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CRC Freshwater Ecology and CRC Catchment Hydrology

Technical Report 01/2003

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Technical Report 01/2003

The Cooperative Research Centre for Freshwater Ecology is a national research centre specialising in river and wetland ecology. The CRC for Freshwater Ecology provides the ecological knowledge needed to help manage the rivers in a sustainable way. The CRC was established in 1993 under the Australian Government's Cooperative Research Centre Program and is a joint venture between:

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Executive Summary

The Murray-Darling Basin Commission is investigating the return of environmental flows to the River Murray System via the 'Living Murray' initiative. This is being done by examining the ecological, social and economic implications of delivering three reference point volumes to the Murray River: 350, 750 and 1500GL per year on average. The Commission is to report its findings so that the Murray-Darling Basin Ministerial Council can consider the reference points at its meeting in November 2003. The Goulburn and Murrumbidgee Rivers are also being considered in the Living Murray initiative, as they are likely to be important contributors of water should the reference point flows, or similar, be adopted in the future.

The Department of Sustainability and Environment (DSE) appointed the Cooperative Research Centre for Freshwater Ecology (CRCFE) and the Cooperative Research Centre for Catchment Hydrology (CRCCH) to convene and manage a Scientific Panel to identify the flows necessary to maintain or improve key environmental values in the regulated section of the Goulburn River, which lies between Lake Eildon and the River Murray. The Scientific Panel also considered which of its recommendations could be achieved with the Goulburn River's likely contribution to the Living Murray reference volumes, being an increase in flows to the Murray of 70 GL, 150 GL and 300 GL per year on average. Social and economic issues related to the Goulburn Rivers' Living Murray contributions will be considered in a separate process, but will be informed by the findings of the Scientific Panel.

The work of the Scientific Panel has been conducted and reported as a 2-stage process, consistent with the FLOWS methodology developed by Victoria for assessing environmental water requirements for rivers and streams. The first stage included investigations of current riverine condition and identification of flow-related ecological issues and objectives that would be the focus of environmental flow recommendations (presented as Appendix 1 of this report). This report presents the findings of Stage 2 of the FLOWS method, which is the development of environmental flow recommendations to meet the ecological objectives identified in Stage 1. Land and water management activities that will complement environmental flow recommendations are also presented.

The project study area includes the Goulburn River and its associated floodplain, downstream from Lake Eildon to the confluence of the River Murray. The river receives releases from Lake Eildon and inflows from tributaries such as the Acheron, Yea, and Broken Rivers (the latter including water from Lake Mokoan), and numerous creeks. The following reaches have been identified for the purposes of this study:

- Reach 1: Lake Eildon to Molesworth
- Reach 2: Molesworth to Seymour
- Reach 3: Seymour to Nagambie
- Reach 4: Nagambie to Loch Garry
- Reach 5: Loch Garry to the River Murray.

In summary, the Scientific Panel considered the following *potential* flow-related risks as it developed environmental flow recommendations for the Goulburn River (see Appendix 1):

- The infilling of armoured riverbed gravels with fine sediments, which can reduce the diversity of habitat available for some invertebrates and fish (Reach 1);
- The seasonal inversion of the flow regime due to high summer-autumn releases (Reaches 1-3), resulting in:

  - High water velocity during summer-autumn (Reach 1); this can limit the growth of submerged and emergent in-channel macrophytes and limit the recruitment of juvenile fish;
  - Constant high water levels during summer-autumn that effectively reduce the riffle habitat available for some invertebrates and fish;
  - Constant high water levels during summer-autumn that inundate river bars and benches, potentially disrupting biochemical processes such as the cycling of carbon and nutrients that contribute to processes such as production and respiration;
  - Constant high water levels during summer-autumn that reduces the availability of shallow-water habitat (less than 0.3m depth) favoured by some in-channel macrophytes and small fish.
- Reduced frequency or duration of out-of-channel flows that inundate the floodplain and fill wetlands (Reaches 1-4);
- Reduced duration of freshes that can serve as life-cycle cues for fish and invertebrates, provide a range of conditions for in-channel and littoral (bank-side) vegetation, mobilise fine particulate material that can smother submerged macrophytes and invertebrate habitat, and help maintain good water quality (Reaches 4 and 5);
- Reduced duration of flows that inundate river benches, potentially disrupting biochemical processes such as carbon and nutrient cycling (Reaches 4 and 5);
- Reduced availability of deep water habitat that helps to support native fish populations (Reaches 4 and 5);
- Lows flows (depth less than 0.2m) that prohibit the movement of native fish along the river (all reaches);
- Low summer-autumn flows that can potentially contribute to water stratification and a decline in water quality (Reach 4 and 5);
- Higher rates of rise and fall in flow pulses associated with operation of Lake Eildon and Goulburn Weir that increase the risk of stranding or washout of biota such as invertebrates and fish (all reaches). Pulses resulting from hydro-electricity generation at Eildon provide a further risk to biota in Reach 1.

Following detailed analysis of flow and hydraulic data, a number of potential issues were found to pose little risk to the ecological condition of the Goulburn River. These included low flows impeding fish movement or contributing to water stratification and deteriorating water quality, and the potential for reduced frequency and duration of freshes that help maintain water quality and serve as life-cycle cues for fish.

The Scientific Panel has identified a number of changes to the current flow regime that could improve or safeguard the ecological condition of the Goulburn River. It is emphasised that the social and economic implications of these recommendations have yet to be considered. Balancing ecological and environmental, social and economic outcomes is to occur as part of the wider Living Murray initiative. Changes to the flow regime of the Goulburn River range from relatively minor interventions (e.g. increase to minimum flows in a particular reach) to combinations of recommendations that address a number of flow related issues along the length of the river, including:

- The provision of an annual inundation event to address the issue of reduced floodplain/wetland wetting frequency (All Reaches);
- Increased minimum flows to maintain the availability of deep water habitat preferred by native fish (Reaches 4 and 5);

- Rules for the rates of rise and fall in river water levels in order to avoid washout or stranding of biota such as juvenile fish and macroinvertebrates (Reaches 1-4).

The Scientific Panel was also concerned that the ecological condition and functioning of the Goulburn River is likely to have been impacted by the release of high volumes of irrigation water during summer-autumn (i.e. a seasonal inversion of the flow regime in Reaches 1-3), and reduced duration of river bench inundation in Reach 4 in spring and summer. The Panel has adopted a precautionary approach, and has recommended changes to the summer flow regime that will improve natural ecological function, based on current understanding of the system. These recommendations, if adopted, would place an upper limit on flows from Lake Eildon of between 1,000-3,000 ML/d. The additional volume delivered to the Murray River if these limits were adopted would be in the order of 350-700 GL, well in excess of the indicative Living Murray reference volumes. The Scientific Panel recognises that adoption of such upper limits on summer flows would be highly contentious from a social and economic viewpoint. However, the Panel chose to identify changes to the summer flow regimes that would be ecologically beneficial, independently of their socio-economic cost. By identifying the 'environmental' components needed, the Panel hopes to inform future benefit/cost assessments of summer releases, as potential risks to the ecological function of the river (e.g. processes such as primary productivity) and changes to the community structure and biodiversity of aquatic biota are acknowledged.

Additional investigations are recommended to better quantify the importance of factors, such as changes to ecological processes and plant and animal community structure, potentially affected by seasonal flow inversion. Studies of the effect of increased duration of river bench inundation on processes such as carbon processing and rates of productivity are also recommended. This additional information will provide valuable insights that will help refine environmental flow recommendations and benefit/cost analyses in the future.

Getting agreement on the ultimate package of flow recommendations to be adopted for the Goulburn River will be the result of communication and negotiations undertaken during the Living Murray initiative and beyond. To assist these negotiations, the Scientific Panel has assigned the following priority (highest to lowest) to the implementation of its recommendations:

1. Provision of an annual floodplain/wetland inundation event of varying magnitude (all Reaches);
2. Provision of deep water habitat for fish (Reaches 4 and 5);
3. Applying upper limits to summer-autumn flows (Reaches 1-3);
4. Experimental increase to the duration of bench inundation (Reach 4);
5. Ensure that rates of rise and fall in river levels are within the natural range (Reaches 1 and 4).

Preliminary modelling estimates suggest that:

- The Goulburn’s likely contribution to the first Living Murray reference volume (70 GL) can easily meet minimum deep-water habitat requirements in Reaches 4 and 5 (which result in an increase in flow to the Murray of 56 GL per year on average);
- The Goulburn’s likely contribution to the second Living Murray reference volume (150 GL) can easily meet minimum deep-water habitat requirements and support an

experimental increase to the duration of bench inundation events in Reach 4 (which result in an increase in flow to the Murray of 115 GL per year on average);
- The Goulburn's likely contribution to the third Living Murray reference volume (300 GL) can easily provide the package of annual floodplain/wetland inundation, maintenance of minimum deep-water habitat and (experimental) extended duration of bench inundation in spring (which result in an increase in flow to the Murray of 220 GL per year on average).

Investigation to refine how the environmental flow recommendations are delivered (particularly how the annual floodplain/wetland inundation is achieved) is likely to identify savings on these preliminary estimates. For example, through piggy-backing environmental releases on floods arising in the tributaries, it may be possible that a package of recommendations that includes an annual flood, minimum flows in Reaches 4 and 5, experimental increase in bench inundation duration and care with rates of rise and fall, can be delivered with significantly less increase in flows to the Murray than the preliminary estimate of 192 GL per year and closer to the second Living Murray reference volume of 150 GL per year.

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The Project Steering Committee:

Pat Feehan	Goulburn Murray Water
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Paulo Lay	Department Sustainability and Environment
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Gordon O'Brien	Goulburn Broken Catchment Management Authority
Tom O'Dwyer	Goulburn Broken Catchment Management Authority
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Ian Park	Landholder
Ross Pogue	Landholder
Hugh Robertson	Deakin University
Wayne Tennant	Goulburn Broken Catchment Management Authority
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1 INTRODUCTION

The Murray-Darling Basin Ministerial Council has directed the Murray-Darling Basin Commission to investigate the return of environmental flows to the River Murray system. This is being done using three reference points: 350, 750 and 1500GL per year additional flow per year for the environment (MDBMC 2002). Council will consider information produced for these reference points in November 2003. The Commission has in turn established '*the Living Murray'* initiative to consider the ecological, social and economic implications of the three reference points for eight river regions along the Murray and lower Darling system. The Goulburn and Murrumbidgee Rivers are also being considered in the Living Murray initiative, as they are likely to be major contributors of water should the reference point flows, or similar, be adopted in the future.

The Goulburn River is the largest Victorian tributary to the Murray system. The contribution required from the Goulburn River in meeting the reference point flows is not yet known. Interim coarse estimates can be based on Cap volumes, which suggest that contributions of 70, 150 and 300GL may be required from the Goulburn System (P. Lay, DSE, pers. comm.). However, the implications of delivering these reference points for the ecology and condition of the Goulburn River are not clear. Thus, an environmental flows study of the Goulburn River is recognised as an important step toward understanding the environmental needs of this major tributary. The output of such a study will be an important factor when opportunities for securing additional flows for the River Murray are considered by the Living Murray initiative.

The Department of Sustainability and Environment (DSE) approached the Cooperative Research Centre for Freshwater Ecology (CRCFE) and the Cooperative Research Centre for Catchment Hydrology (CRCCH) to convene and manage a Scientific Panel to identify the flows necessary to maintain or improve key ecological and environmental values in the regulated section of the Goulburn River, which lies between Lake Eildon and the River Murray. Social and economic issues related to the Goulburn Rivers' Living Murray contributions will be considered in a separate process, but will be informed by the findings of the Scientific Panel.

1.1 Purpose

The Goulburn Scientific Panel undertook the following tasks (listed below) when developing environmental flow recommendations for the Goulburn River. The tasks were consistent with the 2-stage FLOWS process (DNRE 2002a) developed to assist environmental flow studies in Victoria:

Stage 1:

1) Collate and assess relevant information and data on the condition of the Goulburn River.
2) Undertake a field assessment to confirm environmental/ecological values associated with the river system and support the development of flow-related ecological objectives.
3) Develop an issues paper to identify and establish objectives for the key environmental values/assets of the Goulburn River and their likely flow requirements.

Stage 2:

4) Determine an environmental flow regime to sustain the Goulburn River in an ecologically healthy condition, consistent with the Victorian River Health Strategy, the Goulburn

Broken Regional Strategy and the FLOWS method developed for setting environmental flows in Victorian streams (DNRE 2002b).

5) Describe how the water would be used, in terms of a flow regime, to enhance the environmental values of the Goulburn River on a priority basis for each of the following scenarios:
   - Current situation (includes Bulk Entitlement (BE) provision of 80GL[1] and 30GL for flooding and water quality, respectively)
   - BE requirement plus an average annual increase of 70GL from the Goulburn into the Murray (as measured at McCoy's bridge);
   - BE requirement plus 150GL extra flow from the Goulburn into the Murray;
   - BE requirement plus 300GL extra flow from the Goulburn into the Murray.
6) Recommend other management actions that are required to sustain the key environmental values/assets of the Goulburn River.

Advice on social and economic issues related to an environmental flow regime for the Goulburn River and the provision of water as part of the Living Murray initiative will be undertaken as a separate exercise. This will be coordinated by the Goulburn-Broken Catchment Management Authority using the 'RIVAS' (Heron Environmental Consulting & As One Consulting 2003) decision support tool, under the auspices of the Living Murray initiative.

This report addresses milestones related to tasks 4, 5 and 6 listed above. Information collated during Tasks 1, 2 and 3 is reported in the Issues Paper (Appendix 1) prepared by the Scientific Panel during Stage 1 of the project. This report summarises the key flow-related ecological objectives identified in the Issues Paper and presents environmental flow recommendations that, when implemented, will protect or enhance ecological values associated with the Goulburn River below Lake Eildon. Complementary land and water management activities are also outlined, that will help to maximise the benefits expected with the recommended environmental flow regime.

[1] Note that conditions required to trigger the release of the 80 GL have not occurred since these rules were agreed in the BE process (see Appendix 1)

2 APPROACH

2.1 Study Area

The project study area includes the Goulburn River, including its floodplain and distributary channels, downstream from Lake Eildon to the confluence of the River Murray (Figure 2). The river receives releases from Lake Eildon and inflows from tributaries such as the Acheron, Yea, and numerous creeks in its upper reaches, but mainly from the Broken Rivers (the latter including water from Lake Mokoan) in its lowland reaches. Specific environmental flow recommendations for the tributaries have not been developed, as they will be considered through other processes (e.g. Broken River Bulk Water Entitlement process, current investigations on the future of Lake Mokoan, and streamflow management plans). The Scientific Panel considered the implications of current recommendations for tributary streams as environmental flow recommendations were developed for the Goulburn River.

The environmental flow requirements of the Goulburn River system were assessed for the following reaches (see Appendix 2 for information on reach selection):

- Reach 1: Lake Eildon to Molesworth
- Reach 2: Molesworth to Seymour
- Reach 3: Seymour to Nagambie
- Reach 4: Nagambie to Loch Garry
- Reach 5: Loch Garry to the River Murray.

2.2 FLOWS method

The FLOWS method (DNRE 2002a, Figure 3) was developed in Victoria to assess the environmental flow requirements of rivers and streams when setting streamflow management plans or bulk entitlements. FLOWS is based on the natural flow paradigm, which suggests that different parts of the flow regime have different ecological function (Poff *et al*. 1996, Richter *et al*. 1997), and examines changes to components of the flow regime in order to arrive at recommendations (Figure 1).

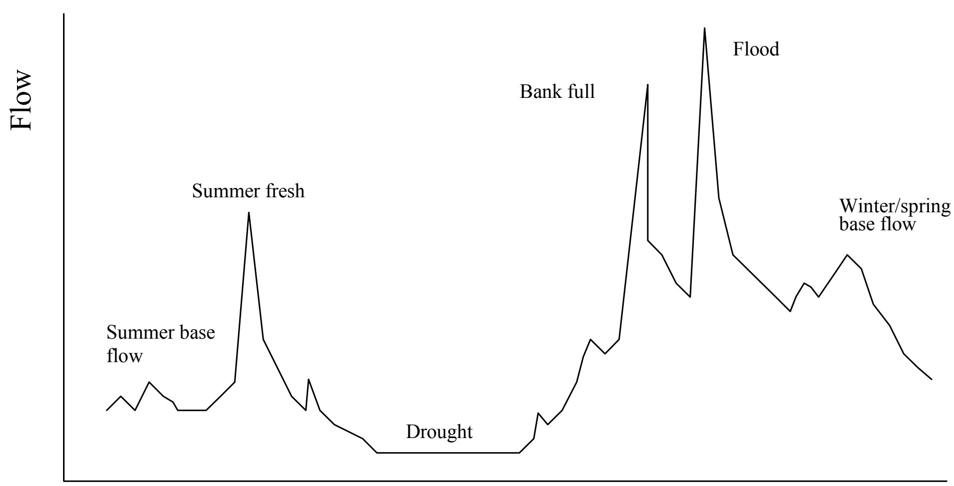


Figure 1: Time series showing different components of a natural flow regime

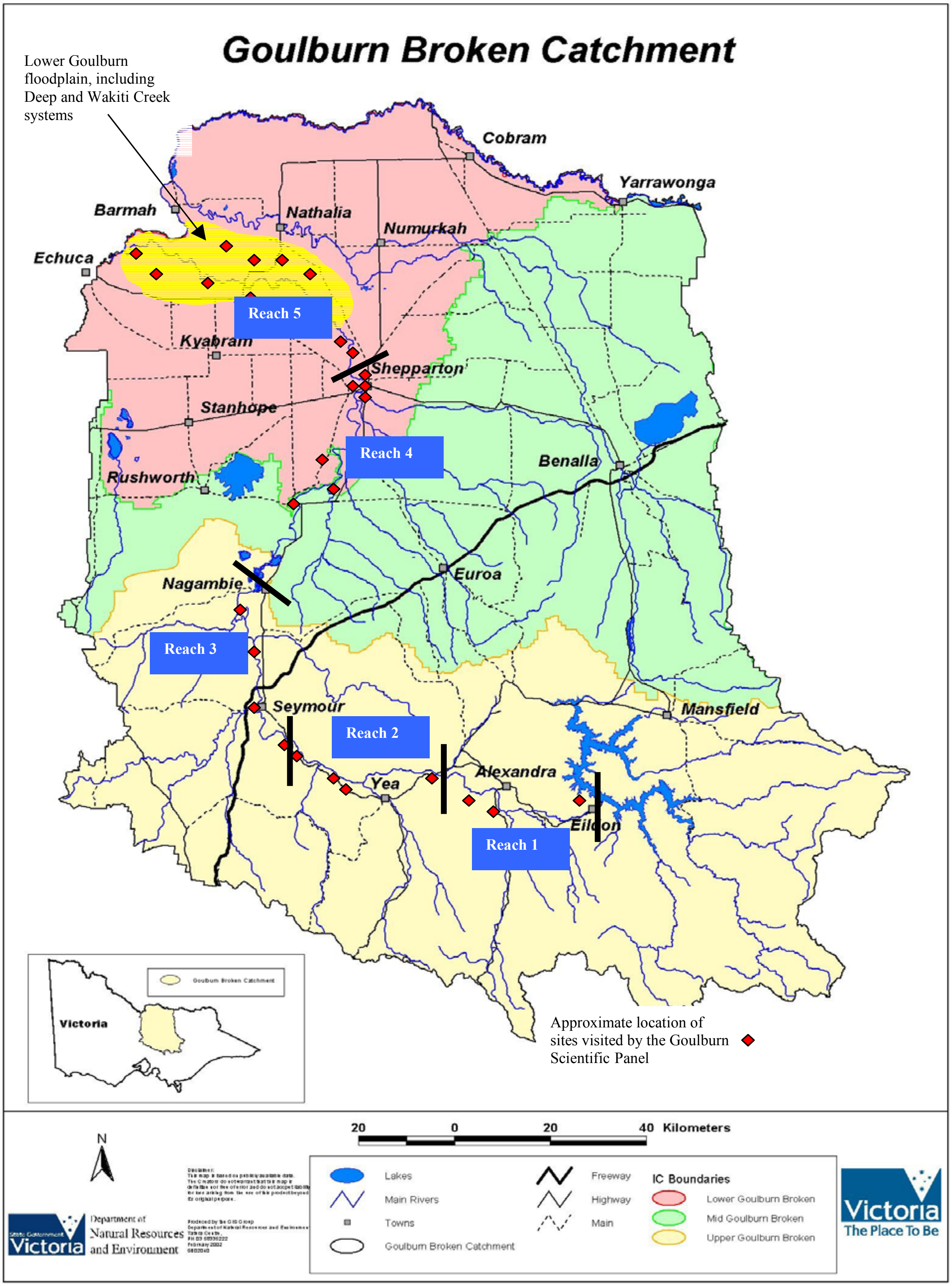


Figure 2: Map of the Goulburn catchment (courtesy DSE) including study area and locations visited by the Goulburn Scientific Panel.

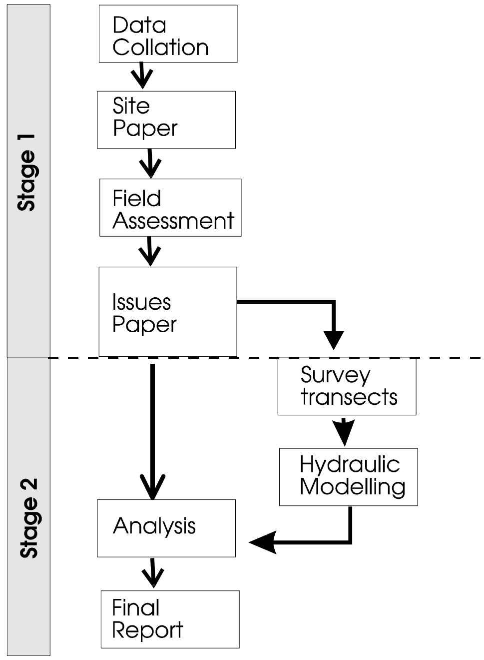


Figure 3: Outline of the FLOWS method (from DNRE 2002a). Note that the survey transects normally undertaken in Stage 2 were completed as part of Stage 1 of this project due to the timing of irrigation releases from Lake Eildon.

This study generally followed the FLOWS method, although with modifications related to (i) the timing of the project and (ii) the use of the eco-hydrological analytical tool Flow Events Method (FEM). The scope of the project was first considered in August 2002, which was at the beginning of the irrigation season. It was recognised that increased stream flow with the release of irrigation water from Lake Eildon would complicate the survey of channel dimensions that is necessary for constructing a hydraulic model of representative river sites. Survey work that would normally be performed in Stage 2 of the FLOWS method was therefore brought forward to the beginning of the project.

Secondly, while the FLOWS method provides a framework to arrive at environmental flow recommendations, the rationale for the recommendations is left to those applying the method, usually a technical or scientific panel. In this study, the Scientific Panel applied the FEM developed by the CRC for Catchment Hydrology (Stewardson 2001) to supplement the FLOWS method. FEM is a framework that facilitates the analyses of key flow events by comparing the current flow regime to natural. FEM was used successfully for the Bulk Water Entitlement (BE) process in the Broken River (Stewardson and Cottingham 2002) and the Loddon River (Loddon River Environmental Flows Scientific Panel 2002). FEM is described in more detail in Chapter 2.3.

A key feature of the FLOWS method is the consideration of different (generic) components of a flow regime that are likely to be ecologically important:

- Cease to flow – periods where no flow is recorded in the river channel, which can lead to partial or complete drying of the riverbed. During these periods, the river can contract to a series of pools that act as a refuge for in-stream biota.

- Low flows – the low flow that generally provides a continuous flow through the channel. The flow may be limited to a narrow area of the channel in the upper reaches of a stream, but will provide flow connectivity between habitats within the channel.
- Freshes – are small and short duration flow events that exceed the baseflow of the previous few days (e.g. following summer rainfall events). These are important to refresh water quality in pools after periods of low flow or cease to flow and to move silt from productive substrates. In this study, freshes were defined as flow pulses greater than 1 standard deviation of the preceding average base flow.
- High Flows (in-channel) – persistent increase in baseflow that occurs with the onset of the wet season. These are flows that cover the bed and some low in-channel benches. This allows full connection between all habitats in the river, important for fish passage during migration.
- Bankfull flows – flows that fill the channel, but do not spill onto the floodplain. They have mainly geomorphologic functions, such as maintaining the channel shape and form, and preventing in-filling of pools. The impact of river regulation practices, such as storing water over the high flow season, is mainly to reduce the frequency of these flows.
- Overbank flows – exceed the bankfull flow and spill out of the channel onto the floodplain. These are ecologically important for wetlands, and for bringing food (either carbon dissolved from the floodplain floor, or in the form of leaves and twigs) to the stream channel. The rising limb of an overbank flow represents the 'commence to flow' for floodplain features such as wetlands. On the receding limb, the bankfull level represent a 'cease to flow' for floodplain features.

These definitions were used in this study and refined where necessary to facilitate data analysis. Thus freshes were specifically defined (Chapter 4.4) as pulses greater than 1 standard deviation from mean base flow.

2.3 FEM method

FEM was used to estimate the frequency of ecologically significant flow events under regulated and modelled natural flow conditions. The word 'event' refers to a particular set or suite of hydrologic or hydraulic conditions, equivalent to the flow components in FLOWS (above) but identified as significant for the study reach or river after consideration as ecologically significant; thus in contrast to FLOWS, there is no *a priori* set of events in FEM.

FEM comprises of two steps: (1) the derivation of "rating curves" to relate flow events to flow magnitude and (2) the analysis of the flow histories at each site.

2.3.1 Rating curves

Rating curves describe the relationship between an ecologically significant flow event (for example bench inundation) and flow rate. The flow events are defined in terms of specific criteria that can be described in a spreadsheet, such as "*areas of a bench inundated with a depth greater than 0.1m*".

The rating curves are derived using the relationship between flow rate and stage. This is established using the hydraulic model HEC-RAS and using cross-section survey data from each of the five sites (one site representative of each study reach). Steady-state flow simulations were run for a range of flow rates from 0.015 m^3/sec (1.3 ML/d) to 590 m^3/sec (51,000 ML/d). In the FEM spreadsheet the river stage at each flow rate and each cross-section was used to calculate the cross-sectional area, mean velocity and other event parameters. From this information the rating curves were generated.

2.3.2 Event analysis

The event analysis is used to determine the frequency and magnitude of ecologically important flow events under regulated and simulated natural flow conditions. The regulated and simulated natural flow records are transformed into records of events using the rating curves. The event record is then analysed using techniques analogous to hydrological analysis techniques.

The most frequently used analysis is the "Range of Values" graph, which is analogous to a flow duration curve. This graph (an example is shown in Figure 4) shows the percentage of time that an event or particular hydrologic set of conditions is exceeded or not exceeded (depending on how the event criteria is defined). Usually this is done for different flow regimes with several years data, such as 'modelled natural' and 'recorded' (in this case, recorded is equivalent to regulated, because recorded data roughly corresponds to the period of regulation for the Goulburn River).

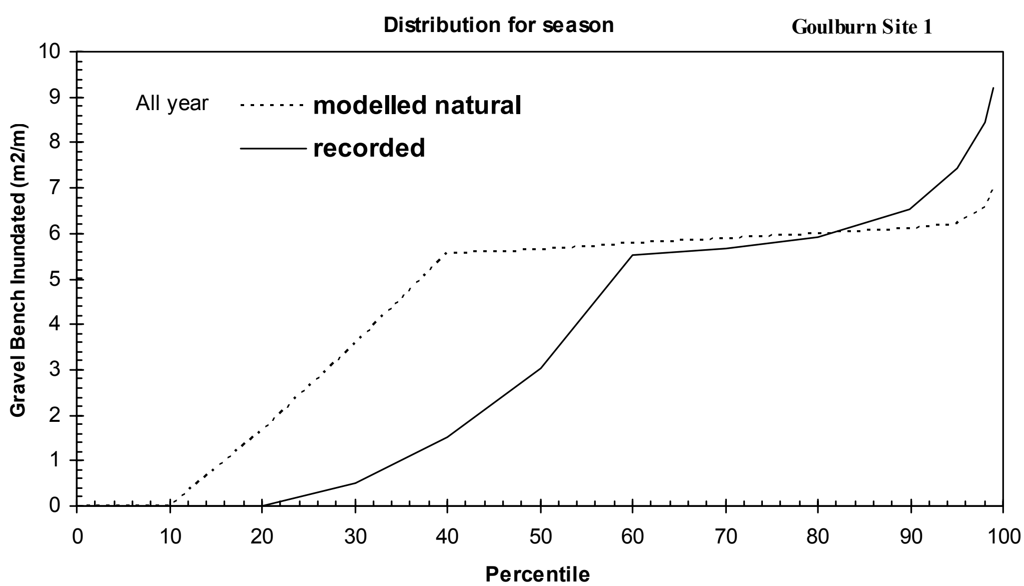


Figure 4: Bench inundation in Reach 1

Figure 4 shows the percentage of time that an area of bench is inundated. For instance, under regulated flows, up to 3 m^2/m of bench area is inundated for approximately 50% of the time, compared with 25% of the time naturally. This type of plot can be generated using all the flow data, or can be restricted to a specific time such as a season.

The "Monthly Percentiles" plots (Figure 5) are generated in the same way as the Range of Values plots, but using flow data on a month by month basis. The columns show the median value for each month (50th percentile) and the whiskers show the 10th and 90th percentile (i.e. 80% of the data fall between the two whiskers).

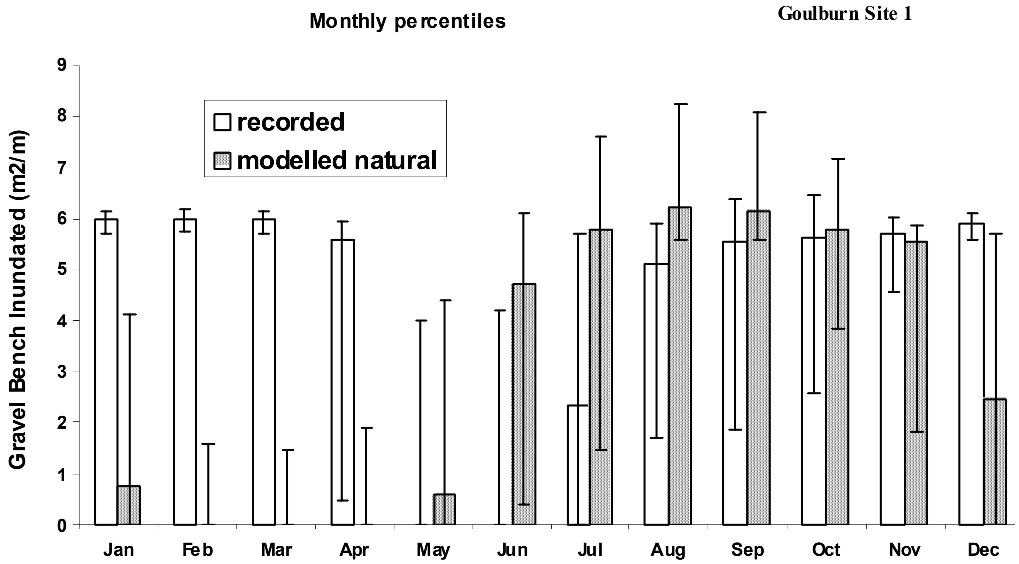


Figure 5: **Percentile plots: monthly summer-autumn bench inundation in Reach 1. Columns show median values and whiskers represent 10th and 90th percentile values**

The Range of Values and Monthly Percentiles are useful for showing the range of values but are not as useful for showing the frequency of the extreme events. "Frequency Analysis" plots are generated in those cases where the extreme events are of interest. This analysis is analogous to partial flood series analysis. These plots show the average return interval (ARI) for events of a particular magnitude. Figure 6 shows the return period for the duration of 'fast water' events in summer. This shows that events that have high water velocity and persist for 20-30 days would have occurred about once every 10 years naturally, but occur almost every year under regulated conditions.

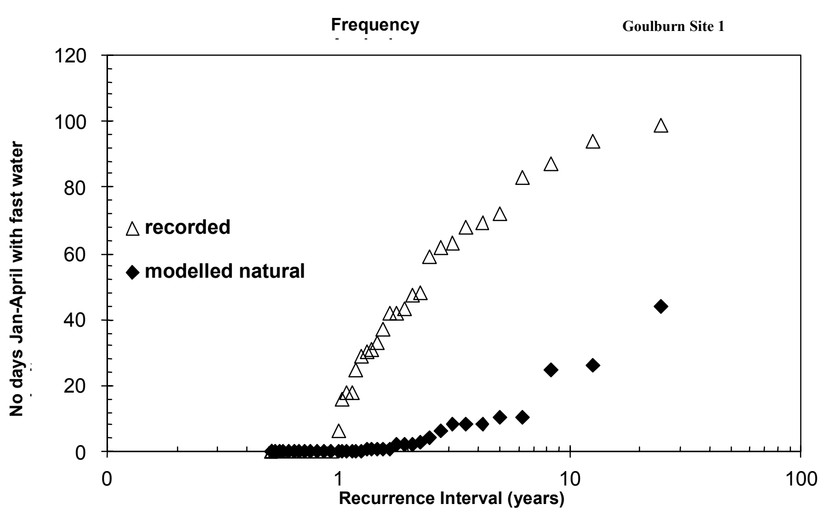


Figure 6: **Comparison of 'fast water' (velocity greater than 0.6 m/s) in summer-autumn for Reach 1.**

2.4 Flow data

For this study, the Scientific Panel used daily flow series for the modelled natural and recorded (current) flow regime for the period 1975-2000 (Appendix 7) to assess the current flow regime and make environmental flow recommedations. The modelled natural flow regime was defined as the daily flow series that would occur in the absence of any impoundments or diversions along the Goulburn River and its major tributaries. For this study, the effects of other historical changes within the catchment such as construction of farm dams, clearing and forestry operations are not accounted for. Flow records for the period 1975-2000 included extreme events such as drought (e.g. 1982/83) and floods (e.g. 1993), and so account for much of the climatic variability expected across the study area.

Once the Scientific Panel had agreed the environment flow recommendations, the REALM hydrological model for the Goulburn River System (GSM) was used to assess the long-term implications of the recommendations. The GSM is a monthly model which simulates as closely as possible the operation of the Goulburn River System under any given set of conditions through the historic sequence of climate for which information is available (112 years, from 1891-2002). Each 'model run' operates the river under a fully described set of conditions to see what would have happened through the historic sequence. The GSM was initially constructed to assess water delivery for the Goulburn system (DCNR 1995) but has been adapted for this project to assess the environmental flow recommendations. In particular, it was used to provide indicative monthly volumes of water delivered to representative reaches of the Goulburn River, and ultimately the Murray River, as a result of environmental flow recommendations, as well as an indication of the decrease in volumes that would be diverted.

3 FLOW-RELATED ISSUES AND ENVIRONMENTAL FLOW OBJECTIVES

3.1 General approach

The Scientific Panel considered a number of flow-related issues that potentially pose a risk to the environmental and ecological values of the Goulburn River (Table 1 to Table 6). These issues and potential ecological objectives are related to changes to the hydrology, geomorphology, vegetation, macroinvertebrate, fish and water quality attributes of the Goulburn River and, along with flow-related ecological objectives, are described in more detail in the Issues Paper (Appendix 1). These objectives are considered further in Chapter 4 where the flows required for each ecological objective are identified. Note that not all of the flow-related objectives can be sensibly satisfied through changes to river flows. In making its recommendations, the Scientific Panel recognises that the Goulburn is a working river (reference), with a long 'working' history and considerable socio-economic importance. The vision of the Goulburn River used by the Scientific Panel as the basis for its deliberations is given at the start of Chapter 4.

Flow recommendations are given in ecological terms, rather than as operational specifications. Organisations such as Goulburn Murray Water (as the responsible authority) and the DSE are best placed to effect the translation of ecological advice into operational rules, especially as some hydrologic and demand modelling may be required.

3.2 Objectives and risks to the Goulburn River

In summary, the Scientific Panel considered the following flow-related perceived risks and their mitigation as the basis for developing environmental flow recommendations for the Goulburn River:

- The infilling of armoured riverbed gravels with fine sediments, which can reduce the diversity habitat available for some invertebrates and fish (Reach 1);
- The seasonal inversion of the flow regime due to high summer-autumn releases (Reaches 1-3), resulting in:
    - ➢ High water velocity during summer-autumn (Reach 1); this can limit the growth of submerged and emergent in-channel macrophytes and the recruitment of juvenile fish;
    - ➢ Constant high water levels during summer-autumn that effectively reduce the riffle habitat available for some invertebrates and fish;
    - ➢ Constant high water levels during summer-autumn that inundate river bars and benches, potentially disrupting biochemical processes such as the cycling of carbon and nutrients that contribute to processes such as production and respiration;
    - ➢ Constant high water levels during summer-autumn that reduce the availability of shallow-water habitat (less than 0.3m depth) favoured by some in-channel macrophytes and small fish.
- Reduced frequency or duration of out-of-channel (flood) flows that inundate the floodplain and fill wetlands (Reaches 1-4);
- Reduced duration of freshes that can serve as life-cycle cues for fish and invertebrates, provide a range of conditions for in-channel and littoral (bank-side) vegetation, mobilise fine particulate material that can smother submerged macrophytes and invertebrate habitat, and help maintain good water quality (Reaches 4 and 5);
- Reduced duration of flows that inundate river benches, potentially disrupting biochemical processes such as carbon and nutrient cycling (Reaches 4 and 5);

- Reduced availability of deep water habitat that helps to support native fish populations (Reaches 4 and 5);
- Lows flows (depth less than 0.2m) that prohibit the movement of native fish along the river (all reaches);
- Low summer-autumn flows that could potentially contribute to water stratification and a decline in water quality (Reach 4 and 5);
- Higher rates of rise and fall in flow pulses associated with operation of Lake Eildon and Goulburn Weir that increase the risk of stranding or washout of biota such as invertebrates and fish (all reaches). Pulses resulting from hydro-electricity generation at Eildon provide a further risk to biota in Reach 1.

3.3 Other considerations

The nature of ecological responses means that benefits of implementing these flow recommendations may take time to become apparent. In some cases, flow recommendations will only be effective if other types of management activities are also implemented. This contingent effect is discussed further in Chapter 4.11. For example, the position of off-takes in Lake Eildon can result in the release of 'cold water' during summer-autumn (Ryan *et al.* 2001). Cold water releases can affect the biology (e.g. growth rates and reproduction) of biota such as some native fish, invertebrates and in-channel macrophytes. The issue of cold water is related to the design of Eildon dam, rather than changes to the flow regime of the Goulburn River. The Scientific Panel considered the issue of cold water as a factor that could confound the intended outcome of environmental flow recommendations, rather than as an issue that required a specific environmental flow recommendation.

Table 1: Ecological features and flow components to be assessed for aquatic, riparian and wetland vegetation of the Goulburn River

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered	Complementary management required
Vegetation	In-channel	• In –channel macrophyte stands provide habitat for fauna such as fish and invertebrates and contribute to river productivity	• Fair	• Enhance the extent and diversity of aquatic vegetation • Increased contribution to processes such as river productivity	✓✓✓	• Armouring of the stream bed (Reach 1) • Cold water releases (Reaches 1-3) • Loss of shallow water areas (Reaches 1-3) • High water velocity (Reaches 1-3) • Sediment accumulation (Reaches 4-5)	• Flushes that initiate the movement of fine sediments • Summer-autumn low flows	• Amelioration of cold water released from Lake Eildon
	River bank	• Longitudinally continuous riparian vegetation, dominated by native species	• Good	• Maintain diversity • Reduce extent and impact of weeds • Maintain continuity and cover	✓	• Constant flows (all reaches)	• Variability of low flow • Variability of high flow	• Riparian rehabilitation and management • Weed control program • Controlled management of livestock access
	Wetland	• Representative and natural plant communities • Habitat and refuge for small wetland and floodplain fauna • Contribute to productivity	• Likely to be variable - poor to good	• Enhance the extent and diversity of aquatic vegetation • Increased contribution to processes such as river productivity	✓✓	• Reduced frequency, seasonality and duration of flood events (all reaches)	• Timing, frequency and duration of out of channel flows	• As above
	Floodplain matrix	• Spatial and structural diversity • Connects floodplain features • Native plant communities	• Likely to be variable - poor to good	• Enhance the extent and diversity of aquatic vegetation • Increased contribution to processes such as river productivity	✓✓	• Reduced frequency, seasonality and duration of flood events	• Timing, variability and duration of flood flows	• Best practice land management

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered	Complementary management required
Floodplain	Connectivity with channel	• Heterogeneous floodplain hydraulic characteristics	• Likely to be variable - poor to moderate	• Flood regime has all the elements of a natural floodplain, including ➢ Seasonality ➢ Frequency ➢ Duration	 ✓✓✓ ✓✓✓ ✓✓✓	• Reduced frequency, seasonality and duration of flood events	• Variability of out of channel flows	• Best practice land management • Review of levees and block banks
	Floodplain matrix	Heterogeneous floodplain mosaic	Likely to be variable - poor to moderate	• Connection of floodplain ecosystem components, including grasslands, woodlands, permanent and temporary wetlands	✓✓	• Reduced frequency, seasonality and duration of flood events	• Variability and seasonal pattern of out of channel flows	• Best practice land management • Review of levees and block banks

Table 2: Ecological features and flow components to be assessed for macroinvertebrates in Reach 1 of the Goulburn River (Lake Eildon to Molesworth)

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered	Complementary management to consider
Invertebrates: In-channel	Functional trophic relationships	• Processing of organic matter and nutrients • Source of food for fish	• Moderate Very variable. May reflect local influence of tributaries, backwaters & other inputs of organic matter	• Trophic structures more closely resembling local tributaries	✓✓✓	• Seasonal flow inversion • Bed armouring • Cold water • Less abundant aquatic and riparian vegetation • Reduced C inputs due to reduced flood frequency and extent • Changed nature of carbon from CPOM to algal-based POM plus dissolved?	• Seasonality of low flows and flushes • Frequency of flushes that initiate sediment movement • Seasonality and frequency of flooding	• Amelioration of cold water releases from Eildon • Control of introduced fish species
	Biodiversity	• Diversity of community structure	• Poor- moderate	• Ausrivas O/E scores = Band A	✓✓			
	Biomass	• Natural rates of river productivity • Source of food for fish	• Probably poor /unbalanced	• Biomass equivalent to nearby tributaries	✓✓	• As above Note also loss of carbon through settling in Lake Eildon	• As above	• As above

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered	Complementary management to consider
Invertebrates: Wetlands (No data available)	Functional trophic relationships	• Processing of organic matter & nutrients. Diverse food for fish and terrestrial vertebrates (birds, bats)	• Probably poor. Likely to be concentrated in a few groups eg midges, mosquitos, microinvertebrates	• Dynamic, diverse food webs	✓✓✓	• Disrupted wetting/drying cycle	• Seasonality and frequency of Out-of-channel flows	• Control of introduced fishes
	Biomass	• Production of food for fish & terrestrial vertebrates	• No information	• Biomass expressed in diverse organisms supporting diverse floodplain system	✓✓✓	• As above	• Seasonality and frequency of Out-of-channel flows	• Modify levees and block banks • Control stock access (pugging and grazing) • Aquatic, emergent, bank vegetation restored.

Table 3: Ecological features and flow components to be assessed for macroinvertebrates in Reach 2 and 3 of the Goulburn River (Molesworth to Nagambie)

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered	Complementary management required
Invertebrates: In-channel	Functional trophic relationships	• Processing of organic matter, nutrients and microbiota • Source of food for fish	• Reduced diversity. Few herbivores, increased omnivores (reflecting turbidity, reduced plants)	• Trophic structure and diversity more closely resembling upstream sites	✓✓✓	• Seasonal flow inversion • Cold water • Less abundant aquatic and riparian vegetation • Reduced C inputs due to reduced flood frequency and extent	• Seasonality of low flows and flushes • Short-term fluctuations to counteract turbidity & encourage plant growth • Seasonality and frequency of flooding	• Amelioration of cold water releases from Eildon • Control of introduced fish species • Aquatic, emergent and riparian vegetation and snags protected or restored
	Biodiversity	• Diversity of community structure	• Reduced (see above)	• Ausrivas O/E scores = Band A	✓✓	• As above	• As above	• Modify levees and block banks • Control stock access (pugging and grazing)
	Biomass	• Natural rates of river productivity • Source of food for fish	• Poor/ unbalanced	• Biomass equivalent to similar streams elsewhere e.g. Ovens	✓✓	• As above • Reduced productivity relating to: - altered wetting/drying cycle - interaction between turbidity and flow variation	• Seasonality and frequency of Out-of-channel flows • Short-term variability	• As above

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered	Complementary management required
In Wetlands (No data seen)	Functional trophic relationships	• Processing Org. Matter & Nutrients. • Diverse Food for fish and terrestrial vertebrates (birds, bats)	• Highly variable – depending on land use	• Dynamic food webs maintaining wetland diversity and productivity	✓✓✓	• Reduced frequency and changed seasonality of over-bank flows	• Seasonality and frequency of Out-of-channel flows	• As above
	Biodiversity	• Provide resilience and trophic support sustainability.	• As above	• Diverse, resilient communities through full range of physical conditions	✓✓✓	• As above	• As above	• As above
	Biomass	• Productivity Food for fish & terrestrials	• As above	• Biomass expressed in diverse organisms supporting diverse floodplain system	✓✓✓	• As above	• As above	• As above

Table 4: Ecological features and flow components to be assessed for macroinvertebrates in Reach 4 and 5 of the Goulburn River (Nagambie to the Murray River)

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered	Complementary management required
Invertebrates: In-channel	Functional trophic relationships	• Processing of organic matter, nutrients and microbiota • Source of food for fish	• Reduced diversity. Few herbivores, increased omnivores (reflecting turbidity, reduced plants?) and detritivores	• Trophic structure and diversity with a more balanced representation of all functional groups	✓✓✓	• Reduced winter flows • Constant summer flows • Smothering by settling material • Less abundant aquatic and riparian vegetation • Reduced C inputs due to reduced flood frequency and extent	• Seasonality of low flows and flushes • Short-term fluctuations to shift fine sediment, counteract turbidity & encourage plant growth • Frequency of flooding	• Protection of riparian vegetation • Limit stock access on banks
	Biodiversity	• Diversity of community structure	• Reduced (see above)	• Ausrivas O/E scores = Band A	✓✓	• As above	• As above	• As above
	Biomass	• Natural rates of river productivity • Source of food for fish	• Moderate to very poor/ unbalanced	• Biomass equivalent to similar streams elsewhere e.g. Ovens	✓✓	• As above • Reduced productivity relating to: - altered wetting/drying cycle - low velocity/ settling sediment - interaction between turbidity and flow variation	• Seasonality and frequency of Out-of-channel flows • Short-term variability	• Modify levees and block banks • Control stock access (pugging and grazing) • Aquatic, emergent, bank vegetation restored

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered	Complementary management required
In Wetlands (No data seen)	Biomass	• Processing Org. Matter & Nutrients. • Diverse Food for fish and terrestrial Verts. (birds, bats)	• Some good. Highly variable – depending on land use	• Dynamic food webs maintaining wetland diversity and productivity.	✓✓✓	• Reduced frequency and changed seasonality of over-bank flows	• Seasonality and frequency of Out-of-channel flows	• As above • Protect natural vegetation
	Functional trophic relationships	• Provide resilience and trophic support sustainability.	• As above	• Diverse, resilient communities through full range of physical conditions	✓✓	• As above	• As above	• As above
	Biodiversity	• Productivity - food for fish & terrestrials	• Often poor but sometimes high	• Biomass expressed in diverse organisms supporting diverse floodplain system	✓	• As above	• As above	• As above

Table 5: Ecological features and flow components to be assessed for native fish populations in Reaches 1-3 (Lake Eildon to Nagambie).

Ecological Attribute	Environmental or ecological value	Ecological objectives	Feature/group	Condition	Extent that objectives are flow related	Flow components to be considered	Complementary management required
Fish	• Diversity of native fish • Naturally reproducing and self sustaining populations of native fish • Populations of threatened and icon species	• Suitable thermal regime for spawning, growth and survival of all life stages	• Flood spawners • Macquarie perch • Main channel generalists • Main channel specialists • Low flow specialists	• Poor • Poor • Poor • Poor • Poor	✓	• Not addressed by flow change	• Mitigation of cold water releases
		• Suitable in-channel habitat for all life stages	• Flood spawners • Macquarie perch • Main channel generalists • Main channel specialists • Low flow specialists	• Poor • Poor • Poor • Poor • Poor	✓✓✓	• Baseflow (all year)	• Protection of existing habitat and habitat restoration • Management of introduced fish
		• Suitable off-channel habitat for all life stages	• Wetland specialists	• Fair	✓✓	• Overbank flows (natural timing and duration)	• Riparian and floodplain wetland management • Removal of unnecessary levees and block banks • Management of introduced fish
		• Passage for all life stages	• Flood spawners • Macquarie perch • Main channel generalists • Main channel specialists • Low flow specialists	• Poor • Poor • Poor • Poor • Poor	✓✓	• Baseflow (all year)	• Removal of instream barriers and/or installation of fish ladders

Ecological Attribute	Environmental or ecological value	Ecological objectives	Feature/group	Condition	Extent that objectives are flow related	Flow components to be considered	Complementary management required
		• Cues for adult migration during spawning season	• Flood spawners • Macquarie perch • Main channel specialists	• Poor • Poor • Poor	✓✓✓	• Freshes (Oct-Feb)*	• Mitigation of cold water releases • Removal of instream barriers
		1. Access to floodplain and off-channel habitats for spawning and/or larval rearing	• Flood spawners	• Poor	✓✓✓	• Overbank flows (Oct-Feb)*	• Riparian and floodplain wetland management • Removal of unnecessary levees and block banks
		2. Low flows for spawning and recruitment	• Low flow specialists	• Poor	✓✓✓	• Low flow periods (Sep-Feb)*	• Protection of existing habitat and habitat restoration • Management of introduced fish
		3. Floodplain and bench inundation for exchange of food and organic material between floodplain and channel	• Flood spawners • Macquarie perch • Wetland specialists • Main channel generalists • Main channel specialists • Low flow specialists	• Poor • Poor • Fair • Poor • Poor • Poor	✓✓✓	Freshes (natural timing and duration) Overbank flows (natural timing and duration)	• Riparian and floodplain wetland management • Removal of unnecessary levees and block banks

* Flow components considered low priority unless cold water releases are mitigated, as temperatures are currently too low to achieve the ecological objective.

Table 6: Ecological objectives for native fish populations in Reach 4 (Nagambie to Loch Garry) and Reach 5 (Loch Garry to the River Murray).

Ecological Attribute	Environmental or ecological value	Ecological objectives	Feature/group	Condition	Extent that objectives are flow related	Flow components to be considered	Complementary management required
Fish	• Diversity of native fish • Naturally reproducing and self sustaining populations of native fish • Populations of threatened and icon species	• Suitable in-channel habitat for all life stages	• Flood spawners • Macquarie perch • Freshwater catfish • Main channel generalists • Main channel specialists • Low flow specialists	• Poor • Poor • Poor • Fair • Fair-Poor • Fair	✓✓✓	Baseflow (all year)	• Protection of existing habitat and habitat restoration • Introduced fish management
		• Suitable off-channel habitat for all life stages	• Wetland specialists • Freshwater catfish	• Fair • Poor	✓✓	Overbank flows (natural timing and duration)	• Riparian and floodplain wetland management • Removal of unnecessary levees and block banks • Introduced fish management
		• Passage for all life stages	• Flood spawners • Macquarie perch • Freshwater catfish • Main channel generalists • Main channel specialists • Low flow specialists	• Poor • Poor • Poor • Fair • Fair-Poor • Fair	✓✓	Baseflow (all year)	• Removal of instream barriers
		• Cues for adult migration during spawning season	• Flood spawners • Macquarie perch • Main channel specialists	• Poor • Poor • Fair-Poor	✓✓✓	Freshes (Oct-Feb)	• Removal of instream barriers

Ecological Attribute	Environmental or ecological value	Ecological objectives	Feature/group	Condition	Extent that objectives are flow related	Flow components to be considered	Complementary management required
		• Access to floodplain and off-channel habitats for spawning and/or larval rearing	• Flood spawners	• Poor	✓✓✓	Overbank flows (Oct-Feb)	• Riparian and floodplain wetland management • Removal of unnecessary levees and block banks
		• Low flows for spawning and recruitment	• Low flow specialists	• Fair	✓✓✓	Low flow periods (Sep-Feb)	• Protection of existing habitat and habitat restoration • Introduced fish management
		• Floodplain and bench inundation for exchange of food and organic material between floodplain and channel	• Flood spawners • Macquarie perch • Wetland specialists • Freshwater catfish • Main channel generalists • Main channel specialists • Low flow specialists	• Poor • Poor • Fair • Poor • Fair • Fair-Poor • Fair	✓✓✓	Freshes (natural timing and duration) Overbank flows (natural timing and duration)	• Riparian and floodplain wetland management • Removal of unnecessary levees and block banks

4 ENVIRONMENTAL FLOW RECOMMENDATIONS

The Scientific Panel adopted the following vision for the Goulburn River as it considered environmental flow requirements:

‘ A healthy working river that supports a diversity of natural ecosystems and processes, thereby sustaining the human community of the Goulburn-Broken catchment’.

It should be noted that the Scientific Panel has only considered flow recommendations from an ecological perspective. Social and economic considerations that are implicit in the vision statement above are to be addressed in the Living Murray initiative.

This vision statement was an important consideration as the Scientific Panel developed its recommendations. It is consistent with the intent of the Victorian River Health Strategy (DNRE 2002b), the Goulburn-Broken Regional Catchment Strategy (O’Neill and McLennan 2002) and draft management plans for Heritage Rivers and Natural Catchment Areas (DNRE 1997). Each of these strategies and plans recognises the concept of the Goulburn as a ‘working river’ that supports activities such as irrigated agriculture, as well as environmental and ecological features such as a diverse flora and fauna, good water quality and natural connection of the river and floodplain habitats. This has important implications for environmental flow recommendations, such as addressing issues related to the seasonal inversion of the flow regime in Reaches 1-3.

4.1 Deposition of fine sediments on the armoured riverbed

An ‘armoured’ layer has formed on the bed of the river in Reach 1 (Lake Eildon to Molesworth) due to the concentration and sorting (imbrication) of coarse gravels (Erskine 1996). This armour layer protects the underlying sediments of the riverbed. Lake Eildon now traps much of the sediment load carried by the Goulburn River. However, the reduced frequency of large flows capable of moving the gravels, combined with sediment inputs from tributaries, means that the armoured gravel layer has become infilled with sediment. Deposition of fine sediment was also noted on hard surfaces such as logs (snags), shallow benches and on the leaves of aquatic macrophytes in other reaches (e.g. Reach 4 - Goulburn Weir to Shepparton). Sediment deposition can affect stream ecosystems in many ways (e.g. Culp *et al.* 1986, Downes *et al*. 1998, O’Connor and Lake 1994, Petts 1988, Williams 1980). For example, sediments can smother and reduce the quality of habitat and food (e.g. biofilm) available for macroinvertebrates and fish, and decrease the photosynthesis of plants.

Erskine (1996) concluded that the development of the armour layer is the main reason there has not been more bed scour below Lake Eildon. Erskine and Terrazzolo (1996) suggested that it would be unwise to disrupt the armour layer because it would then open the riverbed to ‘clear water scour’, which is commonly experienced below large dams (Galay 1983). The Scientific Panel was not able to establish the full extent of armouring when it visited sites along the Goulburn River because of high water levels associated with irrigation releases. However, armouring was noted on every gravel bar observed in Reaches 1 and 2. While armouring can be a natural occurrence, the Scientific Panel surmised that it was now more widespread across the bed, deeper, and possibly more persistent (i.e. turned over less often) than would be the case in the absence of Lake Eildon.

Thus, the Scientific Panel faced the dilemma of not wanting to disrupt the armour layer, but not wanting to have poor habitat quality due to clogged substrate. The disruption of the armour layer in Reach 1 as an objective for releasing environmental flows on a routine basis is not recommended. Repeated disruption of the armour layer is likely to increase the average sediment particle size and so require successively larger flows in the future. The solution is to reduce the amount of surficial fine sediment on the gravels (i.e. drapes of sand and clay over the gravels), but limit the number of events that move the whole bed. The Scientific Panel considered that this could be achieved with regular bank full or out of channel flows, such as those required for filling floodplain wetlands (see Chapter 4.5).

Recommendation: No flow recommendation is specifically made to address this issue.

4.2 In-channel effects of seasonal inversion of the flow regime

The rainfall patterns in the southern half of the Murray-Darling Basin are such that, though highly variable (McMahon 1976), most of the runoff occurs during winter and spring. Storages such as Lake Eildon are designed to capture these flows and make them available downstream for irrigation during the naturally dry summer and autumn. This results in a seasonal inversion of the natural flow pattern, producing high flows in summer-autumn and low flows during winter-spring – an effect particularly evident in river reaches downstream from the storage but upstream from major irrigation offtakes. In the Goulburn River, seasonal flow inversion between Lake Eildon and Goulburn Weir results in:

- High water velocity during summer-autumn creates conditions that are poor or unsuitable for expansion, growth or recruitment of in-channel macrophytes;
- Constant high water levels during summer-autumn that effectively reduce the riffle habitat available for some invertebrates and fish;
- Constant high water levels during summer-autumn that inundate river bars and benches, potentially disrupting biochemical processes such as the cycling of carbon and nutrients that contribute to processes such as production and respiration;
- Constant high water levels during summer-autumn that reduce the availability of shallow-water habitat (less than 0.3m depth) favoured by some in-channel macrophytes and seedlings, and by small fish.

These issues are considered individually in Chapters 4.2.1 to 4.2.4 and summarised in Chapter 4.2.5.

4.2.1 High water velocity

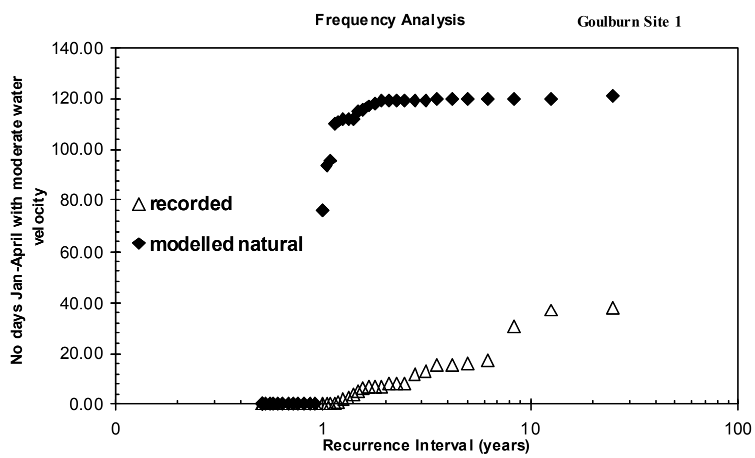
The general clarity of water and the presence of plants in downstream reaches suggest that macrophytes should occur in Reach 1. One reason for their general absence is higher than natural water velocity. The release of summer irrigation flows from Lake Eildon has greatly increased water velocity in the upper Goulburn River towards during the latter part of the growing season for macrophytes. This is evident in Frequency Analysis plots (Figure 7), which show a shift from predominantly moderate velocity under natural conditions to fast velocity under regulated conditions for the summer-autumn months. Madsen *et al*. (2001) have developed a velocity categorisation framework that relates specific flows to in-channel macrophytes and their growth (Table 7). According to this, slow and moderate velocity flows are the most suitable for macrophyte growth. Fast and very fast water flows increase the risk of mechanical damage to plants, of parts breaking off, and of emerging or floating leaves being dragged under the water, effectively reducing rates of photosynthesis and, therefore, growth. The flow categories developed by Madsen *et al.* (2001) are considered relevant to

Australian macrophytes and rivers, and are used here as there has been very little research on the relationship between flow and plant ecology in Australia.

Plots of mean reach velocity suggests that the recorded flow regime has far fewer days with moderate velocity (Table 7, Figure 7) than under natural conditions (typically less than 20 compared with 80-110 days) and conversely, more days with fast and very fast flows. This means that there are now fewer days that are suitable for macrophyte growth. Re-instating velocity conditions suitable for growth and recruitment late in summer will thus require reducing flows from fast to moderate velocity water (Figure 8).

Table 7: Velocity categories for in-channel macrophytes (adapted from Madsen *et al.* 2001)

Velocity category	Velocity range
Slow velocity water – favours macrophyte establishment, growth and expansion in area occupied	<0.1 m/s
Moderate velocity water – likely range over which growth and expansion of macrophytes occurs	0.1 – 0.6 m/s
Fast water – net macrophyte growth unlikely	0.6 – 0.9 m/s
Very fast water – conditions unfavourable for macrophytes	>0.9 m/s



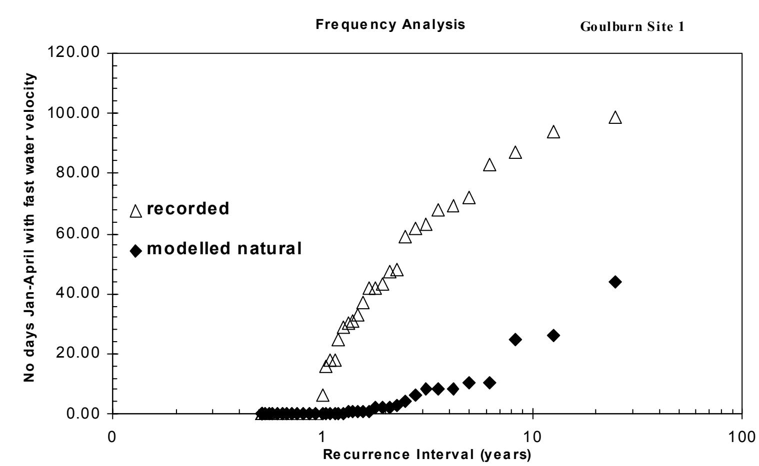


Figure 7: Comparison of summer-autumn 'moderate' and 'fast' water velocity for Reach 1.

The velocity-discharge relationship for Reach 1 (Figure 8) suggests that the recorded conditions, with summer flows of approximately 9-10,000 ML/d, provide velocities that are not conducive to the establishment, growth or expansion of in-channel macrophytes, based on the categories presented in Table 7. At these higher discharges, patches of slow water will be restricted to backwater and shallow areas along the channel margins. This is consistent with the observations of the Scientific Panel when it visited this reach in January 2003 and noted that in-channel macrophytes, if present, were concentrated in the littoral parts of the river. Providing velocity conditions favourable for in-channel macrophytes will mean require mean reach velocities below 0.6 m/s (approximately 2,700 ML/d) or natural (to allow for natural freshes) and even below 0.4 m/s (1,000 ML/d) (Riis and Biggs 2003) or natural (Figure 8). Discharges that provide conditions favourable for increased abundance and biodiversity of in-channel macrophytes in Reach 1 are also likely to benefit the fauna that use macrophytes as habitat (e.g. invertebrates, small fish). However, the Scientific Panel acknowledges that these limits on summer-autumn flows will have significant social and economic implications. This is discussed further in Chapter 4.2.5.

Mean reach velocity in Reaches 2 and 3 is consistently below the 0.6 m/s threshold (Figure 9 and Figure 10), suggesting that velocity is unlikely to be a constraint on macrophyte growth here. The Scientific Panel considered that no environmental flow recommendation was required to address water velocity issues in these Reaches.

Recommendation: A mean reach velocity less than 0.6 m/s (approximately 2,700 ML/d) in Reach 1 is required to improve macrophyte habitat conditions. It is acknowledged that this recommendation, while desirable from an ecological perspective, will be balanced by social and economic considerations as part of the Living Murray initiative. Mean reach velocity in Reaches 2 and 3 is unlikely to be constraining macrophyte growth and hence no velocity-related flow recommendations are needed for these reaches.

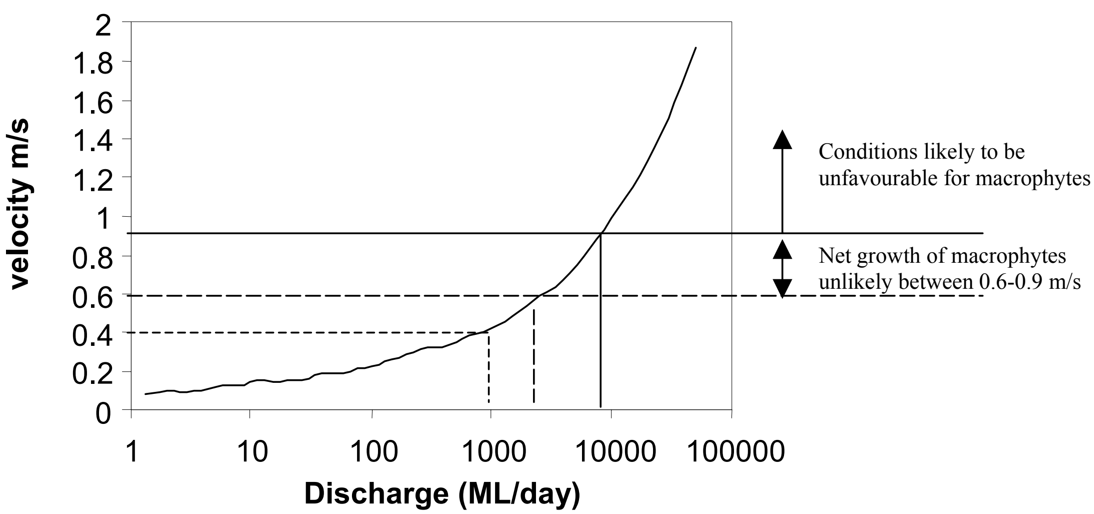


Figure 8: Relationship between the reach mean velocity and discharge for Reach 1. Current mean daily summer flows of approximately 9,000 ML/d are near the limit where conditions are unfavourable for in-channel macrophytes. summer-autumn flows less than approximately 2,000 ML/d and preferably below 1,000 ML/d.

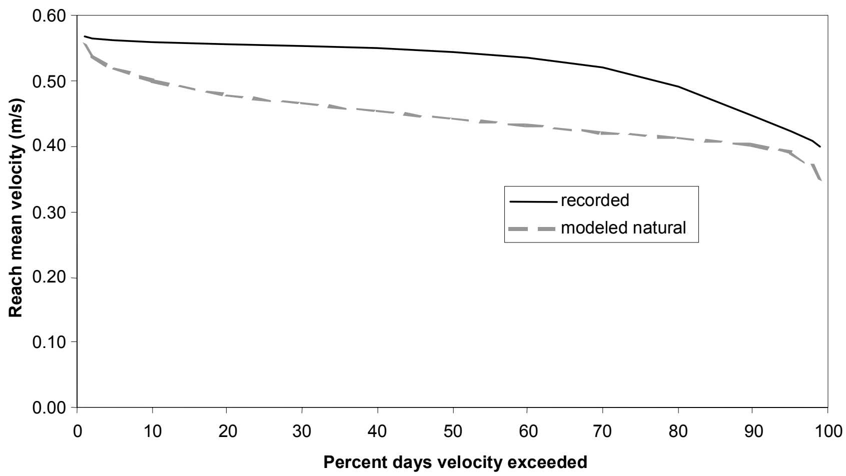


Figure 9: **Mean reach velocity in summer in Reach 2**

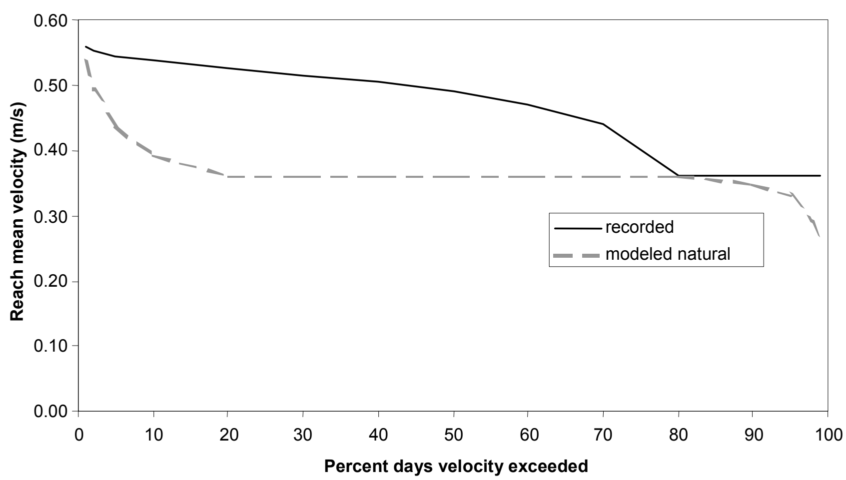


Figure 10: **Mean reach velocity in summer in Reach 3**

4.2.2 Availability of riffle habitat

Most people are familiar with the concept of a riffle in upland streams and their importance as habitat for invertebrates and fish. For the purposes of this study, a riffle is an area of coarse substrate above which water flows with a Froude Number >0.18[#], and at a depth shallow enough to allow photosynthetically active radiation (PAR) to reach the substrate. In practice, this usually equates to a fast-flowing zone with turbulent flow at the surface and a depth of <0.3m.

Increased water levels due to summer discharges from Lake Eildon have drowned out much of the riffle habitat in Reaches 1-3. The modelled natural 10th percentile values for January, February and March (Figure 11) were used as the basis for maximum summer flow

[#] Froude number = ratio velocity to the speed of a gravity wave. It is used to assess if flow is tranquil or fast. Fr > 0.18 represents fast, shallow water and Fr < 0.18 represents slow water.

recommendations in Reach 1[#]. Less than 3,000 ML/d in January and less than 2,000 ML/d in February and March (or natural, to allow for freshes) will be required to improve riffle habitat availability in this reach.

A similar pattern was observed for Reaches 2 and 3 (Figure 12 and Figure 13). Using the lower modelled natural 10^{th} percentile values for February and March indicates that summer flows less than 3,000 ML/d (or natural, to allow for freshes) will be required to improve riffle habitat in Reaches 2 and 3. For each reach, flows less than 1,000 ML/d would be required in order to provide natural levels of riffle habitat, based on median values. The Scientific Panel acknowledges that such recommendations will have significant social and economic implications.

Recommendation: Upper limits in summer-autumn of approximately 2,000 ML/d in Reach 1 and approximately 3,000 ML/d in Reaches 2 and 3 are recommended to increase riffle habitat availability. It is acknowledged that these recommendations, while desirable from an ecological perspective, will be balanced against social and economic considerations as part of the Living Murray initiative.

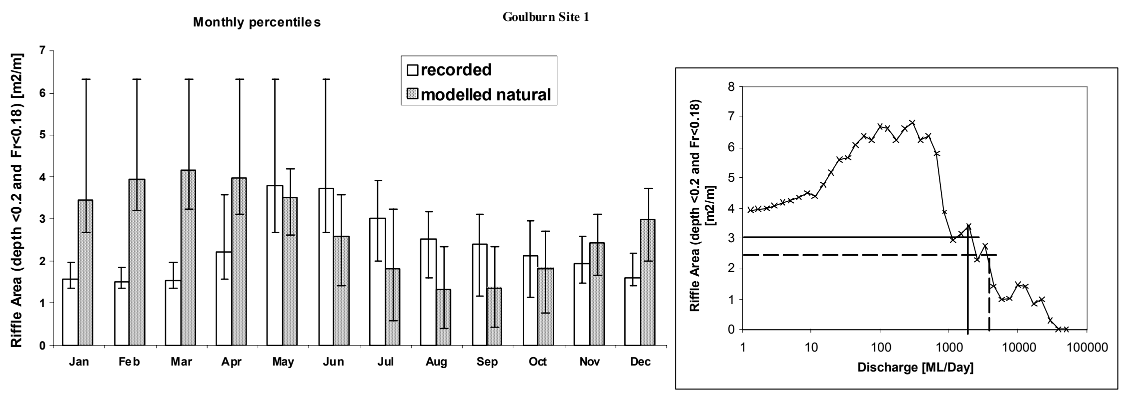


Figure 11: Riffle habitat availability in Reach 1. Columns represent median values and whiskers represent 10^{th} and 90^{th} percentiles.

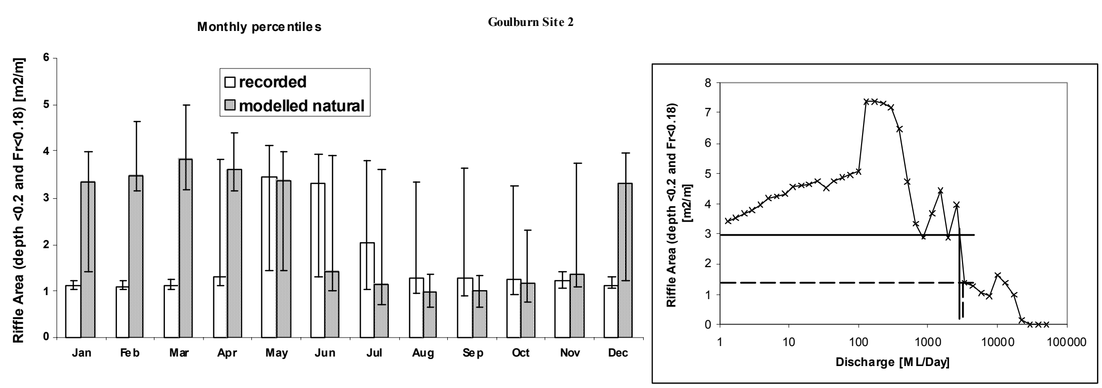


Figure 12: Riffle habitat availability in Reach 2. Columns represent median values and whiskers represent 10^{th} and 90^{th} percentiles.

[#] The Scientific Panel assumed that most biota are adapted to variable flow conditions and could, therefore, tolerate the range of conditions represented by the 10^{th} and 90^{th} percentile values. Values below the 10^{th} percentile represent an increased risk to ecological condition.

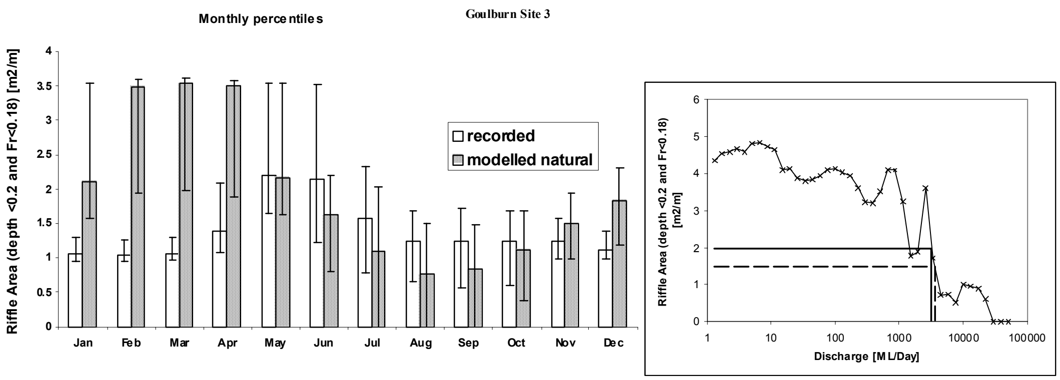


Figure 13: Riffle habitat availability in Reach 3. Columns represent median values and whiskers represent 10th and 90th percentiles.

4.2.3 Habitat and biochemical processes on river benches

High summer water levels have confounded the natural frequency and duration of bench inundation in Reaches 1-3, meaning that the frequency of inundation has been reduced but duration has been increased. For example, benches in Reach 1 were inundated by 3-4 events lasting 1-8 days in summer-autumn period under natural conditions, whereas now they are inundated 1-2 times by events lasting 60-80 days. Benches have thus changed from being intermittently wet to being intermittently dry. Such modifications to patterns of wetting and drying can affect microbial processes, such as those responsible for carbon metabolism and nutrient cycling (Baldwin *et al.* 2000, Mitchell and Baldwin 1998), and influence the plants species that grow on benches (e.g. flood tolerant, short-lived terrestrial, in-channel macrophyte). However, not enough is known about how microbial processes are affected by unnaturally long wetting or drying events, to develop specific environmental flow targets and hence make environmental flow recommendations.

Adopting a precautionary approach to achieve a more natural pattern of bench inundation would require reducing discharge to below approximately 3,000 ML/d, and with increased variability. However, the benefits of such changes in terms of ecological processes such as production, respiration and nutrient cycling are not clear and are not considered sufficient for the formulation of a specific recommendation in this study. The Scientific Panel is reluctant, therefore, to develop an environmental flow recommendation to address the issue of extended periods of bench inundation for Reaches 1-3. However, the Scientific Panel recognises that this is an area requiring further research.

Recommendation: No flow recommendation is made to address extended inundation of in-channel benches.

4.2.4 Shallow water habitat for in-channel macrophytes and small fish

The release of summer irrigation flows has decreased the amount of shallow habitat available for in-channel macrophytes (during the second part of the growing season) and made conditions less favourable for low-flow fish recruitment in summer-autumn in Reaches 1-3

(Figure 14)[#]. This, combined with faster water in Reach 1, makes conditions for in-channel macrophytes unfavourable. In general, there is an inverse relationship between the area of shallow water habitat available and flow (i.e. shallow habitat increases as summer flows decrease).

For Reach 1, the extent of shallow habitat would have naturally ranged from approximately 4 m^2/m[##] to 10 m^2/m during summer (Figure 14). The modelled natural 10th percentile value for the summer months of January (3.9 m^2/m), February (5.3 m^2/m) and March (5.5 m^2/m) was used to represent the lower limit of the natural range of shallow habitat area. The flow required to provide these habitat areas range from approximately 2,400 ML/d for January to approximately 1,400 ML/d for February and March. A similar approach would require flows less than approximately 2,900 ML/d and approximately 3,000 ML/d in Reach 2 and Reach 3, respectively (Table 8). The maximum ecological benefits of adopting these flow limits are likely to be realised with the mitigation of summer cold water releases from Lake Eildon. The Scientific Panel acknowledges that applying such upper flow limits would severely curtail the supply of irrigation water in summer.

Recommendation: Upper limits in summer-autumn between 1,400 ML/d and 3,000 ML/d are recommended to increase the shallow habitat available for macrophytes and fish recruitment. It is acknowledged that these recommendations, while desirable from an ecological perspective, will be balanced against social and economic considerations as part of the Living Murray initiative.

Table 8: Summer flow maxima in Reaches 1-3 to increase shallow water habitat

	Maximum Flows ML/day	
Site	Jan	Feb and March
1	2,400	1,400
2	2,900	1,700
3	3,000	1,800

[#] Shallow water is defined as water less than 0.3m deep.
[##] The unit m^2/m refer to the area of the channel (in plan view) per unit length of river. So $4m^2/m$ means that there is and average 4 m^2 of this habitat for every meter of river length.

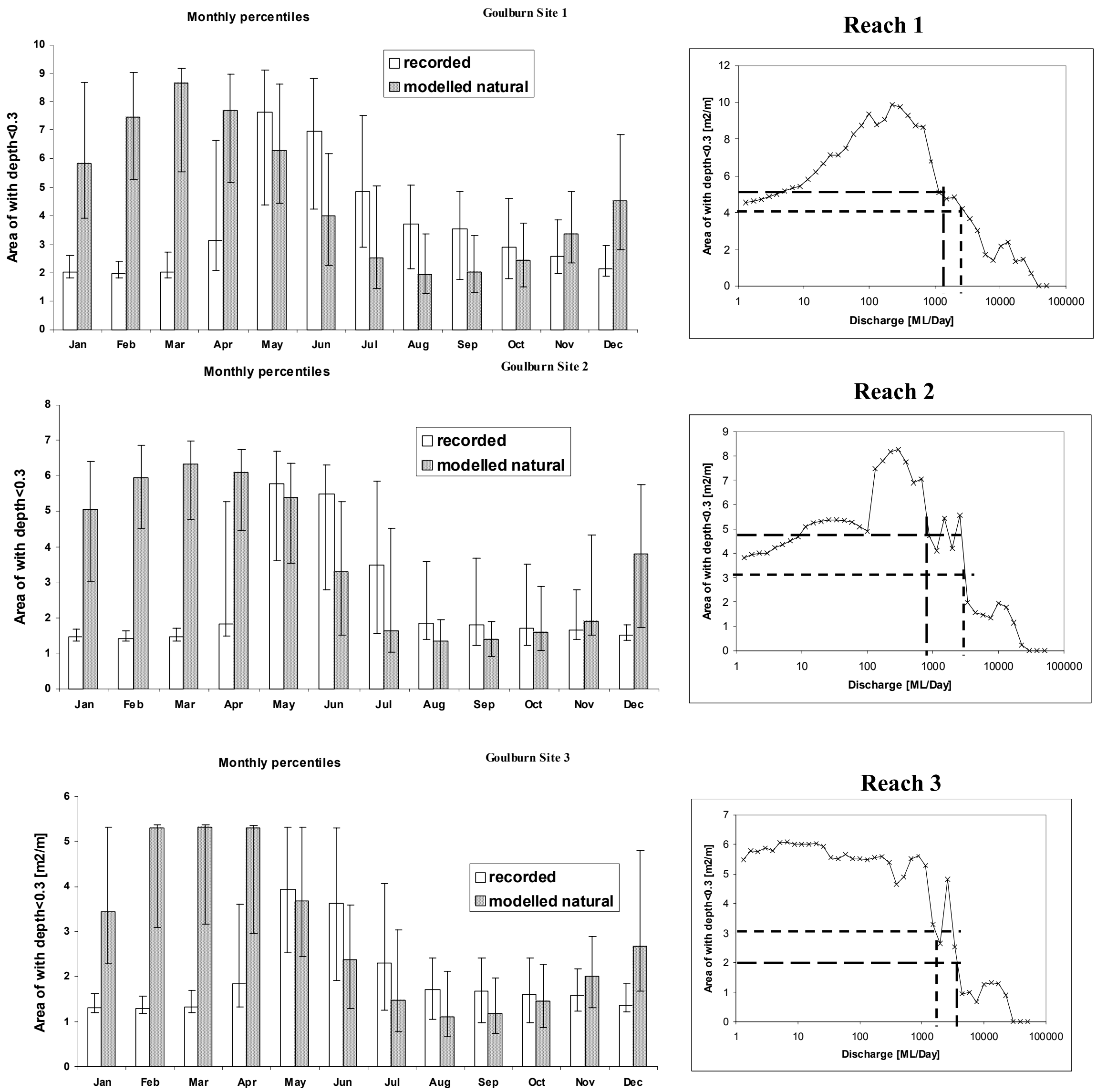


Figure 14: Comparison of current (recorded) versus modelled natural shallow habitat (<0.3 m deep) for macrophytes and small fish in Reaches 1-3. Columns represent median values, while whiskers represent the 10th and 90th percentile values for each month.

4.2.5 Summary of recommendations to address seasonal flow inversion below Lake Eildon

The preceding analyses show that adopting flows to redress several negative ecological effects of seasonal flow inversion would require setting upper flow limits in the order of 1,000 – 3,000 ML/d during the irrigation season. Achieving the greatest ecological benefits would also require mitigation of summer cold-water releases from Lake Eildon (but see also potential ecological risks – Chapter 4.12). The Scientific Panel acknowledges that adopting these upper flow limits would severely curtail the supply of irrigation water in summer-autumn, but see value in articulating some of the trade-offs being made under current management. The Scientific Panel believes that these ecological losses and changes should be stated and acknowledged beside socio-economic losses and changes if the Goulburn River is to be accepted as a 'working' river. The reduced availability of shallow water habitat favoured by in-channel macrophytes and small fish, unfavourable (high) water velocity and reduced riffle habitat means that summer irrigation releases increase the risk of:

- Reduced in-channel diversity of macrophytes, macroinvertebrates and fish;
- Reduced wetland and floodplain biodiversity and productivity due to decreased inundation frequency (see Chapter 4.5); and
- Altered patterns of carbon and nutrient cycling.

All of these factors have the potential to affect the biodiversity and ecological values of the Goulburn River in Reaches 1-3, particularly if combined with other non-flow stressors. It is also possible that the individual risks compound each other, amplifying their individual effects. For example, the combination of the in-filling of armoured substrate (reducing macroinvertebrate habitat protected from high velocity flow), increased stream velocity in summer-autumn, and disruption of the drift patterns of macroinvertebrates (Lauters *et al.* 1996), may make macroinvertebrates more vulnerable to predation or physical removal. Simple cause and effect relationships are rare in complex ecosystems. Whilst the analytical approach here has led to considering risks singly, the Scientific Panel was conscious of possible synergies throughout their discussions.

The Scientific Panel considers that the ecological condition and functioning of the upper Goulburn River is likely to have been impacted by the release of high volumes of irrigation water during summer and autumn. The Scientific Panel has adopted a precautionary approach by making flow recommendations that will provide conditions favourable for natural ecological function, based on our current understanding of the system. The Panel recognises that it is highly unlikely that the recommendations will be acceptable under current management. However, the Panel chose to identify components of summer flow regimes that would be ecologically beneficial, independently of their socio-economic cost. By identifying these environmental needs, the Panel seeks to inform future benefit/cost assessments of summer releases, by articulating potential risks to the ecological function of the river (e.g. processes such as primary productivity), to its community structure and its biodiversity. It may also help in feasibility assessments, such as for alternative methods for delivering irrigation water via a pipeline (e.g. is it feasible to deliver irrigation water via pipelines, rather than via the river channel?).

Additional investigations need to be undertaken to quantify the importance of factors, such as changes to ecological processes and plant and animal community structure, potentially affected by seasonal flow inversion. In particular, research is needed on relationship between nutrient cycles or types of biota and inundation time for benches (see also Chapter 4.3). This information will provide valuable insights that can be used to further develop specific environmental flow recommendations in the future.

Recommendation: The Scientific Panel recommends that research into the effects of seasonal flow inversion and on duration of bench inundation be supported.

4.3 Reduced bench inundation

The issue of extended bench inundation for Reaches 1-3 has been covered in Chapter 4.2.3.

Unlike Reaches 1-3, the current frequency of summer bench inundation in Reach 4 remains similar to natural but the duration of inundation events is now reduced (Figure 15 and Figure

16). The natural pattern was for 2-3 events lasting 40-80 days in spring (now 1-2 events of approximately 15 days), and with 1-3 events lasting 8-16 days in summer (summer events now last approximately 4 days).

Benches in Reach 4 would have had a natural sequence of inundation, starting in winter, then sustained periods of saturation in spring, followed by occasional wetting in summer. Such conditions would probably have helped to promote plant diversity, as these are likely to suit a range of plant species and growth patterns, as follows:

- Seasonal re-growth of cool-season inundation tolerant perennials, such as shrubs;
- Emergent macrophytes that grow early in the season and occur lower down the banks; and
- Flood tolerant tussocks and sedges higher up the banks.

Current management has resulted in shorter and later inundation periods in winter, and shorter duration inundation events in spring and summer. The Scientific Panel noted that many of the plant species found on benches in Reach 4 are introduced short-lived or annual herbs, including wireweed *Polygonum arenastrum* and *P. aviculare*, *Cirsium vulgare* and *Sonchus oleraceus*. Native species noted include perennials such as *Centipeda* spp. (sneezeweed or old man weed) and *Alternanthera* sp., which are not rare or endangered.

There is little detail in the scientific literature on how littoral plant and invertebrate communities respond to changes to inundation duration and frequency, although useful insights can be gained from studies of wetland vegetation. Casanova and Brock (2000) tested depth, frequency, and duration of inundation on plant recruitment from wetland sediment seed-banks. The responses indicated that inundations of short duration (<2 weeks) led to a high proportion of terrestrial and introduced plants, while longer duration favoured native species. Other studies (Bren and Gibbs 1986, Froend and Van Der Moezel 1994) have noted that introduced species can be negatively correlated with flood frequency.

Invertebrates have been shown to hatch rapidly once dry wetland sediments are inundated (Langley *et al*. 2001, Nielsen *et al*. 2002), with diversity and biomass peaking when inundation exceeds 2 weeks. Each species will use the dispersal mechanisms available to it, such as egg dispersal or larval movement (including drift) to maximise its population's exploitation of resources. 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.

As noted in Chapter 4.2.3, the inundation of previously dried sediments can result in a flush of nutrients in forms that may be utilised by microbes, algae and macrophytes (e.g. Mitchell and Baldwin 1998, Baldwin and Mitchell 2000). Current investigation of ecological processes at sites along the Murray River suggest that bench inundation results in higher rates of productivity and respiration than in the main river channel, although it is not clear how long this effect persists (B. Gawne, MDFRC, pers. comm.).

The Scientific Panel recognised that two weeks is clearly too short for bench duration but considered that there was insufficient information available to make specific recommendations as to an appropriate duration for bench inundation events in Reach 4, particularly in spring. Further investigations on changes to ecological processes occurring on river benches in different river reaches in response to inundation duration are recommended, for example as an adaptive management experiment.

Experiments should be designed to evaluate the effect of extending the duration of bench inundation events in both spring and summer. This may be done by returning the duration of summer bench inundation events back to natural and by extending at least one spring inundation event each year beyond the current 15 days. The intention for the extended spring event is not a return to natural (benches in Reach 4 are naturally inundated almost continually in spring), but to provide sufficient duration so that terrestrial and alien plant species are not favoured (e.g. 24 days). The peak magnitude and duration of summer events can be modelled according to the natural magnitude-duration relationship, such as that applied to floodplain inundation for Reach 1 (see Chapter 4. 5). Indicative volumes required for these experimental releases are presented in Chapter 5.

The frequency and duration of bench inundation events in Reach 5 is largely unchanged from natural, presumably due to the nature of channel dimensions and the influence of Broken River inflows. No environmental flow recommendation is required to address bench inundation issues in this reach.

Recommendation: No flow recommendations are made for Reach 4, although bench inundation duration is recognised as an unresolved issue. Targeted field studies are recommended to develop practical flow recommendations.

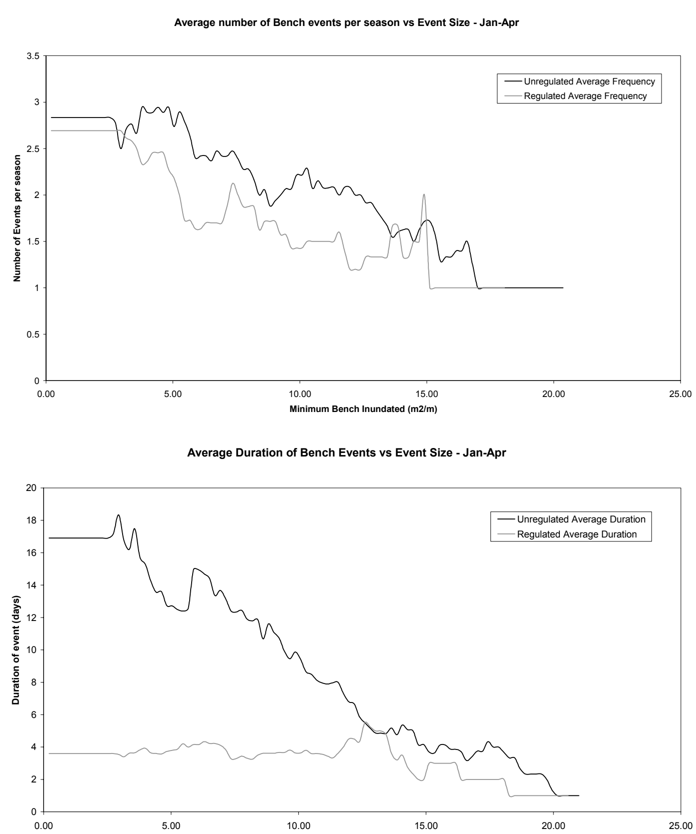
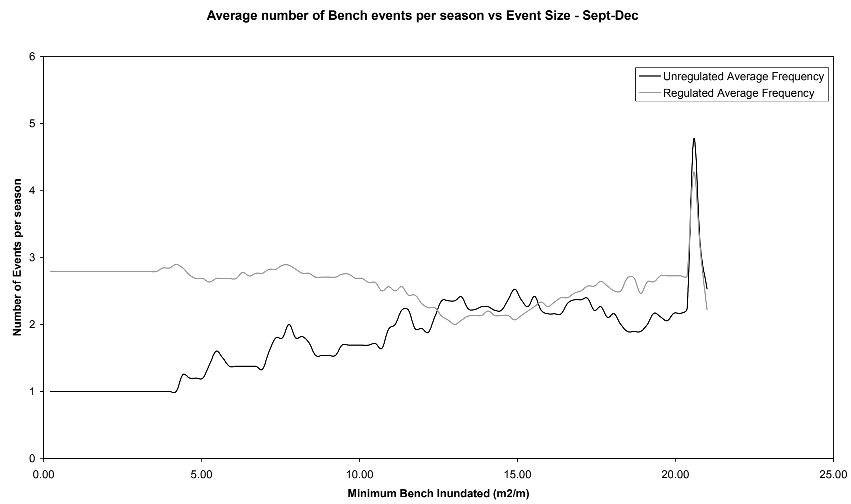


Figure 15: Frequency and duration of summer-autumn (January-April) bench inundation events in Reach 4.



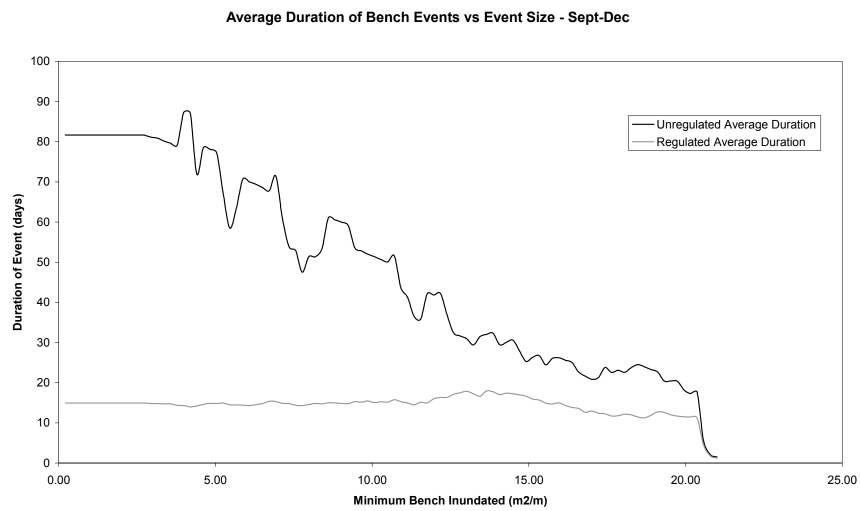


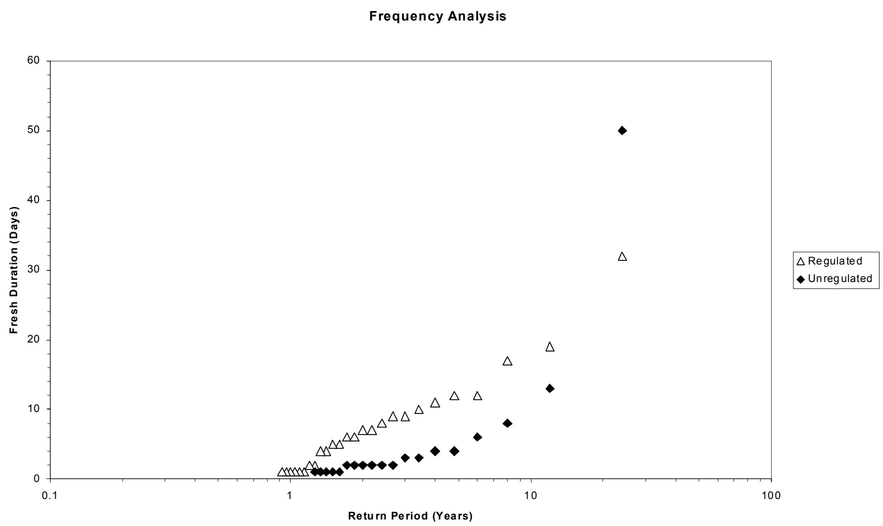
Figure 16: Frequency and duration of spring (September-December) bench inundation events in Reach 4.

4.4 Freshes

Both the frequency and duration of freshes (flow pulses that are greater than 1 standard deviation from mean base flow – see Chapter 2.2) in Reaches 1-3 have been affected by high summer-autumn irrigation flows. For example, summer freshes in Reach 1 are now of longer duration but smaller magnitude than natural (Figure 17). Similar patterns were also observed for Reaches 2 and 3.

The frequency and duration of summer freshes along Reach 4 (below Goulburn Weir) are now higher than natural, while spring freshes are shorter (Figure 18 and Figure 19). The reason for this is not clear, but may be due to factors such as rain rejection flows (cancelled irrigation orders) and increased runoff from saturated land in irrigation areas. For example, releases from Lake Eildon to meet summer irrigation demand are likely to be larger than in late spring. This can mean that there is less capacity to divert rain rejection flows to Waranga Basin than in spring, when demand is less and available channel capacity higher. Similarly, the frequency and magnitude of freshes in Reach 5 were greater than modelled natural in summer but lower than modelled natural in late spring (Figure 20). However, the relative difference in frequency and magnitude in both Reach 4 and 5 was not considered sufficient to warrant specific environmental flow recommendations.

Recommendation: No specific environmental flow recommendation is required for this issue. However, the Scientific Panel considers it important to maintain the natural frequency and duration of spring and summer freshes for Reaches 4 and 5. Goulburn Murray Water has been investigating improvements to the ordering system currently available to irrigators to improve the efficiency of water delivery (B. Klos, GMW, pers. comm.). This is likely to reduce the frequency and volume of rain rejection flows. However, these water savings should not be at the expense of the freshes released to the river below Goulburn Weir, particularly given the higher turbidity and deposition of fine sediments noted in the lower reaches of the river.



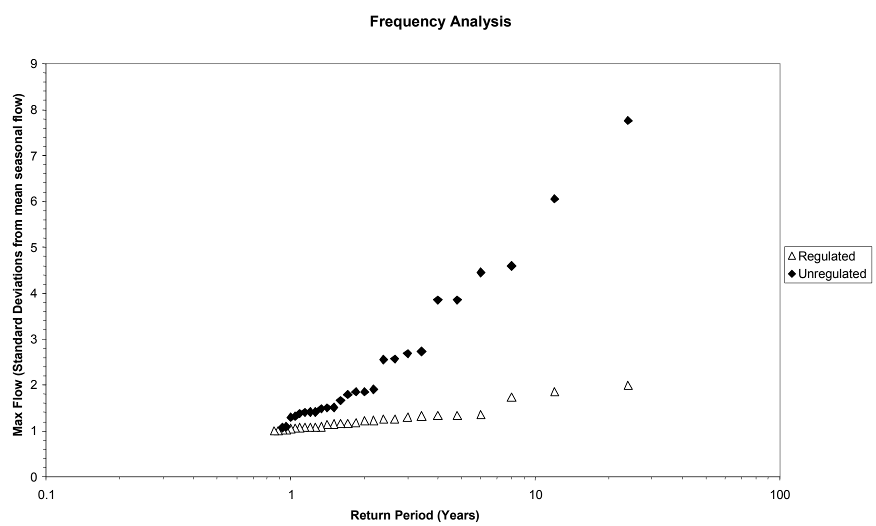
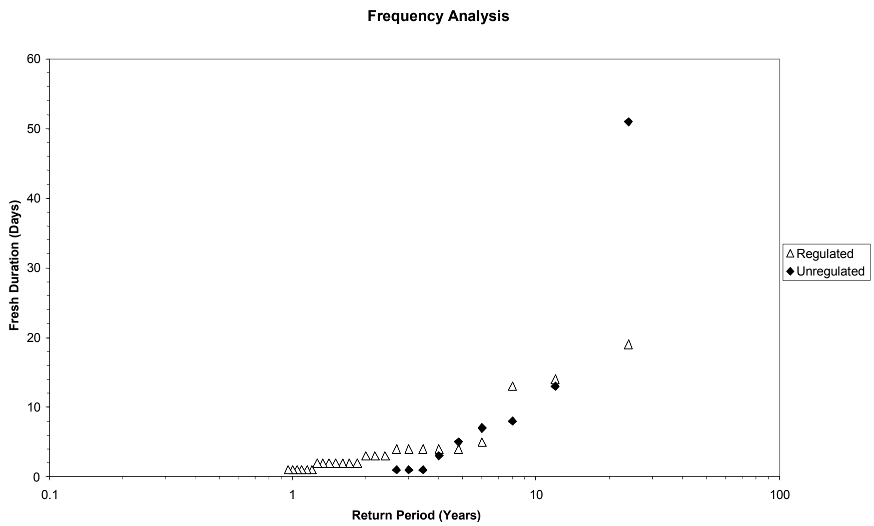


Figure 17: Comparison of summer (February-March) freshes (duration and magnitude) for the current (regulated) versus modelled natural regime in Reach 1.



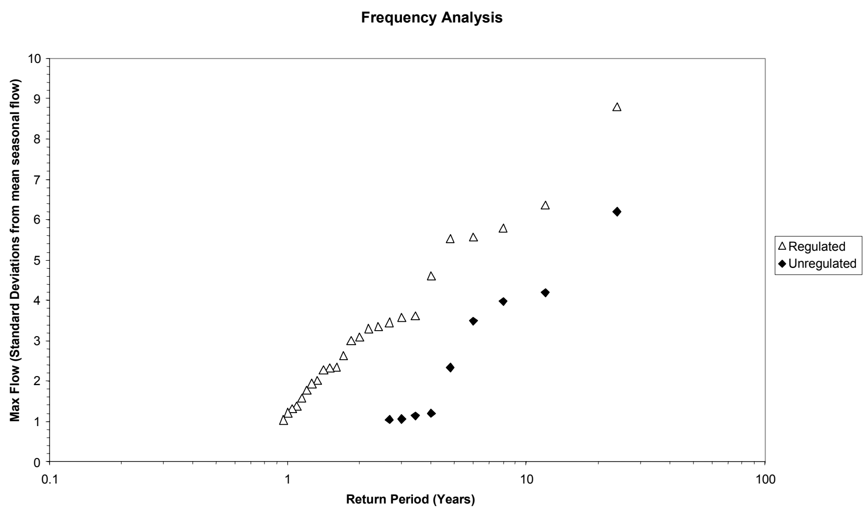


Figure 18: Comparison of summer (February-March) freshes (duration and magnitude) for the current (regulated) versus modelled natural regime in Reach 4.

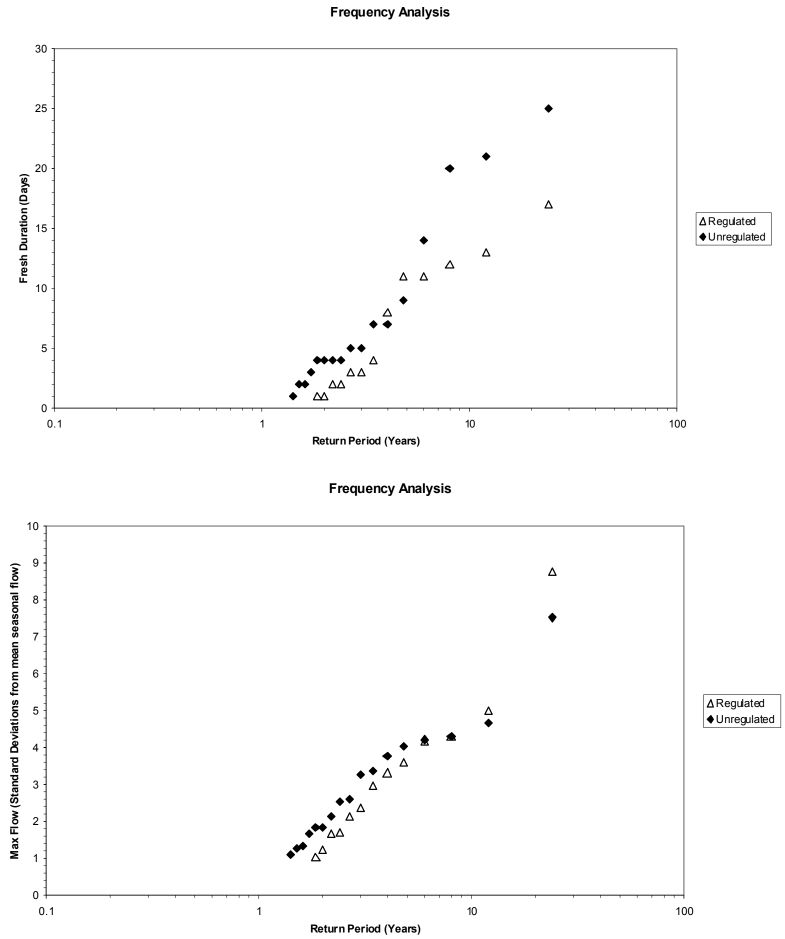
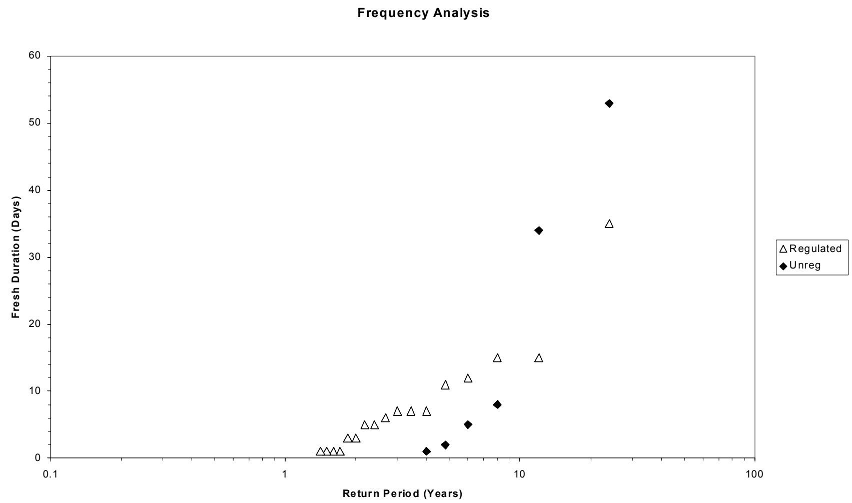


Figure 19: Comparison of spring (November-December) 'freshes' (duration and magnitude) for the current (regulated) versus modelled natural regime in Reach 4.



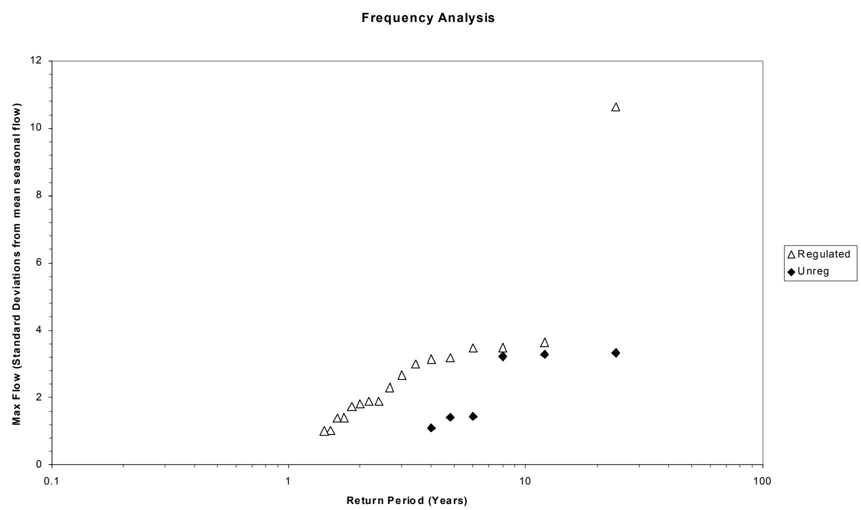


Figure 20: Comparison of summer (February-March) 'fresh' events (duration and magnitude) for the current (regulated) versus modelled natural regime in Reach 5.

4.5 Wetland inundation

Floodplain wetlands provide essential resources for associated terrestrial ecosystems (Parkinson 1996) and make a major contribution to the total biodiversity of floodplain river ecosystems (Boon *et al.* 1990). In other words they represent a key component of landscape function and diversity. In addition, floodplain wetlands make strategic contributions to the main river channel when high flows connect the two systems.

A large proportion of the biota of floodplain wetlands does not occur in the main stream (Hillman 1985) and a significant number of them – particularly amongst the plants and invertebrates – have developed specialised means of surviving dry periods (Brock *et al.* in press). The fact that a significant proportion of these organisms can survive extended dry periods (Boulton and Lloyd 1992, Brock *et al.* 2003) has led to a view that floodplain wetlands are 'tough' ecosystems that can withstand major changes to their hydrology. There is truth in this, but the *resilience* of a system should not be taken as a *lack of sensitivity* (i.e.

survival should not be confused with *preference*). Floodplain systems are sensitive to a number of aspects of the temporal and spatial pattern of inundation (Hillman 1998). It is this sensitivity that is the basis of both the biodiversity found on healthy floodplains and the driving force they exert on surrounding ecosystems. There are floodplain organisms that find a competitive advantage in almost any set of hydrological parameters that can be imagined. Maintaining the biodiversity of any floodplain community will require maintaining the hydrological regime under which it evolved. The mix of species in floodplain communities will in large part be a result of the mix of hydrological conditions.

Recent research into floodplain ecosystems supports this view. Robertson *et al.* (2001) in experiments at Barmah/Millewa Forests showed that summer floods favoured river redgum growth, whilst primary production and biofilm development in the associated wetlands was favoured by spring floods. Casanova and Brock (2001) have demonstrated experimentally that variations in flood frequency, duration, and depth result in quite different communities of plants developing from identical seed-banks. Langley *et al.* (2001) showed that flooding history (ranging from annual inundation to once in 25 years) was a significant factor in determining rotifer emergence from dried sediment. Hillman and Quinn (2002) found that billabong macroinvertebrate communities changed in response to changes in hydrology. Nielsen *et al*. (2002) demonstrated experimentally that changes in seasonality of flooding produced changes in zooplankton communities in temporary and permanent billabongs.

The scientific evidence strongly supports the view that maintenance of the natural level of floodplain biodiversity and function requires, *inter alia*, the retention of all the components of the natural hydrological regime in as close as possible to the original 'mix'. The primary aim in developing environmental flow rules, therefore, must be to ensure that no components of the natural regime (magnitude, seasonality, duration, and frequency) are lost or drastically reduced through regulation practices.

4.5.1 Lake Eildon to Loch Garry

One of the major effects of Lake Eildon and irrigation supply is the reduction of floodplain and wetland inundation frequency along the Goulburn River. For example, an inundation event in Reach 1 that would occur annually under the modelled natural flow regime now occurs every 10 years (Figure 21). Extending the inter-flood duration from one to nearly ten years places considerable stress on wetland and floodplain ecosystems and their fauna. This affects organisms living on the floodplain, especially those that are fixed (i.e. trees, plants) or that have limited mobility (such as some frogs). If not replenished, seed-banks and egg-banks become depleted in number, and depauperate of species as seeds and eggs (of micro-fauna such as invertebrates) lose viability (Brock *et al*. 2003).

The Scientific Panel, therefore, recommends that an annual floodplain inundation event be reinstated to the Goulburn River downstream of Lake Eildon.

Guidelines for operational specifications can be derived from reach-specific patterns of wetland inundation (area or number) as a function of river discharge, if these are available. Inundation-discharge relationships are not readily available for Reaches 1 and 4, however it was possible to develop such a relationship between cumulative wetland area for four wetland types (Figure 23) using historic survey data of commence-to-fill levels for individual wetlands and water surface height, as described in Appendix 7.

Specifications for the inundation event are based on information collated for floodplain wetlands along Reach 1, with the intent that tributary inflows will contribute to the extent and variability of floodplain inundation along the river. This assumes that the event pulse will be passed over Goulburn Weir, rather than being diverted to Waranga Basin.

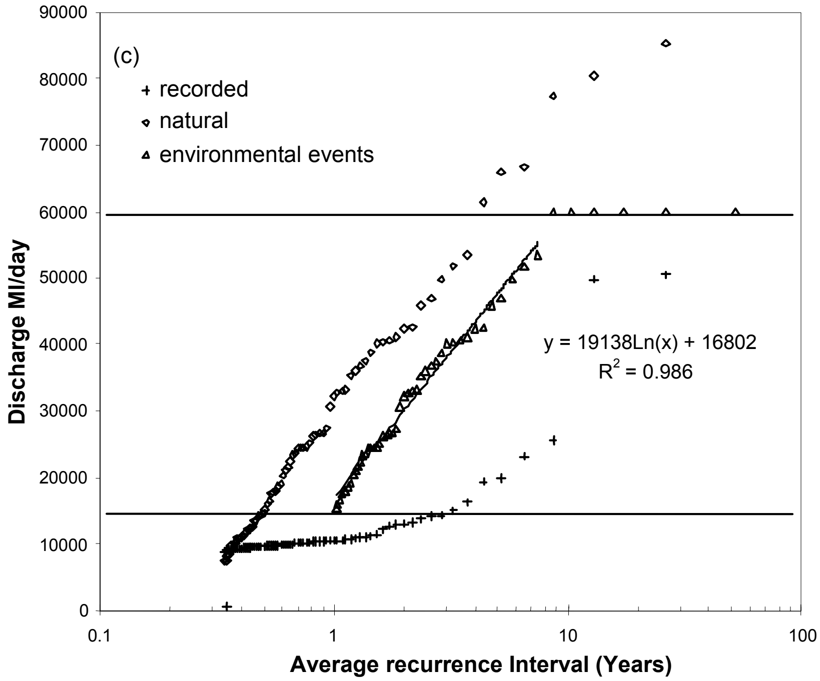


Figure 21: Comparison of floodplain inundation frequency for the recorded (current) and modelled natural flow regime in Reach 1. Environmental events represent a doubling of recurrence interval (i.e. events of a given magnitude occur with half the frequency of the modelled natural regime).

According to the Victorian wetland database, which uses the Corrick wetland classification system, shallow freshwater marsh is the most common wetland type in Reach 1 and covers the greatest area. The area of shallow freshwater marsh inundated between Lake Eildon and Molesworth increases with increasing discharge up to approximately 60,000 ML/d, but with no clear breakpoint in this relationship where an environmental flow recommendation may be targeted (Figure 22). This means that adopting a single threshold value for an event magnitude (e.g. 20,000 ML/d peak discharge) will result in regular inundation of some wetlands, while others at higher positions on the floodplain will regularly miss out on such events. Maintaining heterogeneity of wetting regimes is an essential prerequisite for supporting biodiversity in floodplain ecosystems (Langley *et al.* 2001).

Recommendation: An annual floodplain inundation event should be re-instated for the Goulburn River downstream of Lake Eildon, except in drought years. A drought, where wetland and floodplain inundation would not have occurred naturally, only occurred once during the period of record used in this study (1975-2000), suggesting a return frequency of 1 in 25 years. Additional flow modelling, for example to extend the period of record and include the recent drought year of 2002/03 is likely to indicate that a wetland and floodplain inundation event would be absent every 13-15 years. A review of the frequency of droughts events over a longer period of record is recommended.

In the absence of specific information on an optimal inundation frequency for events of various magnitudes, the Scientific Panel considered that a doubling of the natural recurrence interval for each flow magnitude represented an acceptable risk to floodplain ecosystems (e.g. an event that would have occurred annually prior to regulation now occurs every 2 years; an event that occurred every 2 years before regulation now occurs every 4 years – see Figure 21). However, this is on the proviso that other sources of stress to floodplain systems are ameliorated (e.g. other catchment management activities such as rehabilitation efforts and the control of livestock and invasive species are implemented).

Note that the Scientific Panel places higher priority on variability in peak magnitude than in a fixed value. The following are intended to serve as guidelines for operational modelling to achieve near-annual inundation events:

- If there has not been a natural inundation event in Reach 1 from the start of July to the end of September each year, then one should be targeted for October.
- That the peak magnitude of the annual wetting event be varied between 15,000 ML/d and 60,000 ML/d (the discharge at which nearly all wetlands are inundated in this reach), depending on inflows to Lake Eildon:
  - If September inflow to Lake Eildon is less than the long term median (236 GL), then the flood magnitude should be in the range 15,000 – 37,500 ML/d;
  - If September inflow is greater than the long term median, then the flood magnitude should be in the range 15,000 – 60,000 ML/d;
- The distribution of event peaks within above range should be based on the natural distribution but with a doubling of recurrence interval.

The environmental event relationship presented in Figure 21 can be used to identify the peak magnitude of the event. The specific rule proposed is that environmental events will be provided so that peaks (with mean daily flows greater than 15,000 ML/day) occur with no less than half their natural frequency (i.e. a doubling of the recurrence interval is the maximum allowed). Furthermore, environmental events need not exceed 60,000 ML/day. The hydrograph shape duration of each event should be of a natural form, with increasing duration and volume associated with greater peak magnitudes (Figure 23 and Figure 24).

Operationalising these guidelines will require the selection of event magnitudes based on unregulated flows from tributaries of the Goulburn River or some random selection of event peaks each year. It is estimated that one environmental event will be required each year to meet the target set by the Scientific Panel. Efficiency gains will be achieved if releases are timed to piggyback on unregulated tributary inflows and higher releases are made in wetter years.

The Scientific Panel acknowledges that larger events within the 15,000-60,000 ML/d range have potential socio-economic costs (e.g. flooding private property and infrastructure). As was the case for proposed changes to the summer flow regime below Lake Eildon, the socio-economic implications of more frequent floodplain and wetland inundation need to be considered during the Living Murray initiative.

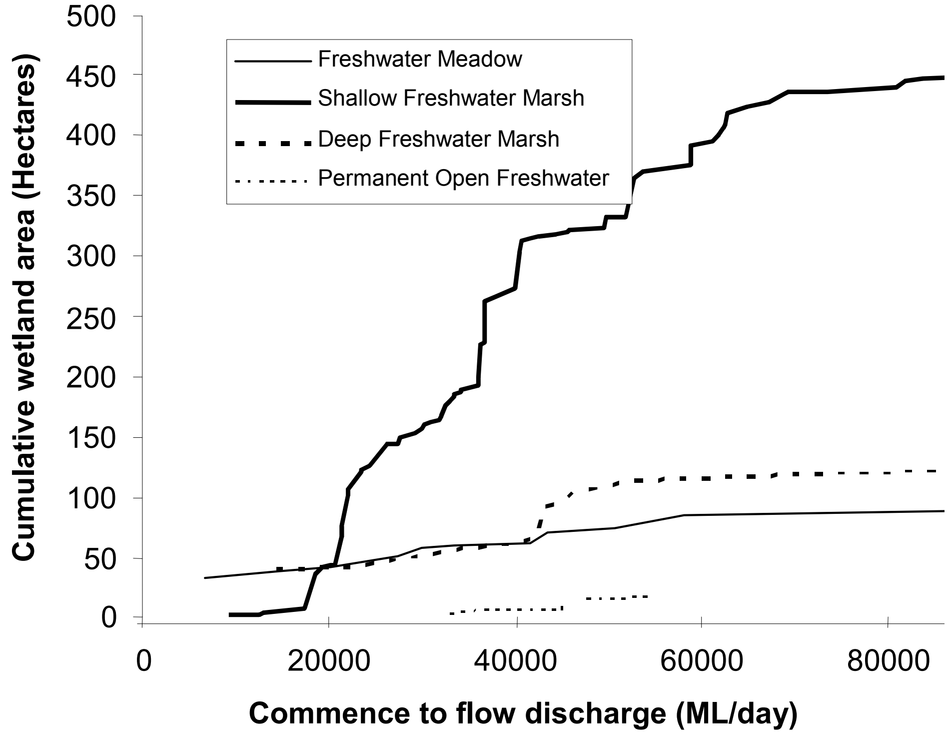


Figure 22: Area of wetlands of various types filled by increasing flows in the Goulburn River between Lake Eildon and Molesworth Bridge (Reach 1).

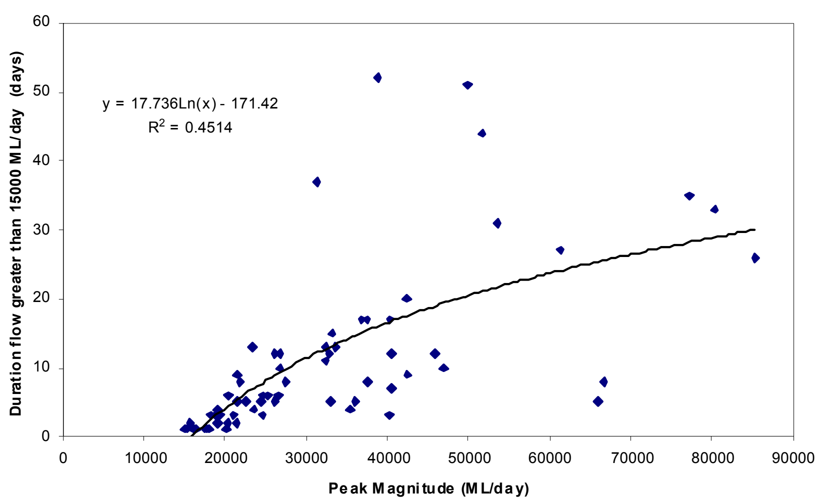


Figure 23: Relationship between peak event magnitude (modelled natural regime) and event duration for Reach 1

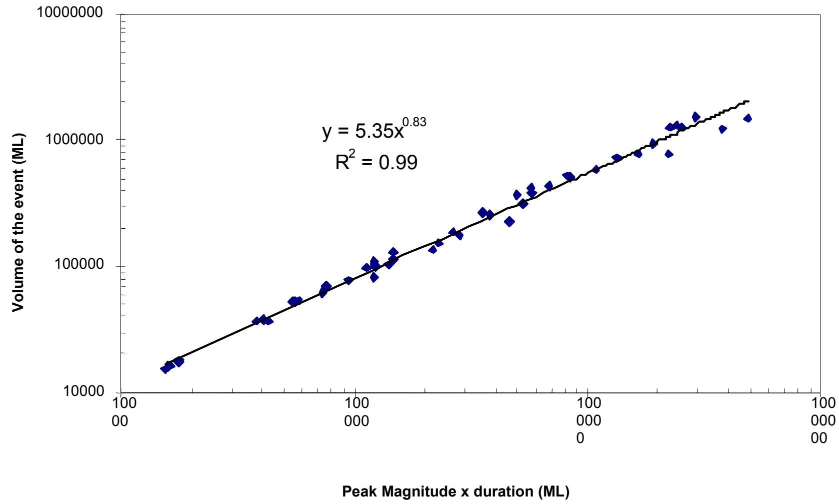


Figure 24: Relationship between event volume and the product of peak magnitude and duration for Reach 1.

4.5.2 Lower Goulburn floodplain

The Lower Goulburn floodplain refers to all of the floodplain downstream of Loch Garry, including the ephemeral effluent system north of the river. This section focuses on the area corresponding to Reach 5, only.

Water Technology Ltd has provided results from the hydraulic model for the lower Goulburn floodplain. These results were for 5 flood events for (1) current conditions and management of levees and (2) for a simulated natural floodplain configuration. These results have been analysed to estimate the area of Type 2 wetlands (classified as Freshwater Meadow in the DSE wetland data base) inundated during the simulated events and the total area of floodplain and effluent channels that are inundated (Figure 25). Table 9 identifies the modelled commence to flow levels for the 4 major northern effluence points, which suggest that water leaves the main channel of the Golburn via downstream effluent channels before water spills over Loch Garry.

Table 9: Commence to flow for northern effluent channels of the lower Goulburn River

	Commence to flow (ML/day)	
Effluent Channel	*Current*	*Natural*
Loch Garry	55,000	48,000
Deep Creek	26,000	25,000
Wakiti Creek	21,000	22,000
Hancocks Creek	23,000	21,000

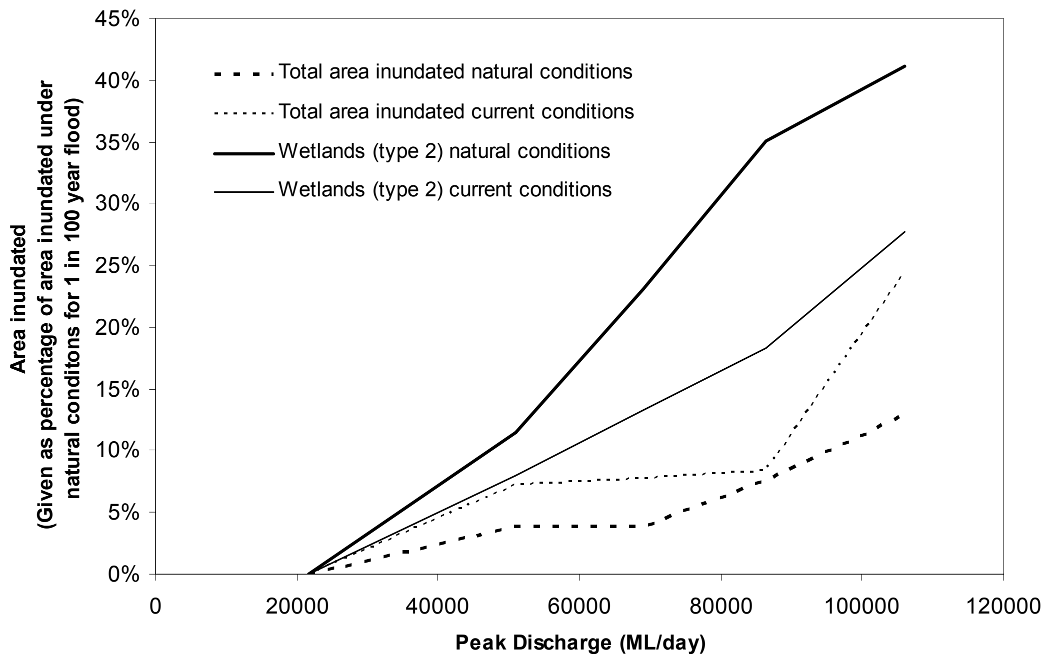


Figure 25: Percent of freshwater meadows and floodplain inundated under natural and current conditions.

The effect of flood management works along the lower Goulburn River is to reduce the area of wetlands inundated for any given event peak. Figure 26 shows the frequency of inundating the floodplain and wetlands as a proportion of the total area of floodplain and wetlands respectively. Flood control works and flow regulation have combined to result in a substantial reduction in the frequency and area of floodplain and wetland inundated (Figure 27). This suggests that while the intent of delivering an annual flood for wetland inundation has the same premise as for Reaches 1-4, wetland inundation in Reach 5 will require a review of Loch Garry operation and of key sections of river levee.

Recommendation: Floodplain and wetland inundation events designed for previous reaches should be allowed to pass through Reach 5. The position of levees and operation of the Loch Garry system should be reviewed so that the key areas of floodplain can be identified and the volume of water required for inundation can be optimised.

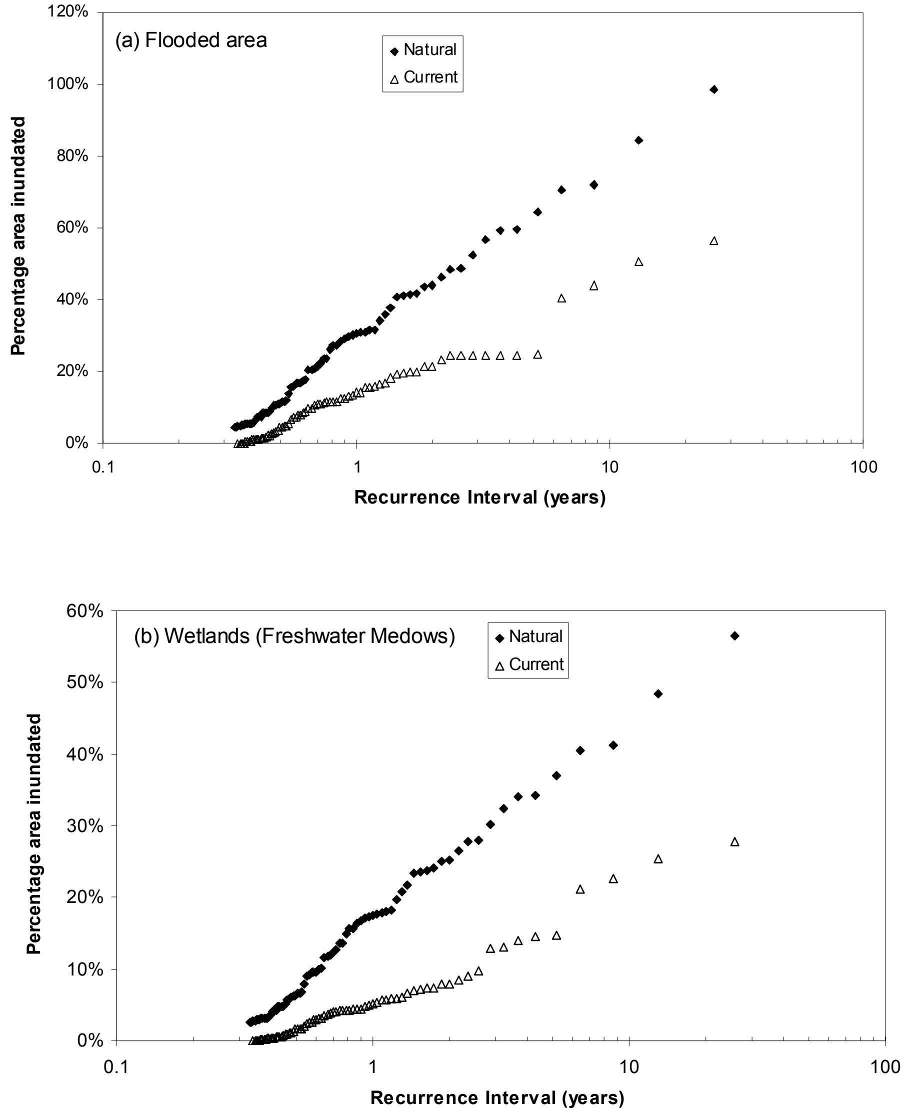


Figure 26: Recurrence interval for floodplain and freshwater meadow inundation of the lower Goulburn floodplain under current and natural conditions.

Current Regime Modelled Natural Regime

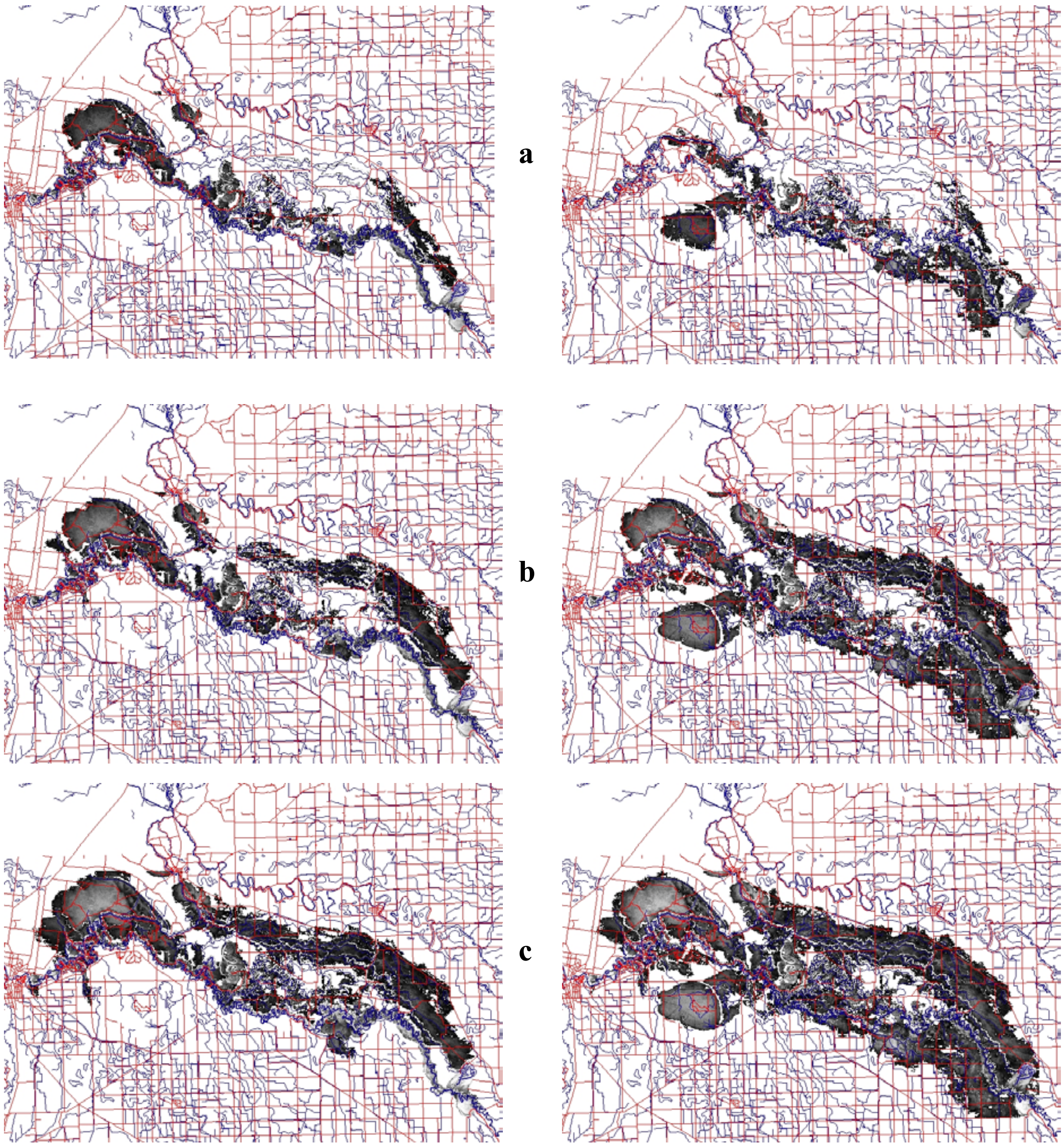


Figure 27: Comparison of floodplain inundation on the lower Goulburn floodplain for the current and modelled natural regimes (a = event of 50,000 ML/d peak magnitude, b = event of 86,000 ML/d peak magnitude, c = event of 103,000 ML/d peak magnitude). Note that the modelled natural regime includes removal of the influence of Loch Garry and levees.

4.6 Barriers to fish movement

The Scientific Panel examined the depths of river cross-sections under modelled natural and current flows to examine the influence of flow regulation on fish passage. This analysis showed that a large proportion of areas within each of the river cross-sections at all five reaches were suitable for fish passage throughout the year under current conditions, based upon a threshold depth criterion of 20 cm (Tunbridge 1988). It was decided, therefore, that no environmental flow recommendations are required to address this issue.

Recommendation: No flow recommendation is required.

4.7 Deep water habitat for fish

Overseas studies of patterns of fish habitat use have clearly demonstrated the importance of deep-water habitats in structuring riverine fish communities (Gorman and Karr 1978; Harvey and Stewart 1991). In particular, the availability of deep habitats has been shown to strongly influence the distributions of large bodied fish (Harvey and Stewart 1991). Although a number of potential functions of deep-water habitats have been identified, fish are primarily thought to utilise deep-water habitats as a means of avoiding terrestrial and aquatic predators (Power 1984). Research in Australian rivers has also shown that the adult stages of many larger native species rely heavily upon the availability of deep-water habitats. For example, Crook *et al.* (2001) showed that Golden perch exhibited strong preferences for deep pool habitats, particularly those greater than 1.5 m in depth, in the Broken River. Similarly, Koehn and Nicol (1998) found that Murray cod require relatively deep habitats with high loads of woody debris.

High summer irrigation releases have increased the amount of deep-water habitat (>1.5 m depth) available in Reaches 1-3. However, the current flow regime has resulted in the reduction of deep-water habitat in Reaches 4 and 5 (Figure 28), from late spring through to early winter (Figure 29). The Scientific Panel recognises the need for a low flow recommendation to protect deep-water habitat and suggests this be based on the 10th percentile value (or natural) in the modelled natural regime for March in Reach 4 (Figure 29). This is equivalent to a minimum flow of 610 ML/d, or natural.

Recommendation: The Scientific Panel recommends that flow in Reaches 4 and 5 is not to be less than 610 ML/d, or natural.

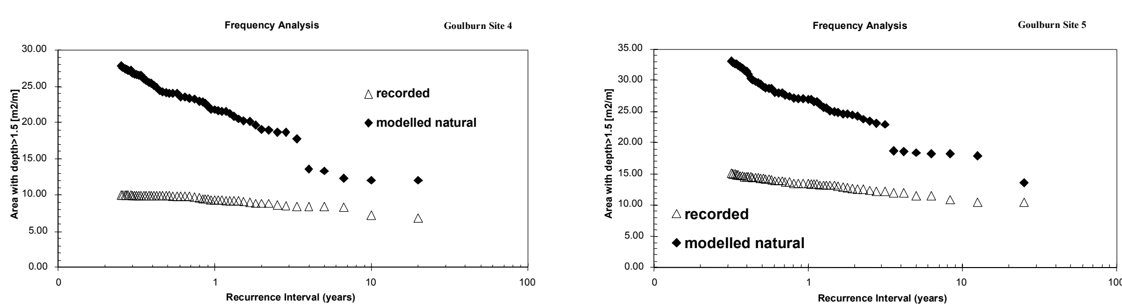


Figure 28: Comparison of deep-water habitat (>1.5 m depth) for the current (recorded) and modelled natural flow regime for Reaches 4 and 5.

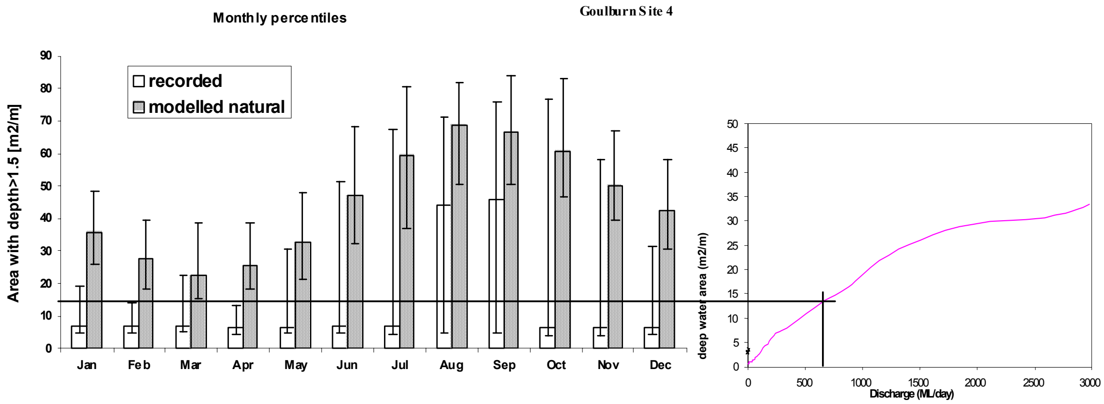


Figure 29: Deep-water habitat (>1.5m depth) available for fish in Reach 4. Column represents median deep-water habitat, whiskers represent the 10th and 90th percentile values.

4.8 Low flow events and low flow variability

Providing additional low flow variability has largely been covered in sections on floodplain and bench inundation and the maintenance of deep-water habitat for fish. One other issue considered by the Scientific Panel in relation to low flow conditions in Reaches 4 and 5 was the potential for poor water quality associated with water stratification in pools. McGuckin (1991b) found that saline groundwater intrusion led to salinity stratification and poor water quality in pools of the Loddon and Little Murray Rivers, such as low dissolved oxygen concentration and very high salinity. McGuckin (1991a) also investigated the potential for stratification in pools along the Goulburn River downstream of Shepparton. He concluded that there was a low risk of stratification in river pools when flow in the river was above 500 ML/d. The Scientific Panel examined minimum water velocity in Reaches 4 and 5 and found them to be consistently above 0.03 m/s. Persistent stratification is unlikely with such minimum velocities (Western and Stewardson 1999).

Recommendation: The Scientific Panel considered that there was no need for a recommendation to address potential water stratification in the Goulburn River.

4.9 Rate of rise and fall in water levels

The operation of dams and weirs to deliver irrigation water can result in larger than natural rates of rise and fall in water levels. Very high rates of rise may increase the risk of biota such as invertebrates and juvenile fish being washed from the system. Very high rates of fall may increase the risk that biota such as invertebrates and small fish are left stranded, and can contribute to increased rates of bank erosion.

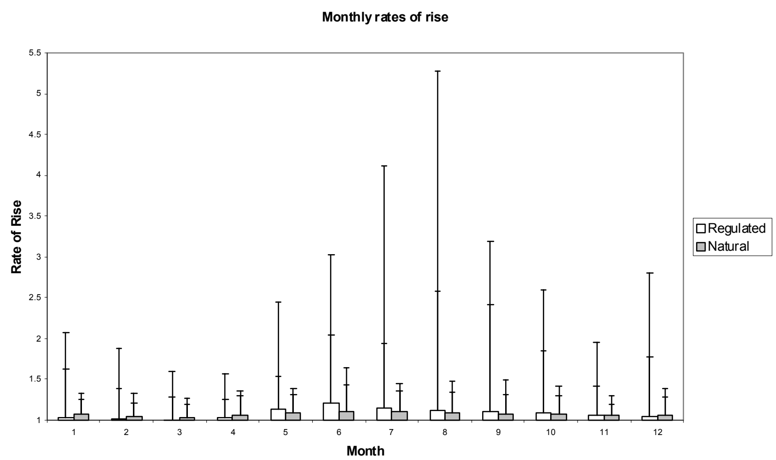
Rates of rise and fall (represented by discharge on day 2 relative to discharge on day 1, calculated as Q_{i+1}/Q_i) in the current regulated regime for each reach is similar to natural. However, there have been occasions when the rates of rise and fall exceed those that would have been experienced naturally (based on modelled natural 90th and 95th percentile values, Figure 30 and Figure 31). Presumably, this has been due to factors such as ramping flows up or down at the beginning and end of the irrigation season.

Recommendation: The Scientific Panel recommends that the 95th percentile of the maximum rates of rise and fall (Q_{i+1}/Q_i) be adopted for Reach 1 and Reach 4 (Table 10), the reaches that are directly affected by the management of Lake Eildon and Goulburn Weir. The values in Table 10 are based on the maximum rates of rise and fall that would be experienced in the modelled natural flow regime.

Table 10: Recommended maximum rates of rise and fall for each reach (Q_{i+1}/Q_i = flow on day 2 divided by the flow on day 1)

Q_{i+1}/Q_i	Reach 1	Reach 4
Maximum rate of rise	1.80	1.35
Maximum rate of fall	0.76	0.85

(a)



(b)

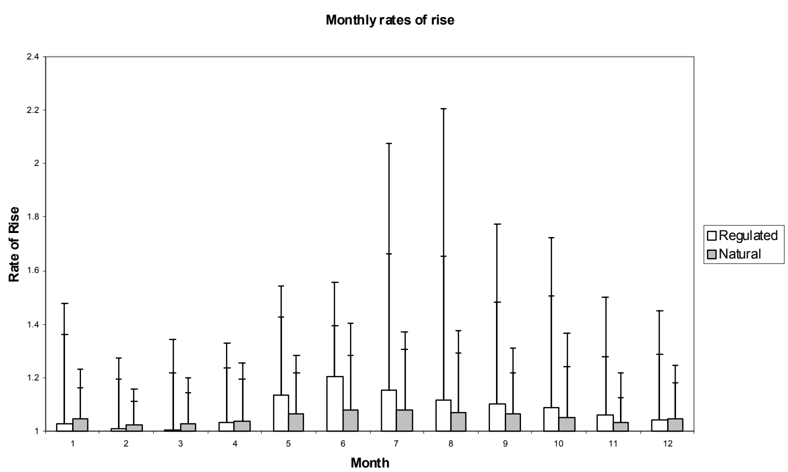
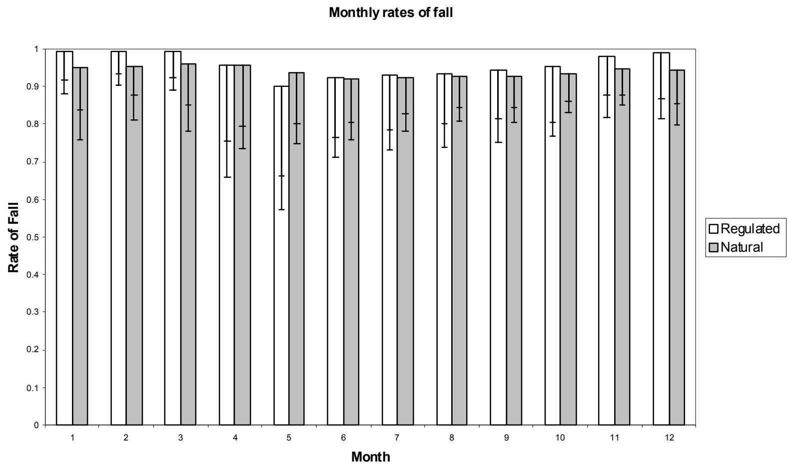


Figure 30: Rates of rise in the Goulburn River represented by discharge on day 2 relative to discharge on day 1, calculated as Q_{i+1}/Q_i for (a) Reach 4 and (b) Reach 5. Bars represent median values and whiskers represent 90th and 95th percentile values.

(a)



(b)

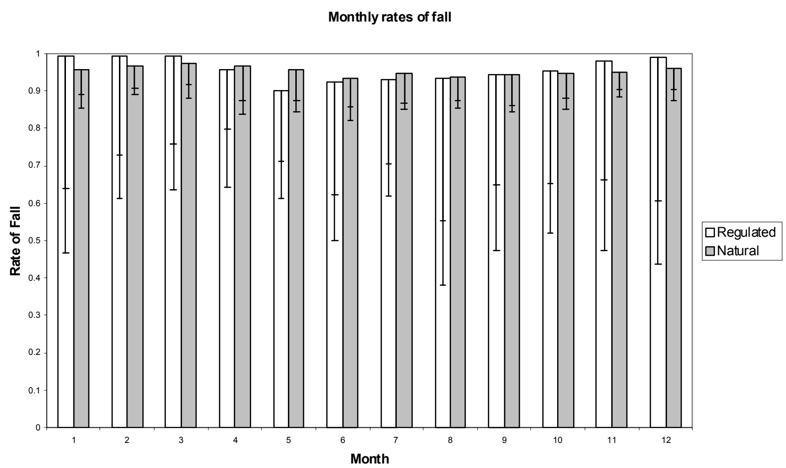


Figure 31: Rates of fall in the Goulburn River represented by discharge on day 2 relative to discharge on day 1, calculated as Q_{i+1}/Q_i for (a) Reach 1 and (b) Reach 4. Bars represent median values and whiskers represent 90th and 95th percentile values.

4.10 Summary of issues and flow-related ecological objectives

Not all issues identified through hydrologic analysis and field inspections were found to require environmental flow recommendations. Issues that are to be addressed with environmental flow recommendations are summarised in Table 11. The Scientific Panel has assigned the following priority (highest to lowest) to the implementation of recommendations, based on the levels of scientific justification and extent of potential impact:

1. Provision of an annual flood of varying magnitude;
2. Provision of deep water habitat for fish in Reaches 4 and 5;
3. Maximum summer-autumn flows in Reaches 1-3;
4. Experimental bench inundation in Reach 4;

5. Ensuring rates of rise and fall are below the 95th percentile values.

The current flow regime delivers the natural frequency of summer freshes in Reaches 4 and 5. The Scientific Panel recommends that future changes to the operation of Goulburn Weir (e.g. more efficient ordering and delivery of irrigation flows) do not reduce the natural frequency and magnitude of summer freshes flowing down the Goulburn River.

Table 11: Summary of issues requiring environmental flow recommendations

Issue	River Attribute	Reach	Flow Component	Flow Recommendation
Inversion of the flow regime in Reaches 1-3:				
• High water velocity	• In-channel macrophytes	1, 2, 3	Summer low flows	Adoption of a precautionary approach suggests indicative summer-autumn base flows below 1,000 – 3,000 ML/d in Reach 1. Further investigations are required to better quantify environmental flow recommendations.
• Duration of bench inundation	• Aquatic macrophytes • Macroinvertebrates • Biogeochemical processes (e.g. cycling of carbon and nutrients)	1, 2, 3, 4	Spring low flow Summer low flow	
• Availability of riffle habitat	• Macroinvertebrates • Fish	1, 2, 3	Summer low flow	
• Availability of shallow water habitat	• In-channel macrophytes • Small fish	1, 2, 3	Summer low flow	
Frequency of freshes	• Geomorphology • Aquatic macrophytes • Macroinvertebrates • Fish	4, 5	Summer freshes	Current frequency of freshes maintained, with natural magnitude and duration.
Frequency of wetland inundation	• Geomorphology • Wetland vegetation • Macroinvertebrates • Fish	1, 2, 3, 4, 5	Spring flood	Annual flood of varying magnitude (15,000 – 60,000 ML/d peak magnitude). No action required if floods occur naturally.
Duration of bench inundation	• In-channel macrophytes • Macroinvertebrates		Spring and summer low flow/freshes	Experiment to evaluate extended duration of bench inundation events
Availability of deep water habitat	• Fish	4, 5	Summer low flow	Minimum flow of 610 ML/d measured at Murchison.
Rate of rise and fall in river levels	• In-channel macrophytes • Macroinvertebrates • Fish	1, 2, 3, 4, 5	Rate of rise and fall	No specific flow volume required. Care is required to avoid rates of rise and fall exceeding 95^{th} percentile values of the natural flow regime.

4.11 Constraints on environmental flow recommendations and complementary river management actions

The Scientific Panel considered a number of operational and environmental constraints, as well as complementary management actions, as it developed its environmental flow recommendations. The ecological condition of the Goulburn River is the result of many factors operating at different spatial and temporal scales. Many of these factors may not be directly related to the flow regime of the river but can certainly reduce or confound the potential effects of environmental flows when they are delivered.

4.11.1 Constraints that may impinge on environmental flow recommendations

The Scientific Panel identified a number of potential constraints that may affect the ecological outcomes sought by implementing its environmental flow recommendations:

- Releases from Lake Eildon are governed by a number of physical constraints (B. James, DSE, pers. comm.):
  - ➢ Release capacity via the Power Station is approximately 17,000 ML/d, depending on the volume of water in storage in Eildon. Some additional pipes allow the power station to be by-passed. However, there is very little information regarding the amount that can be released, and any restrictions on the release. Irrigation releases are currently restricted to a maximum 12,000 ML/d to avoid flooding downstream of the dam;
  - ➢ Up to 10,000 ML/d (depending on storage levels) can also be released through the spillway valves if the level in Lake Eildon is greater than 256 m (approx 600 GL); and
  - ➢ Water can also be released over the spillway gates once the storage level in Lake Eildon exceeds 2625 GL.
- Ecological outcomes expected when addressing issues related to the seasonal flow inversion below Lake Eildon (e.g. setting upper limits on summer-autumn releases) may be reduced or negated if cold water from low-level offtakes is released from Lake Eildon in summer.
- The Panel does not have sufficient resources to model the salinity implications of any of its recommendations.
- High demands for Goulburn water from outside of the catchment and potential future demands, for example in providing more water for the Murray River.
- Balancing differences in the volumes required to inundate floodplain areas in middle reaches with that of downstream reaches.
- Unknown but extensive changes to surface and connections (eg small block banks, excavated channels into and out of wetlands).
- Land management practices, particularly unrestricted grazing by livestock in wetlands and the riparian zone.
- The maintenance of Lake Nagambie as an important recreation and social amenity.

Ecological and socio-economic risks associated with environmental flow recommendations are identified in Chapter 4.12.

4.11.2 Complementary River Management Actions

The reintroduction of elements of the natural flow regime, like most ‘restoration’ activities, is based on the assumption that if missing components of the natural habitat are reinstated then parts of the ecosystem (function or biota) that depended on those components will also return. Experience has shown that this is often the case. However, we also know that reinstating flow components, or other aspects of the physical environment, will not be effective if other factors prevent the ecosystem from responding in the required way. For instance a minor flood cannot be expected to reset wetlands and sweep organic material from the floodplain into the river if its lateral movement is curtailed by levees and/or floodplain land-use has removed the sources of organic material. Likewise, inundation of river benches will not result in healthy riverine plant communities if their seed-bank is too depleted (unlikely in the Goulburn) or if heavy grazing prevents their regrowth. This means that when considering the reinstatement of components of the river's hydrology it is also necessary to protect the desired ecological outcomes through appropriate complementary management actions. Complementary (non flow-related) management actions considered important by the Scientific Panel include:

- Amelioration of cold water release from Lake Eildon if measures to address seasonal flow inversion issues in Reaches 1-3 are addressed;
- Retention of the ban on gravel extraction from the river;
- Review and removal of unnecessary levees and block banks;
- Controlled management of livestock from the riparian zone and wetlands;
- Continuation of rabbit control measures;
- Provision of fish passage past Goulburn Weir;
- Continued implementation of carp control strategies;
- Continued implementation of the Goulburn Broken water quality and revegetation strategies.

4.12 Risks associated with implementing environmental flow recommendations

All river management activities carry with them the potential for ecological or socio-economic risk. The Scientific Panel acknowledged that there are a number of risks associated with the implementation of its environmental flow recommendations and that these risks require more detailed consideration as the Living Murray initiative progresses:

Potential ecological risks:

- Assuming nutrient loads from point sources remain the same, then summer nutrient concentrations may increase in Reaches 1-3 if flows are reduced to less than 3,000 ML/d. The magnitude of any increase in concentration requires further investigation.
- Reduced summer flow may result in increased summer water temperature in the river below Lake Eildon. The magnitude of this increase requires investigation and implications for ecological processes considered (e.g. increased algal growth, reduced dissolved oxygen concentration).
- Repeated wetting and drying has the potential for limiting nutrient cycling on benches in Reaches 1-3 due to carbon limitation, increased reliance on external sources of nitrate for coupled nitrification-denitrification and decreased release of phosphorus from sediments.
- Increased connection between sections of the river and its floodplain may increase the ease with which carp may spread across the study area and can provide conditions suitable for carp breeding (Brown *et al*. 2003, Koehn *et al*. 2000, Stewart and Jones 2002).
- Floodplain and wetland inundation may increase the rates of localised bank erosion where the riparian zone is in poor condition or where desnagging has left the bank unprotected.

Potential socio-economic risks:

- Reduced volumes of water available, and reduced security of supply for irrigators and other users if water is released for environmental purposes such as annual floods, bench inundation, or minimum flows to provide deep water habitat for fish.

- Restrictions placed on irrigators and water users if upper limits on summer-autumn releases are applied. The water would be in storage, and of a higher security, but cannot be transferred to water users at the time required due to the release limits applied.
- Increased flooding frequency and duration and therefore risk to private land and infrastructure.
- Reduced recreational opportunities if upper limits on summer-autumn releases are applied.

The Goulburn-Broken Catchment Management Authority is undertaking a preliminary assessment of socio-economic impacts. Results so far have identified potential economic and social impacts ranging from minor to large (W. Tennant, GBCMA, pers. comm.). Further, more detailed evaluations are recommended to better quantify these potential impacts.

5 COMPARISON OF THE PREFERRED ENVIRONMENTAL FLOW REGIME WITH LIVING MURRAY REFERENCE POINTS

The Scientific Panel compared the increase in flows to the Murray River resulting from implementing various combinations of its flow recommendations, ecological target (seasonal inversion mitigation) and other scenarios, with the Goulburn's likely contribution towards the Living Murray reference points of 70 GL, 150 GL and 300 GL per year on average (Table 12). The REALM model for the Goulburn River was used to assess the monthly volumes associated with the scenarios over a 112 year period, including the volume of water that would be delivered to the Murray River and the impact on diversion volumes. *It is emphasised that the volumes associated with each scenario are indicative only. Further investigations, such as the best way to supplement tributary inflows to provide annual wetland inundation flows, are likely to identify savings from the volumes identified in Table 12, while still meeting ecological objectives.*

Table 12 shows the model run with its run number, the flow-related ecological issue(s) being addressed, specific details of how a flow rule might be implemented, and how much additional water is estimated to reach the River Murray.

Limiting summer releases from Lake Eildon to below flows ranging from 1,000 ML/d to 3,000 ML/d has the potential to realise average volumes between 360 and 700 GL per year for the Murray River (refer to run I803). These volumes are well in excess of all the Living Murray reference volumes. The flow regime that would result would be very close to natural (see Figure 32 to Figure 34) and would severely limit the water available to users, such as the irrigation industries.

Other model runs focus on the return of an annual flood (based on Reach 1, refer to run number L803), minimum flows in Reaches 4 and 5 to maintain deep-water habitat (based on Reach 4, refer to run number H803) and experimental increases to the duration of summer bench inundation events in Reach 4 (refer to run number N803). Figure 35 to Figure 36 illustrate the change in flow frequency for each of the flow scenarios, at each reach. Modelling results suggest that:

- The Goulburn's likely contribution to the first Living Murray reference volume (70 GL) can easily meet minimum deep-water habitat requirements in Reaches 4 and 5 (which result in an increase in flow to the Murray of 56 GL per year on average);
- The Goulburn's likely contribution to the second Living Murray reference volume (150 GL) can easily meet minimum deep-water habitat requirements and support an experimental increase to the duration of summer bench inundation events (which result in an increase in flow to the Murray of 115 GL per year on average);
- The Goulburn's likely contribution to the third Living Murray reference volume (300 GL) can easily provide the package of annual floodplain/wetland inundation, maintenance of minimum deep-water habitat and (experimental) extended duration of spring or summer bench inundation (which result in an increase in flow to the Murray of 220 GL/year on average).

However, further investigation on how to optimise the delivery of these recommendations may well indicate that the preferred recommendations can be met with the second Living Murray reference volume of 150 GL per year on average.

Table 12: Implications of modelled scenarios for water delivered to the Murray River

Run No.	Issue Addressed	Specifics	Extra volume to the Murray	Decrease in diversions	Impact on provision of 100% water right for 112 years modelled	Comments
0800	• Base run	• Current conditions	-	-	-	-
H803	• 1.5 m deep habitat for fish	• Minimum releases from Lake Eildon as per BE (120 - 250 ML/d) (No other minimum for Reaches 1 – 3) • Minimum of 610 ML/d or natural for Reaches 4 and 5 (downstream of Goulburn Weir)	56 GL	52 GL	Years with below 100% water right increases from 4 to 5	• Volume required easily met by the first Living Murray reference point • 1.5 m is the preferred deep water habitat rather than 1.0 m, which is tolerated
N803	• Spring and summer bench inundation in Reach 4 • 1.5 m deep habitat for fish	• Minimum releases from Eildon (120 - 250 ML/d) • Minimum 610 ML/d or natural for Reaches 4 and 5 • Extended bench inundation in spring and summer (inc 1 event of 4,700 ML/d) for Reach 4	115 GL	115 GL	Years below 100% water right increases from 4 to 9	• Releases from Eildon constrained by current physical release capacity
L803	• Wetland and floodplain inundation • Mobilisation of fines from armour layer • 1.5 m deep habitat for fish	• Minimum releases from Eildon (120 - 250 ML/d) • Minimum flow of 610 ML/d or natural for Reaches 4 and 5 • Wetland flooding requirements based on Reach 1	158 GL	174 GL	Years below 100% water right increases from 4 to 20	• Releases from Eildon constrained by current physical release capacity
O803	• Wetland and floodplain inundation • Mobilisation of fines from armour layer • 1.5 m deep habitat for fish • Spring and summer bench inundation experiment	• Minimum releases from Eildon (120 - 250 ML/d) • Minimum 610 ML/d or natural for Reaches 4 and 5 • Extended spring and summer bench inundation for Reach 4 (inc 1 event of 4,700 ML/d) • Wetland flooding requirements based on Reach 1	223 GL	245 GL	Years below 100% water right increases from 4 to 24	• Releases from Eildon constrained by current physical release capacity.
I803	• Summer flow inversion • 1.5 m deep habitat for fish	• Minimum releases from Eildon (120 – 250 ML/d) • Minimum 610 ML/d or natural for Reaches 4 and 5	364 GL	354 GL	Always above 100% due to limited summer release from Eildon – note: this means that while 'security'	• Volume provided exceeds all the Living Murray reference points

Run No.	Issue Addressed	Specifics	Extra volume to the Murray	Decrease in diversions	Impact on provision of 100% water right for 112 years modelled	Comments
		Reaches 4 and 5 • Maximum summer irrigation release from Lake Eildon of 2700 ML/d in January, and 1700 ML/d in February and March			is high, release limits will restrict access to the water by users	• Tributary inflows sometimes make flows exceed the summer maxima
P803	• Mobilisation of fines from armour layer • 1.5 m deep habitat for fish • Spring and summer bench inundation experiment • Wetland and floodplain inundation • Summer flow inversion	• Minimum releases from Eildon (120 - 250 ML/d) • Minimum 610 ML/d or natural for Reaches 4 and 5 • Extended spring and summer bench inundation for Reach 4 (inc 1 event of 4,700 ML/d) • Wetland flooding requirements based on Reach 1 • Maximum summer irrigation release from Lake Eildon of 2700 ML/d in January, and 1700 ML/d in February and March	413 GL	413 GL	Years below 100% water right decrease from 4 to 1 due to limited summer release from Eildon – note: this means that while 'security' is high, release limits will restrict access to the water by users	• Volume provided exceeds all the Living Murray reference points • Tributary inflows sometimes make flows exceed the summer maxima • Releases from Eildon constrained by current physical release capacity.

Flow Frequency Plot Annual series - Site G1

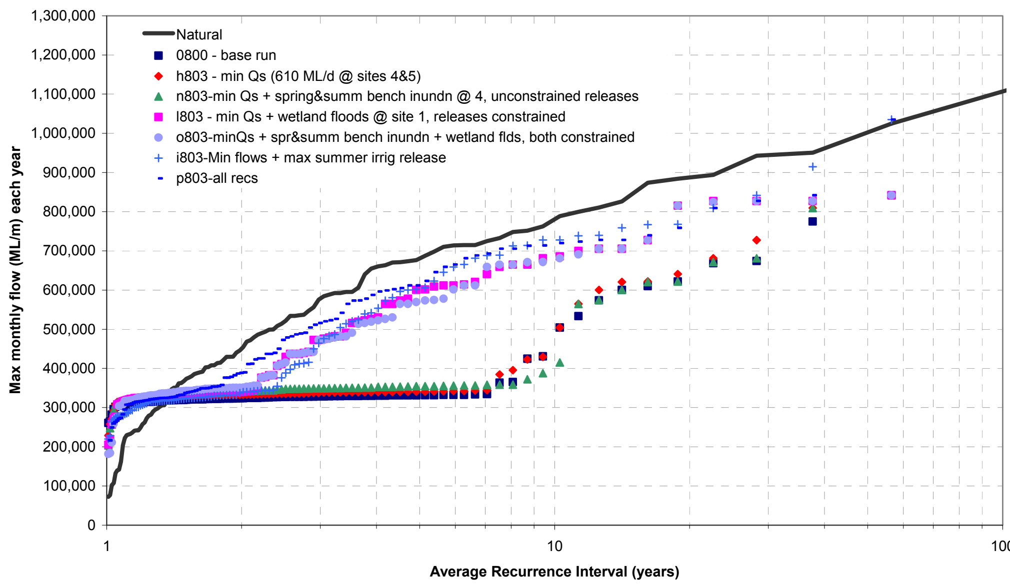


Figure 32: Comparison of flow frequency in Reach 1 for different scenarios considered by the Scientific Panel (see Table 12 for details of model runs)

Flow Frequency Plot Annual series - Site G2

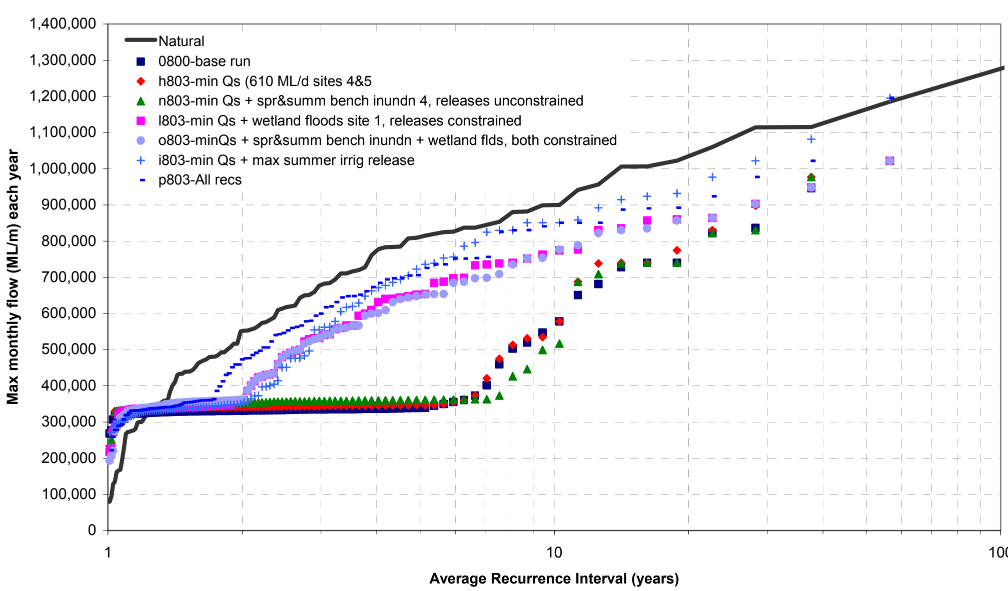


Figure 33: Comparison of flow frequency in Reach 2 for different scenarios considered by the Scientific Panel (see Table 12 for details of model runs)

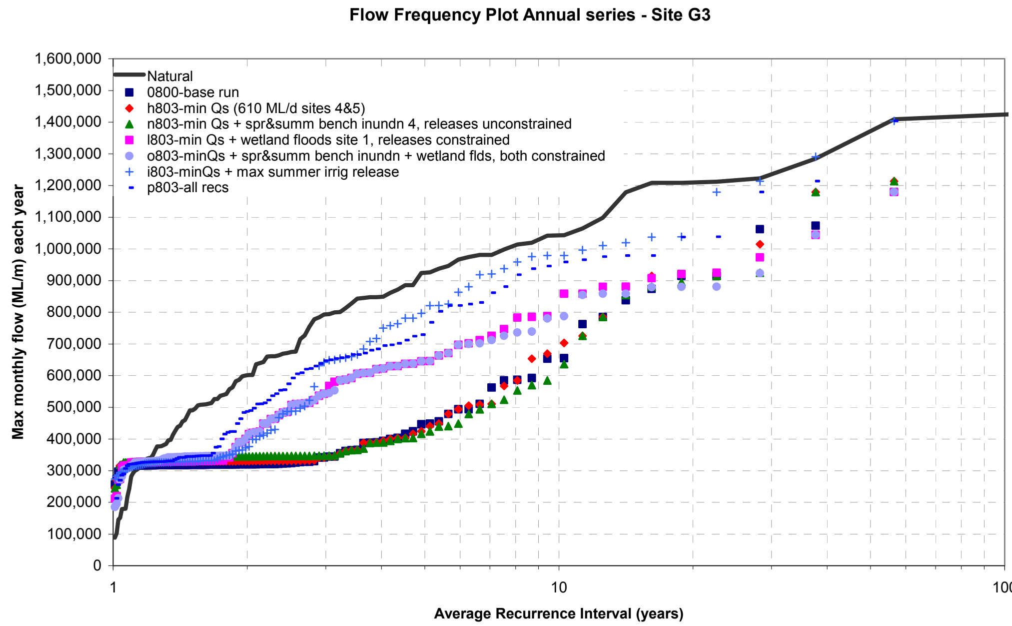
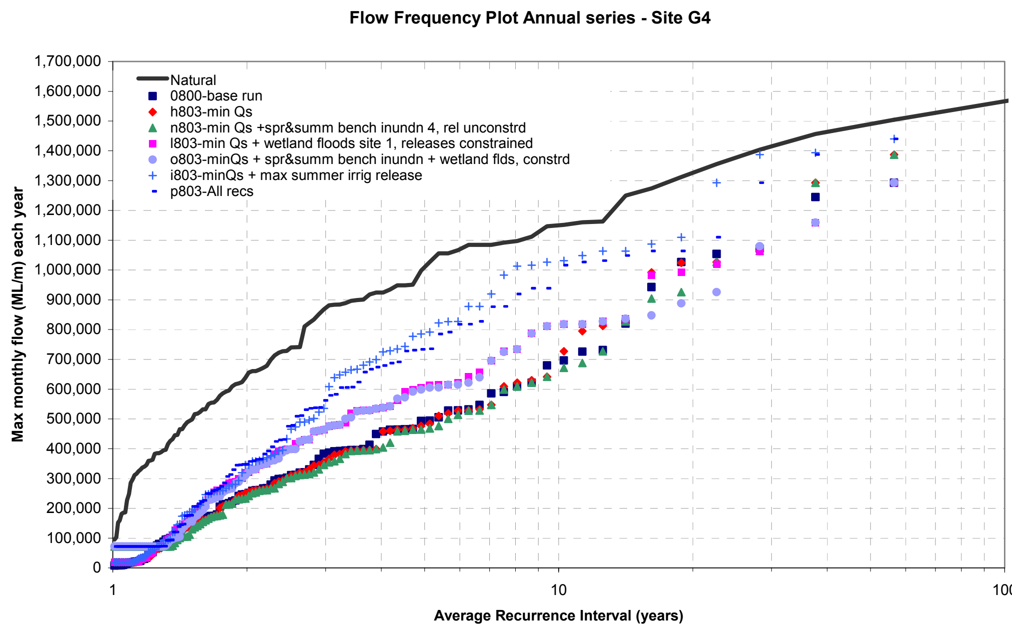


Figure 34: Comparison of flow frequency in Reach 3 for different scenarios considered by the Scientific Panel (see Table 12 for details of model runs)



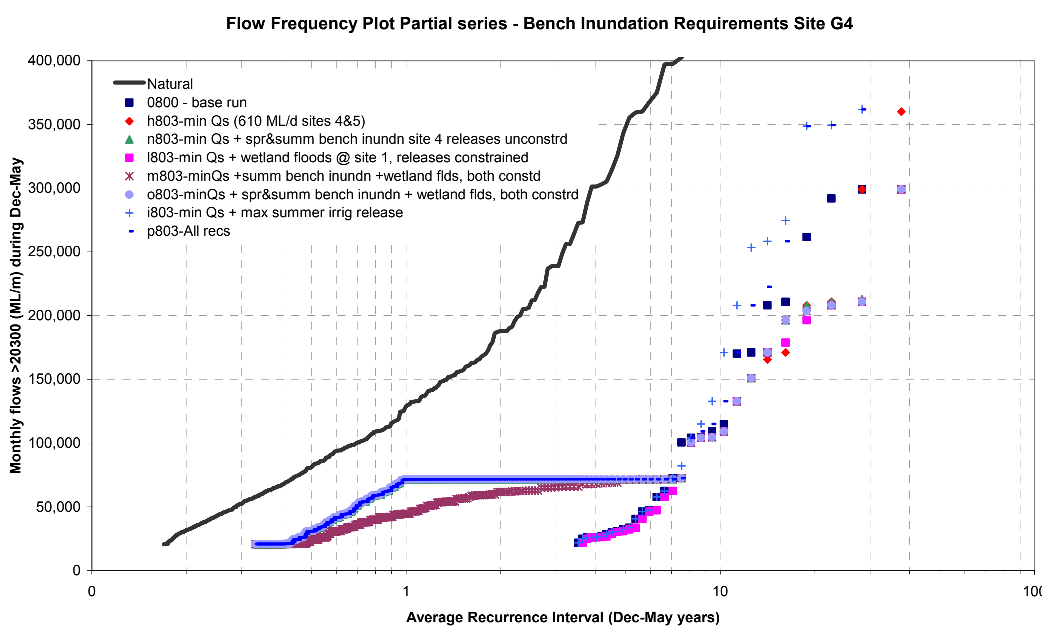
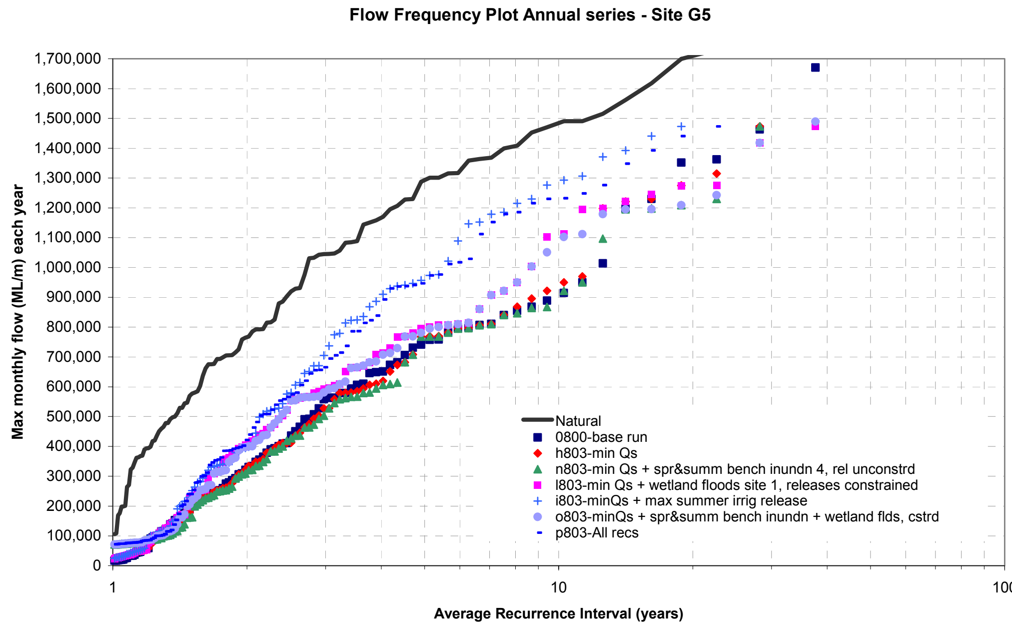


Figure 35: Comparison of flow frequency in Reach 4 for different scenarios considered by the Scientific Panel (see Table 12 for details of model runs)



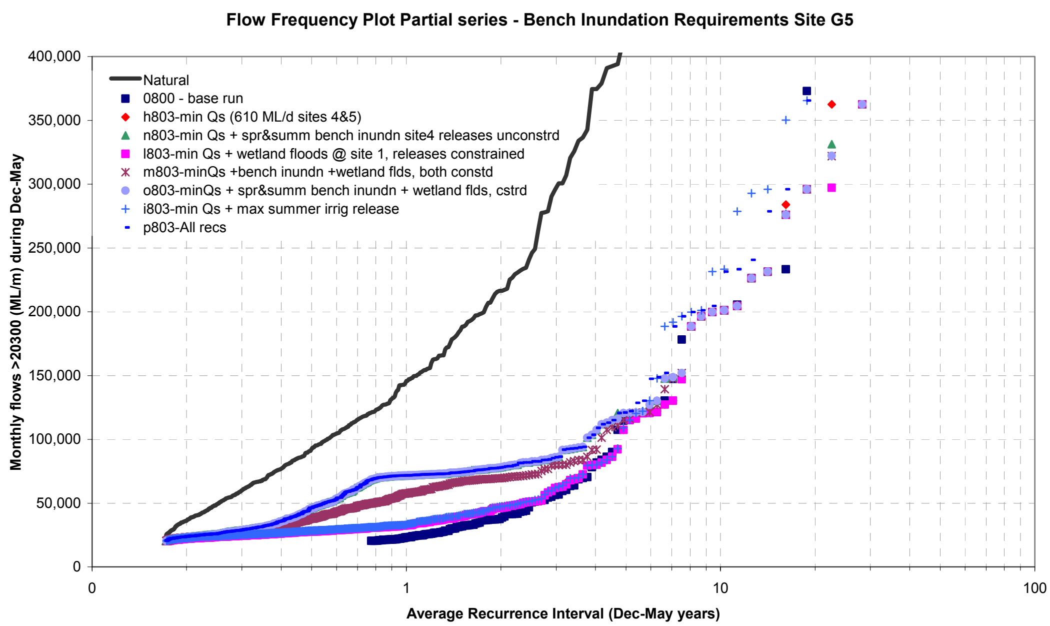


Figure 36: Comparison of flow frequency in Reach 5 for different scenarios considered by the Scientific Panel (see Table 12 for details of model runs)

6 MONITORING THE EFFECTIVENESS OF FUTURE ENVIRONMENTAL FLOWS

The implementation of environmental flow recommendations should be conducted as part of an adaptive management experiment, where the recommendations are linked to specific hypotheses that are tested and evaluated. The results can then be used to inform the future management of the Goulburn River. Potential hypotheses to consider as part of an adaptive management program for the Goulburn River are presented in Table 13.

Table 13: Hypotheses, expected outcomes and suggestions for monitoring environmental flow recommendations

Issue	Hypotheses	Action	Outcome	Monitoring
Frequency of wetland inundation	• Wetland inundation events are of sufficient magnitude to mobilise the fine sediments that accumulate on gravel substrate in Reaches 1-3 • A more natural wetting and drying pattern will increase wetland vegetation diversity and abundance • A more natural floodplain connectivity will increase invertebrate diversity in wetlands and the river channel • Wetland inundation will maintain habitat available for wetland specialist fish	• Provide an annual flood of varying magnitude (15,000 – 60,000 ML/d peak magnitude) if required.	• Fine sediments flushed from gravel substrates in Reaches 1-3 • Floodplains and wetlands have a pattern of wetting and drying closer to natural • Increased macrophyte diversity in wetlands • Increased abundance and diversity of macroinvertebrates • Increased abundance and diversity of wetland specialist fish	• Sediment particle size analysis (annually) • Floristic and structure of aquatic and riparian vegetation (spring and autumn) • Invertebrate populations in the river and wetlands (spring and autumn) • Fish populations in the river and wetlands, including larval and juvenile (spring and autumn)
Duration of bench inundation	• Extended duration of bench inundation will significantly increase rates of primary productivity and respiration • Extended duration of bench inundation will favour native, aquatic and amphibious species over introduced and terrestrial species • Increased primary production and available habitat will result in increased invertebrate abundance and diversity	• Experiment to evaluate extended duration of bench inundation events	• Extended bench inundation increases river productivity and respiration • Increased abundance and diversity of macroinvertebrates due to increased habitat and resource availability • The proportion of introduced or terrestrial plant species reduced	• Rates of productivity and respiration on benches (during inundation events) • Invertebrate populations (during inundation events) • Vegetation community structure (annually) • Community structure of plant and invertebrate seed banks (annually)
Availability of deep water habitat	• Minimum flow of 610 ML/d or natural measured at Murchison will provide area of deep water habitat within	• Provide minimum flow of 610 ML/d or natural measured at	• Deep water habitat for fish within natural range	• Adult fish populations (spring and autumn)

Issue	Hypotheses	Action	Outcome	Monitoring
	natural range	Murchison.		
Rate of rise and fall in river levels	• In-channel macrophytes • Level changes are sufficiently slow to allow riffle macroinvertebrates to move to appropriate habitats during rises and to avoid excessive stranding during falls. • Fish	• Ensure rise and fall remains below natural maxima	• Risks associated with washout or stranding of biota and increased rates of bed and bank erosion minimised	• Rate of change in flow below Lake Eildon and Goulburn Weir • Rate of drift and stranding in macroinvertebrate communities
Fine sediment contamination	• Settlement of fine sediment on surfaces reduces primary productivity in macrophytes and biofilm • Fine sediment disadvantages some macroinvertebrate taxa.	• Ensure occasional freshes resuspend and move fine sediment (Note: levels of fine sediment may be significantly above 'natural' levels).	• Macrophyte and biofilm productivity optimised (including ratio of water column v. surface production?) • Improved O/E scores for edge and snag macroinvertebrates.	• Primary productivity measurements • Organic/inorganic ratios in biofilms. • Macroinvertebrate community assays.

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APPENDIX 1 ISSUES PAPER

Flow-related environmental issues associated with the Goulburn River below Lake Eildon