 50% of years. In other words under current conditions at least one event occurs in each year with a flow volume of 700 ML/d while at least 2 events of 700 ML/d only occur every second year (ie 50% compliance with frequency rec.).

Under natural conditions the median number of events greater than 700 ML/d was 5. The current median duration is 4.5 days and only 40% of events last for at least 7 days. Under natural conditions the median duration of an event greater than 700 ML/d was 17 days.
3. Environmental objectives

The process of setting environmental objectives involves first identifying the environmental assets, setting environmental objectives against these, and then identifying the flow objectives required to meet the environmental objectives. For the purpose of this process, environmental objectives were developed only for those ecological assets that have a clear dependence on some aspect of the flow regime. Environmental objectives were developed for:

- particular species and communities;
- habitats; and
- ecological processes.

Following the FLOWS methodology the direction of a particular objective is expressed as one of three main targets:
1) Maintain – keep the condition of the resource in its current state;
2) Restore – move the condition of the resource back to natural conditions; and
3) Rehabilitate – move the condition of the resource to some different state other than natural (usually less than natural).

The development of reach specific environmental objectives for the Yarra River is detailed in the Issues Paper (SKM 2005c) and tabulated in Table 3.1 to Table 3.9. In summary, objectives have been developed to:

- Maintain channel geometry throughout all reaches;
- Improve access to suitable habitats for fish and macroinvertebrates by providing flows that scour sediment from pool and benthic surfaces in riffles;
- Maintain longitudinal connectivity for fish passage;
- Increase the zone of flood-tolerant vegetation on banks by drowning terrestrial vegetation encroaching on banks;
- Ensure minimum flows do not cause flow related declines in water quality; and
- Preserve inundation of wetlands and floodplains.

For each objective the target flow component or complementary works requirement are identified, as is the expected response and an indication of likely response time (short <3 years, medium 3-10 years and long >10 years).

A number of terms are used to describe environmental objectives and expected function; these terms are defined in Table 3.10.
### Table 3.1 Reach 1 – Upper Yarra dam to Armstrong Creek objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No.</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Maintain current channel hydraulic geometry</td>
<td>G1-1</td>
<td>Sediment accumulation</td>
<td>Bankfull flow</td>
<td>Winter / spring</td>
<td>No further contraction in channel geometry.</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td>Reconstruct instream habitat</td>
<td>G1-2</td>
<td>Riffle sediment accumulation</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>Prevent sediment build up on cobbles in riffle zone.</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G1-3</td>
<td>Pool sediment accumulation</td>
<td>High flow</td>
<td>Winter / spring</td>
<td>Flush fine sediment from pools.</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G1-4</td>
<td>Limit sediment sources</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>Reduced sediment input from Doctors Creek catchment.</td>
<td>Medium</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>Reconstruct macroinvertebrate community to maximum diversity &amp; abundance possible downstream of a large dam with the aim of meeting Yarra SEPP Schedule F7 objectives.</td>
<td>M1-1</td>
<td>Access to riffle habitat</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>The objective is to increase the diversity &amp; abundance to the maximum possible based on the assumption that flows that reduce sediment accumulation will improve access to benthic habitats will result in an increase in invertebrate biodiversity &amp; abundance.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M1-2</td>
<td>Clean cobbles in faster flowing reaches</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>Increase abundance of native species including recolonisation by mountain galaxias.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M1-3</td>
<td>Flush sediment from pools &amp; entrain organic material from littoral zone</td>
<td>High flow</td>
<td>Winter</td>
<td>Self sustaining river blackfish population with a range of age classes in population</td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Reconstruct native fish community composition &amp; abundance (resident &amp; diadromous species) with the aim of meeting Yarra SEPP Schedule F7 objectives.</td>
<td>F1-1</td>
<td>Access to habitat</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>Increase abundance of native species including recolonisation by mountain galaxias.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F1-2</td>
<td>Provide spawning &amp; movement opportunities, flush sediment from spawning sites.</td>
<td>High flow</td>
<td>Winter / spring</td>
<td>Self sustaining river blackfish population with a range of age classes in population</td>
<td></td>
</tr>
<tr>
<td>Vegetation</td>
<td>Maintain current in channel &amp; riparian vegetation extent, structure &amp; composition</td>
<td>V1-1</td>
<td>Bank drying</td>
<td>Low flow</td>
<td>Summer</td>
<td>No decline in the existing vegetation characteristics such as, structure, diversity &amp; abundance of native species.</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1-2</td>
<td>Maintenance of flood tolerant vegetation</td>
<td>Freshes</td>
<td>Throughout year</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1-3</td>
<td>Bank wetting to promote flood-tolerant vegetation &amp; limit terrestrial vegetation</td>
<td>High flow</td>
<td>Winter / spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1-4</td>
<td>Scouring of vegetation encroaching in channel</td>
<td>Bankfull flow</td>
<td>Winter / spring</td>
<td>No further vegetation encroachment in channel.</td>
<td>Medium</td>
</tr>
<tr>
<td>Water quality</td>
<td>Maintain current water quality to meet Yarra SEPP Schedule F7 objectives</td>
<td>W1-1</td>
<td>Ecological processes &amp; beneficial uses</td>
<td>Complementary</td>
<td>As required</td>
<td>No decline in current water quality.</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W1-2</td>
<td>Limit effect of cold water releases</td>
<td>Complementary</td>
<td>As part of release operations</td>
<td>No detrimental impacts of cold water releases from reservoir</td>
<td>Short</td>
</tr>
</tbody>
</table>
### Table 3.2 Reach 2 – Armstrong Creek to Millgrove objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Maintain current channel hydraulic geometry</td>
<td>G2-1</td>
<td>Sediment accumulation</td>
<td>Bankfull flow</td>
<td>Winter / spring</td>
<td>No further contraction in channel geometry.</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td>Engage low level floodplains</td>
<td>G2-3</td>
<td>Connectivity</td>
<td>Bankfull / low overbank flow</td>
<td>Winter / spring</td>
<td>Appropriate frequency of inundation of low level floodplain &amp; billabongs achieved</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>Maintain access to riffle &amp; pool habitat</td>
<td>G2-3</td>
<td>Limit catchment sediment sources</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>Promote Best Practice Guidelines for roading &amp; timber harvesting.</td>
<td>Medium</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>Maintain current macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives</td>
<td>M2-1</td>
<td>Access to riffle habitat</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>Expect Macroinvertebrates scores to continue to meet SEPP objectives</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td>M2-2 Disturbance to scour biofilms &amp; sediment</td>
<td></td>
<td>FRESHES</td>
<td></td>
<td>Throughout year</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M2-3 Disturbance &amp; entrain organic material on benches &amp; high flow channels</td>
<td></td>
<td>High / bankfull flow</td>
<td></td>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Maintain diverse native fish community composition (resident &amp; diadromous species) &amp; comply with Yarra SEPP Schedule F7 objectives</td>
<td>F2-1</td>
<td>Access to habitat</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>No decline in native fish diversity &amp; abundance - expected species include: river blackfish, short-finned eels, short-headed lamprey, pouched lamprey, tupong, Australian smelt, mountain galaxias, spotted galaxias, common galaxias &amp; Australian grayling.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td>F2-2 Provide spawning &amp; movement opportunities, flush sediment from spawning sites.</td>
<td></td>
<td>FRESHES</td>
<td></td>
<td>Throughout year</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>F2-3 Trigger spawning &amp; downstream transport of eggs &amp; larvae</td>
<td></td>
<td>FRESHES</td>
<td></td>
<td>Spring</td>
<td>Increased presence &amp; abundance of Australian grayling through improved spawning opportunities &amp; recruitment success.</td>
<td>Medium to long</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Rehabilitate riparian vegetation extent, structure &amp; composition</td>
<td>V2-1</td>
<td>Bank drying</td>
<td>Low flow</td>
<td>Summer</td>
<td>Increased abundance, diversity &amp; density of flood-tolerant native species on bank.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td>V2-2 Maintenance of flood tolerant vegetation</td>
<td></td>
<td>FRESHES</td>
<td></td>
<td>Throughout year</td>
<td>Decreased terrestrial weed abundance on banks (eg blackberry &amp; wild Watsonia)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V2-3 Bank wetting to promote flood-tolerant vegetation &amp; limit terrestrial vegetation</td>
<td></td>
<td>High / bankfull flow</td>
<td></td>
<td>Spring</td>
<td>Revegetation with riparian species appropriate for the EVC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V2-4 Fencing, revegetation &amp; weed control works</td>
<td></td>
<td>Complementary</td>
<td></td>
<td>Ongoing</td>
<td>Fencing to minimise bank disturbance &amp; exclude stock access</td>
<td></td>
</tr>
<tr>
<td>Water quality</td>
<td>Maintain current water quality to meet Yarra SEPP Schedule F7 objectives</td>
<td>W2-1</td>
<td>Ecological processes &amp; beneficial uses</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>No decline in current water quality.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Implementation of catchment strategies to limit stock access, agricultural runoff &amp; septic tank effluent inputs to river to reduce nutrient &amp; sediment levels &amp; limit excessive algal growth.</td>
<td></td>
</tr>
</tbody>
</table>
### Table 3.3 Reach 3 – Millgrove to Watts River objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No.</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Maintain current channel hydraulic geometry</td>
<td>G3-1</td>
<td>Sediment</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>■ No contraction in channel geometry.</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td>Re Rehabilitate lateral connectivity with billabongs connected around bankfull</td>
<td>G3-2</td>
<td>Bank stability</td>
<td>Rate of fall</td>
<td>Following flow events</td>
<td>■ No increased rate or extent of bank scour above that expected naturally.</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Re Rehabilitate floodplains</td>
<td>G3-3</td>
<td>Connectivity</td>
<td>Bankfull flow</td>
<td>Spring</td>
<td>■ Increased frequency of inundation of billabongs &amp; meander train.</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G3-4</td>
<td>Connectivity</td>
<td>Overbank flow</td>
<td>Spring</td>
<td>■ Increased frequency &amp; duration of inundation of floodplain</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>■ Requires complementary works to prioritise &amp; revegetate floodplain (see V3-6).</td>
<td></td>
</tr>
<tr>
<td>Macro-invertebrates</td>
<td>Maintain current macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives</td>
<td>M3-1</td>
<td>Access to LWD &amp; edge habitats</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>■ Expect Macroinvertebrates scores to consistently meet SEPP objectives.</td>
<td>Short to medium</td>
</tr>
<tr>
<td>Fish</td>
<td>Maintain diverse native fish community composition (resident &amp; diadromous species) &amp; comply with Yarra SEPP Schedule F7 objectives</td>
<td>M3-2</td>
<td>Disturbance to scour biofilm &amp; sediment from LWD</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>■ LWD reintroduction should be undertaken in conjunction with fencing &amp; revegetation of riparian zone (see V3-4).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Re Rehabilitate (reinstate) population of Australian grayling</td>
<td>M3-3</td>
<td>Disturbance &amp; entrainment of organic material</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>■ Increased presence &amp; abundance of Australian grayling through improved spawning opportunities &amp; recruitment success</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M3-4</td>
<td>Reintroduce LWD to channel</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>■ No decline in native fish diversity &amp; abundance - expected species include: river blackfish, short-finned eels, short-headed lamprey, pouched lamprey, tupong, Australian smelt, mountain galaxias, spotted galaxias, common galaxias &amp; Australian grayling.</td>
<td>Short to medium</td>
</tr>
<tr>
<td>Vegetation</td>
<td></td>
<td>V3-1</td>
<td>Bank drying</td>
<td>Low flow</td>
<td>Summer</td>
<td>■ Increased abundance, diversity &amp; density of flood-tolerant native species on bank.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Re Rehabilitate riparian vegetation extent, structure &amp; composition</td>
<td>V3-2</td>
<td>Maintenance of flood tolerant vegetation</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>■ Decreased terrestrial weed abundance on banks (e.g. blackberry &amp; wild Watsonia)</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V3-3</td>
<td>Bank wetting to promote flood-tolerant vegetation &amp; limit terrestrial vegetation</td>
<td>High / bankfull flow</td>
<td>Spring</td>
<td>■ Decreased aquatic weed abundance (e.g. yellow flag iris)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V3-4</td>
<td>Revegetation &amp; weed control works</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>■ Complementary works already underway need to continue for example revegetation with riparian species appropriate for the EVC, weed control &amp; limiting stock access.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Re Rehabilitate billabong vegetation</td>
<td>V3-5</td>
<td>Revegetation</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>■ Complementary works required to fence meander train (billabongs / floodplain located close to channel), remove stock &amp; revegetate with species appropriate for the EVC to take greatest advantage of provision of bankfull flows</td>
<td>Medium to long</td>
</tr>
<tr>
<td>Minimum Environmental Water Requirement and Complementary Works Recommendations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rehabilitate floodplain</strong></td>
<td>V3-6</td>
<td>Revegetation, levee removal</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Water quality</strong></td>
<td>Improve water quality to meet Yarra SEPP Schedule F7 objectives</td>
<td>W3-1</td>
<td>Ecological processes &amp; beneficial uses</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Complementary works required to fence, remove stock &amp; revegetate floodplain with species appropriate for the EVC &amp; remove levees to take advantage of overbank flows.</strong></td>
<td><strong>Increased nutrient compliance with SEPP objectives.</strong></td>
<td><strong>Implementation of catchment strategies to reduce stock access, agricultural runoff &amp; localised urban stormwater inputs to river to reduce nutrient levels &amp; limit excessive algal growth.</strong></td>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 3.4 Reach 4 – Watts River to Yering Gorge objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No.</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Maintain current channel hydraulic geometry</td>
<td>G4-1</td>
<td>Sediment accumulation</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>■ No contraction in channel geometry</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G4-2</td>
<td>Bank stability</td>
<td>Rate of fall</td>
<td>Following flow events</td>
<td></td>
<td>■ No increased rate or extent of bank scour above that expected naturally</td>
</tr>
<tr>
<td></td>
<td>Rehabilitate lateral connectivity with billabongs connected around bankfull</td>
<td>G4-3</td>
<td>Connectivity</td>
<td>Bankfull flow</td>
<td>Spring</td>
<td>■ Increased frequency of inundation of billabongs &amp; meander train</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>■ Requires complementary works to revegetate floodplain (see V4-6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rehabilitate floodplains</td>
<td>G4-4</td>
<td>Connectivity</td>
<td>Overbank flow</td>
<td>Spring</td>
<td>■ Increased frequency &amp; duration of inundation of floodplain</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Geomorphology</td>
<td>M4-1</td>
<td>Access to LWD &amp; edge habitats</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>■ Expect improvement in macroinvertebrates scores to comply with SEPP objectives, particularly towards bottom of reach.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M4-2</td>
<td>Disturbance to scour biofilm &amp; sediment from LWD</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>■ LWD reintroduction to be undertaken in conjunction with fencing &amp; revegetation of riparian zone (see V4-4).</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M4-3</td>
<td>Disturbance &amp; entrainment of organic material</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M4-4</td>
<td>Reinstate LWD to channel</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Macroinvertebrates</td>
<td>Maintain diverse native fish community composition (resident &amp; diadromous species) &amp; comply with Yarra SEPP Schedule F7 objectives</td>
<td>F4-1</td>
<td>Access to habitat (and see M4-4)</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>■ No decline in native fish diversity &amp; abundance – expected species include: river blackfish, short-finned eels, short-headed lamprey, pooled lamprey, tupong, Australian smelt, mountain galaxias, spotted galaxias, common galaxias &amp; Australian grayling.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F4-2</td>
<td>Provide opportunities for spawning, movement &amp; downstream transport of eggs &amp; larvae, flush sediment from spawning sites</td>
<td>High flow</td>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fish</td>
<td>Maintain diverse native fish community composition (resident &amp; diadromous species) &amp; comply with Yarra SEPP Schedule F7 objectives</td>
<td>F4-3</td>
<td>Trigger spawning &amp; downstream transport of eggs &amp; larvae</td>
<td>Freshes</td>
<td>Autumn</td>
<td>■ Increased abundance of Australian grayling through improved spawning opportunities &amp; recruitment success.</td>
</tr>
<tr>
<td></td>
<td>Vegetation</td>
<td>Rehabilitate riparian vegetation extent, structure &amp; composition</td>
<td>V4-1</td>
<td>Bank drying</td>
<td>Low flow</td>
<td>Summer</td>
<td>■ Increased abundance, diversity &amp; density of flood-tolerant native species on bank.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V4-2</td>
<td>Maintenance of flood tolerant vegetation</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>■ Decreased terrestrial weed abundance on banks (eg blackberry, tradescantia &amp; wild Watsonia)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V4-3</td>
<td>Bank wetting to promote flood-tolerant vegetation &amp; limit terrestrial vegetation</td>
<td>High / bankfull flow</td>
<td>Spring</td>
<td>■ Decreased aquatic weed abundance (eg yellow flag iris)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V4-4</td>
<td>Revegetation &amp; weed control works</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>■ Complementary works already underway need to continue for example revegetation with riparian species appropriate for the EVC, weed control &amp; limiting stock access</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rehabilitation billabong vegetation</td>
<td>V4-5</td>
<td>Revegetation</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>■ Complementary works required to fence meander train (billabongs / floodplain located close to channel), remove stock &amp; revegetate with species appropriate for the EVC to take greatest advantage of provision of bankfull flows</td>
<td>Medium to long</td>
</tr>
<tr>
<td>Minimum Environmental Water Requirement and Complementary Works Recommendations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>-------------------</td>
<td>-------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehabilitation floodplain</td>
<td>V4-6</td>
<td>Revegetation, levee removal</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complementary works required to fence, remove stock &amp; revegetate floodplain with species appropriate for the EVC &amp; remove levees to take advantage of overbank flows.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water quality</td>
<td>Improve water quality to meet Yarra SEPP Schedule F7 objectives</td>
<td>W4-1</td>
<td>Ecological processes &amp; beneficial uses</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased nutrient compliance with SEPP objectives.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation of catchment strategies to reduce stock access, agricultural runoff &amp; localised urban stormwater inputs to river to reduce nutrient levels &amp; limit excessive algal growth.</td>
<td>Medium to long</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Minimum Environmental Water Requirement and Complementary Works Recommendations

Table 3.5 Reach 5– Yering Gorge to Mullum Mullum Creek objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No.</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Maintain current channel hydraulic geometry</td>
<td>G5-1</td>
<td>Sediment accumulation</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>No expansion in vegetated bars &amp; island on riffles</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td>Maintain bank stability</td>
<td>G5-2</td>
<td>Bank stability</td>
<td>Rate of rise &amp; fall</td>
<td>All year</td>
<td>Pumping induced rate of rise &amp; fall managed to minimise stranding fauna on riffles.</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>Rehabilitate lateral connectivity with billabongs on Henley floodplain</td>
<td>G5-3</td>
<td>Connectivity</td>
<td>Bankfull flow</td>
<td>Spring</td>
<td>Increased frequency of inundation of billabongs &amp; meander train (&amp; see V5-5).</td>
<td>Short</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>Rehabilitate macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives</td>
<td>M5-1</td>
<td>Access to riffle habitats</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>Expect improvement in macroinvertebrate scores to meet SEPP objectives</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M5-2</td>
<td>Disturbance to scour biofilm &amp; sediment from riffles &amp; LWD</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>May require cease to pump in Yering Gorge to protect wetted width of riffle habitat.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M5-3</td>
<td>Disturbance &amp; entrainment of organic material</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>LWD reintroduction to be undertaken in conjunction with fencing &amp; revegetation of riparian zone (see V5-4).</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M5-4</td>
<td>Reintroduce LWD to channel</td>
<td>Complementary flow</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Maintain &amp; improve diverse native fish community composition (resident, diadromous &amp; potamodromous species) &amp; comply with Yarra SEPP Schedule F7 objectives</td>
<td>F5-1</td>
<td>Access to habitat ( &amp; see M5-4)</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>Maintain &amp; improve native fish diversity &amp; abundance - expected species include: river blackfish, short-finned eels, short-headed lamprey, pouched lamprey, tupong, spotted galaxias, common galaxias, Australian smelt, Australian grayling, Macquarie perch &amp; Murray cod.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F5-2</td>
<td>Provide opportunities for spawning, movement &amp; downstream transport of eggs &amp; larvae, flush sediment from spawning sites</td>
<td>Freshes</td>
<td>Throughout year</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High flow</td>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rehabilitate abundance of Australian grayling</td>
<td>F5-3</td>
<td>Trigger spawning &amp; downstream transport of eggs &amp; larvae</td>
<td>Freshes</td>
<td>Autumn</td>
<td>Increased abundance of Australian grayling through improved spawning opportunities &amp; recruitment success.</td>
<td>Medium to long</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Rehabilitate riparian vegetation extent, structure &amp; composition</td>
<td>V5-1</td>
<td>Bank drying</td>
<td>Low flow</td>
<td>Summer</td>
<td>Increased abundance, diversity &amp; density of flood-tolerant native species on bank.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V5-2</td>
<td>Maintenance of flood tolerant vegetation</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>Decreased terrestrial weed abundance on banks (eg blackberry, tradescantia &amp; wild Watsonia)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V5-3</td>
<td>Bank wetting to promote flood-tolerant vegetation &amp; limit terrestrial vegetation</td>
<td>High / bankfull flow</td>
<td>Spring</td>
<td>Decreased aquatic weed abundance (eg yellow flag iris)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V5-4</td>
<td>Weed control works, particularly in lower section of reach</td>
<td>Complementary flow</td>
<td>Ongoing</td>
<td>Complementary works already underway need to continue for example revegetation with riparian species appropriate for the EVC &amp; weed control, especially in lower section of reach.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rehabilitate billabong vegetation in Henley floodplain</td>
<td>V5-5</td>
<td>Revegetation</td>
<td>Complementary flow</td>
<td>Ongoing</td>
<td>Support current works to fence &amp; revegetate with species appropriate for the EVC &amp; weed control, especially in lower section of reach.</td>
<td>Short to medium</td>
</tr>
<tr>
<td>Water quality</td>
<td>Improve water quality to meet Yarra SEPP Schedule F7 objectives</td>
<td>W5-1</td>
<td>Ecological processes &amp; primary contact beneficial use</td>
<td>Complementary flow</td>
<td>Ongoing</td>
<td>Increase nutrient compliance with SEPP objectives. Continue to improve management of Sewerage Plant effluent to river, septic tank management &amp; urban stormwater to limit nutrient levels &amp; excessive algal growth.</td>
<td>Medium to long</td>
</tr>
</tbody>
</table>
### Table 3.6 Reach 6– Mullum Mullum Ck to Dights Falls objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No.</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Maintain current channel hydraulic geometry</td>
<td>G6-1</td>
<td>Sediment accumulation</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>No contraction in channel geometry</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G6-2</td>
<td>Bank stability</td>
<td>Rate of rise &amp; fall</td>
<td>Following freshes</td>
<td>No increased rate or extent of bank scour above that expected naturally. Caused by increased runoff rates in urban areas - complementary works required – not a main stem flow issue</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td>Rehabilitate lateral connectivity with billabongs connected around bankfull</td>
<td>G6-3</td>
<td>Connectivity</td>
<td>Bankfull flow</td>
<td>Spring</td>
<td>Increased frequency of inundation of billabongs &amp; meander train</td>
<td>Medium to long</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>Rehabilitate macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives</td>
<td>M6-1</td>
<td>Access to LWD &amp; edge habitats</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>Achieve maximum possible macroinvertebrate score to the extent possible given level of urban impact</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M6-2</td>
<td>Disturbance to scour biofilm &amp; sediment from riffles &amp; LWD</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>LWD reintroduction to be undertaken in conjunction with fencing &amp; revegetation of riparian zone (see V6-4).</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M6-3</td>
<td>Disturbance &amp; entrainment of organic material</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M6-4</td>
<td>Reinroduce LWD to channel</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Maintain &amp; improve diverse native fish community composition (resident, diadromous &amp; potamodromous species) to comply with Yarra SEPP Schedule F7 objectives</td>
<td>F6-1</td>
<td>Access to habitat (&amp; see M6-4)</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>Maintain &amp; improve native fish diversity &amp; abundance - expected species include: river blackfish, short-finned eels, short-headed lamprey, pouched lamprey, spotted galaxias, common galaxias, Australian smelt, Australian grayling, Macquarie perch &amp; Murray cod</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F6-2</td>
<td>Provide opportunities for spawning, movement &amp; downstream transport of eggs &amp; larvae, flush sediment from spawning sites</td>
<td>High flow</td>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rehabilitate Australian grayling abundance</td>
<td>F6-3</td>
<td>Trigger spawning &amp; downstream transport of eggs &amp; larvae</td>
<td>Freshes</td>
<td>Autumn</td>
<td>Increased abundance of Australian grayling through improved spawning opportunities</td>
<td>Medium to long</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Rehabilitate riparian vegetation extent, structure &amp; composition</td>
<td>V6-1</td>
<td>Bank drying</td>
<td>Low flow</td>
<td>Summer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V6-2</td>
<td>Maintenance of flood tolerant vegetation</td>
<td>Freshes</td>
<td>Throughout year</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V6-3</td>
<td>Bank wetting to promote flood-tolerant vegetation &amp; limit terrestrial vegetation</td>
<td>High / bankfull flow</td>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V6-4</td>
<td>Revegetation &amp; weed control works</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rehabilitate billabong vegetation</td>
<td>V6-5</td>
<td>Revegetation</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water quality</td>
<td>Improve water quality to meet Yarra SEPP Schedule F7 objectives (Nutrients &amp; bacteriological)</td>
<td>W6-1</td>
<td>Ecological processes &amp; primary contact beneficial use</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

_SINCLAIR KNIGHT MERZ_
### Table 3.7 Reach 7– Yarra estuary objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No.</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response / comment</th>
<th>Response time</th>
</tr>
</thead>
</table>
| Geomorphology  | No specific geomorphological objects                                       |       |                                               |                  |                 | ■ The river is channelised & there are no opportunities to re-engage floodplain elements - 100% of pre 1788 wetland area has been lost.  
■ Upstream sources of sediment may help to build benches that sustain important littoral vegetation such as Phragmites                                                                                                                                                                                                                                                                                                                                                                                                                                                               |               |
| Macroinvertebrates | No specific macroinvertebrate objects                                       |       |                                               |                  |                 | ■ The macroinvertebrate community composition, structure & condition are unknown hence no objective can be set.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |               |
| Fish           | Maintain a diverse estuarine fish community composition                    | F7-1  | Access to littoral habitat                   | Complementary    | Ongoing         | ■ Protect & where possible expand area of Phragmites & other riparian vegetation appropriate for the EVC along littoral zone (see V7-1)  
■ Triggers for spawning that relate to changes in salinity are met through provision of freshwater at critical times to reduce estuary salinity  
■ Triggers for upstream migration are met through provision of freshwater at critical times.  
■ Channelisation has degraded riparian vegetation – Identify opportunities for revegetation with riparian species appropriate for the EVC.  
■ Protect & expand Phragmites & other riparian species as bank protection & habitat for estuarine fish, macroinvertebrates & birds.  
■ May conflict with some social values.  
■ Sufficient low flow required to maintain estuary circulation and minimise the development of anoxic sub-surface waters through mixing.  
■ Ensure movement of the salt wedge up and down the estuary to maintain a range of salinities from fresh to salt, both vertically and longitudinally.  
■ Flush salt wedge from estuary  
■ Increase nutrient & bacteriological compliance with SEPP objectives.  
■ Reduce effective catchment imperviousness in tributaries.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Short to medium|
|                | F7-2 Cues for spawning & movement                                         | High flow | Spring |                  |                 |                                                                                           | Short         |
|                | F7-3 Cues for spawning & movement                                         | High flow | Spring |                  |                 |                                                                                           | Short         |
| Vegetation     | Rehabilitate riparian vegetation extent, structure & composition to the maximum extent possible. | V7-1  | Revegetation & weed control                  | Complementary    | Ongoing         | ■ Sufficient low flow required to maintain estuary circulation and minimise the development of anoxic sub-surface waters through mixing.  
■ Ensure movement of the salt wedge up and down the estuary to maintain a range of salinities from fresh to salt, both vertically and longitudinally.  
■ Flush salt wedge from estuary  
■ Increase nutrient & bacteriological compliance with SEPP objectives.  
■ Reduce effective catchment imperviousness in tributaries.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Short to medium|
| Water quality  | Maintain well oxygenated salt wedge                                       | W7-1  | Ecological processes & access to habitat     | Low flow         | Throughout year |                                                                                           | Short         |
|                | W7-2 Ecological processes & access to habitat                             | F freshes | Through year |                 |                 |                                                                                           | Short         |
|                | W7-3 Ecological processes                                                 | High flow | Winter / spring |             |                 |                                                                                           | Short         |
|                | Improve water quality to meet Yarra SEPP Schedule F7 objectives           | W7-4  | Ecological processes & beneficial uses      | Complementary    | Ongoing         | ■ Sufficient low flow required to maintain estuary circulation and minimise the development of anoxic sub-surface waters through mixing.  
■ Ensure movement of the salt wedge up and down the estuary to maintain a range of salinities from fresh to salt, both vertically and longitudinally.  
■ Flush salt wedge from estuary  
■ Increase nutrient & bacteriological compliance with SEPP objectives.  
■ Reduce effective catchment imperviousness in tributaries.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Medium to long |
## Table 3.8 Reach 8 – Watts River objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No.</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Maintain current channel hydraulic geometry</td>
<td>G8-1</td>
<td>Sediment</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>No contraction in channel geometry</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td>Rehabilitate lateral connectivity with small floodplains &amp; benches</td>
<td>G8-2</td>
<td>Connectivity</td>
<td>High flows</td>
<td>Spring</td>
<td>Increased frequency of inundation of inset floodplains &amp; benches</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>connected below bankfull</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>Rehabilitate macroinvertebrate community to Yarra SEPP Schedule F7 objectives</td>
<td>M8-1</td>
<td>Maintain access to riffles &amp; LWD</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>Expect improvement in macroinvertebrates scores downstream of Donnelly Creek.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M8-2</td>
<td>Disturbance to scour biofilms &amp; sediment</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>LWD reintroduction to be undertaken in conjunction with fencing &amp; revegetation of riparian zone (see V8-4).</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M8-3</td>
<td>Disturbance &amp; entrain organic material on benches &amp; high flow channels</td>
<td>High / bankfull flow</td>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M8-4</td>
<td>Reintroduce LWD habitat</td>
<td>Complementary</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Maintain diverse native fish community composition (resident &amp; diadromous species) comply with Yarra SEPP Schedule F7 objectives</td>
<td>F8-1</td>
<td>Access to habitat (&amp; see M8-4)</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>Maintain &amp; improve native fish diversity &amp; abundance - expected species are: river blackfish, short-finned eels, short-headed lamprey, pouched lamprey, spotted galaxias, common galaxias &amp; Australian smelt</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F8-2</td>
<td>Provide opportunities for spawning, movement &amp; downstream transport of eggs &amp; larvae, flush sediment from spawning sites</td>
<td>High flow</td>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation</td>
<td>Rehabilitate riparian vegetation extent, structure &amp; composition</td>
<td>V8-1</td>
<td>Bank drying</td>
<td>Low flow</td>
<td>Summer</td>
<td>Increased abundance, diversity &amp; density of flood-tolerant native species on bank.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V8-2</td>
<td>Maintenance of flood tolerant vegetation</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>Decreased terrestrial weed abundance on banks (eg blackberry &amp; wild Watsonia)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V8-3</td>
<td>Bank wetting to promote flood-tolerant vegetation &amp; limit terrestrial vegetation</td>
<td>High / bankfull flow</td>
<td>Spring</td>
<td>Decreased aquatic weed abundance (eg yellow flag iris)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V8-4</td>
<td>Revegetation &amp; weed control works</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>Complementary works already underway need to continue for example fencing to exclude stock &amp; revegetation with riparian species appropriate for the EVC &amp; weed control</td>
<td>Short to medium</td>
</tr>
<tr>
<td>Water quality</td>
<td>Maintain current water quality to meet Yarra SEPP Schedule F7 objectives</td>
<td>W8-1</td>
<td>Ecological processes &amp; beneficial uses</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>No decline in current water quality.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Implementation of catchment strategies to reduce stock access, agricultural runoff &amp; urban stormwater inputs to river to reduce nutrient levels &amp; limit excessive algal growth.</td>
<td></td>
</tr>
</tbody>
</table>
### Table 3.9 Reach 9 – Plenty River objectives.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Objective</th>
<th>No</th>
<th>Function</th>
<th>Flow component</th>
<th>Timing</th>
<th>Expected response</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Maintain current channel hydraulic geometry</td>
<td>G9-1</td>
<td>Sediment accumulation</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>No contraction in channel geometry</td>
<td>Medium to long</td>
</tr>
<tr>
<td></td>
<td>Rehabilitate lateral connectivity with swamps &amp; floodplain connected around bankfull (reaches upstream of gorge)</td>
<td>G9-2</td>
<td>Connectivity</td>
<td>Bankfull / overbank flow</td>
<td>Spring</td>
<td>Inundate remnant swamps in mid reaches.</td>
<td>Short</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>Rehabilitate macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives</td>
<td>M9-1</td>
<td>Disturbance</td>
<td>Cease to flow (if naturally occurring)</td>
<td>Summer / autumn</td>
<td>Expect improvement in macroinvertebrate scores</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M9-2</td>
<td>Access to riffle habitats</td>
<td>Low flow</td>
<td>Summer / winter</td>
<td>LWD reintroduction to be undertaken in conjunction with fencing &amp; revegetation of riparian zone (see V9-4).</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M9-3</td>
<td>Disturbance to scour biofilm &amp; sediment from riffles &amp; LWD</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>Increased diversity &amp; abundance of native fish species- expected species are: river blackfish, short-finned eels, short-headed lamprey, pouched lamprey &amp; Australian smelt, mountain galaxias, common galaxias, spotted galaxias &amp; tupong.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M9-4</td>
<td>Disturbance &amp; entrainment of organic material</td>
<td>High / bankfull flow</td>
<td>Winter / spring</td>
<td>Identifying &amp; prioritising removal of artificial barriers to fish passage.</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M9-4</td>
<td>Reinroduce LWD habitat</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>Increased diversity &amp; abundance of native fish species- expected species are: river blackfish, short-finned eels, short-headed lamprey, pouched lamprey &amp; Australian smelt, mountain galaxias, common galaxias, spotted galaxias &amp; tupong.</td>
<td>Short to medium</td>
</tr>
<tr>
<td>Fish</td>
<td>Rehabilitate diverse native fish community composition (resident &amp; diadromous species) &amp; comply with Yarra SEPP Schedule F7 objectives</td>
<td>F9-1</td>
<td>Access to habitat (&amp; see M9-4)</td>
<td>Low flow</td>
<td>Summer / autumn</td>
<td>No decline in character &amp; composition of in-channel &amp; bank vegetation in gorge sections</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F9-2</td>
<td>Provide opportunities for spawning, movement &amp; downstream transport of eggs &amp; larvae, flush sediment from spawning sites</td>
<td>High flow</td>
<td>Summer / autumn</td>
<td>Increased abundance, diversity &amp; density of flood-tolerant native species on bank in agricultural section</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F9-3</td>
<td>Removal of physical barriers to fish passage</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>Decreased terrestrial weed abundance on banks (eg blackberry, tradescantia &amp; wild Watsonia)</td>
<td>Short to medium</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Maintain riparian &amp; in-channel vegetation extent, structure &amp; composition in gorge section. Rehabilitate in agricultural sections.</td>
<td>V8-1</td>
<td>Bank drying</td>
<td>Low flow</td>
<td>Summer</td>
<td>Complementary works already underway need to continue for example revegetation with riparian species appropriate for the EVC &amp; weed control</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V8-2</td>
<td>Maintenance of flood tolerant vegetation</td>
<td>Freshes</td>
<td>Throughout year</td>
<td>Increased abundance, diversity &amp; density of flood-tolerant native species on bank in agricultural section</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V8-3</td>
<td>Bank wetting to promote flood-tolerant vegetation &amp; limit terrestrial vegetation</td>
<td>High / bankfull flow</td>
<td>Spring</td>
<td>Decreased aquatic weed abundance (eg yellow flag iris)</td>
<td>Short to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V8-4</td>
<td>Revegetation &amp; weed control works</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>Complementary works already underway need to continue for example revegetation with riparian species appropriate for the EVC &amp; weed control</td>
<td>Short to medium</td>
</tr>
<tr>
<td>Water quality</td>
<td>Rehabilitate pool water quality</td>
<td>W9-1</td>
<td>Minimise saline pool development</td>
<td>Low flow</td>
<td>Throughout year</td>
<td>Manage agricultural runoff &amp; Whittlesea STP discharge to river to reduce nutrient levels &amp; limit excessive algal growth.</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>Rehabilitate current water quality to meet Yarra SEPP Schedule F7 objectives</td>
<td>W9-2</td>
<td>Ecological processes &amp; beneficial uses</td>
<td>Complementary</td>
<td>Ongoing</td>
<td>Control stock access</td>
<td>Short</td>
</tr>
</tbody>
</table>
Ecological processes

To facilitate the development of environmental objectives, important components of the flow regime have been identified. These flow components perform a variety of functions from providing cues for fish spawning or seed germination through to disturbance of biofilms and resetting of successional processes and ecological processes. The key environmental functions of each of the flow components are described in the sections below and are summarised in Table 3.11. The functions describe how each flow component acts to meet the environmental objectives and their target features.

Table 3.10 Definition of terms used to describe objectives.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Conditions required for long term survival of flora and fauna. Includes availability of sufficient water, food and light to allow for growth and reproduction.</td>
</tr>
<tr>
<td>Recruitment</td>
<td>Recruitment is the addition of new individuals to the population. Recruitment can be considered successful when a generation reaches maturity. Triggers for spawning followed by suitable conditions for growth and maturity are required for successful recruitment.</td>
</tr>
<tr>
<td>Disturbance</td>
<td>Disturbance is an event in time (e.g., cease to flow or high flow) that causes a disruption in some ecosystem component or process. For example, high flows scour biofilms that help maintain a diverse community by resetting successional processes. By their nature, aquatic ecosystems and communities have evolved with disturbance and require this process to support healthy communities and ecosystem functioning.</td>
</tr>
<tr>
<td>Habitat</td>
<td>Habitat is the locality or external environment in which an organism lives. Aquatic habitat can be defined as the local physical, chemical and biological features that provide a suitable environment for instream biota. Habitat is a major determinant of aquatic community potential as it provides refuge, feeding and breeding areas for animals and plants.</td>
</tr>
<tr>
<td>Movement</td>
<td>Ability of fish and other biota to migrate or move between different sections of a river and from a river to a wetland or backwater. Passage can be restricted by barriers such as weirs, dams and lack of connectivity of the river with its floodplain. Movement can be spawning related or for dispersal and recolonisation of new habitats.</td>
</tr>
<tr>
<td>Provision of food resources</td>
<td>Availability of sufficient food to sustain populations. These may include sufficient biofilms, macroinvertebrates or zooplankton to sustain higher order trophic levels.</td>
</tr>
<tr>
<td>Mixing</td>
<td>Regular or seasonal mixing of water within a water body due to wind, currents, or change in temperature. Reduced mixing can lead to a decline in water quality through stratification, deoxygenation, nutrient release from sediments and increased salinity. Mixing helps to flush pools and minimise the risk of anoxic conditions developing. Low and high flows create currents that facilitate water column mixing.</td>
</tr>
<tr>
<td>Engagement</td>
<td>Engagement refers to the connection by surface water between the river and floodplain elements (backwaters, wetlands, floodrunners, anabranches, floodplain surfaces). Rivers often become disconnected from their floodplain or flood runners as a result of flow regulation, construction of levees and diversion of peak flows. The provision of high, bankfull and overbank flow ensures engagement between the river and floodplain habitats.</td>
</tr>
<tr>
<td>Entrainment</td>
<td>Entrainment is the mobilisation and transport of particulate and dissolved organic material and nutrients. Entrainment is an important mechanism for the incorporation of leaf litter and other terrestrially derived organic material accumulated on river banks, in wetlands and on floodplain surfaces into aquatic energy pathways.</td>
</tr>
<tr>
<td>Ecological processes</td>
<td>Autotrophy refers to the process of primary production; the ability of primary producers such as algae to synthesise organic energy from inorganic material such as light. Autotrophic processes are enhanced by low flows and high temperatures. A mix of autotrophic and heterotrophic processes and organisms provides a diversity of carbon and food resources for secondary consumers. Heterotrophy refers to the process of respiration or decomposition; the ability of organisms such as bacteria to synthesise energy through intake and digestion of organic material such as dead animal or plant matter. Heterotrophic processes are supported by higher flows that reduce light penetration.</td>
</tr>
<tr>
<td>Drying and wetting (floodplains &amp; wetlands)</td>
<td>Drying occurs through the cessation of inflows followed by infiltration and evaporation to the point where the sediment dries out and cracks. Drying reoxygenates sediments and promotes the aerobic decomposition of organic material and mineralisation of nutrients. When sediment is re-wetted, carbon and nutrients are released to the water column and provide a pulse of food resources for algae, plants and macroinvertebrates (zooplankton) that in turn provide food for macroinvertebrates, fish, waterbirds and other animals. The seeds of many aquatic species and some terrestrial species will only germinate following a period of drying and then inundation. Areas that experience a wetting and drying regime are typically more diverse than those that are permanently inundated.</td>
</tr>
</tbody>
</table>
Table 3.11 Functions or processes supported by components of the flow regime.

<table>
<thead>
<tr>
<th>Flow component</th>
<th>Response function</th>
</tr>
</thead>
</table>
| Cease to flow     | - Disturb lower channel features by exposing and drying sediment and bed material.  
                    - Promote successional change in community composition through disturbance.  
                    - Maintain a diversity of ecological processes through wetting and drying.         |
| Low flow          | - Allow accumulation and drying of organic matter in the higher areas of the channel such as benches.  
                    - Maintain permanent pools with an adequate depth of water to provide refuge habitat for aquatic biota.  
                    - Slow the process of water quality degradation occurring in pools (avoid complete stagnation).  
                    - Sustain longitudinal connectivity for movement of macroinvertebrates, fish and platypus.  
                    - Sustain inundation of lower benches to maintain habitat for emergent and marginal aquatic vegetation.  
                    - Promote recruitment for fish that spawn during low flow periods.                 |
| Freshes / High flow | - Entrain terrestrial organic matter that has accumulated on benches and in the upper channel.  
                      - Provide cues for spawning and migration cues for fish. For example, to transport eggs and larvae to sea for some diadromous species such as Australian grayling.  
                      - Provide cues for spawning of estuarine fish species through reduction in salinity in the estuary and near shore environs around the river mouth.  
                      - Provide flow variability to maintain species diversity of emergent and marginal aquatic vegetation and to drive zonation patterns across the channel.  
                      - Engage flood runner channels.  
                      - Instigate die back of terrestrial vegetation that has encroached down the bank during the low flow period.  
                      - Increase habitat area available for instream flora and fauna through inundation of benches and LWD located on banks. |
| Bankfull flow     | - Sediment transport (sediment entrainment and deposition with potential for changed channel form).  
                    - Provide spawning cues for fish and assist in dispersal movement within freshwater reaches.  
                    - Provide cues for spawning of estuarine fish species through reduction in salinity in the estuary and near shore environment around the river mouth.  
                    - Disturb aquatic and riparian vegetation and rejuvenate successional patterns; provide cues for Riparian Forest and Floodplain Riparian Woodland EVC recruitment.  
                    - Transport organic matter that has accumulated in the riparian zone and wetlands.  
                    - Instigate die back of terrestrial vegetation that has encroached down the bank during the low flow period through scouring and inundation.  
                    - Increase habitat area, including access to large woody debris and over hanging banks for instream biota.  
                    - Engage the riparian zone and wetlands.                                           |
| Overbank flow     | - Engage entire floodplain.                                                                                                                          |

3.1 Summer/autumn flow period

Cease to flow

The cease to flow is the period of no discernible flow in a river, or in practice when there is no measurable flow at a stream gauge, representative of the relevant reach. This may lead to either total or partial drying of the river channel, depending on the evaporation rate, groundwater exchange, depth of pools and the duration of cease to flow. The Yarra and Watts Rivers are permanent streams and do not experience cease to flows. However, cease to flows frequently occur in the Plenty River under current conditions and according to modelled natural flows would have also occurred naturally from time to time.

Cessation of flow is a common natural occurrence in Australian streams and there are a range of ecological functions provided by this flow component (Poff and Ward 1989, Boulton et al. 2000).
During these periods, the river may contract to a series of isolated pools that are important refugia for recolonisers upon the return of flow. The biota in these pools are likely to be subject to intensified predation and physicochemical stresses (e.g. low dissolved oxygen concentrations and increased salinity). However, stream communities are relatively mobile and will most likely have the ability to recolonise these habitats following the restoration of flow, as long as there are effective refuges (Jowett and Duncan 1990). Drying of habitats and organic matter facilitates the decomposition and processing of organic matter and following rewetting this then provides a fresh pool of nutrient and carbon inputs for the system (Baldwin and Mitchell 2000, Nielsen et al. 2000).

Overall there is a significant ecological benefit from this component. The risks are in the removal or extension of the duration of this component or addition of the component in a system in which it did not naturally occur. The cease to flow period is a period of stress for the ecosystem and extension of the duration of this period can have deleterious effects on the ecosystem. In the Plenty River, the frequency and duration of cease to flow periods has increased due to water resource development and may pose addition stress to aquatic communities, for example through the development of saline pools (Potter 2003). Under the environmental flow recommendations for the Plenty River, it is considered that cease to flows are acceptable provided they would have occurred naturally and do not last longer than the median duration of the natural cease to flow event. This requirement is to ensure that additional stress through prolonged cease to flows is minimised.

**Low flow**
The objective of this flow is to maintain permanent pool and riffle habitats. Low flows typically occur during the low flow period in summer and autumn. The ecological functions of the low flow include the exposure of areas of the streambed (including parts of riffles) and large woody debris (LWD). The exposure of streambed will allow the accumulation of terrestrial organic matter and act as a disturbance to reset successional processes for macroinvertebrate, biofilms and vegetation communities.

The low flow also serves to maintain minimum water levels to preserve wetted riffle areas as refuges for macroinvertebrates and provide adequate depth in pool refuges for fish. Maintaining flows over the riffles and connectivity between pools also helps to slow the deterioration of water quality that occurs in pools during low flow periods. This is particularly important in the Plenty River where extended cease to flow periods contribute to the development of saline pools. Criteria used to determine low flow thresholds include the volume required to maintain a suitable wetted width of riffles, volume required to maintain pool depth (typically 50 to 100 cm for small fish such as river blackfish and 100 to 150 cm for large species such as Murray cod) and volumes below which flow related water quality impacts are known to manifest, for example around 150 ML/d in the Yarra River (Ewert and Pettigrove 2003).

**Freshes and high flows**
Brief increases in flow during the low flow period will help impart some of the flow variability naturally experienced in the Yarra River. This variation in water levels is important for maintaining species diversity in the emergent and marginal aquatic vegetation communities and is...
the principal driver of zonation up the channel banks. Freshes also wet low-lying channel zones such as riffles and benches, thereby helping relieve drought-stress on emergent and marginal vegetation that has become exposed during the low flow period. Fish and other aquatic fauna will become more able to move between pool habitats during freshes because of increased depth across riffles areas. The brief increase in flow will also help to improve water quality by flushing and mixing any pools that have begun to stagnate and become stratified (Potter 2003). Freshes can also serve to desilt riffle areas thereby improving habitat for macroinvertebrates that use these habitats. Changes in discharge can have several impacts including changes in current velocity, changes in the underwater light regime because of changes in depth and turbidity and the initiation of wetting and drying processes. Criteria used to determine the summer/autumn fresh flow included the establishment of increased velocity in riffles to provide a scouring flow. A velocity greater than 40 cm/s was considered suitable to generate scouring flows (Horner and Welch 1981).

High flows in autumn are required in the Yarra River to promote spawning by Australian grayling (O’Connor and Mahoney 2004) and assist in transporting larvae to the estuary where they develop before ascending the river in the following spring. Naturally a high flow event in autumn would typically occur in response to the ‘autumn break’ rainfall. However, the autumn rain event is now captured in water supply dams and farm dams so the reinstatement of an autumn high flow event is important to support the objective of rehabilitating Australian grayling in the Yarra River.

3.2 Winter/spring

Low flow
Low flow during winter and spring will provide conditions of sustained water levels in the river and further increase the area and depth of riffles for macroinvertebrates. The winter low flow will also facilitate fish movement and invertebrate drift and to inundate the lower parts of the banks. Prolonged inundation of the lower banks will drown encroaching terrestrial vegetation while maintaining habitat for emergent and marginal vegetation during the spring growth season. There will also be a general increase in habitat availability for aquatic biota as LWD, branch-piles and riverbanks become inundated and available for colonisation. Habitat diversity will also increase as higher flows create a greater diversity of flow velocity habitats. This may be particularly important for macroinvertebrate community diversity, which can contain species specialised for high velocity habitats.

Freshes and high flows
Freshes describe short duration increases in flow that occur during the high flow period between June and November. In the Yarra River these flows will provide migration or spawning cues for freshwater diadromous fish such as Australian grayling and long-finned and short-finned eels, galaxids, lampreys and tupong. Similar to the summer/autumn freshes, the winter/spring freshes will provide flow variability important for maintaining diverse aquatic vegetation along the edges of the river. Freshes will entrain organic matter that has accumulated in the terrestrial channel sections, and to a lesser degree transport sediment. Entrainment and deposition of sediment is unlikely to result in a net change in channel form during these flow events.

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High flows are longer duration freshes. The prolonged nature of these events provides a significant period of inundation to drown out and scour vegetation on the river banks and influence zonation patterns. These events may negatively impact on aquatic vegetation by scouring the channel bed, however this is a natural process. In the Yarra River, the duration of high flow events in spring has decreased and this appears to have promoted the encroachment of terrestrial vegetation (particularly weeds such as blackberries, wild Watsonia and Tradescantia) on the banks and the establishment of semi-aquatic weeds species (eg. yellow-flag iris) along the water line that are favoured by low flow conditions. A prolonged high flow is required in spring during the active growing period to provide a disturbance flow that enhances conditions for flood-tolerant species and limits the encroachment of terrestrial vegetation down the banks.

High flows that progress to the estuary are important in flushing saline water out of the estuary and in allowing the reestablishment of a well oxygenation salt wedge as flows recede. Changes in salinity associated with high flows provide spawning and migration cues for estuarine and diadromous fish species.

**Bankfull**

Bankfull flow essentially refers to a flood flow that fills a large proportion of the river channel without escape onto the floodplain. A bankfull flow acts as a significant disturbance to the geomorphology and ecology of the river. These large flows can reform the channel by scouring banks and transporting sediment. Ecological succession will be reset in both aquatic and riparian communities as plants and animals are swept downstream or drowned. Organic matter that has accumulated in the higher portions of the channel will be entrained and transported downstream. Included in the organic material will be large woody debris that becomes dislodged and caught up the lower channel sections.

**Overbank**

Overbank flows are flood flows that overtop the banks and spill onto the floodplain. In the Yarra River, overbank flows are typically short lived (1 to 2 days) but the water that is left behind in billabongs and floodplain depressions can linger for weeks to months. The water regime of wetlands and billabongs is driven by the frequency of overbank flows. Even in cleared agricultural landscape wetland inundation is important for contributing to regional biodiversity (Robson and Clay in press).
4. Environmental flow recommendations

4.1 Reach 1: Upper Yarra Dam to Armstrong Creek
Reach 1 is a relatively short reach (~5 km long) from the Upper Yarra Dam to Armstrong Creek, the first major tributary input to the Yarra River downstream of the Upper Yarra Dam. The current minimum flow in this reach is 10 ML/d with some minor variability provided by inflow from Doctors Creek, a small tributary that enters just downstream of the dam wall. The environmental flows assessment site was located approximately 3 km downstream of the dam wall and the gauge for compliance purposes is located downstream of Doctors Creek (upstream of the assessment site).

4.1.1 Current condition

Hydrology
Naturally the Yarra River immediately downstream of the Upper Yarra Dam had a mean annual flow of 416 ML/day. Under current conditions the mean annual flow has been reduced by around 95% to only 23 ML/day, although on most days the flow is 10 ML/day, the minimum environmental flow. Significant differences between current and natural flows are evident with a reduction in the frequency and magnitude of flows across the entire flow range (Figure 4.1). Under current conditions the flow is 10 ML/day for nearly 80% of the time and the 1 in 5 year flood magnitude has reduced from 3500 ML/day to 500 ML/d.

- Figure 4.1 Flow duration curve for Yarra River flows measured at the Doctors Creek gauge.

Under unimpacted conditions the highest daily flows generally occur in September and the lowest flows occur between February and April. Under current conditions there is no seasonal shift in the magnitude of flows (Figure 4.2).
Figure 4.2 Average daily flow at the Doctors Creek gauge.

**Geomorphology and habitat**

Significant channel contraction has occurred in Reach 1 due to the development of lateral bars and in filling of pools. Long periods of very low flow and reduced frequency and magnitude of high flow events have prevented sediment from being flushed from the reach and has also contributed to the encroachment of vegetation in riffles and runs within the active channel. Pools have been partly infilled with fine organic & inorganic sediment that has reduced access to habitat for fish & macroinvertebrates (see Figure 4.3 for a comparison of pool cross sectional area showing the extent of sediment accumulation). Cobbles & LWD in slow velocity areas have been covered in a layer of fine sediment. The source of sediment is unclear but it is likely that the majority of material was deposited during dam construction and is now stabilised in vegetated lateral bars. Fine organic material present in pools is likely to have entered the stream from local riparian inputs and tributary inflows. The major phase of sediment input to the reach has likely ceased so further channel contraction is unlikely. However, reworking of material already in the reach and localised input that is not flushed from the reach will continue to smother benthic surface and limit access to pool and riffle habitats for fish and macroinvertebrates.

The current minimum flow maintains a small active channel but flows are insufficient to flush fine sediment and organic material from pools. Increased frequency of freshes that flush sediment from riffles and the introduction of a flushing flow sufficient to scour pools and transport the accumulated fine sediment in pools downstream are required to increase the area of available habitat for fish and macroinvertebrates. However, it is undesirable to mobilise sediment that has stabilised in lateral bars as this material poses a risk to downstream habitats. Also, removing significant quantities of sediment from the reach will mean that more frequent higher flows are required to maintain the enlarged channel. Despite the channel contraction and sedimentation of pools, there is still a range of habitats available within the reach including LWD, bedrock and
riffles and it is considered that a healthy ecosystem can be established within the current channel provided the fine material in pools is periodically flushed from the reach.

**Figure 4.3** Indication of differences in effective bed level and pool volume under current bed level (Silt) and natural bed level (no silt) at cross section 5.

In addition to the provision of flushing flows, current sources of sediment from catchment activities need to be limited through adherence to best practice management techniques, guidelines and codes of practice for roading and timber harvesting.

**Macroinvertebrates**

Prior to 1991 the macroinvertebrate community was dominated by taxa tolerant of disturbed conditions. Following the introduction of the 10 ML/d minimum flow in the early 1990s there was a small improvement in macroinvertebrate diversity but even after 10 years of minimum releases the overall condition remains below reference (AUSRIVAS band C) and the SIGNAL score fails to meet the SEPP objective. However, the SEPP criteria for the minimum number of families and the number of key families are complied with.

The macroinvertebrate community has likely adjusted to the current minimum low flow regime and there is unlikely to be any further improvement in condition unless there is increased access to suitable benthic habitat. Flows that flush sediment from the reach and increase the area of available pool and riffle habitat are required if there is to be further improvement in the condition of the macroinvertebrate community. However, community composition is likely to remain below reference condition due to non-flow related issues downstream of a large dam such as altered water quality and recolonisation patterns, for example through interrupted drift from upstream reaches.
**Fish**

A range of native & exotic fish has been recorded from this reach. However, the overall fish abundance is low and only one (river blackfish) of the 5 (river blackfish, spotted galaxias, common galaxias, Australian grayling and tupong) SEPP Schedule F7 listed species has been recorded in this reach (SKM 2005c). In particular, the abundance of river blackfish is low compared to similar streams nearby and mountain galaxias are likely absent from the reach.

Loss of habitat through smothering of benthic surfaces by sediment and sedimentation of pool habitat is likely to be the main contributor to reduced river blackfish abundance in the reach. Cold water may also impact on recruitment with temperatures below 16°C limiting spawning potential.

As with macroinvertebrates, the fish community has likely adjusted to the current minimum low flow regime and there is unlikely to be any further improvement in abundance or diversity unless there is increased access to suitable habitat. Higher flows that flush sediment from pools, improve opportunities for local movement and increase spawning habitat are required if there is to be an improvement in abundance of native fish in the reach.

Cold water in release waters from the Upper Yarra Dam may limit spawning if below 16°C during the spring-summer spawning period. An assessment of temperature in the Yarra River upstream and downstream of the Upper Yarra Dam indicates that temperature in the river downstream of the dam is higher than that upstream but that summer temperatures are lower (SKM 2005b). However, this assessment is based on only 18 months of data and in that period temperature both upstream and downstream did not reach 16°C for the entire period. More information is needed on temperature regimes downstream of the dam and in particular an understanding of the risks associated with increased release water from the dam, particularly if releases occur below the thermocline where temperature is likely to be cold.

**Vegetation**

Riparian vegetation in Reach 1 is largely intact. The understorey and groundcover is composed of a diverse range of shrubs, grasses and forbs, ground ferns and sedges. The overstory is predominantly regrowth following clearing associated with dam construction. Instream vegetation consists of flood-tolerant sedges growing within the active channel and on lateral bars. Some beds of *Chara* have developed in pools.

Prolonged low flows have contributed to the colonisation and persistence of vegetation growing within the stream channel, both on lateral bars and in the existing active channel. Vegetation growth on lateral bars has stabilised the sediment material. However, there is limited sediment accumulation around vegetation growing within the active channel. Vegetation within the channel has likely undergone a number of adjustment phases. Prior to the introduction of the minimum flow more of the active channel was covered in vegetation. Since the introduction of the minimum flow the vegetation within the active channel has adjusted to the new regime and a small active channel has established.
Scouring flows may help to reduce some vegetation growth in riffles and runs and further contribute to an increase in available benthic habitat for macroinvertebrates and fish. However, it is undesirable to significantly disturb vegetation that has colonised lateral bars as this could reduce the stability of the bars and lead to mobilisation of the stored sediment.

Independent of the flow regime, as the overstory vegetation matures there should be an increase in the supply of LWD to the channel. This will provide significant complementary habitat improvement for macroinvertebrates and fish over time.

**Water quality**

Water quality data from the reach is limited but is overall expected to be good to excellent. However, as described above, there is a depression in the spring-early summer temperature in the reach immediately downstream of the dam compared to a site upstream of the dam. But over the late summer, autumn and winter periods, the temperatures downstream of the dam are higher than upstream.

There are no specific flow recommendations in relation to water quality. However, if there are increases in the volume of flow released from the dam more investigations are needed of the potential for cold water releases to limit river blackfish spawning during spring if releases occur from below the thermocline. It is also necessary to limit catchment sources of sediment through the adherence to best practice management techniques, guidelines and codes of practice for roading and timber harvesting.

### 4.1.2 Flow recommendations

Based on objectives for Reach 1 flows have been developed to maintain the current channel geometry but to reinstate some variability in the current flow regime and increase access to quality of habitat for fish and macroinvertebrates by scouring sediment from riffles and pools. Returning the channel to its natural dimensions was considered inappropriate due to the potential risks associated with transporting large amounts of sediment to downstream reaches and the need for significantly higher flow volumes required to establish and maintain a natural channel. No cease to flow recommendation has been made because the river is a permanent stream. No overbank flows have been recommended because the channel is confined and no floodplain is present. The environmental flow recommendations for Reach 1 are summarised in Table 4.1.
Table 4.1 Summary of flow recommendations for Reach 1.

<table>
<thead>
<tr>
<th>Season</th>
<th>Flow</th>
<th>Volume</th>
<th>Frequency</th>
<th>Duration</th>
<th>Rise/fall</th>
<th>Objective (refer to objectives tables for ID reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer/autumn low</td>
<td>Low flow</td>
<td>10 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, drying period for bank vegetation M1-1, F1-1, V1-1</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>60 ML/d</td>
<td>4 per season</td>
<td>1 day</td>
<td>1.6/0.7</td>
<td>Maintain suitable riffle habitat by periodically scouring sediment &amp; biofilms, maintain flood-tolerant vegetation on banks G1-2, M1-2, F1-1, V1-2</td>
</tr>
<tr>
<td>Winter/spring low</td>
<td>Low flow</td>
<td>10 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish M1-1, V1-1</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>100 ML/d</td>
<td>3 per season</td>
<td>2 days</td>
<td>1.6/0.7</td>
<td>Maintain suitable riffle habitat by periodically scouring sediment &amp; biofilms, maintain flood-tolerant vegetation on banks, provide local fish passage G1-2, M1-2, F1-1, V1-2, F1-2</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>300 ML/d</td>
<td>Once every two years</td>
<td>3 days</td>
<td>1.6/0.7</td>
<td>Scour sediment from pools to increase habitat availability, provide a disturbance regime to promote flood-tolerant species and limit encroachment of terrestrial vegetation, fish passage, entrain organic material G1-3, M1-3, F1-2, V1-3</td>
</tr>
<tr>
<td></td>
<td>Bankfull</td>
<td>1100 ML/d</td>
<td>1 in 10 year</td>
<td>3 days</td>
<td>1.6/0.7</td>
<td>Maintain existing channel geometry &amp; prevent further vegetation encroachment in channel G1-1, V1-4</td>
</tr>
</tbody>
</table>

Summer/autumn low flow
A low flow of 10 ML/d is recommended for Reach 1. Flows at this level are sufficient to inundate the full width of riffles (eg. Transect 2), yet allow drying of benches and banks (see Figure 4.4). This flow is sufficient to prevent sediment accumulation on riffles by providing an average velocity >40 cm/s in the active part of the channel so low-flow habitat in riffles for macroinvertebrates will be maintained. This flow will also maintain pool depths greater than 50 cm throughout the reach to provide suitable river blackfish habitat.

The current minimum flow is 10 ML/d. Under natural conditions the flow would have fallen below 10 ML/d once or twice per year but only for one to two days at a time (Figure 4.5).
Minimum Environmental Water Requirement and Complementary Works Recommendations

- Figure 4.4 Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for summer/autumn low flows in Reach 1.

- Figure 4.5 Duration (top left, frequency (top right) and start month (bottom left) for flows below the low flow threshold under current and natural conditions for Reach 1.

Summer/autumn freshes

The recommended threshold for summer/autumn freshes is 60 ML/d. This flow introduces some variability in flow during the low flow season. It is sufficient to increase the depth and velocity through riffles (Figure 4.6) and helps to periodically scour fine material that has deposited in riffles during low flow periods. This flow also wets emergent and littoral vegetation that has dried out.
over the low flow period and will help to improve water quality by flushing and reoxygenating pools.

- **Figure 4.6 Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for summer/autumn freshes in Reach 1.**

Outputs from HEC RAS modelling show that 60 ML/d is sufficient to increase depth over riffles by 10-20 cm and achieve a minimum flow velocity through riffles of ~40 cm/s. A lower threshold may fail to create velocity conditions suitable for scouring fine material in riffles and may not extend far enough up the channel side to wet littoral vegetation.

Under natural conditions a flow of 60 ML/d was more indicative of the natural summer low flow (the 80th percentile summer natural flow was 63 ML/d). Under current conditions flows greater than 60 ML/d frequently occur across the summer/autumn period due to unregulated tributary inflows from Doctors Creek (Figure 4.7). The recommended duration of 1 day is also achieved under current conditions.
Winter/spring low flow
The winter/spring low flow recommendation is the same as the summer/autumn recommendation of 10 ML/d. Given the changes in channel geometry and impacts associated with the Upper Yarra Dam and overall reduced flow it is considered that little ecological benefit can be achieved with a higher winter/spring low flow.

Winter/spring freshes
The recommended threshold for winter/spring freshes is 100 ML/d. At this flow all of the channel bottom and tops of rocks in riffles are inundated. The lower parts of the bank and benches are also inundated (Figure 4.8). This flow provides a minimum depth of 30 cm over riffles to provide suitable depths for fish passage. The inundation of benches entrains organic material that has accumulated on benches.

It is recommended that three freshes occur in the winter/spring period for two days duration. This will provide some flow variability during the winter/spring period and the duration is sufficient to entrain organic material and redistribute it through the reach. Fish passage in this reach is required for local movements, so relatively short durations of high flows are required to allow fish to move between pools.

Under natural conditions a flow of 100 ML/d was well below the natural winter low flow (the 80th percentile winter natural flow was 200 ML/d). Under current conditions flows greater than 100 ML/d frequently occur across the winter/spring period due to unregulated tributary inflows from
Doctors Creek (Figure 4.9). However, the recommended duration of 2 days is only achieved in 10% of events.

- **Figure 4.8** Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for winter/spring fresh in Reach 1.

- **Figure 4.9** Duration (top left, frequency (top right) and start month (bottom left) for flows above the winter/spring fresh threshold under current and natural conditions for Reach 1.

**Winter/spring high flows**

A winter/spring high flow threshold of 300 ML/d is recommended. This flow is sufficient to maintain pool habitat relatively free of fine sediment material once an initial bankfull flow has been delivered. A flow of 300 ML/d is sufficient to create the velocity and shear stress in pools required to mobilise and transport sediment and is consistent with the flushing flow recommendation of SINCLAIR KNIGHT MERZ
Wilkinson and Rutherford (2001). This flow will also significantly increase water depth in pools and riffles and inundate vegetation on the banks (Figure 4.10).

The recommended frequency of the high flow is once every two years (following the initial bankfull flow) for a duration of three days to allow sufficient time to transport fine material to downstream reaches where higher flows will further redistribute this material along the river. In addition to maintaining pool habitat, the high flow will provide a disturbance regime for terrestrial vegetation encroaching on banks and will provide further opportunity for local fish movement throughout the reach.

![Figure 4.10 Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for winter/spring high flows in Reach 1.](image)

Under current conditions a flow of 300 ML/d occurs once every 4 years, naturally such a flow would have occurred around two times per year (Figure 4.11). Under natural conditions, the median duration of a flow >300 ML/d was 10 days with 20% of events lasting longer than approximately 120 days. Currently, the median duration of flows >300 ML/d is 1 day. This is shorter than the recommended duration of 3 days.
Bankfull
A bankfull flow threshold of 1100 ML/d is recommended. This flow is sufficient to reach the top of the banks along most of the reach (Figure 4.12). The purpose of this flow is to provide a significant ecosystem and geomorphic disturbance. In particular it is aimed at scouring sediment and fine material from the deepest pools, to partly scour consolidated lateral material along the channel margins but without mobilising the entire sediment load stored in lateral bars and to scour vegetation encroaching on the active channel and lower banks. Higher flows risk mobilising the entire sediment load and this poses a risk to downstream habitat. Flows lower than 1100 ML/d may not be sufficient to scour the deepest pools or redistribute material to downstream reaches where it can be carried further downstream with higher flows. The 1100 ML/d flow is consistent with the flushing flow recommendation of Wilkinson and Rutherford (2001).

The recommended frequency of the bankfull flow is 1 every 10 years for a duration of 3 days. Under natural conditions and flow of this magnitude would have occurred one to two times per year with a median duration of 5 days (Figure 4.13). Under current conditions this flow has only occurred twice in 40 years since the Upper Yarra Dam was completed. The recommended flow frequency is designed, in conjunction with the high flow recommendation, to scour fine sediment from pools and then to maintain pool habitat in the context of the current channel geometry. More frequent bankfull flows would increase the risk of mobilising the entire sediment load. A 1 in 10 year frequency will allow lateral bars to remain relatively stable, but over time will ensure pools do
not become infilled with fine material. To ensure the scoured material is transported and redistributed long distances downstream releases from Upper Yarra Dam need to be made in conjunction with high flows further downstream.

- Figure 4.12 Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for bankfull flows in Reach 1.

- Figure 4.13 Duration (top left, frequency (top right) and start month (bottom left) for flows above the bankfull flow threshold under current and natural conditions for Reach 1.

The ability to achieve ecological objectives for Reach 1 is contingent on the bankfull flow recommendation being delivered to initially scour pools of fine sediment. Subsequent high flows will maintain pool habitat relatively free of fine sediment. To take full advantage of higher flows to

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scour sediment it is important that further sediment input to the reach is minimised through the adherence to best practice guidelines and codes of practice for roading and forest activities in the Doctors Creek catchment. In addition, further investigations are needed to assess the potential for cold water pollution in releases from Upper Yarra Reservoir, current data is insufficient to make a conclusive assessment of potential impacts and temperature profiles are needed from the dam itself to determine temperature at the outlet level.

**Long section**

Figure 4.14 shows a long section of Reach 1 and shows the depth of water over riffles and in pools under each flow threshold. It is evident that the summer/autumn low flow maintains a shallow flow over riffles and sufficient depth in pools. Fresh flows increase depth over riffles to provide fish passage and high and bankfull flows completely drown out riffles structures.

![Figure 4.14 Long section of Reach 1 showing depth in pools and riffles under each flow threshold.](image)

### 4.1.3 Current compliance

Compliance with flow recommendations in Reach 1 is presented in Table 4.2. Under current conditions the summer and winter low flow recommendations are complied with. The summer fresh is currently met in 95% of years and the winter fresh in 80% of years, although the recommended duration of the winter fresh is only met in 10% of events. The winter high flow is only met in 30% of years and the bankfull flow is met in 25% of years, and when they do occur, the duration of the high and bankfull flows only meets the recommended duration in 40% and 30% of events respectively.

Under natural conditions, all flow recommendations would have been met in most years. For comparative purposes the recommended bankfull flow of 1100 ML/d once every ten years now only occurs once every 40 years (ie 25% compliance) but would have occurred nearly every year under natural conditions.

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While the summer and winter fresh recommendations are frequently complied with, they will not be effective until an initial bankfull flow has been delivered and the recommended winter high flows are met. The bankfull flow should be timed to coincide with high flows in downstream reaches to help distribute scoured sediment along a long section of river and minimise the risk of accumulation in the reach immediately downstream.

Releases from Upper Yarra Dam will be required to contribute to all flow components in Reach 1, particularly high and bankfull flows. The compliance point for this Reach is the Doctors Creek gauge.

Table 4.2 Compliance with environmental flow recommendations for Reach 1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Time</th>
<th>Flow Rec</th>
<th>Percentage of years (vol &amp; no.) or events (dur.) when flow recs are complied with for the current flow regime</th>
<th>Differences between each flow component for the current &amp; natural regime for comparative purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current equivalent</td>
</tr>
<tr>
<td>Summer low</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Summer fresh</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>60</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>4</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Summer high</td>
<td></td>
<td></td>
<td></td>
<td>No recommendation</td>
</tr>
<tr>
<td>Winter low</td>
<td>(Jun-Nov)</td>
<td>Volume</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Winter fresh</td>
<td>(June-Nov)</td>
<td>Volume</td>
<td>100</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>3</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Winter high</td>
<td>(Oct-Nov)</td>
<td>Volume</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1:2</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>Bankfull</td>
<td>(Timed to coincide with high flows downstream)</td>
<td>Volume</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1:10</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>3</td>
<td>30</td>
</tr>
</tbody>
</table>

4.2 Reach 2: Armstrong Creek to Millgrove

Reach 2 runs from Armstrong Creek to Millgrove. Armstrong Creek is the first major tributary input to the Yarra River downstream of Upper Yarra Dam and from this point on the channel width increases significantly as tributary inflows increase. The channel is confined in a narrow bedrock-controlled valley with a few small alluvial fans and is characterised by fast flowing water over predominantly pool-riffle structure with cobbled bed and dense riparian forest. Downstream of Millgrove the valley opens in to a wide alluvial floodplain. The environmental flows assessment site is located at East Warburton, downstream of all major tributary harvesting activities. The gauge for compliance purposes is located at Millgrove. There is a current minimum flow policy at Millgrove of 98 ML/d.
4.2.1 Current condition

Hydrology

Naturally the Yarra River Millgrove had a mean annual flow of 1,075 ML/day. Under current conditions the mean annual flow has been reduced by 50% to 527 ML/day. Flows have been reduced across the full range of flows (Figure 4.15). Seasonality has been retained because of unregulated tributary inflows (Figure 4.16). However, the low flow period tends to start earlier and last longer under current conditions compared to natural. In addition, the frequency and duration of flood events has been reduced. Under unimpacted conditions a 1 in 5 year flood had a magnitude of approximately 7,000 ML/day. Under current conditions a flood of this magnitude has a frequency of 1 in 12 years.

- Figure 4.15 Flow duration curve for natural and current flows at Millgrove.

- Figure 4.16 Average flow for each day of the year at the Millgrove gauge.
Geomorphology / habitat
The channel dimensions through this reach increase considerably with increased tributary flows. Although there is still some evidence of channel contraction evident as consolidated sediment deposits and vegetated bars along channel margins, the extent is much smaller than for Reach 1. A reduction in the frequency of scouring flows through this reach has likely contributed to the observed minor channel contraction and vegetation encroachment. Accumulation of fine sediment and excessive algal growth may occur during low flow periods in response to reduced variability and frequency of freshes.

Complex habitat is provided in the form of bedrock bars, deep pools, gravel/cobble riffles and fast flowing runs. Suitable minimum flows are required to maintain access to habitat for fish and macroinvertebrates. Freshes are required to minimise accumulation of fine sediment on benthic surfaces during summer. Higher flows are required to maintain the current channel dimensions and minimise further contraction.

Macroinvertebrates
The condition of the macroinvertebrate community improves in this reach compared to Reach 1. Some variability in community composition is evident between sites and sampling occasions but sites typically comply with SEPP F7 objectives and are equivalent to reference condition (AUSRIVAS Band A). Towards the lower parts of this reach some smothering of benthic habitat, degradation of the riparian zone and runoff associated with increasing urban and agricultural impacts are the main factors that are considered to influence the macroinvertebrate community.

Although in relatively good condition, the future condition of the macroinvertebrate community is at risk from runoff from increasing urban & agricultural impacts & further degradation of the riparian zone. Low, stable flows that contribute to the accumulation of fine sediment on benthic surfaces also pose a risk to macroinvertebrate condition. Freshes are required to minimise the accumulation of fine sediment on benthic surfaces through the low flow summer period. Management of catchment sources of sediment and nutrients, and works to maintain and improve riparian vegetation are also required to ensure SEPP objectives are continued to be met along this reach.

Fish
A range of native and exotic fish have been recorded from this reach and overall diversity is relatively high. Three (river blackfish, spotted galaxias and common galaxias) of the five SEPP listed species have been recorded in this reach. There is anecdotal evidence of Australian grayling in the reach (Zampatti et al. 2002). Mountain galaxias have also been recorded from the reach. Several diadromous species, including common galaxias, lamprey and eels have been recorded in the reach, indicating some fish passage through Dights Falls is occurring. However, there is evidence that the current fishway is ineffective at some flows and improvements in the fishway could significantly increase the numbers and diversity of native species gaining passage through the structure (Zampatti et al. 2002).
Cold water impacts from Upper Yarra Dam appear to have been ameliorated by tributary inflows through this reach (SKM 2005b). However, loss of habitat through past desnagging is likely to have impacted on the fish community. Lack of appropriate flows to provide spawning and migration cues and inefficiencies in the Dights Falls fishway may continue to limit several species, including Australian grayling, which requires an autumn high flow to provide spawning cues and to assist with transporting larvae to the estuary, and suitable fishway conditions in spring for juveniles to ascend the river. Suitable low flows are required to maintain access to habitat and freshes and high flows are required to help flush sediment from riffles and spawning sites.

Vegetation
Riparian vegetation condition in the upper part of the reach is excellent. However, condition declines through the middle and lower parts of the reach due to land clearing for agriculture and township development. There is some evidence of a reduced vertical zone of flood-tolerant plants on the river bank, encroachment of terrestrial weed species down the bank (eg. sweet pittosporum, wild Watsonia and blackberries) and the colonisation along the water line by semi-aquatic species that favour stable water levels (eg. yellow flag iris). However, weed infestation due to poor land management practices and stock access to river banks are still likely to represent the greatest threat to native riparian vegetation.

Stable low flows, particularly during the spring and summer growing period are thought to contribute to the colonisation along the water line by semi-aquatic species that favour stable conditions. Encroachment of terrestrial species down the banks may be indicative of reduced frequency and duration of inundation of the higher bank, hence favouring terrestrial species through reduced disturbance regime.

Stable low flows will continue to favour weed species and contribute to further contraction of the zone of flood-tolerant plants on the lower banks and increased terrestrialisation of the upper banks. A more variable flow regime and increased duration of higher flows in spring to provide a disturbance are required to limit the growth of semi-aquatic plants near the waterline and to reduce the potential for further terrestrialisation of the upper banks. Complementary works such as fencing to limit stock access to banks, active weed control and revegetation with species appropriate for the EVC (riparian forest) are required to gain an improvement in vegetation condition in the lower reaches.

Water quality
Water quality is considered good to excellent with a very high compliance with SEPP objectives for most water quality parameters. However, total nitrogen is elevated through the reach and occasional fails to comply with SEPP objectives. Total nitrogen concentrations increases with increased discharge indicating that catchment sources through runoff associated with agricultural and township development are the most likely contributor to elevated nitrogen concentrations. Toxicant concentrations are low and comply with ANZECC guidelines.

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Catchment activities are likely to cause the greatest impact on water quality parameters. If catchment management activities aimed at reducing nutrient and sediment input to streams are undertaken, water quality is expected to remain good. There are no specific flow recommendations in relation to water quality and increased flow should not be used to dilute poor water quality. Implementation of catchment strategies to limit stock access, agricultural runoff and septic tank effluent inputs to the river are required to reduce nutrient and sediment levels and limit excessive algal growth.

4.2.2 Flow recommendations
The general objective is to move away from long periods of low flow and return some of the high flows, particularly the longer lasting high flows in spring, to inundate the banks with the intent of drowning terrestrial vegetation that is encroaching down the banks. Key flow components are summer freshes to ensure a variable low flow and increased duration of spring high flows to inundate the bank for a longer duration during the main vegetation growing season. The environmental flow recommendations for Reach 2 are summarised in Table 4.3.

Table 4.3 Summary of flow recommendations for Reach 2.

<table>
<thead>
<tr>
<th>Season</th>
<th>Flow</th>
<th>Volume</th>
<th>Frequency</th>
<th>Duration</th>
<th>Rise/Fall</th>
<th>Objective (refer to objectives tables for id reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer/autumn</td>
<td>Low flow</td>
<td>80 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, drying period for bank vegetation M2-1, F2-1, V2-1</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>350 ML/d</td>
<td>3 per season</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td>Maintain suitable riffle habitat by periodically scouring sediment &amp; biofilms, maintain flood-tolerant vegetation on banks M2-2, F2-1, V2-2</td>
</tr>
<tr>
<td></td>
<td>High flow</td>
<td>560 ML/d</td>
<td>1 per season in April/May</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td>Trigger spawning by Australian grayling &amp; transport larvae downstream F2-3</td>
</tr>
<tr>
<td>Winter/spring</td>
<td>Low flow</td>
<td>350 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, inundate flood-tolerant vegetation on lower bank M2-1, F2-1, V2-1</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>700 ML/d</td>
<td>2 events between June and September</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td>Maintain suitable riffle habitat by periodically scouring sediment &amp; biofilms, maintain flood-tolerant vegetation on banks, provide local fish passage, entrain organic material M2-2, F2-1, V2-2</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>700 ML/d</td>
<td>1 in October -November</td>
<td>14 days</td>
<td>1.4/0.85</td>
<td>As per Fresh but provides a prolonged disturbance to favour flood-tolerant vegetation M2-3, F2-2, V2-3</td>
</tr>
<tr>
<td>Bankfull/overbank flow</td>
<td>2700 ML/d</td>
<td>Once every two years</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td>Maintain existing channel geometry &amp; prevent vegetation encroachment in channel, entrain organic material, engage high flow channels &amp; floodplain G2-1, M2-3, V2-3, G2-2</td>
<td></td>
</tr>
</tbody>
</table>

Summer/autumn low flow
The recommended summer low flow threshold in Reach 2 is 80 ML/d. This flow is sufficient to inundate the full width of riffles (eg. Transect 3) and to maintain sufficient depth in pools of around 1 m (eg. Transect 5) (see Figure 4.17). The flow threshold also allows a drying regime for benches and the lower bank. The recommended low flow threshold was compared with the current 98 ML/d low flow and little difference in river height or width of wetted riffles was evident so the 80...
ML/d threshold was considered appropriate. Flows lower than this would reduce the area of riffles available for macroinvertebrates and may introduce water quality problems, particularly deoxygenation in the deeper pools.

- Figure 4.17 Stage height in riffle (Transect 3, left) and pool (Transect 5, right) at the recommended threshold for summer/autumn low flows in Reach 2.

Under current and natural conditions flow has rarely fallen below the low flow threshold (15 times in 100 years under current conditions and only 7 times in 100 years under natural conditions) (Figure 4.18). This is because the current minimum flow requirement at Millgrove of 98 ML/d is greater than the recommended low flow threshold.

- Figure 4.18 Duration (top left, frequency (top right) and start month (bottom left) for flows below the summer/autumn low flow threshold under current and natural conditions for Reach 2.
**Summer/autumn fresh**

A summer/autumn fresh threshold of 350 ML/d is recommended. This flow inundates rocks and boulders located in riffles and pool margins (Figure 4.19) and achieves an average flow velocity through riffles of ~40 cm/s to scour sediment and biofilms. The fresh flow also wets banks to maintain flood-tolerant vegetation through the low-flow period. Higher flows were considered to provide marginal incremental advantage in scouring riffles and runs and significantly higher flows are required to wet further up the banks.

![Figure 4.19 Stage height in riffle (Transect 3, left) and pool (Transect 5, right) at the recommended threshold for summer/autumn freshes in Reach 2.](image)

Three fresh flows of a minimum duration of 2 days are recommended in each summer/autumn period. The current frequency of flows above the fresh threshold is similar to natural (approximately 4 events per year) (Figure 4.20). However, the median duration of each event has more than halved (2 days compared to 5 days), but still meets the recommended 2 day duration. There has been a slight shift in the timing of freshes with the current freshes occurring most often at the start or end of the summer/autumn period. The timing of freshes can be variable but they should occur throughout the season and not be restricted to the start or end of the season.
Summer/autumn high flows

A summer/autumn high flow threshold of 560 ML/d is recommended to provide suitable spawning conditions for Australian grayling, which require a high flow in autumn to trigger spawning and transport of larvae to the estuary (O’Connor and Mahoney 2004). The flow needs to occur during the autumn period and the recommended timing is April or May. There is uncertainty about the flow magnitude required to trigger spawning as no specific studies of Australian grayling life history or flow requirements have been undertaken in the Yarra River. The recommended flow threshold of 560 ML/d is based on the median natural flow May and June. This volume may need to be revised if more information becomes available on the specific flow requirements of grayling. The duration of the flow event is also uncertain; as it is uncertain whether a short duration event is sufficient to trigger spawning or whether a longer duration event is required to ensure larvae are transported to the estuary. A duration of seven days has been specified to provide sufficient duration to transport larvae to the estuary. The flow recommendation would be met if the first high flow in autumn is allowed to progress down the entire system.

In addition to assisting grayling spawning, HEC RAS modelling also shows that the high flow threshold is sufficient to engage high flow channels (eg. Transect 2) and provide a disturbance to vegetation on the lower banks (Figure 4.21).

Under current conditions a high flow of the recommended threshold occurs on average once every year for a median duration of 2 days and a maximum duration of around 5 days (Figure 4.22).
Under natural conditions the flow threshold would have been exceeded on average 2 times each for a median duration of 3 days. However, 30% of events would have lasted between 3 and 10 days and 20% of events would have lasted between 10 and 20 days. This means on average at least one event in each year would have been of a longer duration sufficient to transport larvae long distances downstream. The distribution of start months is similar between natural and current with most events starting in May.

- Figure 4.21 Stage height in riffle (Transect 3, left) and pool (Transect 2, right) at the recommended threshold for summer/autumn high flows in Reach 2.

- Figure 4.22 Duration (top left, frequency (top right) and start month (bottom left) for flows above the summer/autumn high flow threshold under current and natural conditions for Reach 2.
### Winter/spring low flow

The winter/spring low flow threshold is 350 ML/d (the same volume as the summer fresh). This flow is approximately 3.5 times greater than the current minimum flow requirement at Millgrove of 98 ML/d. This flow is sufficient to inundate the full width of riffles to a depth of around 10 cm. The prolonged duration of the higher flow through winter provides a prolonged disturbance on the lower banks to favour flood-tolerant vegetation and provide conditions unfavourable for aquatic plants that prefer stable water levels (eg Yellow flag iris).

Under current conditions flows fall below the recommended winter/spring low flow threshold on average 2.5 times per year for a median duration of 15 days each time with 20% of events lasting between 35 and 55 days (Figure 4.23). Spells below the threshold would have occurred under natural conditions approximately once every 18 months but only for a median duration of 5 days up to a maximum 12 days duration below the threshold. Under current conditions durations below the threshold most often occur in June and November, emphasising the shortening of the high flow period and the lengthening of the low flow period as a result of extractions from upstream reaches.

![Percentile Plot](image1)

![Frequency Plot](image2)

![Frequency of Start Month Plot](image3)

- **Figure 4.23** Duration (top left, frequency (top right) and start month (bottom left) for flows below the winter/spring low flow threshold under current and natural conditions for Reach 2.

### Winter/spring fresh and high flows

The recommended winter/spring fresh threshold is 700 ML/d. Two events between June and September with a 7 day duration are recommended. The recommended flow achieves a minimum flow velocity of approximately 40 cm/s through riffles to scour cobbles and riffles of sediment and algal growth and will assist in resetting successional patterns in algal biofilms. The winter fresh is higher than the summer fresh and wets further up the banks and is sufficient to engage the high flow channel at Transect 2 (Figure 4.24).

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A winter high flow event is also recommended. The flow threshold for the high flow event is also 700 ML/d but the recommended duration is double the fresh duration (14 days) and the recommended timing is October or November, during the active growing season. This flow is aimed at inundating terrestrial vegetation on the banks to minimise the encroachment of terrestrial vegetation, particularly weeds such as blackberry and wild Watsonia. A prolonged high flow in the spring growing season will also help to provide conditions unfavourable to the semi-aquatic weed Yellow flag iris, which prefers stable conditions during its growing season.

- Figure 4.24 Stage height in riffle (Transect 3, left) and pool (Transect 2, right) at the recommended threshold for winter/spring freshes in Reach 2.

Under current conditions the winter fresh occurs on average 4 times per year for a median duration of 4 days (Figure 4.25). Under natural conditions fewer events would have occurred, but the duration of each event was much longer with a median duration of 15-20 days and 30% of events lasting between 20 and 160 days. Under current conditions most events start in July and August. Under natural conditions most events started in June, often running for the entire winter/spring period.
The winter/spring high flow event occurs once each year under both current and natural conditions (Figure 4.26). The median duration event in October and November is 10 days under current conditions and 60 days under natural conditions. Even under current conditions 30% of events last between 10 and 40 days, but as the event only occurs once every year a long duration spring event can only be expected on average every second year; half the recommended frequency.
Bankfull flow

A bankfull flow recommendation of 2700 ML/d is recommended. This flow is sufficient to reach the top of the banks (typically ill defined due to confined nature of channel and steep valley side slopes) along most transects and inundates a small floodplain and high flow channel at Transects 1 and 2 (Figure 4.27). Flow is sufficient to maintain current channel geometry by scouring in-channel vegetation and sediment in deepest pools.

Figure 4.26 Duration (top left, frequency (top right) and start month (bottom left) for flows above the winter/spring high flow threshold under current and natural conditions for Reach 2.

Figure 4.27 Stage height in riffle (Transect 3, left) and pool (Transect 2, right) at the recommended threshold for bankfull flows in Reach 2.
Minimum Environmental Water Requirement and Complementary Works Recommendations

Under current conditions the bankfull flow occurs on average 2 times per year compared to 3 or more times per year under natural conditions (Figure 4.28). The median duration of natural and current bankfull events is 2 days, the same as the recommended duration. However, natural events often lasted much longer than current events with 20% of natural events lasting between 11 and 23 days compared to between 5 and 8 days under current conditions. Most events start in August and September.

![Figure 4.28 Duration (top left, frequency (top right) and start month (bottom left) for flows above the bankfull flow threshold under current and natural conditions for Reach 2.](image)

**Long section**

Figure 4.29 shows a long section of Reach 2 that shows the depth of water over riffles and in pools under each flow threshold. It is evident that the summer/autumn low flow maintains a shallow flow over riffles and sufficient depth in pools. Fresh flows increase depth over riffles to provide fish passage and high and bankfull flows completely drown out riffle structures.
4.2.3 Current compliance

Compliance with flow recommendations in Reach 2 is presented in Table 4.4. Under current conditions the summer low flow is met 99% of the time, although the winter low flow is only met 68% of the time with the 80th%ile winter low flow currently 263 ML/day compared to the recommended minimum of 350 ML/d and the natural 80th%ile winter flow of 724 ML/d.

The summer fresh volume is currently met in 80% of years while the winter fresh volume is met at least once each year but the frequency of events is only met every second year and of those events the recommended duration is only met in 40% of events.

The summer high flow is met in 85% of years but the duration is only met in 5% of years with a current median duration of 2 days compared to a recommended duration of 7 days. The median duration of the summer high flow under natural conditions is 3 days, however the median number of high flow events is 5 so at least one event in each year is likely to last for 7 days.

The winter high flow is currently met in 95% of years but the duration is only met in 45% of events. The median current duration is 10 days compared to the recommended duration of 14 days, and a median duration of 61 days under the natural flow regime. The bankfull flow recommendation is currently complied with.

In summary, most flow components are currently complied with except the current winter low flow, which falls below the recommended flow 32% of the time and the duration of the summer and winter high flows, which are only met for 5% and 45% of events respectively. Low compliance with the summer and winter high flow durations will limit the ability to achieve environmental objectives related to Australian grayling spawning success (for summer high flows) and vegetation zonation on banks (for winter high flows).
Delivery of flow components will require modification to tributary harvesting operations, particularly in order to achieve the recommended duration of fresh and high flow events. Compliance with the bankfull recommendation will be achieved through protecting existing bankfull flows when they naturally occur rather than through specific reservoir releases. It is important that high and bankfull flows in this reach are allowed to progress through the entire system to contribute to equivalent flow components in downstream reaches. The compliance point for Reach 2 is the Millgrove gauge.

Table 4.4 Reach 2 compliance with environmental flow recommendations.

<table>
<thead>
<tr>
<th>Component</th>
<th>Time</th>
<th>Flow Rec</th>
<th>Percentage of years (vol &amp;no.) or events (dur.) when flow recs are complied with for the current flow regime</th>
<th>Differences between each flow component for the current &amp; natural regime for comparative purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Current equivalent</td>
<td>Natural equivalent</td>
</tr>
<tr>
<td>Summer low</td>
<td>(Dec-May)</td>
<td>Volume 80</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>Summer fresh</td>
<td>(Dec-May)</td>
<td>Volume 350</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 3</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 2</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Summer high</td>
<td>(Apr-May)</td>
<td>Volume 560</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Winter low</td>
<td>(Jun-Nov)</td>
<td>Volume 350</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Winter fresh</td>
<td>(June-Sep)</td>
<td>Volume 700</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 2</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 7</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Winter high</td>
<td>(Oct-Nov)</td>
<td>Volume 700</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 14</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Bankfull</td>
<td>(June-Nov)</td>
<td>Volume 2700</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1,2</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Overbank</td>
<td></td>
<td>Duration 2</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

4.3 Reach 3: Millgrove to Watts River
Reach 3 encompasses the upper floodplain reach of the Yarra River between Millgrove and a narrow constriction called the Healesville gorge near the confluence with the Watts River. Several large tributaries enter this reach including the Little Yarra River and Woori Yallock Creek. The channel meanders across the floodplain, which has been predominantly cleared of vegetation for agricultural production. The environmental flows assessment site is located at the lower end of the reach at Everard Park. The channel here is a long pool with steep outer banks and a sandy point bar. A billabong is located within the meander that is inundated at flows around bankfull. Flow in this reach is measured at the Yarra Grange gauge. The Yarra Grange gauge is located downstream of the confluence with the Watts River so adjustments have been made to the daily flow time series.
by subtracting flows contributed from the Watts River. For compliance purposes a gauge may need to be established upstream of the Watts River confluence.

### 4.3.1 Current condition

**Hydrology**

Naturally the Yarra River through Reach 3 had a mean annual flow of 1,933 ML/day. Under current conditions the mean annual flow has been reduced by 40% to 1,175 ML/day. As with Reach 2 flows have been reduced across the entire flow range (Figure 4.31) but seasonality is retained due to further tributary inflows (Figure 4.31). Under unimpacted conditions a 1 in 5 year flood had a magnitude of approximately 15,000 ML/day. Under current conditions a flood of this magnitude has a frequency of 1 in 15 years.

- Figure 4.30 Flow duration curve for the Yarra River at Yarra Grange.
- Figure 4.31 Average flow for each day of the year for the Yarra River at Yarra Grange.
Geomorphology / habitat
The channel through this reach flows through a floodplain. Banks are steep with active erosion on outside bends and accretion on sandy point bars although overall erosion rates are relatively low. The channel has been extensively desnagged reducing the availability of LWD habitat for fish and macroinvertebrates. Desnagging has also likely caused some instability in the channel bed which may have resulted in the infilling of some pools with sand that had previously been retained behind LWD.

The floodplain and billabongs have been extensively cleared for agricultural production and the reduced frequency of high flows has decreased the frequency and duration of connectivity between the river and floodplain.

Overall habitat condition will continue to slowly deteriorate in the absence of rehabilitation works to reinstate appropriate habitat and protect and improve riparian and floodplain condition. However, long periods of low flow and reduced frequency of high flow events has also likely contributed to a decline in quality of available habitat because low flows can allow accumulation of sediment and excessive algal growth on LWD surfaces.

In addition to in-stream habitat restoration (resnagging) and floodplain and riparian rehabilitation (fencing, stock removal and revegetation), it is important to ensure freshes and high flow events occur at an appropriate frequency and duration to minimise accumulation of fine sediment on LWD surfaces during summer, maintain the current channel dimensions and provide connectivity with billabongs and the floodplain.

Macroinvertebrates
The condition of the macroinvertebrate community remains high in the upper part of Reach 3 and complies with SEPP objectives. However, there is evidence of deterioration towards the lower end of the reach. The lower section of the reach is still considered to be equivalent to reference condition (AUSRIVAS Band A) but the SIGNAL score and number of families do not meet SEPP objectives, indicating that declining water quality may be starting to impact on the macroinvertebrate community with the loss of some sensitive species.

Poor quality habitat through desnagging and sedimentation, degradation of the riparian zone and runoff associated with increasing urban and agricultural impacts towards the lower part of the reach are the main factors influencing the macroinvertebrate community. Although still in relatively good condition, the future condition of the macroinvertebrate community is at risk from runoff from increasing urban and agricultural impacts and further degradation of the riparian zone. Low, stable flows that contribute to the accumulation of fine sediment on benthic surfaces also poses a risk to the health of the macroinvertebrate community.

Improved habitat quality in the lower part of the reach is necessary to improve macroinvertebrate health. This can be achieved through a combination of resnagging to increase the amount of available habitat and the provision of low flows and fresh flows to minimise sediment accumulation on LWD surface to maintain access to available habitat. Management of non-flow
related water quality is also required to contribute to improved macroinvertebrate health in the lower part of the reach.

**Fish**
A large range of native and exotic fish has been recorded from this reach and overall diversity is considered to be high. Four (river blackfish, Australian grayling, spotted galaxias and common galaxias) of the 5 SEPP listed species have been recorded in this reach.

Loss of habitat through past desnagging is likely to have impacted on the fish community. While Australian grayling have been recorded in the reach they require an autumn high flow to provide spawning cues and to assist with transporting larvae to the estuary, and suitable fishway conditions in spring for juveniles to ascend the river. Lack of appropriate flows to provide spawning and migration cues and inefficiencies in the Dights Falls fishway may limit the potential for Australian grayling to establish viable populations. Suitable low flows are required to maintain access to habitat and freshes and high flows are required to help flush sediment from spawning sites for a range of fish species. Competition from exotic species for food and habitat may also pose a threat to some native species in this reach.

**Vegetation**
The condition of riparian and floodplain vegetation is degraded and Index of Stream Condition (ISC) scores for the streamside zone sub-index are poor. As in Reach 2 there is continuing evidence of reduced vertical zone of flood-tolerant plants on the river bank, encroachment of terrestrial weed species down the bank (eg. wild Watsonia and blackberries) and the colonisation along the water line by semi-aquatic species that favour stable water levels (eg. yellow flag iris). However, clearing of the riparian zone and floodplain, weed infestation due to poor land management practices and stock access to river banks are still likely to represent the greatest threat to native riparian vegetation.

Stable low flows, particularly during the spring and summer growing period are thought to contribute to the colonisation along the water line by semi-aquatic species that favour stable conditions. Encroachment of terrestrial species down the banks may be indicative of reduced frequency and duration of inundation of the higher bank, hence favouring terrestrial species through reduced disturbance regime.

Stable low flows will continue to favour weed species and contribute to further contraction of the zone of flood-tolerant plants on the lower banks and increased terrestrialisation of the upper banks. As with Reach 2 a variable flow regime and increased duration of higher flows in spring to provide a disturbance are required to limit the growth of semi-aquatic plants near the waterline and to reduce the potential for further terrestrialisation of the upper banks. Complementary works such as fencing to limit stock access to banks, active weed control and revegetation with species appropriate for the EVC (riparian forest) are required to gain an improvement in vegetation condition in the lower reaches.
Prioritisation of floodplain areas and billabongs for fencing and revegetation are required to take full environmental advantage of bankfull and overbank. However, even inundation of remnant wetlands in cleared agricultural landscapes has been shown to benefit regional macroinvertebrate diversity (Robson and Clay in press), but there is a potential impact on pasture production. Short duration flooding (1-4 days) can temporally reduce pasture production while longer duration inundation can kill pasture (Vogel 1997).

**Water quality**

Water quality is still good in the upper part of the reach but deteriorates in the lower part. Compliance with SEPP objectives for salinity, dissolved oxygen, pH and total phosphorus (TP) is high throughout the reach. However, compliance with TN and turbidity objectives declines through the reach and the TN objective is typically not met at the lower end of the reach. Toxican concentrations are low and comply with ANZECC guidelines.

Catchment activities are likely to cause the greatest impact on water quality parameters with deterioration in water quality related to increased turbidity and nutrients along the reach due to past clearing of the riparian zone and floodplain, associated agricultural activities and inputs from catchments that support intensive agriculture (eg. Woori Yallock Creek).

If catchment management activities aimed at reducing nutrient and sediment input to streams are undertaken water quality is expected to remain good in the upper section of the reach and overall improvements can be expected in the lower section. There are no specific flow recommendations in relation to water quality and increased flow should not be used to dilute poor water quality. Implementation of catchment strategies to limit stock access and agricultural and urban runoff to the river are required to reduce nutrient and sediment levels and limit excessive algal growth.

### 4.3.2 Flow recommendations

The general flow objective is to maintain some variability in the summer low flow period, provide flows to assist Australian grayling spawning in autumn, increase the duration of bank inundation to limit encroachment of terrestrial vegetation and provide for appropriate bankfull and overbank flows for inundation of billabongs and the floodplain. The environmental flow recommendations for Reach 3 are summarised in Table 4.3.
### Table 4.5 Summary of flow recommendations for Reach 3.

<table>
<thead>
<tr>
<th>Season</th>
<th>Flow</th>
<th>Volume</th>
<th>Frequency</th>
<th>Duration</th>
<th>Rise/Fall</th>
<th>Objective (refer to objectives tables for id reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer / autumn</td>
<td>Low flow</td>
<td>150 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, drying period for bank vegetation M3-1, F3-1, V3-1</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>450 ML/d</td>
<td>3 per season</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td>Maintain suitable LWD habitat by periodically scouring sediment &amp; biofilms, maintain flood-tolerant vegetation on banks M3-2, F3-1, V3-2</td>
</tr>
<tr>
<td></td>
<td>High flow</td>
<td>900 ML/d</td>
<td>1 in April/May</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td>Trigger spawning by Australian grayling &amp; transport eggs downstream F3-3</td>
</tr>
<tr>
<td>Winter / spring</td>
<td>Low flow</td>
<td>350 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, inundate bank vegetation M3-1, F3-1, V3-1</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>1800 ML/d</td>
<td>2 in June to September</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td>Maintain suitable habitat M3-2, F3-1, V3-2</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1800 ML/d</td>
<td>1 in October -November</td>
<td>14 days</td>
<td>1.4/0.85</td>
<td>Sediment scouring to increase habitat availability, vegetation disturbance, fish passage, entrain organic material M3-3, F3-2, V3-3</td>
</tr>
<tr>
<td></td>
<td>Bankfull</td>
<td>7500 ML/d</td>
<td>1 every 2 years</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td>Maintain existing channel geometry &amp; prevent vegetation encroachment in channel, entrain organic material, engage high flow channels &amp; floodplain G3-1, M3-3, V3-3</td>
</tr>
<tr>
<td></td>
<td>Overbank</td>
<td>9000 ML/d</td>
<td>Once every 4 years</td>
<td>1-2 days</td>
<td>1.4/0.85</td>
<td>Engage billabongs &amp; low level floodplains G3-4, V3-6</td>
</tr>
</tbody>
</table>

**Summer/autumn low flow**

The recommended summer low flow is 150 ML/d. The entire assessment reach was represented by a long pool and the recommended flow is sufficient to inundate the full width of the channel and will also inundate LWD habitat located within the lower part of the channel (Figure 4.32). The low flow threshold will also allow drying of benches located within the channel (eg. Transect 4).
Minimum Environmental Water Requirement and Complementary Works Recommendations

- Figure 4.32 Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for summer/autumn low flows in Reach 3.

Under current conditions the summer low flow falls below the recommended threshold once every two years for a median duration of 3 days (Figure 4.33). Under natural conditions flow fell below the threshold only 8 times in 100 years but the median duration was longer than current.

The provision of suitable in stream habitat is critical to achieving ecological objectives in this reach. A program for reach scale reinstatement of LWD and revegetation of the riparian zone is required. Such a program will complement the gains achieved through the flow recommendations.

- Figure 4.33 Duration (top left, frequency (top right) and start month (bottom left) for flows below the summer/autumn low flow threshold under current and natural conditions for Reach 3.
**Summer/autumn freshes**

The summer/autumn fresh flow recommendation is 450 ML/d three times per season for a duration of 2 days. This flow threshold is sufficient to achieve minimum flow velocity of approximately 40 cm/s around LWD located in the lower parts of the channel. This flow is aimed at scouring sediment that has accumulated on LWD surfaces over the low flow periods and improve quality of habitat for macroinvertebrates. The summer fresh also inundates low benches (eg Transect 4) and periodically wets the lower banks to maintain flood-tolerant vegetation on banks (Figure 4.34).

![Figure 4.34 Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for summer/autumn freshes in Reach 3.](image)

Under current conditions the summer fresh threshold occurs on average 5 times per year for a median duration of 5 days (Figure 4.35). This meets the recommended frequency and duration for most events.
Summer/autumn high flows
The summer/autumn high flow recommendation is 500 ML/d. The rational for this recommendation is based on providing a suitable spawning trigger for Australian grayling and flow to transport larvae to the estuary as described for Reach 2 but the volume has been adjusted to account for increased channel capacity. As in Reach 2, this flow wets further up the banks (Figure 4.36) to maintain flood-tolerant vegetation and provide a disturbance to terrestrial vegetation.

- Figure 4.36 Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for summer/autumn high flows in Reach 3.
Under current conditions the autumn high flow event occurs on average once every year compared to twice per year naturally (Figure 4.37). The current median duration is 3 days compared to 4 days naturally. However, as in Reach 2, under natural conditions a greater number of events lasted for a longer duration and occurred more often hence increasing the chances of a suitable spawning event.

**Winter/spring low flows**

The winter/spring low flow threshold is 350 ML/d. This flow is sufficient to inundate benches in the channel (eg. Transect 4) (Figure 4.38) and provide access to additional LWD habitat located higher in the channel. The prolonged duration of the higher flow through winter provides a prolonged disturbance on the lower banks to favour flood-tolerant vegetation and provide conditions unfavourable for aquatic plants that prefer stable water levels (eg Yellow flag iris).

Under current conditions flows fall below the recommended winter/spring low flow threshold at least once per year for a median duration of 4 days each time with 20% of events lasting between 10 and 18 days (Figure 4.39). Spells below the threshold would rarely have occurred under natural conditions. Under current conditions durations below the threshold most often occur in June and November, emphasising the shortening of the high flow period and the lengthening of the low flow period as a result of extractions from upstream reaches.
Winter/spring freshes and high flows
The recommended winter/spring fresh threshold is 1800 ML/d. Two events between June and September of 7 days duration are recommended. The recommended flow is sufficient to scour sediment that has accumulated on LWD. It also provides short term access to LWD surfaces located higher in the channel and wets higher up the bank than the summer fresh to inundate high
level benches (eg. Transect 2) (Figure 4.40) and entrain organic material that has accumulated on the mid and upper banks.

A winter high flow event is also recommended. The flow threshold for the high flow event is also 1800 ML/d but the recommended duration is double the fresh duration (14 days) and the recommended timing is October or November, during the active growing season. This flow is aimed at inundating terrestrial vegetation on the banks to minimise the encroachment of terrestrial vegetation, particularly weeds such as blackberry and wild Watsonia. A prolonged high flow in the spring growing season will also help to provide conditions unfavourable to the semi-aquatic weed Yellow flag iris, which prefers stable conditions during its growing season.

- Figure 4.40 Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for winter/spring freshes in Reach 3.

Under current conditions the winter fresh occurs on average 4 times per year for a median duration of 5 days and a maximum duration of 30 days (Figure 4.41). Under natural conditions slightly fewer events would have occurred, but the duration of each event was longer with a median duration of 9 days, 30% of events lasting between 9 and 80 days and 20% of events lasting between 80 and 120 days. Under current conditions most events start in July and August. Under natural conditions most events started in June, with some running for most of the winter period.
The winter/spring high flow event occurs 1 to 2 times per year, starting in October, under both current and natural conditions (Figure 4.42). Under current conditions the duration of the high flow event as declined compared to natural with the median duration event in October and November being 5 days under current conditions and 15 days under natural conditions. The recommended duration now only occurs in about 20% of events or once every 3 to 4 years.
Bankfull flows

A bankfull flow of 7500 ML/d once every two years for a duration of 1-2 day is recommended. This flow is sufficient to reach the top of the banks along most transects and allows water to enter wetlands (eg. Transect 2 –note entrance to wetland at top right bank) (Figure 4.43) and inundate low lying parts of the floodplain within meander loops. Flow is sufficient to maintain current channel geometry by scouring in-channel vegetation and sediment in pools. Inundation of wetlands and parts of the floodplain are important for maintain wetland structure. The frequency of events drives vegetation community patterns and even in cleared agricultural landscapes wetland inundation contributes to regional macroinvertebrate biodiversity (Robson and Clay in press). Bankfull and overbank flows also deposit sediment on the floodplain that contributes to floodplain soil fertility and flood flows returning to the river entrain organic material. Some fish species (eg common galaxias) lay their eggs on inundated vegetation along channel margins during floods (Koehn and O'Connor 1990).

There is little difference between the current and natural flow regimes in respect to the recommended bankfull flow. Under natural conditions there are slightly more events per hundred years and they last for slightly longer than current (Figure 4.44). However, even under current conditions the recommended flow is typically met.
The bankfull flow recommendation is aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages. By protecting the existing bankfull flow there will be no increased risk to pasture production above that which already occurs.

- **Figure 4.43** Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for bankfull flows in Reach 3.

- **Figure 4.44** Duration (top left, frequency (top right) and start month (bottom left) for flows above the bankfull flow threshold under current and natural conditions for Reach 3.
Overbank flows

An overbank flow of 9000 ML/d is recommended once every 4 years for a 1-2 day duration to inundate billabongs and higher parts of the floodplain not engaged at bankfull flows. A flow of 9000 ML/d is approximately 80 cm higher than the bankfull flow (Figure 4.45). The overbank flow has a similar purpose as the bankfull flow but inundates a greater area of floodplain. Longer duration flows are not recommended because of the risk to pasture production. Overbank flows longer than 4 days can kill pasture (Vogel 1997).

Under current conditions the overbank flow occurs once every 3 to 4 years for a median duration of 2 days (Figure 4.46). Under natural conditions an overbank flow would have occurred on average every two years, also with a median duration of 2 days, although some event would have lasted up to 6 days. Naturally, most overbank flows would have commenced in September. Under current conditions there has been a slight delay in the onset of overbank flows.

As with the bankfull recommendation, the overbank flow recommendation is aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages. This will ensure there is no increased risk to pasture production over that which already occurs.

While some ecological benefits of overbank flows will be gained under current landscape conditions (eg. see Robson and Clay in press), the full environmental advantage of both bankfull and overbank flows through this reach will be achieved if parts of the floodplain and some billabongs can be fenced and revegetated with species appropriate for the EVC. Cooperation with landholders is needed to take full advantage of overbank flows and to manage risks to agricultural production.
Long section

Figure 4.47 shows a long section of Reach 3 that shows the depth of water in pools under each flow threshold. The long pool characteristics of the reach are evident and each flow threshold provides increased pool depth and progressive bank wetting.

- Figure 4.46 Duration (top left, frequency (top right) and start month (bottom left) for flows above the overbank flow threshold under current and natural conditions for Reach 3.

- Figure 4.47 Long section showing water surface level for all flows in Reach 3.
4.3.3 Current compliance

Compliance with flow recommendations for Reach 3 is presented in Table 4.6. Under the current regime the recommended summer and winter low flow volumes are complied 97 and 95 percent of time respectively. The summer fresh volume is met nearly every year and in at least 80% of years the recommended frequency and duration of the summer fresh is met.

The winter fresh volume is met nearly every year and the recommended number of events (2) is met in 85% of year. The recommended duration is only met for 40% of events, but because the median frequency of events is twice the recommended frequency in most years, two events of the recommended duration could be expected to occur.

The winter high flow volume and frequency is met in 75% of years but the duration is only met in 20% of events.

There is a high compliance with bankfull and overbank flow recommendations.

In summary the volume and frequency of all flow components are frequently met but there is poor compliance with the recommended duration of the summer high flow and winter fresh and high flow events. This limits the ability to achieve objectives related to Australian grayling spawning in the case of summer high flows and encroachment of terrestrial vegetation on the upper banks in the case of winter high flows.

The delivery of low flows, freshes and high flows will require manipulation of storage releases and harvesting operations, particularly in regards to achieving recommended event duration. Bankfull and Overbank flow recommendations should be met through protecting existing events when they occur rather than through specific flow releases.
Table 4.6 Reach 3 compliance with environmental flow recommendations.

<table>
<thead>
<tr>
<th>Component</th>
<th>Time</th>
<th>Flow Rec</th>
<th>Percentage of years (vol &amp; no.) or events (dur.) when flow recs are complied with for the current flow regime</th>
<th>Differences between each flow component for the current &amp; natural regime for comparative purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current equivalent</td>
</tr>
<tr>
<td>Summer low</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>150</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Volume 450</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>3</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>Summer fresh</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>900</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>7</td>
<td>45</td>
</tr>
<tr>
<td>Summer high</td>
<td>(Apr-May)</td>
<td>Volume</td>
<td>1800</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>2</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>Winter low</td>
<td>(Jun-Nov)</td>
<td>Volume</td>
<td>350</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Volume 1800</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>2</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>Winter fresh</td>
<td>(June-Nov)</td>
<td>Volume</td>
<td>1800</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Winter high</td>
<td>(Oct-Nov)</td>
<td>Volume</td>
<td>7500</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1.2</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>1-2</td>
<td>100</td>
</tr>
<tr>
<td>Bankfull</td>
<td>(June-Nov)</td>
<td>Volume</td>
<td>9000</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1.4</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>1-2</td>
<td>100</td>
</tr>
</tbody>
</table>

4.4 Reach 4: Watts River to Yering Gorge
Reach 4 encompasses the middle floodplain reach of the Yarra River between the Watts River confluence and the top of Yering Gorge downstream of Yarra Glen. The Watts River and several small tributaries enter this reach including the Pauls, Steels, Dixoins and Olinda Creeks. The channel meanders across the floodplain, which has been predominantly cleared of vegetation for agricultural production. The environmental flows assessment site is located in the mid section of the reach at Tarrawarra. The channel here is a long pool with steep outer banks and a sandy point bar. Many billabongs and floodplain depressions are located along both sides of the river through this reach, although most have been cleared for pasture production and levee banks exist along sections of the river. Flow compliance in this reach is measured at the Yarra Glen gauge.
4.4.1 Current condition

Hydrology
Naturally the Yarra River at Yarra Glen has a mean annual flow of 2,012 ML/day. Under current conditions the mean annual flow has been reduced by approximately 40% to 1,236 ML/day. A very similar pattern in hydrology is evident in this reach compared to Reach 3 upstream with flow reduction occurring across the entire flow range (Figure 4.48) but seasonality is still retained (Figure 4.49). Under unimpacted conditions a 1 in 5 year flood had a magnitude of approximately 15,000 ML/day. Under current conditions a flood of this magnitude has a frequency of 1 in 12 years. The moderate flood level for Yarra Glen is 4.5 m or 10,300 ML/d. A moderate flood would result in inundation of low lying areas of the floodplain and inundation of associated billabongs. Under unimpacted conditions a flood of 10,300 ML/d would have occurred once every year. Under current conditions an event of this magnitude occurs once every three to four years.

- Figure 4.48 Flow duration curve for Reach 4 at the Yarra Glen gauge.

- Figure 4.49 Average flow for each day of the year in Reach 4.
**Geomorphology / habitat**
The geomorphic and habitat characteristics of Reach 4 are the similar to Reach 3. The channel is characterised by a long sandy pool with steep banks that meanders across the floodplain. Historical desnagging has resulted in loss of habitat for fish and macroinvertebrates. However, recent revegetation works in the last 10 years is starting to result in some renewed LWD supply to the channel. As with upstream reaches, it is important to maintain flows that provide suitable depth in pools for access to habitat, occasional higher flows to reduce sediment accumulation on LWD and reset biofilm successional patterns, and high and bankfull flow to provide a disturbance regime and channel maintenance. Bankfull and overbank flows are also required to engage wetland and floodplain habitats.

**Macroinvertebrates**
The condition of the macroinvertebrate community declines through this reach and typically does not meet SEPP objectives at the lower end. Poor habitat (quality and quantity, degradation of the riparian zone and runoff associated with increasing urban and agricultural impacts towards the lower part of the reach are the main factors that are considered to influence the macroinvertebrate community. As for Reach 3, the condition of the macroinvertebrate community is at risk of further decline from runoff from increasing urban development and more intensive agricultural production. Stock access and further degradation of the riparian zone also pose risks. Low, stable flows that contribute to the accumulation of fine sediment on benthic surfaces also poses a risk to macroinvertebrate condition.

Improved habitat quality in the reach is necessary to improve macroinvertebrate health. This can be achieved through a combination of resnagging to increase the amount of available habitat and the provision of low flows and fresh flows to minimise sediment accumulation on LWD surface to maintain access to available habitat. Management of non-flow related water quality is also required to contribute to improved macroinvertebrate health in the reach.

**Fish**
A large range of native & exotic fish have been recorded from this reach and overall diversity is considered to be high. Three (river blackfish, common galaxias and spotted galaxias) of the 5 SEPP listed species have been recorded from this reach. Australian grayling have not been recorded in this reach but have been recorded upstream and downstream. Murray cod and Macquarie perch have also been recorded from this reach.

Loss of habitat through past desnagging is likely to have impacted on the fish community. Lack of appropriate flows to provide spawning and migration cues and inefficiencies in the Dights Falls fishway may continue to limit Australian grayling as described in Reach 3.

**Vegetation**
The condition of riparian and floodplain vegetation is further degraded through this reach compared to upstream and the ISC score for the streamside zone sub-index is very poor. Some fencing and revegetation has occurred, but plantings have been dominated by silver wattles that are
now starting to fall into the river and contribute to some bank slumping. As for Reach 3 there is evidence of reduced vertical zone of flood-tolerant plants on the river bank, encroachment of terrestrial weed species down the bank (eg. wild Watsonia and blackberries) and the colonisation along the water line by semi-aquatic species that favour stable water levels (eg. yellow flag iris). However, clearing of the riparian zone and floodplain, weed infestation due to poor land management practices and stock access to river banks are still likely to represent the greatest threat to native riparian vegetation.

**Water quality**

Through this reach water quality continues to decline and is overall considered moderate. Compliance with SEPP objectives for salinity, dissolved oxygen, pH and TP is high throughout the reach. However, compliance with TN and turbidity objectives is typically not met throughout the reach. As with upstream reaches elevated TN, TP and turbidity tends to be correlated with increased discharge indicating that catchment sources of nutrients and turbidity are the greatest contributor to poor water quality. Increased flows should not be used to dilute poor water quality, rather catchment activities that address water quality issues at their source should be used to address causes of poor water quality.

### 4.4.2 Flow recommendations

General objective is to maintain some variability in the summer low flow period, provide flows to assist Australian grayling spawning in autumn, increase the vertical range and duration of bank inundation to limit growth of terrestrial species and provide for appropriate bankfull and overbank flows for inundation of billabongs and floodplain.

The environmental flow recommendations for Reach 4 are summarised in Table 4.7.
### Table 4.7 Summary of flow recommendations for Reach 3.

<table>
<thead>
<tr>
<th>Season</th>
<th>Flow</th>
<th>Volume</th>
<th>Frequency</th>
<th>Duration</th>
<th>Rise/Fall</th>
<th>Objective (refer to objectives tables for id reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer / autumn</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low flow</td>
<td>200 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, drying on banks for vegetation</td>
</tr>
<tr>
<td>Fresh</td>
<td>450 ML/d</td>
<td>3 per season</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td></td>
<td>Maintain habitat F4-2, V4-2</td>
</tr>
<tr>
<td>High flow</td>
<td>1100 ML/d</td>
<td>1 in April/May</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td></td>
<td>Trigger spawning by Grayling &amp; transport eggs downstream F4-3</td>
</tr>
<tr>
<td><strong>Winter / spring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low flow</td>
<td>350 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, wet bank vegetation</td>
</tr>
<tr>
<td>Fresh</td>
<td>2000 ML/d</td>
<td>2 in June to September</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td></td>
<td>Maintain suitable habitat M4-2, F4-1, V4-2</td>
</tr>
<tr>
<td>High</td>
<td>2000 ML/d</td>
<td>1 in October -November</td>
<td>14 days</td>
<td>1.4/0.85</td>
<td></td>
<td>Sediment scouring to increase habitat availability, vegetation disturbance, fish passage, entrain organic material M4-3, F4-2, V4-3</td>
</tr>
<tr>
<td>Bankfull</td>
<td>9000 ML/d</td>
<td>1 every 2 years</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td></td>
<td>Maintain existing channel geometry &amp; prevent vegetation encroachment in channel, entrain organic material, engage high flow channels &amp; floodplain G4-1, M4-3, V4-3</td>
</tr>
<tr>
<td>Overbank</td>
<td>12000 ML/d</td>
<td>Once every 4 years</td>
<td>1-2 days</td>
<td>1.4/0.85</td>
<td></td>
<td>Engage billabongs &amp; low level floodplains G4-4, V4-6</td>
</tr>
</tbody>
</table>

The rationale for flow recommendations in Reach 4 are the same as those in Reach 3 however the volumes have been adjusted where necessary to account for larger channel capacity. To avoid repetition the following sections only briefly describe major points associated with flow recommendations in this reach.

**Summer/autumn low flows**

The summer/autumn low flow recommendation is 200 ML/d. This flow is sufficient to wet the full width of the lower channel, provide suitable pool depth for fish and inundate LWD located low in the channel (Figure 4.50).
Figure 4.50 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for summer/autumn low flows in Reach 4.

Under current conditions flow falls below the low flow threshold once per year for a median duration of 5 days (Figure 4.51). Under natural conditions the flow would have rarely fallen below the low flow recommendation.

Figure 4.51 Duration (top left, frequency (top right) and start month (bottom left) for flows below the summer/autumn low flow threshold under current and natural conditions for Reach 4.
Summer/autumn freshes
The summer/autumn fresh recommendation is 450 ML/d 3 times per season for a duration of 2 days. This flow wets the lower banks and inundates LWD and low level benches (eg. Transect 2) (Figure 4.52).

- Figure 4.52 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for summer/autumn fresh in Reach 4.

Under current conditions the summer/autumn fresh occurs on average 4-5 times per year with a median duration of 5 days (Figure 4.53). Under natural conditions events are less frequent but for longer duration. Under current conditions most events start in December or April/May and relatively few events start in mid summer. This suggests that under current conditions events that exceed the fresh threshold occur in association with late spring or autumn rainfall events and that some flow variability is required in the summer months to reduce the duration of prolonged low flow periods.
Summer/autumn high flows
The recommended summer/autumn high flow threshold is 1500 ML/d to occur once in April or May for a duration of 7 days. The rational for this recommendation is based on providing a suitable spawning trigger for Australian grayling and flow to transport larvae to the estuary as described for upstream reaches but the volume has been adjusted to account for increased channel capacity. This flow also wets further up the banks (Figure 4.54) to maintain flood-tolerant vegetation and provide a disturbance to terrestrial vegetation.

Under current conditions the summer high flow threshold is exceed once each year, naturally two events per year would have occurred (Figure 4.55). The current median duration is 3 days compared to the natural median duration of 4 days. However, because under natural conditions two events occurred each year, on average one of these events would have been of longer duration with 30% of events lasting between 4 and 10 days and 20% of events lasting between 10 and 19 days, hence typically meeting the required duration of one 7 day event each year. Under current conditions the recommend duration is met in less than 20% of events. In other words, an event of appropriate duration only occurs in April or May once every 4 to 5 years. This poses a significant risk to spawning opportunities for Australian grayling because they are a short lived species, only surviving for two to three years, so frequent spawning events are required to maintain opportunities for successful recruitment.
Figure 4.54 Stage height in pools (Transect 1, left and Transect 4, right) at the recommended threshold for summer/autumn low flows in Reach 4.

Figure 4.55 Duration (top left, frequency (top right) and start month (bottom left) for flows above the summer/autumn high flow threshold under current and natural conditions for Reach 4.

Winter/spring low flows
The recommended winter/spring low flow threshold is 350 ML/d. This flow wets the full width of the channel and lower banks (Figure 4.56). This flow is equivalent to the winter low flow threshold for upstream reaches. Even though the channel capacity is increasing, higher winter low flows do not significantly increase pool depth or provide access to additional habitat.
Under current conditions flows occasionally fall below the winter low flow threshold (Figure 4.57), most often in June indicating that the summer/autumn low flow period has been prolonged under current conditions. Under natural conditions flow would not have fallen below the winter low flow threshold.

- **Figure 4.56** Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for winter/spring low flows in Reach 4.

- **Figure 4.57** Duration (top left, frequency (top right) and start month (bottom left) for flows below the winter/spring low flow threshold under current and natural conditions for Reach 4.

**Winter/spring freshes and high flows**
The recommended winter/spring fresh is 2000 ML/d on 2 occasions between June and September for a duration 7 days. The winter/spring high flow recommendation is for the same volume but
timed to occur once in October/November for a duration of 14 days. HEC RAS outputs show this flow is sufficient to inundate benches and a significant portion of the lower and mid banks (Figure 4.58).

Under current conditions the winter/spring fresh threshold is exceeded on average 3 to 4 times per year for a median duration of 6 days (Figure 4.59). This is similar to the natural event, however, under natural conditions a high proportion of events lasted for significantly longer duration, up to 120 days compared to the maximum duration of 35 days under the current regime.

- Figure 4.58 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for winter/spring freshes and high flows in Reach 4.

- Figure 4.59 Duration (top left, frequency (top right) and start month (bottom left) for flows above the winter/spring fresh threshold under current and natural conditions for Reach 4.
Under current and natural conditions the winter high flow threshold is exceeded 1-2 times per year (Figure 4.60). However, the current median duration is only 6 days compared to 11 days under natural conditions. Under current conditions only about 20% of events meet the recommended 14 day duration.

- **Figure 4.60 Duration (top left, frequency (top right) and start month (bottom left) for flows above the winter/spring high flow threshold under current and natural conditions for Reach 4.**

**Bankfull flows**

The bankfull flow recommendation is 9000 ML/d once every 2 years for 1-2 days duration. This flow is sufficient to reach the top of the bank at most transects and inundates wetlands with a direct connection to the river at around the bankfull level (eg. Transect 2) (Figure 4.61). Under current conditions the bankfull flow is reach once in every 1 to 2 years, under natural conditions a bankfull flow would have been achieved each year (Figure 4.62). The median current and natural duration is 2 days but events occur slightly later in the season under current conditions compared to natural.
Overbank flows
The recommended overbank flow threshold is 12000 ML/d once every 4 years for a duration of 1-2 days. This flow is sufficient to overtop banks (eg Transect 2) (Figure 4.63) and inundate a greater number of wetlands and area of floodplain than the bankfull flow. Under current conditions, an overbank flow occurs on average once every 4 to 5 years, naturally an overbank flow would have occurred once every 2 years (Figure 4.64). The median duration is 1 to 2 days with most natural and current events commencing in September.
As with the bankfull and overbank flow recommendation the Reach 3, the bankfull and overbank flow recommendations for Reach 4 are aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages. While some ecological benefits of overbank flows will be gained under current landscape conditions (e.g. see Robson and Clay in press), the full environmental advantage of both bankfull and overbank flows through this reach will be achieved if parts of the floodplain and some billabongs can be fenced and revegetated with species appropriate for the EVC. There are several locations along this reach where clusters of billabongs and wetlands exist that could be targeted for rehabilitation. For example, there is a cluster of billabongs at the bottom end of the reach immediately before the river enters Yering Gorge. These wetlands are frequently inundated due to the ponding effects of Yering Gorge. Another wetland cluster is located on the south side of the river approximately 3 km upstream from Yarra Glen. Selective removal of levees, fencing and revegetation would greatly benefit the environmental value of these wetlands and take full advantage of the bankfull and overbank flows. These wetlands are located on private property so further investigations are needed to identify and prioritise wetlands and floodplain areas for rehabilitation. Such investigations also need to involve landholder input and commitment to improved environmental conditions and to manage potential risks to pasture production associated with inundation events.

- Figure 4.63 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for overbank flows in Reach 4.
Minimum Environmental Water Requirement and Complementary Works Recommendations

Long section
Figure 4.65 shows a long section of Reach 4 that shows the depth of water in pools under each flow threshold. The long pool characteristics of the reach are evident and each flow threshold provides increased pool depth and progressive bank wetting.

Figure 4.64 Duration (top left, frequency (top right) and start month (bottom left) for flows above the overbank flow threshold under current and natural conditions for Reach 4.

Figure 4.65 Long section showing water surface level for all flows in Reach 4.
4.4.3 Current compliance

Compliance with flow recommendations for Reach 4 is presented in Table 4.8. The summer and winter low flow recommendations are complied with for most of the time under the current regime.

Under the current regime the summer fresh volume is met at least once very year but the recommended number of events only occurs in 85% of years and of these events 80% comply with the recommended duration. Under natural conditions the summer low flow is higher than the recommended fresh hence the frequency of events is low (because the flow is nearly always above the volume threshold) but the duration is long.

Under current conditions the summer high flow volume recommendation is met in 70% of years but the duration is only met in 15% of events. Under natural conditions, the median number of events in each year was 2 compared to the current one event per year so under natural conditions there was a higher likelihood of at least one long duration summer high flow event. Of note is the effective reduction in duration of the summer high flow event between reaches 3 and 4. The volume of high flow events increases between the reaches but the duration decreases. This suggests that under the current regime the reduction in inflows from the Watts River as a consequence of harvesting autumn rainfalls in Maroondah Dam is has an effect on compliance of the summer high flow in Reach 4.

The winter fresh volume is met in 95% of years and the frequency is met in 90% of years. The recommended duration is only met in 45% of events.

The winter high flow recommendation is met in 80% of years but the duration is only met in 20% of events. The median duration of the winter high flow event under natural conditions was significantly longer than under current conditions.

The bankfull recommendation is frequently met under current conditions, however the overbank flow is only met 76% of the time. The current frequency of overbank event is one every five years compared to the recommended frequency of 1 every 4 years and the natural frequency of one every three years. As with the summer high flow, the impact of reduced flows in the Watts River due to Maroondah Dam is evident in reduced compliance of overbank flows in Reach 4 compared to Reach 3.

The delivery of low flows, freshes and high flows will require manipulation of storage releases and harvesting operations, particularly in regards to achieving recommended event duration. Bankfull and overbank flow recommendations should be met through protecting existing events when they occur rather than through specific flow releases.
Table 4.8 Reach 4 compliance with environmental flow recommendations.

<table>
<thead>
<tr>
<th>Component</th>
<th>Time</th>
<th>Flow Rec</th>
<th>Percentage of years (vol &amp; no.) or events (dur.) when flow recs are complied with for the current flow regime</th>
<th>Differences between each flow component for the current &amp; natural regime for comparative purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer low</td>
<td>(Dec-May)</td>
<td>Volume 200</td>
<td>94</td>
<td>Current equivalent: 269, Natural equivalent: 549</td>
</tr>
<tr>
<td>Summer fresh</td>
<td>(Dec-May)</td>
<td>Volume 450</td>
<td>100</td>
<td>Current equivalent: 408, Natural equivalent: 819</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 3</td>
<td>85</td>
<td>Current equivalent: 4, Natural equivalent: 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 2</td>
<td>80</td>
<td>Current equivalent: 5, Natural equivalent: 80</td>
</tr>
<tr>
<td>Summer high</td>
<td>(Apr-May)</td>
<td>Volume 1100</td>
<td>70</td>
<td>Current equivalent: 742, Natural equivalent: 1439</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1</td>
<td>70</td>
<td>Current equivalent: 1, Natural equivalent: 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 7</td>
<td>15</td>
<td>Current equivalent: 2.5, Natural equivalent: 4</td>
</tr>
<tr>
<td>Winter low</td>
<td>(Jun-Nov)</td>
<td>Volume 350</td>
<td>97</td>
<td>Current equivalent: 629, Natural equivalent: 1324</td>
</tr>
<tr>
<td>Winter fresh</td>
<td>(June-Nov)</td>
<td>Volume 2000</td>
<td>95</td>
<td>Current equivalent: 1231, Natural equivalent: 2377</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 2</td>
<td>90</td>
<td>Current equivalent: 3, Natural equivalent: 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 7</td>
<td>45</td>
<td>Current equivalent: 6, Natural equivalent: 6</td>
</tr>
<tr>
<td>Winter high</td>
<td>(Oct-Nov)</td>
<td>Volume 2000</td>
<td>80</td>
<td>Current equivalent: 2673, Natural equivalent: 4143</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1</td>
<td>80</td>
<td>Current equivalent: 1, Natural equivalent: 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 14</td>
<td>20</td>
<td>Current equivalent: 6, Natural equivalent: 11</td>
</tr>
<tr>
<td>Bankfull</td>
<td>(June-Nov)</td>
<td>Volume 9000</td>
<td>84</td>
<td>Current equivalent: 9000, Natural equivalent: 9000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1:2</td>
<td>80</td>
<td>Current equivalent: 1, Natural equivalent: 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 2</td>
<td>100</td>
<td>Current equivalent: 2, Natural equivalent: 2</td>
</tr>
<tr>
<td>Overbank</td>
<td>(preferred timing is spring to early summer, but can occur anytime)</td>
<td>Volume 12000</td>
<td>76</td>
<td>Current equivalent: 12000, Natural equivalent: 1200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1:4</td>
<td>76</td>
<td>Current equivalent: 1:5, Natural equivalent: 1:3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 1-2</td>
<td>100</td>
<td>Current equivalent: 2, Natural equivalent: 1</td>
</tr>
</tbody>
</table>

4.5 Reach 5: Yering Gorge to Mullum Mullum Creek
Reach 5 runs from the top of Yering Gorge to the confluence with Mullum Mullum Creek at the downstream end of the Warrandyte Gorge and upper end of the lower floodplain. The reach includes two gorges (Yering and Warrandyte) and a short floodplain (Henley floodplain). Mullum Mullum Creek represents the first major urban tributary input to the river, although a number of smaller tributary streams enter the river in this reach that input storm water and treated sewerage effluent to the river. The reach also includes the Melbourne Water pumping station at Yering Gorge where water is pumped to Sugarloaf Reservoir for water supply purposes. The pumps have a maximum capacity of 1000 ML/d and there is a current minimum environmental flow requirement of 245 ML/d downstream of the pumps.

Two environmental flow sites were assessed in this reach, one in the Yering Gorge downstream of the pump station (Site 5a) and one in the Warrandyte Gorge downstream of the Warrandyte township (Site 5b). At both sites the full environmental flows assessment was conducted, including channel survey and flow modelling. Flow recommendations are consistent between sites and for explanatory purposes HEC RAS outputs for Site 5a are presented below. Flow is measured at the...
Warrandyte gauge but compliance should be measures at the new Yering gauge downstream of the pumps location.

### 4.5.1 Current condition

**Hydrology**

Naturally the Yarra River at Warrandyte has a mean annual flow of 2,203 ML/day. Under current conditions this has been reduced by 40% to 1,298 ML/day. As with upstream reaches, the reduction in flows has occurred across the entire flow range (Figure 4.66). Of particular note, the current flow-duration curves at Warrandyte and Chandler Hwy (further downstream) are lower than those at Yarra Glen during periods of low flow. This behaviour is not observed under historic and natural conditions and is considered to be attributable to the operation of the Yering pumps.

Seasonality is retained due to tributary inflows (Figure 4.67). However there has been a significant reduction in the frequency of flood flow events. For example, under natural conditions a 1 in 5 year flood had a magnitude of approximately 18,000 ML/day. Under current conditions a flood of this magnitude has a frequency of 1 in 28 years.

**Figure 4.66 Flow duration curve for the Yarra River in Reach 5 measured at the Warrandyte gauge.**
Geomorphology / habitat
The river through Reach 5 flows through two confined gorges separated by a short floodplain that retains a number of billabongs. Habitat is provided by deep pools, bed rock bars and gravel riffles and runs. The bed and banks are stable and well vegetated. Some desnagging has occurred and there is some evidence of sediment accumulation on benthic surface and excessive algal growth during low flow periods but overall habitat value is high. The ISC physical form score is excellent. Limited public access to the river through the gorge sections, low urban development and protection in the Warrandyte State Park has helped to protect the condition of the riparian zone. The stable nature of the bed and banks due to bedrock control has contributed to retention of in-stream physical habitat features.

Reduced flow variability is likely to contribute to accumulation of some fine sediment on benthic surfaces during low flow periods and reduced frequency of higher flows has decreased the frequency and duration of connectivity with the Henley floodplain. Sediment accumulation in riffles may impact on the quality of spawning sites for some fish, including Macquarie Perch.

The bed rock control through this reach means channel form will remain stable. However, accumulation of fine sediment and degradation of billabongs is an ongoing threat if not managed. In addition, pumping rates at the Yering Pumps need to be managed to ensure rates of fall associated with pump operation do not exceed the recommended rates of fall. Rapid fluctuations in water level beyond that experienced naturally may pose a risk to biota that can become stranded if river levels drop rapidly when pumps are initially turned on.
**Macroinvertebrates**

There is an improvement in macroinvertebrate indices in this reach compared to upstream. The SEPP objective for the number of families is met, although SIGNAL score and key families just fail to comply with objectives, indicating some potential water quality impacts on sensitive taxa.

The improvement in macroinvertebrate condition in Reach 5 compared to upstream reaches can be attributed to improved habitat quality and condition of the riparian zone. However, declining water quality is likely to be the factor limiting overall SEPP compliance. And low, stable flows that contribute to the accumulation of fine sediment on benthic surfaces may also pose a risk to macroinvertebrate condition.

Water quality improvements through improved stormwater management and treatment of sewage treatment plant effluent are likely to contribute to further improvement in the macroinvertebrate community health. Minimum flows that maintain access to habitat and freshes that minimise the accumulation of fine sediment and excessive algal growth on benthic surfaces through the summer period will also help maintain habitat quality.

**Fish**

A large range of native and exotic fish has been recorded from this reach and overall diversity is considered to be high. Australian grayling, Murray Cod and Macquarie perch have been recorded from this reach. A range of age classes for Murray cod and Macquarie perch indicate successful recruitment is occurring. Four (river blackfish, Australian grayling, common galaxias and spotted galaxias) of the 5 SEPP listed species have been recorded in this reach. The fifth SEPP listed species, the diadromous Tupong, has not been recorded in Reach 5, although it has been recorded downstream in Reach 6.

The middle section of Reach 5 between Wonga Park and Warrandyte is considered significant as providing suitable spawning and adult habitat for Macquarie perch. This habitat includes rock bars and deep pools with cover provided by submerged boulders. Sections of river around Warrandyte contain gravel run that provided suitable spawning habitat.

The lower section of the reach between Warrandyte and Eltham is thought to be significant for spawning and adult habitat for Murray cod. Habitat in this section of the reach includes deeper slower flowing pools that contain LWD.

As with upstream reaches, diadromous species have been recorded from Reach 5, including Australian grayling. Loss of habitat through past desnagging is likely to have impacted on the fish community. However, lack of appropriate flows to provide spawning and migration cues and inefficiencies in the Dights Falls fishway may continue to limit Australian grayling as described in Reach 3.

Despite the flow changes in this reach, the presence of Australian grayling, Macquarie perch and Murray cod in this reach indicates that conditions remain suitable for successful recruitment of these threatened species. However, it is important to retain or enhance certain elements of the flow...
regime to ensure the continued good health of the native fish community in this reach. Freshes and high flows are required to provide opportunities for local movement, especially over shallow rock bars. An autumn high flow is required to provide spawning cues for Australian grayling and to assist with transporting larvae to the estuary. Sedimentation of spawning sites is considered a significant threat to Macquarie perch (Cadwallader 1978) and there is some evidence that Macquarie perch recruitment success is enhanced when high flows occur prior to the spawning season to flush spawning sites of sediment.

**Vegetation**

There is significant improvement in the condition of riparian vegetation in this reach compared to upstream; the ISC scores for the streamside zone sub-index are moderate. Much of the reach is protected in the Warrandyte State Park and the steepness of the slopes means little widescale vegetation clearance, except in the Henley floodplain, has occurred. However, weed infestation is an issue around and downstream of Warrandyte as a result of urban development.

As for upstream reaches, there is still evidence of a reduced vertical zone of flood-tolerant plants on the river bank, encroachment of terrestrial weed species down the bank (e.g., wild Watsonia, tradescantia and blackberries) and the colonisation along the water line by semi-aquatic species that favour stable water levels (e.g., yellow flag iris). Encroachment of terrestrial species down the banks may be indicative of reduced frequency and duration of inundation of the higher bank, hence favouring terrestrial species.

A variable flow regime and increased duration of higher flows in spring to provide a disturbance are required to limit the growth of semi-aquatic plants near the waterline and to reduce the potential for further terrestrialisation of the upper banks. Complementary works such as fencing to limit stock access to banks, active weed control and revegetation with species appropriate for the EVC (riparian forest) are required to gain an improvement in vegetation condition in the lower reaches.

There is a significant opportunity to rehabilitate billabongs and the Henley floodplain to take advantage of bankfull flows through this reach.

**Water quality**

Water quality through this reach improves slightly and is overall considered good. There is improved compliance of turbidity, although TN remains elevated and typically exceeds SEPP objectives, particularly in winter during high flow events when catchment inputs and stormwater runoff increases nutrient loads to the river. Toxicant concentrations are low and comply with ANZECC guidelines.

Recent improvements to the quality of discharge from sewage treatment plants is a factor that has likely contributed to improved water quality in the reach. Increased instream processing and assimilation may also be contributing to improved water quality. Further improvements could be expected with improved stormwater management in tributary catchments.
Under very low flow conditions in this reach some water quality problems have become evident, particularly reduced oxygen concentration in pools at flows less than 150 ML/d (Ewert and Pettigrove 2003). Minimum flows are required to limit the potential risks associated with water quality decline are very low flows.

4.5.2 Flow recommendations
The general objective for Reach 5 is to maintain access to habitat during low flows, minimise water quality risks associated with low flows, introduce some variability in the summer low flow period, provide flows to assist Australian grayling spawning in autumn, increase the duration of bank inundation to limit growth of terrestrial species, manage the rate of rise and fall associated with pumping and provide for appropriate bankfull flows for inundation of billabongs in Henley floodplain. The environmental flow recommendations for Reach 5 are summarised in Table 4.9.

- **Table 4.9 Summary of flow recommendations for Reach 5.**

<table>
<thead>
<tr>
<th>Season</th>
<th>Flow</th>
<th>Volume</th>
<th>Frequency</th>
<th>Duration</th>
<th>Rise/Fall</th>
<th>Objective (refer to objectives tables for id reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer/autumn</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low flow</td>
<td>200 ML/d</td>
<td>All season</td>
<td>3 events between December &amp; April</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td>Maintain access to habitat for bugs &amp; fish, drying on banks for vegetation M5-1, F5-1, V5-1</td>
</tr>
<tr>
<td>Fresh</td>
<td>750 ML/d</td>
<td>750 ML/d</td>
<td>1 per year April/May &amp; April</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td>Maintain habitat M5-2, V5-2</td>
</tr>
<tr>
<td>High flow</td>
<td>1500 ML/d</td>
<td>1500 ML/d</td>
<td>1 in October -November</td>
<td>14 days</td>
<td>1.4/0.85</td>
<td>Trigger spawning by Grayling &amp; transport eggs downstream F5-3</td>
</tr>
<tr>
<td><strong>Winter/spring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low flow</td>
<td>350 ML/d</td>
<td>All season</td>
<td>2 events between June and September</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td>Maintain access to habitat for bugs &amp; fish, wet bank vegetation M5-1, F5-1, V5-1</td>
</tr>
<tr>
<td>Fresh</td>
<td>2000 ML/d</td>
<td>2000 ML/d</td>
<td>1 in October -November</td>
<td>14 days</td>
<td>1.4/0.85</td>
<td>Maintain suitable habitat Scour gravel ripples to improve conditions for Macquarie perch spawning M5-2, F5-1, F5-2, V5-2</td>
</tr>
<tr>
<td>Winter</td>
<td>2000 ML/d</td>
<td>2000 ML/d</td>
<td>1 in October -November</td>
<td>14 days</td>
<td>1.4/0.85</td>
<td>Sediment scouring to increase habitat availability, vegetation disturbance, fish passage &amp; spawning habitat, entrain organic material M5-3, F5-2, V5-3</td>
</tr>
<tr>
<td>Bankfull</td>
<td>10000 ML/d</td>
<td>10000 ML/d</td>
<td>1 event every two years in winter/spring</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td>Maintain existing channel geometry &amp; prevent vegetation encroachment in channel, entrain organic material, engage high flow channels &amp; floodplain Engage billabongs &amp; low level floodplains. G5-1, M5-3, V5-3, G5-3, V5-5</td>
</tr>
</tbody>
</table>

**Summer/autumn low flows**
The recommended summer low flow threshold is 200 ML/d. This wets the full width of riffles (eg. Transect 2) and maintains suitable depth in pools (eg. Transect 1) (Figure 4.68). Flows higher than the threshold, for example the current minimum flow, resulted in little increase in the wetted width
of riffle. However, flows lower the 150 ML/d are through to contribute to potential water quality problems, particularly deoxygenation of pools. A flow of 200 ML/d provides a suitable buffer to protect water quality in pools.

- Figure 4.68 Stage height in a pool (Transect 1, left) and riffle (Transect 2, right) at the recommended threshold for summer/autumn low flows in Reach 5.

Under current conditions flow falls below the low flow threshold on average three times per year, typically in late autumn for a median duration of 5 days, although 10% of spells last for longer than 18 days (Figure 4.69). Under natural conditions the flow rarely fell below the threshold but when it did the duration of the low flow spell was typically longer than current conditions. This difference is due to actions aimed at maintaining the current minimum flow requirement in this reach of 245 ML/d at Warrandyte. Under low flow conditions, pumping at Yering Gorge is suspended and in some situations releases are made from the Maroondah aqueduct to maintain minimum flow requirements.
Summer/autumnfreshes

The recommended summer/autumn fresh flow is 750 ML/d 3 times per season for a duration of 2 days. This flow fully inundates riffles and rock bars to a minimum depth of around 10 cm and an average velocity of 40 cm/s to scour sediment and biofilms (eg. Transect 2) and wets the lower banks in pools to maintain flood-tolerant vegetation (eg. transect 1) (Figure 4.70).

Under current conditions the fresh threshold is achieved 2 times every year compared to five times per year under natural conditions (Figure 4.71). The median duration remains similar to natural at 4 days exceeding the recommended duration of 2 days. However, under natural conditions 20% of events last between 38 and 66 days. The maximum duration under current conditions is 32 days. Under current conditions there has also been a shift in the start month with most events now starting in December or May compared to March under natural conditions.
Figure 4.70 Stage height in a pool (Transect 1, left) and riffle (Transect 2, right) at the recommended threshold for summer/autumn fresh flow in Reach 5.

Figure 4.71 Duration (top left, frequency (top right) and start month (bottom left) for flows above the summer/autumn fresh flow threshold under current and natural conditions for Reach 5.

Summer/autumn high flows
The recommended summer/autumn high flow threshold is 1500 ML/d to occur once in April or May for a duration of 7 days. The rational for this recommendation is based on providing a suitable spawning trigger for Australian grayling and flow to transport larvae to the estuary as described for upstream reaches but the volume has been adjusted to account for increased channel capacity based on the median of the natural May/June flow. This flow also wets further up the banks (Figure 4.72) to maintain flood-tolerant vegetation and provide a disturbance to terrestrial vegetation.

SINCLAIR KNIGHT MERZ
Figure 4.72 Stage height in a pool (Transect 1, left) and riffle (Transect 2, right) at the recommended threshold for summer/autumn high flows in Reach 5.

Under current conditions the summer/autumn high flow threshold is only achieved about once every 2 years compared to almost 2 times per year under natural conditions (Figure 4.73). The duration remains the same at a median of 3 days, but like upstream reaches there is a greater proportion of longer duration events under natural conditions and with 2 events per year and higher likelihood of at least 1 long duration summer high flow occurring naturally.

There is some uncertainty regarding the required duration of the summer/autumn high flow event. The duration needs to be sufficient to transport Australian grayling larvae to the estuary and in the absence of more specific biological information on the requirements of Australian grayling in the Yarra River a duration of 7 days for the summer/autumn high flow event has been specified for the whole river. It may be possible to reduce the duration of the high flow event in downstream reaches because of the closer proximity to the estuary. Further investigations into the specific spawning requirements for Australian grayling are required to provide more certainty around the magnitude, timing and duration of summer/autumn high flows required to facilitate grayling spawning and larval transport.
Winter/spring low flows

The winter/spring low flow threshold is 350 ML/d. This flow is 150 ML/d higher than the recommended summer/autumn low flow and ~100 ML/d higher than the current minimum flow through this reach. The flow threshold is sufficient to inundate riffles to a deeper depth than the summer/autumn low flow, provides improved opportunities for local fish passage and access to increased habitat for macroinvertebrates, and inundates vegetation on the lower banks (Figure 4.74). Further flow increases do not significantly increase the area of riffle habitat or wetted perimeter of pool available for macroinvertebrates or fish.

Under current conditions the winter/spring flow falls below the threshold approximately once per year for a median duration of 9 days, although 10% of spells last longer than 48 days (Figure 4.75). Most low flow events start in June indicating that the summer/autumn low flow period often extends into the winter season. The winter/spring flow would not have fallen below the 350 ML/d low flow threshold under natural conditions.

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**Figure 4.73 Duration (top left, frequency (top right) and start month (bottom left) for flows below the summer/autumn high flow threshold under current and natural conditions for Reach 5.**

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Winter/spring low flows

The winter/spring low flow threshold is 350 ML/d. This flow is 150 ML/d higher than the recommended summer/autumn low flow and ~100 ML/d higher than the current minimum flow through this reach. The flow threshold is sufficient to inundate riffles to a deeper depth than the summer/autumn low flow, provides improved opportunities for local fish passage and access to increased habitat for macroinvertebrates, and inundates vegetation on the lower banks (Figure 4.74). Further flow increases do not significantly increase the area of riffle habitat or wetted perimeter of pool available for macroinvertebrates or fish.

Under current conditions the winter/spring flow falls below the threshold approximately once per year for a median duration of 9 days, although 10% of spells last longer than 48 days (Figure 4.75). Most low flow events start in June indicating that the summer/autumn low flow period often extends into the winter season. The winter/spring flow would not have fallen below the 350 ML/d low flow threshold under natural conditions.
Minimum Environmental Water Requirement and Complementary Works Recommendations

- Figure 4.74 Stage height in a pool (Transect 1, left) and riffle (Transect 2, right) at the recommended threshold for winter/spring low flows in Reach 5.

- Figure 4.75 Duration (top left, frequency (top right) and start month (bottom left) for flows below the winter/spring low flow threshold under current and natural conditions for Reach 5.

Winter/spring freshes and high flows
A winter/spring fresh and high flow of 2000 ML/d is recommended. Two freshes between June and September of a duration of 7 days and one high flow in October or November of 14 days duration are recommended. The volume threshold is sufficient to achieve a minimum flow velocity of 40 cm/s through riffles and runs to scour sediment and biofilms, provide more than 1 m depth over riffles for fish passage and inundates the lower and mid banks to provide a disturbance regime for vegetation (Figure 4.76). As in upstream reaches, the prolonged duration of the high flow event is aimed at drowning terrestrial vegetation encroaching down the banks. Scouring sediment from gravel runs is an important function in Reach 5 to provide suitable conditions for Macquarie perch.
spawning in spring and the recommended flow threshold is sufficient to create a suitable velocity through gravel runs to provide a flushing flow.

- Figure 4.76 Stage height in a pool (Transect 1, left) and riffle (Transect 2, right) at the recommended threshold for winter/spring freshes and high flows in Reach 5.

Under current conditions the recommended fresh threshold is exceeded 3 to 4 times per year for a median duration of 7 days (Figure 4.77). Under natural conditions fewer events above the threshold occurred each year, but the duration was longer with 30% of events lasting between 7 and 110 days and 20% of events lasting 110 to 140 days.

The high flow event occurs 1.5 times each year in October or November under both natural and current conditions (Figure 4.78). However, the median duration under current conditions is only 6 days compared to 17 days under natural conditions. Most events commence in October under both current and natural conditions.
Figure 4.77 Duration (top left, frequency (top right) and start month (bottom left) for flows below the winter/spring fresh flow threshold under current and natural conditions for Reach 5.

Figure 4.78 Duration (top left, frequency (top right) and start month (bottom left) for flows below the winter/spring high flow threshold under current and natural conditions for Reach 5.
Bankfull flows

The bankfull flow recommendation is 10,000 ML/d once every two years for 1-2 days duration. Due to the confined nature of the reach the bankfull flow provides a significant disturbance regime for vegetation on the banks and growing in riffles (Figure 4.79). Most of Reach 5 is bedrock controlled, however the bankfull flow will help maintain pool habitat by scouring sediment in deepest pools and scouring vegetation growing in riffls. The bankfull flow will also inundate billabongs in the Henley floodplain.

Under current conditions the bankfull flow threshold is exceeded on average once every 2 to 3 years, whereas under natural conditions the bankfull flow would have been exceeded nearly 3 times every 2 years (Figure 4.80). Under both natural and current conditions the median duration of the bankfull event is around 2 days and the majority of events commence in August, September or October.
As with the upstream reaches, the bankfull recommendation is aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages.

**Long section**

Figure 4.81 shows the water surface level for each flow threshold along a long section of Reach 5. Low flows and freshes provide some increased depth over riffle however the riffle at Transect 3 is not drowned until high flows and bankfull flows are reached.
4.5.3 Current compliance

Compliance with flow recommendations for Reach 5 is shown in Table 4.10. The summer low flow recommendation is complied with 85% of the time and the winter low flow recommendation is complied with 93% of the time under the current regime.

Under current conditions at least one summer fresh occurs in 88% of years but the recommended number of freshes (3) only occurs in 45% of years. The recommended duration is met in 80% of events when they do occur. Under natural conditions the median number of events would have been seven compared with the current median of two events per year. The median duration of summer freshes has not changed between natural and current. Under current conditions the summer high flow recommendation is only met in 25% of years. And the recommended duration is only met in 15% of events.

The winter fresh is met in 98% of years and the recommended frequency of two events per year is met in 95% of years but the recommended duration is only met in 50% of events. Under natural conditions there are fewer events but of slightly longer median duration.

The winter high flow is met in 75% of years under current conditions. However, the recommended duration is only met in 25% of events.

The bankfull flow recommendation of one event every two years is met 70% of the time (ie the current frequency is one event every three years) years under current conditions. Under natural conditions the bankfull flow would occur two in every three years. The recommendation duration of two days is met in 100% of events when they occur.

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In summary, the volume of low flow events and freshes is frequently complied with and the frequency of summer freshes, winter high flows and bankfull flows is often met. However, the summer high flow is only rarely met and the duration of winter fresh and high flow events is only occasionally met. The poor compliance with the summer high flow event will limit the ability to achieve environmental objectives related to Australian grayling spawning.

The delivery of low flows, freshes and high flows will require manipulation of pumping schedules and harvesting operations and may require releases to be made from the Maroondah aqueduct to maintain low flows and the duration of high flow events. Achievement of fresh and high flow recommendations in upstream reaches will typically allow recommendations to be met in downstream reaches provided events are allowed to progress down the entire system. Bankfull and overbank flow recommendations should be met through protecting existing events when they occur rather than through specific flow releases.

### Table 4.10 Reach 5 compliance with environmental flow recommendations.

<table>
<thead>
<tr>
<th>Component</th>
<th>Time</th>
<th>Flow Rec</th>
<th>Percentage of years (vol &amp;no.) or events (dur.) when flow recs are complied with for the current regime</th>
<th>Differences between each flow component for the current &amp; natural regime for comparative purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer low</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>200</td>
<td>Current equivalent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>Summer fresh</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>750</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>Summer high</td>
<td>(Apr-May)</td>
<td>Volume</td>
<td>1500</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>Winter low</td>
<td>(Jun-Nov)</td>
<td>Volume</td>
<td>350</td>
<td>93</td>
</tr>
<tr>
<td>Winter fresh</td>
<td>(June-Nov)</td>
<td>Volume</td>
<td>2000</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
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<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td>Winter high</td>
<td>(Oct-Nov)</td>
<td>Volume</td>
<td>2000</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>14</td>
<td>25</td>
</tr>
<tr>
<td>Bankfull</td>
<td>(June-Nov)</td>
<td>Volume</td>
<td>10000</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1.2</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>Overbank</td>
<td></td>
<td></td>
<td></td>
<td>No recommendation – provided for by bankfull recommendation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Differences between each flow component for the current &amp; natural regime for comparative purposes</th>
<th>Current equivalent</th>
<th>Natural equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>241</td>
<td>594</td>
</tr>
<tr>
<td></td>
<td>288</td>
<td>890</td>
</tr>
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<td></td>
<td>2</td>
<td>7</td>
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<td></td>
<td>667</td>
<td>1625</td>
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<td>10000</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

### 4.6 Reach 6: Mullum Mullum Creek to Dights Falls

Reach 6 extends from the confluence with Mullum Mullum Creek to Dights Falls. Dights Falls marks the downstream freshwater extent. The river through this reach flows across the lower floodplain before flowing through a short gorge section downstream of Chandler Highway to Dights Falls. The catchment is heavily urbanised through this reach and several urban tributaries...
enter, including Mullum Mullum Creek, Plenty River, Darebin Creek and Merri Creek. The
floodplain adjacent to the river is mostly parkland and sporting facilities such as ovals and golf
courses. There are several significant billabongs that retain important environmental values in an
urban landscape. The environmental flows assessment site (Site 6a) was located halfway along the
reach at Banyule Flats and included the regionally significant Banyule wetland. A second site was
visually inspected at Dights Falls (Site 6b), although hydraulic surveys were not undertaken. Flow
is measured at the Chandler Highway gauge at the downstream end of the floodplain section, which
is the recommended compliance point this reach.

4.6.1 Current condition

Hydrology

Naturally the Yarra River at the Chandler Highway had a mean annual flow of 2,571 ML/day. This
has been reduced by 38% under current conditions to 1,571 ML/day. Unregulated tributary inflows
downstream of the Yering pumps contribute to the slightly higher current mean annual flow as a
proportion of the natural mean annual flow. However, the current summer base flow is still lower
than that in reaches upstream of the Yering pumps. The reduction in flow has occurred across the
entire flow regime but is most noticeable at lower flows (Figure 4.82). As with upstream reaches,
unregulated tributary inflows mean the natural seasonality is retained (Figure 4.83).

The frequency of flood events has also decreased. Under natural conditions a 1 in 5 year flood had
a magnitude of approximately 28,000 ML/day. Under current conditions a flood of this magnitude
has a frequency of 1 in 50 years.

Billabongs through this reach are expected to commence to fill at bankfull flows around 13,000
ML/d. Under natural conditions a 13,000 ML/d flow occurred once every year. Under current
conditions this has reduced to once every three to four years. All billabongs along this reach would
be expected to be filled under moderate flood conditions (~26,000 ML/d). The return interval of
this flow has reduced from 1:3 to 1:30 years. The peak flow in the recent February 2005 event was
5.7 m or ~24,000 ML/d, equivalent to a 1:2-3 year event under natural conditions or a 1:25 year
event under current conditions. All billabongs through the reach were inundated by the recent
February flow event.
Figure 4.82 Flow duration curve for Reach 6 at the Chandler Highway gauge.

Figure 4.83 Average flow for each day of the year in Reach 6.

**Geomorphology / habitat**

The river through this reach flows through a floodplain within urban Melbourne. The channel comprises pools with occasional gravel riffles and runs. Although Dights Falls has artificially raised water levels upstream of the falls through the Study Park Gorge section, instream habitat is provided by LWD, although historical desnagging has reduced the overall habitat availability. Bed and banks are relatively stable and well vegetated, although somewhat weedy.

The floodplain has been predominantly cleared but several billabongs of local and regional significance are present and retain high environmental values (Mitchell et al. 1995, Beardsell and Beardsell 1999). Reduced frequency of higher flows has decreased the frequency of connectivity with the floodplain and may result in a shift in vegetation community composition if prolonged dry periods occur.
There is some evidence of sediment accumulation on LWD surfaces during low flow periods and reduced flow variability is likely to contribute to this accumulation. Tributary streams such as Diamond and Mullum Mullum Creek maybe sources of excess sediment.

The overall channel condition is relatively stable. Significant improvement in habitat quantity and quality can only be expected if the condition of the riparian zone improves and if instream habitat restoration, such as resnagging, occurs. Freshes are also required to minimise accumulation of fine sediment on LWD surface and gravel riffles during summer, and appropriate bankfull and overbank flows are required to maintain connectivity with the floodplain and billabongs.

**Macroinvertebrates**

Macroinvertebrate scores through this reach are typically below reference and indicative of mild pollution. The total number of families meets the SEPP objective in the upper part of the reach but all Index scores progressively decline through the reach and are at their lowest at Dights Falls where scores are well below reference.

Poor quality habitat, degradation of the riparian zone and poor water quality associated with urban runoff are the main factors that are considered to influence the macroinvertebrate community. However, low stable flows that contribute to the accumulation of fine sediment on benthic surfaces also pose a risk to macroinvertebrate condition.

Water quality improvements through improved stormwater management are needed to significantly improve macroinvertebrate community health. As above, freshes are required to minimise the accumulation of fine sediment on benthic surfaces through the summer period to maintain habitat quality.

**Fish**

A large range of native and exotic fish has been recorded from this reach and overall diversity is considered to be high. All 5 SEPP listed species have been recorded in this reach including Australian grayling. Murray Cod and Macquarie perch have also been recorded in this reach and the upper section of the reach around Templestowe and Eltham is considered significant for spawning and adult habitat for Murray cod.

This is the furthest downstream freshwater reach and all diadromous species have been recorded in this reach, including Tupong. Conditions in this reach are critical because all diadromous species must pass through this reach on their way to upstream reaches. A fishway was constructed on Dights Falls in 1993 and a range of species have been recorded moving through the fishway (Zampatti et al. 2002). However, the overall efficiency of the fishway has been questioned and surveys during spring high flow periods have recorded significant numbers of fish accumulating below the fishway that appear unable to ascend the fishway because of high velocities (Zampatti et al. 2002). This poses a risk because many diadromous species, including Australian grayling and several galaxias species, ascend to freshwater reaches in spring in their juvenile stage. If suitable
passage is not available at this time because of inefficiencies in fish passage through the fishway 
then populations will not reach their potential abundance.

There are some suggestions that sediment loads in this reach have declined over the past 20 years 
and this, along with limited passage through the fishway on Dights Falls has likely lead to 
 improved conditions for fish. However, it is important that critical components of the flow regime 
are retained to provide access to habitat, local fish passage opportunities and spawning and 
migration cues.

**Vegetation**
The condition of riparian vegetation in this reach is considered moderate. The riparian zone is 
relatively continuous due to significant revegetation works along the reach. However, it is heavily 
infested with weeds. As with upstream reaches there is still evidence of a reduced vertical zone of 
flood-tolerant plants on the river bank and encroachment of terrestrial weed species down the bank 
(eg wild Watsonia & blackberries). Encroachment of terrestrial species down the banks may be 
indicative of reduced duration of inundation of the higher bank.

Stable low flows will continue to favour terrestrial weed species and contribute to further 
contraction of the zone of flood-tolerant plants on the banks and increased terrestrialisation of the 
upper banks. A more variable flow regime and increased duration would help to reduce the 
potential for further terrestrialisation of the upper banks, although active weed control is also 
required as part of ongoing revegetation and habitat management works.

Wetland vegetation communities have also been impacted by altered flow regimes. In particular, 
there is evidence of a shift in the vegetation community of Banyule wetland over the past ten years. 
In the mid 1990s the wetland was predominately open water (Mitchell et al. 1995). However, the 
wetland has been dry for the past ten years and river red gums have colonised the bed of the 
wetland. The recent November 2004 and February 2005 flood event inundated the Banyule 
wetland and this event may be successful at limiting the establishment of red gums in the wetland 
and at restoring an open water system. However, the change in the vegetation community over just 
ten years of dry conditions demonstrated that alterations in community composition can occur over 
relatively short periods of time and that prolonged dry periods can significantly alter wetland 
vegetation structure.

**Water quality**
Nutrient concentrations increase through this reach and TN and TP typically fail to comply with 
SEPP objectives. However, compliance with salinity, DO, pH and turbidity objectives remain 
relatively high. Toxicant concentrations also increase through this reach and typically fail to 
comply with ANZECC guidelines for 95% level of ecosystem protection for zinc, lead and copper. 
The overall water quality is considered moderate to poor.

The predominant water quality issues in the reach are related to urban development and stormwater 
runoff and will not be improved through the provision of environmental flows. Although
prolonged low flows may pose a risk to water quality through the development of anoxic conditions in pools. Also, low flows in conjunction with elevated nutrients and warm weather conditions may contribute to the development of algal blooms. Water quality improvements will only be achieved through implementation of stormwater management actions and efforts to identify and reduce areas of effective imperviousness.

4.6.2 Flow recommendations

The general flow objective for Reach 6 is to maintain access to habitat during low flows, ensure variability in the summer low flow period, provide flows to assist Australian grayling spawning in autumn, increase the duration of bank inundation to limit growth of terrestrial species, ensure appropriate bankfull and overbank flows for inundation of billabongs connected around bankfull and provide suitable flows to the Yarra estuary to sustain estuary processes and the requirements of estuarine biota where they are dependant upon freshwater inputs.

The environmental flow recommendations for Reach 6 are summarised in Table 4.11.

- **Table 4.11 Summary of flow recommendations for Reach 6.**

<table>
<thead>
<tr>
<th>Season</th>
<th>Flow</th>
<th>Volume</th>
<th>Frequency</th>
<th>Duration</th>
<th>Rise/Fall</th>
<th>Objective (refer to objectives tables for id reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer / autumn</td>
<td>Low flow</td>
<td>200 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, drying on banks for vegetation M6-1, F6-1, V6-1</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>750 ML/d</td>
<td>3 events between December &amp; April</td>
<td>2 days</td>
<td>1.4/0.85</td>
<td>Maintain habitat, trigger Grayling spawning M6-2, V6-2</td>
</tr>
<tr>
<td></td>
<td>High flow</td>
<td>1500 ML/d</td>
<td>1 per year in April / May</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td>Trigger spawning by Grayling &amp; transport eggs downstream F6-3</td>
</tr>
<tr>
<td>Winter / spring</td>
<td>Low flow</td>
<td>350 ML/d</td>
<td>All season</td>
<td></td>
<td></td>
<td>Maintain access to habitat for bugs &amp; fish, wet bank vegetation M6-1, F6-1, V6-1</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>2200 ML/d</td>
<td>2 between June and September</td>
<td>7 days</td>
<td>1.4/0.85</td>
<td>Maintain suitable habitat Scour gravel riffles to improve conditions for Macquarie perch spawning M6-2, F6-1, F6-2, V6-2</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>2200 ML/d</td>
<td>1 in October -November</td>
<td>14 days</td>
<td>1.4/0.85</td>
<td>Sediment scouring to increase habitat availability, vegetation disturbance, fish passage &amp; spawning habitat, entrain organic material M6-3, F6-2, V6-3</td>
</tr>
<tr>
<td></td>
<td>Bankfull</td>
<td>13,000 ML/d</td>
<td>once every 2 years</td>
<td>1-2 days</td>
<td>1.4/0.85</td>
<td>Maintain existing channel geometry &amp; prevent vegetation encroachment in channel, entrain organic material, engage high flow channels &amp; floodplain G6-1, M6-3, V6-3</td>
</tr>
<tr>
<td></td>
<td>Overbank</td>
<td>21,500 ML/d</td>
<td>Once every 4 years</td>
<td>1-2 days</td>
<td>1.4/0.85</td>
<td>Engage billabongs &amp; low level floodplains G6-3, V6-5</td>
</tr>
</tbody>
</table>
Summer/autumn low flow

The recommend summer/autumn low flow threshold is 200 ML/d. This flow is sufficient to inundate the full width of a gravel run at Transect 6 (Figure 4.84), to inundate LWD located low in the channel and maintain depth in pools of greater than 1.5 m for fish habitat for large bodied fish such as Murray cod. Higher flows do not significantly increase the amount of available low flow habitat, while lower flows may pose a risk to water quality. However, suitable LWD is required in the channel to provide habitat for fish during low flows periods and reach scale reinstatement of LWD would assist in improving the overall low flow condition of the reach.

Figure 4.84 Stage height in a pools (Transect 5, left) and gravel run (Transect 6, right) at the recommended threshold for summer/autumn low flows in Reach 6.

Under current conditions, flows fall below the low flow threshold approximately twice per year for a median duration of 3 days and occasionally up to 15 days (Figure 4.85). Under natural conditions flows would have only fallen below the low flow threshold on less than 10 occasions in 100 years.
Summer/autumn freshes

The recommended summer fresh is 750 ML/d to occur 3 times for a duration of 2 days. This flow is sufficient to achieve average velocities of 40 cm/s through gravel riffles and around LWD located low in the channel to scour sediment and excessive algal growth. However, in urban reaches the potential reduction in algal growth is likely to be relatively short lived due to elevated nutrient concentrations that contribute to rapid regrowth (Taylor et al. 2004). Summer freshes will also wet the lower banks to maintain flood-tolerant vegetation.

Figure 4.85 Duration (top left, frequency (top right) and start month (bottom left) for flows below the summer/autumn low flow threshold under current and natural conditions for Reach 6.

Figure 4.86 Stage height in a pool (Transect 5, left) and a gravel run (Transect 6, right) at the recommended threshold for summer/autumn freshes flows in Reach 6.
Under current conditions the summer fresh threshold is exceeded on average 4 times per year for a median duration of 3 days and a maximum duration of 30 days (Figure 4.87). Naturally, the flow threshold would have also been exceeded 4 times per year but for a median duration of 12 days and a maximum duration of approximately 80 days. There has also been a slight shift in the distribution of freshes with the majority of freshes now commencing in late autumn compared to early autumn under natural conditions.

![Frequency Plot](#)

**Figure 4.87** Duration (top left, frequency (top right) and start month (bottom left) for flows above the summer/autumn fresh flow threshold under current and natural conditions for Reach 6.

### Summer/autumn high flows

The summer/autumn high flow recommendation is 1500 ML/d to occur once per year in April or May for a duration of 7 days. This event is of the same magnitude and duration as upstream reaches and is aimed at triggering spawning in Australian grayling and to assist in transporting larvae to the estuary. This flow also wets further up the banks (Figure 4.88) to maintain flood-tolerant vegetation and provide a disturbance to terrestrial vegetation. Achieving the high flow objective in upstream reaches should contribute to its achievement in Reach 6 by allowing the flow event to pass unhindered by pumping along the entire system.

Under current conditions the high flow threshold occurs on average once per year, whereas under natural conditions 2 events per year would have occurred (Figure 4.89). The median duration under current conditions is 3 days compared to 5 days under natural conditions, but like upstream reaches there is a greater proportion of longer duration events under natural conditions and with two events per year and higher likelihood of at least one long duration summer high flow occurring naturally.
As described for Reach 5, further investigations into the specific spawning requirements for Australian grayling are required to provide more certainty around the magnitude, timing and duration of summer/autumn high flows required to facilitate grayling spawning and larval transport.

- Figure 4.88 Stage height in a pool (Transect 5, left) and gravel run (Transect 6, right) at the recommended threshold for summer/autumn high flows in Reach 6.

- Figure 4.89 Duration (top left, frequency (top right) and start month (bottom left) for flows below the summer/autumn high flow threshold under current and natural conditions for Reach 6.
**Winter/spring low flows**

The recommended winter/spring low flow threshold is 350 ML/d. This flow is sufficient to inundate vegetation on the lower banks and also inundates a small backwater area at Transect 6 (Figure 4.90). Backwaters are important habitats for fish and macroinvertebrates in lowland rivers so flows that increase the area of these habitat types are important.

Under current conditions winter flows fall below the recommended threshold up to once a year for a median duration of 6 days and maximum duration of 20 days (Figure 4.91). Under natural conditions the winter flow would not have fallen below the threshold. In reality, the winter low flows through Reach 6 will be higher than the 350 ML/d threshold because unregulated tributary inflows downstream of the Yering pumps will increase base flows above the minimum flow in Reach 5.
Winter/spring freshes and high flows
A winter/spring fresh and high flow of 2200 ML/d is recommended. Two freshes between June and September for a duration of 7 days and one high flow in October or November of 14 days duration are recommended. The volume threshold is sufficient to achieve a minimum flow velocity of 40 cm/s through riffles and runs to scour sediment and biofilms, provide more than 1 m depth over runs (eg Transect 6) for fish passage and inundates the lower and mid banks to provide a disturbance regime for vegetation (eg. Transect 5) (Figure 4.92).

Freshes and high flows in this reach also provide important flows to the Yarra estuary where they provide migration cues for diadromous fish to ascend to freshwater reaches and assist in reducing salinity by mixing the salt wedge. However, the efficiency of Dights Falls fishway is questionable. A recent survey found large accumulations of fish below the falls during spring that appeared unable to ascend the fishway due to high velocities and vertical barriers within the fishway under high flows (~1000-2000 ML/d) (Zampatti et al. 2002). Zampatti et al. (2002) have made a number of recommendations aimed at improving fish passage over Dights Falls during high flows, including, improved attractant flows, improved hydraulic conditions within the fishway and modifications to the fishway entrance to improve access. A current project is underway to further consider design options for the fishway to improve fish passage. Modifications to the fishway are needed to take full advantage of freshes and high flows for fish migration.
Figure 4.92 Stage height in a pool (Transect 5, left) and gravel run (Transect 6, right) at the recommended threshold for winter/spring freshes and high flows in Reach 6.

Under the current conditions the winter/spring fresh threshold is exceeded three to four times per year for a median duration of 7 days (Figure 4.93). Under natural conditions there are fewer freshes but the threshold is exceeded for a much longer duration.

Figure 4.93 Duration (top left, frequency (top right) and start month (bottom left) for flows above the winter/spring fresh threshold under current and natural conditions for Reach 6.

The high flow threshold is exceeded one to two times per year under current and natural conditions (Figure 4.94). The median duration under current conditions is only 5 days compared to 12 days under natural conditions. Under natural conditions the recommended duration of 14 days would be met in about 45% of events, or once every one to two years, but under current conditions the recommended duration is only met in 20% of events, or once every three to four years. The current...
low compliance poses a continuing risk to vegetation community composition on the banks because the high flow duration is typically too short to create a suitable disturbance that drowns encroaching terrestrial vegetation.

Bankfull flows
The bankfull flow recommendation is 13000 ML/d once every two years for 1-2 days duration. This flow is sufficient to reach the top of the bank at most transects and inundates wetlands with a direct connection to the river at around the bankfull level (Figure 4.95). Under current conditions the bankfull flow is reached once every two years, under natural conditions one to two bankfull flow would have occurred each year (Figure 4.96). The median current and natural duration is 2 days with most events commencing in September or October under both current and natural conditions.

As with the upstream reaches, the bankfull recommendation is aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages.
Figure 4.95 Stage height in a pool (Transect 5, left) and a gravel run (Transect 6, right) at the recommended threshold for bankfull flows in Reach 6.

Figure 4.96 Duration (top left, frequency (top right) and start month (bottom left) for flows above the bankfull flow threshold under current and natural conditions for Reach 6.

Overbank flows
The recommended overbank flow threshold is 21500 ML/d once every fours years for a duration of 1-2 days. This flow is sufficient to overtop banks (eg. Transect 5) and spill into the Banyule wetland downstream of Transect 6 (Figure 4.97). Under current conditions an overbank flow occurs on average once every 10 years, naturally an overbank flow would have occurred once every two to three years (Figure 4.98). The median duration is one day and while most events occur in winter or spring, they can occasionally occur at other times of the year.
Of all the bankfull and overbank flow recommendations in all upstream reaches, the overbank flow threshold in Reach 6 is least often achieved. In particular, there is evidence of the effect of reduced frequency of overbank flows on vegetation community composition in Banyule wetland as described in Section 4.6.1. Compliance with the recommended frequency of overbank flows in Reach 6 will be difficult because it is not possible to release the quantities of water from upstream storages required to achieve overbank flows in Reach 6 without causing serious flooding. So it is critical that overbank flows are allowed to progress down the river when they do occur.

The recommended frequency has been based on protecting the existing values associated with billabongs such as the Banyule wetland. An inability to achieve the objective may result in a shift over time in the composition and structure of some wetlands that experience a reduced frequency of inundation. However, there are other mechanisms that could be used to deliver water to important wetlands, such as pumping or the artificial lowering of sill levels so that flows enter wetlands at a lower level, but at a more appropriate frequency. Further recommendations for such opportunities are presented in Section 6 on complementary works.

- Figure 4.97 Stage height in a pool (Transect 5, left) and a gravel run (Transect 6, right) at the recommended threshold for overbank flows in Reach 6.
Minimum Environmental Water Requirement and Complementary Works Recommendations

Figure 4.98 Duration (top left, frequency (top right) and start month (bottom left) for flows above the overbank flow threshold under current and natural conditions for Reach 6.

Figure 4.99 Long section showing water surface level for all flows in Reach 6.

**Long section**

Figure 4.99 shows the water surface level for each flow threshold along a long section of Reach 6. The predominantly pool nature is evident in this reach, although there is a gravel run at the lower end and water surface levels indicate sufficient depth is achieved over this run for fish passage.
4.6.3 Current compliance

Compliance with environmental flow recommendations for Reach 6 is presented in Table 4.12. Under current conditions the summer low flow recommendation is met 92% of the time and the winter low flow recommendation is met 98% of the time.

The volume and frequency of summer and winter freshes are typically complied with. However, the duration of the summer fresh is only complied with for 65% of events and the duration of the winter fresh is complied with for only 50% of events.

The summer high flow volume is met on 78% of occasion but the frequency is only met every second year and the duration is only met in 35% of events. The median duration of the summer high flow under natural conditions is five days compared with the recommended seven days. However, because two events typically occur in most years, at least one event of seven days duration would have occurred. The winter high flow recommendation is complied with in 80% of years. However, the duration is only met in 40% of events.

The bankfull recommendation is complied with in 80% of years. However, the overbank recommendation is only complied with 25% of the time. The recommended frequency is one event every four years but the current frequency is one event every 10 to 20 years. Under natural conditions an overbank flow would have occurred once every two to three years. When an event does occur the recommended duration is met.

In summary, the recommended volume and frequency of most flow components is frequently complied with. However, the duration of fresh and high flow events is only occasionally complied with and the frequency of overbank flows is rarely complied with. Low compliance with the duration of summer and winter high flows will limit the ability to achieve environmental objectives related to Australian grayling spawning success (for summer high flows) and vegetation zonation on banks (for winter high flows). The low compliance with the frequency of overbank flow recommendations mean that it is important to protect these high flow events when they do occur and allow them to progress down the entire river system and into the estuary reach.

The delivery of low flows, freshes and high flows will require manipulation of pumping schedules and harvesting operations and may require releases to be made from the Maroondah aqueduct to maintain low flows and the duration of high flow events. Achievement of fresh and high flow recommendations in upstream reaches will typically allow recommendations to be met in downstream reaches provided events are allowed to progress down the entire system. Bankfull and overbank flow recommendations should be met through protecting existing events when they occur rather than through specific flow releases.

In urban reaches, the ability to meet low flow recommendations may be improved through the implementation of catchment-wide low-impact stormwater drainage systems. Recent research by Walsh et al. (2005) suggests that low-impact urban drainage systems that result in an increase in infiltration rather than rapid runoff may lead to higher and sustained low flows through improved groundwater inflows to urban streams. In addition, low-impact drainage design reduces the
‘flashyness’ of flows associated with rainfall runoff in urban catchments and can help contribute to significant water quality improvements (Walsh et al. 2005)

- Table 4.12 Reach 6 compliance with environmental flow recommendations.

<table>
<thead>
<tr>
<th>Component</th>
<th>Time</th>
<th>Flow Rec</th>
<th>Percentage of years (vol &amp;no.) or events (dur.) when flow recs are complied with for the current flow regime</th>
<th>Differences between each flow component for the current &amp; natural regime for comparative purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current equivalent</td>
</tr>
<tr>
<td>Summer low</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>200</td>
<td>92</td>
</tr>
<tr>
<td>Summer fresh</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>750</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>3</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>2</td>
<td>95</td>
</tr>
<tr>
<td>Summer high</td>
<td>(Apr-May)</td>
<td>Volume</td>
<td>1500</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>Winter low</td>
<td>(Jun-Nov)</td>
<td>Volume</td>
<td>350</td>
<td>98</td>
</tr>
<tr>
<td>Winter fresh</td>
<td>(June-Nov)</td>
<td>Volume</td>
<td>2200</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td>Winter high</td>
<td>(Oct-Nov)</td>
<td>Volume</td>
<td>2200</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>14</td>
<td>50</td>
</tr>
<tr>
<td>Bankfull</td>
<td>(June-Nov)</td>
<td>Volume</td>
<td>13000</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1</td>
<td>80</td>
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<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>Overbank</td>
<td>(preferred timing is spring to early summer, but can occur anytime)</td>
<td>Volume</td>
<td>21500</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>1-2</td>
<td>100</td>
</tr>
</tbody>
</table>
4.7 Reach 7: Yarra Estuary

The Yarra Estuary extends a distance of 22 km from approximately 500 m below Dights Falls at a riffle beneath the Johnston Street Bridge to the Yarra mouth at Williamstown where it discharges to Hobsons Bay. The estuary can be broken into 3 sections, the upper reach upstream of Grange Road, the middle reach between Grange Road and Spencer Street and the lower or port reach downstream of Spencer Street. It flows through the inner eastern suburbs of Melbourne, the Melbourne central business district and the docklands and port precincts before reaching the bay. A number of tributary streams enter the estuary including Gardiners Creek in the upper section and Moonee Ponds Creek and the Maribyrnong River in the Port of Melbourne.

For most of its length the banks have been stabilised with rock beaching. Some remnant riparian and littoral vegetation exists in the upper reaches. However, downstream of Punt Road banks are manicured grassed areas or pavement and rockwalls. Downstream of Spencer Street the estuary has been significantly modified to form a series of docks and wharves and has been dredged to depths greater than 10 m. Upstream of Spencer Street the estuary channel is typically 3-4 m deep and downstream of Dights Falls it is 1-2 m deep (Beckett et al. 1978).

4.7.1 Current condition

Hydrodynamics

The most comprehensive study of the hydrodynamics of the Yarra estuary has been undertaken by Beckett et al. (1978, 1982). This study examined salinity and water movement patterns along the entire Yarra estuary. Other studies have concentrated on the lower Yarra estuary and Hobsons Bay in association with Port of Melbourne activities (eg. Hinwood 1979, Walker et al. 1998). The Yarra Estuary can be classified as a mature riverine estuary, that is it comprises a permanently open channel where there is significant river flows for much of the year (Deeley and Paling 1999). Hydrodynamics are related to river inflows, tides and wind and the physical characteristics of the channel. In the Yarra estuary, flow and tides are considered the dominant factors in determining circulation patterns (Beckett et al. 1978, Hinwood 1979). Tides at Williamstown are semidiurnal with an average range of 0.5 m but can vary between 0.3 and 0.9 m (Beckett et al. 1978).

The combination of flows and tides in the Yarra estuary results in the establishment of a ‘salt-wedge’ (Beckett et al. 1978). The presence of a salt-wedge means the water column is stratified for most of the time with a layer of fresher river water (salinity <5000 mg/L) on the surface overlaying more saline water (Beckett et al. 1978, Poore and Kudenov 1978). The surface layer flows continually downstream to Hobson Bay while the lower layer moves up and down the estuary with inflowing and out flowing tides but the net movement is slowly upstream (Figure 4.100). The tip of the salt-wedge (salinity >30,000 mg/L) migrates up and down the estuary depending upon the volume of river inflows and slowly mixes with the surface layer (Beckett et al. 1978).
To our knowledge there is no hydrodynamic model of the Yarra estuary, however, the study of Becket et al. (1978, 1982) provides useful information on the movement of the salt wedge and residence times under different inflows to the estuary, and a study of water quality in the estuary by McGuckin (2003) presents data on salinity profiles at a number of sites and for a range of inflows.

Figure 4.101 shows longitudinal salinity profiles for a range of flows considered by Becket et al. (1978) to represent low, medium and high flows and Figure 4.102 shows salinity depth profiles for sites sampled by McGuckin (2003). The data presented in Figure 4.101 and Figure 4.102 is used to make the following observations. Under low flows (~350 ML/d), fresh surface waters extend downstream to around Punt Road and the tip of the salt wedge is estimated to be located just upstream of Punt Rd. However, saline bottom waters (salinity 5000-25,000 mg/L) extend to Bridge Road in the upper reaches of the estuary. Under medium to high flows (~2000 ML/d) the tip of the salt wedge remains around Punt Road. However, fresher surface waters extend downstream to the port section and the water column is fully mixed in the upper reaches to a point around Grange Road. Under high flows (~9000 ML/d) the tip of the salt wedge is located near King Street and fresh surface waters extend to the Westgate Bridge. The water column is well mixed to around King Street, but stratification is still evident in the port region.
Figure 4.101 Longitudinal salinity profiles (salinity is in mg/L) in the Yarra estuary showing the pattern of stratification and approximate location of the tip of the salt wedge under a range of flows (adapted from Beckett et al. 1982).
Figure 4.102 Salinity profiles for a number of estuary sites and Yarra River inflow volumes in February and June 2002 (adapted from McGuckin 2003).

Based on a simple compartmentalised mixing model, Becket et al. (1982) determined residence times for surface and sub-surface waters at Bridge Road, Punt Road, King Street and near Westgate Bridge for low, medium and high flows. Residence time, in days, refers to the length of time water remains in the estuary at a particular location. Figure 4.103 plots residence time for each location across the range of flows sampled by Becket et al. (1982). Under low flows the residence time for surface water in the upper estuary (Bridge Rd) is estimated at 1.3 days, 1.0 to 0.5 days in the mid estuary (Punt Rd to King St) and 1.3 days in the port section near Westgate Bridge. Under low inflows, residence time in sub-surface waters in the upper estuary around Bridge Rd remain low.
(1.3 days), in other words, a flow of around 350 ML/d is still sufficient to maintain mixing in the upper estuary. However, residence time increases further downstream with a sub-surface residence time at Punt Road of around 15 days, decreasing to around 6 days at King Street and increasing again to around 13 days in the port. The decrease in residence time between Punt Road and Kings Street is likely due to increased tidal influence in the lower reaches. However, through the port section tidal influence is offset by the large increase in cross-sectional area and hence volume of sub-surface water that must be mixed.

Under medium flows the residence time decreases in both surface and sub-surface waters. In other words, higher flows result in increased circulation and mixing of sub-surface waters with surface waters and hence shorter residence times. For a flow of around 2000 ML/d the residence time of surface waters is less than 1 day throughout the estuary reach. Sub-surface residence times range from 0.8 days in the upper to 2.3 days in mid estuary. Higher flows result in full mixing of the water column and force the salt wedge downstream, hence reducing residence time. Sub-surface residence time increases in the lower sections of the estuary, up to around 11.6 days through the port sections. As described above, this increase is likely due to the increased cross-sectional area and hence volume of water that must be mixed.

Under high flows the salt wedge is forced downstream to around King Street and full mixing of the water column occurs with a residence time in surface and sub-surfaces waters of around 0.3 days for the majority of the estuary. Even under high flows there is still some evidence of stratification in the port region, although even there, residence time in sub-surface waters is reduced to around 3 days.

The dynamics of the salt wedge, mixing patterns and residence times can have a significant influence on the condition of the estuary, particularly water quality. These influences are described in more detail in the water quality section below.
Figure 4.103 Residence time (days) for surface and sub-surface waters at various locations and for a range of flows in the Yarra estuary (based on Beckett et al. 1982).

**Geomorphology / habitat**

The estuarine section of the river has been channelised and the banks lined with rock and bluestone along the waterline. The ISC physical form score is good in the upper part of the estuary but very poor through the mid and lower sections. Channelisation has isolated the floodplain and all
wetland areas have been lost. Channelisation is the main driver behind the current geomorphic condition of the estuary reach. Routine dredging, to a depth of around 12 m, occurs in the Port section of the estuary below Bolte Bridge to maintain a suitable depth for ships. Some small scale dredging for recreation crafts may take place in the mid reaches of the estuary in the future (David Ritman, Parks Victoria, pers.com.).

Sediment inputs from upstream reaches may help build benches that support littoral vegetation, such as Phragmites, that provides important habitat. However, high flows can also create bed scour and large floods may undermine and erode benches (David Ritman, Parks Victoria, pers.com.). Critical flow thresholds for sediment deposition and scour are unknown, but bed scour in particular may be an important process that can influence water quality in the estuary and Hobsons Bay. For example, a number of studies have reported high levels of heavy metals, hydrocarbons and other contaminants in Yarra estuary sediments (eg. Smith and Milne 1979, Ellaway et al. 1982, Smith and Maher 1984). Moreover, Fabris and Monahan (1995) reported an 8 to 25 fold increase in the load of metals contributed to Port Phillip Bay during a high flow event (~17,000 ML/d) in the Yarra River compared to normal (no rain) conditions. This increase is likely due to increased stormwater runoff and perhaps mobilisation and transport of contaminated sediments during high flow events.

Benthic fauna

The condition of the macroinvertebrate community in the estuary is poorly known. Few studies have been undertaken and these have mostly been from the lower Port section where the benthic infauna has a low diversity that is dominated by worms, crustaceans and molluscs indicative of disturbed environments (Poore and Kudenov 1978, Walker et al. 1998). The macroinvertebrate community composition in the upper estuary is unknown, although sampling has occurred in the freshwater section immediately downstream of Dights Falls; these results are considered in relation to Reach 6.

Fish

A large range of native and exotic fish has been recorded from the estuary and overall diversity is considered to be high. The estuary is a critical conduit for the movement of diadromous fish between freshwater and estuary/marine waters. All five SEPP listed fish have been recorded from this reach.

The estuary and near shore marine environment at the mouth of the Yarra River is also critical habitat for a range of estuarine and marine species, some of which have recreational and commercial significance (eg black bream and Australian anchovy). Habitat availability and interactions between fresh and salt water are likely to be important drivers of the fish community in the estuary. For example, black bream are thought to require well oxygenated water with salinities around 11,000 to 18,000 mg/L for successful egg and larval development (Sherwood and Backhouse 1982 cited in, Haddy and Pankhurst 1998), while Haddy and Pankhurst (1998) themselves found reproducively mature fish over a larger range of salinity from 13,900 to 35,000 mg/L. Based on the salinity profiles of Beckett et al. (1982) salinity within the range preferred by
black bream are likely to be found within the Yarra estuary under all but the highest flood flows. However, the specific salinity dynamics in relation to black bream spawning and location within Yarra estuary are not known.

The salinity and freshwater requirements of other species are more poorly understood. Although freshes and high flows are likely to be important in providing cues for migration and spawning of some species. For example, it is thought that the juveniles (white bait) of common galaxias require increased freshwater inflows to estuaries in spring to commence upstream migrations (Benzie 1968). Likewise, low flows may also provide cues for migration. For example the juveniles of tupong are thought to require a decrease in flow and increased temperature in late spring and early summer to commence upstream migrations (Sloane 1984).

Water quality improvements through improved stormwater management in urban catchments and protection and enhancement of littoral habitat throughout the estuary are important complementary works required to maintain the current fish community.

**Vegetation**
The condition of riparian vegetation in this reach is considered poor. It is highly modified and native vegetation is absent from long sections of the reach. However, some littoral vegetation, predominately *Phragmites*, is present and is likely to provide critical habitat for fish, macroinvertebrates and birds. Parks Victoria has placed control structures to minimise disturbance to littoral vegetation, although some wave wash disturbance may occur (David Ritman, Parks Victoria, pers.com.). There is no riparian vegetation in the lower section of the reach.

Specific flow requirements of riparian and littoral vegetation in the estuary reach are unknown. However, high flows that deposit sediment on benches may help to maintain littoral vegetation, although extremely high floods can also erode benches.

There are significant opportunities to improve the condition of riparian and littoral vegetation in the upper and mid sections of the reach with appropriate revegetation and management practices. Littoral vegetation, predominantly *Phragmites*, is likely to be critical habitat for a range of estuarine species, particularly juveniles of fish such as black bream that spawn in estuaries. Revegetation of the riparian zone and protection and enhancement of littoral vegetation along the entire reach are considered priority complementary works.

**Water quality**
There is limited water quality available for the estuary. A current routine monitoring site is located at Princes Bridge upstream of King Street, some historic data and salinity profiles are presented by McGuckin (2003) and Becket *et al.* (1982) present some data on dissolved oxygen in sub-surface waters. The overall water quality is considered poor to very poor with urban runoff from tributary streams and direct stormwater drain outfalls the greatest contributors to poor water quality. Nutrient and heavy metal concentrations through this reach are high and typically fail ANZECC water quality objectives (There are no SEPP Schedule F7 objectives for nutrients or heavy metals...
in this reach). However, DO, pH and turbidity in surface water samples typically comply with SEPP objectives (McGuckin 2003 and see the Issues paper for more details).

In addition to catchment sources of poor water quality, the hydrodynamics of the estuary can have a significant influence on water quality. Prolonged low flows that result in a long residence time of saline bottom waters can lead to anoxic conditions which can result in the release of nutrients and toxicants from sediments. Increased residence time in surface waters can lead to retention of nutrients that increase the potential for algal blooms to develop with consequent environmental, social, and economic impacts.

McGuckin (2003) considered salinity and dissolved oxygen concentrations in the estuary to be acceptable for aquatic biota, although these were based mostly on surface water samples. However, Becket et al. (1982), while acknowledging that dissolved oxygen in sub-surface estuary waters is often depleted, reported sub-surface concentrations to occasionally fall below 50% saturation at King Street. They did not provide details of the specific flows for which low dissolved oxygen concentrations. Thus, it would appear that even under low flow conditions, dissolved oxygen in surface waters remain high and acceptable for aquatic biota but prolonged low flow periods that result in long residence times for sub-surface waters have the potential to impact water quality and aquatic biota through reductions in dissolved oxygen. A more detailed study of the Yarra estuary is required to explicitly determine ecological thresholds and critical flow levels and residence times to minimise risks to water quality and aquatic biota.

Water quality issues associated with stormwater runoff and catchment inputs will not be mitigated through the provision of environmental flows. Stormwater management actions, improvement in sewerage infrastructure that reduce overflows to the drainage system and catchment wide implementation of low-impacts stormwater drainage design is required will help to improve water quality in the reach. However, low flows that result in long residence times of saline sub-surface waters have the potential to impacts water quality and critical low flow thresholds to protect water quality in relation to hydrodynamic processes need to be determined.

### 4.7.2 Flow recommendations

In the absence of specific hydrodynamic information on critical flow thresholds and ecological responses in the Yarra Estuary it is difficult to quantify specific flow requirements for the estuary and it is recommended that a detailed hydrodynamic model of the Yarra estuary be developed and used to specify environmental flow requirement. In the interim, based on a recent study in the Werribee River estuary (Sherwood and Crook 2005), important flow components for the Yarra estuary are likely to be:

- Winter/spring flows sufficient to flush salt water from the estuary to reoxygenate bottom waters and sediments;
- Summer/autumn low flows sufficient to maintain estuarine circulation and in particular vertical and longitudinal salinity gradients ranging from fresh to marine throughout the entire estuary; and
Avoidance of long periods of constant flow.
The flow recommendations for Reach 6, immediately upstream of the estuary reach, contain recommendations for a range of flow components from low flows to freshes, high, bankfull and overbank flows aimed at supporting ecological objectives in that reach. While no specific flow recommendations are made for the estuary reach (a hydrodynamic model is required to perform such a task) the following discussion considers the applicability of the Reach 6 recommendations to the estuary reach and identifies where more detailed investigations may be required to better understand specific estuary flow requirements. Pierson et al. (2002) outline a checklist that can be used to consider the major ecological processes by which changes to estuary freshwater inflows may impact on estuarine ecosystems. This checklist has been used as the basis for considering the implications of upstream flow recommendations for the estuary.

**Low magnitude inflows**

*Increased hostile water quality conditions at depth*

Prolonged low flows may decrease dissolved oxygen concentration in sub-surface waters while low dissolved oxygen may result in nutrient release from sediments and restrict access to benthic habitats but the critical flow thresholds & residence times are not known for the Yarra. The low flow recommendations for Reach 6 of 200 and 350 ML/d in summer and winter respectively may result in a residence time in sub-surface waters of around 15 days at Punt Road and 6 days at King Street (based on Beckett et al. 1982). A rough extrapolation of residence times based on those from Beckett et al. (1982) is presented in Figure 4.104. Even under more natural low flows, for example the natural summer 80th%ile flow of around 700 ML/d in Reach 6, residence time in sub-surface waters would still have been around 10 to 12 days in the Punt Road area and 3 to 4 days at King Street. Under all flows the residence time of surface waters is estimated to be less than 2 days. The specific ecological consequences of varied residence times are unknown and it is not known whether an increase in residence time from 10 days to 15 days would be critical in the context of the Yarra estuary. Further investigations are needed to quantify any risks associated with low flows and to identify if critical ecological thresholds exist.
Extended duration of elevated salinity in the upper-middle estuary adversely affecting sensitive fauna and flora

The salt wedge penetrates upper reaches at flows around 350 ML/d and the middle estuary at flows around 2000 ML/d (Figure 4.101). However, even under low flows there is a range of salinities from fresh to salt both vertically and longitudinally through the estuary. Flora is unlikely to be significantly affected because existing littoral vegetation is well adapted to a range of salinities. For example, littoral vegetation such as *Phragmites* can tolerate salinities of at least 10,000 mg/L (Lissner and Schierup 1997). *Phragmites* is present upstream of Punt Road and even under low flows (~350 ML/d) fresh surface water extends this far downstream, further downstream the river is rockwalled, there is no riparian vegetation with little potential for littoral growth. The low flow recommendations are unlikely to represent a risk to littoral vegetation as surface water salinities would not be expected to extend further up the estuary for prolonged periods, the greatest risk to littoral vegetation is from disturbance due to wave wash from water craft and perhaps from the eroding of sediment banks under extreme flows resulting from rapid runoff from urban tributaries.

Fauna in the estuary is also adapted to a range of salinities, although species specific requirements are not well understood. A wide range of salinities will still be present throughout the estuary but timing and specific location of the salt wedge may be important for some species and changes in salinity gradients at certain times may be important to trigger spawning and movement events or to satisfy various life history stages. However, the flow recommendations for Reach 6 retain significant elements of natural seasonality and variability. Even so, further investigation of the salinity requirements of key biota is required and a better...
understanding of flow effects on salinity gradients through the development of a hydrodynamic model is necessary.

- **Extended duration of elevated salinity in the lower estuary allowing the invasion of marine biota**
  Prolonged high salinities may favour marine species in the lower estuary and infestation by pest species is a particular risk. A number of marine pests are present in Port Phillip Bay and the port section of the Yarra estuary (e.g., northern Pacific sea star and giant European fanworm, Walters 1996). Under the recommended low flows for Reach 6 the salt wedge would extend to Punt Road, but most marine pests are sensitive to low salinity, so even short duration high flow events that decrease salinity in the majority of the water column would prevent marine species from extending further up the estuary. In fact, it has been observed that the giant European fanworm colonises the lower part of wharf pylons in port section, but not the upper parts. This has been attributed to the predominantly saline sub-surface waters of the port compared to fresher surface waters (Walters 1996). The overall risk of invasion of marine species further up the estuary beyond the port section is considered low.

- **Extended duration when flow-induced currents cannot suspend and/or transport eggs or larvae**
  The Yarra estuary is an important spawning and nursery area for a range of estuarine and diadromous fish species. It is unknown to what extent eggs and larval suspension and transport is reliant on flow and at what velocity. Even under low flows the predominant flow is in a downstream direction, however, critical velocities are unknown. The specific egg, larval and juvenile requirements of aquatic biota is also not well understood, so the specific risks of low flows cannot be assessed.

- **Aggravation of pollution problems**
  The Yarra estuary receives significant stormwater inflow from urban catchments. Reduced flows may allow accumulation of pollutants in surface waters, but even under low flows, the residence time of surface waters is short hence minimising the risk of significant accumulation of pollutants. Management of urban runoff is a critical requirement to minimise the water quality impacts on the estuary.

- **Reduced longitudinal connectivity with upstream river system**
  Dights falls represents the only barrier between the estuary and upstream reaches. Connectivity risks are associated with ineffective fishway design rather than specific flow components.

### Middle and high magnitude flows

- **Diminished frequency that the estuary bed is flushed of fine sediment and organic material.**
- **Diminished frequency that deep sections of the estuary are flushed of organic material.**
- **Reduced channel-maintenance processes.**
Critical flow thresholds that flush fine sediment and organic material and maintain channel processes are not known. Based on the results of Becket et al. (1982), a flow of 8900 ML/d would flush the upper and middle sections of the estuary but not necessarily the deepest parts of the port section. However, it is unknown whether the velocity of such a flow is sufficient to entrain and transport fine sediment or organic material from the bed of the estuary. The extent to which the recommended bankfull channel maintenance flow for Reach 6 of 13,000 ML/d could flush the port section is unknown, however it would be expected that flows equivalent to channel maintenance flows in the lower freshwater reaches would be sufficient to maintain estuary physical processes, at least in the middle and upper sections of the estuary where significant channel enlargement has not occurred. Again, a hydrodynamic model that considers variables such as velocity and shear stress is needed to confirm specific flows required to mobilise sediment and organic material in the estuary.

- **Reduced inputs of nutrients and organic material**

  Given the nature of the Yarra’s urban catchment, the supply of nutrients and organic material to the estuary is unlikely to be limited by flows. However, the degraded state of the riparian vegetation may mean the form of organic material may not support the desired range of ecosystem processes. This is not a specific flow related issue, rather, revegetation of the riparian zone and consequent supply of coarse particulate organic material to the river is the preferred approach to restoring the supply of organic material.

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

  The main estuary channel has been channelised and there has been a total loss of wetlands associated with the Yarra estuary, thus all lateral connectivity has been lost and cannot be further impacted by flows.

**Across all inflow magnitudes**

- **Altered variability in salinity structure**

  As described above, under the low flow recommendation for Reach 6 the residence time for sub-surface waters in the middle to upper reaches of the estuary are estimated to be around 15 days. This is an increase from around 10 to 12 days for the natural low flow and is likely to be about equivalent to the current residence time during low flow periods. The estimated residence time under recommended freshes and high flows (1500 to 2200 ML/d) is less than 3 days in both surface and sub-surface waters throughout the estuary except the sub-surface waters in the lower port section where channel deepening has increased the residence time. While some alteration to salinity structure has likely occurred between natural and current conditions the effect of this is unknown. The flow recommendations for Reach 6 are unlikely to further significantly alter salinity structure. However, the preferred structure is not well understood and should be the subject of further investigation.
Dissipated salinity/chemical gradients used for animal navigation and transport and decreases in the availability of critical physical-habitat features, particularly the component associated with higher water velocities

The degree to which salinity and chemical gradients, and availability of critical habitat features has changed are not well understood, nor are any effects on specific aquatic biota. Further investigations are required to determine the specific salinity and habitat requirements of aquatic biota and critical thresholds in regards to salinity, velocity and habitat characteristics to support various life history stages.

Summary
While the low flow recommendation for Reach 6 could result in residence times in sub-surface waters of around 2 weeks, this is not much greater than estimated residence times under natural low flows of 10 to 12 days (Figure 4.104). Freshes and high flow recommendations for Reach 6 will result in flows through the estuary that, while unlikely to flush the salt wedge through the port section, will mix the majority of the upper and middle estuary and reduce residence times to less than 3 days. Based on estimates in Figure 4.104, the recommended duration of high flow events of between 7 and 14 days will be sufficient to turnover both surface and sub-surface waters, even in the surface waters of the port section. In addition, the recommended bankfull flow of 13,000 ML/d is likely to be sufficient to mix a significant proportion of the deeper water through the port section, although a hydrodynamic investigation is needed to confirm this.

On the basis of the above discussion the flow recommendations for Reach 6 are unlikely to present a significant increased risk to the Yarra estuary. However, the specific flow requirements of the estuary cannot be determined without further investigation beyond the scope of the current study, including the development of a hydrodynamic model. A specific estuary study similar to that undertaken in the Werribee River estuary by Sherwood and Crook (2005) is recommended. In addition, an estuary module for the FLOWS method is currently being developed and its application to the Yarra estuary should be considered. Any further investigation needs to consider at a minimum, the specific salinity, velocity and habitat requirements of estuarine biota and diadromous fish and an understanding of critical thresholds relating to residence times and estuary processes such as nutrient processing and decomposition that influences patterns in dissolved oxygen.

4.8 Reach 8: Watts River downstream of Maroondah Reservoir
Reach 8 on the Watts River is located downstream of Maroondah Dam to the confluence with the Yarra River. There is a 1 ML/d continual release from the dam to the Watts River. The first tributary inflow (Donnellys Creek) occurs approximately 1.5 km downstream with subsequent inflows from Chum Creek and Grace Burn. The environmental flows assessment site is located downstream of the major tributary inflows adjacent to River Rd in the township of Healesville. The gauge location is also in this vicinity and downstream of major tributary inflows at the Healesville-Kinglake Road.
4.8.1 Current condition

Hydrology
Naturally the Watts River at Healesville has a mean annual flow of 275 ML/day. This has been reduced by 46% to 148 ML/day. The greatest impact on flow reduction has been in the low flow range (Figure 4.105) and in some instances cease to flow events now occur. Despite the flow reduction seasonality is retained (Figure 4.106), partly due to tributary inflows and partly due to frequent spills from Maroondah dam in winter and spring. However, the frequency of larger flood events has decreased. Under natural conditions a 1 in 5 year flood had a magnitude of approximately 2,800 ML/day. Under current conditions a flood of this magnitude has a frequency of 1 in 18 years.

- Figure 4.105 Flow duration curve for the Watts River at Healesville.

- Figure 4.106 Average flow for each day of the year in the Watts River at Healesville.
Geomorphology / habitat
The river through this reach flows through a confined valley before crossing the Yarra floodplain and entering the Yarra River. The channel comprises a pool/riffle structure with the bed composed of a mix of cobbled riffles and sandy pools. Some instream habitat is provided by LWD, although desnagging has reduced the overall habitat availability. Bed and bank condition is variable. Urban impacts through Healesville and degradation of the riparian zone due to stock access has likely contributed to some instability in the banks in some sections of the reach. There is also some evidence of sediment accumulation on benthic surface during low flow periods and reduced flow variability is likely to have contributed to this. The ISC physical form score is moderate.

Revegetation and erosion protection works are required to minimise further degradation of the banks and instream habitat restoration is required if habitat condition is to improve. However, important components of the flow regime are also required to maintain access to habitat for macroinvertebrates and fish, fish passage and to scour sediment that accumulates during low flow periods.

Macroinvertebrates
Macroinvertebrate scores through this reach comply with the SEPP objectives for total number of families and key families but fail to meet the SIGNAL Score objective. Overall condition is considered good and only just below reference condition. Degradation of the riparian zone, water quality impacts from local urban and agricultural runoff and sedimentation of riffles habitats are the main factors that are considered to influence the macroinvertebrate community.

Improvements in the condition of riparian vegetation, stormwater management and freshes and high flows to scour benthic surfaces are required to improve the macroinvertebrate community health.

Fish
A large range of native and exotic fish have been recorded from this reach and overall diversity is considered high for a relatively small stream. However, loss of habitat through desnagging, degradation of the riparian zone and sedimentation pose threats to the fish community. In addition, altered flow regimes have likely reduced opportunities for local movement and colonisation by diadromous species. In a small stream with reduced habitat competition from exotic species for food and habitat may also pose a threat to some native species.

Riparian and instream habitat restoration will provide increased habitat for fish. However, suitable flows are also required to maintain access to habitat and provide fish movement opportunities.

Vegetation
Degradation of the riparian from agricultural activities, stock access, weed infestation and urban development is evident in this reach and the ISC score for the streamside zone is moderate. However, recent weed control and revegetation works has improved condition in some locations through Healesville township, including at the assessment site.
Stock access and weed infestation have contributed to the degradation of the riparian vegetation and reduced duration of high flows may be contributing to increased terrestrialisation of the upper banks.

The major phase of degradation has probably passed. However, fencing to exclude stock access, revegetation and active weed control are needed to significantly improve the condition of the riparian zone. Longer duration high flows are required to limit the encroachment of terrestrial weeds downs the bank.

**Water quality**

Water quality is moderate through this reach. Compliance with TP, salinity, DO, pH and turbidity SEPP objectives remain relatively high but TN typically fails to meet objectives. Toxicant concentrations are low and comply with ANZECC guidelines.

Agricultural and urban runoff are key drivers of reduced water quality through this reach. Improvements in the condition of the riparian zone through fencing and revegetation and improved stormwater management would be expected to result in an improvement in water quality through the reach. The predominant water quality issues in the reach will not be mitigated through the provision of environmental flows.

**4.8.2 Flow recommendations**

The general flow objective is to provide access to habitat for fish and macroinvertebrates, minimise prolonged stable low flow periods by ensuring some variability and to ensure appropriate high flows in the winter period.

The environmental flow recommendations for Reach 8 are summarised in Table 4.13.
**Table 4.13 Summary of flow recommendations for Reach 8.**

<table>
<thead>
<tr>
<th>Season</th>
<th>Flow</th>
<th>Volume</th>
<th>Frequency</th>
<th>Duration</th>
<th>Rise/Fall</th>
<th>Objective (refer to objectives tables for id reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer / autumn</td>
<td>Low flow</td>
<td>20 ML/d</td>
<td>All season</td>
<td>. . . . . . .</td>
<td>1.6/0.7</td>
<td>Maintain access to habitat for bugs &amp; fish, drying on banks for vegetation</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>80 ML/d</td>
<td>4 events</td>
<td>2 days</td>
<td>1.6/0.7</td>
<td>Maintain habitat</td>
</tr>
<tr>
<td>Winter / spring</td>
<td>Low flow</td>
<td>130 ML/d</td>
<td>All season</td>
<td>. . . . . . .</td>
<td>1.6/0.7</td>
<td>Maintain access to habitat for bugs &amp; fish, wet bank vegetation</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
<td>180 ML/d</td>
<td>2 times per year</td>
<td>2 days</td>
<td>1.6/0.7</td>
<td>Maintain suitable habitat</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>300 ML/d</td>
<td>1 per period</td>
<td>3 days</td>
<td>1.6/0.7</td>
<td>Sediment scouring to increase habitat availability, vegetation disturbance, fish passage &amp; spawning habitat, entrain organic material</td>
</tr>
<tr>
<td></td>
<td>Bankfull</td>
<td>1000 ML/d</td>
<td>1 in October – November</td>
<td>2 days</td>
<td>1.6/0.7</td>
<td>Maintain existing channel geometry &amp; prevent vegetation encroachment in channel, entrain organic material, engage high flow channels &amp; floodplain</td>
</tr>
</tbody>
</table>

**Summer/autumn low flows**

The recommended summer/autumn low flow threshold is 20 ML/d. This flow is sufficient to inundate the full width of riffles (eg. Transect 5) and provides suitable depth to maintain access to pool habitats (eg. Transect 4) (Figure 4.107). This flow also allows drying of benches and the lower banks.

**Figure 4.107 Stage height in a pool (Transect 4, left) and a riffle (Transect 5, right) at the recommended threshold for summer/autumn low flows in Reach 8.**
Under current conditions flows fall below the low flow threshold on average twice per year for a median duration of 15 days, although 30% of spells below the threshold can last up to 140 days (Figure 4.108). Under natural conditions spells below the threshold occur less than one each year but only for very short durations. The distribution of spells below the threshold has changed between current and natural with the majority of spells commencing in December under current conditions compared to March under natural conditions. In addition a large number of spells commence in May indicating that currently the summer/autumn low flow period has increased in length with low flows occurring earlier in summer and lasting longer in autumn compared to natural conditions.

**Summer/autumn freshes**

The recommended summer/autumn fresh threshold is 80 ML/d, 4 times per year for a duration of 2 days. This flow increases depth over riffles (Figure 4.109) and is sufficient to create velocities in riffles sufficient to scour sediment and to mix and freshen pools. Higher flows do not appreciably increase the scouring potential in riffles.
Figure 4.109 Stage height in a pool (Transect 4, left) and a riffle (Transect 5, right) at the recommended threshold for summer/autumn fresh flows in Reach 8.

Under current conditions the fresh threshold is exceeded on average 2 times a year compared to 4 times per year under natural conditions (Figure 4.110). The median duration of the freshes under current conditions is 2 days compared to 14 days naturally. There has also been a shift in the commencement of freshes. Freshes need to be relatively evenly spaced across the summer/autumn low flow period to ensure suitable variability in flow is provided.

There is no specific summer/autumn high flow recommendation. In other reaches a summer high flow has been recommended to enhance opportunities for spawning by Australian grayling. There is no specific objective for Australian grayling in Reach 8 so a high flow has not been recommended.
Minimum Environmental Water Requirement and Complementary Works Recommendations

Minimum Environmental Water Requirement and Complementary Works Recommendations

Winter/spring low flows

The recommended winter/spring low flow threshold is 130 ML/d. This flow is sufficient to inundate vegetation on the lower banks for a prolonged period (Figure 4.111).

Figure 4.110 Duration (top left, frequency (top right) and start month (bottom left) for flows above the summer/autumn fresh flow threshold under current and natural conditions for Reach 8.

Figure 4.111 Stage height in a pool (Transect 4, left) and a riffle (Transect 5, right) at the recommended threshold for winter/spring low flows in Reach 8.
Under current conditions flows fall below the threshold on average two times per year with a median duration of 24 days for each spell (Figure 4.112). A similar frequency of spells below the threshold would have occurred naturally but the duration was much shorter. Spells below the threshold most often commence in June, indicating that in many years the onset of higher winter base flows occurs later in the season.

Winter/spring freshes
The recommended flow threshold for winter/spring freshes is 180 ML/d twice per year with a duration of 2 days. This is sufficient to inundate low and mid level benches (eg. Transect 5), reduce sediment accumulation on gravel and cobbles in riffle zones and provide increased depth over raffles for fish passage (Figure 4.113)
Figure 4.113 Stage height in a pool (Transect 4, left) and a riffle (Transect 5, right) at the recommended threshold for winter/spring fresh flows in Reach 8.

Under current and natural conditions the fresh threshold is exceeded on average 2 to 3 times per year with a current and natural duration of 4 days and 8 days respectively (Figure 4.114). Under natural conditions the winter base flow was typically higher than the recommended fresh flow threshold hence the duration of spells above the threshold under natural conditions is long. Even under current conditions the 30% of spells above the threshold last for 3 to 70 days.

Figure 4.114 Duration (top left, frequency (top right) and start month (bottom left) for flows above the winter/spring fresh flow threshold under current and natural conditions for Reach 8.
Winter/spring high flows

The recommended winter/spring high flow is 300 ML/d once per year in October or November for 3 days duration. This flow inundates benches and banks to a greater depth than fresh flows (Figure 4.115) providing a high disturbance flow and entraining organic material that accumulated on the banks.

Under current conditions the high flow threshold is exceed once every two years compared to three times per year naturally (Figure 4.116). The median spell duration is 6 days under current conditions and 3 days under natural conditions. However, a large proportion of spells last for several weeks. Most spells commence in October under current conditions although under natural conditions there was more even distribution of events between October and November.
Bankfull flows
A bankfull flow of 1000 ML/d is recommended once every 2 years for a duration of 2 days. This flow reaches the top of the bank along most transects in the reach and inundates a low floodplain at Transect 4 (Figure 4.117). This flow is sufficient to maintain current channel geometry by scouring sediment in deepest pools and also inundates small low lying floodplains and high benches located along the reach.
Under current conditions the bankfull threshold is exceed on average 1 to 2 times per year under current conditions and 2 times per year under natural conditions (Figure 4.118). In actual fact, bankfull flows only occur every second year, but when they do occur more than one event tends to occur hence giving the impression of more frequent occurrence based on the frequency analysis in Figure 4.118.

The median duration of bankfull flows is 2 days under both natural and current conditions and the distribution of start months is similar. The relatively small storage capacity in Maroondah Dam means the dam spills in most years and this contributes to the frequent bankfull flow events.

There is no overbank flow recommendation for Reach 8. The confined nature of the channel means there are few floodplain areas and the bankfull flow provides inundation of some small inset floodplains and low lying parts of the riparian zone.

**Long sections**

Figure 4.119 shows the water surface level for each flow threshold along a long section of Reach 8. Water surface levels indicate sufficient depth is achieved over the riffle at Transect 5 for all but the summer low flow threshold.
Figure 4.119 Long section showing water surface level for all flows in Reach 8.

4.8.3 Current compliance
Compliance with environmental flow objectives for Reach 8 is presented in Table 4.14. The current summer low flow is only 2.4 ML/d compared to the natural summer low flow of 64 ML/d and under current conditions the summer low flow recommendation is complied with 38% of the time. The current winter low flow is 52 ML/d compared to 181 ML/d under natural conditions and the recommended winter low flow is complied with 57% of the time.

The summer high flow volume is met in 93% of years but the recommended frequency of 4 freshes per year is only met in 30% of years. When a summer fresh does occur the recommended duration is met in 65% of events.

The recommended winter fresh volume is met in 98% of years, the recommended frequency is met in 65% of years and the recommended duration is met in 75% of events. A greater number of events occurred naturally but median duration was slightly shorter.

The recommended winter high flow volume and frequency is only met in 45% of years and the recommended duration is met in 75% of events. The bankfull recommendation is met in 100% of years and for 100% of events.

In summary compliance with the low flow recommendations is relatively low and the effect of Maroondah Dam on the summer low flow is particularly noticeable. Compliance with the winter high flow recommendation is also poor but compliance with the bankfull recommendation is high because Maroondah Dam spills in most years and this results in a bankfull flow downstream.
Delivery of flow recommendations, particularly low flows, will require releases from Maroondah Reservoir and/or alterations to tributary harvesting on tributary streams such as Donnelly’s Creek and Grace Burn.

- **Table 4.14 Reach 8 compliance with environmental flow recommendations.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Time</th>
<th>Flow Rec</th>
<th>Percentage of years (vol &amp;no.) or events (dur.) when flow recs are complied with for the current flow regime</th>
<th>Differences between each flow component for the current &amp; natural regime for comparative purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current equivalent</td>
</tr>
<tr>
<td>Summer low</td>
<td>(Dec-May)</td>
<td>Volume 20</td>
<td>38</td>
<td>2.4</td>
</tr>
<tr>
<td>Summer fresh</td>
<td>(Dec-May)</td>
<td>Volume 80</td>
<td>93</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 4</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 2</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>Summer high</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter low</td>
<td>(Jun-Nov)</td>
<td>Volume 130</td>
<td>57</td>
<td>52</td>
</tr>
<tr>
<td>Winter fresh</td>
<td>(June-Nov)</td>
<td>Volume 180</td>
<td>98</td>
<td>163</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 2</td>
<td>65</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 2</td>
<td>75</td>
<td>3</td>
</tr>
<tr>
<td>Winter high</td>
<td>(Oct-Nov)</td>
<td>Volume 300</td>
<td>45</td>
<td>414</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1</td>
<td>45</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 3</td>
<td>75</td>
<td>6</td>
</tr>
<tr>
<td>Bankfull</td>
<td>(preferred timing is spring to early summer, but can occur anytime)</td>
<td>Volume 1000</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number 1-2</td>
<td>100</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration 2</td>
<td>100</td>
<td>2</td>
</tr>
</tbody>
</table>

4.9 **Reach 9: Plenty River downstream of Toorourrong Reservoir**

Reach 9 runs from Toorourrong Reservoir to the Plenty Gorge, just upstream of the majority of current urban development. There is a current minimum flow release from Toorourrong Reservoir of 0.2 ML/d. The environmental flows assessment site was located at the start of the Plenty Gorge in an area known as Noika Bush Camp upstream of Gordons Lane. Flow is measured at the Mernda gauge upstream of the assessment site.

4.9.1 **Current condition**

**Hydrology**

Naturally the Plenty River at Mernda has a mean annual flow of 115 ML/day. There is some discrepancy between the modelled current and historical daily flows in the Plenty River at Mernda (natural, current and historic flows are defined in Section 2.3). The mean daily flow under modelled current conditions has been reduced by 29% to 82 ML/day but historically the mean daily flow has been reduced by 67% to 38 ML/d. Normally, it would be expected that historical flow would be higher than current flow and it is uncertain as to the cause of the discrepancy but it may
be related to the accuracy of models used to derive daily flows. For this study, environmental flow recommendations are compared with natural and both current and historical flows.

The reduction in flows between natural and historic has occurred across the entire flow range but is most noticeable under low flows (Figure 4.120). In particular, the magnitude of low flows has decreased by nearly two orders of magnitude and the cease to flow period has increased by one third from 9% of the time to 14% of the time, typically during summer months.

- **Figure 4.120 Flow duration curve for the Plenty River at Mernda.**

Despite the reduced flows, seasonality is retained, although the summer/autumn low flow period now commences earlier and lasts longer compared to natural conditions (Figure 4.121). Of note is that regulation of the Plenty River commenced with the completion of the Yan Yean Reservoir in 1857 and Toorourrong Reservoir in 1885, so many of the current characteristics of the river are based on over 100 years of impacted flows. Also of note is the highly variable nature of the flow regime with significant high flow events occurring in nearly every month.

- **Figure 4.121 Average flow for each day of the year in Reach 9.**
**Geomorphology / habitat**
The Plenty River has a variable form. The upper reaches flow through cleared agricultural land and the lower reaches flow through a gorge and confined valley. Sections of the upper reaches have been channelised and swampland areas have been drained. However, the gorge section is stable and riparian condition is relatively intact. The ISC physical form score is moderate in the upper reaches and good to excellent in the mid and lower reaches.

Clearing and draining of swamps and channelisation are key factors influencing channel form in the upper reaches. Reduced flows have also lead to channel contraction in the upper reaches above Whittlesea. Degradation of the riparian zone, establishment of willows and uncontrolled stock access has likely contributed to some instability in the banks in some sections of the reach.

The channel form and habitat is stable in the gorge reaches. However, revegetation of the riparian zone and exclusion of stock access is required to halt further channel degradation and resnagging is required to improve habitat quality in the upper and mid reaches.

Important flow components from a geomorphic and habitat perspective in the Plenty River are minimum flows to maintain access to habitat and high flows to create a disturbance that scours sediment that has accumulated on benthic habitats and LWD. High flows are also important to provide connectivity with remnant swamp scrub in the mid sections of the reach downstream of Whittlesea.

**Macroinvertebrates**
Macroinvertebrate scores through this reach are moderate. The upper sections typically fail to comply with SEPP objectives. Sites in the gorge section tend to comply with SIGNAL score, total families and key families objectives.

Degradation of the riparian zone and poor water quality are the main factors that are considered to influence the macroinvertebrate community. Water quality improvements through improved stormwater management and the recent elimination of discharge from the Whittlesea sewerage treatment plant is likely to contribute to improvement in the macroinvertebrate community health. However, urban development in the Plenty growth corridor needs to be managed to minimise future water quality impacts and continued rehabilitation of the riparian zone and fencing to exclude stock access is also required.

Important flow components are minimum summer flows to maintain access to suitable habitat for macroinvertebrates and to minimise the development of saline pools that may pose a risk to sensitive taxa. High flows are required to provide a disturbance regime and scour benthic surfaces.

**Fish**
Eight native fish have been recorded from the reach. Three (river blackfish, common galaxias and spotted galaxias) of the 5 SEPP listed species have been recorded. Two other regionally significant species (mountain galaxias & southern pygmy perch) have also been recorded.
Loss of habitat through desnagging and the draining of swamps are likely to have impacted on the fish community in the upper reaches. Suitable pool and riffle habitat exists in the gorge reach. Small barriers to fish passage still exist in the lower reaches and water quality issues such as salinity may limit some species. Although the maximum recorded salinities in saline pools is typically below the upper limits for fish recorded in the reach.

Competition from exotic species, such as mosquito fish, for food and habitat may pose a threat to some small bodied native species. Barriers to fish passage, poor water quality and lack of access to suitable habitat may continue to limit several species. There is the potential for colonisation by Australian grayling, broad-finned galaxias and tupong if fish passage is further improved and suitable habitat and flow cues are available.

Minimum flows are required to maintain access to existing habitat and freshes and high flows are required to improve opportunities for local movement and to provide spawning and migration cues for diadromous species.

**Vegetation**

Riparian and floodplain vegetation has been extensively cleared in the upper sections of the reach and the ISC score for the streamside zone is poor. However, remnant swamp scrub EVC exists in a short section downstream of Cades Road south of Whittlesea, and significant remnant vegetation in relatively good condition remains in the gorge section. The ISC score for the streamside zone is moderate through this section.

Clearing for agriculture, draining of swamps and stock access are the key impacts on riparian vegetation condition. Although low flows in the reach downstream of Toorourrong Reservoir has contributed to the growth of Phragmites and associated channel contraction.

Urban development through the Plenty growth corridor presents a continuing risk to riparian condition, although it also presents an opportunity to protect and rehabilitate the streamside zone as part of development activities.

Freshes and high flows are important flow components to maintain flood-tolerant vegetation along the banks and provide a disturbance regime to terrestrial vegetation on mid and upper banks. Bankfull flows are important in the mid sections of the reach to inundate remnant swamp vegetation.

**Water quality**

Water quality typically complies with pH, turbidity and salinity objectives. However, compliance with DO is moderate and compliance with TN and TP is very low. Toxicant concentrations are low & generally comply with ANZECC guidelines. The ISC score for water quality is poor to very poor.

Agricultural and urban runoff are key factors that influence water quality through this reach. Discharges from the Whittlesea sewerage treatment plant were a significant contributor to elevated...
nutrients in the reach. Discharge of treated effluent has recently ceased so an improvement in nutrient concentrations may be expected. However, flows, albeit low, may have assisted in maintaining some environmental benefits downstream of the discharge point.

Despite the relatively high compliance with salinity, saline pools can develop under cease to flow conditions. It is unclear the extent to which saline pool development is a natural process resulting from local geology. However, cease to flow periods contribute to saline pools and under current conditions there has been an increase in the duration of cease to flow spells. So, while saline pools may be a natural occurrence in this reach, prolonged cease to flows may have exacerbated their development. Saline pools and consequent anoxic conditions pose a threat to aquatic fauna and may restrict access to suitable habitat for fish and macroinvertebrates at times.

Improvements in the condition of the riparian zone through fencing and revegetation, and improved stormwater management and implementation of catchment-wide low-impact stormwater drainage would be expected to result in an improvement in water quality through the reach. Maintaining a low flow that minimises the duration of cease to flow periods is likely to represent the greatest potential to minimise saline pool development.

4.9.2 Flow recommendations

The general flow objectives in this reach are to maintain a wetting and drying regime that avoids prolonged low flow period and preserves high and bankfull flows as these appear to be important drivers in maintaining an appropriate disturbance regime. Meeting flow recommendations for freshes and high flow at this reach through provision of flow from upstream of Cades Rd, eg via outfalls from Toorourrong Reservoir or clearwater channel will support objectives for inundation of remnant swamp scrub downstream of Cades Rd.

The environmental flow recommendations for Reach 9 are summarised in Table 4.15.
Table 4.15 Summary of flow recommendations for Reach 9.

<table>
<thead>
<tr>
<th>Season</th>
<th>Flow</th>
<th>Volume</th>
<th>Frequency</th>
<th>Duration</th>
<th>Rise/Fall</th>
<th>Objective (refer to objectives tables for id reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer / autumn</strong></td>
<td>Cease to flow</td>
<td>Natural frequency</td>
<td>Max 5 days</td>
<td>Disturbance</td>
<td>M9-1</td>
<td></td>
</tr>
<tr>
<td>Low flow</td>
<td>10 ML/d or natural if lower</td>
<td>All season</td>
<td>2.5/0.6</td>
<td>Maintain access to habitat for bugs &amp; fish, drying on banks for vegetation Minimise saline pool development</td>
<td>M9-2, F9-1, V9-1, W9-1</td>
<td></td>
</tr>
<tr>
<td>Fresh</td>
<td>55 ML/d</td>
<td>4 per season</td>
<td>2 days</td>
<td>2.5/0.6</td>
<td>Maintain habitat</td>
<td>M9-3, V9-2</td>
</tr>
<tr>
<td><strong>Winter / spring</strong></td>
<td>Low flow</td>
<td>20 ML/d or natural</td>
<td>All season</td>
<td>Maintain access to habitat for bugs &amp; fish, wet bank vegetation</td>
<td>M9-2, F9-1, V9-1</td>
<td></td>
</tr>
<tr>
<td>Fresh</td>
<td>70 ML/d</td>
<td>4 per season</td>
<td>3 days</td>
<td>2.5/0.6</td>
<td>Scour gravel riffles to improve conditions for Macquarie perch spawning</td>
<td>M9-3, F9-2, V9-2</td>
</tr>
<tr>
<td>High flow / Bankfull</td>
<td>600 ML/d</td>
<td>1 per year</td>
<td>2 days</td>
<td>2.5/0.6</td>
<td>Sediment scouring to increase habitat availability, vegetation disturbance, fish passage &amp; spawning habitat, entrain organic material. Maintain existing channel geometry &amp; prevent vegetation encroachment in channel, entrain organic material, engage high flow channels &amp; floodplain</td>
<td>M9-4, F9-2, V9-3 G9-1 G9-2, M9-4, V9-3</td>
</tr>
</tbody>
</table>

**Summer/autumn low flows and cease to flows**
The summer/autumn low flow recommendation is 10 ML/d or natural if the natural flow is lower. A continuous low flow is likely to be more effective at minimising the development of saline pools, or at least in providing a layer of freshwater that can be accessed by biota to avoid saline water at depth in pools. However, a cease to flow period is acceptable if it would have occurred under natural conditions, but the maximum duration of any cease to flow should be no longer than the median duration of the natural cease to flow, which is 5 days, to avoid prolonged disturbance associated with cease to flows in an already stressed system.

A flow of 10 ML/d is sufficient to inundate the full width riffles (eg. Transect 3) and provides a drying regime for lower banks (Figure 4.122).
Figure 4.122 Stage height in a riffle (Transect 3, left) and pool (Transect 6, right) at the recommended threshold for summer/autumn low flows in Reach 9.

Under natural conditions flows would have fallen below the recommended low flow threshold around 4 times per year for a median duration of 5 days and 10% of spells would have had a duration longer than 25 days (Figure 4.123). Under historic conditions there were fewer cease to flow periods but they were of much longer duration with a median duration of 35 days and with 30% of spells lasting between 35 and 145 days with most starting in December and lasting for long periods through the summer.

Figure 4.123 Duration (top left, frequency (top right) and start month (bottom left) for flows below the summer/autumn low flow threshold under natural, current and historic conditions for Reach 9.

Figure 4.124 shows the start month, duration and frequency for cease to flows (<0.1 ML/d). Cease to flows occur on average 3 to 4 times per year for a median duration of around 5 days. However,
under historic conditions a high proportion of cease to flows last significantly longer than they would have naturally, with 10% of cease to flow events under historical conditions lasting longer than 34 days compared to 24 days naturally. Under historic conditions cease to flows have occurred in all months except August and September. Naturally, cease to flows would only have occurred between November and April.

**Summer/autumn freshes**

The recommended summer/autumn fresh is 55 ML/d 4 times per year for a duration of 2 days. This flow is sufficient to reduce sediment accumulation in riffle zones and turn over pools (Figure 4.125). The duration is expected to be long enough to dilute any poor quality water that may have developed in pools during low or cease to flow periods. Short duration flows above 40-60 ML/d have been shown to be effective at mixing pools (Potter 2003).
Figure 4.125 Stage height in a riffle (Transect 3, left) and pool (Transect 6, right) at the recommended threshold for summer/autumn fresh flows in Reach 9.

Under natural conditions the fresh threshold would have been exceeded 6 to 7 times per year compared to the historical frequency of one event per year (Figure 4.126). Under historical conditions the median duration would be 3 days compared to 7 days under natural conditions. The occurrence of freshes is evenly distributed throughout the summer/autumn period under all modelled flows.

There is no specific summer/autumn high flow recommendation. In other reaches a summer high flow has been recommended to enhance opportunities for spawning by Australian grayling. There is no specific objective for Australian grayling in Reach 9 so a high flow has not been recommended.

Figure 4.126 Duration (top left, frequency (top right) and start month (bottom left) for flows above the summer/autumn fresh flow threshold under natural, current and historic conditions for Reach 9.
**Winter/spring low flows**

The winter/spring low flow recommendation is 20 ML/d. This flow provides an increased depth over riffles (eg. Transect 3) (Figure 4.127) compared to the summer low flow to facilitate fish passage and provide increased habitat for macroinvertebrates. It also inundates vegetation on lower banks.

- **Figure 4.127** Stage height in a riffle (Transect 3, left) and pool (Transect 6, right) at the recommended threshold for winter/spring low flows in Reach 9.

Under historic conditions flow would have fallen below the winter/spring low flow threshold 3 to 4 times per year for a median duration of 15 days, 10% of spells would have lasted longer than 80 days (Figure 4.128). Under natural conditions spells below the threshold would have occurred around 3 times per year for a median duration of 5 days but with 10% of spells lasting longer than 18 days.
Winter/spring freshes

The recommended winter/spring fresh is 70 ML/d 4 times per year for a duration of 3 days. This flow provides an average depth of 30 cm over riffles to facilitate fish passage and inundates banks to maintain flood-tolerant vegetation and provide a disturbance regime for terrestrial vegetation (Figure 4.129). The fresh flow will also create zones of high velocity that will scour biofilms and assist in resetting successional patterns.

Under historic conditions the fresh threshold would have been exceeded around 3 times per year for a median duration of 5 days (Figure 4.130). Naturally, the fresh threshold would have been exceeded on average 6 times per year for a median duration of 9 days.

There is no separate high flow recommendation. It is considered that freshes and an annual bankfull flow provide an appropriate disturbance regime in this reach.
- Figure 4.129 Stage height in a riffle (Transect 3, left) and pool (Transect 6, right) at the recommended threshold for winter/spring fresh in Reach 9.

- Figure 4.130 Duration (top left, frequency (top right) and start month (bottom left) for flows below the winter/spring fresh flow threshold under natural, current and historic conditions for Reach 9.
Bankfull

The recommended bankfull flow is 600 ML/d once per year for 1 to 2 days. This flow inundates benches and high flow channels (e.g. Transect 6) (Figure 4.131) and reaches the top of ill-defined banks along the reach. The bankfull flow provides a significant disturbance to vegetation growing on banks and scours sediment from pools and riffles. If a proportion of the bankfull flow is provisioned from upstream of Cades Road then it will support objectives for inundating remnant swamps downstream of Cades Rd and will assist in channel maintenance flows upstream of the bed rock controlled sections of the Plenty Gorge.

Under historical conditions the bankfull threshold is exceeded once every 1 to 2 years for a median duration of 2 days (Figure 4.132). Under natural conditions a bankfull flow would have occurred 4 times per year for a median duration of 2 days. Bankfull flows can occur at any time during the year.

- Figure 4.131 Stage height in a riffle (Transect 3, left) and pool (Transect 6, right) at the recommended threshold bankfull flows in Reach 9.
Long section

Figure 4.133 shows the water surface level for each flow threshold along a long section of Reach 9. Water surface levels indicate sufficient depth for fish passage is achieved over the riffle at Transect 3 for most flows and significant pool depth would be retained even under low and cease to flows.

Figure 4.133 Long section showing water surface level for all flows in Reach 9.
4.9.3 Current compliance

Compliance with environmental flow recommendations for Reach 9 is presented in Table 4.16. Unlike all other reaches, there is a large difference between the current, natural and historical flow series for the Plenty River. Under the apparent current regime there is a relatively high compliance with the flow recommendations and little difference in flow equivalents between the natural and current regimes. However, when compared with the historical or measured flow regime there is poor compliance with the flow recommendations.

The differences between the current regime and the historical regime warrant further investigation. The current flow series is derived from Melbourne Water’s headworks REALM model for the Plenty catchment. The historical time series is based on measured flow at the Mernda gauge. At this point, compliance should be compared with the historical regime as it appears the current flow regime is not an accurate representation of the actual current flow. The differences between the current and historical regimes need resolving.

Historically the summer low flow recommendation would have only been complied with 15% of the time. Summer freshes would have occurred in 44% of years but would have only met the recommended frequency in 10% of years.

Historically the winter low flow recommendation would have been complied with 34% of the time. The recommended winter fresh volume would have been achieved in 83% of years but the recommended frequency would only have been met in 40% of years. And the bankfull flow would have been met in 50% of years. Under the historical regime the duration of all fresh and bankfull events would have frequently complied with recommended durations.

Delivery of flow recommendations in Reach 9 is likely to require increased releases from Toorourrong reservoir.
### Table 4.16 Reach 9 compliance with environmental flow recommendations.

<table>
<thead>
<tr>
<th>Component</th>
<th>Time</th>
<th>Flow Rec</th>
<th>Percentage of years (vol &amp; no.) or events (dur.) when flow recs are complied with for the historical &amp; current flow regime</th>
<th>Differences between each flow component for the historical, current &amp; natural regime for comparative purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Historical</td>
</tr>
<tr>
<td>Summer low</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>10*</td>
<td>15</td>
</tr>
<tr>
<td>Summer fresh</td>
<td>(Dec-May)</td>
<td>Volume</td>
<td>55</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>Summer high</td>
<td></td>
<td></td>
<td>No specific recommendation</td>
<td>3</td>
</tr>
<tr>
<td>Winter low</td>
<td>(Jun-Nov)</td>
<td>Volume</td>
<td>20*</td>
<td>34</td>
</tr>
<tr>
<td>Winter fresh</td>
<td>(June-Nov)</td>
<td>Volume</td>
<td>70</td>
<td>83</td>
</tr>
<tr>
<td>Winter high</td>
<td></td>
<td>Volume</td>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration</td>
<td>1-2</td>
<td>100</td>
</tr>
<tr>
<td>Bankfull</td>
<td></td>
<td></td>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td>Overbank</td>
<td></td>
<td></td>
<td>No recommendation – provided by bankfull flow if provisioned from upstream of Cades Road</td>
<td>1</td>
</tr>
</tbody>
</table>

* or natural whichever is lower (cease to flows are acceptable if they would have occurred naturally and for a duration no longer than 5 days)
5. **Priority flow components, risks and monitoring**

While the FLOWS method provides an objective process for determining environmental flow requirements to meet reach-based environmental objectives, a number of risks and uncertainties exist in the development of flow recommendations. Flows can be determined with confidence for objectives where there is some understanding of the physical or biological response to flows. However, for some processes the response to flows is not well understood, is inferred from other systems or is based on expert opinion. The use of a multi-disciplined technical panel is aimed at reducing the uncertainty in flow recommendations by providing a suitable level of experience and understanding of flow responses. However, there are still some uncertainties in the specific flow requirements of some biota and the expected physical or biological responses to different flow components.

In addition to uncertainty of flow requirements or response, there are various levels of risks associated with not meeting certain flow recommendations. The flow recommendations are aimed at delivering the minimum flows required to support objectives. However, some objectives may be more critical than others, for example in relation to threatened species, and it stands that delivering flows to support these objectives may be of a higher priority than for other objectives. Conversely, if it is not possible to provision for all flow recommendations then components that are repeatedly not met will become higher priorities for delivery over time. Despite this, the flow recommendations are considered the minimum required to achieve an ecologically healthy ecosystem as defined by the ecological objectives for the Yarra River and any reduction in the recommended flows will compromise the ability to achieve an ecologically healthy river.

Because the FLOWS method relies on an understanding of flow needs and expected physical and biological responses it lends itself to comprehensive monitoring of flow implementation. Monitoring enables a direct assessment of the physical and biological responses to flows and can be used to gain further information where there are uncertainties regarding expected responses. Monitoring may reveal that flow thresholds, frequency or duration are insufficient to achieve the desired response, in which case objectives would need to be revised or the flow recommendations revised. In other instances, monitoring may indicate that flow is not a limiting factor and that other factors are more important or limiting the achievement of environmental objectives. There have been a number of studies undertaken to determine programs and frameworks for monitoring environmental flows (e.g. Sharpe and Quinn 2004, Cottingham et al. 2005). The Environmental Flows Monitoring and Assessment Framework (Cottingham et al. 2005) outlines an approach to developing a flows monitoring program that should be followed to initiate a monitoring program prior to the implementation of flow recommendations.

In the Yarra River there are a number of risks and uncertainties associated with ecological response to flows and priorities for implementation; these are described in the following sections. It is beyond the scope of the FLOWS process to describe a detailed monitoring program, however an
indication of where particular monitoring requirements exist and which should be considered as part of the development of a detailed monitoring program are also considered.

5.1 Cease to flow

5.1.1 Rationale

Cease to flows occur in some systems during summer and provide a significant disturbance that stresses water dependant biota and resets successional patterns. In systems where cease to flow events are natural the biota have adapted to such events, and can survive cease to flow periods provided refuge habitat is available in pools or damp sediments, or where recolonisation potential has not been disrupted, for example by barriers to fish passage. There are no specific cease to flow recommendations for reaches in this study as all streams retain permanent flow except for the Plenty River.

Based on the current recommendations a cease to flow in the Plenty River is acceptable if it would have occurred naturally but only for a maximum duration of 5 days (the median duration of the natural cease to flow event). This is to limit the development of saline pools and minimise additional stress on aquatic biota.

5.1.2 Risks and uncertainties

In the Plenty River, natural cease to flows would have occurred in most summers for a short duration (around 5 days). Under current regulated conditions cease to flow events now last for a significantly longer duration. Even in natural systems, cease to flows exert a significant stress on biota so any increase in the cease to flows above the naturally occurring event can pose significant additional risks. In fact, in systems that are stressed through other factors, such as poor water quality, degraded habitat or loss of refuge habitat any cease to flow event can pose a significant risk.

In the Plenty River, prolonged cease to flows increase the risk of the development of saline pools that can reduce access to deep pool habitat by aquatic biota, ironically in the time they most need access to refuge habitat. It is likely that saline pool development is a natural occurrence in the Plenty River but prolonged low flows and cease to flows have probably exacerbated the problem.

There is considerable uncertainty regarding the environmental impacts associated with cease to flows in the Plenty River, on the role cease to flows play in the development of saline pools and the additional stress that this adds to aquatic biota. A recent study of cease to flows and saline pool development in the Plenty River by Potter (2003) showed that pool salinities can rapidly increase to around 3000 µS/cm in bottom waters and that as the period between mixing events increases the salinity in surface waters slowly increase as well. Flows of around 50 ML/d are required to fully mix pools and reduce salinity, however once low flows return, salinity in bottom waters again rapidly increase.

The biota in the Plenty River is likely adapted to naturally high salinities. In particular, river blackfish can survive at salinities up to around 4500 µS/cm (Koehn and O’Connor 1990). So the
current observed salinities do not pose a significant risk to river blackfish. On this basis, a cease to flow and the development of saline pools is an acceptable risk in the Plenty River, although prolonged cease to flows are likely to increase the stress levels experienced by aquatic biota and may impact on the systems ability to achieve its full diversity potential. Given this, a cease to flow is not specifically recommended, however, it is acceptable if it would have occurred under natural conditions provided the duration does not exceed the natural duration. This ensures risks associated with prolonged cease to flows are minimised. Maintaining a continuous low flow should be a priority as this is likely to be effective at limiting the development of saline pools in the first instance (Potter 2003).

5.1.3 Monitoring and investigations
Ongoing monitoring of the mechanisms around saline pool development, water quality and the responses of biota should be undertaken, particularly once environmental flows are implemented.

5.2 Summer low flows

5.2.1 Rationale
Summer low flows have been determined based on criteria to wet the full width of riffles, to maintain access to habitat in pools and to minimise the risk to water quality associated with saline pool development and anoxia. The flow threshold is based on physical characteristics of the channel with respect to availability of habitat under different flows and knowledge of the potential risks to water quality if flows are too low for a prolonged period. For example, monitoring data that shows the effects of low flows on water quality in Reach 5 (Ewert and Pettigrove 2003) and Reach 9 (Potter 2003) has been used to help define the low flow thresholds in those reaches where poor water quality is considered a potential risk under low flow conditions.

5.2.2 Risks and uncertainties
Channel surveys and hydraulic modelling mean that we can be confident in the water levels required to maintain the full width of riffles wet, to inundate specific habitats or to provide a certain depth in pools. However, there is some uncertainty about the impacts that very low flows have on water quality, particularly reduced mixing of pools and the potential for increases in salinity and reduction in dissolved oxygen. More detailed and complicated modelling would be required with better data to model mixing and water quality changes under low flows: this is beyond the scope of the current assessment. However, based on monitoring that has taken place during actual low flow events in Reach 5, water quality impacts have been observed when flows fall below 150 ML/d (Ewert and Pettigrove 2003). To this end, the recommended summer low flow has been based on providing access to habitat but with a suitable buffer to minimise the risks associated flows falling too low.

The greatest risk from low flows is that prolonged low flows, even at the recommended threshold, may result in water quality declines under some circumstances. For this reason fresh flows have been recommended to provide a periodic flushing flow that would help mix pools and improve water quality. If fresh flows are not provided as recommended there is an increased risk that water
quality problems may develop under prolonged low flows. Hence the implementation of the summer low flow recommendation requires that freshes are also provided. Reaches most at risk are those in agricultural and urban areas (all reaches except Reaches 1 and 2).

The recommended summer low flow threshold is the minimum flow required to maintain a healthy ecosystem. Flows higher than the minimum flow threshold do not pose a risk to environmental values or objectives unless those flows are due to significant unseasonal releases from reservoirs for irrigation supply purposes. This is not an issue in the Yarra River or its tributaries.

5.2.3 Monitoring and investigations
Monitoring water quality issues associated with low flows is a relatively straightforward exercise. A suitable program would require frequent monitoring over the low flow period of a range of indicators likely to respond to low flows (for example, temperature, dissolved oxygen, salinity and nutrients). Continuous remote monitoring is the preferred approach because it enables changes in water quality variables to be linked to external events such as variations in flow, diel patterns and local rainfall and runoff events.

5.3 Summer freshes
5.3.1 Rationale
Summer freshes have been determined based on criteria relating to the generation of velocities in riffles to help scour sediment and biofilms from benthic surface and around LWD and to mix pools to ameliorate any declines in water quality (eg, Reach 9 in the Plenty River). The overall aim is to reduce the accumulation of sediment and excessive biofilm growth to maintain the quality of habitat for macroinvertebrates during subsequent low flows and to minimise the potential for water quality decline due to prolonged low flows. The criteria for determining fresh flows was based on generating an average velocity of 40-50 cm/s in riffles or around LWD, or at achieving flows considered sufficient to mix pools.

Note that biofilms provide an important ecological function as a site for nutrient assimilation and as a food resource for microbes and macroinvertebrates. However, excessive growth can reduce access to habitats for macroinvertebrates and late successional filamentous species offer a reduced food quality to macroinvertebrates compared to early successional species (Lamberti et al. 1989, Lamberti 1996, Sheldon and Walker 1997). Maintaining biofilms in an early successional state through frequent disturbance through scouring and wetting and drying may result in a more palatable food resource for macroinvertebrates (Treadwell 2002).

5.3.2 Risks and uncertainties
While the summer fresh volume has been determined based on specified criteria, the variable nature of aquatic ecosystems means that responses to specific flows are not always predictable and there will always be a level of uncertainty regarding specific physical and biological responses to flows. However, fresh flow volumes, timing and duration have been based on the best available information and opinions of the EFTP at the time of the assessment. If further information...
becomes available or monitoring reveals the desired ecological response is not being achieved then the flow recommendation may need to be revised – this applies to all recommendations.

Specific risks associated with freshes are that the volume is insufficient to create scouring flow over a significant area of riffle or is insufficient to mix pools.

In the Yarra River reaches it is considered that the fresh flow volume is sufficient to create scouring flows through riffles and around LWD. However, there is some risk that in urban reaches elevated nutrients may result in a rapid recovery in algal biomass and any effect of a scouring flow will be short lived (see Taylor et al. 2004). In urban reaches, seasonal factors such as light intensity and temperature are likely to be greater drivers of algal biomass accumulation than flow (Taylor et al. 2004). Efforts to improve water quality, particularly nutrient concentrations and sediment inputs are likely to yield greater benefits in terms of reducing excessive algal growth and sedimentation in urban waterways. This can be achieved through the implementation of stormwater management plans and catchment-wide implementation of low-impacts stormwater drainage design.

In the Plenty River, the study of Potter (2003) demonstrated that flows between 40 and 60 ML/d were sufficient to mix stratified pools and resulted in a short term improvement in water quality. The recommended fresh flow in the Plenty River of 55 ML/d is based on this work and the recommended frequency is aimed at reducing the prolonged nature of current low events. It is considered the risk of freshes being too low in the Plenty River to achieve the desirable physical and ecological response is low.

5.3.3 Monitoring and investigations
监测沉淀物积累和生物膜生物量，以及在特定地点和不同基质上的监测，是建立流量与流量关系的最佳方法，并用于测试流量推荐的效果。
5.4 Summer high flows
5.4.1 Rationale
Summer high flows have been specified to provide a spawning cue for Australian grayling and to transport larvae to the estuary.

5.4.2 Risks and uncertainties
There is little information on the biological requirements of Australian grayling and what is available is from systems other than the Yarra. It is thought that grayling spawn in response to a drop in temperature and increased flows in autumn (Hall and Harrington 1989), and that these flows may assist in transporting larvae to the estuary. In a study of grayling spawning in the Barwon River, O’Connor and Mahoney (2004) found that if high flows did not occur prior to June then ovarian involution occurred and spawning did not take place. However, there is uncertainty regarding the specific flow volume required to trigger spawning, the duration required to transport larvae to the estuary and the preferred timing.
With regards to flow, it is uncertain whether the volume increase has a critical threshold that must be exceeded for spawning to occur or whether any increase above the low flow is suitable. The flow recommendation for the Yarra River is based on providing a flow increase from base flow to the median of the natural flow in May and June. Based on HEC RAS modelling in each reach this flow provides a significant increase in water level. Specific research is needed of local populations to determine if there is a critical flow threshold that must be exceeded and whether there are other environmental factors, such as temperature, that may influence spawning in the Yarra River.

With regards to duration, there is uncertainty about whether the flow increase is the same flow that transports larvae to the estuary, in which case the duration needs to be sufficient to enable the flow increase to progress through the whole system, or whether larvae drift to the estuary with subsequent flows. It is also uncertain whether the flow increase needs to be maintained for a particular period of time before spawning occurs or whether even short duration increases are sufficient. On the basis of this, we have erred on the conservative side and recommended that the high flow event be of a relatively long duration (7 day) to provide sufficient time for larvae to be transported and to provide a number of days over which spawning can occur. In some reaches this duration is longer than median natural duration. However, in most years under natural conditions several high flow events would have occurred, some for relatively long duration, hence providing a number of opportunities for spawning to occur. More research is needed to determine the specific duration of flows and to better understand larval drift requirements.

With regards to timing, there is uncertainty about specific timing and whether flows are required to coincide with particular events. In coastal NSW streams spawning has been observed in February to March (Bishop and Bell 1978), while in eastern Victoria, spawning occurred in the Tambo River in April to May (Berra 1982) and in the Barwon River, spawning occurred in May (Hall and Harrington 1989). Other environmental factors may also be important, for example, Hall and Harrington (1989) concluded that spawning occurred following high flows in May after a drop in temperature and in the full moon to last quarter of the lunar phase, and that declining day length may also be a factor. For the Yarra River, we have recommended that the high flow be provided in April to May, consistent with the apparent timing of spawning in southern Victorian coastal streams. However, it is unclear whether this flow needs to coincide with a particular lunar phase and more research may be needed in this regard.

Based on uncertainties there are a number of risks associated with the recommended high flow and also in failing to achieve a high flow event.

If the recommended volume is too low or duration is too short then there is a significant risk that spawning will not occur, or that spawning will occur but that larvae will not reach the estuary. Either of these will result in poor recruitment success. Australian grayling are a short lived species (2-3 years), so poor recruitment in successive years, either through in inappropriate flow recommendation or failure to provision the flow recommendation, poses a risk to the entire population, particularly if grayling have a high site fidelity. If site fidelity is high and each river/estuary system has its own discrete population, failure to spawn and recruit over successive
years poses a significant risk to the viability of local populations. If larvae mingle in coastal waters and ascend any available river then this risk is reduced provided each year some proportion of the population successfully recruits.

Provision of suitable fish passage for larvae to ascend to freshwater reaches in spring is also critical. This is further discussed below for winter/spring freshes and high flows.

If the recommended volume is too high or duration too long there is no risk to spawning or recruitment success but the excess water may not be being used to its greatest efficiency.

5.4.3 Monitoring and investigations
As indicated above, more information is required on the specific spawning requirements of Australian grayling. Based on studies from other systems there is significant uncertainty regarding specific flows, timing and other environmental factors that trigger spawning. It appears that site specific issues and conditions are important, so understanding the specific life history requirements of the Yarra grayling population is critical. Such studies should be undertaken in the Yarra River and should also involve monitoring of spawning behaviour and larval drift as part of any monitoring program undertaken to assess the effectiveness of environmental flows.

5.5 Winter low flows
5.5.1 Rationale
The winter low flow is based on providing an increased area of habitat for macroinvertebrates, improved opportunities for local fish passage and also inundates vegetation on the lower banks. Increased area of available habitat in winter for macroinvertebrates is important because primary production is lower in winter so less food resources are available. This can be compensated for by providing access to additional habitat.

5.5.2 Risks and uncertainties
The low flow volume is based on physical characteristics of the channel and the inundation of specific habitats such as low benches, or in providing increased depth over riffles for fish passage. The FLOWS method provides an objective approach to determining flow requirements to meet objectives and on this basis the recommended flows are considered appropriate to achieve the specified objectives.

The winter low flow is the minimum flow required to meet objectives. Flows below this threshold represent an increased risk to achieving objectives. However, higher flows and variability above the minimum flow are not a risk. Any risks associated with the minimum winter low flow threshold are considered low. However, as with other flow components, if further information becomes available or monitoring reveals the desired ecological response is not being achieved then the flow recommendation may need to be revised.
5.5.3 Monitoring and investigations
Routine monitoring of a range of water quality and biotic variables is required to ensure desired objectives are achieved. The development of a comprehensive monitoring program is beyond the scope of the current study.

5.6 Winter freshes and high flows

5.6.1 Rationale
Freshes and high flows are aimed at providing flow variability in the winter period, inundation of benches to entrain organic material, inundation of banks to provide a disturbance to vegetation and providing opportunities for fish passage. The winter/spring high flow is particularly aimed at providing a prolonged inundation of the banks to drown terrestrial vegetation where it is encroaching down the banks and to make growing conditions less favourable for semi-aquatic weeds that have colonised the waterline in some reaches, particularly Reaches 3, 4 and 5.

5.6.2 Risks and uncertainties
The flow volume for freshes and high flows has been determined based on an assessment of physical channel features and levels of inundation required to achieve objectives. The timing and duration of the high flow is based on providing a prolonged high flow event in the main growing season for plants. Based on HEC RAS modelling the risks that important channel features are not inundated to the appropriate depth are low. There is a risk that the duration of inundation of the high flow event is insufficient to depress the growth of terrestrial vegetation. However, the specified duration is based on the best available information at the time and opinion of the EFTP. If the duration is too short then terrestrial vegetation will not experience the appropriate disturbance regime to limit encroachment on the banks. Fortunately, this is easy to monitor. In addition, repeated inundation over several years is likely to be required to achieve an acceptable long term response, so infrequent delivery of the flow recommendation in unlikely to result in an acceptable ecological response that will meet objectives.

The freshes and high flows are likely to be sufficient to assist fish passage. However, there is some uncertainty regarding the effectiveness of the Dights Falls fishway during high flow events (Zampatti et al. 2002) and this is also supported by anecdotal evidence from members of Native Fish Australia (Ron Lewis Pers. com.).

There is also uncertainty regarding the freshwater flows needed to mix and flush ‘aged’ salt water from the estuary and allow reestablishment of a well-oxygenated salt wedge and vertical and longitudinal salinity gradients from the upper to lower reaches. Analysis of residence times of surface and sub-surface waters in the estuary indicate that flow volumes equivalent to freshes and high flow recommendations will mix sub-surface waters in less than 3 days. However, the specific ecological requirements of the estuary for mixing and flushing of the salt wedge are unknown.
5.6.3 Monitoring and investigations
Monitoring of freshes and high flows should focus on the key objective of providing a disturbance regime to terrestrial vegetation encroaching on banks. In particular, the duration of the high flow events needs to be assessed to determine if it is appropriate to drown out terrestrial vegetation.

Further investigations are needed into opportunities for improvement in the Dights Falls fishway, particularly during the spring high flow period when the majority of diadromous species are attempting upstream migrations. Further investigations are also needed to establish relationships between freshwater inflows to the Yarra estuary, mixing mechanisms and vertical and longitudinal salinity gradients and the ecological implications of these.

5.7 Bankfull and overbank flows
5.7.1 Rationale
Bankfull flows are aimed at providing a channel maintenance flow by scouring accumulated sediment and maintaining channel geometry. Bankfull and overbank flows are also aimed at engaging wetlands and floodplains. Flows are determined by the physical characteristics of the reach, wetland inlet levels and floodplain form.

5.7.2 Risks and uncertainties
There is little uncertainty in recommended volumes, timing or duration of bankfull and overbank flow events as they are determined based on specific channel characteristics and relatively well understood physical and ecological responses. The risks associated with these flows are that the recommendations are not met and that the desirable physical and ecological responses do not occur. Under current conditions the Bankfull flow recommendation is mostly met in all reaches, except Reach 1, so there is little risk associated with failing to achieve the Bankfull flow. The frequency of overbank flows has reduced significantly but provisioning for overbank flows from upstream storages is unfeasible so overbank flows when they do occur are of significant importance in engaging wetlands and floodplains. Thus it is critically important to protect bankfull and overbank flows when they do occur and allow them to progress down the entire river system. In other words, any water harvesting operations need to be undertaken in such a way that they do not impact on the current frequency and duration of bankfull or overbank flows.

There are significant risks associated with reductions in the frequency of bankfull and overbank flows, these include the instigation of channel contraction, reduced disturbance of vegetation on banks and altered water regimes for wetlands that can result in changes in vegetation community composition and wetland processes.

With additional regard to wetlands and floodplain, most wetlands and floodplain in Reaches 3 and 4 have been cleared of vegetation and are now colonised by pasture grasses. There is some uncertainty regarding the specific benefits to the river of providing overbank flows in these degraded systems. However, recent research in Western Victoria has demonstrated that inundation of pasture wetlands still provide a valuable contribution to regional biodiversity and links between the river and even degraded wetland environments are important for maintaining both riverine and
wetland diversity and function (Robson and Clay in press). To this end, inundation of the wetlands and floodplain is considered important. However, there are social and economic risks that need to be managed. For example, prolonged inundation of pasture grasses can result in death and subsequent economic loss to farmers. In addition, to take full advantage of bankfull and overbank flows that inundate wetlands and floodplain, opportunities to restore sections of floodplain should be investigated and fencing, stock removal and revegetation undertaken in these areas.

The provision of a bankfull flow in Reach 1 is the exception to the above discussion. Bankfull flows in this reach have been eliminated due to the impacts of Upper Yarra Dam. It is undesirable to implement an annual bankfull flow to restore the natural channel geometry. However, a one in ten year bankfull event is recommended to scour sediment from pools and restore access to habitat for fish and macroinvertebrates. Failure to deliver this flow recommendation will mean that all other flow recommendations for Reach 1 will be compromised in their ability to achieve environmental objectives until the bankfull flow and subsequent high flows are implemented.

5.7.3 Monitoring and investigations
Monitoring of bankfull and overbank flows should focus on the key objective of providing a channel maintenance flow and inundation of wetlands. Changes in the vegetation community composition of wetlands should be tracked to determine if undesirable changes are occurring if it is not possible to deliver overbank flows.

Investigations are needed to identify and prioritise wetlands and areas of floodplain for more targeted restoration work to take full advantage of bankfull and overbank flows. In addition, the role of urban tributaries in contributing to overbank flows in the Reach 6 need to be investigated. Significant overbank flows as a result of runoff from urban tributaries may contribute poor water quality to wetlands that could compromise their values. The potential benefits and impacts of direct inflows of urban stormwater to wetlands should also be investigated. For example, whether it is possible to use stormwater as a surrogate for overbank flows to provide water to wetlands, or whether the potential water quality impacts outweigh any benefits.

5.8 Flow and reach priorities
In most reaches the low flow threshold and fresh volume are complied with. However, in many reaches the frequency and duration of freshes and high flows is not met in every year. Failure to meet the recommendations will impact on the ability to achieve environmental objectives and establish and sustain an ecologically healthy river. The specific flow priorities in each reach are listed below:

Reach 1
The highest flow priority in Reach 1 is to provide an initial bankfull flow to scour sediment from pools and restore access to pool habitat for macroinvertebrates and fish. Access to habitat is limiting the ability to achieve an ecological healthy river in this reach. Once a bankfull flow has been delivered it is necessary to maintain the channel with high flows at the recommended frequency.
Reach 2
Most flow recommendations are complied with in Reach 2. Maintaining flows above the low flow threshold is important, as is protecting high flow events that contribute to bankfull and overbank flows in downstream reaches. Actions to prevent degradation of the riparian zone are important to protect existing values.

Reaches 3 and 4
Low flow thresholds are mostly met in Reaches 3 and 4. However, the duration of freshes and high flows is not achieved. The highest priority flows are the summer/autumn high flow to support opportunities for Australian grayling spawning and winter/spring high flows to disturb terrestrial vegetation on banks. Protecting bankfull and overbank flows when they occur and allowing them to pass to downstream reaches is also important.

Instream habitat restoration, fencing and rehabilitation of the riparian zone and rehabilitation of the floodplain are all required to take full advantage of environmental flow recommendations.

Reach 5
Maintaining low flow thresholds and the frequency of freshes to ensure variability is important in this reach. Meeting the minimum duration of the summer/autumn high flow event is also important to support opportunities for Australian grayling spawning. Protecting bankfull flows when they descend from upstream reaches is also important.

Reach 6
The highest priority flows in this reach are the summer/autumn high flow to support opportunities for Australian grayling spawning and winter/spring high flows to disturb terrestrial vegetation on banks, provide migration flows for fish and flows to mix the Yarra estuary. Catchment management activities to reduce water quality and sediment impacts are also critical and the effectiveness of the Dights Falls fishway is important.

Reach 7
Winter/spring high flows from upstream reaches are important to mix the estuary and flush aged salt water out of system. High flows are also important for reducing salinities that may provide cues for spawning of estuarine species and migration of diadromous species to freshwater reaches. An improved understanding of the relationship between flows and the dynamics of the salt wedge and salinities is needed to confirm the specific flow requirements for the estuary. Catchment management activities to reduce water quality and sediment impacts are also critical.

Reach 8
The summer low flow is the highest priority flow component in this reach followed by the frequency of summer freshes to maintain variability in the low period. Instream habitat restoration, rehabilitation of the riparian zone and management of water quality impacts are also important.
Reach 9
The summer and winter low flow thresholds and freshes are critical in this reach to minimise the stresses associated with prolonged saline pool development. Provision of high flows and bankfull flows from upstream of Cades Road is important to protect remnant swamps in the middle reaches.
6. Complementary waterway works and further investigations

Throughout the report references have been made to a range of complementary waterway works and further investigations. Complementary works are aimed at creating opportunities for improvements in ecological health independent of flows and also at maximising the opportunity to achieve the full ecological advantage of environmental flow provisions. Further investigations are needed where there is insufficient data or understanding to enable an objective assessment of flow requirements or to be confident in predicted ecological responses to flow or complementary works.

Table 6.1 summaries the recommended complementary works and further investigations. A more detailed discussion of the priority works relating to wetland rehabilitation, riparian revegetation and LWD reinstatement and water quality management is also presented. Most of the recommended works and investigations are consistent with recommendations from current strategies (eg. the Regional River Health Strategy), or are already being implemented (eg. revegetation works and stormwater management plans).

A detailed environmental flows monitoring program also needs to be prepared based on the framework developed by Cottingham et al. (2005).

6.1 Wetland rehabilitation

Significant floodplain and wetlands areas exist along Reaches 3, 4 and 6, and to a lesser extent Reach 5. In Reaches 3, 4 and 5 the floodplain and wetlands have been extensively cleared for agricultural production and converted to pasture grass. In Reach 6 a number of regionally significant wetlands remain protected within an extensive network of urban parks, but changed hydrology poses a threat to their values.

Connectivity between riverine and floodplain environments are important for a number of ecological reasons, including transfers of nutrients and sediment and contribution to life history requirements for both riverine and floodplain biota, particularly wetland plants and macroinvertebrates. The clearing of floodplains reduce the value of floodplain inundation to riverine systems, although recent research indicates that inundation of pasture dominated wetlands can still be important for regional biodiversity (Robson and Clay in press), particularly for water birds and macroinvertebrates.

Bankfull and overbank flows have been recommended for all floodplain reaches along the Yarra River. With the recommendations basically aimed at retaining the current frequency and duration of such events. However, to take full advantage of these flows there is a significant opportunity to rehabilitate wetlands and floodplain areas. Such works would involve fencing, removal of levees and other structures that may restrict flow paths and revegetation with suitable wetland and floodplain vegetation.
Priority areas for wetland and floodplain rehabilitation are Reaches 3 and 4 and the Henley floodplain in Reach 5. Particular locations where rehabilitation could take place are shown in Figure 6.1 and include Henley floodplain, Yering Backwater and Spadonis Reserve at Coldstream, upstream of Yarra Glen and around Tarrawarra, the Melba Highway and Woori Yallock. In Reach 6, the management of urban wetlands requires the development and implementation of specific wetland management strategies. A management plan has previously been recommended for three priority in the Yarra Flats wetlands; Banyule Billabong, Annulus Billabong and Bollin Bollin Billabong (Mitchell et al. 1995). It is unclear the extent to which active management of these system to maintain and enhance environmental values is occurring and management strategies and recommendations should be revisited considering the environmental flow recommendations presented in this report.

Prior to any specific rehabilitation activities, a through survey and investigation of the floodplain reaches is required to survey and further prioritise wetland areas for rehabilitation. Such a strategy has been recommended in the Regional River Health Strategy and its development is strongly encouraged. As most wetlands are located on private land any rehabilitation activities need to be fully supported by local landholders and community stakeholders. The development of a region-wide wetland strategy would greatly assist in the identification of wetland areas for rehabilitation and provide a strategic framework for ongoing management.

6.2 Riparian revegetation and LWD reinstatement

Significant resources and effort has gone into fencing and revegetation of the riparian zone throughout the Yarra catchment, including tributaries. However, the riparian corridor is still discontinuous in many locations, particularly through Reaches 3, 4 and 9. In addition, where revegetation has taken place the corridor width is generally very narrow and in some instances bank erosion may threaten revegetation works. In future, riparian revegetation needs to include a wider corridor, even to the extent that the meander train is fenced rather than fences following the top of banks. Specific locations for riparian revegetation have not been identified. Strategies need to be developed at a reach scale and implemented at a local level with the assistance of local landholders and facilitated through dedicated staff with appropriate resources and community support. Priority reaches for riparian revegetation are Reaches 3, 4 and 9 and to a lesser extent Reach 7 and 8 (Figure 6.1). Management of existing riparian vegetation, particularly weed control, is required in Reaches 2, 5 and 6.

The Yarra River has a long history of desnagging along its entire length and this has had a significant impact on the availability of physical habitat for fish, but also on geomorphic and hydraulic processes. The protection of existing LWD habitat and supply from the riparian zone is essential. In addition reinstatement at a reach scale is also required to take full advantage of environmental flow recommendations. For many objectives related to fish and macroinvertebrates, the availability of suitable snag habitat is likely to be more limiting than specific flow components, particularly in low flow periods. Priority reaches for LWD reinstatement are Reaches 3, 4 and 9, and to a lesser degree Reaches 6 and 8 (Figure 6.1). The protection of existing LWD habitat and supply from existing riparian vegetation is required in Reaches 2, 5 and 6.
There are a number of useful guidelines available for assisting with the planning and implementation of riparian revegetation and LWD reinstatement (e.g. Abernethy and Rutherford 1999, Treadwell 1999, Rutherford et al. 2000a, 2000b, Koehn et al. 2001). It is recommended that reach scale habitat restoration and management plans be included in ongoing waterway action planning activities. The above guidelines may provide useful information for assisting with the development and implementation of such plans.

6.3 Water quality management

Poor water quality is a significant risk to ecosystem health in the Yarra catchment. Indeed, in urban reaches, such as Reaches 6 and 7, water quality is likely to be a significant factor in limiting the achievement of environmental objectives for an ecologically healthy river. Most of the water quality issues associated with the Yarra River cannot adequately be addressed by increased flows. In fact, increased flows will only mask the problem. Water quality needs to be managed at the source, in the catchments of urban tributaries and to a lesser degree in relation to agricultural activities.

In urban areas, stormwater management plans need to be implemented, although the greatest benefit is more likely to be achieved through the implementation of catchment-wide low-impact stormwater drainage. Increased catchment imperviousness is regarded as the greatest factor in contributing to water quality decline and consequent decline in ecological condition. Catchment imperviousness levels greater than 8 to 10% appears to represent a critical threshold for a range of ecosystem processes and biological community responses (Walsh et al. 2005). To address this, Walsh et al. (2005) provide a model for low-impact stormwater design in urban areas that has the effect of reducing catchment imperviousness below critical levels by reducing the frequency of runoff from urban catchments. Design elements are based at the local scale rather than end-of-pipe solutions and are aimed at matching runoff from urban catchments to those experienced in natural catchments. They demonstrate how this can be achieved through local retention such as rainwater tanks and infiltration through the use of porous pavements and grass swales as opposed to the standard concrete kerb and drain system. At the very least, such elements should be incorporated into new urban development but opportunities to retrofit retention elements in established neighbourhoods should also be investigated.

6.4 Further investigations

In addition to complementary works a number of further investigations are recommended. Some of these relate to complementary works, for example, the development of a wetland management strategy, others are required to fill knowledge gaps in our understanding of ecological responses and to enable better management of flow related issues. For example, it remains unclear as to the specific risk to biota in Reach 1 from potential cold water releases from the Upper Yarra Dam. Further data is needed to clarify the potential issues, particularly to investigate thermal regimes in the dam itself and to model potential impacts. Also, the biology of Australian grayling is not well understood, and while a significant effort has gone into identifying flows aimed at assisting spawning, there is uncertainty regarding specific requirements and further research is needed in this
regard. Other recommendations include the development of a hydrodynamic model for the Yarra Estuary and a more complete study of the environmental flow requirements of the estuary, the assessment of options for allowing passing flows down tributary streams to retain elements of flow variability and to contribute to meeting flow recommendations and the development of a comprehensive monitoring program for implementation of flow recommendations.
Figure 6.1 Location for priority works: wetland rehabilitation, riparian revegetation and LWD reinstatement.
### Table 6.1 Complementary waterway works and further investigations.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Complementary works</th>
<th>Further investigations</th>
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<tbody>
<tr>
<td>1</td>
<td>● Adhere to best practice guidelines &amp; codes of practice for roading &amp; forest activities in the Doctors Creek catchment</td>
<td>● Further investigate potential for cold water pollution in release waters from Upper Yarra Dam. Current data is insufficient to make a conclusive assessment of potential impacts. Temperature monitoring in dam itself is needed.</td>
</tr>
</tbody>
</table>
| 2     | ● Protect existing remnant riparian vegetation.  
● Undertake weed control & rehabilitation of degraded riparian vegetation  
● Undertake selected restoration of LWD habitat  
● Implement catchment management plans to limit water quality impacts | ● Investigate opportunities to allow the first autumn rainfall runoff event to pass down tributary streams to contribute to achieving the summer/autumn high flow recommendation. |
| 3     | ● Protect existing remnant riparian vegetation.  
● Undertake fencing, weed control & rehabilitation of degraded riparian vegetation with species appropriate for the EVC  
● Undertake reach scale restoration of LWD habitat  
● Undertake fencing and revegetation of floodplain & wetlands areas | ● Survey wetlands & floodplain to identify priority areas for rehabilitation (potential locations include upstream of Healesville-Woori Yallock Road and upstream and downstream of the Melba Highway) and develop wetland management plans. |
| 4     | ● Undertake fencing, weed control & rehabilitation of degraded riparian vegetation with species appropriate for the EVC  
● Undertake reach scale restoration of LWD habitat  
● Undertake fencing and revegetation of floodplain & wetlands areas | ● Survey wetlands & floodplain to identify priority areas for rehabilitation (potential locations include upstream of Yering gorge, around Spadonis Reserve & upstream of Yarra Glen) and develop wetland management plans. |
| 5     | ● Undertake fencing and revegetation of floodplain & wetlands areas in the Henley floodplain  
● Protect existing littoral vegetation & undertake weed control & rehabilitation of degraded riparian vegetation  
● Implement catchment management and stormwater management plans to limit water quality impacts | ● Investigate specific spawning and life history requirements of Australian grayling |
| 6     | ● Undertake reach scale restoration of LWD habitat  
● Undertake weed control & rehabilitation of degraded riparian vegetation  
● Implement stormwater management plans to limit water quality impacts  
● Catchment wide implementation of low-impacts stormwater drainage design  
● Undertake recommended improvements to Dights Falls fishway or undertake further investigations to assess effectiveness  
● Revise and implement wetland management plans | ● Investigate opportunities for alternative water sources to wetlands (eg pumping or lowering of sill level) if overbank flow recommendations cannot be achieved  
● Investigate the benefits or impacts of urban stormwater inflows to wetlands.  
● Investigate how overbank flows in urban reaches are influenced by runoff from urban tributaries. |
| 7     | ● Implement stormwater management plans to limit water quality impacts  
● Catchment wide implementation of low-impacts stormwater drainage design  
● Protect existing littoral vegetation & undertake weed control & rehabilitation of degraded riparian vegetation | ● Investigate estuary hydrodynamics to determine the relationship between inflows, mixing & salinity gradients  
● Gather site specific data on macroinvertebrate & fish community health to better understand current condition |
| 8     | ● Undertake reach scale restoration of LWD habitat  
● Undertake fencing, weed control & rehabilitation of degraded riparian vegetation with species appropriate for the EVC  
● Implement stormwater management plans to limit water quality impacts | ● Further investigate and monitor the development of saline pools |
| 9     | ● Undertake fencing, weed control & rehabilitation of degraded riparian vegetation with species appropriate for the EVC, particularly in mid and upper reaches  
● Restoration of LWD habitat in mid and upper reaches  
● Implement stormwater management plans to limit water quality impacts from rapid urban development  
● Catchment wide implementation of low-impacts stormwater drainage design |
7. References


