Victorian environmental flows monitoring and assessment program: Monitoring and evaluation of environmental flow releases in the Glenelg River

Yung En Chee, Angus Webb, Michael Stewardson and Peter Cottingham
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The University of Melbourne and eWater CRC

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1 Introduction

1.1 Victorian Environmental Flows Monitoring and Assessment Program

The provision of water to meet environmental objectives is a key feature of the Victorian River Health Strategy (DNRE 2002), which recognises the importance of the flow regime to river function and health. To this end, the Victorian Government is establishing Environmental Water Reserves (EWRs) that define a legally recognised share of water to be set aside to maintain or improve the environmental values of Victoria’s river systems (DSE 2004). Water will be delivered as environmental flows to achieve specific ecosystem outcomes in a number of Victoria’s large regulated rivers.

It is important to demonstrate whether or not the EWRs are achieving the desired ecosystem outcomes. The delivery of environmental flows represents a considerable investment in river protection and rehabilitation, especially given the competing demands for consumptive uses of water. Future decisions about the provision of environmental flows will rely on evidence that demonstrates the benefits or otherwise of these water allocations. Additionally, the large-scale delivery of environmental flows is a relatively new form of river rehabilitation. Evaluating ecosystem responses to changes in the flow regime will provide valuable information to support future decision-making within an adaptive management cycle.

The intention of the Victorian Government (Cottingham et al. 2005b) is to:

*Evaluate ecosystem responses to environmental flows in the eight high-priority regulated rivers that are to receive enhancements (of various degrees) to their flow regime.*

The Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP) has been established to coordinate the monitoring of ecosystem responses to environmental flows. To establish a robust and scientifically defensible monitoring program, the Department of Sustainability and Environment (DSE) requires:

- A consistent, scientifically defensible, framework for monitoring environmental flows across Victoria;
- Detailed, hypothesis based, monitoring plans for each of the eight high-priority rivers where the delivery of environmental flows is expected or underway;
- Sufficient flexibility in the monitoring framework and plans so that they can be adapted in light of changing conditions and information generated from annual analysis of monitoring data; and
- Ongoing scientific support to review the data and critically analyse the monitoring programs as implemented by the Catchment Management Authorities (CMAs). A full-scale data analysis and a review of progress against the program objectives for each monitoring program are anticipated every three years.
The high-priority rivers (and associated environmental flow studies) to be initially included in the Statewide program are the:

- Broken River (Cottingham et al. 2001)
- Goulburn River (Cottingham et al. 2003a, b)
- Campaspe River (Marchant et al. 1997, SKM 2005, 2006a, b)
- Loddon River (LREFSP 2002a,b, 2005)
- Thomson River (Earth Tech 2003)
- Macalister River (SKM 2003a)
- Glenelg River (SKM 2003b).

Separate reports discuss environmental flow monitoring in each of these rivers. This report deals with monitoring and assessment of environmental flows in the Glenelg River.

### 1.2 VEFMAP Process and Report Structure

The Statewide program is being developed and delivered in three main stages:

1. Development of an overarching Victorian (statewide) framework for monitoring ecosystem response to environmental flow releases (Cottingham et al. 2005a, b);
2. Development of targeted monitoring and assessment plans for individual river systems (this report, and those for the other rivers); and
3. Data analysis and interpretation, and program review after three years, including testing the value of taking a statewide approach to monitoring environmental flows.

For Stage 2, the framework and associated recommendations from Stage 1 (Cottingham et al. 2005b) were applied to develop the present monitoring and evaluation plan.

In developing this monitoring and evaluation plan, the general approach has been to:

- Define the conceptual understanding of flow–ecology relationships and the hypotheses to be tested using the original environmental flow reports and other literature;
- For the conceptual models developed, seek feedback from Scientific Panel members (involved in the original environmental flow studies for the individual river systems), the project Advisory Panel, DSE and CMA staff;
- Confirm key conceptual models and hypotheses that will form the basis of the monitoring and evaluation program;
- Consider the EWR releases expected for the next 2–3 years in individual rivers. Confirm the relevant hypotheses to be tested and from these, what variables are to be monitored in each river reach;
• Examine current monitoring arrangements in each river system (if any) and discuss how this aligns recommendations in the VEFMAP; and

• Consider Bayesian and other analyses that are appropriate, their assumptions and data requirements, and implications for the study design and interpretation of results.

The logical process used to arrive at recommendations for monitoring, along with the structure of the report is summarised in Figure 1. In each of the reaches previously identified for environmental flow enhancement in the Glenelg River (SKM 2003b), environmental flows and other major influences (e.g. land use) will drive the ecosystem responses. We have synthesised the conceptual models previously developed to obtain integrated conceptual models that illustrate our belief of how certain ecosystem components will respond to environmental flows. The models suggest measurement endpoints (e.g. bank erosion, fish abundance) that can be obtained from various field programs (e.g. channel surveys and electrofishing for the two endpoints above). We expect these endpoints will respond to environmental flows, and these responses will be tested using Bayesian or other analytical approaches. The models also contain areas of uncertainty that reduce our ability to predict the effects of environmental flows on certain ecosystem outcomes. These knowledge gaps are noted, and recommended as questions for specific research to be carried out concurrently with the monitoring program. Failure to carry out such research will not necessarily prevent predictions from being made, but they are likely to be more uncertain.

Figure 1. Process followed in developing the individual monitoring plans. The report is also structured according to this logic.
1.3 Environmental Flow Objectives for the Glenelg River

Environmental flow objectives for the Glenelg River (SKM 2003b, Table 1) were based on biodiversity and hydrological considerations. Flow recommendations to meet these objectives (Appendix 1) were developed for the following reaches of the Glenelg River (see Figure 2):

Reach 1 – Rocklands Reservoir to Chetwynd River Confluence
Reach 2 – Chetwynd River Confluence to Wannon River Confluence
Reach 3 – Wannon River Confluence to Tidal Extent.

The flow recommendations were designed to meet biodiversity and flow objectives. Biodiversity objectives related to a desired future state of key listed or threatened fauna within each reach, flora and fauna of value, or those with a strong relationship with flow. Biodiversity objectives also included objectives for the physical nature of the channel or ecological processes (e.g. connectivity) that have an indirect influence on biodiversity through some physical response. Flow objectives related to the important flow components required to achieve the Biodiversity Objectives.

Table 1. Summary of Glenelg River environmental flow objectives (from SKM 2003b)

<table>
<thead>
<tr>
<th>Environmental Objective</th>
<th>Process Objectives</th>
<th>Relevant Flow Component</th>
<th>Timing of Flow Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a Self sustaining populations of River Blackfish</td>
<td>Habitat</td>
<td>Low</td>
<td>All year</td>
</tr>
<tr>
<td>1b Self sustaining populations of Mountain Galaxias</td>
<td>Recruitment Movement</td>
<td>Freshes High</td>
<td>Winter/Spring</td>
</tr>
<tr>
<td>1c Self sustaining populations of Yarra Pygmy Perch</td>
<td>Recruitment Movement</td>
<td>Low</td>
<td>All year</td>
</tr>
<tr>
<td>2a Self sustaining populations of Southern Pygmy Perch</td>
<td>Habitat</td>
<td>Low</td>
<td>All year</td>
</tr>
<tr>
<td>2b Self sustaining populations of Variegated Pygmy Perch</td>
<td>Recruitment</td>
<td>Freshes</td>
<td>Winter/Spring</td>
</tr>
<tr>
<td>3 Self sustaining populations of Dwarf Galaxias</td>
<td>Recruitment</td>
<td>Low</td>
<td>All year</td>
</tr>
<tr>
<td>4a Sustainable River Swamp Wallaby-grass</td>
<td>Maintenance</td>
<td>Bankfull flows</td>
<td>Spring</td>
</tr>
<tr>
<td>4b Maintain diversity in channel form</td>
<td>Habitat diversity</td>
<td>High</td>
<td>Winter/Spring</td>
</tr>
<tr>
<td>5a Maintain of estuary ecosystem</td>
<td>Resevoir of natural flooding events</td>
<td>High flows</td>
<td>Spring</td>
</tr>
<tr>
<td>6a Maintain benthic community diversity</td>
<td>Disurbance</td>
<td>Cease to Flow</td>
<td>Summer</td>
</tr>
<tr>
<td>6b Maintain of water quality in pools</td>
<td>Mixing, destratification</td>
<td>Low</td>
<td>Summer</td>
</tr>
<tr>
<td>7b Mixing, destratification</td>
<td>Fresh</td>
<td>All year</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Map of Glenelg River catchment. Mean annual discharge of the environmental flow reaches are shown as different shades of blue (where darker blue indicates greater relative discharge); flood extent associated with those reaches also shown. The boundaries of the reaches are marked by pink bars.
2 Conceptual Models, Hypotheses and Response Variables Relevant to the Glenelg River

2.1 Intended Uses for Conceptual Models

The proposed conceptual models are described in the following sections to illustrate how models and/or relationships that will underpin monitoring and testing of statewide hypotheses may be derived. Knowledge gaps, key questions and potential monitoring endpoints have been highlighted. The models presented are generic, and would need to be modified to be more river-specific.

At this stage however, it is not proposed that these models will form the basis of quantitative models to be used to make predictions about the expected level of response to a change in flow regime in any particular system. Hence, the river-specific modifications have not been made. Rather, they seek to synthesise our current understanding, to depict qualitatively our expectation of how an environmental component will react to a given flow intervention. At this early stage of knowledge concerning responses of the biota to flows, the models state our expectation of:

1. Which aspect of the flow regime (and when and where) to measure in order to confirm that the hypothesised flow requirements for the endpoint are being met;
2. What ecological endpoint (or endpoints) to measure to determine if a response has occurred;
3. Where there are known major gaps in our knowledge as to the effects of an aspect of the flow regime on the ecological endpoint/s. This can then be used as a guide for the conducting of specific research projects designed to fill such gaps; and
4. The presence of other overriding effects within the causal network that may prevent the beneficial effects of environmental flows from being realised (e.g. cold water pollution).

We recognise that no conceptual representation will be complete or adequate for all circumstances. Thus there is no expectation that these models provide a detailed representation of any particular system. However, as these models summarise the best scientific understanding we currently have on the relationship between specific flow components and their desired ecological outcomes, they are crucial to formulating and testing the key questions of this project. Refinements and additions to the models should only be undertaken if there is a belief that this will lead to a change in how we monitor whether or not an ecological endpoint is being affected, and by which aspects of the flow regime or another overriding influence.
2.2 Model Development

We performed an exhaustive review of the scientific and management literature that collated and summarised all the conceptual models and predicted ecosystem responses associated with the environmental flow recommendations for the eight high-priority river systems. The review also documented the relevant evidence cited in support of the conceptual models and the environmental flow recommendations, and incorporated more recent evidence that adds to our conceptual understanding. The draft was circulated amongst members of the Scientific Panels involved in the environmental flow studies and to other scientists of high international standing in stream ecology and management for comment.

This process resulted in a very large collection of conceptual models and potential hypotheses to be tested (Appendix 2). We applied a number of criteria to select the groups of conceptual models and hypotheses that would be addressed both for the Glenelg River and at the statewide level.

Conceptual models and hypotheses were selected according to the criteria that they should:

1. Be scientifically ‘sound’ – well-founded and supported by appropriate theoretical or empirical data from scientific studies and/or expert opinion;
2. Involve responses to recommended environmental flows that will be detectable – expected responses must be of sufficient magnitude to be detectable within a useful management timeframe (nominally 10 years);
3. Address questions that are relevant to the Victorian River Health Strategy (VHRS);
4. Where possible, have general applicability to multiple reaches within Victorian rivers receiving an Environmental Water Reserve;
5. Be realistic, given the quantity of water available for implementing the recommended environmental flow releases;
6. Be targeted to components of the flow regime that can most feasibly be returned to a more natural pattern using the environmental flow recommendations;
7. Acknowledge potential constraints on ecosystem response because of river-specific characteristics and/or regulation activities (e.g. cold water releases from large dams);
8. Make use of available relevant historical data; and
9. Address potentially adverse outcomes associated with implementing the recommended environmental flow releases (e.g. blackwater events).

The individual conceptual models assembled by the review were stratified into groups (e.g. fish responses, geomorphological responses) from which we chose a number of groups to develop into synthesised conceptual models. A subjective rating system applied to each group for criteria 1–3 above. The details of this process and the final groups of models chosen for development are outlined in Appendix 2.
The various groups of conceptual models were synthesised into diagrammatic representations supported by descriptions using the information from the review, and on occasion other information from literature sources (detailed in each section below). More inclusive models were developed for geomorphic responses, biochemical responses, habitat, macroinvertebrates, fish, and aquatic and riparian vegetation. These conceptual models were collectively reviewed in a workshop (30th March 2006) attended by scientific experts and senior DSE and CMA staff (see Acknowledgements). Adjustments to the conceptual models were made following feedback from this workshop. A decision was taken at this time to drop biochemical responses from further consideration, due to a lack of current knowledge about the ecological implications of specific values for measures of production and respiration, which could make it difficult to set targets. In addition, the macroinvertebrate model was subsumed into the habitat model because all the important environmental requirements for macroinvertebrates should be provided in an environment where sufficient habitat exists (see § 2.4). In general, the conceptual modelling approach to the development of the monitoring and evaluation program was strongly endorsed by workshop attendees.

In the sections below we describe the final conceptual models, presenting each diagrammatically, and with a comprehensive verbal description supported by references. The models lead to the identification of possible monitoring variables, which are identified within each of the conceptual model sections, and then summarised in a table in § 2.8 along with recommendations for monitoring methods. The full range of possible variables has been presented, and will thus need to be refined for each river system.

In identifying response variables for monitoring, we have been guided by the following considerations:

1. Relevance – variable must be demonstrably linked to components in the conceptual model;
2. Responsiveness – variable should respond to the planned intervention at the spatial and time scales of interest;
3. Reliability – variable can be measured in a reliable and reproducible way;
4. Interpretability – what does it mean with respect to the issue of concern? Can one obtain meaningful interpretations that are useful for drawing inferences, making decisions and/or reporting? For example, some multivariate measures are difficult to interpret and their practical value may be limited; and
5. Cost effectiveness.

### 2.3 Geomorphic Processes

#### 2.3.1 Description of Conceptual Model

It is likely that many channels have not fully adjusted to the altered flow and sediment regimes introduced through regulation over the last century. For this reason we must consider the geomorphic effects of additional environmental flows in the context of on-going channel adjustment, not a change imposed on
channels at equilibrium. Flow modifications in Victorian regulated rivers generally occur at two main locations along the channel. An initial stage of modification occurs at the reservoir, normally located in the upland section of the river. Flow may be diverted directly from the reservoir but is more often released in the dry season and diverted once the river emerges onto areas of floodplain farming. The effect of flow regulation is attenuated downstream of the reservoir by unregulated tributary inflows.

The historic effect of irrigation and urban water supply reservoirs on geomorphic processes and the downstream floodplain and channel geometry will depend on release policy, catchment physiography, distance downstream of the reservoir and time since construction of the reservoir (Knighton 1998). Limited understanding of these effects makes generalisation of these responses difficult. However, there is likely to be a general response of sediment starvation immediately downstream of the reservoir as a consequence of sediment trapping in the reservoir (Zone 1 in Figure 3). In Zone 1 we would expect erosion, channel enlargement, bed degradation, and armouring. The extent of sediment starvation will depend on the size of the reservoir relative to inflow volumes (the sediment trapping efficiency) and the impact of flow release policy on the flood regime. Consequent downstream erosion will be inhibited by resistant boundary material and in particular bedrock. As erosion progresses, the bed will become armoured thus slowing the process of erosion. Bed degradation downstream of dams has also been reported to reduce channel gradients and hence erosive forces. In most cases, high flow pulses released in Zone 1 will either have no effect or enhance these erosional processes.

Further downstream, unregulated tributaries with a higher gradient than the main channel may deliver sediment loads that exceed the transport capacity of the main channel. In Zone 2 we would expect development of in-channel bars and slow development of benches leading to bed aggradation and channel narrowing. Additional high flows released as part of an environmental flow may impede or reverse these trends by scouring sediments from the channel bed and promoting bank erosion and channel widening.

Further downstream in Zone 3, large lowland sediment stores will tend to buffer effects of altered upstream sediment regime and responses will be slow and difficult to detect. Flow diversions from the midland or lowland river could result in reduced flows in the lowland channel leading to sedimentation of pools and narrowing through development of benches. High flow freshes in this section will flush fine sediments deposited in pools and promote bank erosion which can offset the narrowing effects of bench development.

Petts & Gurnell (2005) present a thorough review of the effects of dam on channel morphology and point out that there can be great variation in the rate of response as a consequence of variable sediment loads (relative to sediment transport capacity), variable erosion resistance of the channel bed and banks and variable rates of growth and colonisation by riparian vegetation (which has the potential to stabilise sediment deposits). Figure 4 conceptualises the geomorphic responses to flow regulation adapted from the above discussion and models presented in Petts & Gurnell (2005). Habitat responses are related to changes in channel bed level, width and stability.
The main drivers of morphological change are flow and sediment and these are represented in the third level of Figure 4 by (i) flood magnitude, (ii) duration and frequency of high in-channel flows and (iii) total sediment load. In a regulated river, these will be a function of unregulated tributary flows and the influence of upstream impoundments and diversions. These are represented in the first row of the diagram. As one moves downstream of a dam, the flow and sediment regime is modified through the effects of catchment physiography including the location of confluences. These effects are represented by the box labelled “valley geometry” although this is likely to be better represented as a multi-dimensional effect of valley relief and the proportion of catchment upstream of impoundments.

The “response times” box refers to the rate of responses to flow regulation. Fast response rates are hypothesised to increase with sediment supply (relative to transport capacity) which is a function of flow regime, sediment load and channel slope (closely related to valley slope although slightly modified by sinuosity). Rapid colonisation of sediment deposits by riparian vegetation and reduced bed and bank resistance will also promote rapid adjustment in depositional and erosional phases respectively.

The types of adjustment and subsequent effects on physical habitats are described at the bottom of the diagram. In Zone 1, one would expect channel widening, bed degradation and a reduction in the frequency of geomorphically significant events. In Zone 2, changes would typically include bed aggradation, bench development and eventually channel narrowing. With reduced frequency of high flow events, one might expect a reduced frequency of geomorphically significant events although oversupply of sediments at confluences may offset this to some extent. With increased geomorphic stability, one would expect
reduced complexity of the bed and bank morphology. In such situations, the geomorphic objective of environmental flows is commonly to promote geomorphic events (which involve both erosion and deposition of bed and bank material) to increase channel complexity or specific habitats associated with complex channels. Such habitats might be deeper pools, bed sediments free of fine particulates, benches of different heights and billabongs formed through meander cutoffs. These habitats are all products of natural erosion and deposition processes in dynamic channels and can be adversely affected by regulation.

2.3.2 Selected Sub-Hypotheses and Response Variables to be Monitored

Based on this conceptual model, we propose that key endpoints to be monitored in the VEFMAP are (i) changes in channel geometry (i.e. channel width, depth and complexity) (ii) changes in channel alignment (i.e. rates of bank erosion and deposition on benches) and (iii) changes in the frequency of geomorphologically significant events (i.e. frequency of events during which bed sediments are redistributed or there is development of meander bends and benches) (Table 2). The first two aspects can be monitored using periodic re-survey of the channel. The third requires targeted and ongoing monitoring. These monitoring tasks are covered by the channel features and channel dynamics surveys outlined in Table 6, which includes information on variable definitions, sample timing and sampling protocols.

We recommend monitoring in carefully selected reaches associated within Zone 2 in Figure 3. There is little hope of returning natural geomorphic processes to Zone 1 using environmental flows because the fundamental problem is sediment starvation. Responses of river morphology to environmental flow releases in Zone 3 will be slow (decades to centuries) and probably not detectable within a practical management timeframe. Zone 2 represents the zone in which the intended geomorphic effects of environmental flows may be detectable. Zone 2 begins at the first major input of sediment to the regulated river downstream of the dam. This zone extends downstream to either (a) the base of an alluvial fan forming where the river flows onto an unconfined floodplain or (b) the estuary.

It is probably best to target monitoring in river reaches at the upstream end of Zone 2 to have the greatest chance of detecting responses to environmental flows in the short term. Further downstream, the effects will be attenuated and may proceed at a slower rate. Where there is a second major point of flow regulation (e.g. a diversion weir), it may be prudent to locate further geomorphic monitoring below this point if it is in Zone 2. Site location will need to consider the proximity of upstream tributaries supplying sediment. There is likely to be a dynamic zone downstream of tributary confluences, with increased channel complexity associated with depositional features. Ideally, monitoring would be undertaken downstream of the immediate zone of influence of these tributaries.
Figure 4. Conceptual model of geomorphic responses to flow regulation.
Table 2. Geomorphic conceptual model – summary of subhypotheses and corresponding variables associated with the various flow components

<table>
<thead>
<tr>
<th>Flow Component</th>
<th>Subhypotheses</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter–Spring Freshes</td>
<td>In Zone 2 reaches, does increased frequency of winter–spring fresh events: a) increase the frequency of geomorphologically significant events (e.g. redistribution of bed and bank sediments)? b) increase channel complexity (e.g. areas of the stream bed which are flushed free of fine deposits, deeper pools and variability in bench elevations)? c) increase channel width and depth? d) increase rates of meander development (i.e. bank erosion on the outside bank, point bar development, increased sinuosity and eventually bend cut-off and billabong formation)?</td>
<td>Frequency of channel disturbances Frequency of bed disturbances Rate of bench deposition Bed complexity Bench development and variability Mean channel top width, cross-section area and thalweg depth Bank erosion on outside of meander bends Point bar development</td>
</tr>
<tr>
<td>Bankfull Flows</td>
<td>As for winter–spring freshes</td>
<td>As for winter–spring freshes</td>
</tr>
<tr>
<td>Overbank Flows</td>
<td>As for winter–spring freshes</td>
<td>As for winter–spring freshes</td>
</tr>
</tbody>
</table>

2.3.2.1 Complementary Research Issues

A non-exhaustive list of complementary research issues that have been identified as being relevant to the conceptual model are as follows:

1. Surveying extent of bed armouring downstream of dams and monitoring changes through time;
2. Effect of riparian vegetation on channel narrowing downstream of dams; and
3. Effect of tributary sediment load on channel form and habitat complexity downstream of tributaries in regulated rivers.

2.4 Habitat Processes and Macroinvertebrates

2.4.1 Description of Conceptual Model

Physical factors of ecological significance include streamflow, current velocity, channel shape, water depth, substrate, and temperature, and water quality indicators such as dissolved oxygen (DO) concentration, salinity and pH. Habitats are defined by a complex interaction of physical factors and the ecological requirements of aquatic flora and fauna, such as light, shelter, food and flow-mediated chemical exchanges.

The conceptual model is for a reach (ranging from 10s to 100+ km in length) in a regulated mid- to lowland river. It focuses on hypotheses relating to the maintenance of hydraulic habitat for vegetation, invertebrates and fish during the summer–autumn low flow period and habitat creation associated with the
reinstatement of more natural levels of winter–spring baseflows and patterns of freshes (Figure 5). The effects of other flow components (i.e. summer high flows, bankfull and overbank flows) are less understood from the point of view of habitat creation and maintenance, but have other known positive ecosystem-level effects, which are discussed for the other conceptual models. The individual conceptual models for vegetation and fish spawning and recruitment (presented later) provide greater detail on flow relationships and ecological requirements at various stages in the life histories of these groups.

Habitat patches in rivers are formed by interactions of hydrology, geomorphological features (e.g. pools, runs, bars, benches, overhanging banks and anabranches) and structural elements (e.g. boulders, tree roots, coarse woody debris and macrophytes). These habitat patches are dynamic and respond to various characteristics of the flow regime. For instance, freshes can create new habitat patches through inundation where none existed previously and can alter the nature of a habitat patch from a pool to a run. The persistence of habitat patches depends on the temporal characteristics of the flow regime (e.g. timing, duration, frequency and variation of various flow features).

Provision of adequate levels of summer–autumn low flows and freshes helps to maintain adequate depth and water quality in permanent pools, riffle/run sections and shallow water areas as well as provide longitudinal connectivity. The combination of high temperatures, high evaporation rates and lower flows over summer can lead to a decrease in surface area and volume of surface water and increases in extremes of physicochemical water quality parameters such as dissolved oxygen (DO) concentration. Loss of continuous surface water may lead to the drying of riffle/run sections and shallow areas to the detriment of biota dependent on these habitats (e.g. macrophytes, invertebrates and larval and juvenile fish). Furthermore, loss of lateral and longitudinal connectivity may affect processes such as drift which may be a necessary step in the life history of some macroinvertebrate species and fish. Adequate levels of low flows should maintain shallow water areas, trickling flows over riffle/run sections and adequate depth for maintaining connectivity and passage of biota to alternative habitats.

During periods of drying, permanent pools are critical for faunal persistence by providing a refuge in which individuals can survive to recolonise when streams reconnect (Boulton 2003, Magoullick & Kobza 2003). The provision of summer–autumn low flows and freshes of adequate magnitude, frequency and duration helps to replenish and maintain water quality in permanent pools, through such mechanisms as dilution of salt and nutrients and the increase of DO by mixing/aeration. Improved water quality may increase the number and diversity of pollution-sensitive taxa. Such freshes may also re-establish temporary connectivity along the stream channel allowing for the dispersal of mobile organisms to alternative habitats.

In systems with seasonal flow inversion, constant high water levels in summer can alter the distribution and reduce the area and persistence of shallow and slow water patches favoured by some inchannel macrophytes and larval, juvenile and small-bodied fish.
‘Slackwater’ areas, typically small shallow areas of still water formed by sand bars, woody debris and bank morphology, have also been found to contain many more larval and small-bodied fish than flowing water patches in lowland rivers. In their study involving hydraulic manipulations to create slackwater and flowing water patches, an order of magnitude more fish and shrimp were collected from slackwaters, both created and natural (Humphries et al. 2006). Slackwaters have been hypothesised as providing refuge from current (and therefore energetic advantages) for the young stages of fish and shrimp and/or predation and as sites where food is abundant (Humphries et al. 1999, 2006, King 2004a,b, Richardson et al. 2004). These hypotheses are largely untested. However, some workers have suggested that refuge from current may be a more important factor than food availability in explaining why slackwaters are favoured. Several studies have found evidence that it is energetically advantageous for fish larvae inhabit still or low-velocity patches (Flore & Keckeis 1998, Matthews 1998, Flore et al. 2001). King (2004a) has also shown that the density of benthic meiofauna, seemingly an important food source for larval fish, was not different between still and flowing habitats in the Broken River. Similarly, Humphries et al. (2006) found that the density of benthic meiofauna and zooplankton did not differ consistently between flowing and slackwater patches. They concluded that the greater abundance of fish and shrimp in created slackwater patches and lower abundance in created flow patches could not be explained by the density of potential prey. They did however, find a significant difference in the community composition of benthic meiofauna between slackwater and flowing patches and also found that slackwater patches had a greater amount of benthic organic matter – a potential food resource for shrimp (Burns & Walker 2000).

Reinstatement of more natural levels of winter–spring baseflows will produce a sustained increase in channel depth over the winter–spring period. The provision of winter–spring freshes will produce temporary additional increases in channel depth that will vary depending on the magnitude and duration of the fresh. Increase in channel stage height will increase the volume of pool habitat. Where the increase in stage height results in inundation of physical structures and features (e.g. inchannel macrophytes, channel-edge macrophytes, tree roots, woody debris, branch piles, inchannel bars, benches and overhanging/undercut banks), it makes these substrates available for colonisation and attachment by invertebrates. When inundated these physical features provide important habitat for feeding, shelter, current refuge and spawning, and represent an increase in the quantity, diversity and complexity of physical habitat for both invertebrates and fish (Crowder & Cooper 1982, O’Connor 1991, Crook & Robertson 1999).

Freshes during winter and spring may lead to the flushing of fine sediments and organic mater from areas of coarse streambed substrate (e.g. riffles). This flushing reduces armouring of the stream bed and leads to greater availability of interstitial spaces in the coarse substrate. These spaces are available as habitat for invertebrates. It is widely assumed that flushing flows as described here will have beneficial effects for macroinvertebrate assemblages in riffle environments, but there has been little investigation as to whether this is the case (P.S. Lake, pers. comm.). Thus at present, the link between sediment
flushing and invertebrate response remains as a hypothesis to be tested through monitoring.

Reinstatement of more natural levels of winter–spring baseflows increases the overall area of shallow and slow water within the channel. Increases in flow velocity can increase the area of riffle/run habitat, and together with the increase in shallow and slow water habitat and pool habitat, contributes to an overall increase in the quantity and diversity of different hydraulic habitat types. Shallow and slow water areas provide suitable conditions for the growth of aquatic macrophytes. Run areas also provide a site for production of some species that thrive in elevated velocities (e.g. some species of *Vallisneria* and *Myriophyllum*, M.J. Kennard, pers. comm.). Hence, the increased availability of shallow and slow waters, as well as runs is expected to lead to increased abundance of macrophytes over the main growing season in spring. Macrophytes are widely recognised as important habitat for some invertebrates and fish (Crowder & Cooper 1982; Minshall 1984; Humphries 1996).

Macrophytes are a direct and indirect source of food (e.g. from epiphytic periphyton growing on them and organic detritus found at their base), provide protection from predators and current, and increase the amount of available habitat per unit area of substrate (Crowder & Cooper 1982; Minshall 1984; Newman 1991; Weatherhead & James 1991). Seasonal growth and increased abundance of inchannel macrophytes with a range of growth-forms creates additional physical substrate and contributes to the increase in the quantity and diversity of instream physical habitat.

Slow water habitats produce higher densities of planktonic microinvertebrates due to increased residence time (Ferrari *et al.* 1989, Pace *et al.* 1992, Basu & Pick 1996, King 2004a). Hence, increased availability of slow water habitat can be expected to increase the abundance of microinvertebrates. Diversity in flow velocities *per se* may also be important for macroinvertebrate community diversity because moderate–fast current velocity riffle/run habitats may support species specialised for those conditions. While this seems reasonable and plausible, there is uncertainty about the link between flow velocity habitat and its influence on invertebrate community diversity/condition (L. Metzeling, pers. comm.), and existing studies suggest complex interactions with other biological processes (e.g. Hart & Finelli 1999).

An increase in the quantity and diversity of habitats should increase assemblage diversity by allowing aquatic organisms with different habitat requirements to coexist. For example, the complexity of macroinvertebrate communities and the abundance of individual species have been correlated with habitat complexity created by woody debris, macrophytes and organic debris, coarse substrates and substrate stability (Schlosser 1982; O’Connor 1991; Cobb *et al.* 1992, Pusey & Kennard 1996; Bond & Lake 2003; Pusey & Arthington 2003; Pusey *et al.* 1993, 1995, 1998, 2000, 2004).

Direct knowledge of the effects of environmental flows on macroinvertebrate assemblages is poor. However, given the links between habitat diversity and species diversity, potential macroinvertebrate responses to flow manipulation are captured by the conceptual model for habitat processes. The expected responses of macroinvertebrates to environmental flows have been presented
only in terms of the expected effects of flow on macroinvertebrate habitat, and the potential subsequent effects on assemblages.

We have deliberately chosen this type of conceptual model for two reasons. First, by focusing on habitat, the causal network for macroinvertebrates is kept relatively simple. Simple conceptual models stand a far better chance of being developed into predictive numerical models in the future. Second, we believe that the flow characteristics necessary to fulfruit the habitat requirements for macroinvertebrates will, as a general rule, lead to the provision of other resources necessary for the maintenance of assemblages. For instance:

- Water quality may affect macroinvertebrates. The provision of adequate flows, particularly freshes, during periods of low flow should maintain water quality at adequate levels;
- Freshes that lead to bench inundation may stimulate the hatching of some macroinvertebrate species that produce resting stages in these previously dry environments; and
- Higher flows will lead to the introduction of organic matter into the stream system, stimulating primary productivity and providing food resources for macroinvertebrates.

There are certainly other linkages that could be made between flows and effects on macroinvertebrates. We believe however, that there are no important linkages that will occur independently of those flow characteristics that will provide adequate macroinvertebrate habitat. This approach to modelling macroinvertebrate response to flows does not address the question of where colonists are to come from. It may be that macroinvertebrates in heavily flow impacted systems take some time to respond to a change in flow regime because of the need for passive dispersal of colonists from less impacted tributaries, which may be well upstream of the target reaches.

With respect to fish assemblages and fish population structure, an increase in the quantity and diversity of physical habitat and flow velocities, as well as an increase in food supply due to increased invertebrate abundance is predicted to increase survival of young fish and consequently recruitment of fish within the reach. Increased habitat and food resources are also likely to increase the health and survival of adult fish, and may also lead to an increase in fish immigration to the reach. Both factors will impact on the fish community structure within the reach. It is noted that many fish species are very territorial, so the availability of habitat resources may be a more influential limiting factor on fish community dynamics than the availability of food resources (P.S. Lake, pers. comm.).
Figure 5. Conceptual model of habitat processes. (WQ = water quality)
2.4.2 Selected Sub-Hypotheses and Response Variables to be Monitored

First, the monitoring program should determine whether the implemented flows deliver the expected habitat features. Then, monitoring should attempt to determine whether implemented flows result in the expected ecological responses (Table 3). The achievement of the expected abiotic features not accompanied by the expected ecological response may indicate gaps or errors in our conceptual understanding of the system, or the presence of other limiting factors. The relevant monitoring field program, variable definitions and sampling timing and sampling protocols are presented in Table 6.

The physical dimensions and water quality parameters at shallow and slow water, riffle/run, and pool habitats will show short term responses to implemented environmental flows. At this stage we are not proposing specific monitoring of water quality parameters at permanent pools, shallow and slow water and run habitats. The question of whether water quality in these microhabitats during the summer–autumn low flow period is sufficiently different to that measured at VWQMN stations (and therefore warrants dedicated monitoring) is flagged as a complementary research issue. With regard to this, we propose that priority be given to investigating water quality in permanent pools because they have a greater potential for developing water quality problems (particularly at depth) due to temperature (and in some rivers, salinity) stratification.

Detecting responses of macroinvertebrates to flow augmentation at the scale of a river reach is made difficult by the high levels of small-scale spatial and temporal variability that characterise macroinvertebrate assemblages (Rosenberg & Resh 1993, Downes et al. 2000, 2006). In addition, species-level identifications require advanced taxonomic skills, and quantitative sampling is time-consuming with most samples being dominated by a few numerically abundant species. In response to the difficulties of sampling, various standardised rapid-sampling protocols have been developed (e.g. Barbour et al. 1999, Growns et al. 1995, 1997). These protocols are often characterised by presence/absence sampling (rather than quantitative), and by the identification of macroinvertebrates to coarser taxonomic levels, usually Family. Presence/absence sampling precludes the possibility of analysing changes in the abundance of individual species in response to flow augmentation. It also reduces the amount of information that can be incorporated in multivariate analyses. Similarly, collecting taxonomic data at the family level prevents examination of species-specific effects of environmental flows. Some authors have argued that the effects of large-scale interventions may be more easily detected by analyses conducted at coarser taxonomic levels than for data collected at species level (e.g. Warwick 1988a, b). They hypothesise that species are likely to respond to fine scale natural environmental differences, but changes at coarser taxonomic levels are more likely to be seen in response to larger-scale ‘treatments’. Data for marine benthic infauna support this hypothesis (Warwick 1988a,b). In freshwater studies, data collected at family level give a similar picture of community composition to those collected at species level (Marchant et al. 1995, Hewlett 2000).
### Table 3. Habitat processes and macroinvertebrates conceptual model: summary of subhypotheses and corresponding variables associated with the various flow components

<table>
<thead>
<tr>
<th>Flow Component</th>
<th>Subhypotheses</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer–Autumn Low Flow and Freshes</strong></td>
<td>Do implemented environmental flows maintain in-channel shallow and slow water area?</td>
<td>Shallow and slow water area</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows maintain adequate area and depth of at least 0.1 m in shallow, slow water and riffle/run habitats?</td>
<td>Riffle/Run depth and area</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows maintain adequate volume and depth in permanent pools?</td>
<td>Permanent pool depth and volume</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows maintain connectivity?</td>
<td>Connectivity</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows maintain macroinvertebrate community structure?</td>
<td>Number of invertebrate families index, AUSRIVAS score, SIGNAL biotic index, EPT biotic index, Presence/Absence and number of ‘flow-sensitive’ taxa</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase fish recruitment?</td>
<td>See conceptual model for Fish Spawning and Recruitment</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows maintain fish assemblages and/or population structure?</td>
<td>Fish species composition, Relative abundance of adult/sub-adult native and exotic fish species, Population structure and size–class distribution of native and exotic fish species</td>
</tr>
<tr>
<td><strong>Winter–Spring Baseflows</strong></td>
<td>Do implemented environmental flows increase in-channel shallow and slow water area?</td>
<td>Shallow and slow water area</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase area of riffle and/or run habitat?</td>
<td>Riffle and/or Run area</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase volume of permanent pool habitats</td>
<td>Permanent pool depth and volume</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows result in sustained inundation of in-channel macrophytes, channel-edge macrophytes, tree roots, woody debris, branch piles, in-channel bars, overhanging or undercut banks?</td>
<td>Inundation of representative physical habitat features</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase abundance of submerged and amphibious macrophytes?</td>
<td>See conceptual model for Aquatic and Riparian Vegetation, Cover of submerged and amphibious species in Zone A</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows improve macroinvertebrate community structure?</td>
<td>Number of invertebrate families index, AUSRIVAS score, SIGNAL biotic index</td>
</tr>
<tr>
<td>Flow Component</td>
<td>Subhypotheses</td>
<td>Variables</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Winter–Spring Baseflows (contd) | Do implemented environmental flows improve fish assemblages and/or population structure? | EPT biotic index  
Presence/Absence and number of ‘flow-sensitive’ taxa |
|                       | Do implemented environmental flows increase area of riffle and/or run habitat? | Fish species composition  
Relative abundance of adult/sub-adult native and exotic fish species  
Population structure and size–class distribution of native and exotic fish species | Riffle and/or Run area |
|                       | Do implemented environmental flows increase volume of pool habitats          | Permanent pool depth and volume |
| Winter–Spring Freshes | Do implemented environmental flows result in temporary inundation of higher-level channel edge macrophytes, tree roots, woody debris, bars, benches, overhanging/undercut banks? | Inundation of higher elevation representative physical habitat features |
|                       | Do implemented environmental flows improve macroinvertebrate community structure? | Number of invertebrate families index  
AUSRIVAS score  
SIGNAL biotic index  
EPT biotic index  
Presence/Absence and number of ‘flow-sensitive’ taxa |
|                       | Do implemented environmental flows improve fish assemblages and/or population structure? | Fish species composition  
Relative abundance of adult/sub-adult native and exotic fish species  
Population structure and size–class distribution of native and exotic fish species |

There are marked cost advantages to employing a rapid sampling protocol. Many more samples can be processed for same investment of time and money, and the level of training required of the operators is far less. We support the use of the EPA rapid bioassessment protocol (EPA Victoria 2003). The only exception to this would be extra sampling effort designed to pick up ‘flow sensitive’ taxa. One response to flow augmentation may be the immigration of flow-sensitive species (L. Metzeling, pers. comm.). Such taxa could be used as a simple bioindicator of the success or otherwise of flow augmentation. The first requirement is for a list of such taxa to be developed through expert consultation. With regards to subsequent monitoring, it will be necessary to invest some extra training and effort in the laboratory identification of flow-sensitive taxa, as these taxa are likely to require identification to species level, rather than family level as specified in the EPA rapid bioassessment protocol (EPA Victoria 2003).
Data collected using rapid sampling protocols are most amenable to analysis using either multivariate statistics, or some form of index that collapses the multivariate data to some univariate measure. Because of the nature of community level data (many species, many low or zero counts), non-parametric multivariate analyses (Clarke 1993) are usually appropriate. Results may be visualised as ordinations of the multivariate data. Such results are problematic from the point of view of target-setting and inference of ‘improvement’. While it is possible to track an assemblage through time in an ordination, we cannot from the ordination alone infer whether or not the assemblage condition has improved, merely that is has (or has not) changed. The only solution is to define a target assemblage (i.e. species list) and to include this in the multivariate analysis as another ‘sample’. It can then be determined whether the actual assemblage is moving towards this state through time. Defining a target assemblage for lowland rivers, however, would be very difficult (G.P. Quinn, pers. comm.). Multivariate analyses are, however, powerful visual tools for communication of findings, and are very sensitive in picking up changes in assemblages. There are also a number of indices that present community-level data as a univariate response (e.g. AusRivAS; Simpson et al. 1997, SIGNAL; Chessman 1985, RivPACS, Wright et al. 1985). Built into these indices is some assumption about what constitutes a ‘better’ assemblage, and a higher index score implies an improvement. Thus it is possible to infer improvement in an assemblage from the index scores alone, and target setting is also possible. These indices are also often amenable to analysis by commonly used statistical methods.

2.4.2.1 Complementary Research Issues

A non-exhaustive list of complementary research issues that have been identified as being relevant to the conceptual model are as follows:

- Is water quality in permanent pools, shallow and slow water and run habitats sufficiently different to that measured at VWQMN stations to justify dedicated monitoring, and how does relative water quality respond to environmental flows?
- Role of permanent pools as refuge habitat ensuring persistence and allowing recolonisation;
- Connectivity characteristics for upstream and downstream movement of macroinvertebrates and fish for movement to alternative habitats. When is this connectivity most important?
- From the original environmental flows documents, it was the general consensus of opinion that the direct effects of flow augmentation on macroinvertebrate assemblages are likely to be minor compared to other potential restoration actions, such as the introduction of large woody debris to the system. This assertion could be investigated.
2.5 Aquatic and Riparian Vegetation

2.5.1 Description of Conceptual Model

Streams and their riparian zones are nonequilibrium ecosystems that provide habitat for a wide range of plants with a variety of adaptations (Nilsson & Svedmark 2002). The flow regime interacts with river geomorphic features to produce different seasonal patterns of availability and persistence of free water in the different portions of a channel. These temporal and spatial patterns of wetting and drying are a major determinant of plant community structure, floristics and dynamics.

The conceptual model is for a reach (ranging from 10s to 100+ km in length) in a regulated mid- to lowland, unconfined river. The conceptual model concentrates on the processes of habitat maintenance, seasonal growth as well as plant establishment from seed germination in response to flow manipulation. It focuses on the main growing seasons of spring and summer, when day length is longer, which maximises the energy available for photosynthesis, and temperature is higher, which maximises rates of physiological processes (Roberts et al. 2000). It depicts predicted responses of key attributes such as spatial distribution of measures of community structure and floristic composition, as well as system viability in the form of regeneration. We do not distinguish between native and exotic species, as the major effects predictable with current knowledge apply to functional groups (see below) rather than individual species. We expect that native and exotic species within the same functional group will respond similarly to a given flow regime.

Responses are predicted to (a) stable flow conditions (spring and summer baseflows) as well as (b) fluctuating flow conditions (spring–summer freshes and bankfull flows) (Figure 6).

There is a consistent and distinct transverse zonation about streams as vegetation responds to transverse environmental gradients such as soil moisture conditions. Following Christie & Clark (1999), three channel zones may be defined. These zones are:

- Zone A: from mid-channel to stream margin (or the area covered by water during times of baseflow)
- Zone B: from stream margin to a point mid-way up the flank of the bank (or the area that is infrequently inundated)
- Zone C: from mid-way up the flank of the bank to just beyond the top of the bank.

Following Brock & Casanova (1997), three main groups of plant species may be distinguished according to the amount of free water in which species grow. These groups are described as ‘terrestrial’, ‘amphibious’ and ‘submerged’. The terrestrial group may be further split into species that germinate, grow and reproduce in either ‘dry’ or ‘damp’ places (Casanova & Brock 2000). The amphibious group includes species found throughout the wet–dry ecotone and may be further divided into ‘fluctuation-responders’ and ‘fluctuation-tolerators’. Fluctuation-responders germinate in flooded conditions, grow in both flooded and damp conditions using their ability to alter their growth pattern or morphology in response to the presence or absence of water and reproduce
above the water surface (Casanova & Brock 2000). This group includes some floating-leaved species (e.g. Nymphaoidea spp.) and species with some degree of morphological plasticity (e.g. Myriophyllum spp.) (Brock & Casanova 1997). Fluctuation-tolerators germinate in damp or flooded conditions; tolerate variation in water levels without major changes in growth or morphology, and some species may reproduce above the water surface (Casanova & Brock 2000). This group includes low-growing species (e.g. Hydrocotyle spp.) and emergent species (e.g. Eleocharis spp., Persicaria spp. and Typha spp.). The submerged group is not split and includes species that germinate, grow and reproduce under water (e.g. Vallisneria spp.).

Alternating wet and dry periods within a flow regime can affect seed bank germination and establishment. For instance, wet periods modify oxygen availability in the soil; mediate decomposition of organic matter and subsequent concentrations of nutrients and toxic substances; stimulate or inhibit germination; suppress terrestrial or flood-intolerant plants; and alter the light regime depending on turbidity and depth of inundation (Casanova & Brock 2000). Dry periods following flooding may desiccate and kill submersed species, but may also stimulate or inhibit germination depending on a species’ ability to respond to or tolerate fluctuations in flooding and drying (Casanova & Brock 2000).

The following sections draw heavily on the work of Casanova & Brock (2000) who used experiments to investigate the relative importance of depth, duration and frequency of inundation on plant community germination from wetland seed banks. They found that duration, frequency of flooding and depth all affected plant community development in some way, but concluded that duration of individual inundation events was the major determinant of plant community composition. Frequency and depth exerted a secondary influence which further differentiated plant community composition. This study was relatively short-term compared to the time frame of response to environmental flows of some species (e.g. River Red Gum), but provides the best indication available of the types of responses that might be seen in early life history stages, and also of responses of terrestrial species to inundation. Casanova & Brock’s (2000) main experimental results are summarised below.

Under a continuously flooded treatment (16 weeks of inundation), the resultant plant community was found to be dominated by submerged species and some amphibious fluctuation-responder species. Overall species richness was low.

Long inundation events lasting more than two weeks at a time produced a plant community dominated by amphibious fluctuation-responder species, although some terrestrial ‘damp’ species also occurred. Overall species richness and biomass was also low.

Shorter inundation events lasting less than two weeks produced a species-rich plant community dominated by amphibious fluctuation-responder, fluctuation-tolerator and terrestrial ‘damp’ species. A similar suite of functional groups resulted when short inundation events occurred at a higher frequency (i.e. more than twice within 16 weeks), but the biomass of terrestrial ‘damp’ species was lower under the regime of increased inundation frequency. In addition, Casanova & Brock (2000) found that water depth during short and frequent inundation events determined dominance within the amphibious group, with
fluctuation-tolerator species favoured at shallower depths and fluctuation-responder species favoured at greater depths.

When the seed bank was wetted and maintained in a damp condition without flooding and drying, the resultant plant community was dominated by terrestrial ‘damp’ and ‘dry’ species, but amphibious fluctuation-tolerator species were also present. Of the various treatments, this resulted in the highest species-richness, but most species had low biomass.

In summary, duration of inundation events determined what combination of submerged, amphibious or terrestrial species germinated and established. Protracted inundation tends to favour germination, establishment and growth of submerged species although some amphibious fluctuation-responder species are also expected. Shorter durations of inundation allow amphibious species to germinate and establish and the brief periods of anoxia are tolerable by terrestrial ‘damp’ species. Frequency governs the length of dry phases between inundation events and influences the relative survival and growth of species in the terrestrial and amphibious groups. Long, dry intervals enable terrestrial ‘damp’ species to establish, flourish and attain high biomass. Whereas more frequent inundation, implying shorter dry intervals, might favour amphibious fluctuation-responder and fluctuation-tolerator species over terrestrial ‘damp’ species. Depth affects light levels and the ability of emergent species to reach the surface and is an important determinant of plant community composition when water levels are stable. However, in the context of a fluctuating water regime, depth alone is less important than duration and frequency of inundation in influencing plant community composition (Casanova & Brock 2000).

This conceptual model does not consider the contribution of vegetative reproduction and dispersal processes to plant community establishment and development. In this restricted context, the composition of resulting plant communities is dependant on the composition and viability of the seed bank present in the soil. Different flow regimes can select for different plant communities, but only if the seed bank contains the potential for different plant communities to develop (Casanova & Brock 2000). The seed bank of a species-poor site might only allow the development of a community of limited species richness and diversity. The relative proportion of exotic plant species to total plant species will also depend on the composition and viability of the seeds present in the seed bank, as well as differences in the capacity of exotics to exploit (or alternatively, to withstand) the prevailing wetting–drying regime in the relevant channel zone.

During spring baseflows, increasing temperatures and shallow, slow water and run areas in Zone A provide favourable conditions for germination and seasonal growth of submerged and some amphibious fluctuation-responder macrophyte species. Run areas also provide a site for some species that thrive in elevated velocities (e.g. some species of Vallisneria and Myriophyllum, M.J. Kennard, pers. comm.). Where regulation activities have reduced the magnitude of spring baseflows, reinstatement of more natural (i.e. higher) flows should increase the amount of shallow and slow water and run habitat within the river channel for submerged and some amphibious fluctuation-responder species. If the river channel is geomorphically complex, the provision of spring–
summer baseflows and freshes that sustain inundation of geomorphic features in Zone A (e.g. channel bed, low-lying bars and benches, channel edges, runners and anabranches), will increase the quantity of damp or flooded substrate and ensure reliable water supplies for the germination and growth of submerged and amphibious fluctuation-responder species. This may be reflected in an increased number of submerged and amphibious fluctuation-responder species and better growth performance such as greater height, more projected foliage cover and greater stem densities of plants in Zone A.

In addition to the above effects, increased baseflows will affect terrestrial ‘dry’ species (including agricultural weeds) in the channel. Terrestrial ‘dry’ species that may have encroached into Zone A during dry periods lack the physiological adaptations needed to survive sustained inundation and are expected to drown and dieback. Sustained inundation will also inhibit germination of these species. These conditions should result in lower species richness and biomass of terrestrial ‘dry’ species in Zone A.

Spring freshes may inundate higher-elevation geomorphic features in Zone A such as inchannel bars and islands as well as benches, runners and anabranches in Zone B. Long spring freshes that last for more than two weeks at a time may be expected to result in a plant community dominated by amphibious fluctuation-responder species and some terrestrial ‘damp’ species within the areas inundated.

Short, infrequent (e.g. one or two) spring freshes that last for less than two weeks at a time and are separated by long dry intervals may result in a species-rich plant community dominated by amphibious fluctuation-responder, fluctuation-tolerator and terrestrial ‘damp’ species within the areas inundated. If short freshes occur with greater frequency, a similar combination of amphibious fluctuation-responder, fluctuation-tolerator and terrestrial ‘damp’ species would be expected, but the biomass of terrestrial ‘damp’ species would likely be lower.

Spring freshes and bankfull flows may wet geomorphic features in Zones B and C (e.g. high-level benches, upper banks, runners and anabranches) dampening the soil without flooding. This may result in:

1. germination and establishment of mainly terrestrial ‘damp’ and ‘dry’ species but also some amphibious fluctuation-tolerator species;
2. growth pulse in terrestrial species including riparian seedlings and saplings;
3. increased vigour in the canopy of terrestrial trees and shrubs in the riparian zone.

Provision of summer low (base) flows helps to maintain the area and water quality of shallow and slow water and run habitats for submerged and amphibious species through the remainder of the growing season. Provision of summer freshes results in wetting of Zone A geomorphic features such as inchannel bars, low-lying benches, channel edges, runners and anabranches. This may alleviate desiccation of in situ macrophytes that have become exposed as the channel stage height dropped over summer. It may also result in improvement in the condition of the canopy of riparian trees and shrubs that are adjacent to the wetted channel zones.
In systems with seasonal flow inversion, extended periods of artificially high late-spring and summer flows can alter the distribution and reduce the area and persistence of shallow and slow water habitats for macrophytes. Increased summer flow magnitude also often means deeper and colder water, which may translate to poorer growing conditions for submerged macrophytes (J. Roberts, pers. comm.). Shear stress associated with high velocity flows also increase the risk of mechanical damage to plants, of parts breaking off, and of emerging or floating leaves being dragged underwater, reducing rates of photosynthesis and consequently growth (Madsen et al. 2001). Elevated summer flows with little variation in water level also means a shift in the inundation pattern of geomorphic features in Zone A (and possibly B), from transitory inundation to prolonged inundation. This may favour germination and establishment of submerged and amphibious fluctuation-responder species over terrestrial ‘damp’ species. The likely consequence is an altered plant community composition with lower species richness.

To investigate the effects of flow manipulations on aquatic and riparian vegetation, it is proposed that variables relating to community structure, floristic composition and regeneration be monitored in each channel zone.

2.5.2 Selected Sub-Hypotheses and Response Variables to be Monitored

First, the monitoring program should determine whether the implemented flows deliver the expected habitat features. Then, monitoring should attempt to determine whether implemented flows result in the expected ecological responses (Table 4). The achievement of the expected abiotic features not accompanied by the expected ecological response may indicate gaps or errors in our conceptual understanding of the system, or the presence of other limiting factors. The relevant monitoring field program, variable definitions and sampling timing and sampling protocols are presented in Table 6.

2.5.2.1 Complementary Research Issues

A non-exhaustive list of complementary research issues that have been identified as being relevant to the conceptual model are as follows:

- Minimum conditions necessary to drown and affect dieback of invasive terrestrial agricultural weed species in channel zones A and B.
- Variation in growth pulse response in riparian seedlings and saplings to spring–summer fresh events of differing frequency, magnitude and duration.
- The conceptual model focussed on seed germination responses to the spring freshes. However, it may also be important to understand the relative importance of vegetative reproduction (regeneration from pre-existing plant parts such as rhizomes, stolons and turions) on the maintenance and recruitment of aquatic and riparian vegetation. It is possible that regeneration from rhizomes and other plant parts may be similar to seed germination responses, but this comparison has apparently not yet been done (J. Roberts, pers. comm.). This question represents a knowledge gap which warrants further investigation.
Figure 6. Conceptual model of aquatic and riparian vegetation responses to Spring and Summer flows.
Another potential area of investigation is to understand the role of winter–spring floods and the consequences of their absence on aquatic and riparian vegetation (J. Roberts, pers. comm.). However, this conceptual model was not articulated in any of the environmental flow study reports and there is little ecological research that addresses this issue (J. Roberts, pers. comm.). Hence this is flagged here as another knowledge gap that needs to be addressed.
Table 4. Aquatic and riparian vegetation conceptual model: summary of subhypotheses and corresponding variables associated with the various flow components

<table>
<thead>
<tr>
<th>Flow Component</th>
<th>Subhypotheses</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spring Baseflow</strong></td>
<td>Do implemented environmental flows increase in-channel shallow and slow water area?</td>
<td>Shallow and slow water area</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase run area?</td>
<td>Run depth and area</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows result in sustained inundation of channel bed, channel edges, in-channel bars, low-lying benches, runners and anabranches in Zone A?</td>
<td>Inundation of geomorphic features in Zone A</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows a) increase germination and seasonal growth of submerged and amphibious fluctuation-responder species in Zone A?</td>
<td>Cover of submerged and amphibious species in Zone A</td>
</tr>
<tr>
<td></td>
<td>b) reduce species richness of terrestrial ‘dry’ species in Zone A?</td>
<td>Species composition, number of submerged, amphibious and terrestrial species in Zone A</td>
</tr>
<tr>
<td></td>
<td>What is the pattern of inundation and drying in Zones A and B imposed by the implemented environmental flows?</td>
<td>Cover of amphibious and terrestrial species in Zones A and B</td>
</tr>
<tr>
<td></td>
<td>What is the composition of the resultant plant community?</td>
<td>Species composition, number of amphibious and terrestrial species in Zones A and B</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows wet high-level benches, upper banks, runners and anabranches in Zones B and C?</td>
<td>Proportion of exotic plant species</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase germination and establishment of terrestrial ‘damp’, terrestrial ‘dry’ and amphibious fluctuation-tolerator species?</td>
<td>Species composition, number of amphibious and terrestrial species in Zones B and C</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows improve canopy condition of in situ riparian trees and shrubs?</td>
<td>Germination of seedlings of overstorey and midstorey species</td>
</tr>
<tr>
<td><strong>Summer Baseflows</strong></td>
<td>Do implemented environmental flows maintain area of in-channel shallow and slow water and run habitats?</td>
<td>Canopy condition</td>
</tr>
<tr>
<td></td>
<td>See conceptual model for Habitat Processes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shallow and slow water area</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Run depth and area</td>
<td></td>
</tr>
<tr>
<td><strong>Summer Freshes</strong></td>
<td>Do implemented environmental flows wet in-channel bars, low-lying benches, channel edges, runners and anabranches in Zone A?</td>
<td>Wetting of geomorphic features in Zone A</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows improve canopy condition of adjacent riparian trees and shrubs?</td>
<td>Canopy condition</td>
</tr>
</tbody>
</table>
2.6  Native Fish – Spawning and Recruitment

2.6.1  Description of Conceptual Model

The conceptual model is for a hypothetical regulated lowland river that contains both diadromous and non-diadromous species. This distinction should be borne in mind when using the model. It focuses on the pre-spawning habitat and spawning and recruitment requirements of diadromous and non-diadromous fish.

River fishes are typically seasonal in their breeding habits, with temperature and flow being the two major factors that dictate when fish spawn (Humphries et al. 1999). Fish tend to spawn during the warmest months of the year, partly because rates of egg, embryo and larva development are positively correlated with temperature, and partly because food for larvae and juveniles is most abundant at this time of the year in temperate systems (Jobling 1995). Rates of growth and development are critical to larval survival because the longer an individual spends as a highly vulnerable larva, the greater the cumulative risk of predation by larger fish (Jobling 1995). Also the larger a fish is, the greater its swimming ability and potentially, the greater its ability to forage and to avoid predators (Margulies 1990, Bone et al. 1995). In temperate systems, high temperature and flooding may only be weakly correlated. In cases where high temperatures and flooding do not coincide, temperature will often be the dominant variable that influences the timing of spawning (Humphries et al. 1999). There is a great variety in the spawning styles of Australian freshwater fish species.

Humphries & Lake (2000) note that river regulation can affect fish via reproduction and recruitment. The effects of river regulation on reproduction include the removal of appropriate conditions for gonad maturation, migrations, pre-spawning interactions and spawning (Humphries & Lake 2000). River regulation may also impact upon recruitment when it decouples the production of larvae and the environmental conditions needed to sustain them until they become juveniles. This may include desiccation or dispersal of eggs and/or larvae and the loss of hatching and/or rearing habitat (Humphries & Lake 2000). Reproduction effects are manifested as a failure to spawn or an absence of viable eggs and larvae following spawning. Recruitment effects imply that larvae are produced but do not survive to become juveniles (Humphries & Lake 2000).

Environmental flow recommendations have been developed to address some aspects of the reproductive and recruitment effects of river regulation, and these have been incorporated into the different sections of the conceptual model (Figure 7). They are briefly explained in the following notes.

High flows in autumn and early winter (represented here as freshes and bankfull flows) are required to trigger spawning in diadromous fish species such as galaxiids, eels and Australian Grayling (Koehn & O’Connor 1990). Following spawning, high flows (represented here as freshes) within the same period, are required to transport the larvae to the sea/estuary (Koehn & O’Connor 1990). This requires that sufficient flows for larval transport be maintained along the entire river length between the spawning zones and river mouth.
Figure 7. Conceptual model for fish spawning and recruitment into the juvenile population.
Reinstatement of more natural levels of baseflows as well as freshes in winter and early spring will increase the overall quantity and diversity of instream habitat and food resources (see conceptual model on Habitat Processes) and provide favourable feeding and growth conditions for adult fish. These conditions may be important for physiological preparation and conditioning of adults prior to spawning. We note that while this is widely believed to be true and considered to be appropriate, this assumption has not been tested (A.J. King, pers. comm.).

The occurrence of spring/early summer bankfull or overbank flows may be a direct spawning trigger for some non-diadromous fish species such as Golden Perch and Silver Perch, which appear to be ‘flood specialist’ species (Lake 1967). If the adult fish have had the benefit of pre-spawning conditioning in favourable habitats over the winter–spring period, they may produce a greater number of larvae. Bankfull flows, while not leaving the main river channel, may result in the inundation of low-lying runners and anabranches. Overbank flows are expected to inundate low-lying runners and anabranches as well as floodplain areas including billabongs and wetlands. These areas become slackwater habitat (velocity < 0.01 m/s) after recession of the bankfull or overbank flows and are highly productive environments in spring/early summer. They provide suitable hatching, rearing, feeding and refuge environments for non-diadromous larvae. The bankfull and overbank flows also lead to increased habitat within the channel and the introduction of nutrients to the system, with resulting effects on primary productivity, and in turn, food resources for larval fish. In general terms, the spring/summer bankfull and overbank flows can be expected to result in greater numbers of fish larvae of all breeding strategies recruiting into the population of juvenile fish (King et al. 2003a).

The reinstatement of more natural levels of spring and early-summer baseflows will help to maintain instream habitats for adult fish and slackwater habitat for larval fish. Low flow conditions in spring, summer and autumn may also provide favourable spawning conditions for ‘low flow specialists’ such as Carp Gudgeons and Gambusia (King et al. 2003a) as well as generalist species such as Australian Smelt and Flathead Gudgeon. Humphries et al. (1999) noted that spawning and recruitment into juvenile stocks of Flathead Gudgeon, Australian Smelt, Crimson-spotted Rainbowfish and three species of Carp Gudgeon can occur in mid-summer when the prospect of flooding is remote but the predictability of high temperatures and low flows are high.

Slackwater areas have also been found to contain many more fish than flowing water patches in lowland rivers. Humphries et al. (2006) collected an order of magnitude more fish and shrimp from slackwaters, both created and natural. King (2004b) found widespread use of natural slackwaters by the larvae and juveniles of most species of fish, irrespective of whether they were limnophilic or rheophilic as adults. Humphries et al. (2006) also reported that recent work (Price, unpublished data) has indicated that the abundance of fish larvae increases with slackwater area.

Slackwaters have been hypothesised as providing refuge from current for the young stages of fish and shrimp and/or predation and as sites where food is abundant (Humphries et al. 1999, 2006; King 2004a, b; Richardson et al.)
2004). Some workers believe that mortality due to starvation is highest during the critical stages of first feeding, when larvae are poorly developed and have limited mobility (Bone et al. 1995). Low flow conditions may concentrate appropriately sized prey in sufficient densities and slackwater habitats tend to have higher densities of microinvertebrates due to increased residence time (Ferrari et al. 1989, Pace et al. 1992, Basu and Pick 1996, King 2004b). These conditions may increase the likelihood of larvae surviving through the critical stages of first feeding. There is also evidence that in energetic terms, it is advantageous for fish larvae to be associated with still or low-velocity patches (Flore & Keckeis 1998, Matthews 1998, Flore et al. 2001), presumably because they expend less energy to retain their position in the water column.

Although there remains debate over whether refuge from current or food availability is more important in explaining the preference of larvae and young fish for slackwaters, the importance of slackwaters as rearing, feeding and refuge habitats for larvae and young fish appears to be well-supported. The maintenance of adequate baseflows throughout spring and summer to maintain essential slackwater habitats is therefore expected to increase the number of fish completing the larval stage.

In reaches directly downstream of major regulatory structures, excessive rates of rise during the spawning season may lead to the loss of fish eggs and larvae. In addition, in systems with seasonal flow inversion, constant high water levels in summer can alter the distribution and reduce the area and persistence of slackwater habitats, thereby potentially affecting the recruitment success of fish (Humphries et al. 2006).

2.6.2 Selected Sub-Hypotheses and Response Variables to be Monitored

First, the monitoring program should determine whether the implemented flows deliver the expected habitat features. Then, monitoring should attempt to determine whether implemented flows result in the expected ecological responses (Table 5). The achievement of the expected abiotic features not accompanied by the expected ecological response may indicate gaps or errors in our conceptual understanding of the system, or the presence of other limiting factors. The relevant monitoring field program, variable definitions and sampling timing and sampling protocols are presented in Table 6.

2.6.2.1 Complementary Research Issues

A non-exhaustive list of complementary research issues that have been identified as being relevant to the conceptual model are as follows:

1. Larval transport for diadromous fish. What levels of flow are required to successfully transport diadromous fish larvae to estuarine/marine habitats? This has important implications for the allowable level of extraction in the downstream reaches of major rivers.
Table 5. Native fish spawning and recruitment conceptual model: summary of subhypotheses and corresponding variables associated with the various flow components. Note that hypotheses concerning adult fish are generally dealt with under the Habitat Processes conceptual model

<table>
<thead>
<tr>
<th>Flow Component</th>
<th>Subhypotheses</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn–early Winter Freshes/ Bankfull Flows</td>
<td>Do implemented environmental flows trigger spawning of diadromous fish? (Only relevant in river reaches inhabited by diadromous fish species such as galaxiids, eels and Australian Grayling)</td>
<td>Presence/Absence of diadromous fish larvae</td>
</tr>
<tr>
<td>Winter–Spring Baseflows and Winter–Spring Freshes</td>
<td>Do implemented environmental flows increase overall quantity and diversity of in-stream habitat?</td>
<td>See conceptual model for Habitat Processes • Shallow and slow water area • Run area • Permanent pool depth and volume • Inundation of physical habitat features • Inundation of higher elevation physical habitat features • In-channel and littoral cover of macrophytes</td>
</tr>
<tr>
<td>Spring–early Summer Bankfull Flows</td>
<td>Do implemented environmental flows inundate low-lying runners and anabranches to create increased slackwater habitat?</td>
<td>Area of slackwater habitat in runners and anabranches</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase the number of fish completing larval stages?</td>
<td>Density of post-larval fish</td>
</tr>
<tr>
<td>Spring–early Summer Overbank Flows</td>
<td>Do implemented environmental flows inundate floodplain areas to create increased slackwater habitat?</td>
<td>Area of slackwater habitat in floodplain</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows provide appropriate conditions for spawning and larval production of ‘flood specialist’ non-diadromous fish species?</td>
<td>Presence/Absence of ‘flood specialist’ non-diadromous fish larvae</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase the number of fish completing larval stages?</td>
<td>Density of post-larval fish</td>
</tr>
<tr>
<td>Spring–early Summer Baseflows</td>
<td>Do implemented environmental flows provide appropriate conditions for spawning and larval production of ‘low flow specialist’ and generalist fish species?</td>
<td>Presence/Absence of ‘low flow specialist’ and generalist fish larvae</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows maintain adequate in-stream habitat for adult and larval fish?</td>
<td>See conceptual model for Habitat Processes • Shallow and slow water area • Run area • Permanent pool depth and volume • Connectivity</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase the number of fish completing larval stages?</td>
<td>Density of post-larval fish</td>
</tr>
<tr>
<td>Summer–Autumn Low Flows</td>
<td>Do implemented environmental flows maintain adequate in-stream habitat for adult and larval fish?</td>
<td>See conceptual model for Habitat Processes • Shallow and slow water area • Run area • Permanent pool depth and volume • Connectivity</td>
</tr>
<tr>
<td></td>
<td>Do implemented environmental flows increase the number of fish completing larval stages?</td>
<td>Density of post-larval fish</td>
</tr>
</tbody>
</table>
2. Role of winter–spring baseflows and freshes in creating conditions conducive for pre-spawning conditioning and pre-spawning interactions for adult fish. As noted above, it is widely assumed, but not known that pre-spawning conditions are an important determinant for the success of spawning, and therefore recruitment. Pre-spawning conditions will vary between sites and years, and such data on conditions coupled with spawning in recruitment data may reveal the importance (or otherwise) of pre-spawning conditions.

3. ‘Condition factor’ may be useful as an indicator of ‘fish health’ based on length/weight ratios. However, basic research is required to test the utility of this index, and to develop standards for individual species.

4. What is the impact of exotic fish species on native fish assemblages, and how is this affected by environmental flows?

2.7 Water Quality

In designing the monitoring program, we have sought to link flow-related effects back to ecosystem endpoints through conceptual models. Water quality per se has not been identified as an endpoint to be improved through the provision of environmental flows, and is more likely to be seen as a link between flow and a given ecosystem endpoint.

However, improved water quality is frequently cited as one of the goals in the various environmental flow reports – notwithstanding the fact that the improved water quality is often linked to some ecological effect. Moreover, there was support at the inaugural meeting of the VEFMAP Implementation Committee to include water quality monitoring as a program in its own right. The reasons for including water quality can be summarised as follows:

- Water quality is already well-accepted by regulators and the community as an indicator of environmental health through such programs as Waterwatch, the VWQMN, and through the inclusion of water quality variables in the State Environment Protection Policy (SEPP; EPA 2001a,b);
- We expect that water quality variables will react to environmental flow events more quickly than ecological variables. This possibility alone makes water quality a strong candidate for the VEFMAP program;
- Water quality variables do not show the same level of small-scale unexplained variation that is typical of many ecological variables. Thus it should be easier to demonstrate a beneficial effect of flows on water quality; and
- Water quality could affect most of the ecosystem endpoints outlined above, and knowledge of the effects of environmental flows on water quality may help to improve models of ecosystem response to flow events.

Inclusion of water quality in the monitoring program falls outside of the protocol laid down to select other endpoints for monitoring. Hence, no conceptual model has been developed for the effects of different flow components on water quality, and no sub-hypotheses from environmental flow reports have been identified. The inclusion of water quality has been justified on other grounds,
and it would be circular logic to go back and justify its inclusion using the same process as for the other endpoints.

A standard water quality monitoring program broadly of the type employed at VWQMN stations would be sufficient to address whether overall water quality changes in response to environmental flows. The program already instituted in the Glenelg River to monitor the effects of environmental flows on water quality (SKM 2006c) should be used as a guide, although this program was designed with null-hypothesis testing of water quality responses to flow in mind, which contrasts our own recommendations to quantify flow–response relationships within a Bayesian framework (see below). The number of parameters to be monitored would be less than that of VWQMN sites, and these are detailed in Table 6. If a VWQMN site is located close to a chosen environmental flow monitoring site, the data from that site may be used to reduce costs. It is likely, however, that additional water quality monitoring data will need to be collected at some environmental flow monitoring sites in order to give sufficient coverage of the reaches.

Because water quality monitoring has not been justified based on a conceptual model, there are no criteria for including it or excluding it based on reach specific characteristics. We recommend monitoring water quality in all reaches, and do not discuss it individually within the reach by reach recommendations. Conceptual refinements of the VEFMAP program in the future may lead to revisions of the recommendation.

2.7.1 Selected Sub-Hypotheses

2.7.1.1 Complementary Research Issues

Small-scale spatial patchiness in water quality is poorly understood. As stated above, we do not know whether water quality in slackwater areas and pools will be of different quality to that in the main channel. Results from the Glenelg River (SKM 2006c) suggest that water quality in pools differs from the main channel when pools were >3 m deep. Whether this result will hold for other rivers and years is unknown. It would be a relatively simply research project to determine whether a single monitoring point per site can effectively represent the water quality for the whole site.

Also not addressed by the current recommendations for water quality monitoring is the question monitoring specifically tailored to particular flow assess the effects of particular flow components. Two potential negative effects of environmental flows on water quality are blackwater events and saline fronts (see §2.10). In order to assess whether environmental flows are causing such events, fine temporal-scale monitoring around specific flow components will be required. This is a different research project to the standard water quality monitoring being recommended here.
2.8 Summary of Variable Definitions and Sampling Timing and Protocols

We have identified six field programs (in addition to monitoring flow), with several of these consisting of several subcomponents. The programs are delineated by background colour in Table 6. These programs cover the conceptual models, and associated hypotheses and variables developed for the statewide program. In addition, we have provided definitions of variables, recommendations for the timing and frequency of sampling, and sampling protocols for each variable (Table 6). River-specific monitoring programs will be based on a selection of these hypotheses and associated variables.

We recognise several types of variables in Table 6. Flow-related effects are seen as the primary drivers of response in the rivers, and are labelled as such. Other variables will also influence responses in the rivers, and these may be built into models as covariates that explain why some sites react differently to similar flows. Some of these covariates will be collected as part of the field programs. Other covariates will relate to data collected in the field programs but will need to be collected independently. This latter group of covariates appear at the end of Table 6, colour-coded according to the field program they are most relevant to. We have considered two main types of responses: intermediate endpoints and endpoints. The intermediate endpoint classification recognises the central role that habitat is expected to play in mediating ecological response to flow releases. Although habitat may not be the only requirement for the ecological response to be realised, there is a strong expectation that no response will be seen unless there is an improvement in habitat attributable to the environmental flow. It is necessary to monitor habitat to see if this requirement is being met. Habitat data may also then be built into ecological response models as covariate data as described above. Some ecological endpoints (such as in-channel macrophytes) may also be intermediate endpoints (and covariates) for other ecological responses (e.g. macrophytes act as macroinvertebrate habitat). Thus the classification of variables is not intended to be mutually exclusive, and there is likely to be discussion about the labels assigned. The labels below reflect our current opinion about the most likely use for the data.

2.9 Refining the Conceptual Models and Variables for the Glenelg River

The conceptual models presented above and the potential monitoring variables presented in Table 6 are generic in that they have not been specifically developed for the Glenelg River. In designing the detailed monitoring program for the Glenelg, contractors will need to take account of details in the reach-by-reach monitoring recommendations (§ 3.3).
Table 6. Summary of field programs, variable definitions and sampling timing, frequency and protocols. Background colour refers to the field program with which the individual variables are associated. Cells on multiple rows have been merged where the same description applies to more than one variable.

<table>
<thead>
<tr>
<th>Field Program</th>
<th>Type</th>
<th>Variable</th>
<th>Definition and Measure</th>
<th>Timing and Frequency</th>
<th>Sampling Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>Field</td>
<td>Flow</td>
<td>Timing, magnitude, frequency and duration of flow components (base flows, freshes and bankfull flows)</td>
<td>Continuous</td>
<td>Obtainable from gauging records</td>
</tr>
<tr>
<td>Endpoint</td>
<td>Frequency of channel disturbances</td>
<td>Geomorphically significant events are defined as events where bed or bank sediments are mobilised. Geomorphic events will be identified by increased turbidity in the main channel associated with increased flows in the main channel. This monitoring technique is novel and may require some development following the first year of monitoring.</td>
<td>Continuous sampling</td>
<td>Continuous monitoring of turbidity in the main channel and upstream tributary using automated turbidity sensors. The magnitude of the event will be measured relative to baseflow turbidity rather than absolute values eliminating concerns of “drift” in turbidity observations. Observations of turbidity in the upstream tributary are required to remove effects of tributary inputs from observed fluctuations in turbidity within the main channel.</td>
<td></td>
</tr>
<tr>
<td>Endpoint</td>
<td>Frequency of bed disturbances</td>
<td>A bed disturbance is defined as a flow event during which there is movement of coarser bed sediments. This and the following endpoint (rate of sediment deposition on benches) should be related to the frequency of geomorphically significant events.</td>
<td>After the passage of Winter–spring freshes or bankfull or overbank flows</td>
<td>Monitoring of painted lines on exposed point bars (recorded in photographs)</td>
<td></td>
</tr>
<tr>
<td>Endpoint</td>
<td>Rate of bench deposition</td>
<td>In an alluvial channel we would expect there to be erosion of bank material on the outside bank of meander bends and deposition of finer fraction of these bank sediments in slackwater areas such as benches. Thus deposition on benches is a surrogate measure of bank erosion rates and channel dynamics.</td>
<td>After the passage of Winter–spring freshes or bankfull or overbank flows</td>
<td>Sample mass of sediment deposited on sediment mats (e.g. artificial turf mats) placed on bench surfaces. The number of replicate mats to be used will depend on bench area and size of sediment mats. Sediment may either be removed by water using a high pressure washer or through careful brushing after drying (Steiger et al. 2003, Vietz et al. 2006).</td>
<td></td>
</tr>
<tr>
<td>Field Program</td>
<td>Type</td>
<td>Variable</td>
<td>Definition and Measure</td>
<td>Timing and Frequency</td>
<td>Sampling Protocol</td>
</tr>
<tr>
<td>---------------</td>
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<td>-----------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Endpoint</td>
<td>Endpoint</td>
<td>Bed complexity</td>
<td>Bed complexity can be characterised by analysis of the longitudinal bed profile surveyed along the channel thalweg (Bartley &amp; Rutherfurd 2005).</td>
<td>Once every 5 years</td>
<td>Channel survey: cross-sectional and longitudinal bed profiles. Survey should use at least 15 permanently marked cross-sections surveyed to a fixed datum. The monitoring site should include at least one full meander wavelength.</td>
</tr>
<tr>
<td>Endpoint</td>
<td>Endpoint</td>
<td>Bench development and variability</td>
<td>Bench development can be measured by the increased cross-sectional area occupied by benches. Variability in benches can be measured by variability in their elevation relative to bankfull and/or water surface at the time of survey.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endpoint</td>
<td>Endpoint</td>
<td>Mean channel top width, cross-section area and thalweg depth</td>
<td>Channel size is characterised by the top width, depth at the thalweg and the total cross-section area. Appropriate and consistent means should be used to identify the bankfull level.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endpoint</td>
<td>Endpoint</td>
<td>Bank erosion on outside of meander bends</td>
<td>Bank erosion on the outside of meander bends are a surrogate measure for the rate of meander development. This is measured by re-survey of cross-section profiles at meander bends.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endpoint</td>
<td>Endpoint</td>
<td>Point bar development</td>
<td>Point bar development on the inside of meander bends is a surrogate measure for the rate of meander development.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Program</td>
<td>Type</td>
<td>Variable</td>
<td>Definition and Measure</td>
<td>Timing and Frequency</td>
<td>Sampling Protocol</td>
</tr>
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</tr>
<tr>
<td>Intermediate endpoint</td>
<td>Shallow and slow water area</td>
<td>Shallow and slow water areas are defined as areas where the depth is between 0.1–0.3 m and the velocity is &lt;0.1 m/s (e.g. m² of shallow and slow water area per m² of stream channel area)</td>
<td>During summer–autumn low flows and winter–spring baseflows</td>
<td>Field survey at 3–4 stages over the range of baseflows typically encountered during summer–autumn and winter–spring baseflows. The relevant variable (i.e. shallow and slow water area, riffle/run area and permanent pool depth and volume) is interpolated from these surveys. Survey from channel bank towards the channel centre until depth exceeds 0.3 m or velocity exceeds 0.1 m/s for shallow and slow water area. Riffle/run areas can be identified visually</td>
<td></td>
</tr>
<tr>
<td>Intermediate endpoint</td>
<td>Riffle/Run depth and area</td>
<td>Riffle areas are defined as regions with coarse bed material and shallow, fast-flowing water. Run areas are defined as regions with low to moderate laminar flow and smooth, unbroken water surface (e.g. m² of riffle/run area per m² of stream channel area)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate endpoint</td>
<td>Connectivity</td>
<td>Maximum channel depth in shallow cross-sections</td>
<td>During summer–autumn low flows and freshes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Covariate</td>
<td>Size–class distribution of streambed substrate</td>
<td>e.g. % cover of substrate size categories where substrate size categories include: • Bedrock • Boulder &gt;256 mm • Cobble 64–256 mm • Pebble 16–64 mm • Gravel 2–16 mm • Sand 0.06–2 mm • Silt/Clay &lt;0.06 mm</td>
<td>Annually, during periods of low flow</td>
<td>Visual rating using EPA Rapid Bioassessment protocol (EPA Victoria 2003) substrate size categories along with % cover categories</td>
<td></td>
</tr>
<tr>
<td>Covariate</td>
<td>Organic matter</td>
<td>Refers to fine and coarse organic material (e.g. leaf-packs, twigs, branch piles, root masses, etc) e.g. % cover of organic material per m² of stream channel area</td>
<td></td>
<td>Visual rating using % cover categories. See for example, Anderson &amp; QNRM (2003) and EPA Victoria (2003)</td>
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<tr>
<td>Field Program</td>
<td>Type</td>
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<td>Definition and Measure</td>
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<td>Sampling Protocol</td>
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<tr>
<td>Habitat Field Survey (Repeate</td>
<td>Covariate</td>
<td>Woody debris loading</td>
<td>e.g. Woody debris (≥ 0.1 m in diameter) loading per unit stream area (e.g. volume loading such as m³ of woody debris per m² of stream channel area or surface area loading such as m² of woody debris per m² of stream channel area)</td>
<td>Once every 5 years, during periods of low flow</td>
<td>We recommend quantifying woody debris loading using a combination of the census method (Gippel et al. 1996) and the line-intersect method (van Wagner 1968, Wallace &amp; Benke 1984). The census method entails measurement of the diameter and length of every piece of WD above a predetermined threshold size (e.g. min. 0.1 m diameter, min. 1 m length) within a given stream area. The line-intersect method involves recording the diameter of every piece of WD (above the predetermined threshold size) intersected by a transect of given length. The census method gives accurate, repeatable estimates of woody debris loading, but is intensive and time-consuming. The line-intersect method is much quicker and provides consistent, repeatable estimates, but may grossly overestimate the actual loading (Marsh et al. 1999). Both methods should be used in the initial survey to calibrate the line-intersect method (see Marsh et al. 1999 for full details). Woody debris loading can then be estimated in subsequent (repeat) surveys using the line-intersect method.</td>
</tr>
<tr>
<td>Intermediate endpoint</td>
<td>Area of slackwater habitat in runners and anabranches</td>
<td>Slackwater areas are defined as areas where the velocity is &lt;0.01 m/s. In practice, these are areas where the flow is imperceptible. e.g. m² of slackwater area per m² of stream channel/floodplain area</td>
<td>Following spring–early summer bankfull or overbank flows</td>
<td>Same protocols as for quantifying ‘Shallow and slow water area’ and ‘Riffle/Run area’</td>
<td></td>
</tr>
</tbody>
</table>
## Habitat Survey in Conjunction with 1-D Hydraulic Modelling

<table>
<thead>
<tr>
<th>Field Program</th>
<th>Type</th>
<th>Variable</th>
<th>Definition and Measure</th>
<th>Timing and Frequency</th>
<th>Sampling Protocol</th>
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</thead>
<tbody>
<tr>
<td>Intermediate endpoint</td>
<td>Intermediate endpoint</td>
<td>Permanent pool depth and volume</td>
<td>Depth and volume of water in selected permanent pools within the monitoring site</td>
<td>During summer–autumn baseflows and following summer–autumn freshes</td>
<td>A stage recorder should be installed at the downstream end of the monitoring site. A rating curve should be established for the downstream cross-section based on measurements of discharge or observations of discharge at a nearby gauge. Cross-sections should be surveyed using at least 15 permanently marked cross-sections surveyed to a fixed datum. HEC-RAS or similar hydraulic model should be used to model water surface profiles along the monitoring site over the range of in-channel flow. Observations of stage at a number of points along the channel should be used to verify the model at a range of flow magnitudes from low flows up to bankfull. The model can then be used to estimate the depth and volume of water in selected permanent pools within the monitoring site during summer–autumn baseflows and following summer–autumn freshes.</td>
</tr>
<tr>
<td>Intermediate endpoint</td>
<td>Intermediate endpoint</td>
<td>Inundation of representative physical habitat features</td>
<td>Physical habitat features include in-channel macrophytes, channel edge macrophytes, tree roots, branch piles, woody debris, in-channel bars and overhanging or undercut banks</td>
<td>During winter–spring baseflows</td>
<td>A feature survey should be used to locate representative physical habitat features and geomorphic features (in channel zones A, B and C) and establish their elevation at the monitoring site.</td>
</tr>
<tr>
<td>Intermediate endpoint</td>
<td>Intermediate endpoint</td>
<td>Inundation of higher elevation representative physical habitat features</td>
<td>Higher elevation physical habitat features include channel edge macrophytes, tree roots, woody debris, branch piles, bars, benches and overhanging or undercut banks</td>
<td>During winter–spring freshes</td>
<td>The hydraulic model developed according to the protocol described in the cell directly above can then be used to estimate the discharge at which physical habitat and geomorphic features (in the various channel zones) are inundated or wetted. (cont. below)</td>
</tr>
<tr>
<td>Field Program</td>
<td>Type</td>
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<td>Definition and Measure</td>
<td>Timing and Frequency</td>
<td>Sampling Protocol</td>
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<tr>
<td>Habitat Survey with 1-D modelling (cont.)</td>
<td>Intermediate endpoint</td>
<td>Inundation/ Wetting of geomorphic features in Zone A</td>
<td>Geomorphic features in Zone A include channel bed, channel edges, low-lying bars and benches, runners and anabranches</td>
<td>During spring baseflows and summer freshes</td>
<td>Repeat feature surveys are required once every three years as the distribution of physical habitat features may be altered by events such as large flow events, bank slumping, tree fall and macrophyte growth/dieback.</td>
</tr>
<tr>
<td>Intermediate endpoint</td>
<td>Wetting of geomorphic features in Zones B and C</td>
<td>Geomorphic features in Zones B and C include higher elevation bars and benches, upper banks, runners and anabranches</td>
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<tr>
<td>Macroinvertebrate Survey</td>
<td>Endpoint</td>
<td>Number of invertebrate families</td>
<td>Number of invertebrate families</td>
<td>Autumn and spring in same year OR Spring and autumn in consecutive year</td>
<td>EPA Rapid Bioassessment protocol (EPA Victoria 2003) with separate assessments for riffle and edge habitats. Must be based on data from sampling in both autumn and spring. Family-level sampling would provide cost-savings over species-level sampling. However, the environmental flows to be implemented are likely to represent subtle rather than substantial changes to the current flow regime in many rivers. There is uncertainty over whether macroinvertebrate responses to minor flow augmentation can be detected at the family level. Consequently, we recommend sampling to species level for an initial 3 years. The data should then be reviewed to determine if it is necessary to continue sampling to the species level.</td>
</tr>
<tr>
<td>Endpoint</td>
<td>AUSRIVAS score</td>
<td>AUSRIVAS predicts the invertebrates that should be present in specific stream habitats under reference conditions. By comparing the number of expected families with the number of families actually found, a ratio can be calculated for each test site. This ratio is expressed as the observed number of families/expected number of families (the O/E score).</td>
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<tr>
<td>Endpoint</td>
<td>SIGNAL biotic index</td>
<td>Index of water quality based on the tolerance of aquatic biota to pollution. Calculated by summing together the sensitivity grades for each of the families found at a site that have been assigned a sensitivity grade, and then dividing by the number of graded families present.</td>
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<td>Field Program</td>
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<tr>
<td><strong>Macroinvertebrate Survey (cont.)</strong></td>
<td>Endpoint</td>
<td>EPT biotic index</td>
<td>Total number of families in the generally pollution-sensitive insect orders of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). Calculated by summing together the number of families in these three orders present at a site. May not be that useful in lowland streams and rivers where such taxa are rare.</td>
<td>See above</td>
<td>See above</td>
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<td></td>
<td>Endpoint</td>
<td>Presence / Absence and number of ‘flow sensitive’ taxa</td>
<td>e.g. some leptophlebiid mayfly species</td>
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<tr>
<td><strong>Vegetation Survey</strong></td>
<td>Intermediate endpoint and Endpoint</td>
<td>In-channel and littoral cover of macrophytes</td>
<td>Includes submerged and amphibious (e.g. free-floating, floating-leafed and emergent) macrophytes e.g. % cover of in-channel macrophytes per m² of stream channel area</td>
<td>If assessing as Habitat intermediate endpoint, sample during late-spring baseflows If assessing as Vegetation endpoint, sample in late spring for quick responders, and late summer for integrative effects over whole growing season</td>
<td>If assessing as Habitat intermediate endpoint, visual rating of each functional group using ordinal scales such as the Braun–Blanquet % cover scale or % cover categories will suffice (see Werren &amp; Arthington 2002). If assessing as Vegetation endpoint, quadrat sampling recommended. Cover by species is desirable but requires species-level knowledge. Cover by growth-form (e.g. submerged, free-floating, floating-leafed and emergent) may be sufficient? (cont. below)</td>
</tr>
<tr>
<td></td>
<td>Intermediate endpoint and Endpoint</td>
<td>Cover of submerged and amphibious species in Zone A</td>
<td>Cover refers to the real proportion of a horizontal plane at a given height occupied by vegetation biomass. A coarse indicator of the amount of vegetation occupying different canopy layers, but also a measure of the quantity of canopy available to absorb sunlight. (cont. below)</td>
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<tr>
<td>Field Program</td>
<td>Type</td>
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<td>Definition and Measure</td>
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<tr>
<td>Endpoint</td>
<td>Cover of amphibious and terrestrial species in Zones A and B</td>
<td>e.g. % cover of submerged macrophytes per m² of Zone A area</td>
<td>Late spring–early summer (preferably a fixed time such as 7 weeks after the passage of Spring freshes).</td>
<td>Standard protocols do not exist. Will need to do some experimentation on minimum sample sizes required.</td>
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<tr>
<td>Endpoint</td>
<td>Species composition, number of submerged, amphibious and terrestrial species in Zone A</td>
<td>Assessment of species present at a site provides information on the vegetation’s structural and floristic diversity and weediness. Vegetation diversity is usually interpreted as an indicator of the community’s stability and capacity to respond to disturbance (Baldwin et al. 2005).</td>
<td>In late spring for quick responders, and late summer for integrative effects over whole growing season</td>
<td>Species composition data may be obtained by quadrat or point sampling in the relevant channel zone. Plant collection and identification are likely to be required to determine species composition. Plant identification to species level can be time-consuming and may require taxonomic expertise. May be difficult to assess submerged species.</td>
<td></td>
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<tr>
<td>Endpoint</td>
<td>Species composition, number of amphibious and terrestrial species in Zones B and C</td>
<td></td>
<td>Late spring–early summer (preferably a fixed time such as 7 weeks after the passage of spring freshes).</td>
<td></td>
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<tr>
<td>Endpoint</td>
<td>Proportion of exotic plant species</td>
<td>Proportion of total number of plant species that are exotic species in each relevant zone</td>
<td></td>
<td>Obtainable from species composition data</td>
<td></td>
</tr>
<tr>
<td>Endpoint</td>
<td>Germination of seedlings of overstorey and midstorey species</td>
<td>Number of native and exotic seedlings of overstorey and midstorey species per m² of Zone C area</td>
<td>Summer (preferably a fixed time such as 7 weeks after the passage of spring freshes) OR Fixed time after the passage of bankfull/overbank flows</td>
<td>Quadrat sampling in the channel zone C Identification of exotic weed seedlings should be fairly easy, but identification of native seedlings may be more difficult (J. Catford, pers. comm.).</td>
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<td>Field Program</td>
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<tr>
<td>Vegetation Survey (cont.)</td>
<td>Endpoint</td>
<td>Canopy condition</td>
<td>The physiological condition of vegetation affects its survivorship, growth, reproduction, habitat quality and ability to perform ecosystem functions. Assessment of the condition of a plant’s canopy provides information about the physiological condition of that individual (Baldwin et al. 2005). e.g. a) visual rating of canopy condition for trees of different age/size classes</td>
<td>Dyer &amp; Roberts (2006) recommend that canopy condition be assessed annually in early summer (and preferably a fixed time (e.g. 7 weeks) after the passage of spring fresh(es)). And possibly at a fixed time after the passage of summer freshes.</td>
<td>Canopy condition can be assessed using a visual rating system aided by % ‘cover’ diagrams. Baldwin et al. (2005) recommended that the assessment of canopy condition be based on visual survey of four components: i) % of branches which are dead; ii) % of canopy represented as epicormic growth; iii) % of canopy which is discoloured; and iv) canopy density (% cover) for that individual. They suggest that on-ground measurement might involve applying the visual ratings system to 10 randomly selected individuals for each species under study. Dyer &amp; Roberts (2006) suggest a procedure involving the visual rating of canopy condition for a random sample of 30–50 trees in a pre-designated area at each site. They also recommend stratification if the trees are clearly of different age/size classes. Other methods include spherical densiometers and the use of fish-eye lens photography and computerised analyses of images using appropriate software (Werren &amp; Arthington 2002).</td>
</tr>
<tr>
<td>Fish abundance and composition survey</td>
<td>Endpoint</td>
<td>Fish species composition and distribution</td>
<td>e.g. Ratio of species actually collected at a site compared to total suite of species believed to be present in the reach (from past records, anecdotal information, Sustainable Rivers Audit models etc.)</td>
<td>Report on pilot studies for the Sustainable Rivers Audit (SRA) considered that fish were best sampled during baseflow conditions and that autumn was the best time to sample fish (MDBC 2004)</td>
<td>Adult fish may be sampled using backpack, bank- and boat-mounted electrofishing and fyke nets, although fyke netting has generally been found to be a cost-ineffective survey method (A.J. King pers. comm.) (cont. below)</td>
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<td>Field Program</td>
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<td>Timing and Frequency</td>
<td>Sampling Protocol</td>
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<tr>
<td>Fish abundance and composition survey (cont.)</td>
<td>Endpoint</td>
<td>Relative abundance of adult/sub-adult native and exotic fish species</td>
<td>e.g. Abundance of adult/sub-adult native and exotic fish per unit effort (expressed as catch per unit effort)</td>
<td>See above</td>
<td>Individual fish measured to the nearest millimeter with Total Length (TL) for round-tailed fish and Caudal Fork Length (LCF) for fork-tailed fish. In the SRA, all individual fish larger than 15 mm were counted and identified to species. Individuals smaller than 15 mm were not counted in the sample as there were concerns that the gear types used (electrofishing, fyke and light traps) might be relatively ineffective for fish of that size and smaller (MDBC 2004)</td>
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<tr>
<td></td>
<td>Endpoint</td>
<td>Population structure and size–class distributions of native and exotic fish species</td>
<td>e.g. Size–class distribution by length or weight of native and exotic fish species</td>
<td></td>
<td>A variety of methods may need to be used for sampling fish larvae, such as the use of drift nets and light traps in run areas and trawl nets and light traps in pool areas (Humphries &amp; Lake 2000). Humphries et al. (2002) reported that drift nets (500 μm mesh, 1.5 m long with a 0.5 m diameter mouth and tapered to a 90 mm diameter cod end to which a reducing bottle was fitted) and light traps were used in runs and plankton tow nets and light traps were used in pools. They also reported that seine netting proved relatively ineffective in collecting fish larvae of any species</td>
</tr>
<tr>
<td></td>
<td>Endpoint</td>
<td>Presence/ Absence of diadromous fish larvae</td>
<td>Diadromous fish species include galaxiids, eels and Australian Grayling</td>
<td>Throughout autumn and winter.</td>
<td>Minimum sampling frequency of once a month. According to Humphries &amp; Lake (2000) fish larval sampling must be carried out at least monthly because of the variation in the behaviour of larvae of different species of fish</td>
</tr>
<tr>
<td></td>
<td><strong>Larval Fish Survey</strong></td>
<td><strong>Endpoint</strong></td>
<td>Presence/ Absence of ‘flood specialist’ non-diadromous fish larvae</td>
<td>‘Flood specialist’ species include Golden Perch and Silver Perch</td>
<td>Throughout spring and summer.</td>
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(cont. below)
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<tr>
<th>Field Program</th>
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<th>Variable</th>
<th>Definition and Measure</th>
<th>Timing and Frequency</th>
<th>Sampling Protocol</th>
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<tbody>
<tr>
<td>Larval Fish Survey (cont.)</td>
<td>Endpoint</td>
<td>Presence/ Absence of 'low flow specialist' and generalist fish larvae</td>
<td>'Low flow specialist' species include Crimson-spotted Rainbow fish and Carp Gudgeons. Generalist fish species include Australian Smelt and Flathead Gudgeon</td>
<td>See above</td>
<td>Data from drift and tow nets may be expressed as number of larvae per unit volume of water (m³). Data from light traps may be expressed as number of fish per trap</td>
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<tr>
<td></td>
<td>Endpoint</td>
<td>Density of post-larval fish</td>
<td>e.g.: a) number of larvae per unit volume of water (m³) b) number of fish per trap</td>
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<tr>
<td>Water Quality Survey</td>
<td>Endpoint</td>
<td>Standard Water Quality parameters</td>
<td>Parameters: pH, total phosphorus, total nitrogen, turbidity, suspended solids, dissolved oxygen, temperature, salinity</td>
<td>Monthly as a minimum frequency. Fortnightly preferred</td>
<td>Follow standard protocols for sampling methodology used by the VWQMN</td>
</tr>
<tr>
<td></td>
<td>Covariate</td>
<td>Bed/Bank Erosivity</td>
<td>Resistance to erosion characterised categorically (low medium, high)</td>
<td>Initial survey, followed by infrequent repeats as channel evolves (5 yrs +)</td>
<td>Method described in Annandale (1996)</td>
</tr>
<tr>
<td></td>
<td>Covariate</td>
<td>Rate of riparian grass growth on benches and point bars</td>
<td>Grass cover</td>
<td>Surveys at the start and end of the spring–summer period.</td>
<td>Survey of grass cover on benches and bars</td>
</tr>
<tr>
<td></td>
<td>Covariate</td>
<td>Active habitat management activities</td>
<td>e.g. a) Re-snagging b) Other activities</td>
<td></td>
<td>Anecdotal data</td>
</tr>
<tr>
<td></td>
<td>Covariate</td>
<td>Revegetation activities</td>
<td>e.g. a) Passive regeneration by fencing off/restricting stock access riparian zone b) Direct seeding and/or replanting</td>
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<tr>
<td></td>
<td>Covariate</td>
<td>Stock access</td>
<td>e.g. a) No stock access at any time b) Partial stock access (e.g. watering points)</td>
<td></td>
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<td>Field Program</td>
<td>Type</td>
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<td>Definition and Measure</td>
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<tr>
<td>Covariate</td>
<td>In-stream barrier(s) to fish movement</td>
<td>e.g. Presence/absence of effective in-stream barriers to fish movement into the reach</td>
<td></td>
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<tr>
<td>Covariate</td>
<td>Fish stocking practices</td>
<td>e.g. a) Fish species stocked. b) Number, size class, location and frequency of stocking</td>
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2.10 Potentially Important Adverse Effects

The aim of this program is to determine whether the desired ecological outcomes from the implementation of environmental flow components have occurred. It should be noted that the implementation of environmental flows may also be accompanied by non-desirable outcomes. The FLOWS method is based on the natural flow paradigm (Poff et al. 1997), which was developed as a conceptual model to explain the relationship between flow and ecological outcomes. In the transfer of this scientific, explanatory model to the management context it has become clear that practical restrictions often prevent the application of a flow regime in its entirety (e.g. infrastructure risks associated with overbank flows generally make the delivery of a flow component unrealistic, or there simply is not enough water to deliver all components). Commonly only a limited number of flow components can be delivered, and at this stage it is unclear what this means for the conceptual links in the natural flow paradigm. Future work should include a more comprehensive analysis of the potential risks associated with such partial deliveries of flow components.

Aside from the high-level concern noted above, other more easily definable adverse effects may occur as a result of the instigation of an environmental flows program. Such adverse effects include, but are not restricted to:

- Provision of environmental flows from below the thermocline of a storage may cause cold water pollution;
- Increased shallow and slow water areas following reinstatement of more natural levels of baseflows year-round may increase the availability of habitat for adult and subadult carp;
- Increased slackwater areas may increase the availability of suitable habitat for carp larvae and juveniles and consequently improve survival, recruitment and population size of carp in the reach;
- Spring and summer freshes/bankfull/overbank flows may flush eggs, larval and juvenile fish from slackwater habitats;
- Winter–spring freshes/bankfull/overbank flows may deliver large quantities of organic matter into the river and cause blackwater events. If these events lead to low oxygen levels in constrained (i.e. between weirs) sections of the river, it may lead to fish kills and other detrimental biotic effects;
- Winter–spring freshes/bankfull/overbank flows may flush highly saline and/or deoxygenated water from the bottom of stratified pools into the water column to the detriment of aquatic biota; and
- Environmental flow events may lead to the dispersion of invasive plant and animal species. At present, very little is known about dispersal and proliferation in relation to environmental flows and there is little scientific data, but it is likely that the benefits of environmental flows to native flora and fauna will also be experienced by invasive species.
3 Monitoring Program Design and Data Analysis

A monitoring design consists of directions that stipulate what, where, when and how many observations or sampling units should be taken to assess whether or not a change has occurred in a system. The design of a monitoring program should link the delivery of environmental flows components to the relevant environmental and ecological responses outlined in the conceptual models.

3.1 Background

3.1.1 Practical Constraints for Monitoring the Effects of Environmental Flows

Fully replicated monitoring studies that compare changes in response variables at Control, Impact and Reference locations both Before and After the prescribed environmental flows (BACI designs and derivatives; Underwood 1991, 1992, 1994) would enable the strongest conclusions (sensu Downes et al. 2002) about whether the interventions are having the predicted effect (Cottingham et al. 2005a, b).

However, a number of factors prevent the application of BACI-type designs to many of the river systems in the statewide program. Some of these are as follows:

Lack of ‘Before’ data. Defining ‘Before’ conditions is not straightforward as a clear definition of ‘Before’ conditions is not possible. Environmental flows implementation will not be a ‘step change’ whereby all recommendations are delivered in full after a certain date. Rather, it will be an incremental and variable process, contingent on natural variability in climatic and hydrologic conditions, as well as and operational and logistical constraints. Furthermore, some environmental flow components have already been delivered in some of the eight nominated rivers, and it is unlikely that data that can be used to test Before–After hypotheses have already been collected. Extant data collected prior to environmental flow provision as part of existing monitoring programs might be useful, but it is unlikely that such data will be suitable for testing the hypotheses of interest at the appropriate spatial and temporal scale (Chessman & Jones 2001).

Lack of Control locations. It can be very difficult to identify a suitable set of Control locations in other river systems, because there are likely to be important environmental differences in physiographic, geomorphic, hydrologic and ecological characteristics. In addition, there are likely to be differences in water resource development and historical and current land use. One might expect that the upstream reaches or tributaries of rivers might be able to act as controls. But in reality there may be natural systematic, longitudinal changes in geomorphological, physicochemical and biological characteristics in the river or between the main river channel and its tributaries (Downes et al. 2002). For example, we expect to see natural changes in composition of the river biota proceeding from upstream to downstream environments (Vannote et al. 1980, Schlosser 1982).
Lack of Reference locations. Given that nearly all of our catchments are developed to some degree, Reference locations can also be difficult or impossible to identify. If upstream reaches and tributaries are chosen as Reference locations, one would also need to be aware of the possibility of natural systematic, longitudinal differences in geomorphological, physicochemical and biological characteristics of the river or differences between the main river channel and its tributaries.

No Factorial Treatment. BACI-type designs rely on being able to identify a site as being either Control or Impact. Implicitly, this assumes that all Impact sites are subjected to a similar level of the treatment. Thus, for environmental flows, we either consider a site as ‘flow enhanced’ or not. In reality, different sites will receive different proportions of the recommended flows, depending on water availability and competing uses. The amount delivered from year to year at any one site will also vary for the same reasons. Thus the environmental flows ‘Impact’ will be continuous rather than factorial in nature. It would be possible to draw an arbitrary line through this continuum and describe all flow enhancement less than a certain amount as Control, and all above it as Impact, but this would be very poor practice and would be less likely to tell us anything useful about the effects of environmental flows than would an analysis that treats the flow ‘treatment’ as a continuous variable.

3.1.2 Proposed Approach to the VEFMAP Monitoring Program Design

The difficulty in applying BACI-type designs means there is a need for targeted monitoring and innovative analytical approaches that will enable us to accommodate and, if possible, profit from the anticipated variation in environmental flow implementation, starting conditions and lack of Control/Reference locations.

Based on the expectation that different sites within river reaches are likely to be subject to different environmental flow regimes, we recommend that response variables be measured at multiple sites within each river, representing different levels of a continuous ‘treatment’ along a continuum of environmental flow interventions. Thus, information will be collected on flow and response along a gradient, allowing us to build up a picture of the relationship between flow and response. This is in contrast to the BACI approach, which collects information at the two extreme ends of the gradient and applies a test to see whether or not the two ends are significantly different to one another.

For responses that are discrete in time (i.e. they can be conceptually tied to the flow regime at the site over the last year or perhaps slightly longer), variation in the amount of environmental flows delivered over time will also result in response data that can be treated as a function of the continuous flow ‘treatment’. For such responses, there will be periods of time at most sites when environmental flows are not delivered at all due to a lack of available water. Data collected during these years would lie at one extreme end of the ‘treatment’ value (i.e. no treatment applied). These data can be thought of as
‘control’ in the sense of the BACI analysis, and will be very useful for inferring causal linkages between flow and response. Conversely, for some rivers, it may be possible to find reference sites on nearby rivers that are sufficiently similar to the ‘treatment’ river to be considered in the same analysis. Data from such sites would lie at the other end of distribution of treatment values (i.e. natural flow regime), and would again be very useful for inferring cause and effect. On the whole, however, the approach steps away from the BACI-type designs, and recognises that we are unlikely to be able to define specific Control or Reference sites, that the concept of Before/After is problematic for environmental flows interventions, and that the environmental flow ‘treatment’ can not be treated as a factorial Control/Impact variable. The approach relies on collecting data at multiple sites and times, and treating these in the broadest sense, as replicate measurements. That means that where the data permit it, results from multiple sites, reaches and potentially rivers will be combined in analyses to infer the effects of flow releases. The challenge will be to account for other variation that will inevitably occur between sites and times so that the effect of different flow regimes, and not of other extraneous variables, is being tested in statistical analyses. As stated above, the aim of this type of program will be to quantify and describe the relationship between flow augmentation and various ecosystem responses, and this is in contrast to BACI-type designs that primarily aim to infer whether or not an effect has occurred through a null hypothesis test, without necessarily quantifying the size of that effect (although this is possible). For example, we might seek to quantify the relationship between the frequency of freshes and germination of a certain species of riparian vegetation. We can use this relationship to infer whether or not there has been a beneficial effect of enhanced flows at individual sites, and also to make predictions about the potential benefit of different flow regimes. This example is developed in detail in Appendix 3.

Spatial variability is characteristic of river systems, and a sample taken at one place will differ from another sample taken at a second location. Even where flow delivery is approximately equal (most likely at the reach scale), replicate sites are necessary to provide some measure of the site-to-site variability of each response variable, and to provide a better estimate of average response at the reach scale. This is important for statistical analysis of any contrast between reaches. For a given level of natural variability in a response variable, more precise estimates can be obtained with a larger number of samples. However, the larger the number of sites, the more intensive and expensive the monitoring effort becomes. We recommend a similar compromise to that proposed by Sharpe & Quinn (2004), which is to use a minimum of two sites per reach so that one can at least obtain an estimate of variability, but to use more sites per reach if the resources allow for it. If there are previous data that allow a calculation of the between site variability, preliminary power analyses may be useful for determining the number of sites necessary for certain variables. Power analysis techniques are well-developed for frequentist null-hypothesis testing analysis frameworks. Little work has been done for power analysis of Bayesian techniques, although the principles will be the same (Cottingham et al. 2005). However, even if Bayesian techniques are to be used for final data analysis, a power analysis done with frequentist techniques will...
give an indication of the necessary degree of site replication, and is likely to be conservative.

Generic criteria for selecting monitoring sites within a river reach are outlined as follows:

1. **Representative** – sites should be physically representative or typical of the reach in terms of characteristics such as hydrology, channel morphology, abundance of instream vegetation and woody debris and riparian vegetation. Sites should not be located immediately downstream of major tributary confluences, or at road crossings, bridges, gauging stations, weir pools and any other built structures that may have created artificial flow and habitat characteristics;

2. **Proximity to gauging station** – sites should be located at reasonable proximity to an operational gauge that can provide reliable flow data (including contributions from tributaries) for tracking flow characteristics such as the timing, magnitude, duration and frequency of the various flow components. Sites that were assessed using HECRAS modelling during the original environmental flows studies should be used if they are suitable by the other criteria supplied. For these sites we have a parameterised model of expected changes to habitat components under different flow regimes;

3. **Accessibility** – should be reasonably accessible. As Sharpe & Quinn (2004) point out accessibility has been an issue of over-riding concern and while accessible sites may not be representative, some compromise may be inevitable;

4. **‘Independence’** – response variables may be spatially autocorrelated between upstream and downstream sites. It is difficult to know a priori how far apart we have to keep measurements to ensure that they are independent estimates. We follow Sharpe & Quinn (2004) and recommend that sites should be at least 1 km apart. If necessary, the effects of spatial autocorrelation can be accounted for during the analysis of data; and

5. **Availability of relevant historical data.** Environmental flows may already have commenced in some rivers, either in full or in part, so the opportunity to collect ‘before’ data might have passed. The availability of relevant historical data may provide us with some information for making useful inferences once the monitoring data are in hand. Such data may exist as part of routine monitoring programs or specific research programs that have previously been carried out.

Given the requirements detailed above, particularly ones such as proximity to a gauge and accessibility, sites cannot be chosen at random from all possible sites within a reach. Nevertheless, it is important to try and ensure as far as possible that the chosen sites are physically representative of the reach in which they are located. This is not a trivial exercise as some of the reaches span a great distance (e.g. 60–100+ km long) and the notion of ‘typical’ becomes more tenuous in those situations.

We recommend the following practical approach for site selection:
1. Plot the (1) annual mean discharge, (2) valley width and (3) meander wavelength against river distance for the entire length of river to be monitored (These data are available from the eWater project team if required);

2. Draw reach boundaries (as delineated in the original environmental flow study) on this graph and confirm that there are no major step changes in these three characteristics within the reaches. If there are, consider adding an additional reach (with a division at the largest step change in the relevant attribute);

3. Visually classify each reach into two or three sub-reach types based on meander wavelength and valley width (local expertise will help with this). The river may switch back and forth between sub-reach types (e.g. as the valley contracts and widens then contracts again);

4. On the graph produced in step 2, locate (1) major tributaries (2) active streamflow gauging stations (3) channel cross-sectional survey sites used to develop hydraulic models for the environmental flow study and (4) sections of the river where access is feasible for monitoring (allowing for the possibility of arranging access with riparian landholders where this is known); and

5. Choose to sample sites within each of the two or three sub-reach types where (i) access is possible; (ii) are not located at or within 1 km of a major tributary confluence; (iii) are not unique in terms of wavelength, geomorphology, valley width or other known characteristic of the river (e.g. sites with recent engineering works should not be used) and (iv) mean flow is as close as possible to that of an active streamflow gauge. As discussed above, if the channel survey sites used to develop hydraulic models for the environmental flow study satisfy these criteria, they should be selected.

3.2 Bayesian Hierarchical Approach to Data Analysis

The data can be analysed by any statistical method that can accommodate the following features:

- The main driver of ecological effect, stream flow is continuous, rather than categorical;
- There will be other drivers of ecological effects that will vary between replicate measurements;
- Given the linear nature of rivers, data may be spatially autocorrelated. Data collected at the same site over time may be temporally autocorrelated; and
- The method can utilise data from multiple sites and/or times to infer the effects of environmental flows.

We advocate the use of a regression-based approach within a Bayesian hierarchical modelling (BHM) framework. This approach may have certain advantages with regards to the inclusion of data from multiple, partially different, sites within a single analysis. It will also allow the inclusion of prior
knowledge of the effects of flow on the biota to be formally incorporated in models.

A regression-based approach describes a mathematical relationship between variables based on the data available. This is in contrast to BACI type designs that explicitly test for differences between two or more data sets.

The basis of Bayesian statistical modelling is briefly covered in Cottingham et al. (2005b). We believe that the central advantage of Bayesian hierarchical modelling, in particular, to the analysis of data in the VEFMAP program, is a property known as 'borrowing strength' (Gelman et al. 1995). Practically, this means that the data from one site will lead to stronger conclusions being drawn from the data at a second site when the two sites are considered in the same model. The site-level conclusions are stronger for each site than would have been possible if the data were considered in separate analyses. Given the relatively small number of sites likely to be sampled in each reach / river, and given that data may only be collected once or twice a year, any means to strengthen conclusions from these sparse data sets needs to be applied.

The increase in inferential strength relies on the two sites behaving in similar (but not necessarily identical) fashion to the flow augmentation, and that the two sites also be similar in terms of other environmental variables. This second condition is likely to be problematic for many sites. However, it is also possible to build site-specific differences into Bayesian hierarchical models such that the results can still be considered together (Gelman et al. 1995). If sites show very different responses to flow augmentations, the flow regimes are completely different, or site specific differences are too great, the data should not be analysed within the same model. Such differences would show up in pre-analysis checks of the data that are mandatory no matter what statistical approach is being used.

It is important to note that we are not necessarily committed to the use of Bayesian statistics by the design of monitoring program being advocated. Nor is the design of the program being driven by a particular desire to use BHM. Although our recommended program would not be amenable to analysis by a BACI model, this is a result of the spatially and temporally variable nature of the environmental flows interventions, along with restrictions in the types of sites available, and the overall budget for monitoring. BHM is one practical approach to the type of data that will be produced when studying the effects of environmental flows. Other approaches that can accommodate the points above could also be used. These would include multiple regressions of various types and meta-analysis. However, we believe that these other approaches would provide inferior results compared to Bayesian modelling.

An introduction to Bayesian statistics was provided in the VEFMAP Stage 1 report (Cottingham et al. 2005b; Appendix 1). In addition, a technical discussion of Bayesian hierarchical modelling is provided in Appendix 3 of this report, along with a hypothetical case-study that demonstrates the effects of considering data from multiple sites, reaches and rivers within the same model.
3.3 Reach-by-Reach Monitoring Design

The information presented in the sections below should be used by consultants to design the individual monitoring programs. In particular, Table 10 provides a summary of the field programs (detailed in Table 6) that apply to each reach in the Glenelg River. Thus, in order to use this report in the development of a specific monitoring program, the user should first refer to Table 10 to identify which broad sections of Table 6 are relevant to a particular reach in the Glenelg River. Using this information, the user can then refer to the relevant section in Table 6 to get specific details about variables to be considered, and details on how these variables should be sampled. In addition, the user can refer back to the tables summarising conceptual models in § 2.3–2.7 to identify the hypotheses that are being tested by sampling particular variables. The user can also relate these hypotheses to the conceptual understanding of the relationship between environmental flows and objectives by referring to the details of the conceptual models presented in these sections.

As mentioned above (§ 2.9), the details of the individual reaches will determine which aspects of the generic conceptual models are applicable, and hence which variables should be monitored. Differences in the proposed delivery of water compared to the original recommendations may also affect what variables to monitor. A detailed monitoring program for a particular year need to be based on information about the likely volumes of water committed for that water year (i.e. based on the annual watering plan) and the flow components that this water will deliver. The program then monitors the expected ecological outcomes for those flow components. For each reach, the sections below make general recommendations for monitoring.

When designing detailed monitoring programs, consultants should consider the following:

- Reach description (hydrology including current flow regime; seasonal flow inversions, etc., special features of geomorphology, barriers, condition of vegetation, fish, and macroinvertebrates);
- Intended program of delivery of environmental flows with reference to recommended environmental flows (including details on the priority of different flow components and delivery rules/conditions, if any exist). This will change from year to year, and the program will need to be updated accordingly;
- Comparison of recommended environmental flows with i) current delivery of environmental flows and ii) intended program of delivery of environmental flows;
- The differences to the current flow regime that will be caused by the intended delivery of environmental flows;
- Statewide hypotheses that apply in the reach based on information provided on intended program of delivery of environmental flows;
- Availability of relevant historical and current data pertaining to response variables to be monitored for hypothesis-testing;
• Implications of intended program of delivery of environmental flows and availability of historical/current data for the testing of statewide hypotheses; and

• Any reach-specific characteristics that might have implications for i) site selection; ii) timing of sampling; iii) number of samples; iv) frequency of sampling in the monitoring of response variables.

In this report, we have concentrated on the environmental flow reaches, and have not attempted to identify reference systems. Consultants will need to identify whether potential reference systems exist (there may already be information on proposed reference systems), and whether parallel monitoring to that in the environmental flows reaches can be implemented in the reference system within budget.

Similarly, we have not tried to identify existing data sets that may be useful as ‘Before’ data. The existence of such data should be investigated, and the program designed with these data in mind. A prime example of such a data set is that collected in the Campaspe and Broken Rivers during the 1990s (e.g. Humphries & Lake 2000, Humphries et al. 2002, Humphries & Cook 2004).

Our treatment in the sections below of the specific links between ecological response hypotheses and various flow components is also superficial. This was unavoidable, due to the requirement to provide broad monitoring recommendations across eight rivers. As part of the fine-tuning of field programs process, consultants should return to the original environmental flows recommendations and to the information contained in the conceptual models in § 2 and Appendix 2 to ensure that monitoring carried out relates to the specific hypotheses developed for the river.

3.3.1 Reach 1: Rocklands Reservoir to Chetwynd River Confluence

3.3.1.1 Reach Description

This section is based on information in SKM (2003b, 2004). The reach from Rocklands Reservoir to Chetwynd River confluence is about 114 km long.

A resource allocation model (REALM) was constructed to quantify flows under natural and contemporary conditions. Natural flows were calculated by adding rural and urban water demands to gauged flow data. All catchment storages were accounted for during the process (SKM 2004). Private diversions from the Glenelg River and its other tributaries were considered to be small relative to its flows and were assumed to be negligible (SKM 2004). It is important to note that modeled ‘natural’ flows generated in this manner do not reflect potential changes to flows as a result of land use changes. The comparison of modeled ‘natural’ and current (recorded) flows is based on flow data for a 10 year period in the 1990s (exact period unspecified). The data are disaggregated daily data from a weekly REALM model (SKM 2004).

Rocklands Reservoir has a significant impact on the seasonal flow pattern of the river downstream of the reservoir, although the impact decreases with distance from the dam. At Rocklands Outlet, median monthly (and indeed up to 20th percentile) winter–spring flows are very drastically reduced from May–Nov
and reduced, but less drastically, over summer (Dec–Apr). Under modelled 'natural' conditions, zero flows would only have occurred for <5% of the time over Jan–Feb. Under current conditions, zero flows occur more than 50% of the time over May–Nov (zero flows over Jun–Jul, 100% of the time; zero flows >80–90% of the time over May and Aug–Nov). In the remaining months (i.e. Dec–Apr), zero flows occur 15–40% of the time. At Fulham Bridge, median monthly (and indeed up to 20th percentile) Winter–Spring flows are drastically reduced from May–Nov and somewhat reduced over Dec–Jan, but not very different from modelled 'natural' conditions over Feb–Apr. Under natural conditions, the Glenelg River commonly ceased to flow at Balmoral over summer (Feb–Apr), sometimes for months or longer. Cease to flow does not occur within the current flow regime, which is a summer–autumn flow release.

The section of the Glenelg River between Rocklands Reservoir and Fulham Bridge was characterised by shallow sections (<3 m deep) interspersed with deep elongated pools (>8.5 m deep). This section was salinity-affected. Saline groundwater intrusion appeared to be most pronounced above Fulham Bridge (McGuckin et al. 1991) and resulted in stable stratification under low to moderate flow conditions. Deoxygenation also prevailed in this river section, with the lowest concentrations of dissolved oxygen coinciding with high bottom conductivities (McGuckin et al. 1991). Adverse temperature was also closely associated with saline pools in this reach. It was also noted that Rocklands Reservoir has a bottom-release outlet that may be a source of cold water pollution resulting from flows released from below the thermocline.

At Five Mile Outlet (just downstream of Balmoral) the channel was characterised by a deep pool upstream (>2 m deep), a glide/run section with a mid-channel island, mid-reach, and an anastomosing section downstream. The anastomosing reach was comprised of two primary channels and a number of secondary channels, which dissect the floodplain. The streambed was dominated by sands and silt, and streambank sediments were mainly sandy loams. There was some fine sediment siltation. In-stream habitat was considered to be reasonably diverse and included aquatic vegetation (5%), large woody debris (15%), organic debris (branch piles, leaves and bark 20%) and small areas of undercut bank (SKM 2003b).

At Pine Hut Hole, the channel was characterised by a deep pool upstream (>2 m deep) and an anastomosing reach comprising several channels. Streambed and banks were comprised of fine sands and sandy loams. Just upstream of Harrow, adjacent hillslopes confine the channel with only narrow, discontinuous alluvial flats developed on the stream margins (<20 m wide). Channel constriction through partial revegetation of large sandbars by Common Reed, Cumbungi and Paperbark was also evident. This section was characterised by a diversity of hydraulic habitats including pool, run, riffle and glide. The streambed was dominated by coarse sand (75%) with small areas of gravel (20%) and overlying silt (5%). The in-stream habitat varied substantially between the pool and anastomosing sections of the site surveyed. Pool areas comprised mostly open water habitats (85% wetted area of site) with stands of aquatic vegetation and some large woody debris along the stream margin. In the anastomosing section, aquatic vegetation (30%), large woody debris (5%)
and organic debris (leaves, branch pile and bark 10%) provided most of the habitat.

No reach-specific macroinvertebrate data were presented by SKM (2003b). A PhD project (Lind 2004) looked at macroinvertebrates within the Glenelg and Wimmera rivers, although nothing has been published from this study to date.

At Five Mile (just downstream of Balmoral), in-stream vegetation was relatively diverse although restricted mostly to the margins of deep pools. Aquatic vegetation included Common Reed (*Phragmites australis*), Water Ribbons (*Triglochin sp.*), Stonewort (*Nitella sp.*) and submerged grasses. The riparian zone was highly disturbed and comprised relatively sparse stands (~50% cover) of River Red Gum with an understorey of native/exotic grasses with some native shrubs, predominantly Tea-Tree (*Leptospermum sp.*) and Paperbark (*Melaleuca sp.*). Floodplain vegetation community was open grassy woodland with a Box and River Red Gum overstorey and native/exotic grass understorey that was generally in poor condition.

At Pine Hut Hole, in-stream vegetation was relatively diverse. In the pool, aquatic vegetation was dominated by stands of Common Reed, Spike Rush (*Eleocharis sphacelata*), Cumbungi and Tassled Sedge (*Carex fascicularis*). Open water areas in an anastomosing section downstream of the pool also contained a diversity of aquatic plant species. In this section, Common Reed, Cumbungi, Water Ribbons, Elodea (*Elodea sp.*), Ribbon Weed (*Vallisneria gigantea*) and Pond Weed (*Potamogeton sp.*) were widespread and abundant.

The riparian zone was open grassy woodland community dominated by a River Red Gum overstorey and native/exotic grass, *Phragmites*, Paperbark (*Melaleuca*) and Cumbungi understorey. Floodplain vegetation was an open grassy woodland community dominated by River Red Gum overstorey and native/exotic grass and sedge understorey. Some eucalypt regeneration was observed.

At a survey site just upstream of Harrow, the in-stream vegetation consisted of a diverse array of aquatic vegetation including Common Rush (*Juncus usitatus*), Water Ribbons, Cumbungi (*Typha sp.*) and filamentous algae. Riparian vegetation was open woodland with River Red Gum overstorey, with some *Melaleuca* and Casuarina species. The understorey consisted of native shrubs and a mixture of native and exotic grasses.

Native fish species that have been recorded in this reach include Common Galaxis, Mountain Galaxis (recorded between Rocklands Reservoir and Harrow), Dwarf Galaxis (recorded between Rocklands Reservoir and its tributaries to Balmoral), Southern Pygmy Perch (recorded between Balmoral and Chetwynd), Yarra Pygmy Perch (recorded between Balmoral and Casterton), Variegated Pygmy Perch (recorded between Harrow and Strathdownie), Short-finned Eel (recorded near Balmoral), Short-headed Lamprey (recorded near Harrow), Flathead Gudgeon and Tupong. Exotic fish species that have been recorded include *Gambusia*. Carp have also more recently been found in Five Mile Hole (M. O'Brien, GHCMA, pers. comm.).
3.3.1.2 Intended Program of Environmental Flows Delivery

A substantial volume of water is required to meet environmental flows recommendations for the Glenelg River, but drought conditions over the past several years have resulted in very low levels in storages of the Wimmera–Mallee System. Due to the restricted quantities available for environmental allocation, reach prioritisation has been necessary. Reach 1 of the Glenelg River has been identified as a priority reach for environmental flows delivery because it a) contains native fish fauna with high conservation value; b) is the reach most affected by flow regulation; and c) has been judged to have the greatest potential of benefiting from the small quantities of environmental flows available. Delivery of recommended flows to Reach 1 will provide downstream flows to reaches 2 and 3, although these are likely to fall short of recommendations. Therefore, although Reach 1 is designated as the priority reach, there should be some further downstream benefits (M. O’Brien, GHCMA, pers. comm.). According to the Annual Watering Plan for the Wimmera and Glenelg catchments 2005/2006, in the future environmental flow releases will extend to Reach 2.

The following comments were provided by Matt O’Brien (GHCMA) and apply to all three Glenelg River reaches (bearing in mind that no environmental flow releases have been planned for Reaches 2 and 3 at the moment).

Environmental flow allocations for the Glenelg River depend on Bulk Entitlement available water calculations and water sharing arrangements with Wimmera CMA. Consequently, it is difficult to predict what components will be delivered in any given year. The delivery of summer–autumn (Dec–May) low flows and freshes is of high priority. The release of summer–autumn freshes is dependent upon trigger inflows to Rocklands Reservoir. The delivery of June ‘transitional’ flows, winter–spring (Jul–Oct) baseflows and November ‘transitional’ flows is of medium priority. Winter–spring freshes and bankfull flows are of low priority and infrastructure constraints means that delivery of winter–spring freshes must rely on ‘piggybacking’ to natural high flows. The release of winter–spring freshes and bankfull flows is also dependent upon trigger inflows to Rocklands Reservoir.

There are three release points for delivering environmental flows to Glenelg River Reach 1: a) Rocklands Reservoir Dam Wall Outlet, b) Five Mile Outlet (of the Rocklands–Toolondo channel), and c) Twelve Mile Outlet (of the Rocklands–Toolondo channel).

The recent and intended program for delivery of environmental flows is summarised in Table 7 along with details on the modelled ‘natural’ and recorded (current) flow regime and recommended environmental flows.

Key Features:

- Due to the way in which environmental flow allocations are calculated, it is difficult to predict what flow components will be delivered in any given year.
- Summer low flows and freshes have been identified as the highest priority flow components for delivery, followed by winter/spring baseflows and so-called ‘transitional’ flows, with winter/spring freshes and bankfull flows of lowest priority.
Summer–autumn baseflow release magnitudes have been exceeded in recent years, but this has not led to recommended flows at the compliance point.

Summer–autumn freshes have been provided during some years, but the magnitude, duration and frequency were different to recommendations. No provision made in other years.

No June transitional flows have been provided in recent years.

Winter–spring baseflows, freshes and bankfull flows have not been provided in recent years.

November transitional flows have been provided in recent years, but at substantially lower magnitudes than recommended.

There are no plans for overbank flows, although a current project is examining floodplain ecological health. Results from this may lead to a re-appraisal of the need for floodplain water (M. O’Brien, GHCMA, pers. comm.).

Table 7. Comparison table for Reach 1 of the Glenelg River. a) recommended environmental flows, b) modelled ‘natural’ vs recorded flow regime, and c) recent and intended program of delivery of environmental flows  

<table>
<thead>
<tr>
<th>Season</th>
<th>Recommendation</th>
<th>Modeled ‘Natural’</th>
<th>Recent and Intended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec–May</td>
<td>Minimum 11 ML/d throughout Dec–May</td>
<td>No spell analysis provided</td>
<td>In 2004/5 and 2005/6, 25 ML/d from Dec–May released from Rocklands Reservoir. This often resulted in &lt;11 ML/d at the compliance point</td>
</tr>
<tr>
<td>Dec–May</td>
<td>&gt;64 ML/d, 5 per year, min. 6 days</td>
<td>Modeled ‘natural’: exceeded 64 ML/d flows about 5 times per Dec–May period for a median duration of 6 days each time</td>
<td>In 2004/5, no provision. In 2005/6, three 40 ML/d freshes lasting 5 days each and one 130 ML/d fresh lasting 6 days (not delivered due to flow allocations)</td>
</tr>
<tr>
<td>June#</td>
<td>100 ML/d throughout June</td>
<td>No flow–duration curve provided</td>
<td>In 2004/5 and 2005/6, no provision</td>
</tr>
<tr>
<td>Jul–Oct</td>
<td>Minimum 150 ML/d throughout Jul–Oct</td>
<td>No spell analysis provided</td>
<td>In 2004/5 and 2005/6, no provision</td>
</tr>
<tr>
<td>Sep</td>
<td>&gt; 450 ML/d, 2 per year, 10 days</td>
<td>Modeled ‘natural’: flows &gt;450 ML/d would have occurred about 2.3 times per winter–spring period for a median duration of 10 days each time</td>
<td>In 2004/5 and 2005/6, no provision</td>
</tr>
<tr>
<td>Jul–Oct</td>
<td>&gt; 1,400 ML/d, 3 per year, 3 days</td>
<td>Modeled ‘natural’: flows &gt;1,400 ML/d would have occurred about 3 times per winter–spring period for a median duration of 3 days each time</td>
<td>In 2004/5 and 2005/6, no provision</td>
</tr>
<tr>
<td>Nov#</td>
<td>130 ML/d throughout Nov</td>
<td>No flow–duration curve provided</td>
<td>In 2004/5 and 2005/6, 25 ML/d for whole of Nov</td>
</tr>
</tbody>
</table>

# June and November are the transitional months between the high and low flow seasons. The ramping up and ramping down of flow through these transitional months should be a gradual change in flow.
3.3.1.3 Monitoring Recommendations

Because environmental flow releases for Reach 1 may be sourced from any or all of three outlet points, there is potential for part of the reach to only be exposed to part (or none) of the allocated environmental flow. However, if monitoring is only conducted downstream of Twelve Mile Outlet, sections of the reach that may be expected to show the most directly attributable effects to environmental flows (those near the outlet points) will not be considered. With this in mind, we recommend that monitoring sites in Reach 1 be located without special regard to the locations of the outlet points, but that data on flows released from the individual outlet points be recorded so that results can be interpreted in light of flows released above a monitoring point, rather than the total flows released for the reach.

Reach 1 is very long at ~114 km, and the average annual discharge varies substantially along its length (Figure 2). Using the methods described in §3.1.2, the CMA will need to decide if the reach is sufficiently homogeneous to be considered as a single reach for monitoring purposes or whether it should be divided into two or more sub-reaches with replicated monitoring sites within each reach. In the event that the reach is subdivided, the recommendations below will apply to all sub-reaches.

The field monitoring programs applicable to Reach 1 are shown in Table 10. The presence of Rocklands Reservoir will lead to sediment starvation in the upper sections of this reach, which would thus be classified as geomorphic zone 1. Thus we would not expect any beneficial effects of environmental flows on channel form or dynamics. There are significant areas of sediment deposition downstream of the confluences with Frechmans and Mathers creeks (M. O’Brien, GHCMA, pers. comm.). Geomorphic monitoring should be confined to these sections of Reach 1.

The provision of summer–autumn baseflows has been identified as high priority, but has varied between years, and is likely to continue to do so. When released, the baseflow has been greater than the recommended minimum at Rocklands Reservoir, but not at the compliance point. Habitat surveys will assess the effects of the supplied low flows on shallow, slow and slackwater habitats. Results from these surveys may be useful in arguing for a change to the operating rules such that greater summer baseflows are released.

The provision of summer–autumn freshes has also been identified as high priority, but has varied between years, and is likely to continue to do so. When released, the fresh magnitudes and frequencies have differed slightly from the recommendations. Habitat surveys will assess whether the freshes supplied have the desired effects on habitat and connectivity, or whether they should be tuned more closely to the recommendations or some other regime.

Bankfull or overbank flows are not part of the intended delivery of environmental flows. These may occur naturally on occasions, but their frequency will not change relative to current conditions. Accordingly, there is no need to monitor off-stream slackwater habitats as post-event surveys.

The provision of winter/spring baseflows is of lower priority than the delivery of summer baseflows, and no provision has been made in recent years. The...
habitat field survey will help determine if the level of winter–spring baseflows is sufficient for maintaining shallow and slow water and riffle/run areas, including longitudinal connectivity. The comparison between years with and without winter baseflow provisions will be important here, and the results may be useful in arguing for a greater priority for winter/spring baseflows in the watering plans. The habitat survey, in conjunction with one-dimensional hydraulic modelling, will track whether the winter–spring flows delivered are effective in maintaining permanent pool depth and volume, and providing sustained inundation of representative physical habitat features.

There is little information on macroinvertebrate communities in this reach, but the recent study by Lind (2005) will assist with basic information. A macroinvertebrate survey program will help to enhance baseline information on macroinvertebrate community structure.

Instream vegetation assemblages are generally diverse, although restricted to certain parts of the channel. Riparian vegetation is generally disturbed, with reasonable overstorey cover of River Red Gum but degraded middle and lower storey components. No quantitative baseline information is available for either type of assemblage. Winter/spring freshes, bankfull and overbank flows that might improve canopy condition of riparian trees and shrubs, and increase germination and establishment of amphibious and terrestrial species, are low priority flow components for delivery. These flow components will occur in the future, although probably at lower rates than recommended. Hydraulic-modelling assisted habitat surveys, examining the inundation of geomorphic features in channel zones A, B and C, along with vegetation surveys of variables such as cover, species composition, canopy condition and germination of seedlings, will provide valuable baseline data on community structure, floristic composition and regeneration of overstorey and midstorey plant species.

A good diversity of native fish has been found in this reach. A fish abundance and composition fish survey program will help to establish basic fish community structure (including information on what exotic fish species are present in this reach). This information will help to fine-tune necessary coverage of larval sampling, but the presence of diadromous species and generalists such as the Flathead Gudgeon will probably necessitate year-round larval sampling in the reach.

### 3.3.2 Reach 2: Chetwynd River Confluence to Wannon River Confluence

#### 3.3.2.1 Reach Description

This section is based on information in SKM (2003b, 2004). The reach from Chetwynd River confluence to Wannon River confluence is about 82 km long. A resource allocation model (REALM) was constructed to quantify flows under natural and contemporary conditions. Natural flows were calculated by adding rural and urban water demands to gauged flow data. All catchment storages were accounted for during the process (SKM 2004). Private diversions from the Glenelg River and its other tributaries were considered to be small relative to
its flows and were assumed to be negligible (SKM 2004). It is important to note that modeled ‘natural’ flows generated in this manner do not reflect potential changes to flows as a result of land use changes. The comparison of modeled ‘natural’ and current (recorded) flows is based on flow data for a 10 year period in the 1990s (exact period unspecified). The data are disaggregated daily data from a weekly REALM model (SKM 2004).

Downstream of Chetwynd River, flows are continuous due to the diminishing influence of Rocklands Reservoir and natural inflow from the catchment adding to the river flows. At Casterton, the magnitude of the median monthly winter–spring flows is reduced from May–Dec and slightly reduced from modelled ‘natural’ conditions over Jan–Apr. At Roseneath, cease to flow events would have occurred about 30% of the time from Dec–May under modelled ‘natural’ conditions. The duration of cease to flow events over this period were relatively short, ranging from 1–13 days (median of 4 days, interquartile range of 2–8 days). The frequency of occurrence of these summer–autumn cease to flow events was estimated at 3.5 per annum.

At Burke’s Bridge, the channel is confined by hillslopes on its right side. The floodplain (>500 m wide) formed on the left side of the channel has some shallow secondary channels and billabongs. The channel has been extensively filled with sand that forms large point bars and braided channel characteristics in some areas. At Roseneath, the channel is confined by hillslopes on its left side. A floodplain (>500 m wide) exists on the right bank. At the site, the channel bifurcates around a large vegetated island. The reach is characterised by riffle and pool hydraulics, active erosion of the channel, unstable bed and banks (mass failures on outer banks). The streambed was dominated by sand, and streambank sediments were sandy loams. A high load of large woody debris (LWD) was observed. In-stream habitat was dominated by LWD (70% wetted area) with small areas of aquatic vegetation, organic debris and rock habitat.

At Section Road, the wide, shallow channel meanders across a broad floodplain. Stream substrate was dominated by deposits of fine sand (75%), coarse sand (5%) and small areas of gravel (20%). In-stream cover was very sparse with only small amounts of aquatic vegetation (2%) and logs (2%).

No reach-specific macroinvertebrate data were presented by SKM (2003b).

At Burke’s Bridge, the in-stream vegetation was generally sparse with the exception of the Common Reed, which formed dense stands along the right-hand stream margin. Only small areas of Common Rush and Weed Ribbon were present at the site. Riparian vegetation communities were open woodland with an overstorey of River Red Gum and an understorey of Acacia spp., Bracken, native/exotic grasses, herbs, Common Reed, Common Rush and Tea-Tree. The floodplain vegetation consisted of open woodland with an overstorey of River Red Gum and an understorey of wattles (Acacia spp.), Bracken, native/exotic grasses and herbs. At Roseneath, the in-stream vegetation was sparse and included Common Reed and Water Ribbons. The riparian zone was predominantly cleared and replaced with exotic pasture grasses. Isolated River Red Gum woodland was present on both banks, including some regeneration on the left bank. The floodplain vegetation had predominantly been cleared and replaced with exotic pasture grasses. At Section Road, the in-stream vegetation was in relatively poor condition and
dominated by emergent species such as Common Reed and Cumbungi. The riparian zone was highly disturbed and comprised cleared eucalypt woodland with some signs of regeneration. The floodplain vegetation comprised predominantly cleared eucalypt woodland that has been replaced with exotic pasture grasses.

Native fish species that have been recorded in this reach include Common Galaxis, Variegated Pygmy Perch (recorded between Harrow and Strathdownie), Yarra Pygmy Perch (recorded between Balmoral and Casterton), Short-finned Eel (recorded near Chetwynd and Casterton), Short-headed Lamprey (recorded near Chetwynd), Pouched Lamprey (known from a record in 1928 near Casterton), Tupong, Australian Smelt and Flathead Gudgeon. Exotic fish species that have been recorded include Gambusia. Carp have also been recorded more recently (M. O’Brien, pers. comm.)

3.3.2.2 Intended Program of Environmental Flows Delivery

A substantial volume of water is required to meet environmental flows recommendations for the Glenelg River, but drought conditions over the past several years have resulted in very low levels in storages of the Wimmera–Mallee system. Due to the restricted quantities available for environmental allocation, reach prioritisation was necessary. Reach 1 of the Glenelg River has been identified as a priority reach for environmental flows delivery because it a) contains native fish fauna with high conservation value; b) is the reach most affected by flow regulation; and c) has been judged to have the greatest potential of benefiting from the small quantities of environmental flows available. Delivery of recommended flows to Reach 1 will provide downstream flows to reaches 2 and 3, although these are likely to fall short of recommendations. Therefore, although Reach 1 is designated as the priority reach, there should be some further downstream benefits (M. O’Brien, GHCMA, pers. comm.). According to the Annual Watering Plan for the Wimmera and Glenelg catchments 2005/2006, in the future environmental flow releases will extend to Reach 2.

The following comments were provided by Matt O’Brien (GHCMA) and apply to all three Glenelg River reaches (bearing in mind that no environmental flow releases have been planned for Reaches 2 and 3 at the moment).

Environmental flow allocations for the Glenelg River depend on Bulk Entitlement available water calculations and water sharing arrangements with Wimmera CMA. Consequently, it is difficult to predict what components will be delivered in any given year. The delivery of summer–autumn (Dec–May) low flows and freshes is of high priority. The release of summer–autumn freshes is dependent upon trigger inflows to Rocklands Reservoir. The delivery of June ‘transitional’ flows, winter–spring (Jul–Oct) baseflows and November ‘transitional’ flows is of medium priority. Winter–spring freshes and bankfull flows are of low priority and infrastructure constraints means that delivery of winter–spring freshes must rely on piggybacking of natural high flows. The release of winter–spring freshes and bankfull flows is also dependent upon trigger inflows to Rocklands Reservoir.
The intended program for delivery of environmental flows is summarised in Table 8 along with details on the modelled ‘natural’ and/or recorded (current) flow regime and recommended environmental flows.

### Table 8. Comparison table for Reach 2 of the Glenelg River

<table>
<thead>
<tr>
<th>Season</th>
<th>Recommendation</th>
<th>Modeled ‘Natural’</th>
<th>Intended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec–May</td>
<td>Cease to flow, 3 per year, max. 8 days</td>
<td>Naturally, cease to flow events would have occurred about 3.6 times per Dec–May period for a median duration of 4 days each time</td>
<td>Will not be delivered until water quality improves</td>
</tr>
<tr>
<td>Dec–May</td>
<td>Minimum 16–77 ML/d, throughout Dec–May, excluding CTF period</td>
<td>Naturally, flows would have fallen below 16 ML/d about 3.4 times per Dec–May period for a median duration of 7 days each time. And flows would have exceeded 16 ML/d about 3.5 times per Dec–May period for a median duration of 30 days each time</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Dec–May</td>
<td>&gt;77 ML/d, 4 per year, 7–15 days</td>
<td>Naturally, &gt;77 ML/d flows would have occurred about 4.2 times per Dec–May period for a median duration of 15 days</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Jun#</td>
<td>83/93 ML/d (discrepancy between value given in table and text in original EFlow report) throughout Jun</td>
<td>No flow–duration curve provided</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Jul–Oct</td>
<td>Minimum 385 ML/d throughout Jul–Oct</td>
<td>No spell analysis provided</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Sep</td>
<td>&gt;700 ML/d, 2–3 per year, 5 days</td>
<td>Naturally, &gt;700 ML/d flows would have occurred about 2.8 times per Jul–Oct period for a median duration of 10 days.</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Jul–Oct</td>
<td>&gt;3,600 ML/d, 2 per year, 4 days</td>
<td>Naturally, &gt;3,600 ML/d flows would have occurred about 2.6 times per Jul–Oct period for a median duration of 4 days</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Nov#</td>
<td>110 ML/d throughout Nov</td>
<td>No flow–duration curve provided</td>
<td>NA – not a priority reach</td>
</tr>
</tbody>
</table>

# June and November are the transitional months between the high and low flow seasons. The ramping up and ramping down of flow through these transitional months should be a gradual change in flow.
Key Features:

- There are currently no intended flow provisions for this reach, but it is hoped that environmental water will be available in the future. There should be some benefits from water flowing through from Reach 1.

- Summer low flows and freshes have been identified as the highest priority flow components for delivery, followed by winter/spring baseflows and so-called ‘transitional’ flows, with winter/spring freshes and bankfull flows of lowest priority.

- Cease to flow events will not be deliberately created unless water quality improves.

3.3.2.3 Monitoring Recommendations

The lack of any intended program of environmental flow delivery to Reach 2 makes it difficult to recommend field programs for monitoring. However, we can extrapolate from Reach 1 upstream and make recommendations based on the assumption that delivery of flows may eventually be similar to those. It is certainly the intention that environmental flows will be delivered to this reach when sufficient water is available.

If this is true, and environmental flows are delivered to Reach 2 at some time in the future, then data collected prior to that time will be valuable as ‘before’ data against which to compare environmental condition following the instigation of flows. For this scenario, we might assume that eventual flow regimes will be similar to those in Reach 1 (and this is not unreasonable) when making monitoring recommendations. Alternatively, the CMA may make predictions about the types of flow components that are likely to be made available as part of a future environmental allowance for Reach 2, and match monitoring to this prediction in the same manner as has been done for Reach 1. The best case scenario will be if future environmental flow releases for Reach 2 match the recommendations.

The second alternative is that no environmental flow releases are made in the future. Although this would go against the intentions of GHCMA, it must be retained as a realistic possibility. In this case, data collected from monitoring programs similar to those in Reach 1 may still be valuable as ‘control site’ data, as long as we can account for the other reach-specific characteristics in statistical models.

Results of monitoring within Reach 2 may also be useful for arguing for an environmental allocation in the future, if storage volumes increase. If few changes occur within this reach while ecological condition improves in the reach with flow allocations, this makes a strong case for the provision of more environmental water.

However, in terms of the monitoring budget for the entire river, monitoring in Reach 2 is probably of lower priority than in Reach 1. This is due to the uncertain nature and extent of any environmental flows.

Reach 2 is also long at ~82 km, and the average annual discharge varies substantially along its length (Figure 2). Using the methods described in §3.1.2,
the CMA will need to decide if the reach is sufficiently homogeneous to be considered as a single reach for monitoring purposes or whether it should be divided into two or more sub-reaches with replicated monitoring sites within each reach. In the event that the reach is subdivided, the recommendations below will apply to all sub-reaches. However, the decision to sub-divide, and thus generate an increase in monitoring effort, must be made in light of the lower priority of this reach compared to Reach 1.

Assuming that the environmental flows that may be delivered in Reach 2 are qualitatively similar to those delivered in Reach 2, the field monitoring programs applicable to this reach are shown in Table 10.

The entire reach can probably be considered as belonging to geomorphic zone 2. Therefore we may expect to see beneficial effects of future environmental flow releases on the channel. Surveys of channel dynamics and channel features are recommended.

Habitat surveys will assess the effects of the non-enhanced flow regime on shallow, slow and slackwater habitats. The habitat survey, in conjunction with one-dimensional hydraulic modelling, will track whether the flows can maintain permanent pool depth and volume in winter and spring, and provide necessary inundation of representative physical habitat features.

Bankfull or overbank flows are not part of the intended delivery of environmental flows upstream in Reach 1. It is highly unlikely therefore that they will ever be delivered in Reach 2. They may occur naturally on occasions, but their frequency will not change relative to current conditions. Accordingly, there is no need monitor off-stream slackwater habitats as post-event surveys.

There is little information on macroinvertebrate communities in this reach. It is not known whether the study by Lind (2005) included sites within this reach. A macroinvertebrate survey program will help to furnish baseline information on macroinvertebrate community structure, and may provide valuable ‘before’ or ‘control’ data for comparison against other data.

In-stream vegetation assemblages are generally sparse, and restricted to certain parts of the channel. Riparian vegetation is generally disturbed, with some overstorey cover of River Red Gum but degraded middle and lower storey components. Clearing of riparian zones is also common. No quantitative baseline information is available for either type of assemblage. Hydraulic-modelling assisted habitat surveys, examining the inundation of geomorphic features in channel zones A, B and C under current flow conditions, along with vegetation surveys of variables such as cover, species composition, canopy condition and germination of seedlings, will provide valuable baseline data on community structure, floristic composition and regeneration of overstorey and midstorey plant species, and may provide valuable ‘before’ or ‘control’ data for comparison against other data.

A good diversity of native fish has been found in this reach. A fish abundance and composition fish survey program will help to establish basic fish community structure (including information on what exotic fish species are present in this reach). This information will help to fine-tune necessary coverage of larval sampling, but the presence of diadromous species and generalists such as the
Flathead Gudgeon will probably necessitate year-round larval sampling in the reach.

3.3.3 Reach 3: Wannon River Confluence to Tidal Extent

3.3.3.1 Reach Description

This section is based on information in SKM (2003b, 2004). The reach from Wannon River confluence to the tidal extent is about 90 km long.

A resource allocation model (REALM) was constructed to quantify flows under natural and contemporary conditions. Natural flows were calculated by adding rural and urban water demands to gauged flow data. All catchment storages were accounted for during the process (SKM 2004). Private diversions from the Glenelg River and its other tributaries were considered to be small relative to its flows and were assumed to be negligible (SKM 2004). It is important to note that modeled ‘natural’ flows generated in this manner do not reflect potential changes to flows as a result of land use changes. The comparison of modeled ‘natural’ and current (recorded) flows is based on flow data for a 10 year period in the 1990s (exact period unspecified). The data are disaggregated daily data from a weekly REALM model (SKM 2004).

At Dartmoor, the median (and up to 20th percentile) monthly winter–spring flows are reduced from Jun–Oct as compared to modelled ‘natural’ flows. However, current median monthly flows are comparable to modelled ‘natural’ conditions for the remaining months.

At Bahgallah Road, the channel was deeply incised (up to 10 m) with steep, unstable banks formed in sandy loams. The channel is some 50 m wide with a broad sheet of sand and some sandy bars. In-stream habitat was dominated by algae (65%). At Dartmoor, the site was characterised by a diversity of hydraulic habitats including pool, run, riffle and glide. The streambed was dominated by sand which had formed bars on the inside bends and benches on both banks. Streambanks formed in silty loams. In-stream habitat was reasonably diverse and included aquatic vegetation (50%), large woody debris (8%) and organic debris (branch piles, leaves and bark 2%).

No reach-specific macroinvertebrate data were presented by SKM (2003b).

At Bahgallah Road, the in-stream vegetation was in relatively poor condition and comprised Water Ribbons, Common Reed and algae. The riparian zone was disturbed and comprised remnant River Red Gum woodland and an understorey of exotic grasses. The floodplain vegetation comprised only pasture grasses and was generally in poor condition. At Dartmoor, the in-stream vegetation was in good condition and comprised predominantly submerged species including Water Ribbons, filamentous algae and Elodea spp. The riparian zone comprised River Red Gum woodland with an understorey dominated by exotic groundcover species. Regeneration of River Red Gum and Acacia spp. was evident.

Native fish species that have been recorded in this reach include Common Galaxis, Dwarf Galaxis (recorded near Dartmoor in Scott Creek, a tributary of the lower Glenelg River, and from the upper Crawford River, upper Wannon River and various other tributaries and wetlands), Tupong and Flathead
Gudgeon. Recent surveys have also found more species in this reach (M. O’Brien, GHCMA, pers. comm.).

3.3.3.2 Intended Program of Environmental Flows Delivery

A substantial volume of water is required to meet environmental flows recommendations for the Glenelg River, but drought conditions over the past several years have resulted in very low levels in storages of the Wimmera–Mallee system. Due to the restricted quantities available for environmental allocation, reach prioritisation was necessary. Reach 1 of the Glenelg River has been identified as a priority reach for environmental flows delivery because it a) contains native fish fauna with high conservation value; b) is the reach most affected by flow regulation; and c) has been judged to have the greatest potential of benefiting from the small quantities of environmental flows available. Delivery of recommended flows to Reach 1 will provide downstream flows to Reaches 2 and 3, although these are likely to fall short of recommendations. Therefore, although Reach 1 is designated as the priority reach, there should be some further downstream benefits (M. O’Brien, GHCMA, pers. comm.). According to the Annual Watering Plan for the Wimmera and Glenelg catchments 2005/2006, in the future environmental flow releases will extend to Reach 2.

The following comments were provided by Matt O’Brien (GHCMA) and apply to all three Glenelg River reaches (bearing in mind that no environmental flow releases have been planned for Reaches 2 and 3 at the moment).

Environmental flow allocations for the Glenelg River depend on Bulk Entitlement available water calculations and water-sharing arrangements with Wimmera CMA. Consequently, it is difficult to predict what components will be delivered in any given year. The delivery of summer–autumn (Dec–May) low flows and freshes is of high priority. The release of summer–autumn freshes is dependent upon trigger inflows to Rocklands Reservoir. The delivery of June ‘transitional’ flows, winter–spring (Jul–Oct) baseflows and November ‘transitional’ flows is of medium priority. Winter–spring freshes and bankfull flows are of low priority and infrastructure constraints mean that delivery of winter–spring freshes must rely on piggybacking of natural high flows. The release of winter–spring freshes and bankfull flows is also dependent upon trigger inflows to Rocklands Reservoir.

The intended program for delivery of environmental flows is summarised in Table 9 along with details on the modelled ‘natural’ and/or recorded (current) flow regime and recommended environmental flows.

Key Features:

• There are currently no intended flow provisions for this reach. There should be some benefits from water flowing through from Reach 1.

• Summer low flows and freshes have been identified as the highest priority flow components for delivery, followed by winter/spring baseflows and so-called ‘transitional’ flows, with winter/spring freshes and bankfull flows of lowest priority.
Table 9. Comparison table for Reach 3 of the Glenelg River. a) recommended environmental flows, b) modelled ‘natural’ vs recorded flow regime, and c) intended program of delivery of environmental flows

<table>
<thead>
<tr>
<th>Season</th>
<th>Recommendation</th>
<th>Modeled ‘Natural’</th>
<th>Intended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec–May</td>
<td>Minimum 83 ML/d throughout Dec–May</td>
<td>No spell analysis provided</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Dec–May</td>
<td>&gt;216 ML/d, 4 per year, min. 5 days</td>
<td>Modeled ‘natural’: &gt;216 ML/d flows would have occurred about 4 times per Dec–May period for a median duration of 20 days.</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Jun</td>
<td>180 ML/d throughout Jun</td>
<td>No spell analysis provided</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Jul–Oct</td>
<td>Minimum 629 ML/d throughout Jul–Oct</td>
<td>No spell analysis provided</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Sept</td>
<td>&gt;2,200 ML/d, 2–3 per year, min. 5 days</td>
<td>Naturally, &gt;2,200 ML/d flows would have occurred about 2.5 times per Jul–Oct period for a median duration of 15 days.</td>
<td>NA – not a priority reach</td>
</tr>
<tr>
<td>Nov</td>
<td>130 ML/d throughout Nov</td>
<td>No spell analysis provided</td>
<td>NA – not a priority reach</td>
</tr>
</tbody>
</table>

### 3.3.3.3 Monitoring Recommendations

The lack of any intended program of environmental flow delivery to Reach 3 makes it difficult to recommend field programs for monitoring. However, we can extrapolate from Reach 1 upstream and make recommendations based on the assumption that delivery of flows may eventually be similar to those. This is less likely to occur than is the case for Reach 2, since that reach was specifically identified as being a target for an environmental allocation in the future, but Reach 3 has not been similarly identified.

If environmental flows are delivered to Reach 3 at some time in the future, then data collected prior to that time will be valuable as ‘before’ data against which to compare environmental condition following the instigation of flows. For this scenario, we might assume that eventual flow regimes will be similar to those in Reach 1 (and this is not unreasonable) when making monitoring recommendations. Alternatively, the CMA may make predictions about the types of flow components that are likely to be made available as part of a future environmental allowance for Reach 3, and match monitoring to this prediction in the same manner as has been done for Reach 1. The best case scenario will be if future environmental flow releases for Reach 3 match the recommendations.

The second alternative is that no environmental flow releases are made in the future. This must be considered as perhaps the most likely possibility. In this
case, data collected from monitoring programs similar to those in Reach 1 may still be valuable as 'control site' data, as long as we can account for the other reach-specific characteristics in statistical models.

Results of monitoring within Reach 3 may also be useful for arguing for an environmental allocation in the future, if storage volumes increase. If few changes occur within this reach, while ecological condition improves in the reach with flow allocations, this makes a strong case for the provision of more environmental water.

However, in terms of the monitoring budget for the entire river, monitoring in Reach 3 must be considered as of the lowest priority for the Glenelg River. This is due to the uncertain nature and extent of any environmental flows.

Reach 3 is also long at ~90 km, and the average annual discharge varies substantially along its length (Figure 2). Using the methods described in §3.1.2, the CMA will need to decide if the reach is sufficiently homogeneous to be considered as a single reach for monitoring purposes, or whether it should be divided into two or more sub-reaches with replicated monitoring sites within each reach. In the event that the reach is subdivided, the recommendations below will apply to all sub-reaches. However, the decision to sub-divide, and thus generate an increase in monitoring effort, must be made in light of the lower priority of this reach compared to Reaches 1 and 2.

Assuming that environmental flows that may be delivered in Reach 3 are qualitatively similar to those delivered in Reach 2, the field monitoring programs applicable to this reach are shown in Table 10.

Most of this reach can probably be considered as belonging to geomorphic zone 2. Therefore we may expect to see beneficial effects of future environmental flow releases on the channel. Surveys of channel dynamics and channel features are recommended, but these should be restricted to sites above the confluence with Moleside Creek, below which the geomorphic zone may change to zone 3.

Habitat surveys will assess the effects of the non-enhanced flow regime on shallow, slow and slackwater habitats. The habitat survey, in conjunction with one-dimensional hydraulic modelling, will track whether the flows can maintain permanent pool depth and volume in winter and spring, and provide necessary inundation of representative physical habitat features.

Bankfull or overbank flows are not part of the intended delivery of environmental flows upstream in Reach 1. It is highly unlikely therefore that they will ever be delivered in Reach 3. They may occur naturally on occasions, but their frequency will not change relative to current conditions. Accordingly, there is no need monitor off-stream slackwater habitats as post-event surveys.

There is little or no information on macroinvertebrate communities in this reach. It is not known whether the study by Lind (2005) included sites within this reach. A macroinvertebrate survey program will help to furnish baseline information on macroinvertebrate community structure, and may provide valuable ‘before’ or ‘control’ data for comparison against other data.

In-stream vegetation and riparian assemblages are generally in poor condition, but no quantitative baseline information is available for either type of
assemblage. Hydraulic-modelling assisted habitat surveys, examining the inundation of geomorphic features in channel zones A, B and C under current flow conditions – along with vegetation surveys of variables such as cover, species composition, canopy condition and germination of seedlings – will provide valuable baseline data on community structure, floristic composition and regeneration of overstorey and midstorey plant species, and may provide valuable ‘before’ or ‘control’ data for comparison against other data.

Fewer fish species have been recorded in this reach compared to Reaches 1 and 2. However, recent surveys suggest greater fish diversity (M. O’Brien, GHCMA, pers. comm.). A fish abundance and composition fish survey program will help to establish basic fish community structure (including information on what exotic fish species are present in this reach). This information will help to fine-tune necessary coverage of larval sampling, but the presence of diadromous species and generalists such as the Flathead Gudgeon will probably necessitate year-round larval sampling in the reach.

3.4 Other conceptual models and hypotheses of local importance in each reach

As mentioned previously (§ 2.2) we collated and summarised all the conceptual models and predicted ecosystem responses associated with the environmental flow recommendations for the eight river systems that are likely to receive significant environmental flow allocations. A selection of these conceptual models was further developed for inclusion in the VEFMAP. Of the remaining conceptual models and hypotheses, some may be of local importance to individual reaches in the Glenelg River. Table 11 contains a non-exhaustive selection of conceptual models, some of which may be applicable to the Glenelg River. Like the other models presented in this report, these models are generic, and only certain parts of each model may be applicable to any given river. Consultants and the CMA should use river-specific knowledge of the biota and environments present to determine which parts of the models may apply. The recommendation of which reaches are suitable for the investigation of individual hypotheses is based solely on the intended flow delivery for that reach.
Table 10. Summary of recommended field survey programs for each reach.

Subcomponents of the individual programs that are applicable within each reach must be determined through examining the detailed monitoring recommendations and the reach descriptions (above). The field programs are described in detail in Table 6.

<table>
<thead>
<tr>
<th>Field Program</th>
<th>Reach 1</th>
<th>Reach 2</th>
<th>Reach 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rocklands to Chetwynd River Confluence</td>
<td>Chetwynd River Confluence to Wannon River Confluence</td>
<td>Wannon River Confluence to Tidal Extent</td>
</tr>
<tr>
<td>Flow</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Channel Dynamics</td>
<td>✓¹</td>
<td>✓²</td>
<td>✓³,4</td>
</tr>
<tr>
<td>Channel Features Survey</td>
<td>✓¹</td>
<td>✓²</td>
<td>✓³,4</td>
</tr>
<tr>
<td>Habitat Field Survey (Repeated)</td>
<td>✓</td>
<td>✓²</td>
<td>✓³</td>
</tr>
<tr>
<td>Habitat Field Survey (Post-Event)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitat Survey in Conjunction with One-dimensional</td>
<td>✓</td>
<td>✓²</td>
<td>✓³</td>
</tr>
<tr>
<td>Hydraulic Modelling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macroinvertebrate Survey</td>
<td>✓</td>
<td>✓²</td>
<td>✓³</td>
</tr>
<tr>
<td>Vegetation Survey</td>
<td>✓</td>
<td>✓²</td>
<td>✓³</td>
</tr>
<tr>
<td>Fish Abundance and Composition Survey</td>
<td>✓</td>
<td>✓²</td>
<td>✓³</td>
</tr>
<tr>
<td>Larval Fish Survey</td>
<td>✓</td>
<td>✓²</td>
<td>✓³</td>
</tr>
<tr>
<td>Water Quality</td>
<td>✓</td>
<td>✓²</td>
<td>✓³</td>
</tr>
</tbody>
</table>

¹ Downstream of confluences with Frechmans and Mathers Creeks
² Lower priority because no specific environmental flow releases are planned
³ Lowest priority because no general environmental flow releases are planned
⁴ Upstream of the confluence with Moleside Creek
Table 11. Additional conceptual models and hypotheses which may be of local importance to individual reaches in the Glenelg River

<table>
<thead>
<tr>
<th>No.</th>
<th>List of other hypotheses of local relevance in the Glenelg River</th>
<th>Reach 1</th>
<th>Reach 2</th>
<th>Reach 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Biogeochemical process</strong> – During periods of flow cessation or summer low flows, exposure of the streambed allows accumulation and drying of terrestrial organic matter in dry areas of the channel such as benches. Drying and subsequent rewetting facilitates the decomposition and processing of this organic matter and produces a fresh pool of nutrient and carbon inputs for the system. Winter–spring Freshes, High Flows, Bankfull Flows and Overbank Flows can inundate higher portions of the channel such as benches and banks and entrain organic matter accumulated in the elevated channel features and terrestrial channel sections. This will provide inputs of dissolved and fine particulate organic matter to maintain nutrient/carbon cycling inputs to the river. Organic matter and nutrients in this form can be used by macrophytes, algae, microfauna, zooplankton and microbes. Their influx may result in higher rates of productivity and respiration on benches than in the main river channel, although it is uncertain how long this effect persists. In the case of Overbank Flows which result in inundation of the floodplain, there may be significant carbon returns to the river after a period of significant production</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>2</td>
<td><strong>Ecological Process, Drying Disturbance</strong> – During periods of flow cessation or summer low flows, the river may contract to a series of isolated pools, or portions of the channel may dry out. Biota in these pools is likely to be subjected to physicochemical stresses (e.g. Low DO concentrations, changes in EC and temperature), intensified predation and competition. Exposure of large areas of the streambed acts as a disturbance mechanism which resets successional processes for macroinvertebrate and vegetation communities. For instance, by allowing certain plant species to regenerate on bars and benches. Desiccation disturbance prevents the system from being dominated by any particular group of organisms. And in particular, any macroinvertebrate species as many macroinvertebrate species would be reduced in their abundance and distribution over the dry period. Desiccation disturbance maintains aquatic and riparian species characteristic of dryland river systems where flow cessation and summer low flows naturally occur. Biota in these arid environments has special physiological or behavioural adaptations that allow them to persist in harsh conditions in locations that they might otherwise be displaced by dominant but less tolerant species. In the short-term there may be localised extinction of certain species. And in the long-term, changes in diversity and biomass. Recolonisation of &quot;stressed&quot; habitats upon flow restoration should be feasible provided there are effective refuges for biota during cease-to-flow periods. However, although drying may be a stress for some species such as obligate aquatics, it also represents an opportunity for transient terrestrial as well as exotic species to establish or expand</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>3</td>
<td><strong>Ecological Process, Mechanical Disturbance</strong> – Bankfull flows may act as a disturbance mechanism that resets ecological processes for both aquatic and riparian flora and fauna communities by drowning and/or sweeping plants and animals downstream</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td><strong>Biofilms</strong> – Winter–Spring Freshes and High Flows provide scouring flows over biofilm habitats and this acts as a disturbance mechanism for maintaining species composition and health. Summer Freshes are also expected to perform this function</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aquatic and Riparian Vegetation, Flow Variability – Change in flow variability can take many forms which have different consequences for vegetation patterns. Prolonged stable water levels allow plants to establish and persist close to the water line; with the species doing this being more associated with lentic (wetland) environments than lotic (flowing water) environments. Loss of flow variability may also result in wider zones of terrestrial or flood intolerant plant species and a shrinking in the width of the zone characterised by flood tolerant species. Freshes provide short-term flow variability and variation in water levels is important for maintaining species diversity in the emergent and marginal aquatic vegetation communities. Variation in water levels is the principal driver of zonation patterns across the channel and up the river banks. Providing Freshes and ensuring the occurrence of flow variability and variation in water levels will help (a) restore/maintain/increase species diversity in the emergent and marginal aquatic vegetation communities; (b) maintain/restore distinctive riparian vegetation community and structure with zonation up the bank</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aquatic and Riparian Vegetation, Dispersal – High Flows deliver seed from the upper catchment to help maintain/restore distinctive riparian vegetation community and structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Invertebrates – High Flows and Bankfull Flows that inundate previously dry sediments in higher portions of the channel such as benches may provide a stimulus for hatching to invertebrates, with diversity and biomass peaking when inundation exceeds 2 weeks. Loss of habitat through decreased inundation duration increases the risk of egg mortality, and the loss of early instars (early life stages) and adults of those species not stimulated to drift. For the others the outcome will depend on factors such as the availability of alternative habitat and predation pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Native Fish, Movement – Protection or reinstatement of more natural levels of winter–spring baseflows will provide conditions of sustained water levels in the river which will provide sustained longitudinal connectivity for fish movement, including the permanent movement of large-bodied fish throughout the river reach in the lead up to the breeding season. Freshes (which produce a minimum depth of 0.5 m over the shallowest point) over the irrigation season (Nov–Apr) provide for temporary local movement of bigger fish such as Murray Cod and Golden Perch. These Freshes may be important in allowing upstream/downstream movement of Golden Perch to spawn. Autumn–early winter High Flows/Freshes are important for transporting larvae of diadromous species such as Australian Grayling, galaxiids and eels to the estuary/sea. Winter–spring High Flows and Freshes and Bankfull Flows may provide the cue which triggers movement and/or migration in some native fish species, for instance, in Australian Grayling and in Tupong. This migration is associated with spawning and hence may have an impact on species reproduction and recruitment. Spring–early summer High Flows/Freshes are important for the upstream movement and recruitment of juvenile diadromous fish. Summer Freshes will increase water depth over low-lying channel zones such as riffles and increase longitudinal connectivity, thereby temporarily facilitating greater movement of fish between different instream habitats such as pools</td>
<td>² ² ²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ Probably only applicable to the ‘flow cessation’ parts of this hypothesis
² Connectivity in lower ‘non-priority’ reaches is of great importance given the presence of diadromous species in the priority Reach 1. Lack of connectivity with the ocean will prevent breeding, even if flows are provided within Reach 1.
4 Implementing the Monitoring Design

4.1 VEFMAP implementation group

The DSE has established an Implementation Group, made up of representatives of the relevant CMAs, DSE, and the current eWater science project team. This group will provide a forum for resolving implementation issues, including the provision of advice to CMAs and their consultants for implementing plans in individual rivers. It is important to establish processes to ensure that monitoring and evaluation plans are implemented to appropriate standards and in a consistent manner. It is recommended that quality assurance and control measures are developed to ensure the collection and management of high quality data and information.

4.2 Quality Assurance / Quality Control

A quality assurance / quality control (QA/QC) plan is recommended as an essential step in collecting high quality and reliable data and the minimisation of sampling errors to acceptable levels (ANZECC & ARMCANZ 2000, Baldwin et al. 2005, Cottingham et al. 2005). Such a plan should be based around four elements:

- project management
- measurement/data acquisition
- assessment and oversight, and
- data validation and usability.

The QA/QC plan should identify important standards to be maintained for the life of the monitoring program. For example, the plan should state the minimum training standards and qualifications of staff that collect field and laboratory data, and the format required for the management and reporting of data, including database structures (e.g. ANZECC & ARMCANZ 2000, Baldwin et al. 2005). QA/QC considerations are particularly important, as it is the intention of DSE to have the analysis and interpretation peer reviewed. In addition, the VEFMAP as a whole will be reviewed after three years.

The collection of high quality data will be critical to the evaluation of environmental flow releases along the Glenelg River and at State or regional levels. Consistency and repeatability of the sampling protocol is essential if trends both within and between river systems are to be detected. It is recommended that the Glenelg–Hopkins CMA have representation on the proposed Implementation Group so that the QA/QC plan for the Glenelg complements that developed for other river systems and the need for reporting at the State level. It is also recommended that the detailed sampling programs developed from the information in this report are reviewed to assess the applicability of conceptual model components, variables to be sampled, and methods for specific variables.

As described in detail by Baldwin et al. (2005), key project management considerations for the Implementation Group are to confirm:
• The list of the key personnel involved in the project, and their specific roles and responsibilities;
• The problems/questions being addressed in the monitoring program;
• The project tasks to be undertaken;
• Quality objectives for measurement data (e.g. statements about the precision, accuracy, representativeness, completeness, comparability and measurement range of the data);
• Any training and certification requirements for key personnel;
• The documentation required/generated in the project (including copies of all forms used in the project); and
• Identification of potential occupational, health, safety and environment hazards, risk assessment and risk minimisation plans.

A QA/QC plan should include a description of the experimental design to be applied, including the location of sampling sites, sampling frequency, and the sampling methods and protocols to be applied.

The monitoring variables described in previous sections fall into the following broad categories:

**Physical** – channel cross-sections, longitudinal surveys, hydraulic modelling (e.g. HECRAS), sediment size–class distributions, and mapping of habitat elements (e.g. snags, benches, riffles, pools)

**Physico-chemical** – water quality parameters

**Biological** – macroinvertebrates, in-channel and riparian vegetation, fish.

Data collection and sample analysis will require a mixture of field and laboratory measurements and activities. A QA/QC plan should therefore detail the requirements for:

• Field staff and equipment
• Field sample collection
• Field data collection and storage
• Laboratory staff and equipment
• Laboratory sample processing
• Laboratory data storage, and
• Centralised data storage and management.

Field staff should be competent in sampling and be able to demonstrate competence in field procedures, including being able to adhere to established protocols, being able to avoid contaminating samples, and being able to calibrate field instruments and make field observations. Where possible, a requirement for formal training and testing of contractor competency should be built into the monitoring program. Such training includes the EPA course for macroinvertebrate sampling (L. Metzeling pers. comm.). For fish collection, there are no formal qualifications, but extensive experience of practitioners is necessary (A.J. King pers. comm.). For sampling by electrofishing, contractors should undertake to follow the Australian Code of Electrofishing Practice (NSW Fisheries 1997). Similarly, there are no formal qualifications for contractors
taking physical measurements, but as a general guide, geomorphic assessments should only be undertaken by experience fluvial geomorphologists, and hydraulic surveys should be undertaken by the same consultant who will do the hydraulic modelling. The choice of consultant for hydraulic modelling should be based upon their track record of successful model use, evidence of suitable training by the practitioners, and a demonstrated awareness of potential pitfalls in channel survey methods and model calibration. All equipment and field instruments should be kept in good working order, with calibrations and preventative maintenance carried out according to the schedule recommended by manufacturers or other accepted standards.

Sampling protocols for the collections of physico-chemical and biological data are well established as part of the Victorian Water Quality Monitoring Network (VWQMN) and State Biological Monitoring Program (AWT 1999). It is recommended that these protocols, methods for sampling and measurement, and data handling processes be adopted for monitoring environmental flow releases in the Glenelg River. This will ensure that data collected for the Glenelg can be compared with that collected in other river systems, and combined with other rivers to inform a statewide assessment of ecosystem responses to environmental flows. The VWQMN has detailed requirements for:

- Sample handling and chain of custody documentation;
- Instrument and equipment QA, including calibration and frequency of maintenance;
- Analytical methods to be used;
- Routine field and laboratory QC activities; and
- A description of data acquisition and storage requirements.

Macroinvertebrate community composition has long been used as a measure of river health in Victoria. EPA Victoria (2003) provides a protocol for rapid biological assessment using macroinvertebrates. It is recommended that these methods be adopted for collecting macroinvertebrate data from the Glenelg River.

The sampling of fish populations and collection of fish data should follow methods appropriate for the particular circumstances and questions. Data should be recorded and stored in a format that will allow easy inclusion in the DSE Victorian Fish Database. It is currently a requirement for fish collection permits that the data be supplied to DSE for entry into the database in a prompt fashion.

There are no standard approaches to the sampling and collection of vegetation data. It is important that the Implementation Group agree to the methods to be adopted, and ensure consistency of methods as far as possible amongst the different CMAs. Furthermore, a vegetation technical expert should be consulted to ensure consistency across all programs that are a part of the VEFMAP.

The implementation of the monitoring and evaluation plan for the Glenelg River will be the responsibility of the Glenelg–Hopkins CMA.
The CMA will inform the Implementation Group of progress as part of their regular reporting on VEFMAP activities to DSE, including any difficulties encountered and any corrective action required. Baldwin et al. (2005) note a number of factors to consider:

- That data are consistent/compatible with the Australian and New Zealand Land Information Council National Standard;
- There are agreed protocols to transfer field and laboratory data to electronic data-bases;
- Original data sheets, laboratory records, chain-of-custody documentation and/or QA/QC data associated with an entry to an electronic database are preserved;
- There are procedures for validation of data entered, including accuracy of transcription and whether or not any of the data recorded is outside the range expected for that type of system (cross-checked against QA/QC data associated with a given entry);
- There are documented procedures for determining who can enter or change data on the data-base and appropriate security measures to stop unauthorised access to the database;
- Data bases are flexible enough to accommodate a range of different data types;
- Retrieval of data using a variety of fields (time, place, flow etc.) is relatively straightforward;
- There are agreed procedures for handling chemical data that are below the detection limit (see ANZECC & ARMCANZ 2000);
- There are agreed protocols for updating the data-base to account for improvements/changes in software and hardware; and
- Agreed ownership of the data-base and procedures to be followed during organisational restructuring.

The CMA will also be a partner in the 3-year review of collected data, particularly in terms of interpreting results given the potential influence of local management and restoration efforts that may occur across the Glenelg River catchment.
5 References


Appendix 1: Environmental Flow Recommendations for Reaches of the Glenelg River

(from SKM 2003b)

Specific objectives for each reach are described in the flows study (SKM 2003b) and are then referred to in the objective column of Tables 12–14. Consultants developing and implementing river specific monitoring programs will need to refer to the original flow study to ensure that the methods develop sample the correct response variable (e.g. spawning of a particular fish species in response to a particular flow component).

Table 12. Environmental flow recommendations for Reach 1, Rocklands Reservoir to Chetwynd River Confluence

<table>
<thead>
<tr>
<th>River</th>
<th>Glenelg River</th>
<th>Reach</th>
<th>Rocklands – Chetwynd River</th>
<th>Gauge No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compliance Point</td>
<td>Harrow</td>
<td>238 219</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Season</th>
<th>Magnitude</th>
<th>Frequency</th>
<th>Duration</th>
<th>Objective</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer (Dec – May)</td>
<td>Minimum 11 ML/d</td>
<td>Annual</td>
<td>Dec – May</td>
<td>1a, 2a, 3, 4a, 5a, 6a, 10b, 11a</td>
<td>Self-sustaining populations of small bodied fish</td>
</tr>
<tr>
<td></td>
<td>&gt; 64 ML/d</td>
<td>5 annually</td>
<td>Minimum 6 days</td>
<td></td>
<td>Self-sustaining populations of small bodied fish</td>
</tr>
<tr>
<td>June</td>
<td>100 ML/day</td>
<td>Annual</td>
<td>June</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter (Jul–Oct)</td>
<td>Minimum 150 ML/d</td>
<td>Annual</td>
<td>July-Oct</td>
<td>1a, 2a, 3, 4a, 6a, 9, 11a</td>
<td>Minimum Flow Maintained occurrence of large flow</td>
</tr>
<tr>
<td></td>
<td>&gt; 1400 ML/d</td>
<td>3 annually</td>
<td>3 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring (Sept)</td>
<td>&gt; 450 ML/d</td>
<td>2 annually</td>
<td>10 days</td>
<td>1b, 1c, 2b, 4b, 5b, 6b, 11b</td>
<td>Self-sustaining populations of fish (Mountain Galaxias, River Blackfish, Common Galaxias, Spotted Galaxias), Off-stream habitats wetted</td>
</tr>
<tr>
<td>November</td>
<td>130 ML/day</td>
<td>Annual</td>
<td>November</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 13. Environmental flow recommendations for Reach 2, Chetwynd River Confluence to Wannon River Confluence

<table>
<thead>
<tr>
<th>River</th>
<th>Glenelg River</th>
<th>Reach</th>
<th>Chetwynd River – Wannon River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compliance Point</td>
<td>Roseneath</td>
<td>Gauge No.</td>
<td>238 211</td>
</tr>
<tr>
<td>Flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rationale</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer (Dec – May)</td>
<td>0 ML/d</td>
<td>3 annually</td>
<td>Maximum 8 days</td>
</tr>
<tr>
<td>Minimum</td>
<td>18 – 77 ML/d</td>
<td>Annual</td>
<td>Dec – May (excl. OTF)</td>
</tr>
<tr>
<td>&gt; 77 ML/d</td>
<td>4 annually</td>
<td>7 – 15 days</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>63 ML/d</td>
<td>Annual</td>
<td>June</td>
</tr>
<tr>
<td>Winter (July – Oct)</td>
<td>Minimum</td>
<td>Annual</td>
<td>July – Oct</td>
</tr>
<tr>
<td>&gt; 3000 ML/d</td>
<td>2 annually</td>
<td>Minimum 4  days</td>
<td></td>
</tr>
<tr>
<td>November</td>
<td>110 ML/d</td>
<td>Annual</td>
<td>November</td>
</tr>
<tr>
<td>Spring (Sept)</td>
<td>&gt; 700 ML/d</td>
<td>2 – 3 annually</td>
<td>5 days</td>
</tr>
</tbody>
</table>

### Table 14. Environmental flow recommendations for Reach 3, Wannon River Confluence to Tidal Extent

<table>
<thead>
<tr>
<th>River</th>
<th>Glenelg River</th>
<th>Reach</th>
<th>Wannon River – Tidal Extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compliance Point</td>
<td>Dartmoor</td>
<td>Gauge No.</td>
<td>238206</td>
</tr>
<tr>
<td>Flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rationale</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer (Dec – May)</td>
<td>Minimum</td>
<td>Annual</td>
<td>Dec – May</td>
</tr>
<tr>
<td>&gt; 216 ML/d</td>
<td>4 annually</td>
<td>Minimum 5 days</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>180 ML/d</td>
<td>Annual</td>
<td>June</td>
</tr>
<tr>
<td>Winter (July – Oct)</td>
<td>Minimum</td>
<td>Annual</td>
<td>July – Oct</td>
</tr>
<tr>
<td>&gt; 620 ML/d</td>
<td>130 ML/d</td>
<td>Annual</td>
<td>November</td>
</tr>
<tr>
<td>Spring (Sept)</td>
<td>&gt; 2200 ML/d</td>
<td>2 – 3 annually</td>
<td>Minimum 5 days</td>
</tr>
</tbody>
</table>
Appendix 2: Selection of Conceptual Models

Conceptual models provide a means by which we can represent our understanding and beliefs about how a particular system functions. This explicit representation can also help to reduce confusion between various stakeholders, and to highlight knowledge gaps in our understanding of a system. For this report, conceptual models were developed to make the link between the various flow components to be supplied and expected ecosystem responses, and from this the appropriate variables for monitoring were specified. The models were thus developed specifically for the purpose of identifying variables for monitoring, and were never meant to be a complete or ‘correct’ representation of the system, and were. That is not to say, however, that they were not well-researched. The models presented in this report were synthesised from the literally hundreds of conceptual models presented in the various environmental flows reports, and from the published literature on flow–ecosystem relations. The models were then peer reviewed by experts in the respective fields, and revised according to these reviews. Further revision is also possible, and these models should not be considered as a final product. As information is collected through the monitoring program, it may become apparent that some previously accepted aspect of a conceptual model is incorrect. Similarly, additional important links between flow and response may become apparent that can better explain why a particular variable responds to a given flow component. At this stage, however, there were a large number of conceptual models and potential hypotheses that could be tested for the Glenelg River and at a statewide level. The information and processes used to synthesise conceptual models are presented below.

A number of criteria were used to consolidate the conceptual models and hypotheses that would be addressed, both for the Glenelg River and at the statewide level. Conceptual models and hypotheses should:

- Be scientifically ‘sound’ – well-founded and supported by appropriate theoretical or empirical data from scientific studies and/or expert opinion;
- Involve responses to recommended environmental flows that are detectable – expected responses must be of sufficient magnitude to be detectable within a useful management timeframe (nominally 10 years);
- Address questions that are relevant to the Victorian River Health Strategy (VHRS) (see Box below);
- Where possible, have general applicability to multiple reaches within the Victorian Rivers receiving an EWR;
- Be realistic, given the quantity of water available for implementing the recommended environmental flow releases;
- Include components of the flow regime that can most feasibly be returned to a more natural pattern using the environmental flow recommendations;
- Acknowledge potential constraints on ecosystem response because of river-specific characteristics and/or regulation activities (e.g. cold water releases from large dams);
• Acknowledge potentially adverse outcomes associated with implementing the recommended environmental flow releases (e.g. blackwater events); and
• Availability of relevant historical data.

Criteria 1–3 were used to develop a preliminary list of priority conceptual models/hypotheses applicable to all the 8 rivers (process described below).

Box: The Victorian River Health Strategy

The Victorian River Health Strategy (VHRS) is the overarching framework for making decisions about the management and restoration of Victoria’s rivers (DNRE 2002b). The VHRS is informed by an ecological understanding of ‘river health’ (Section A), guided by aspirations or a vision for Victoria’s rivers (Section B), governed by a particular management philosophy towards restoration (Section C) and assessed with the aid of Statewide targets (Section D). Conceptual models and hypotheses to be tested must be demonstrably relevant and consistent with the considerations described in Sections A–D.

Section A: VHRS Understanding of ‘river health’ (adapted from DNRE 2002b)

VHRS clearly states that ‘river health’ goes beyond water quality and the flora and fauna present in the river. It explicitly recommends that proper understanding of ‘river health’ should take into account:
1. the diversity of habitats and biota;
2. the effectiveness of linkages; and
3. The maintenance of ecological processes.

Three key processes are highlighted in relation to the ‘maintenance of ecological processes’:
1. Energy and nutrient dynamics, including primary production and microbial respiration which maintain food webs within the entire ecosystem.
2. Processes which maintain animal and plant populations, such as reproduction and regeneration, dispersal, migration, immigration and emigration.
3. Species interactions, which can affect community structure. These include predator–prey, host–parasite and competition relationships.

Section B: VHRS Vision for Victoria’s rivers (adapted DNRE 2002b)

The VHRS Vision for Victoria’s Rivers is based on ecological sustainability and envisages rivers that:
1. support a diverse array of indigenous plants and animals within their waters and across their floodplains
2. are flanked by a mostly continuous and broad band of native riparian vegetation
3. have flows that rise and fall with the seasons, inundating floodplains, filling billabongs and providing a flush of growth and return of essential nutrients back to the river
4. have water quality that sustains critical ecological functions
5. have native fish and other species moving freely along the river and out of the floodplains and billabongs to feed and breed during inundation
6. replenish productive estuaries or terminal lakes

Section C: VHRS Management philosophy towards restoration (adapted from DNRE 2002b)

In the VHRS Strategy Background on the Management Drivers of River Health, a philosophy towards restoration is outlined and it reflects a realistic, pragmatic approach that:

a) postulates that river systems have a tiered number of viable, functioning, self-sustaining ecological states and proposes that the aim of management may be to prevent transition from one state to a less desirable one, rather than to restore the system to its original condition;

b) considers that all systems have some ecological values; even heavily degraded systems always have some functioning aspect of the ecology present and some ecological values;

c) predicts that the effort that is required to restore a heavily degraded system will be very much larger than that required to restore a system in a reasonable condition; and

d) recognises that the impaired conditions in some heavily degraded systems may be irreversible.

Section D: VHRS Statewide Targets (adapted from DNRE 2002b)

In working towards the vision, the following targets for river protection and restoration will be used to measure progress across the State.
All Heritage Rivers to be maintained at least to their current condition and their Heritage River values protected.

By 2005:
- An increase in length of river accessible to native fish by an additional 2000 km;
- Significant improvement in floodplain linkages in ten areas of national and/or State significance;
- All rivers with either sustainable catchment limits or negotiated environmental flows in place;
- Report on the second benchmarking of the environmental condition of Victorian rivers; and
- A quarter of agricultural production produced from natural resources that are managed within their capacity. By 2015, this will increase to half of agricultural production (as stated in Victoria’s Salinity Management Framework).

By 2011: *(project team emphasis in bold)*
- An improvement in the status of designated freshwater-dependent focal species;
- Significant improvements achieved in environmental flow regimes of 20 high value river reaches currently flow stressed;
- 4800 km of rivers with improvement of one rating in the measurement of riparian condition;
- An increase of 7000 ha of riparian areas under management agreements;
- 600 km of rivers where instream habitat has been reinstated;
- 95% of all highland and upland and 60% of all lowland monitoring sites will meet SEPP environmental quality objectives; and
- 1000 high-value public assets provided with appropriate level of protection.

By 2021:
- One major representative river reach in ecologically healthy condition in each major river class; and
- An increase of 3000 km in the length of rivers in excellent or good condition.

Progress towards the achievement of these targets will be measured through regular reporting on river protection and restoration activities, and through regular resource condition monitoring.

Criteria 1 to 3 were used to prioritise a sub-set of these for more detailed consideration as the basis for the VEFMAP. Each conceptual model/hypotheses was rated against these three criteria. Each hypothesis was given a score from 1 to 3 (1: weak, 3: strong) for each criteria. Our scores are listed in Table 15 and were tallied to identify a preliminary list of the conceptual models we would use in designing the environmental flow monitoring program.

We acknowledge the subjectivity of this scoring procedure. Our intent is to prioritise the hypotheses/models in a systematic and transparent way. The table of scores can also be used in the upcoming workshop as a focus for debate around the logic of this selection. It should be noted that this exercise was carried out prior to the first round review of this document by our subject-matter specialists and scientists who had served on Scientific Panels involved in producing the environmental flow studies for the various river systems.

Conceptual models/hypotheses relating to desiccation disturbance associated with cease to flow periods (Attribute 3, Table 16), the effects of summer low flows on instream habitats (Attribute 5, Table 16), and water quality (Attribute 7, Table 16) were excluded from this exercise. These conceptual models are a component of a concurrent study on the ecology and hydrology of temporary streams in Victoria (Nick Bond, Monash University). It was decided that the present project should draw upon the results of that study rather than duplicating the effort.
Table 15. Scores of conceptual models/hypotheses for selection criteria 1–3

<table>
<thead>
<tr>
<th>Conceptual Model/Hypotheses</th>
<th>Score for:</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>Relevance to VHRS</td>
<td>Strength of a priori support</td>
</tr>
<tr>
<td>1  Biogeochemical Processes</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2  Geomorphic Processes</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3  Ecological Process</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>4  Habitat Processes</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>5  Habitat Processes</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>6  Habitat Processes</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>7  Habitat Processes</td>
<td>3</td>
<td>2.5</td>
</tr>
<tr>
<td>8  Biofilms</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>9  Invertebrates</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>10 Fish – Habitat</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>11 Fish – Movement</td>
<td>2.5</td>
<td>2</td>
</tr>
</tbody>
</table>
Fish – Maturation, Reproduction/Spawning, Recruitment

- Low Flows may be important for recruitment of some native fish in lowland rivers because Low Flows maintain or increase the availability of slow-water habitats which are important as refuge and rearing habitats for larval and juvenile fish. High water velocity over summer–autumn displace eggs and larvae from spawning and rearing habitat thus limiting recruitment.
- Winter–Spring Freshes may provide spawning cues for freshwater diadromous fish such as Australian Grayling and Long-finned and Short-finned Eels

| Conceptual models/hypotheses which scored ≥8 in our trial application of the selection criteria are shown in the last column of Table 15. It was felt that although the conceptual model/hypotheses associated with biofilms rated well, there is a general lack of familiarity and appreciation of the role of biofilms in riverine systems and this would present difficulties in communicating their relevance to management stakeholders and the community at large. The surprise finding of invertebrates no being amongst the top-rated conceptual models/hypotheses turned out to be an artefact of the way the information in Table 16 is organised, with the conceptual model relating flow regime to habitat availability for macroinvertebrates being subsumed in the conceptual model for habitat processes. It was therefore decided that macroinvertebrates should be included in the preliminary shortlist and a more cohesive conceptual model linking flows, habitat availability, connectivity, drift and stimulus for hatching would be developed for macroinvertebrates. Hence, our preliminary list included six conceptual models relating to 1) biogeochemical processes; 2) geomorphic processes; 3) habitat processes; 4) aquatic and riparian vegetation; 5) macroinvertebrates and 6) fish – spawning and recruitment.

The underlying basis for each of the above conceptual models was reviewed by scientists who are recognised experts in the area of ecosystem monitoring and evaluation, including a number who were on the Scientific Panels that developed flow recommendations for many of the eight rivers in the program. The models were also explored at a workshop attended by scientific experts, DSE staff and managers (see acknowledgements). The rationale of the models and how they were to be used was strongly endorsed at the workshop. It was agreed that the biogeochemical processes model would not be pursued further, as there was insufficient knowledge of what represents ‘target’ conditions for processes such as production and respiration (making it difficult to interpret any results). In addition, the macroinvertebrate model was subsumed into the habitat responses model. A full model of macroinvertebrate responses to flow enhancement was very complex, and unlikely to be of use in designing a monitoring program. However, we noted that any environment with sufficient macroinvertebrate habitat would most likely also include the other requirements for successful macroinvertebrate populations (see § 2.4).
Explanatory notes for Table 16.

1. In examining the flow recommendations for individual rivers, it became evident that there was some variation (and inconsistency) in the way the FLOWS method flow component terms were used in the original environmental flow study reports. For instance, High Flows which refers to the persistent increase in seasonal baseflow that remains in the channel and which does not fill the channel to bankfull, was sometimes also referred to as Winter Low Flow or Winter Baseflow. This can lead to some confusion, for example, recommendations to meet the Winter Low Flow requirements might be misconstrued as a recommendation that the winter flow be reduced, when in fact, the intent is to recommend protection or reinstatement of a level of baseflows appropriate the eight rivers which are southern winter-rainfall dominated systems. The wording in Table 16 has, in some instances, been amended from that in the original environmental flow reports to help minimise linguistic ambiguity (e.g. recommendations for ‘winter low flows’ have been amended to ‘protection or reinstatement of more natural levels of winter baseflows’).

2. Each statement within the description of the conceptual model and generic predictions (column 2) is accompanied by letters in square brackets, [], which refer to the respective environmental flow studies of the various river systems from which the statement is taken.
   (B – Broken; Go – Goulburn; T – Thomson; M – Macalister; L – Loddon; C – Campaspe; W – Wimmera; Gl – Glenelg)

3. References in black are citations provided in the environmental flow study reports for the various river systems.

4. Statements in blue are comments or additional notes from the literature.

5. References in red are potentially relevant references from the literature.

6. Table 16 was reviewed by subject-matter specialists as well as scientists who had served on scientific panels involved in producing the environmental flow studies for the various river systems. These reviewers were Mark Kennard, Alison King, Sam Lake, Terry Hillman, Leon Metzeling and Jane Roberts. Statements in green are comments from the reviewers. References in violet are relevant references suggested by these reviewers.
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Conceptual Model and Generic Prediction(s)</th>
<th>Reference(s) Cited</th>
</tr>
</thead>
</table>

Geomorphic Process

| Bankfull Flows are important geomorphologically in shaping and maintaining river and distributary channels. | [D] Bankfull Flows can reform channels by scouring and sediment transport and help to maintain/rehabilitate channel form. For instance: by scouring and effecting the removal of vegetation which has encroached into the channel [M,T]; or by scouring and removing sediment from in-filled pools [L]; or by mobilising sand build-up within channels [Gl]; or by depositing sediments on benches [T] and constricting sandy channels [C]. (The rationale here is as follows: granite catchments tend to have sand-dominated sediment loads. Sand ‘slugs’ and flat sand sheets are unstable, create inimical conditions for macroinvertebrates, and produce conditions of limited variability in water depth. Hence, in such rivers, possible enhancements to in-stream habitat include measures to store as much as possible of the sand in lateral benches within the river; to encourage deepening |
| No reference cited for the conceptual model. [M,T,L,Gl,C] |

of the channel, to re-establish a more stable gravel substrate and to re-establish greater heterogeneity in depth and more varied pool–riffle morphology. It was proposed in [C] that this might be achieved by narrowing the channel and encouraging the development of a sinuous course by establishing vegetation on point bars.)

1A qualifier might be added to indicate that this applies to constrained streams (Lake, pers. comm.)

and causes. Ecological Monograph, 64: 45–84.

### Ecological Process – Disturbance (Drying)

During periods of flow cessation or summer low flows, the river may contract to a series of isolated pools, or portions of the channel may dry out.

(a) Biota in these pools are likely to be subjected to intensified predation and physicochemical stresses (e.g. Low DO concentrations).1 [D]

(b) Exposure of large areas of the streambed as a disturbance mechanism which resets successional processes for macroinvertebrate and vegetation communities.2 [M]

Desiccation disturbance prevents the system from being dominated

No reference cited for the conceptual model. [W, Gl]

3 Ecological Process – Disturbance (Drying)

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(b) Exposure of large areas of the streambed as a disturbance mechanism which resets successional processes for macroinvertebrate and vegetation communities.2 [M]

Desiccation disturbance prevents the system from being dominated

No reference cited for the conceptual model. [W, Gl]
by any particular group of organisms.\(^3\) [W, Gl]

In particular, any macroinvertebrate species as many macroinvertebrate species would be reduced in their abundance and distribution over the dry period. [Gl] Desiccation disturbance maintains aquatic and riparian species characteristic of dryland river systems where flow cessation and summer low flows naturally occur. Biota in these arid environments have special physiological or behavioural adaptations that allow them to persist in harsh conditions in locations which they might otherwise be displaced by dominant but less tolerant species. In the short term there may be localised extinction of certain species. And in the long term, changes in diversity and biomass. Recolonisation of “stressed” habitats upon flow restoration should be feasible provided there are effective refuges for biota during cease-to-flow periods. [D]

\(^1\) Competition should also be added to the list of stresses (Lake, pers. comm.)

\(^2\) Drying may be a stress for some species (especially obligate aquatics) but is an opportunity for transient terrestrial species to establish or expand, or for certain plant species to regenerate on bars and benches (Roberts, pers. comm.)

\(^3\) Depends on the place and the species involved. For example, in periods of low flow in south-west US streams, *Tamarix*, a non-native invader, proliferates and becomes dominant. (Shafroth et al. (2005) Control of *Tamarix* in the western United States: implications for water salvage, wildlife use, and riparian restoration. *Environmental Management* 35: 231–246. – Lake, pers. comm.)

| Cooper et al. (1990) – cited in text [D], but not in Reference list. |
Bankfull flows may act as a disturbance mechanism which resets ecological processes for both aquatic and riparian flora and fauna communities by drowning and/or sweeping plants and animals downstream. [M]

No reference cited for the conceptual model. [M]


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<th>5</th>
<th>Ecological Process – Habitat Processes</th>
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</table>
Protection or reinstatement of more natural levels of Winter–Spring baseflows also increases the quantity and diversity of flow velocity habitats by increasing the area of riffle and run habitat. [M] Diversity in flow velocity habitats may be particularly important for macroinvertebrate community diversity, which can contain species specialised for high velocity habitats. [M] Runs provide a site for aquatic macrophyte growth thus increasing habitat complexity. [W,M] However, excessive growth of submerged macrophytes degrades physical habitat quality by decreasing instream habitat diversity. [W]

Spring Freshes make available in-channel habitat such as vegetated bars, benches and undercuts and these habitats may be important for the colonisation of macroinvertebrates and as spawning sites and refuges for native fish. [W,Gl]

Bankfull Flows enable the recruitment of woody habitat for the channel [T] and also provide lateral connectivity between in-channel and floodplain habitats. [W,Gl]

Overbank Flows are critical for maintaining longitudinal and lateral connectivity between stream channel and floodplain areas. [D] Overbank Flows restore natural wetland hydrology and connectivity and help restore biodiversity of floodplain wetlands. [T] [No details on exactly how overbank flows are important in this respect.]

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<th>6</th>
<th>Ecological Process – Habitat Processes</th>
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<td></td>
<td>Freshes, High Flows and Bankfull Flows can help to flush and remove accumulations of fine sediment and organic matter from gravel, areas of the streambed such as riffle areas, and benthic habitats such as large woody debris and leaf-packs thereby preventing the smothering of these habitats for biota that utilise them. [D,M,T,L,Gl,W–winter/spring freshes] Bankfull Flows may also dislodge and redistribute large woody debris caught up in lower channel sections. [M]</td>
</tr>
<tr>
<td></td>
<td>No reference cited for the conceptual model. [M, T,L,Gl,W]</td>
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</tbody>
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Milhous, R.T. (1998) Modeling of instream flow needs: the link between sediment...
<table>
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<th>7</th>
<th>Water Quality</th>
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| Provision of Low Flows will help ameliorate water quality \([D,C]\) and help minimise the increase in temperature and the decrease in DO. \([M]\) Summer/Autumn Low Flows help to slow the deterioration of water quality that occurs in pools during summer low flow periods (avoid stagnation). \([M, GI]\)
Summer Freshes help maintain/improve water quality in rivers by providing an input of fresh water and mixing and/or flushing pools which may have stagnated or and/or stratified after prolonged periods of zero/low flow. \([D,M,W,GI,C]\)
However, floodplain inundation and connectivity of large previously dry areas [which results in an influx or organic matter] can decrease dissolved oxygen concentrations in waters (particularly during warm summer conditions), and under some conditions cause fish kills \([King, pers. comm.]\).

No reference cited for the conceptual model. \([C, M, GI]\)

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<th>8</th>
<th>Biofilms</th>
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</table>
| Winter/Spring Freshes and High Flows provide scouring flows over biofilm habitats and this acts as a disturbance mechanism for maintaining species composition and health. \([T,L]\) Summer Freshes are also expected to perform this function \([L]\).

No reference cited for the conceptual model. \([T,L]\)


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<th>Aquatic and Riparian Vegetation</th>
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</table>
| 9 | Protection or reinstatement of more natural levels of Winter–Spring baseflows will provide conditions of sustained water levels in the river and inundate lower channel portions. Sustained inundation of riffles, lower benches and channel margins will maintain shallow water habitat for emergent and marginal aquatic vegetation during the spring growing season. [M, G] Prolonged winter/spring inundation of lower channel portions will drown and cause dieback of terrestrial vegetation (mainly agricultural weeds) which have encroached down the bank during the low flow period. [M]
|   | Winter/Spring Freshes which inundate vegetation for a minimum of 4 days will allow regeneration of hydrophilic species. \(^1\) [T]
|   | Summer Low Flows will help to maintain appropriate/adequate soil moisture conditions for aquatic and riparian vegetation. [D]
|   | Summer Flows will maintain shallow water (defined as <0.3m) habitat for in-channel macrophytes (e.g. smaller submerged and floating-leaved aquatic macrophytes) during the latter part of the growing season. [B, Go]
|   | Low Flows also mean low–moderate flow velocities within the instream environment (e.g. mean reach velocities of <0.06 m/s or even <0.04 m/s) which are suitable for macrophyte growth. [Go]
|   | Fast and very fast velocity flows increase the risk of mechanical damage to plants of parts breaking off and of emerging or floating leaves being dragged underwater, effectively reducing rates of photosynthesis and consequently growth. [Go]
|   | Summer Freshes wet low-lying channel zones such as riffles and benches and help to alleviate drought stress on emergent and aquatic vegetation that has become exposed during the low flow period. [M, T]
|   | With flow inversion (e.g. higher summer–autumn flows, reduced winter–spring baseflows due to regulation activities) water is deeper and colder during the growing season and is expected to result in poor growing conditions for submerged macrophytes. Sustained flow inversion also eliminates flood intolerant plant species from No reference cited for the conceptual model. [M, Gl, T, C]


<table>
<thead>
<tr>
<th>Riverbanks. (Roberts, pers. comm.)</th>
<th>Water Resources Research and Development Corporation, Canberra.</th>
</tr>
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<tbody>
<tr>
<td>Flows which inundate benches/riparian zone will help to:</td>
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<tr>
<td>(a) maintain riparian vegetation [C]</td>
<td></td>
</tr>
<tr>
<td>(b) promote regeneration of native species, including river red gum. [C]</td>
<td></td>
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<tr>
<td>(c) control invasion by terrestrial and/or weed species if sustained for a sufficiently long period. [T,M,C,L,Go]</td>
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<tr>
<td>Results from a study of depth, duration and frequency of flooding on plant recruitment from wetland sediments suggest that flows which inundate areas for short durations (e.g. &lt;2 weeks) lead to a higher proportion of terrestrial and introduced plants, while native species are believed to be favoured by inundation periods of longer duration. [Go]</td>
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<tr>
<td>In addition, [with flow inversion] inundation of benches at a time when they would naturally have been dry can affect the mix of aquatic/terrestrial species and increase the risk of weed invasion (e.g. willows). [B] For instance, higher than natural summer flows change the bed environment from an opportunity for summer-growing annual/perennial herbaceous forms and short benthic submerged macrophytes, to one that is too challenging for these weakly growing and non-robust species. This may result in a shift in vegetation on benches from stress-tolerant, but less competitive, to competitive invading species and a loss of diversity. [B]</td>
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<td>In a mesocosm experiments using billabong soils, Nielsen and Chick (1997) found that prolonged inundation of artificial billabongs (summer flooding followed by high winter/spring flows) led to lower plant diversity compared to artificial billabongs that experienced extended periods of drying followed by spring flooding. The lower plant diversity was due to the absence of ephemeral and terrestrial plant taxa.</td>
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<td>In developing an approach for monitoring vegetation response to environmental flows in the Wimmera, Dyer and Roberts (2006) identified expected responses to environmental flows recommended for the Wimmera River system that were site-specific and linked to specific flow components. They are presented here in generic form because many of these predictions have not previously been expressed in the environmental flow reports for the</td>
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8 case study rivers and they represent potentially useful monitoring endpoints. This list is also relevant to Attribute 10.

Vegetation responses:
1. Increased vigour/improvement in canopy of adjacent trees and shrubs
2. Growth pulse (e.g. in seedlings/saplings);
3. Increased flowering intensity / flowering seed set
4. Germination of riparian trees and shrubs
5. Recruitment of riparian trees and shrubs
6. Slowing of mortality rate in riparian trees
7. Development of ‘recession’ flora in flood runners, anabanches, depressions
8. Stimulate regrowth of forbs and herbs in flood runners
9. Change in relative abundance of submerged macrophytes; shift/turnover in species composition and/or functional types
10. Change in understorey composition and/or functional groups from grasses and sedges to amphibious plants
11. Increase in overall diversity in channel/channel edge/bank through establishment of a mix of sedges, grasses, herbs and forbs; diversity expressed over length of channel
12. More vigorous growth of Phragmites such as increased stand height. Density, greater flowering intensity of culms; build up of rhizome starch reserves
13. Colonization and expansion by Phragmites
14. Flushing of senescent plant parts from in-channel macrophytes

¹ Unproven that inundating vegetation for a minimum of 4 days over the Winter–Spring period will allow regeneration. If there is a factual basis for this, then the statement most likely refers to a single species or small group (Roberts, pers. comm.)

² The time for plants to respond to inundation varies very widely between species (from days to weeks and even months) and cannot be easily connected to a single attribute or plant type (i.e., hard to predict) (Roberts, pers. comm.)

10 Aquatic and Riparian Vegetation

Freshes provide short-term flow variability and variation in water levels is important for maintaining species diversity in the emergent and marginal aquatic vegetation communities. Variation in water levels is an important factor in maintaining species diversity in emergent and marginal aquatic vegetation communities.

levels is the principal driver of zonation patterns across the channel and up the river banks. [M,T,L]

Providing Freshes and ensuring the occurrence of flow variability and variation in water levels will help:
(a) restore/maintain/increase species diversity in the emergent and marginal aquatic vegetation communities.
(b) maintain/restore distinctive riparian vegetation community and structure with zonation up the bank.

Change in flow variability can take many forms which have different consequences for vegetation patterns. For instance, prolonged stable water levels allow plants to establish and persist close to the water line, with the species doing this being more associated with lentic (wetland) environments than lotic (flowing water) environments. Loss of flow variability may also result in wider zones of terrestrial or flood intolerant plant species and a shrinking in the width of the zone characterised by flood tolerant species. (Roberts, pers. comm.)

Bankfull flows lasting a minimum of 3 days can prevent encroachment of riparian terrestrial vegetation and maintain riparian vegetation diversity and structure. [T] However, Bankfull flows may also remove aquatic and riparian vegetation through scouring of the channel bed. [M]

1 This statement applies to upland rivers. What is the source of the number of days? Inference from hydrological analysis? (Roberts, pers. comm.)


11 Aquatic and Riparian Vegetation

High Flows deliver seed from the upper catchment to help maintain or restore distinctive riparian vegetation community and structure. [T]

No reference cited for the conceptual model. [T]


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<tr>
<td><strong>14</strong></td>
<td><strong>Invertebrates</strong></td>
</tr>
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</table>
|   | High Flows and Bankfull Flows which inundate previously dry sediments in higher portions of the channel such as benches may provide a stimulus for hatching to [micro]invertebrates, with diversity and biomass peaking when inundation exceeds 2 weeks. [Go]
|   | Loss of habitat through decreased inundation duration increases the risk of egg mortality, and the loss of early instars (early life stages) and those species not stimulated to drift. For the others the outcome will depend on factors such as the availability of alternative habitat and predation pressure. [Go]
|   | Ballinger papers?

| **15** | **Invertebrates** |
|   | Overbank Flows play an important role in invertebrate colonisation. [D] [Unclear what is meant by invertebrate colonisation. Is it of instream habitats or floodplain wetland habitats? No details on exactly how overbank flows are important in this respect.]

| **16** | **Fish – Habitat** |
|   | Low Flows year round help to maintain/enhance native fish community structure through habitat availability and inundation of large woody debris which provides food sources and shelter. [T, L, GI]
|   | Protection or reinstatement of more natural levels of baseflows from late Spring through to early Winter under regulated conditions will help to maintain or increase the amount of deepwater habitat available for large-bodied fish. Overseas studies of patterns of fish habitat use have clearly demonstrated the importance of deepwater habitat in structuring riverine fish communities and the availability of deepwater habitats strongly influences the distributions of large-bodied fish. Research in Australia rivers has also shown that the adult stages of many larger native species rely heavily upon the
|   | No reference cited for the conceptual model. [T, L, GI]
In systems with seasonal ‘flow inversion’ (e.g. high summer–autumn flows, low winter flows due to regulation activities), constant high water levels during summer can effectively reduce the area of riffle habitat available for some fish. This flow inversion may also reduce the area of shallow water (e.g. <0.3 m depth) habitat favoured by some small-bodied fish.


Protection or reinstatement of more natural levels of Winter–Spring baseflows will provide conditions of sustained water levels in the river. This will provide sustained longitudinal connectivity for fish movement, including the permanent movement of large-bodied fish throughout the river reach in the lead up to the breeding season. Summer Freshes will increase water depth over low-lying channel zones such as riffles and increase longitudinal connectivity, thereby temporarily facilitating greater movement of fish between different in-stream habitats such as pools.

Freshes (which produce a minimum depth of 0.5 m over the shallowest point) over the irrigation season (Nov–Apr) are important in lower river reaches for temporary local movement of bigger fish such as Murray Cod and Golden Perch. These Freshes allow upstream movement of Golden Perch to spawn. Summer (Jan/Feb) Freshes may act as an attractant flow for Golden Perch from the Kerang Weir.

Winter and Spring High Flows and Freshes and Bankfull Flows may provide the cue which triggers movement and/or migration in some species. No reference cited for the conceptual model.


No reference cited for the conceptual model.


native fish species [Gl], for instance, in Australian Grayling [T] and in Tupong [M]. This migration is associated with spawning and hence may have an impact on species reproduction and recruitment. [M]

1 Statement is too broad to be useful. Diadromous species (particularly Australian Grayling, galaxiids and eels) require:
   • High flows/flushes for larval transport to sea/estuary in Autumn/early Winter
   • High flows/freshes for juvenile upstream movement and recruitment during Spring/early Summer

Reasonable evidence exists for galaxiids and eels and this is current belief for Australian Grayling. (King, pers.com.)

2 No data to support this statement; however, is a reasonable statement to include and what most experts think. (King, pers. comm.)

| 18 | Fish – Maturation, Reproduction/Spawning, Recruitment | Low Flows may be important for recruitment of some native fish in lowland rivers. [D] Low Flows maintain or increase the availability of slow water (e.g. velocity<0.05 m/s) habitats which are important as refuge and rearing habitats for larval and juvenile fish. [B] (High velocity flows may 'wash out' larvae.)
High water velocity over summer–autumn displace eggs and larvae from spawning and rearing habitat [B] thus limiting recruitment.2 [B,Go]
In systems with 'flow inversion' (e.g. higher summer flows, lower winter flows due to irrigation schedule) lower winter flows means that there is less habitat and food available for native fish at a time that may be critical for reproductive development prior to spawning. [B]
Winter/Spring Freshes may provide spawning cues for freshwater diadromous fish such as Australian Grayling and Long-finned and |

No reference cited for the conceptual model. [Go]
No reference cited for the conceptual model. [M,W,Gl,C]
Short-finned Eels.³ [M].

High Flows and Bankfull Flows have been linked to requirements for fish breeding and may act as triggers for breeding in some species.¹[D]

¹ Backwaters/slackwaters (King, pers. comm.)

² Recruitment of low flow specialists (King, pers. comm.)

³ Diadromous species (such as grayling and eels) require high flows or freshes in Autumn/early Winter to trigger spawning (as well as for larval transport, see Attribute 17) (King, pers. comm.)

⁴ A broad statement. Some species (particularly Golden Perch and Silver Perch) are thought to require freshes/high flows/floodplain inundation during spring and/or early summer to trigger spawning. (Lake 1967a, Mackay 1973, Cadwallader 1977, King, pers. comm., King unpub. data). Recent evidence has confirmed increased abundance of spawning occurs on floods. However, spawning of these species also occurs (in reduced numbers) during sustained high flows in the Murray (King et al. 2005; King, unpub. data). In addition, we also know that Golden Perch are able to recruit successfully in years where no floods occur only in-channel rises (Mallen-Cooper and Stuart 2003).


²⁰ MacKay, N.J. (1973) Histological changes in the ovaries of the golden perch, Plectroplites ambiguus, associated with the reproductive cycle.


19 Fish –

<table>
<thead>
<tr>
<th>Community diversity</th>
<th>Sites of fish community diversity not specified: in the in-stream channel or on floodplain wetlands? No details on exactly how overbank flows are important in this respect.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Fish – Exotic species management</th>
<th>Summer/Spring Low Flows can expose banks and beds leading to the drying of carp eggs and contributing to exotic fish management. High summer flows and less annual flow variability also provides habitat conditions favourable for introduced species such as carp and Gambusia.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Needs validation. A falling limb of a flow may strand carp eggs as they can be attached. However, carp can spawn in any conditions.</td>
<td></td>
</tr>
<tr>
<td>2 To some extent, but low flows also enable Gambusia to successfully spawn and recruit (King et al. 2003, King 2004a – King, pers. comm.). Less variability in flows (e.g. reaches affected by sustained river regulation) provides suitable conditions for carp breeding, recruitment and habitat for adults (King et al. 1995, Stuart and Jones 2002 – King, pers. comm.). Floodplain inundation events in spring and early summer also trigger spawning and recruitment events for carp and represent a potential adverse event.</td>
<td></td>
</tr>
<tr>
<td>No reference cited for the conceptual model.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waterbirds</th>
<th>Overbank Flows are important for waterbirds.</th>
</tr>
</thead>
<tbody>
<tr>
<td>[D] No details given on exactly how overbank flows are important in this respect.</td>
<td></td>
</tr>
<tr>
<td>Driver, P., Chowdhury, S., Wetton, P. and Jones, H. Models to predict the effects of environmental flow releases on wetland inundation and the success of colonial bird breeding in the Lachlan River, NSW. Proceedings of the 4th Annual Stream</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 3: Bayesian Hierarchical Modelling and Illustrative Case Study

Bayesian hierarchical modelling has been advocated as being applicable to the analysis of the VEFMAP data. This approach represents a substantial innovation for the analysis of the outcomes of environmental flow management, and thus was discussed at length in the technical meetings associated with this project. In order to expand on the technical reasons for the consideration of Bayesian modelling in this project we have developed the hypothetical case study discussed below.

The simple mock analysis demonstrates the effects of using Bayesian hierarchical modelling in the analysis of environmental monitoring data. We aim to demonstrate that the hierarchical approach leads to more precise estimates of site-level parameters, while at the same time having minimal effects on mean values.

The Logical Basis of Bayesian Hierarchical Modelling (drawn largely from Gelman et al. 1995, Chapter 5)

Many problems involve estimating multiple parameters that may be able to be regarded as related in some way. The hierarchical analysis framework allows us to formalise this relatedness by setting up a joint probability model that reflects the dependence among parameter values.

For data concerning the ecological effects of environmental flow augmentations, we will collect data (e.g. plant germination rate), and estimate parameter values (e.g. relationship coefficient between germination and fresh frequency) from a number of sites. We can take three positions with regards to the relatedness of the data from each site. Firstly, we could regard the parameter estimates from each site as being independent estimates of the same true parameter value. That is, the sites are considered to respond identically to flow augmentation. In such a case, we could pool data from the various sites to obtain the best estimate of the true parameter value, acting in effect as if we had many more data points from the one site. Such a step would be regarded as pseudoreplication by most ecologists, with the individual sites being the appropriate unit of replication (Hurlbert 1984). Second, we might believe a priori that the sites are so different to one another that the parameter estimate at any site tells us nothing about the parameter value at another site. In this case, the data could be analysed separately for each site, or handled with some form of nested analysis, with the explicit assumption that the sites are fully independent. Neither of these attitudes to the data seems particularly satisfying for most ecological questions, where we might believe that a parameter value at one site should be similar to that at another site (within reason, given the diversity of possible sites). We would like to use the information contained within the data for other sites to improve inference, but it cannot simply be pooled. This is achieved by the third possibility; that we regard the sites neither as identical nor completely independent, but exchangeable. Exchangeability implies that the parameter estimates from each
site will differ, but that they can be thought of as being drawn from a possible
distribution of parameter values. Differences among parameter values exist,
but we cannot a priori predict what these differences might be, as the
parameter values themselves are viewed as samples from a random variable.

Computationally, the above is achieved by specifying a joint probability model
for all sites, where the data for each site are modelled as being conditional on
certain parameters (e.g. a regression slope), which themselves are conditional
on higher-level parameters – termed hyperparameters. The hyperparameter
becomes the prior distribution for the site-level parameter, and a prior
distribution must be specified for the hyperparameter.

Practically, the consequence of taking this approach is that the means of site-
level parameter estimates will be drawn towards the overall mean of the sites.
This property is known as shrinkage. The means for sites with more data will
be less affected than those for sites with fewer data. This seems intuitively
correct, because we will have more confidence in the parameter estimates for
sites with more data. The posterior estimates for the site-level parameters will
also be more precise in the hierarchical model than those for the individual
sites models, because the hierarchical model effectively encodes information
from the other sites into the prior distribution, thereby tightening the posterior
estimate.

Hierarchical models tend to avoid over- or underfitting of large data sets. A
non-hierarchical model cannot fit a large data set very well with few
parameters. In the example above, pooling data from many sites and analysing
with a simple model would tend to underfit the data due to site-to-site
differences ignored in the pooled model. Conversely, a non-hierarchical model
with many parameters may overfit the data, in that it will fit the data well, but
will be of little use in making predictions about new or unobserved data.
Hierarchical models can have sufficient parameters to fit the data, while using
hyperparameters to model some dependence between parameter estimates,
which avoids overfitting.

The idea that sites will be exchangeable will be appropriate for some
parameters, but may not be for others. In some aspects, we would expect the
response to flow augmentation to differ systematically between rivers for
reasons that we both understand and can measure. In this case, we cannot in
good conscience model the parameter values as being drawn from the same
distribution. Nor would we wish to, as we know something about each site that
leads us to believe that the parameter values will be different. In such a case,
the concept of conditional exchangeability may apply. The parameter estimates
are seen as being drawn from the same distribution, conditional upon the value
of one or more covariates. The simplest way of explaining this is to consider a
simple linear regression where the data fit perfectly, and to ignore for the
moment any uncertainty. When we analyse the data, we fit each data point to a
model – a straight line described by two parameters: the slope ($\alpha$) and
intercept ($\beta$). Using this model, we can then predict new $y$ values, using the
relationship $y_i = \alpha + \beta x_i$, where $x_i$ is a value of the independent variable not
included in the original analysis (but usually not beyond either extreme of the
previous data). This prediction is only possible because we are treating the
original $y_{1-n}$ values as identical conditional upon the calculated values of $\alpha$ and
β and the measured values x₁₋ₙ. In the real world, the data will not fit the model perfectly. There will be uncertainty in α and β, meaning that we treat the data as exchangeable conditional on α, β, and x₁₋ₙ. Any predicted data point yᵢ will also be uncertain, but the model still uses the information encoded in the original data to make the prediction. The only difference between this situation and a Bayesian hierarchical model is that the Bayesian model will use information from the other data points to inform inference about each individual data point (e.g. its measurement uncertainty) as well as to inform the estimates of α and β. Practically however, the mean calculated values of α and β from a Bayesian regression will be almost identical to those from a least squares regression if vague prior distributions are used for these parameters. Conditional relationships underlie all models where data are fitted to some function. They are not confined to Bayesian analyses. From the point of view of monitoring ecological effects of environmental flows, conditional exchangeability may allow us to consider within the same model sites that behave quite differently, as long as we have a conceptual basis that allows us to build these differences into the model structure.

**Case Study – Germination of Riparian Vegetation**

The hypothetical (and rather fanciful) case study chosen concerns the rates of germination of species X of native riparian vegetation. The question is whether or not, at the site level, environmental flows (measured as the frequency of spring freshes) leads to increased germination of the species. The measurement endpoint is the density of shoots observed following spring freshes designed to inundate benches and initiate germination. At each site, we have a single density estimate taken each spring over a three year period, giving a sample size of three in all. At this time, we have ignored concerns such as temporal (and also spatial) autocorrelation of data. When real data are collected, these effects will need to be incorporated in models, a step more elegantly achieved in Bayesian modelling (e.g. Congdon 2001) than the ad hoc solutions usually applied to frequentist models (reviewed in Lloyd 2001).

The main driving variable is the proportional achievement each spring of the recommended number of bench-inundating flows. Due to operational constraints, the recommended number may not be met each year, and the actual number will differ from year to year. At its simplest, therefore, the analysis at each site is a linear regression of shoot density versus flow achievement.

We also have a priori reasons to expect that the density of shoots at a site will partly be a function of the condition of riparian vegetation for a certain distance (say 10 km) upstream of the site. Good quality riparian zones will supply more propagules of the species of interest, and hence can be expected to affect the amount by which flow augmentation increases the density of shoots.

Beyond this, we expect that the elevation of the site might also affect flow augmentation of germination, with species X previously shown to favour slightly higher elevations. In terms of data for this hypothetical situation, we have three points per site (one each year), with two sites per reach, two reaches per river, and two rivers.
The most all-inclusive model for the above data is a Bayesian hierarchical model where the regression slope between flow and germination at each site is modelled as a linear function of riparian condition for that site within each reach. The reaches are at different elevations, and so the relationship between riparian condition and flow effects are modelled as a linear function of elevation within each river. Finally, the rivers are considered as exchangeable entities, in that for this endpoint, we believe that the flow–germination relationships for each river could be drawn from the same distribution of parameter values. These assumptions can all be tested by using post-hoc predictive tests (Gelman et al. 1995) to determine whether the data could have been produced by the model proposed. We do not perform such tests here, but they should be a mandatory part of any analysis of real data.

The above analysis considers all the data simultaneously, and uses all available information to come up with estimates of parameter values. If the sites / reaches / rivers are behaving similarly, conditional on the covariates already discussed, this will lead to more precise estimates of parameter values than is possible if a subset of the data is considered. We will also examine a situation where one site behaves differently to the others, in a way that is not consistent with the conditional relationships proposed.

However, it is not essential that the data be considered together. For the dataset described above, we present results for analyses conducted at the site level (i.e. the simple regressions, although conducted as Bayesian analyses), together with analyses of increasing levels of hierarchies. At the reach level, data from two sites are considered simultaneously, along with the riparian condition covariate. At the river level, data from four sites from each of two reaches are considered simultaneously along with the riparian and elevation covariates. All of the results discussed, however, relate to responses at the site level. The only difference between the analyses is that in the increasingly hierarchical models, the prior distribution for each site-level parameter is informed by data from more and more sites. For the simplest analyses, we are conducting regressions with three data points. This will obviously result in low-powered tests. Thus it is desirable to consider at least multiple sites in the same reach to improve inferential strength.

The models described above were written and run in WinBUGS 1.4.1 software using made up data. We present results for two parameters of interest. The first is the predicted density of shoots of species X, given 100% delivery of recommended ‘bench inundating flows’. This parameter facilitates comparison of the flow–germination relationship between sites that are exposed to different levels of flow augmentation. As a continuous parameter, this result is presented along with the 95% credible interval for parameter values. The second parameter is the probability associated with the hypothesis test of ‘benefit of flow on germination’ – simply what is the probability that more bench inundating flows will lead to more germination, given the data at hand? A high probability (near 1) indicates strong support for the stated hypothesis. A low probability (near 0) indicates support for the opposite hypothesis, rather than the absence of an effect. Thus a probability of 0.1 would indicate that flows are leading to reduced recruitment. A probability near 0.5 supports the absence of an effect – the null hypothesis. In the hierarchical models, only the slope
parameters of the regression were modelled hierarchically. The intercept parameters were calculated separately for each site/reach/river. This was an arbitrary decision, and is open to challenge in the future. There are no hard and fast rules about how such models should be created. All continuous means were assigned vague normal prior probability distributions, and precision parameters were assigned vague gamma distributions.

The data used in the analysis are reproduced here (Table 17). Riparian condition was assumed constant over the three years (maybe a poor assumption), and elevation was assumed equal for the two sites in each reach (probably more defensible).

<table>
<thead>
<tr>
<th>Flow</th>
<th>Germ</th>
<th>Rip</th>
<th>Elev</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>29</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>40</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>0.3</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>25</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>38</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>41</td>
<td></td>
<td>200</td>
</tr>
<tr>
<td>0.5</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>62</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>27</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>40</td>
<td></td>
<td>170</td>
</tr>
<tr>
<td>0.7</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>12</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>38</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>41</td>
<td></td>
<td>190</td>
</tr>
<tr>
<td>0.5</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>65</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>67</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results for the 2 parameters are presented graphically on the following pages (Figs 8 and 9). The effect on the median predicted shoot density at 100% flow recommendations is very small. It is worth noting however, that if more than two sites had been included for each reach, or more than two reaches for each river, the effect may have been greater if there were any non-linearities in the covariate relationships. As discussed above, omitting the covariates would also have drawn the means for various sites closer together, but his would probably be an inappropriate model structure. More noticeable is the effect of the hierarchical analysis on parameter uncertainty. The 95% credible intervals are
Figure 8. Median and 95% credible intervals for the predicted number of germinations at each site when the full environmental flow recommendations are met as calculated by site-level analysis, and reach-, river- and ‘state’-level hierarchical analyses.
Figure 9. Probabilities for the hypothesis test of ‘beneficial effects of flow augmentation on germination rate’ for each site as calculated by site-level analysis, and reach-, river- and ‘state’-level hierarchical analyses.
smaller for the analyses conducted at greater hierarchical levels, although the difference is greatest between the site-level versus reach-level analyses.

Unsurprisingly, the effect of this increased precision is that the hypothesis test is more strongly supported in the hierarchical analyses. There is one exception to this, for site 7. Although there was no attempt to make it as such, the data for this site may not support the covariate models as well as that for other sites.

Data with an ‘odd’ site

The hierarchical analysis works very well for the above data, where the same general relationship is seen at all sites, and where the effects of riparian vegetation is constant between sites, and that of elevation is constant between reaches. What if the data for one site are very different to all others?

We altered the data for site seven such that a decline in germination is observed with increased flow, despite good riparian condition upstream. The new data are shown below (Table 18). This contradicts results for all other sites. Perhaps in this case, the flow leads to erosion of benches, and thus loss of propagules. If such information was known, it may be able to be factored into the larger model, but if we are ignorant of such effects, we may seek to analyse the data along with the others, using an inadequate model.

Table 18. Data for site 7

<table>
<thead>
<tr>
<th>Flow</th>
<th>Germ</th>
<th>Rip</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>38</td>
<td>0.6</td>
</tr>
<tr>
<td>0.8</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>34</td>
<td>1.0</td>
</tr>
<tr>
<td>0.8</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

We explore the effects (Table 19) of including this analogous site on the same two variables from the full hierarchical model.

Table 19. Site level analysis of new site 7 data

<table>
<thead>
<tr>
<th>Flow</th>
<th>Germ</th>
<th>Rip</th>
<th>Original hierarchical results</th>
<th>Results with new site 7 data</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5th %</td>
<td>Median</td>
<td>97.5th %</td>
<td>Pr(benefit)</td>
<td>2.5th %</td>
</tr>
<tr>
<td>20.7</td>
<td>40.7</td>
<td>61.3</td>
<td>0.91</td>
<td>20.1</td>
</tr>
<tr>
<td>2.8</td>
<td>35.6</td>
<td>66.4</td>
<td>0.90</td>
<td>1.9</td>
</tr>
<tr>
<td>35.3</td>
<td>44.2</td>
<td>53.2</td>
<td>0.95</td>
<td>36.2</td>
</tr>
<tr>
<td>45.7</td>
<td>71.3</td>
<td>95.7</td>
<td>0.94</td>
<td>44.4</td>
</tr>
<tr>
<td>28.1</td>
<td>41.7</td>
<td>54.8</td>
<td>0.97</td>
<td>15.1</td>
</tr>
<tr>
<td>22.1</td>
<td>29.5</td>
<td>39.1</td>
<td>0.99</td>
<td>21.1</td>
</tr>
<tr>
<td>18.7</td>
<td>44.7</td>
<td>63.2</td>
<td>0.86</td>
<td>5.6</td>
</tr>
<tr>
<td>40.8</td>
<td>74.3</td>
<td>116.7</td>
<td>0.93</td>
<td>14.6</td>
</tr>
</tbody>
</table>

-13.14 19.01 51.00 0.01
It is apparent that the change in data has affected the results from other sites, but in general only by a small amount. The median number of shoots predicted is virtually unaffected by the change in site 7 data, except for site 8, where the dependency among sites within reaches means that the expected shoot number is decreased by approximately 5. The probabilities are similarly affected; the conclusion for site 5 is also somewhat weaker than it was with the original data. For the sites where probability has changed, it is noticeable that the credible intervals are wider. The sites from river 1 (1–4) are virtually unaffected by the change in data for site 7. Comparing the hierarchical result for the new data set to a site-level analysis of the new data shows that the median is again only slightly affected by the data from other sites, but that the probability has been ‘dragged’ towards that for the other sites within the hierarchical analysis.

With only two sites per reach, the effects of one ‘bad’ site will be exacerbated on the other site in that reach, but the other sites in the analysis will be less affected. If there were more than two sites, the effects would be noticeable on more sites, but these effects would be smaller.

**Practical Implementation**

The examples above make a relatively strong argument for the use of hierarchical models. Indeed, it seems impossible to avoid some form of hierarchical model unless we commit to only analysing data from the same site within a single analysis. However we do not advocate the blind use of large-scale hierarchical models in situations where they may be inappropriate. For instance, the reaction to a given environmental flow regime in say, the Wimmera River, may be very different to that observed in the Thomson, and we may not be able to explain these differences by the use of covariates in statistical models (i.e. the rivers are just different, and we don’t know why). In such a case, we should not analyse the data together in the same model, and would negatively impact on quality of inference for both rivers. Similarly, if two rivers are experiencing vastly different flow augmentation programs, and we cannot logically express the differences within the model, their results should be analysed separately. These types of difference should become apparent during exploratory data analysis, and the appropriate models chosen. All statistical models should only be used when the data fit the assumptions of the model, and the use of an inappropriate model is not confined to Bayesian analyses. Bayesian models do allow us, however, to conduct posterior predictive checks to determine whether the data are consistent with the model. Such tests should always be carried out to determine the validity of any inference.

**Conclusions**

This analysis has demonstrated that the main advantage of a hierarchical analysis is the increased precision with which site-level parameters may be estimated. Because the hierarchy exists at many levels (reach, river, state) it is not the case, as perhaps previously implied, that data must be analysed at a state-wide level to take advantage of this analysis framework. However, the
more analyses that can be done at this level, the stronger the inference, and commonality of monitoring programs, where practical, should still be sought so that this option is available when data are analysed. The ‘odd’ site example shows that results from other sites can be affected by a site that behaves very differently, but that the effects are probably not that serious. In any case, if we noted that one site was behaving very differently to all others in preliminary data examinations, we would probably seek an explanation that could be built into a large scale model or analyse that site’s data separately.