Evaluation of summer inter-valley water transfers from the Goulburn River

Prepared for the Goulburn-Broken Catchment Management Authority

by

Peter Cottingham, Mike Stewardson, David Crook, Terry Hillman, Rod Oliver, Jane Roberts and Ian Rutherfurd

June 2007

Evaluation of summer inter-valley water transfers from the Goulburn River

Prepared by Peter Cottingham & Associates on behalf of the Goulburn Broken Catchment Management Authority

CITATION:
This report can be cited as:
Cottingham P. Stewardson M., Crook D., Hillman T., Oliver R., Roberts J. and Rutherfurd I. (2007). Evaluation of summer inter-valley water transfers from the Goulburn River. Report prepared for the Goulburn Broken Catchment Management Authority.

COVER PHOTOGRAPH:
Goulburn river at Murchison (top) and Goulburn River near Kerrisdale (bottom), October 2003. Photographs by Peter Cottingham.

Executive Summary

The expansion of water markets and resultant inter-valley trade has the potential to increase water demand in areas such as the Sunraysia district in north-west Victoria. The Goulburn-Broken system is pivotal in meeting any increase in demand in this region, given constraints on delivering additional water from Lake Hume (e.g. due to the Barmah Choke) and limited additional storage capacity along the River Murray. Inter-Valley Transfers (IVTs), when required, are most likely to be delivered between January and March and there is concern about the risk posed by higher than natural summer and autumn flows to Goulburn river assets and values if IVTs are to be delivered solely via the lower Goulburn River.

An environmental flow study conducted in 2003 was used to examine how water that might be released from Lake Eildon to the River Murray as part of the Living Murray Initiative could be used to protect or enhance the ecological condition of the Goulburn River. The study recommended that minimum summer-autumn flows could be increased to above 610 ML/d to maintain habitat availability for native fish. No upper bounds were put on this recommendation, as the need for frequent or increasingly large IVTs delivered via the Goulburn River was not then identified. The study was not part of any formal review of the existing Goulburn Bulk Water Entitlement, and could only make limited assessments of future scenarios, as there was at that time no information on the volume and timing of water that might be required for the River Murray. The question of whether IVTs can be delivered in a manner that poses little risk, or result in a gain to ecosystem assets and values was not addressed.

The Scientific Panel that developed environmental flow recommendations in 2003 was reconvened to consider the implications of IVTs for the lower Goulburn River. This work also provided the principles and basis from which to assess the implications of IVTs delivered via nearby rivers (i.e. Campaspe and possibly the Loddon) in the future. Rules for inter-valley water trade currently reflect capacity and delivery constraints and commercial and contractual obligations, and do not yet formally consider potential environmental effects. This project will also help inform any future review of trading rules that includes principles and provisions for environmental protection.

The study area is the two representative reaches below Goulburn Weir identified in the previous environmental flow study of the Goulburn River:

- Goulburn River: Goulburn Weir to Shepparton (Reach 4);
- Goulburn River: Shepparton to the River Murray (Reach 5).

This report describes:

- Changes to river hydrology and operation expected with the delivery of IVTs (Chapter 2),
- Ecological principles and criteria by which IVTs are assessed in terms of potential risk to ecosystem assets and values (Chapter 3),
- The conceptual basis of ecosystem response to IVTs (Chapter4),
- Ways in which IVTs may be released in order to protect or enhance ecosystem assets and values (Chapter 5),

- Previous environmental flow recommendations and presents them in a way that enables DSE to undertake water system modelling (Chapter 6), and
- Elements that should be considered as part of a monitoring and evaluation program (Chapter 7).

The Panel adopted a number of guiding principles when deliberating on recommendations in relation to summer IVTs:

- IVTs must, where possible, be consistent with the intentions of previous environmental flow recommendations and considerations.
- IVTs must not lead to a decline in ecosystem condition, structure or function, and be used to improve conditions if possible.
- IVTs must not be to the detriment of existing regional, State or national programs or strategies for river protection and rehabilitation.
- IVTs will be considered in terms of their potential impacts on components of the natural flow regime that are considered important for ecosystem function and the protection or rehabilitation of assets and values.
- IVTs will be considered in terms of re-introducing missing components of a natural flow regime, from the perspective of the total flow regime (including intra- and inter-annual variability), and in terms of potential negative ecosystem impacts due to the inversion of the natural seasonal pattern of flow.

The Panel was appointed to provide an ecosystem perspective of the implications of future IVTs. While it is recognised that IVTs have potential economic and social implications, considering these was beyond the scope of this project.

The Panel considered its previous recommendations, and the potential for achieving ecological benefits as well as potential problems that might arise with IVTs. Flow-related ecological objectives from the perspective of various riverine attributes (river geomorphology, riverine productivity, aquatic and bankside vegetation, macroinvertebrates and native fish) were considered in relation to changes to the flow regime as a result of IVTs. This provided the conceptual basis for identifying flow stressors or elements of ecological significance (e.g. flows that affect the amount and timing of habitat available to riverine plants and animals). These flow stressors and elements were modelled and the Panel then identified limits that (i) were considered to pose little risk to achieving flow-related ecosystem objectives and (ii) that represented the boundary of a moderate risk to ecological objectives; beyond this boundary and the flow elements were considered to pose a high risk to achieving ecosystem objectives. The 26 flow elements considered by the Panel related to issues such as:

- Mean residence time;
- Euphotic depth in relation to mean depth;
- Shear stress;
- Variability in water level fluctuations;
- Periods of inundation at various stage heights;
- Rates of rise and fall.

In summary:

- For each ecological objective, relevant flow stressors (characterised by one or more flow elements) were identified and analysed for one or more seasons; and
- Inter-annual variability in these flow stressors/elements was characterised by five percentiles of the annual series plus the minimum and maximum values and these percentiles are calculated for the pre- and post-regulation series.

The environment flow method used in this project is a development of the FLOWS method adopted for many environmental flow studies across Victoria. The four main improvements are as follows.

- Previous studies using the FLOWS method have often recommended a changes to a single flow component in order to achieve multiple environmental objectives. While a pragmatic approach, there is often little transparency around the specification of and individual flow component and how it relates to each objective. This study took the approach of recommending the flows believed necessary to achieve individual environmental objective.
- Previous studies have recommended static environmental flows that allowed for little variation between years. This study explicitly deals with inter-annual variability, allowing more flexible operation of the water resource and the protection of important inter-annual variation in flows.
- This project has also provided two levels of environmental flow recommendation (i) the recommended environmental flow to achieve the environmental flow objective with a high degree of confidence (low risk) and (ii) a flow that represents a "moderate risk" to achieving the environmental flow objective. These two levels are provided in recognition of the inherent uncertainty in flow-ecology linkages and the need to trade off environmental risks with consumptive water use. The bounds associated with these two levels are based on best-available scientific information and the opinion of Scientific Panel members.

These developments, while an advance in considering flow variability, mean that there is an increased number of flow recommendations for each reach. These recommendations are expressed in tables within this report and are also presented in an accompanying decision support tool (DST), which can be used to evaluate the compliance of any proposed flow regime with the regime recommended by the Panel. Panel recommendations were based on deviations from modelled pre-regulation conditions and provide an envelope within which water authorities can operate the river whilst still achieving environmental flow objectives.

The DST is in the form of a Microsoft Excel spreadsheet that has been developed to help assess the implication of various IVT scenarios. A separate DST has been established for each study reach, containing the relevant ecological objectives, the flow stressors and elements, and bounds for individual flow elements to be achieved during the relevant season. The spreadsheets automatically update and present results as colour codes that indicate compliance against the flow recommendations of the Panel:

- Green indicates compliance against the recommended bounds;
- Yellow indicates compliance against the moderate risk bounds; and

- Red indicates the flow scenario does not comply with the moderate risk bounds.

Environmental flow recommendations made by the Panel apply to three different aspects of the flow regime:

- the frequency distribution of flows,
- flow spells, and
- the rates of rise and fall in stage

In applying the DST, it is suggested that attention be paid firstly to recommendations for the median year as a means of considering 'typical' conditions (although recognising the potential for year to year variability). Recommendations may be expressed in terms of the magnitude or the duration of a particular flow event, or even in the magnitude of a habitat metric (which might have an inverse relation with flow). After considering results for median years, consideration may be given to the examination of absolute maximum and minimum recommendations (the maximum and minimum values for the metric over the period of record, 1975-2000) and the recommendations for other "percentile years" to provide more detail on the inter-annual distribution for the particular flow element.

Given the variability that has been considered, a simple summary of results is difficult. As an example however, examination of the upper and lower bounds for flow duration relevant to ecological objectives for Reach 4 provide some interesting observations for a median year:

- Recommended lower limits to achieve macroinvertebrate and native fish objectives are such that discharge in the range 310 - 856 ML/d should be exceeded for between 95% and 100% of the time all year round. This is consistent with the previous Panel recommendation of a minimum flow of 610 ML/d or natural.
- Summer flows up to 1,500 ML/d can occur for 90% of the time with little risk to ecological objectives, but should only exceed 1,660 ML/d for 63% of the time, 2,220 ML/d for 40% of the time, and 3,140 ML/d for 20% of the time. Should water managers choose to adopt a moderate level of risk, then the proportion of time each of these discharges may be exceeded can be increased.
- Short duration peak flows of approximately 4,500 ML/d (for 5% of the time) over summer are also considered to pose little risk to ecological objectives, subject to other constraints such as appropriate rates of rise and fall in river levels.
- Flow events above approximately 6,500 ML/d in summer would not be expected to occur in a median year but are considered to pose little risk to ecological objectives in wet years.
- Short duration events exceeding 24,000 ML/d in spring are considered to pose little risk to ecological objectives (e.g. for native fish).

A similar pattern to that described above is evident for Reach 5.

It should be noted that the discharges and associated duration stated above are indicative of how IVTs can be managed. The information in Chapter 5 and the accompanying DST provides a large degree of flexibility and better accounts for climatic variability than would a relatively static expression of a flow recommendation (e.g. a single upper or lower limit).

Ongoing IVTs in summer imposes a new flow regime on the lower Goulburn River. It will be important to monitor and evaluate ecosystem changes that result from this within the context of an adaptive management program, particularly if the permanent transfer of water entitlements from the Goulburn system continues to expand as predicted.

The basis of a monitoring and evaluation program to measure ecosystem response to environmental flow recommendations for the Goulburn River has been considered in detail as part of the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP). However, this program, as well as the previous environmental flow study for the Goulburn River on which it was based, did not consider upper limits on summer flows, as the call for IVTs were not then a prominent management issue. The Panel has, therefore, identified additional variables that should be considered in order to evaluate ecosystem responses to IVTs.

Contents

Figures:

Tables:

Acknowledgments

Wayne Tennant (Goulburn-Broken Catchment Management Authority), Geoff Earl (Goulburn-Broken Catchment Management Authority), Paulo Lay and Barry James (Department of Sustainability and Environment), and Brian Lawrence (MDBC) have provided considerable advice and information that was invaluable for the work of the Panel and in compiling this report. Brad Sherman (CSIRO) provided valuable insight on the likely response of water temperature to IVTs. Our thanks are extended to each of them.

1 INTRODUCTION

The expansion of water markets and resultant inter-valley trade, along with commitments to programs such as the Living Murray Initiative, increases the potential requirement for inter-valley transfers (IVTs) from the Goulburn-Broken system to downstream areas. For example, current and future expansion of irrigation industries in the Sunraysia district in northwest Victoria has the potential to greatly increase the volume of water required to meet both permanent water rights and demand for temporary sales water. The Goulburn-Broken system is pivotal in meeting any increase in downstream demand, given constraints on delivering additional water from Lake Hume (e.g. due to the Barmah Choke) and limited additional storage capacity along the River Murray.

Currently, minimum passing flows of 250-350 ML/d are released from Goulburn Weir and flow is usually between 350-600 ML/d at McCoy's Bridge during summer-autumn. Based on the experience of the past two summer-autumn periods (2005 and 2006), daily flows anticipated with IVTs are likely to be in the range 1,000 – 2,500 ML/d. In 2006, a total of 111,000 ML was transferred from the Goulburn System to the Murray System as the result of water trading and the transfer of water savings (Geoff Earl, GB CMA, *pers. comm.*). This was the first year that such large volumes have been transferred in this way and the volume was unusually large because it included trade water that had been 'banked' from previous years. However, it is likely that transfers of similar or greater magnitude will be required in future years as water entitlements continue to trade out of the Goulburn system.

IVTs, when required, are most likely to be delivered between January and March and there is concern about the risk posed by higher than normal summer and autumn flows to river assets and values if IVTs are to be delivered solely via the lower Goulburn River. An environmental flow study conducted in 2003 (Cottingham et al. 2003) recommended that minimum summer-autumn flows could be increased to above 610 ML/d (or natural) to maintain habitat availability for native fish. No upper bounds were put on this recommendation, as the need for frequent or increasingly large IVTs was not then identified. The 2003 environmental flow study was used to examine how water that might be released to the River Murray as part of the Living Murray Initiative could be used to protect or enhance the ecological condition of the Goulburn River. The study was not part of any formal review of the existing Goulburn Bulk Water Entitlement, and could only make limited assessments of future scenarios, as there was at that time no information on the volume and timing of water that might be required for the River Murray. The question of whether IVTs can be delivered in a manner that poses little risk (or result in a gain) to ecosystem assets and values was not addressed.

The issue of increased summer flows is also relevant to systems other than the Goulburn River. The principles by which changes to the summer flow regime in the lower Goulburn River are assessed can provide a basis from which to consider potential impacts and the delivery of IVTs in other lowland systems (e.g. the lower Campaspe River).

The Scientific Panel that developed environmental flow recommendations in 2003 has been reconvened to consider the implications of IVTs for the lower Goulburn

River. The Goulburn-Broken Catchment Management Authority (GB CMA) and the Department of Sustainability and Environment (DSE) regard this project as a pilot from which to consider the science and principles required to ensure that IVTs are delivered in an environmentally sensitive manner. Lesson learnt will be captured so that IVTs delivered via nearby rivers (i.e. Campaspe and possibly the Loddon) can be considered in a consistent manner in the future. Rules for inter-valley water trade currently reflect capacity and delivery constraints and commercial and contractual obligations, but do not yet formally consider potential environmental effects. This project will also help inform any future review of trading rules that includes principles and provisions for environmental protection.

1.1 Project Objectives

The objectives stated in the project proposal are to:

- Undertake additional investigations that better quantify the importance of factors, such as changes to ecological processes and plant and animal community structure, potentially affected by seasonal flow inversions
- Establish ecological principles for summer flows in Goulburn River and use these as the basis for assessing priority river systems (DSE may wish to apply the principles developed for the Goulburn River to systems such as the Campaspe River and Loddon River).
- Develop criteria and an approach to assessing the implications of increased seasonal flow that can be applied in other systems.
- Refine, if necessary, existing environmental flow recommendations for the Goulburn River below Goulburn Weir.

1.2 Scientific Panel Approach

The project adopted similar methods to that used by the previous Goulburn Scientific Panel (Cottingham *et al*. 2003), but with a focus on in-channel flows between Goulburn Weir and the River Murray. Particular attention is be paid to assessing the ecological risks associated with increasing summer low-flows in the channel. Unseasonably high and longer duration summer flows are known to pose a risk to the river condition and ecological processes (e.g. Bergkamp et al. 2000, McAllister et al. 2001). The approach was therefore to:

- Consider the current condition of the lower Goulburn River;
- Provide a series of questions (hypotheses) about the interaction of the river ecosystem and its summer flow regime;
- Consider the potential ecosystem risks and benefits posed by increased summer flows in the river;
- Recommend a summer flow regime that will protect or improve the ecological condition of the Goulburn River below Goulburn Weir.
- Recommend the principles, criteria and approach that can be applied to summer flows in other priority river systems where this issue is relevant.

1.3 Study Area

The study area is based on the two representative reaches established for the previous environmental flow study of the Goulburn River (Cottingham *et al*. 2003):

- Goulburn River: Goulburn Weir to Shepparton;
- Goulburn River: Shepparton to the River Murray.

These two reaches were Reaches 4 and 5 in the previous environmental flow study.

1.4 Project Tasks

The project brief identified the following major tasks:

1. Development of principles and criteria by which an upper limit on summer-autumn flows below Goulburn Weir can be identified. These principles will be applied to flows to protect the integrity of the river's environmental assets in the study area.

2. Clarification of existing recommendations to confirm the objectives, assumptions, rational and components of the recommendations. This will include specification of the timing, magnitude and duration of flow components in a manner that will allow stakeholders to model water releases from Lake Eildon to meet current the demands of the Northern Sustainable Water Strategy and the Living Murray Initiative.

3. Analysis of regimes (recommended) to protect the river's environmental assets. This can include analysis of impacts of summer flows within a number of scenarios (e.g. X = 250 ML/day, X+500, X+1000, etc.) to explore flow-benefit/disbenefit relationships.

4. Present a flow benefit/disbenefit curve for acceptable low flows up to high in-channel flows that are clearly unacceptable from an ecosystem perspective. Consideration will be given to how water may be transferred in a fashion that would increase the benefits or at least reduce the potential disbenefits (e.g. pulsing, higher flow limits for spring/late autumn). Maximum rates of rise and fall will also be considered.

The intention of the flow benefit/disbenefit curves is to identify an envelop providing upper and lower summer flow limits, within which assets and values would be protected or improved. For example, "610 ML/d is likely to be better than the current 350-400 ML/d, but beyond 2,000 ML/d there are risks associated with …." However, it was recognised in discussions with the CMA and DSE that stating flow-ecology/geomorphology relationships for the lower Goulburn River in this way may not be possible, and that in such circumstances relationships will be presented as a set of rules to guide future decisions.

The project was undertaken as a 3-stage process:

- Stage 1 involved establishing the scientific principles by which risks to the river ecosystem will be considered. This step made use of the advances in scientific understanding of the role of the flow regime in maintaining ecological processes gained since the previous Scientific Panel developed its recommendations. Stage 1 activities included:
  - The review of recent scientific information relevant to the project;

  - A field visit and workshop to share information and insights on how proposed changes to the flow regime might impact on the ecosystem assets and values of the study area.
  - Confirmation of the hydrological and hydraulic modelling required to explore scenarios in Stages 2 and 3.

- Stage 2 involved the development of a method and criteria by which summer-autumn low flows can be assessed as beneficial or detrimental to ecosystem assets and values. This allowed the Panel to consider the merits of alternative flow scenarios provided by the CMA and the DSE Water Sector Group. Stage 2 also considered how the principles, criteria and assessment of summer releases in the Goulburn could be applied to other, similarly affected systems.

- Stage 3 provided the preferred alternative for delivering IVTs and stated the main features of monitoring and evaluation activities from which to assess ecosystem response to a new flow regime. The monitoring and evaluation activities are to be integrated into Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP), which includes provisions for the Goulburn River.

This report describes:

- Changes to river hydrology and operation expected with the delivery of IVTs (Chapter 2),
- Ecological principles and criteria by which IVTs are assessed in terms of potential risk to ecosystem assets and values (Chapter 3),
- The conceptual basis of ecosystem response to IVTs (Chapter4),
- Ways in which IVTs may be released in order to protect or enhance ecosystem assets and values (Chapter 5),
- Previous environmental flow recommendations and presents them in a way that enables DSE to undertake water system modelling (Chapter 6), and
- Elements that should be considered as part of a monitoring and evaluation program (Chapter 7).

2 OUT-OF-VALLEY WATER DEMAND AND POTENTIAL CHANGES TO THE HYDROLOGY OF THE LOWER GOULBURN RIVER

The Goulburn supply system harvests water at Lake Eildon and Goulburn Weir, with most water diverted from the river at Goulburn Weir. Goulburn River flows during summer between Goulburn Weir and the confluence with the River Murray have usually been relatively low and steady, governed by meeting prescribed minimum flows and some water use from the river in this reach. In recent times, the requirement for the Goulburn supply system to transfer water to the River Murray has increased significantly.

The three most likely sources of demand resulting in IVTs come from (i) expansion of irrigation industries in the Sunraysia region, (ii) releases to meet commitments related to the Living Murray Initiative, and (iii) releases to provide Snowy River environmental flows.

2.1 Water demand in the Sunraysia region

Factors such as the Cap on diversions in the Murray Darling Basin, and the advent of market instruments associated with water trade (Environment and Natural Resources Committee 2001) have contributed to an increase in the value of irrigation water over the last decade. In that time, the scope of water trade has also expanded from within-valley transfers to transfers between river systems. In the Sunraysia region, increased water trade has been driven by the activation of sleeper licences, more intensive use of available sales water, and changing crops (SKM 2006). This has resulted in a 9% increase in entitlements in the Sunraysia region over the last decade (DSE 2003, cited in SKM 2006), predominantly from the Torrumbarry and Goulburn systems (Figure 1). Much of the irrigation in the Sunraysia region is associated with high value, high summer uses such as horticulture and viticulture.

There continues to be considerable development pressure in the Sunraysia region, as land and infrastructure costs are lower than in upstream irrigation areas, such as the Goulburn Valley, and the climate is predictable. At the start of the 2004/05 water year, 65 GL of water had been permanently traded into developments in Sunraysia (SKM 2006) and increased to approximately 70 GL during the 2005/06 water year (Geoff Earl, GB CMA, *pers. comm.*). An additional 90 GL of development is expected over the next five years (SKM 2006) and DSE is currently considering the implications of the permanent trade of up to an additional 500 GL over the next five to fifteen years (Paulo Lay, DSE, *pers. comm.*). The Goulburn system is pivotal in meeting future demand in the Sunraysia region because of constraints related to the Barmah Choke and limited additional storage capacity in the Torrumbarry system. Approximately two-thirds of any increase in demand from Sunraysia would be met by releases from the Goulburn system. This would result in the Goulburn supply system being run 'harder', potentially increasing risks to environmental assets and values.

Figure 1: **Map of irrigation districts in the Goulburn-Murray region (from Goulburn Murray Water www.g-mwater.com.au)**

2.2 Living Murray initiative

In June 2004, First Ministers of New South Wales, Victoria, South Australia the Australian Capital Territory and the Commonwealth Government signed the *Intergovernmental Agreement on Addressing Water Overallocation and Achieving Environmental Objectives in the Murray-Darling Basin* (the Intergovernmental Agreement) (MDBC 2004). The Intergovernmental Agreement gave effect to the 'First Step' decision of August 2003 by southern Murray-Darling Basin jurisdictions to commit $500 million over five years to address water over-allocation, with an initial focus on achieving specific environmental outcomes for six significant ecological assets along the River Murray:

- Barmah-Millewa Forest;
- Gunbower and Koondrook-Perricoota Forests;
- Hattah Lakes;
- Chowilla Floodplain (including Lindsay-Wallpolla);
- The Murray Mouth, Coorong and Lower Lakes; and
- The River Murray channel.

The ecological objectives associated with the First Step (e.g. to promote recruitment of fish, birds, vegetation and a variety of other river and floodplain plants and animals) are to be achieved through recovery and accumulation of water over a period of five years to an estimated average 500 GL per year of 'new' water (MDBC 2005). Releases to enhance natural freshes or floods are likely to be the major opportunities in any given season for meeting the objectives for ecological assets listed above. This is unlikely to impact on the supply of irrigation water along the Murray during peak demand periods (SKM 2006). An exception may be the proposed ‘River Murray estuary environmental entitlement’ of approximately 180 GL in every year, which has been proposed to meet objectives for the Murray Mouth, Coorong and Lower Lakes in South Australia. In dry years, this could be released as approximately 2,000 ML/d during summer and autumn. In wet or moderately wet years, the entitlement could be released at 4,000 ML/d to top up flows for 1.5 months in spring (or a different temporal pattern) (SKM 2006). Securing the volume required to supply these flows is proposed from water savings projects or the purchase of existing entitlements currently supplied below the Choke. The provision of these flows during the peak demand period could reduce the available channel capacity in the Murray from which to supply existing irrigation entitlements.

2.3 Snowy River Environmental Flows

The Victorian and NSW Governments have committed to increase environmental flows in the Snowy River. This is currently being achieved by undertaking water savings projects in water supply systems in both States. Where these savings are on tributaries of the River Murray, such as in the Goulburn supply system, the saved water is then supplied to the River Murray in summer to meet water use demand, allowing a reduction in the supply to the River Murray from the Snowy system.

Hence, some Snowy environmental flows will result in an increased need to transfer water from the Goulburn system to the Murray system in summer, in the same way as water trading from the Goulburn supply system to the Sunraysia region does.

2.4 Implication of IVTs on water management in the Goulburn system

2.4.1 Current release patterns

Comparison of the current regulated and the modelled ‘pre-regulation’ regime (1975-2000) suggests that management and diversion of water from Goulburn Weir has greatly reduced the small to medium sized flow events in the lower Goulburn River from the pre-regulated state (Figures 2 - 5). For example, median summer flows under the current regulated flow regime at Murchison are an order of magnitude below that which would have prevailed in an unregulated flow regime (Figure 2). The duration of flow events has also been greatly reduced (Figure 4). For example, flow events greater that 1,000 ML/d at Murchison that would naturally have lasted for up to 80 days prior to regulation would last up to 4 days under the current regulated regime. Similarly, a 2,000 ML/d or greater event at Murchison that would have lasted 15 days under pre-regulated conditions now lasts for only 2 days.

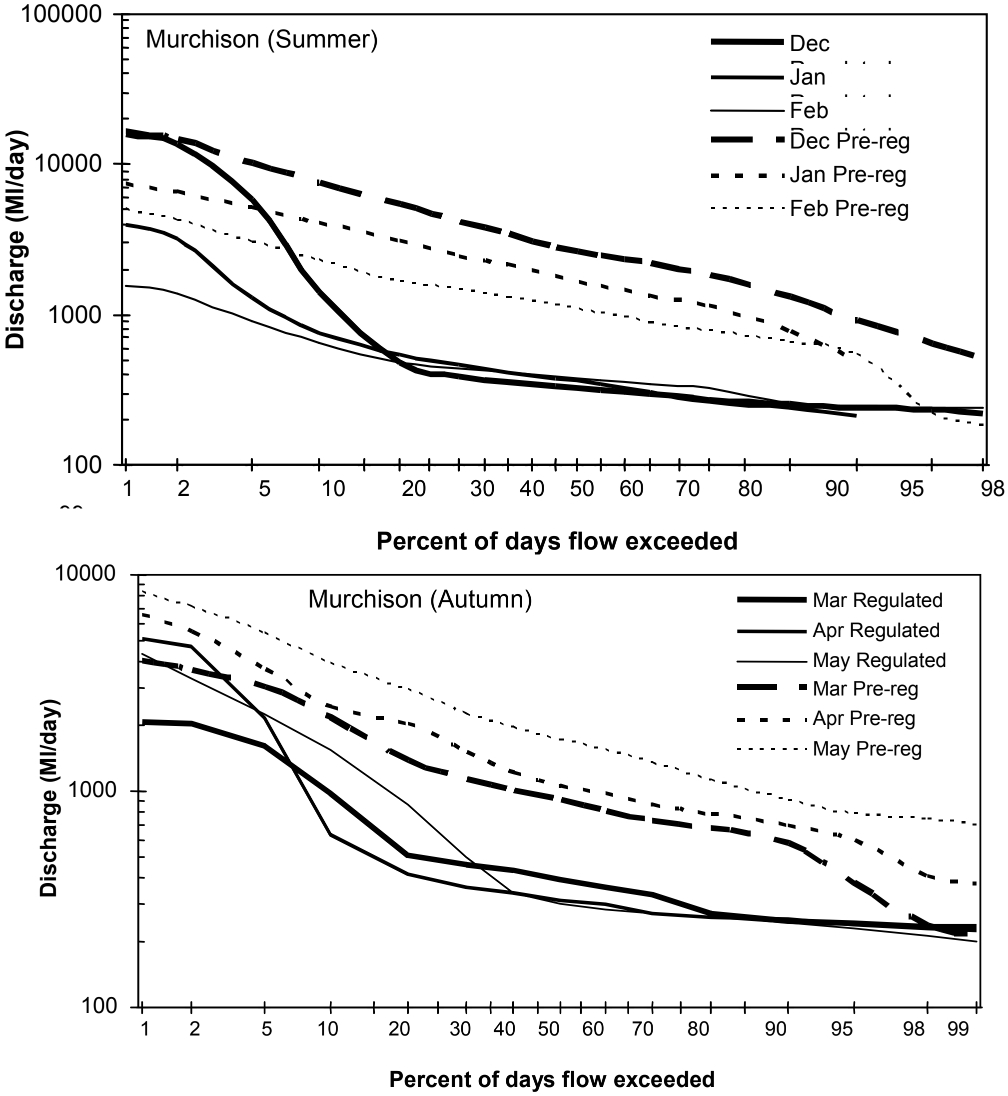


Figure 2: **Comparison of regulated and pre-regulated summer and autumn flows in the Goulburn River at Murchison (1975-2000).**

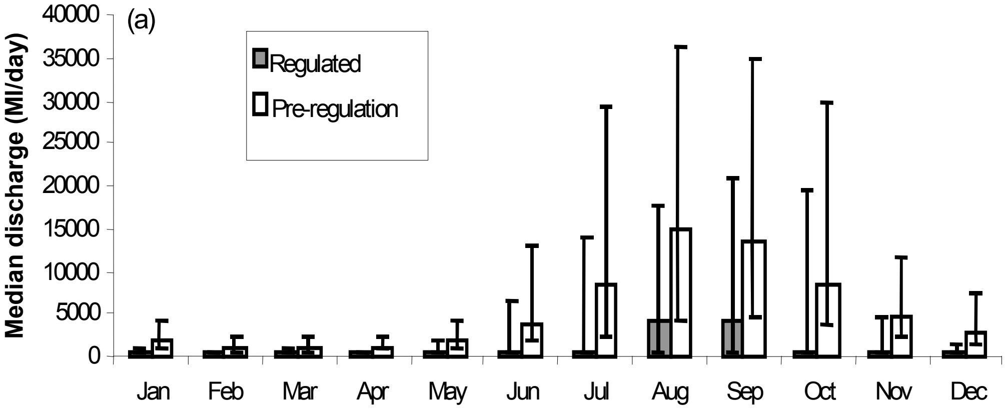


Figure 3: Median monthly flows in the Goulburn River at Murchison (1975-2000).

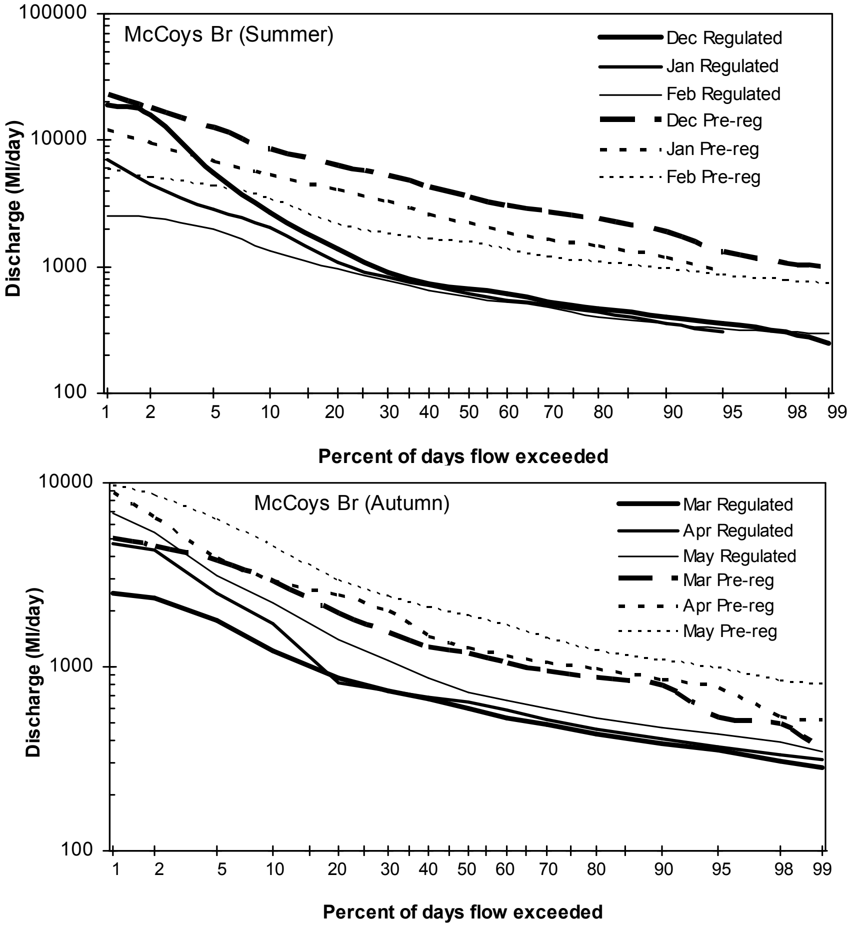


Figure 4: Comparison of regulated and pre-regulated summer and autumn flows in the Goulburn River at McCoy's Bridge (1975-2000).

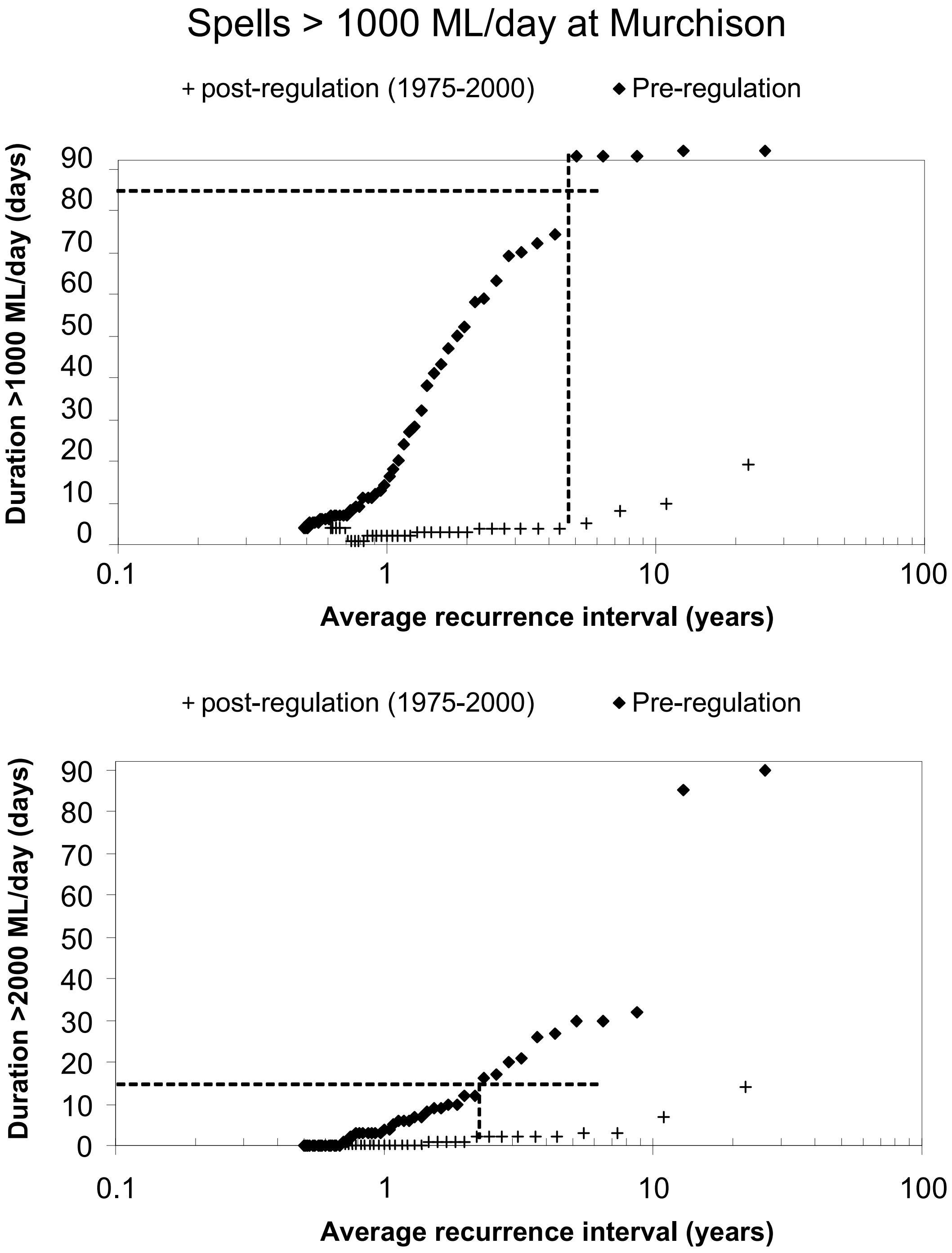


Figure 5: Comparison of spell duration greater than 1,000 ML/d and 2,000 ML/d at Murchison for regulated and modelled pre-regulation conditions (1975-2000).

2.4.2 Recent IVT release pattern

IVTs are most likely to impact on summer-autumn flows in the Goulburn River below Goulburn Weir. The management of winter and spring flows from Lake Eildon and Lake Nagambie would remain largely unchanged. However, the proposed decommissioning of Lake Mokoan is expected to increase winter-spring flows in the Goulburn River below Shepparton by up to 2,400 ML/d in the future (Geoff Earl, GB CMA, *pers. comm*).

As permanent trade from the Goulburn system to Sunraysia continues, the pattern of summer-autumn demand is also likely to change. Large volumes are likely to be spread across the irrigation season, with smaller volumes delivered as shorter duration, but higher magnitude peaks (Figure 6). Transmission time from the lower Goulburn to Sunraysia is approximately 3-4 weeks, so where possible, smaller volumes of water are likely to be delivered in short duration peaks to meet short-term demand peaks.

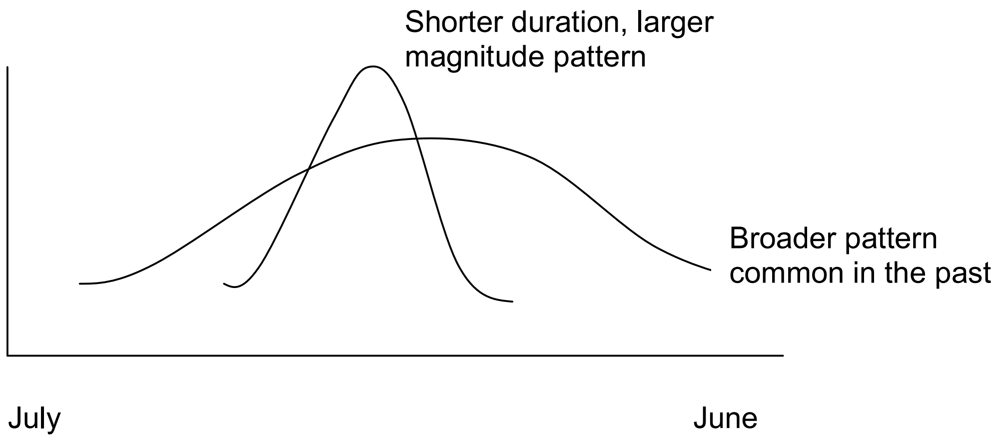


Figure 6: General hydrological pattern of IVT releases from the Goulburn system

In 2005/06, IVTs were delivered as a single block (albeit with distinct peaks) (Figure 7), but delivery as both large and small (i.e. short-duration) blocks are possible in any one year. Expectations are that water trades will result in typical IVTs of 1,000 – 2,000 ML/d, with peaks of up to 4,000 ML/d. However, short duration peaks of up to 8,000 ML/d are considered possible (Geoff Earl, GB CMA, *pers. comm.*). Also, delivery of the 70 GL of permanent trade is dependent on water availability. For example, if only 20% of entitlement is available in the Goulburn system, then only 20% of the 70 GL can be transferred.

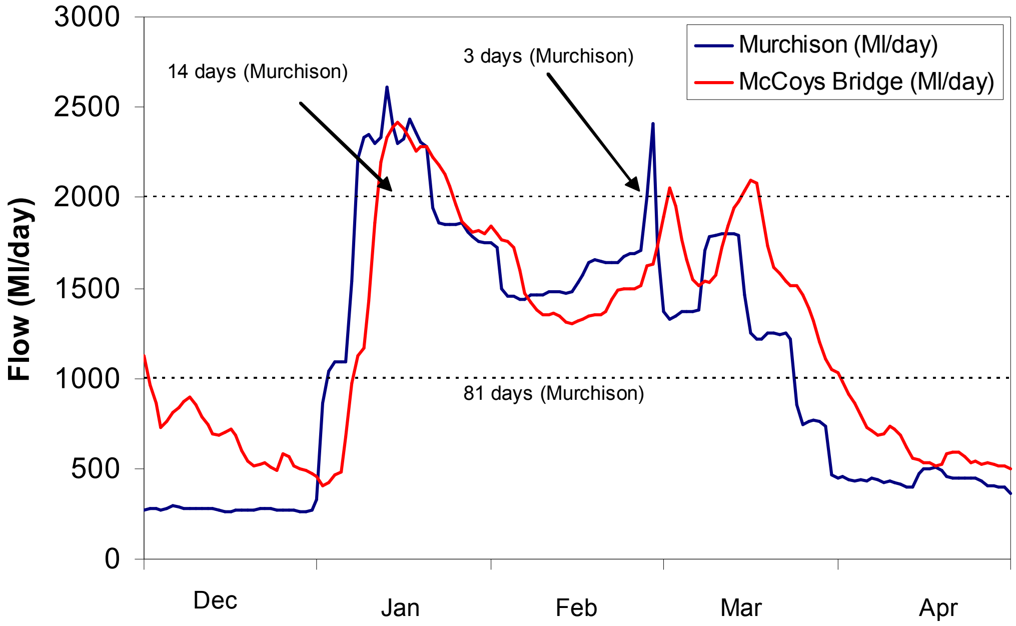


Figure 7: **Pattern of flow at Murchison and McCoy's Bridge during the summer and autumn of 2005/06. Duration of events above 1,000 ML/d and 2,000 ML/d at Murchison are indicated.**

DSE has recently modelled 3 trade scenarios (Barry James, DSE, *pers. comm.*) to meet increasing Murray demands:

1. 200GL from Goulburn + 100GL from Torrumbarry = 300GL
2. 300GL from Goulburn + 150GL from Torrumbarry = 450GL
3. 350GL from Goulburn + 200GL from Torrumbarry = 550GL

The preferred release pattern from the perspective of transferring water with a minimum of losses and lowest risk to security of supply is presented in Table 1.

Table 1: **An optimised IVT release pattern used in scenarios 1 to 3 to minimise Murray shortfall in supply over the modelled period from 1975 to 2000.**

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
%	0	0	0	0	5	25	25	25	20	0	0	0

Minimum flow requirements specified in the Goulburn Bulk Entitlement at McCoy's Bridge are 350 ML/d from November to June and 400 ML/d from July to October. The release patterns associated with the DSE trade scenarios are presented in Figure 8.

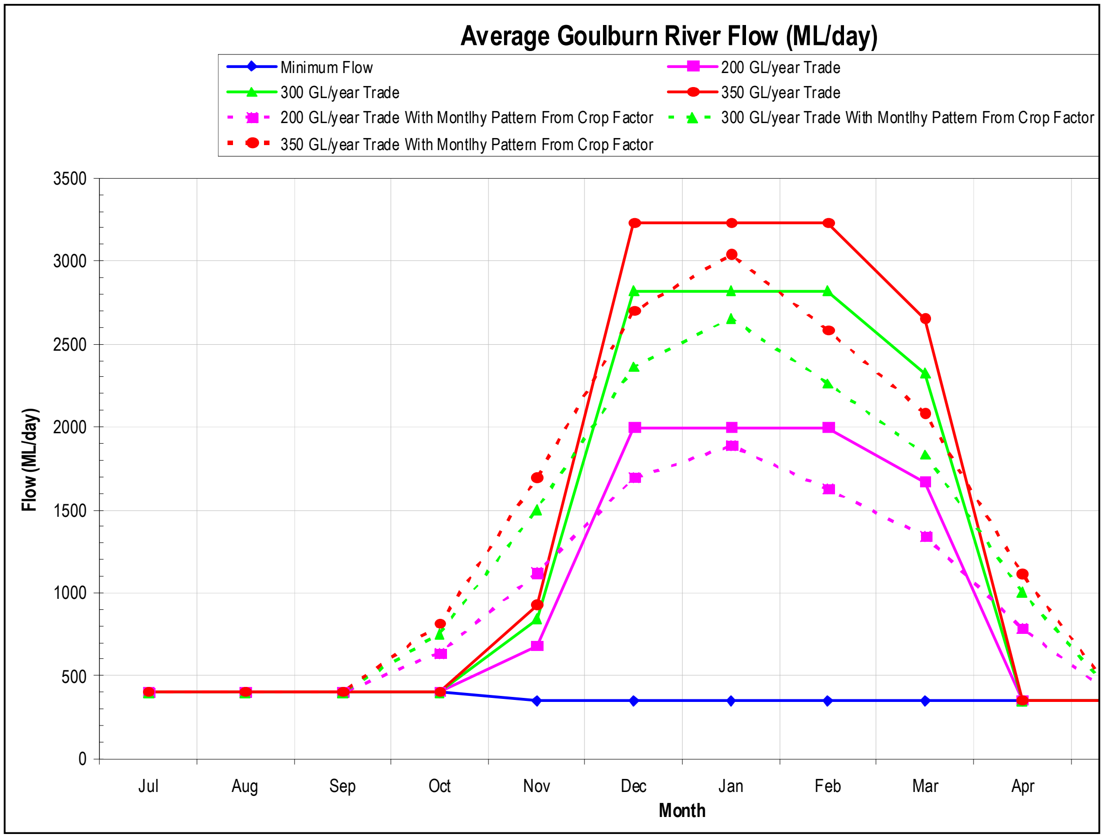


Figure 8: **Release patterns associated with modelled DSE trade scenarios (Barry James, DSE, pers. comm.). The dotted lines represent the minimum releases required to meet almond crop demand under each scenario.**

3 GUIDING PRINCIPLES

3.1 Guiding principles

The Panel adopted the following principles as a guide when deliberating on upper limits to summer IVTs via the lower Goulburn River:

- IVTs must, where possible, be consistent with the intentions of previous environmental flow recommendations and considerations.
- IVTs must not lead to a decline in ecosystem condition, structure or function, and be used to improve conditions if possible.
- IVTs must not be to the detriment of existing regional, State or national programs or strategies for river protection and rehabilitation.
- IVTs will be considered in terms of their potential impacts on components of the natural flow regime that are considered important for ecosystem function and the protection or rehabilitation of assets and values.
- IVTs will be considered in terms of re-introducing missing components of a natural flow regime, from the perspective of the total flow regime (including intra- and inter-annual variability), and in terms of potential negative ecosystem impacts due to the inversion of the natural seasonal pattern of flow.

The above principles are consistent with principles and tools proposed for river protection in Australia (Bennett et al. 2002, Phillips 2001) (Table 2), and the relevant principles that guide the Living Murray Water Plan (MDBC 2005). The latter address the general principle of seeking to ensure that the delivery of environmental water should be complementary among different environmental water allocations, with the following considerations:

- Do no harm to the tributaries in implementing actions at the significant ecological assets;
- Managers of environmental water allocations to maximise complementary use where possible; and
- Minimise impacts on existing users.

The Panel also recognised the aspirations of the Goulburn Broken Regional River Health Strategy (GBCMA 2005a), which aims to achieve four main objectives for the rivers and streams of the Goulburn Broken basin:

- Enhance and protect the rivers that are of highest community value (environmental, social and economic) from any decline in condition;
- Maintaining the condition of ecologically healthy rivers;
- Achieving an ‘overall improvement’ in the environmental condition of the remainder of rivers;
- Preventing damage from inappropriate development and activities.

Table 2: Principles aimed at protecting rivers (from Phillips et al. 2001).

Principles
That the ecological function of rivers be protected.
That rivers be managed in an ecologically sustainable manner.
That rivers be managed to ensure their benefits to future generations.
That State, national and international agreements that affect river management be reflected in river management strategies.
That the biological, hydrological and geomorphological diversity of rivers be maintained.
That the ecological structure and functioning (ecological integrity) of rivers be maintained.
That natural streamflow characteristics be maintained or mimicked through the provision of water for the environment.
That the longitudinal, lateral and vertical dimension of rivers be incorporated into management processes.
That the non-substitutable nature of rivers be recognised in river management processes.

3.2 Important assets and values of the lower Goulburn River

The study area is the 195 km stretch of the Goulburn River from Goulburn Weir to the confluence with the River Murray near Echuca. This coincides with management unit L1 identified in the Goulburn-Broken Regional River Health Strategy (GBCMA 2005b), which is rated highly for its environmental assets and values, including:

- Heritage River listing,
- Presence of significant (e.g. EPBC Act listed) fauna and flora,
- Presence of wetlands of national significance and rare wetland types,
- Presence of self-sustaining native fish communities,
- Native fish migration,
- Riparian width and longitudinal connectivity.

The study area lies with the Land Conservation Council designated Heritage River corridor, which extends from Eildon Reservoir to the confluence with the Murray River. Ecosystem-related heritage values (LCC 1991) relevant to the study area include:

- Areas with intact understorey in River red gum open forest/woodland, and yellow box and grey box woodland/open forest communities, particularly downstream of Murchison;
- Areas of significant habitat for vulnerable or threatened wildlife including Squirrel gliders, Largefooted myotis, Barking march frogs, Barking owls and Brush-tailed phascogales;
- Native fish diversity and Murray cod habitat below Goulburn Weir;
- Fishing opportunities – native species below Goulburn Weir;
- Scenic landscapes – from below Seymour to Echuca.

3.3 Potential benefits and difficulties associated with IVTs

From the above, it can be seen that the lower Goulburn River contains many high value assets and values. While the delivery of IVTs, if managed appropriately, has the potential to maintain or improve such values, the Panel identified a number of potential difficulties associated with changing the flow regime management of the river (Table 3). The potential benefits and difficulties provided a starting point in terms of flow-related ecosystem objectives and relevant flow components that were reviewed by the Panel.

Table 3: Potential benefits and difficulties arising from the delivery of IVTs via the lower Goulburn River.

Potential Benefits	Potential Difficulties
Potential to return summer low flows to within the natural range. IVTs may reset biofilm, potentially increasing biofilm production and mobilise fine sediments that reduce habitat quality for macroinvertebrates. IVTs may serve as an attractant for native fish from the Murray River. IVTs may provide increased deep water habitat and spawning cues for native fish IVTs may increase the recruitment or survival of riparian vegetation (e.g. wattles and river red gum) in certain parts of river channel. Increased flow variability with IVTs may increase plant biodiversity on the banks. Higher summer flows may restore some geomorphic processes (e.g. disturbance of low-lying benches). Deep pools are unlikely to be affected, as the river is sediment starved.	It is difficult to identify a benchmark or target condition for many river attributes. Increased summer flows may result in more uniform seasonal flow patterns and possibly an inversion of the seasonal pattern of flow. This may affect processes such as breeding and migration cues for native fish. IVTs may result in decreased primary production: less benthic area in the euphotic zone and decreased retention time in the river. IVTs may serve as an attractant for carp from the Murray River. Increased depth for prolonged periods may result in dieback of bank vegetation (e.g. Poa spp.). Prolonged deep flows may, if turbid, adversely impact growth of some aquatic or amphibious species. Longer duration of higher flows may increase bank erosion. Increased rates of rise and fall may increase bank erosion. IVTs when Lake Eildon is at higher levels may result in temperature depression, which may in turn affect primary production and the distribution of native fish.

4 ECOSYSTEM OBJECTIVES AND CONCEPTUAL UNDERSTANDING OF ECOSYSTEM RESPONSES TO A CHANGED SUMMER FLOW REGIME

4.1 FLOWS Method

Previous environmental flow recommendations for the Goulburn River (Cottingham et al. 2003) were derived using the FLOWS method, which was developed to assess the flow requirements of rivers and streams when setting streamflow management plans or bulk entitlements in Victoria (DNRE 2002). The FLOWS method 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 9).

Flow recommendations for the Goulburn River were 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.

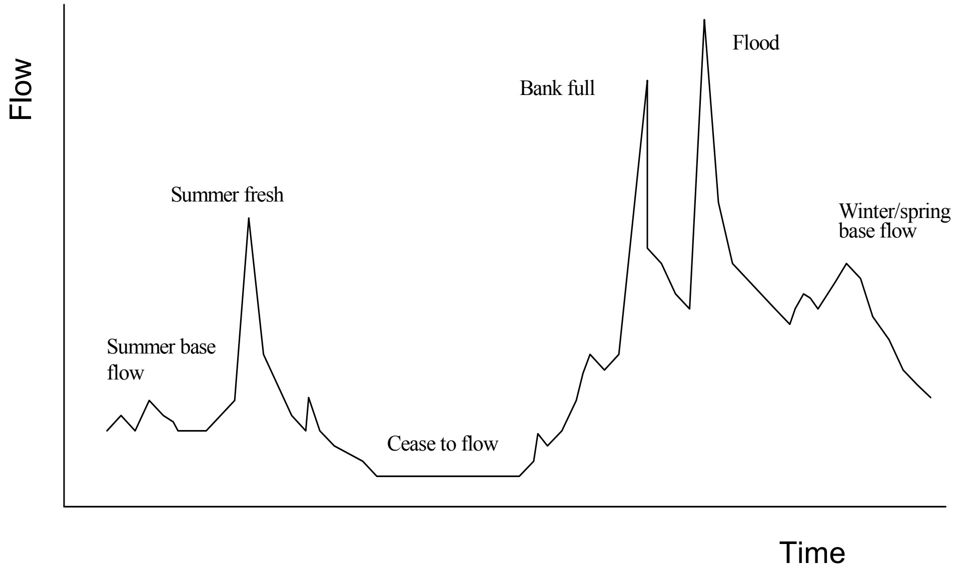


Figure 9: Time series showing different components of a natural flow regime

Flow components can act either directly or indirectly on biota and ecosystem processes (Figure 10). For example, flows that alter stressors such as shear stress and sediment mobilisation pattens can affect macroinvertebrate communities directly by depositing sediments and smothering susceptible taxa (Figure 11). Alternatively, shear stress can act indirectly by removing the biofilm that is a food source for grazing taxa. Ecosystem response may, therefore, be a result of one or many flow components acting via the effects of various flow stressors (Figure 12).

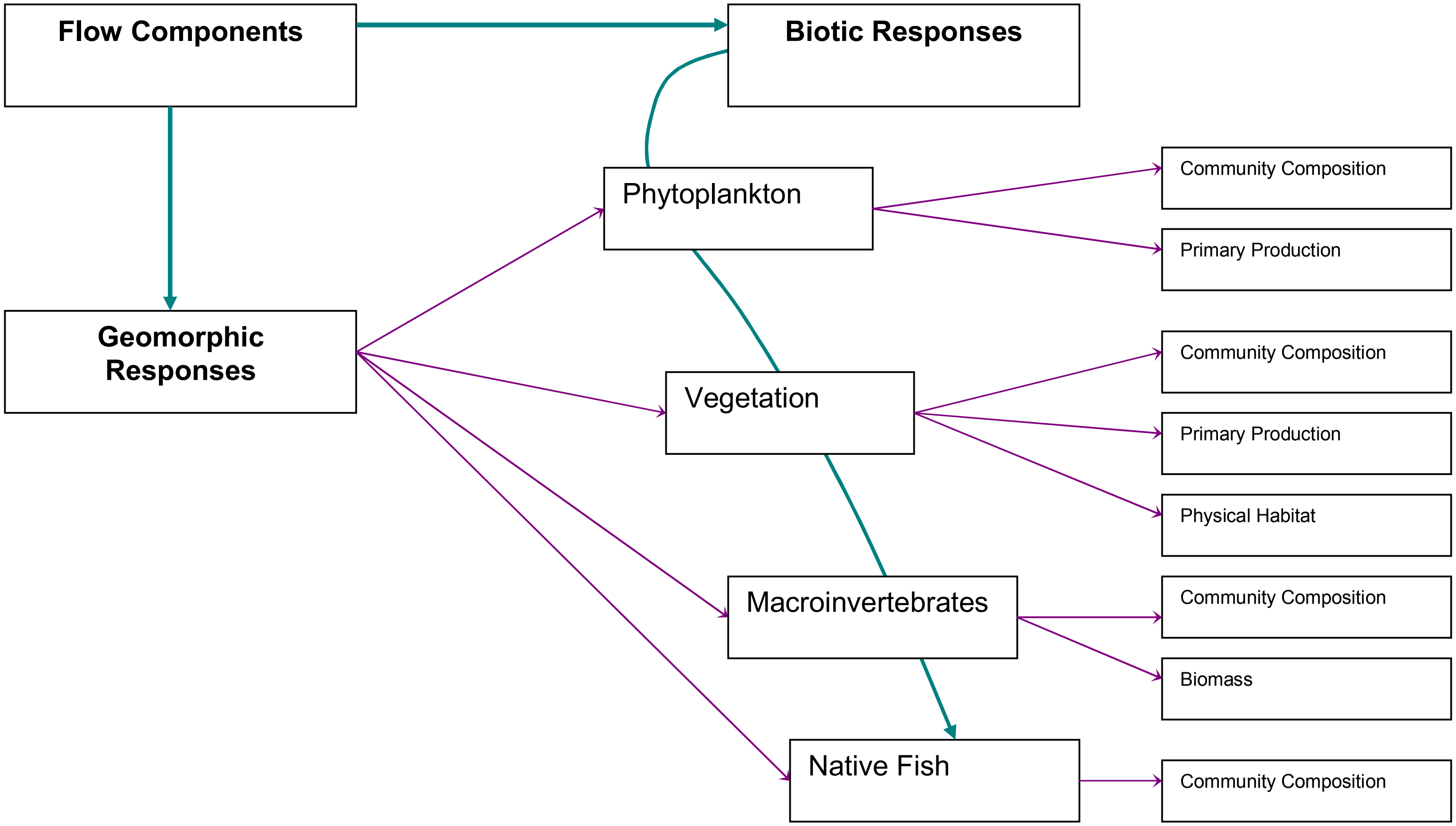


Figure 10: Flow components can affect ecosystem responses directly or indirectly, for example via geomorphic processes. This conceptual diagram summarises the interactions of most interest to the Scientific Panel, given the potential effect of IVTs (see section 4.2).

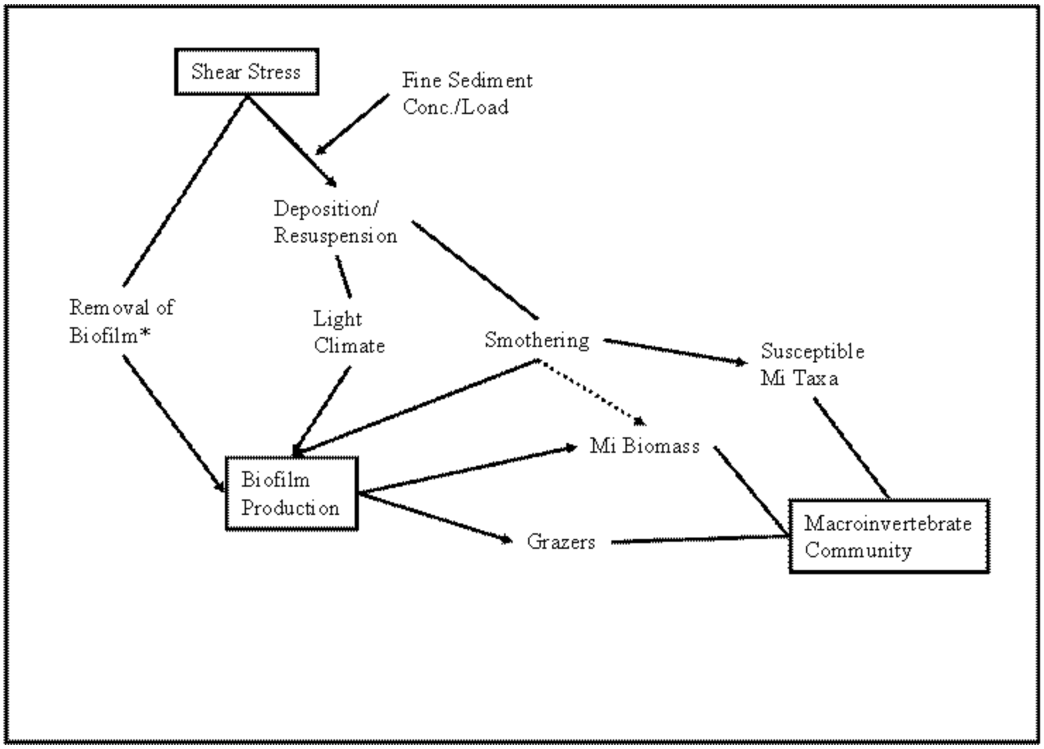


Figure 11: **Potential interaction of shear stress with sediment mobilisation processes and biofilm production and effects (direct and *indirect) on macroinvertebrate communities.**

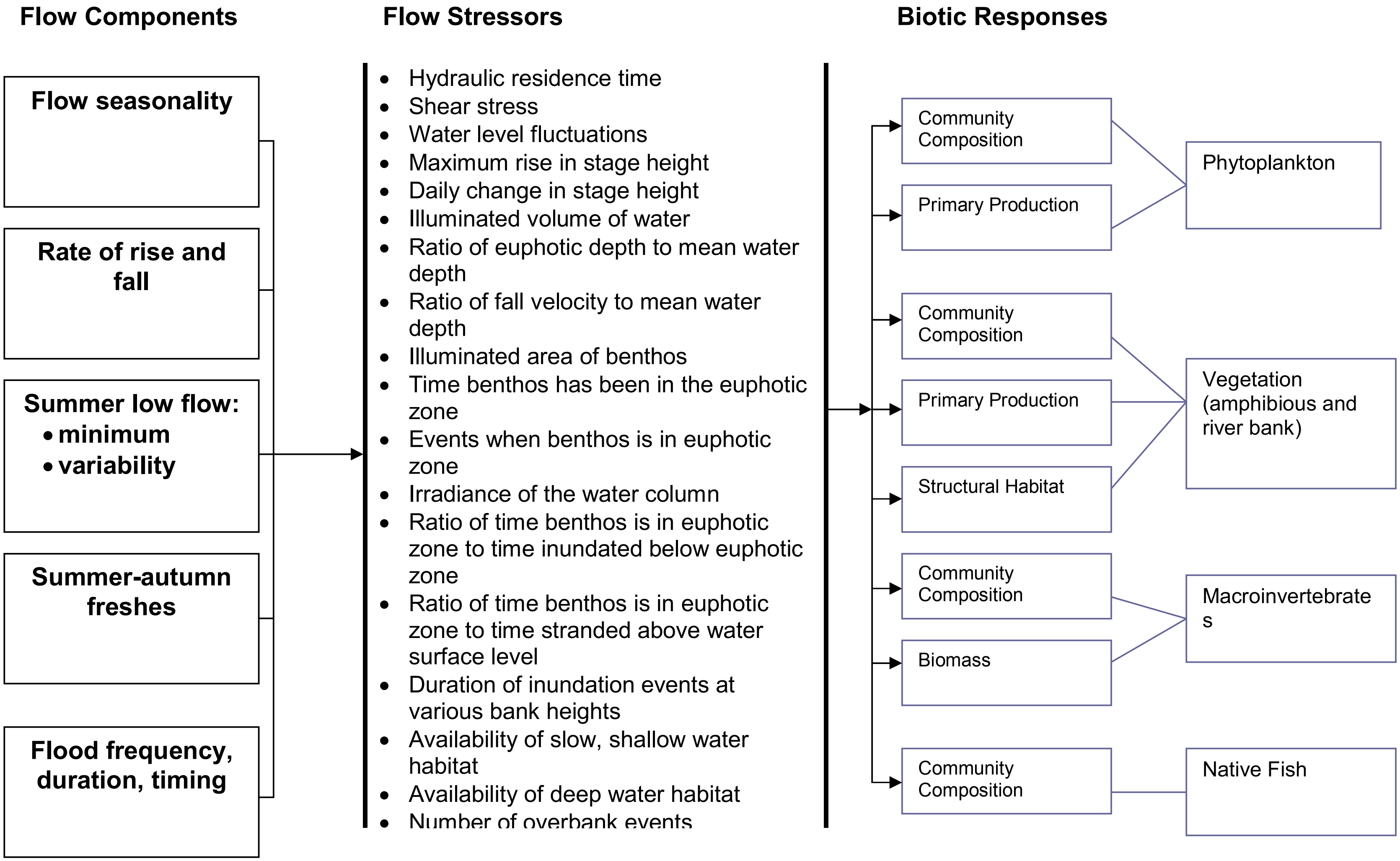


Figure 12: **Overview of potential links between flow components, flow stressors and biotic response related to summer IVTs.**

4.2 Flow-related ecosystem objectives

The previous Scientific Panel (Cottingham et al. 2003) identified a number of flow-related ecosystem objectives from which it developed environmental flow recommendations. The objectives relevant to this project (i.e. those with a focus on in-channel and riparian processes) are listed in Appendix 1, and relate to maintaining or returning important ecosystem processes and elements of community structure (diversity and dynamics of biota such as macroinvertebrates, plants and native fish). The Panel is of the opinion that the flow-related objectives listed in Appendix 1 are still relevant for the evaluation of ecosystem responses to a changed summer flow regime. The Panel also considered a number of additional issues and objectives based on investigations, information and insights gained since the original recommendations of 2003. These include objectives related to:

- Maintained or improved riverine productivity,
- The encroachment of terrestrial vegetation down the banks of the river,
- Potential geomorphology issues associated with the disturbance of bank vegetation with higher summer flows.

In summary, flow related objectives[1] considered relevant when exploring the implications of IVTs include:

Geomorphology

- Sediment dynamics:
    - Natural rates of erosion and deposition
    - Maintenance of natural patterns of geomorphic diversity within reaches.

In-channel Primary Production

- Planktonic algae:
    - Biomass levels resembling sites unimpacted by flow regulation;
    - Productivity resembling sites unimpacted by flow regulation;
    - Community composition resembling sites unimpacted by flow regulation;
- Periphytic algae and biofilms:
    - Biomass levels resembling sites unimpacted by flow regulation;
    - Productivity resembling sites unimpacted by flow regulation;
    - Community composition resembling sites unimpacted by flow regulation;
- Submerged macrophytes:
    - Biomass levels resembling sites unimpacted by flow regulation;
    - Productivity resembling sites unimpacted by flow regulation;
    - Community composition resembling sites unimpacted by flow regulation.

Macroinvertebrates

Diversity:

- Full range of habitat types present and functional – supporting a range of aquatic macroinvertebrates that would occur without the impact of flow regulation:
    - Aquatic vegetation (especially emergent or amphibious plants) habitat on banks and bars variable over years but similar (in sum) to natural;
    - Range of snag habitats available, with natural inter- and intra-year distribution not significantly diminished;

---

[1] Note: specific ecological objectives for wetlands were not included as the IVTs being considered fall well below commence to fill levels along the study reaches.

  - ➢ Low-flow and slackwater zones availability similar to unregulated conditions;
  - ➢ Litter packs available, augmented and free of excess sediment;
  - ➢ Habitat heterogeneity over time (i.e. interannual variability similar to unregulated conditions).

Biomass:

- Maintain quantity and quality of food and habitat resources.

River Bank Vegetation

- Persistent cover of terrestrial grassy vegetation (flood sensitive) maintained over the upper part of the river bank (equivalent to natural flow percentiles where bank inundation frequency and duration have not changed under the current or historic flow regime).
- Reduced cover of terrestrial grassy vegetation (flood sensitive) for lower parts of bank that fall below the threshold (flow percentile where natural duration of inundation is approximately equal to historic).
- Maintain vegetation cover and flow refuge (fish and macroinvertebrate?) habitat across a flow range and across seasons.
- Maintain community composition that is predominantly native species (notionally at least 75% by cover).
- Avoid conditions that favour significant riparian and aquatic weeds known to occur in the area (e.g. Arrow-head *Sagittaria*).
- Prevent further encroachment of terrestrial shrubs and trees (i.e. distribution of plants beyond their normal range).
- Reverse encroachment of terrestrial shrubs and trees.
- Protect vigour of trees in existing River Red Gum woodland established on inset benches.

Native Fish

- Suitable thermal regime for spawning, growth and survival of all life stages;
- Suitable in-channel habitat for all life stages;
- Suitable off-channel habitat for all life stages;
- Floodplain inundation for exchange of food and organic material between floodplain and channel;
- Passage for all life stages;
- Cues for adult migration during spawning season;
- Low flows for spawning and recruitment;
- Bench inundation for exchange of food and organic material between floodplain and channel.

Much of our conceptual understanding of flow-ecosystem responses has been described in the 2003 report (Cottingham et al. 2003) and summarised as part of the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP, Chee et al. 2006). This work is explored in the following sections, with an emphasis on those relationships most likely to be affected by IVTs. This provides the basis for identifying and modelling relationships between the hydrological regime and flow stressors from which recommendations for managing IVTs were developed (see Chapter 5).

4.2.1 Geomorphic processes

Geomorphic processes

The geomorphic history of the lower Goulburn was described in the previous environmental flow study (Cottingham et al. 2003b). Of relevance to the present study is that the Goulburn River below Goulburn Weir emerges as a low gradient river typical of the Riverine Plains, and cuts into the resistant alluvial sediments of the Shepparton Formation (Bowler 1978). The size and bedload of the river has changed over the last 40,000 years in response to climate change and changes to the course of the river due to channel avulsion. Between Goulburn Weir and Loch Garry, the present Goulburn River has cut a sinuous channel within the broad trench of a larger, broader ‘ancestral’ river. Below Loch Garry, channel avulsions have seen the present Goulburn River migrate to the south and become narrower, presumably because this younger section of the river has had less time to cut a larger trench. Evaluation of LIDAR data, cross-section data and aerial photographs held by the GBCMA and DSE have confirmed that the cross-sectional and hydraulic characteristics of the two sample reaches in Reach 4 and 5 are representative of the morphology of these two reaches.

The upstream reach of the study area (Lake Nagambie to Loch Gary) corresponds to Reach 4 of the environmental flow studies (44 km long). Because this reach occupies the ‘ancestral trench’ of the Goulburn River, it has had longer to develop laterally. As a result, it has more complex geomorphology than the longer (100 km) Reach 5 from Loch Gary to the Murray Junction. Reach 4 is characterised by three distinctive geomorphic features (Figure 13 to Figure 15):

1. Sandy point bars. These are classical lateral migration features developed at the inside of bends. They are associated with ridge and swale topography that is built to the height of the bankfull channel.
2. *Point benches*. At the inside of several tight bends the sandy point bar is replaced by a small, sandy platform. Unlike the point bar, the point bench is flat, and only rises about 1m above the low summer flow of 400 Ml/d. The bench does not extend to the top of the bank.
3. *Concave benches*. Where erosion of the outer bank moves the bank down-valley, a concave bench forms in the dead-water zone at the upstream edge of the bend (the recirculation zone). These benches are actively accreting, burying the base of trees.

Because of the limited period that has been available for lateral migration of bends in Reach 5, there are no well developed pointbars, and no concave benches (Figure 16). The main deposits are the vestigial point benches. The channel of Reach 5 is characterised by a regular and featureless parabolic cross-section.

Figure 13: Sandy point bar in Reach 4. Note that, in height, the sand extends toward top of the bank that is evident at the back of the photo (flow toward observer).

Figure 14: Point bench at Cable Hole (Reach 4). These surfaces will be fully inundated at higher IVTs (flow is 400 ML/d, flow away from observer).

Figure 15: Concave bench on the left bank of the Goulburn River (Reach 4).

Figure 16: Reach 5 of the lower Goulburn River. Note the simple parabolic cross-section. The major source of physical diversity in this channel is the large wood in the bed of the channel.

Coarse Sediment supply

An important point to note about the lower reaches of the Goulburn River is the lack of sediment sources. The only source of sand and bedload sediment into the lower

Goulburn River is from a few minor tributaries, and from bank erosion. The combination of Eildon and Nagambie Weirs traps essentially all of the coarser load entering the river. Whilst the Seven Creeks tributaries (Castle, Creightons etc.) have abundant sand load, that sand is trapped upstream in slow moving slugs that have not yet reached the Goulburn River. As a result, changes in sediment transport associated with new regulation regimes of the lower Goulburn River relate more to redistribution of sand, than to new sand. Fine clays will remain in suspension, and are unlikely to be in sufficient volumes to alter deposition of the fine fraction.

Geomorphic changes associated with summer regulated flows

Chee et al. (2006) describe the changes in geomorphic processes that might be expected in three functional zones in regulated rivers, such as the Goulburn River below Lake Eildon (Figure 17). The first zone, immediately below major storages, is one characterised by sediment starvation due to trapping within the reservoir, and erosional processes as the river has the capacity to entrain sediments. The second zone is one characterised by sediment deposition where tributary inputs deliver sediments larger than the river is capable of transporting. The third zone is usually buffered by large instream sediment stores.

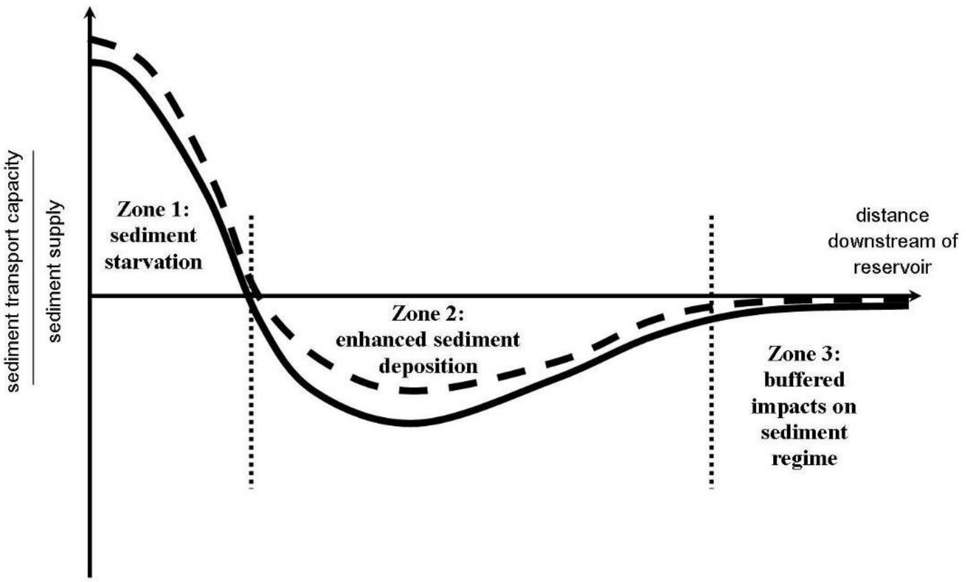


Figure 17: Conceptualisation of the change in sediment and flow regimes downstream of dams (from Chee et al. 2006). The X-axis represents distance downstream from the reservoir, with zone 1 being immediately downstream. Solid line: regulated flow conditions; dashed line: with environmental flow allocation.

The main drivers of morphological change are (i) flood magnitude, (ii) duration and frequency of high in-channel flows and (iii) total sediment load. In a regulated river, these will be a function of unregulated tributary flows and the influence of upstream impoundments and diversions. No specific environmental flow recommendations related to geomorphic processes were proposed in the 2003 study (Cottingham et al.

2003), as the flows required to water floodplain wetlands were also sufficient to generate geomorphic responses.

The Summer IVTs in the Goulburn River, however, may increase summer flows to the point where geomorphic processes will change. The flows are most likely to influence features such as riparian vegetation and bank roughness, and possibly result in increased erosion due to persistent high flows and higher than normal rates of fall in stage height. These processes can result in notching of the bank (Figure 18), bank slumping, and possibly increased transport of sand into pools.

Long duration summer regulated flows on the Murray River have led to dramatic bank erosion due to notching and wave erosion. The major issue here is the duration of the flow at a single stage. The higher the flow, the more critical the period of stable flow becomes, because the higher the average flow velocity that erodes the banks. Thus, the higher the flow, the less deviation from natural duration is desirable. This erosion also relates to loss of protective bank vegetation. If grasses are lost from the bank face, the result will almost certainly be notching, increased bank erosion, and increased turbidity.

In cohesive stream banks, rapid drawdown of the river can lead to bank slumping. Again, the higher the flow the more critical the rate of draw-down becomes.

The other possible effect of IVTs is on redistribution of sand into pools (loss of habitat diversity at large scale). The premise is that flows toward bankfull (as on the Murray) transport the majority of sediment through bends and so are able to keep pools open. On the Goulburn River the IVT may be increasing exactly those flows that transport most sand into the pools, but transport least through the pools (because of increased resistance at medium flows, and less secondary circulation). Our premise is that increase in duration of summer flows above 4000 ML/d up to 8000 ML/d becomes progressively less desirable as it moves more sand into pools (thus more deviation at higher flows is worse).

Macrophytes in the bed of the river reduce sediment transport in the channel. It is likely that at flow velocities above 0.3 m/s these macrophytes (Figure 19) will be eroded (with the likelihood increasing as the duration of flow increases). Velocities exceed 0.3 m/s at flows of 2,500 ML/d or 3.4m stage in Reach 4.

Figure 18: Notching at the toe of the bank possibly related to the long-duration IVT of summer 2006 (Reach 5, view downstream).

Figure 19: Grasses on the bank face will be killed by higher, long-duration flows, leading to bank notching. Photograph was taken in Reach 5 at flow of 400 ML/d.

In considering the implications of IVTs, the ecosystem objective from a geomorphic perspective is to maintain natural rates of sediment dynamics (erosion and deposition) and natural patterns of geomorphic diversity (objectives Geo 1, Geo 2, Geo 3 and Geo 6 in Appendix 1). Relevant flow stressors considered when establishing IVT recommendations therefore include:

- The distribution of daily falls in stage characterised by the n th percentile values (m) for flow bands defined by the flows Q_i ML/day *(to assess the occurrence of rapid falls in stage that may contribute to increased bank slumping*);
- Proportion of time water level is within a range defined by water surface levels corresponding to the *m*% exceedence flows (in the pre-regulation regime*) (to assess extended periods of stable flow at different stage heights, which may contribute to increased rates of bank notching*).

4.2.2 In-channel Primary Production

Discharge regulates riverine productivity
Riverine foodwebs are supported by two major sources of organic materials: that generated within the river (i.e. primary production by phytoplankton, periphyton and submerged and emergent macrophytes) and that generated by external sources and transported by wind and water into the channel from the surrounding landscape. Wash-in of terrestrial organic material can result either from rainfall run-off or, on a much larger scale, floodplain inundation.

As different organisms have different requirements for organic material and many are highly selective about what is useable as a food resource, the sources of organic material play an important part in determining the condition of a river system. Variation in the **type** of organic material available influences the diversity and community structure of secondary producers, while the **quantity** of useable organic material determines the biomass of secondary producers that can be supported. The organisms of the microbial loop are similarly affected by the characteristics of the organic material supply. This has significant implications for the relative extent of energy re-packaging compared to energy dispersion and so the degree of linking between the microbial loop and higher trophic levels.

The relative supply of internal to external organic material is influenced by a range of environmental conditions, of which river discharge is an important one. Changes in river discharge alter several elements of the flow regime that affect the growth of plants within the river channel, particularly water depth and velocity and the degree of connectivity between the river channel and its surrounding floodplain. An understanding of these interactions is required in order to assess the effect on the delivery of organic material to the Goulburn River of changes in discharge resulting from delivering IVT's. The following sections provide a synopsis of the major effects of changes in discharge on riverine production. The analysis attempts to quantify these interactions from general principles in order to provide indicator variables that might be used as a basis for assessment and the development of environmental flow recommendations. A challenge is to provide a basis for recommendations in light of the multiple sources of riverine production that may operate to different degrees at various stages of the flow regime. For example, recommendations might be set to maximise the production of one component of the system, yet the resultant flow conditions might occur only rarely when flow was unregulated. While biotic processes may often not operate at maximum rates under more variable natural conditions, the way that they respond to environmental fluctuations defines the structure of the ecosystem. It is for this reason that "natural" regimes are so frequently used as a benchmark against which change is measured. This does not necessarily suggest a return to original conditions as a target condition, but does serve to indicate how far removed the new conditions are from the original and to determine whether this shift is detrimental to maintaining the desired ecosystem characteristics.

Water depth

Water depth influences riverine plant production mainly through its effect on the underwater light climate. Light energy penetrating the water column declines exponentially with depth, confining the growth of photosynthetic organisms to the well-illuminated layers. For those organisms attached to the bottom sediments, such as benthic algae and submerged macrophytes, the area of wetted sediment sufficiently illuminated to support their growth is generally estimated as the area delimited by the depth to which at least 1% of incident sunlight penetrates, commonly called the euphotic depth (z_{eu}). This limit is used extensively for algal production both planktonic and benthic and is based on extensive field measurements (Reynolds 1984).

Where other environmental conditions are suitable for growth, the maximum depth of colonization of the macrophyte *Vallisneria americana* has been estimated using the mean light intensity supporting zero relative growth rate (Blanch et al 1998). This was found to be ca. 26 µmoles/m^{-2}/s^{-1} and falls in the range 3.5-47.3 µmoles/m^{-2}/s^{-1} reported for charophytes and angiosperms (Blanch et al 1998). Assuming mean summer irradiance in the Goulburn River of ca. 900 µmoles/m^{-2}/s^{-1} this range of critical light intensities represents 0.5-5% of incident irradiance, and is similar to that of the limits of algal growth.

However, macrophytes and periphyton are impacted by other environmental conditions in addition to light, including water velocity, and so the extent of their growth may be limited by these factors to shallower depths. Similar critical light ranges were found by Hudon et al (2000) but they reported that the order of significance of environmental conditions explaining biomass of macrophytes were flow forces (current, wind and waves), plant growth form (e.g. whether canopy forming or not), water depth and light (depth enabling plant extension), and seasonal versus permanent inundation (3cm minimum water depth used as an indicator). When other conditions are suitable it appears reasonable to use euphotic areas delineated by 1% or 5% light penetration levels.

The 1%, or euphotic depth, is a function of the vertical attenuation coefficient (k_d) for photosynthetically active radiation (350-700nm) and is described by the relationship:

$z_{eu} = 4.605/k_d$

Unfortunately k_d has not often been measured in the Goulburn River, but a large set of measurements taken across the Murray and Murrumbidgee Rivers (Figure 20) show a significant relationship between k_d and water turbidity measured in nephelometric turbidity units (NTU). If it is assumed that scattering by turbidity and absorption by dissolved colour are similar in the Goulburn River then Figure 20 can be used to estimate the vertical attenuation coefficient from the regular monitoring of turbidity. Some support for using the relationship in Figure 20 comes from a series of 25 measurements made in Nagambie Weir and the East Channel by Webb and

Chan (2004). Their Winter-Spring measurements support Figure 20 whereas their Summer-Autumn values generally predict lower k_d values. More extensive measurements in the Goulburn River would help to resolve these differences but for the present the relationship in Figure 20 is used in the analyses.

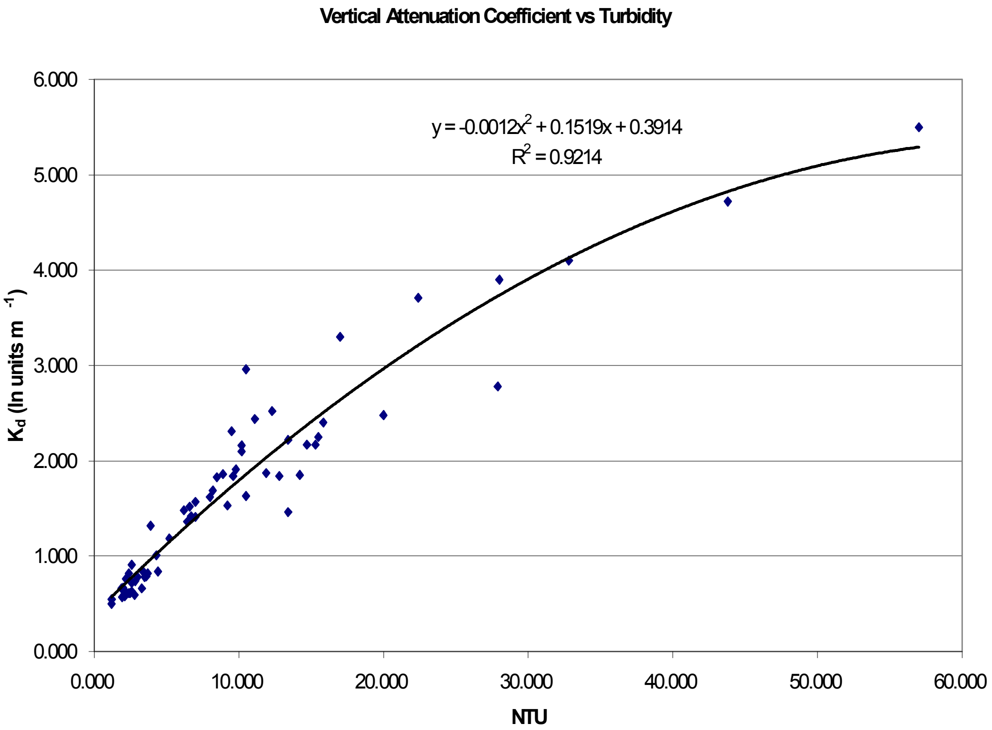


Figure 20: Vertical attenuation coefficient as a function of turbidity.

Average channel cross-sections were estimated for two reaches of the Goulburn River and depth was related to flow so that changes in area of the illuminated benthos at different flow levels could be calculated.

Previous assessment (Cottingham et al. 2003b) has highlighted the difficulty in establishing clear turbidity-flow relationships. The majority of turbidity values at Murchison ranged between 0 and 20 NTU and the corresponding range in k_d is relatively small. Therefore, average turbidity over the period of record (12.7 NTU) was used to determine k_d (2.13) and hence z_{eu} (2.16 m). Comparison of euphotic depth with discharge in Reach 4 at Murchison (Figure 21) indicates that the area of illuminated benthic production increases rapidly up to a discharge of 500 ML/d, declines at discharges between 500 ML/d to 1500 ML/d, but then increases at discharges up to 6000 ML/d. The area of illuminated benthic production then declines steeply at discharges between 6000 and 8000 ML/d.

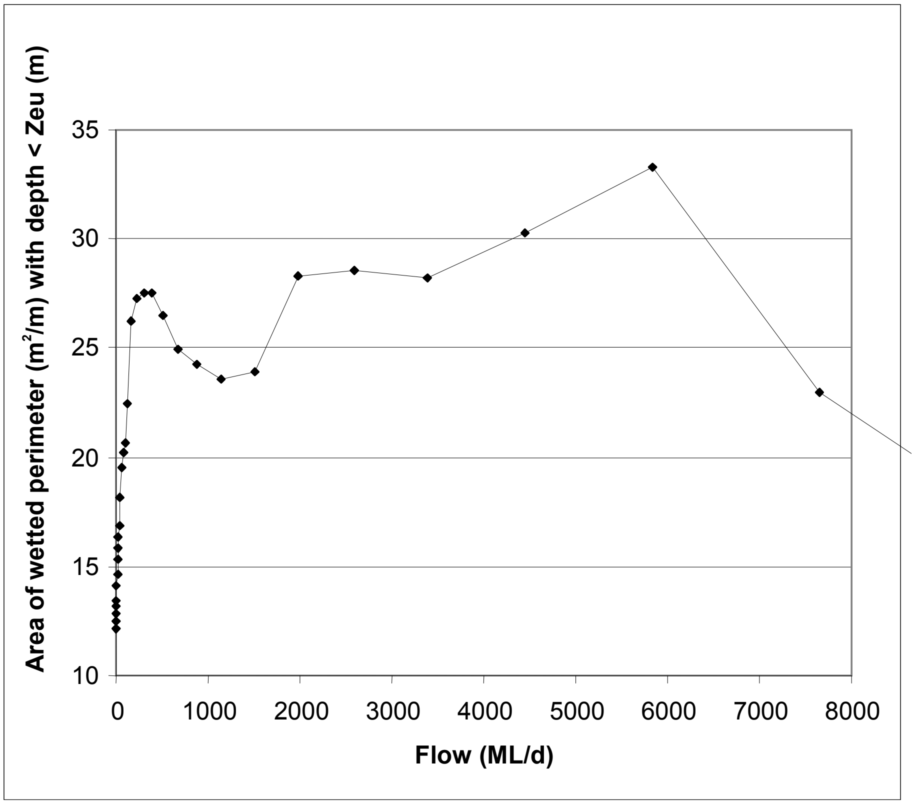


Figure 21: Average wetted perimeter within the euphotic zone at Murchison.

Interestingly, the results for Reach 5 at McCoy's Bridge are very different to that of Reach 4 (Figure 22). As for Reach 4, the area of illuminated benthos increases rapidly in discharges up to 500 ML/d, but then drops rapidly to a relatively small illuminated area at discharges between 1500 and 2000 ML/d and remains small at higher discharge. This indicates that higher discharge levels will lead to greatly reduced areas of benthic production in this section of the river.

River regulation has affected median discharge along both reaches. For example, the median summer (January) flow at Murchison has been reduced from approximately 2000 ML/d to 400 ML/d, but the area of illuminated benthos remains largely unchanged. However, the reduction in summer flows in Reach 5 from 2500 ML/d to 700 ML/d has greatly increased the availability of illuminated benthos. This is an example where regulation appears to have increased the area available for benthic production.

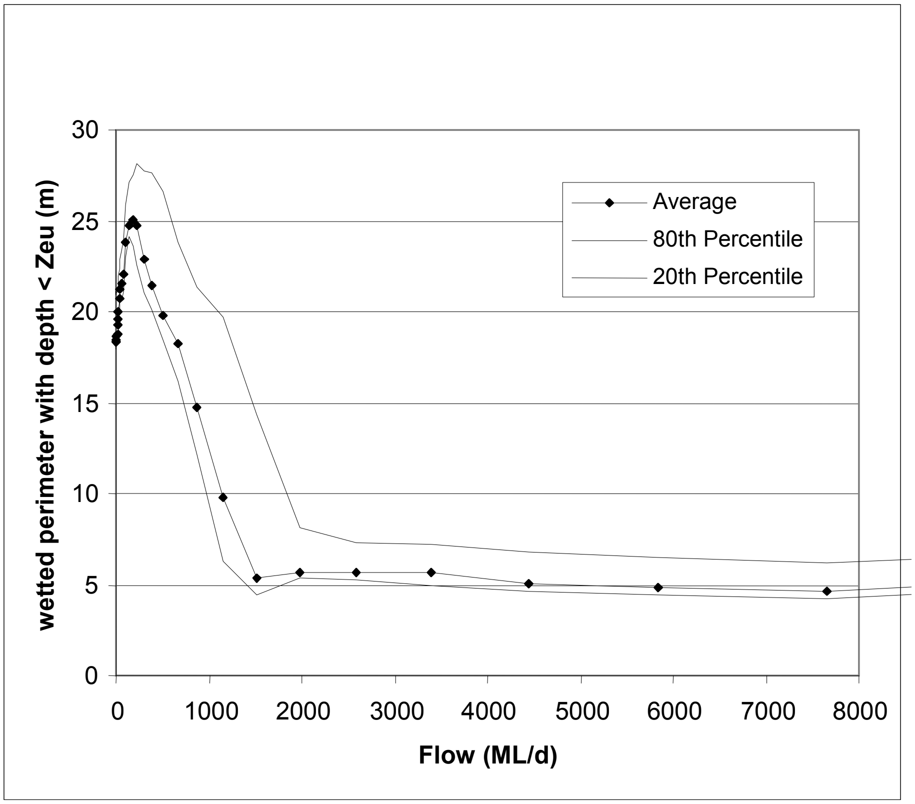


Figure 22: Average wetted perimeter within the euphotic zone at McCoy's Bridge. The upper and lower bounds represent the 20th and 80th percentiles, respectively.

Changes in water depth also influence the light climate encountered by phytoplankton suspended within the water column, so affecting planktonic production. Net phytoplankton production (*NP*) is a function of the depth of the euphotic zone relative to the mean depth of the water column. This ratio determines the time that cells circulating through the mixing water column spend in the upper illuminated region where photosynthesis can occur, relative to the time spent in the deeper unilluminated region where respiration of cellular reserves provides the energy for continued activity.

Models developed from empirical data to describe integral daily photosynthesis and respiration rates can be used to demonstrate that a shift from light sufficiency to light limitation occurs when the ratio $z_{eu}/z_{average} < 0.2$-0.3 (Talling, Reynolds 1984, Oliver et al. 1999) and this is the point where net production is zero. At lower ratios the respiration requirements exceed energy fixed by photosynthesis and growth is not possible. Conversely the light intensity increases as the $z_{eu}/z_{average}$ ratio increases and when $z_{eu}/z_{average}$ is ≥ 1 the bottom sediments are illuminated. Given the value for z_{eu} of 2.16 m (see previous discussion) at Murchison (Reach 4) and z_{eu} of 1.00 m for reach 5 and applying $z_{eu}/z_{average} < 0.25$, light sufficiency occurs when the mean depth is less than approximately 9 m and 4 m for reach 4 and 5, respectively. In both instances, this represents discharge above 8,000 MLd/ (Figure 23 and Figure 24), which is well above the IVT discharges being considered. This analysis suggests that phytoplankton net production is possible at most discharge levels, but it does not demonstrate how the phytoplankton growth rate may diminish as conditions within the water column approach the point where net production is zero.

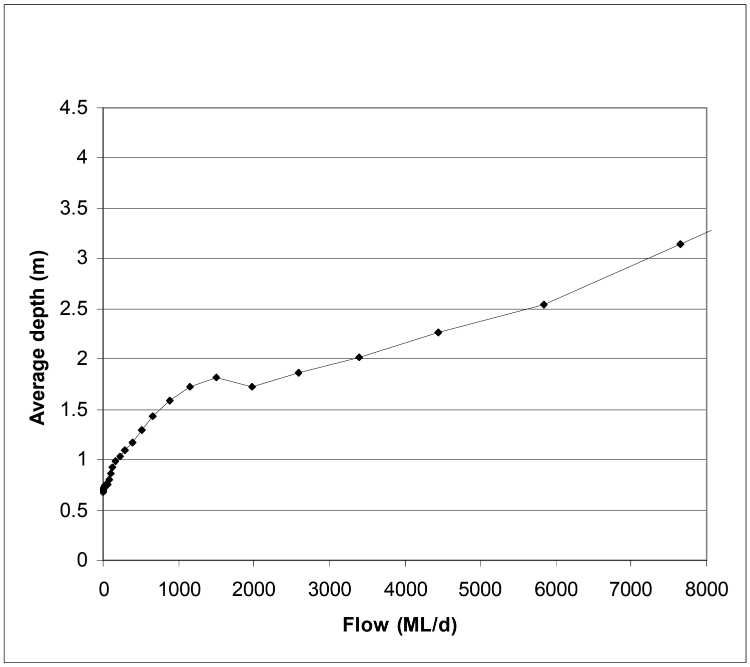


Figure 23: Mean depth at Murchison

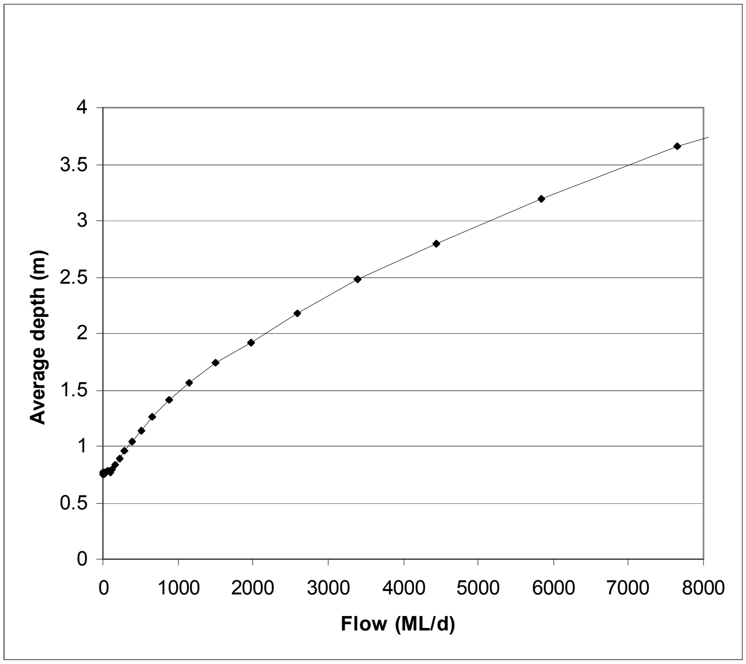


Figure 24: Mean depth at Wyuna

Where the average depth of the river exceeds the euphotic depth ($z_{eu} < z_{average}$) the mean irradiance ($\bar{I}$) encountered by algae as they are vertically mixed through the water column is related to the incident irradiance (*I*) and the ratio of the euphotic and average depth:

$$\bar{I} = \frac{I * Zeu}{4.605 * Zave}$$

Primary production studies in the Murray River have shown that gross phytoplankton production (*GPP*) is a linear function of the mean irradiance over a wide range of values (Oliver and Merrick 2006). The influence of changing water depths on GPP in the Goulburn River can be investigated by assuming a similar relationship to that measured for the Murray River, and using a typical daily average incident irradiance during summer of 900 µE/m^2/s and expressing results in the form of a maximum potential specific growth rate. Results suggest that over the relevant discharge levels there is only a small decline in production in Reach 4 (Figure 25) as average depth exceeds the euphotic depth. However, increased depth in Reach 5 is likely to have a substantial effect on production, leading to a halving of gross production (Figure 26).

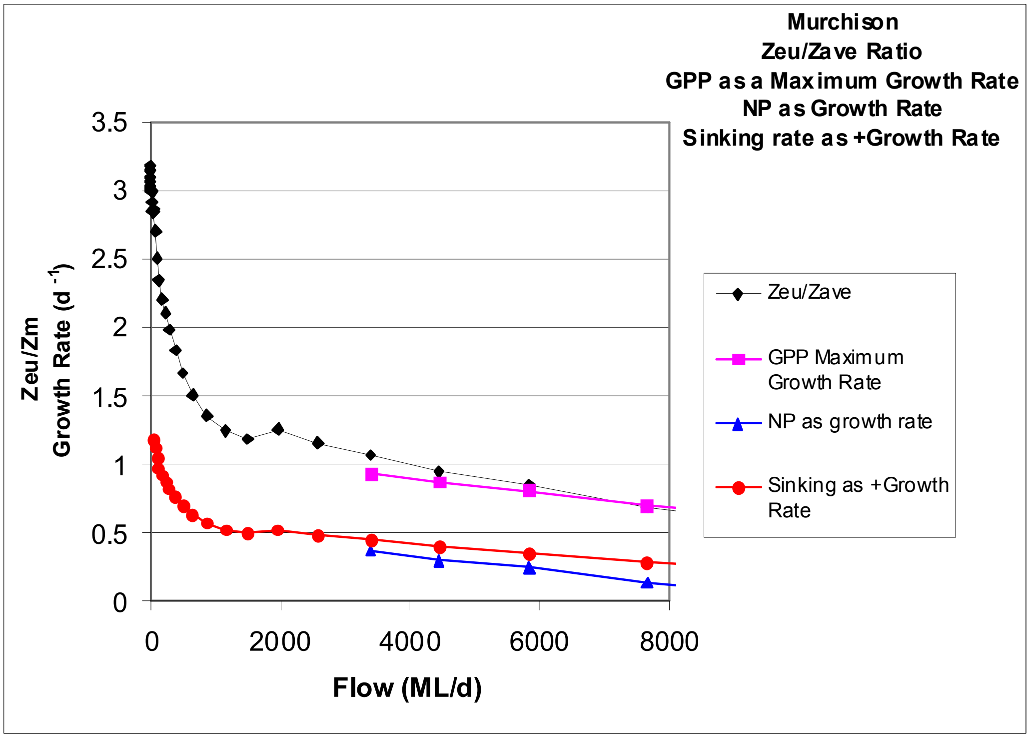


Figure 25: Maximum potential growth and net production in Reach 4.

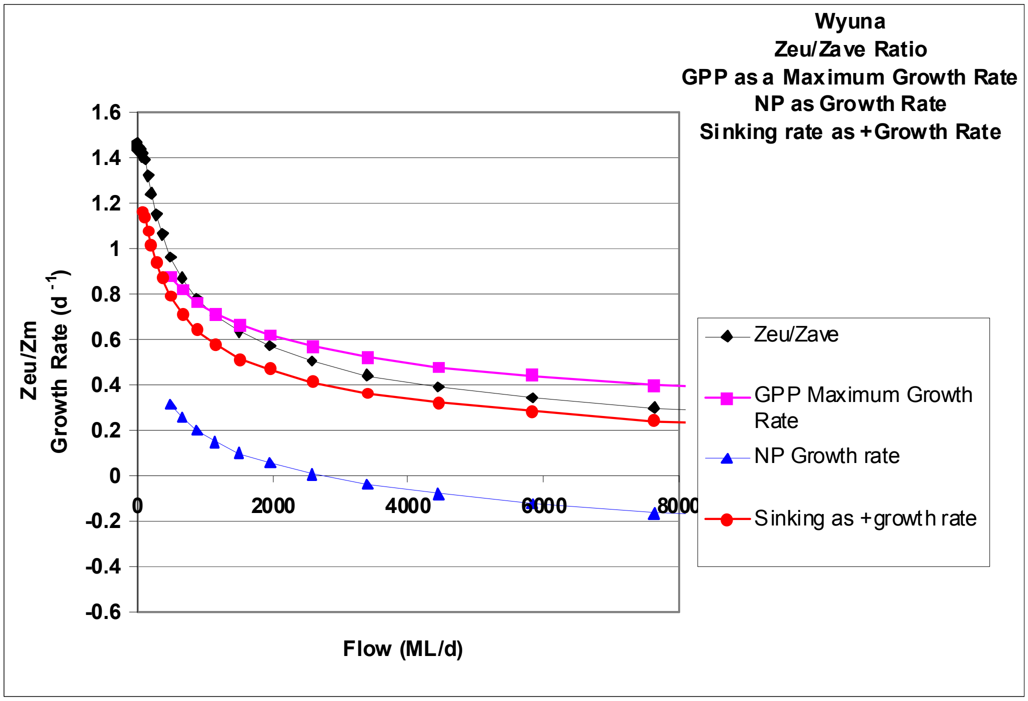


Figure 26: Maximum potential growth and net production in Reach 5.

Water velocity:

The ability of particular organisms to maintain themselves within the river channel is influenced by water velocities. Phytoplankton biomass production in the Murray River has been noted to increase exponentially as flow declined below 0.2 m s^{-1}. Similar observations have been reported for other large rivers (Reynolds 1988; Bowles & Quennell 1971). It is assume that this reflects the inability of phytoplankton to establish large populations in river reaches with short retention times. Increases in the effective retention time within a river reach can result in increased phytoplankton production, especially if these zones are shallow and well illuminated.

Average velocity of 0.2 m/s occurs at discharges of 875 ML/d at Murchison and 1100 ML/d at Wyuna (Figure 27 and Figure 28). At discharges higher than this, the likelihood of substantial phytoplankton populations developing is reduced, despite there being a light climate sufficient to support significant phytoplankton net production. Phytoplankton can be retained within a river reach in the presence of slack water zones (e.g. crenulated areas of the bank), if flows allow connectivity with larger backwaters, or if there are large low-flow pools present. To effectively retain phytoplankton, these zones would need to have exchange rates of the order 0.01 - 0.02 h^{-1} and so require 2 - 4 days for theoretical hydraulic replacement. Phytoplankton growth rates are often such that doubling occurs every 3-4 days (or longer), so hydraulic replacement less than this can lead to reduced biomass.

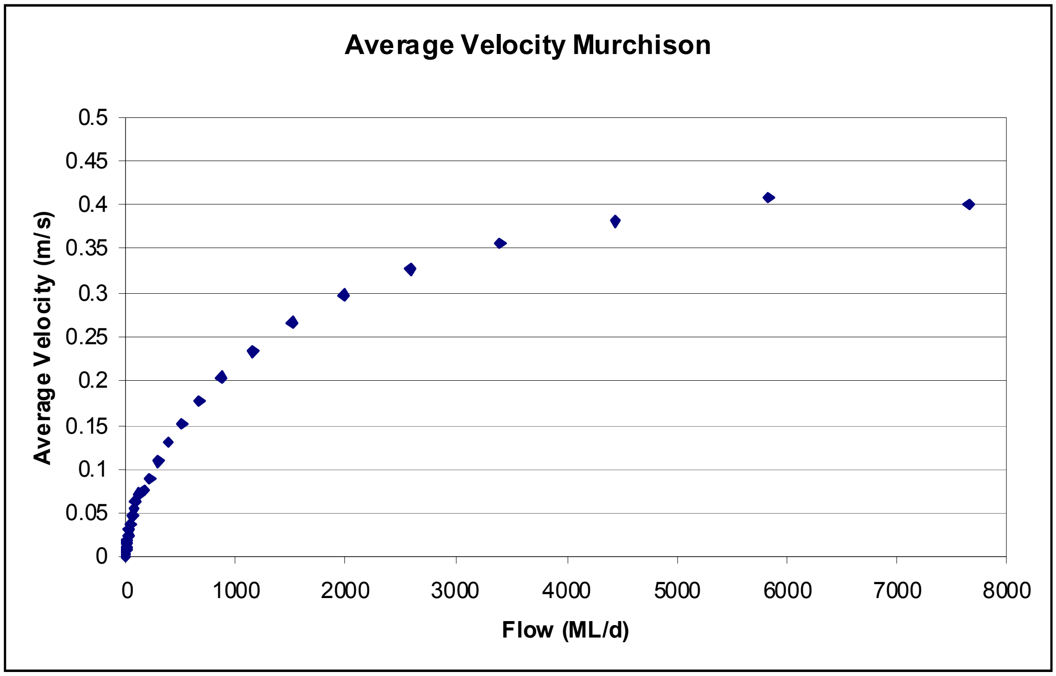


Figure 27: Average velocity versus flow in Reach 4.

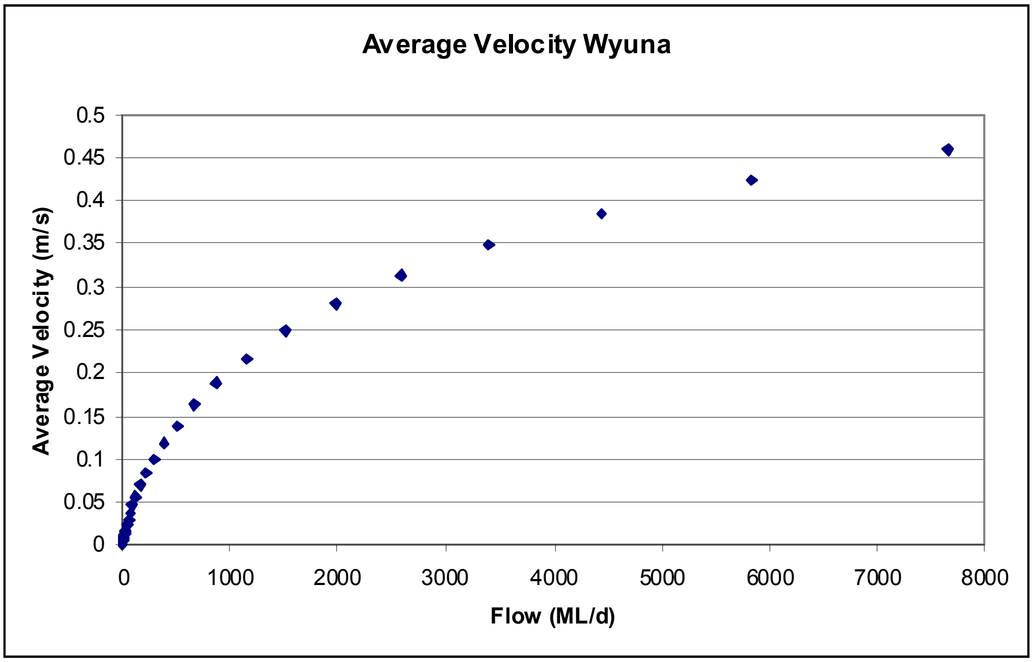


Figure 28: Average velocity versus flow in Reach 5.

Loss factors such as sinking of cells are not considered in the net production calculations and these can be high. Sinking loss rates can be estimated for a well mixed water column assuming that it is bounded on the lower surface by a non-mixing zone or surface, such that sedimented cells cannot be resuspended. The simplest formulation is for a well mixed water column where the concentration of phytoplankton (N) declines exponentially as a function of their sinking rate (v) and the depth of the water layer (Reynolds and Wiseman 1982);

$$N_t = N_0 e^{-vt/Zave}$$

The diatom *Aulacoseira granulata* commonly occurs in river systems such as the Murray and Goulburn and has a relatively high sinking rate of around 0.95 m/d (Sherman et al 1998). The daily loss rate of such cells are depicted in Figure 25 and Figure 26 as a specific growth rate (ln(Nt/No)/t = -v/Zave, presented graphically as a positive growth rate) to indicate how sinking rate changes with water depth and for comparison with NP. At both sites the relationship between depth and discharge are similar and so the sinking loss rates are also similar. The loss rate does not alter greatly at discharges above 1500 ML/d but increases dramatically at values below this because of the more rapid reduction in depth. At Murchison the net growth rates are of similar magnitude to sinking rates while at Wyuna sinking rates for the diatom significantly exceed the expected production rates. This changing balance between positive and negative net production along rivers has been widely reported (Reynolds and Descy 1996; Wehr and Descy 1998; Leland 2003).

As discharge is reduced there is also a greater chance of thermal stratification occurring, especially during summer. This has the potential to improve the light climate and so favour the growth of phytoplankton able to maintain themselves within the illuminated layers (e.g. buoyant cyanobacteria). The interaction between flow, water turbulence and thermal stratification has been studied in lowland rivers in south-eastern Australia and persistent stratification generally occurs below average cross-sectional velocities of ca. 0.05 m s^{-1} (Bormans & Webster 1997; Mitrovic et al. 2003). The discharge-velocity relationships at the two Goulburn sites suggest that problems of cyanobacterial surface blooms are most probable below flows of 80 ML/d at Murchison and 34 ML/d at Wyuna.

Changes in species composition occur along rivers in response to flow changes as well as to seasonal conditions (Reynolds and Descy 1996; Wehr and Descy 1998; Bahnwart et al 1999; Leland 2003). In the Warnow River (Germany) centric diatoms and cyanobacteria dominated in summer, while small centric diatoms dominated the river in autumn (Bahnwart et al 1999). Downstream changes reflected longitudinal variations in flow with biomass highest in slow flow, fluvial lakes. Cyanobacteria, cryptophytes and diatoms showed large biomass losses in fast flowing shallow river sections, whereas chlorophytes were favoured showing less loss. Diatoms and cryptophytes benefited from low flow velocity and increased water depth (Bahnwart et al 1999). In zones where water velocity declined during summer, green algae became more numerous.

Water velocities also impinge on the structure and function of biofilms that grow attached to the bottom sediments or other submerged surfaces. Studies of periphyton and biofilms have indicated some general controlling principles. Jowett and Biggs (1997) found that chlorophyll contents and ash free dry mass (AFDM) were more dependent on time of accrual than flow velocity, but there was a trend of increasing amounts of both as velocities decreased, especially below 0.3m/s. Silt accumulation was strongly related to periphyton biomass, suggesting a trapping effect, but it was found in general that ADFM and silt accrual diminished as flow increased. In the Tongariro River, there was a pronounced increase in AFDM and silt at velocities less than c. 0.3 m s^{-1} (Jowett and Biggs 1997). This supports the belief that there is little movement of sediment of any size on the stream bed when velocities are less than about 0.3m/s. Erosion of sand particles occurs at ca. 0.2 m/s and although silt and clay are finer, higher velocities are usually required because of their cohesiveness. A classic study by Hjulstrom (1935) related the mean velocity for initiation of sediment movement to particle size. He and others (e.g.,Eisma 1993) have shown that there is no movement of sediment (specific gravity c. 2.65) of any size on the stream bed when velocities are less than 0.2—0.3 m s^{-1}. The variation in sediment movement, and thus abrasion, with velocity was given as a possible explanation for the increase in periphyton accumulation where water velocities in the Tongariro River were less than 0.3 m s^{-1}.

Biggs et al (1998) demonstrated that the growth form of biofilms is an important characteristic, with dense and coherent forms of mucilaginous diatom/cyanobacterial mats resisting flow generated shear stress better than the open matrix mats of filamentous green algae. Measurements indicated that the mucilaginous forms showed maximum biomass at near bed velocities of ca. 0.2 m/s whereas the maximum of the filamentous type occurred at near bed velocities <0.2 m/s but at faster flows biomass declined exponentially to less than 10 mg/m^2 at velocities >0.4 m/s. Similarly Ryder (2006) showed that at velocities above 0.3 m/s the biofilms on red-gum blocks showed reduced biomass and species richness.

In rivers where the photic depth is limited by colour or turbidity, or where changing water levels move biofilms to low light levels then benthic algal production is limited and heterotrophic microbial-detrital biofilms prevail. In contrast stable water levels promote late-successional biofilms favouring benthic algae (Sheldon and Walker 1997). For some organisms, such as snails it has been suggested that microbial-detrital biofilms are a better food source and that the changes in flow brought about by river regulation have led to the reduction of some snail populations (Sheldon and Walker 1997). Oscillations in water level thus affect the presence and composition of biofilms.

Algal biomass was observed to peak when biofilms were exposed for less than 3 consecutive days in a 90 day observation period provided they were not degraded by desiccation and wave action, with the minimum organic biomass consistently at the surface and the maximum towards the bottom of the euphotic zone (Burns and Walker 2000). Ryder (2004) reported that the maximum net primary productivity of biofilms developing on red gum blocks occurred after 29 days of submersion but then fell rapidly. Blocks undergoing a high frequency oscillation (5 d submerged and 9 d emersed) had developed a heterotrophic film after 75 days with negative NPP, while those exposed to a moderate cycle (11 d submerged and 21 d emersed) had an autotrophic biofilm with highest NPP relative to algal biomass and higher NPP than the permanently inundated blocks. Although the dry mass remaining on the two oscillating treatments after 79 days was similar to each other, they were only 10% of that on the submerged blocks, even though algal biomass levels were comparable across all treatments. This was thought to reflect the accumulation of sediment within the submerged biofilms and corresponds with the findings of Jowett and Biggs (1997). Ryder (2004) concluded that the regime of high inundation/emersion frequency resulted in a biofilm dominated by diatoms and unicellular cyanophytes but were heterotrophic, whereas assemblages in the regime of intermediate inundation/emersion frequency were dominated by filamentous diatoms and chlorophytes and were autotrophic. Sufficient time for development of desiccation-tolerant algae or recolonization is required in biofilms rapidly oscillating between wet and dry."

Water velocity also influences the distribution and condition of submerged macrophytes. Biggs (1996) found in streams with high temporal hydraulic stability at the time of peak biomass (often summer) that where mean reach velocities are <0.2 m/s up to 75% can be covered with macrophytes whereas less than 10% may be covered where velocities exceed 0.9 m/s. Madsen et al (2001) suggest that for velocities between 0-0.1 m/s photosynthetic rates increase with flow, while above this the biomass of macrophytes is negatively correlated with flow up to ca. 1 m/s when they are no longer present. Some macrophytes such as Bryophytes are able to withstand higher velocities but are specifically adapted for this.

The previous discussion highlights that the influence of water depth and velocity on the occurrence and growth of the various primary producers (submerged macrophytes, benthic algae, periphyton/biofilms) is not as different as might have been expected. A velocity of 0.2-0.3 m/s seems to have important physical implications that impact on these attached plants. In addition, this same velocity marks a change in channel retention time that influences the growth of phytoplankton. One reported effect is that this velocity in general marks the initiation of significant bed movement which is disruptive to the attached organisms, especially if not well established, and increases the sediment in suspension and so the risk of siltation. If this is the case then part of the impact on phytoplankton growth might be related to a reduction in light penetration at velocities above this range due to resuspended sediment. However, this would not explain the continuing increases in phytoplankton biomass as velocities continue to fall. It seems likely that this is related to a change in distribution of water velocities across the channel.

In summary, flow stressors related to depth and velocity were examined in relation to their effect on the phytoplankton and submerged macrophyte production.

In summary, flow stressors to be assessed from an instream production perspective were:

- Planktonic Algae:
  - mean residence time (hours/km);
  - mean ratio of fall velocity (0.40 m/s) to mean water *depth (assess sinking losses from the water column of average plankton*);
  - mean ratio of fall velocity (0.95 m/s) to mean water *depth (assess sinking losses of the diatom Aulacoseira granulata*);
  - proportion of time when euphotic depth is less than 0.3 times the mean depth (*assess when in-channel production exceeds respiration i.e. NPP is zero or negative*);
  - mean ratio of euphotic depth to mean water depth (assess light limited GPP and *NPP in the channel*);
- Periphytic algae:
  - mean illuminated area of benthos (m^2 per m length of channel*) (assess relative area of benthic production*);
  - mean illuminated area of benthos with velocity less than 0.2 m/s (m^2 per m length of channel) (*assess velocity conditions suitable for benthic production*);

  - mean illuminated area of benthos with velocity less than 0.3 m/s (m^2 per m length of channel) (*assess illumination and velocity conditions suitable for benthic production)*;
  - mean illuminated area of benthos with velocity less than 0.4 m/s (m^2 per m length of channel) (assess illumination and velocity conditions suitable for benthic production);
  - proportion of time the bank has been within the euphotic zone for at least 14 days, at selected stages above the bed corresponding with various exceedence flows in the natural regime.
- Macrophytes:
  - mean illuminated area of benthos (m^2 per m length of channel) (*assess relative area suitable for macrophyte production)*;
  - mean illuminated area of benthos with velocity less than 0.4 m/s (m^2 per m length of channel) (*assess velocity conditions suitable for macrophyte production)*;
  - mean illuminated area of benthos with velocity less than 0.9 m/s (m^2 per m length of channel) (assess illumination and velocity limits for macrophyte production);
  - proportion of time the bank has been within the euphotic zone for at least 42 days, at selected stages above the bed corresponding with various exceedence flows in the natural regime.

4.2.3 River Bank Vegetation

Summer and autumn low flow periods are important for maintaining shallow, low velocity habitat that favours the growth or recruitment of aquatic macrophytes (Chee et al. 2006) (Figure 29). Although Chee et al. (2006) provided a conceptual model to support the need to increase very low summer-autumn flows for aquatic and amphibious macrophytes, the implications for higher-than-natural summer flows as a result of IVTs was not considered (Figure 30), particularly in terms of their impact on bank vegetation. This section considers ecological objectives and flow stressors related to the dynamics of vegetation of the riverbank. Ecological objectives and flow stressors for aquatic macrophytes have been addressed in the previous section on Riverine Production (section 4.2.2) and in the subsequent section on Macroinvertebrates (section 4.2.4).

The Panel has observed that vegetation on the bank of the Goulburn River has become increasingly terrestrial in nature over the last 5 years. This is presumably due to the reduced frequency and duration of moderate to high flows under the current flow regime that would prevent encroachment of terrestrial vegetation and provide conditions favourable for amphibious and aquatic species. The face of the bank commonly carries Silver Wattle *Acacia dealbata* and sometimes young River Red Gum *Eucalyptus camaldulensis*. The understorey may be sedgy or grassy, with species such as Warrego Summer Grass *Paspalidium jubiflorum* and *Poa labillardieri*. Tufted or tussocks of emergent macrophytes of medium height (notionally 0.5 to 1.5 m - mainly rushes (Juncaceae) and sedges (Cyperaceae)) have a restricted (vertical) distribution, occurring at or close to the water line. Herbs that are not fully aquatic but require wet conditions such as *Lythrum salicaria* also are limited to the waterline.

The vegetation occurring on the banks of large rivers has been little studied in Australia. Whilst it is well accepted that flow-related processes are important for maintaining riverbank and riparian vegetation, processes such as propagule dispersal and establishment are little known. From the few Australian studies (notably Lowe 2002), it is known that flow regime (pattern of submergence through time) and siltation adversely affect the growth and survival of riverbank species and hence will also influence community and vegetation attributes such as abundance and composition. Perennial plants are an important part of riverbank vegetation and are present as trees, shrubs, grasses and herbs. The Aquatic and Riparian Vegetation model proposed for VEFMAP, with its emphasis on establishment from the seedbank, does consider terrestrial and perennial species. However, it does not explicitly consider how terrestrial species growing on the river banks respond to flow regime, in particular to submersion.

Insights on how non-woody terrestrial species of riverbanks respond to changes in the flow regime can be drawn from overseas studies. Initially, this research was ecophysiological, and focused on understanding the mechanisms of inundation tolerance, so tended to concentrate on a small number of ‘model’ species, mostly herbs in the genus *Rumex*. This gave a sound understanding of adaptations in plants in the more frequently flooded areas or wet-dry zones, an understanding effectively summarised by Voesenek et al. (2006). Research on the effect of floods on species lacking such adaptations, the flood-sensitive or terrestrial species, has proceeded in parallel. Of particular interest to this study is an understanding of how the timing (or altered seasonality) of high discharge events leave a legacy on the landscape. This understanding is useful as a model for rivers and riverbanks in south-eastern Australia because the ecological implications of altered seasonality and extreme events for riverine vegetation are poorly understood.

The effect of inundation on non-woody terrestrial plants, ie on grasses, forbs and herbs, brings together two themes: duration of inundation, and controls on the upper and lower distribution of species on a vertical elevation gradient. Plants from ‘frequently’ flooded riverbank sites are ***flood tolerant*** due to having one or more of the following responses when they are partly or completely flooded (Voesenek et al. 2006):

- rapid development of adventitious aerenchymatous roots, to facilitate the downward transport of oxygen;
- stem hypertrophy, also to facilitate the downward transport of oxygen;
- elongation of stem or leaves, carrying leaves into air following flooding; and
- underwater photosynthesis.

These adaptations are not equally expressed between species. The capacity to elongate, for example, differs between species and also depends on the developmental stage reached when flooding begins (van der Sman et al. 1993). Adaptations are not without some cost; in some species, there is a trade-off between capacity to elongate and subsequent reproductive output. ‘Frequently’ as used by Blom et al. (1994) is not quantitatively defined but descriptions in the text show it means several times (short) within a growing season, making it comparable to ‘fluctuations’ and to Zone B in VEFMAP model of Aquatic and Riparian Vegetation (Chee et al. 2006) (Figure 30).

Plants from higher up the riverbank, from the zone that is seldom or very infrequently flooded, lack the adaptations found in the flood-tolerant species described above, so are ***flood sensitive***. These are terrestrial plants. Inundation is stressful for these as it imposes multiple stresses: oxygen depletion (due to soil water-logging), carbon deprivation or starvation (due to comparatively low amounts of available carbon in the water), and reduced capacity to photosynthesise (due to shading effects associated with turbid flood waters). With no adaptations to either directly compensate for these stresses or by-pass their effects, terrestrial plants can survive inundation only as long as their internal resources last. Duration is thus very significant. Survival experiments routinely use LT_{50} (units in days), meaning the duration at which 50% of plants have died, to compare between species or between experimental treatment such as shading or depth. Duration of inundation is widely recognised as the most significant aspect of water regime for wetland species (eg Casanova and Brock 2000) and is also significant for riverbank species. This part of the riverbank corresponds to Zone C in Chee et al. (2006).

In wetland and riparian ecology, zonation patterns are interpreted as differential species responses to water regime. A general model describing species distribution along an elevation gradient is that competition (biotic factors) controls the upper limit, and that some aspect of water regime (abiotic factors) controls the lower limit. In the case of tall emergent macrophytes with the capacity to pressure-ventilate their rhizomes, such as *Typha* sp., the lower limit is controlled by water depth. In the case of terrestrial species on riverbanks, it is the duration of unusual or rare floods during the growing season (summer) that defines a species' lower limits down a riverbank, rather than average winter floods (eg van Eck et al. 2006).

For terrestrial species, season is now known to be critically important. Growth and survival experiments using 10 grassland species originating from different elevations of the floodplain found that all survived inundation longer (and some much longer) when flooded in winter than in summer (van Eck et al. 2006). The experiments also showed that survival, as LT_{50}, differed between ecological groups. Thus survival for two species considered to be flood-tolerant (e.g. Blom et al. 1994) was 38 to 55 days in summer, and increased to 95 to 100 days in winter (van Eck et al. 2006). In contrast, survival of flood-sensitive species was much lower, with LT_{50} ranging from about 5 to 10 days in summer.

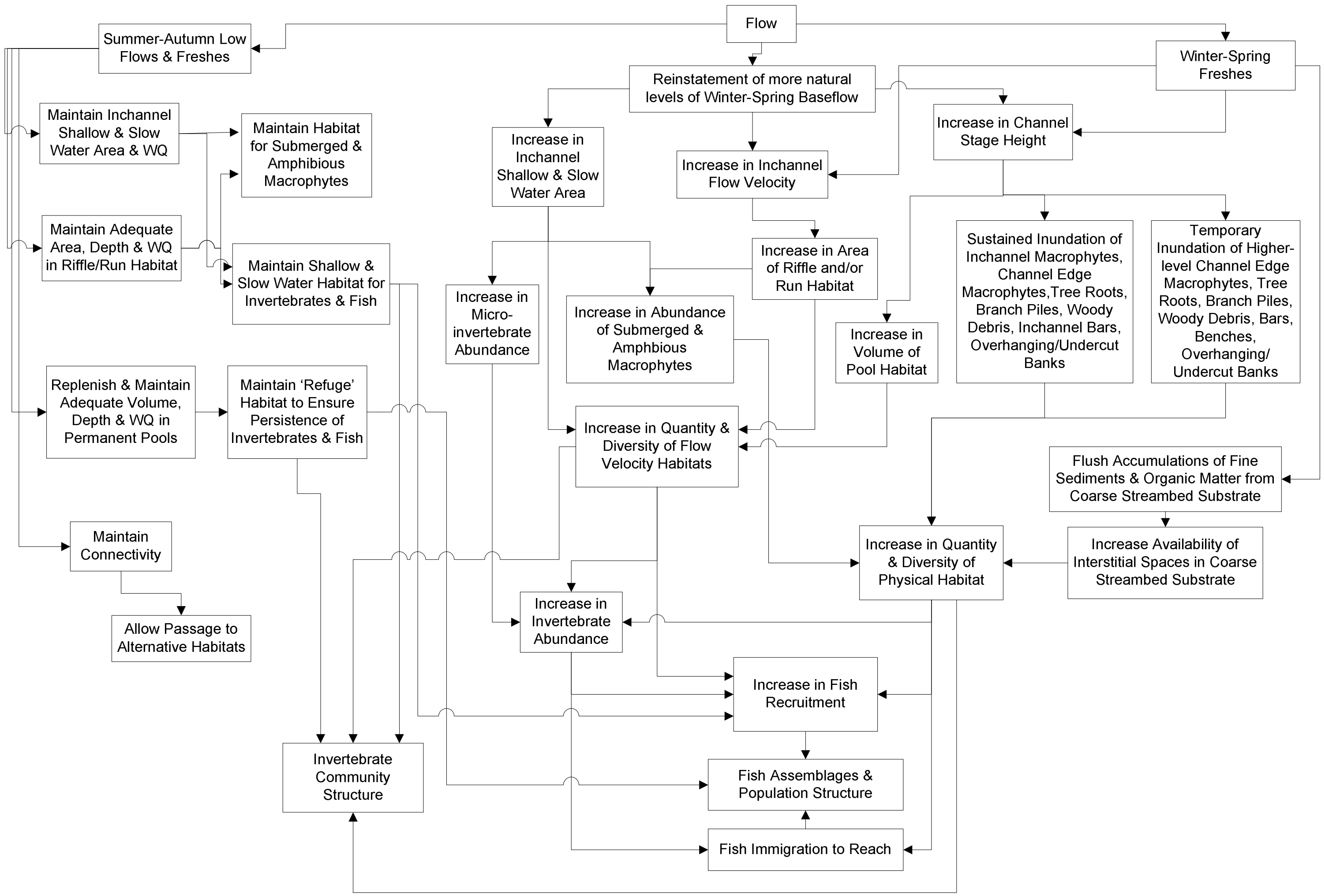


Figure 29: **Conceptualisation of vegetation, macroinvertebrate and fish habitat responses to flow components (from Chee et al. 2006).**

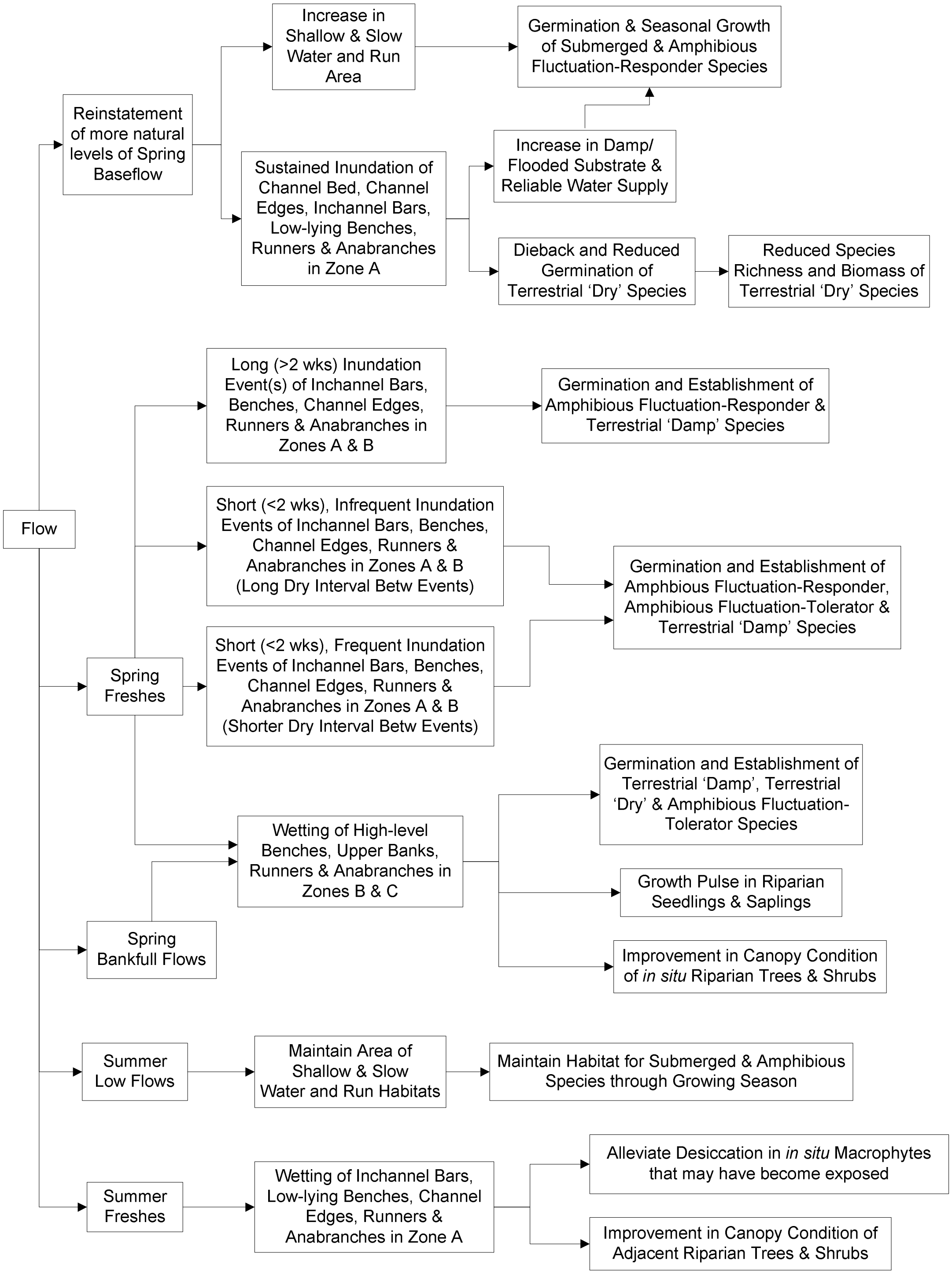


Figure 30 : Conceptual model of aquatic and riparian vegetation responses to Spring and Summer flows. Zone A: from mid-channel to stream margin (or the area covered by water during times of baseflow); Zone B: from stream margin to a point mid-way up the flank of the bank (or the area that is infrequently inundated): Zone C: from mid-way up the flank of the bank to just beyond the top of the bank (from Chee et al. 2006).

As a group, however, flood-sensitive species had a quite variable survival response to winter submergence. Some were quite sensitive with low survival rates (an LT_{50} of about 15 days) whilst others were much more tolerant with LT_{50} ranging from about 40 to 100 days. Although variability in survival within this group can be attributed, in part, to species differences (van Eck et al. 2005b), water quality (clarity) also plays a role, affecting the light climate around the submerged plant or even smothering it through sedimentation (Mommer et al. 2005, van Eck et al. 2005a). The ecological effects of winter flooding on terrestrial species appear to be very limited, especially compared with summer flooding. Studies in the Netherlands have shown that winter flooding and winter itself are not opportunities for down-slope colonisation by terrestrial species (eg van Eck et al. 2005a). Winter flooding does not exert the strong influence on species distribution down riverbanks that summer flooding does (Vervuren et al. 2003, van Eck et al. 2006), as shown by correlations between flood stage and species survival, estimated as LT_{50}.

The importance of summer flooding as a 'resetting' mechanism for the encroachment of terrestrial vegetation down the riverbank was used as the basis for exploring the potential impact of increasing IVTs. Under an unregulated flow regime in the Goulburn River, summer flows would have been sufficient to exclude terrestrial vegetation from much of the riverbank (Figure 31).

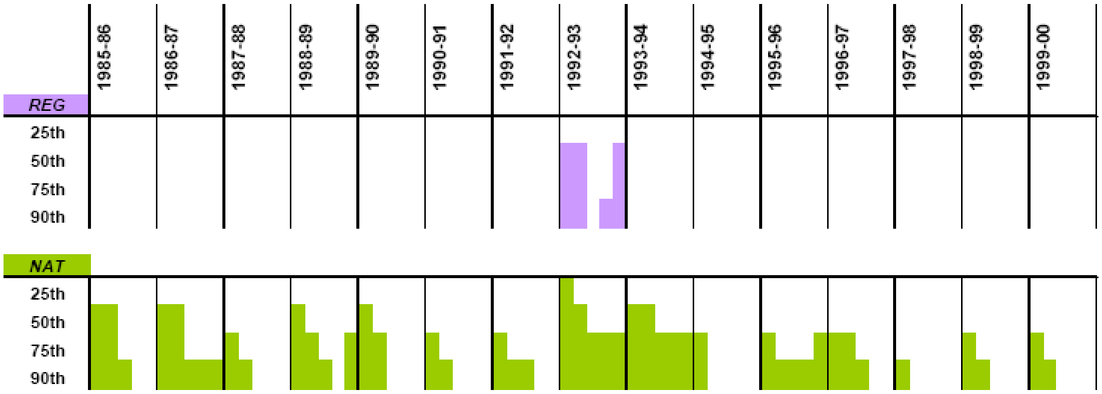


Figure 31: Occurrence of "terrestrial-excluding" inundation events based on the conceptual understanding that inundation events in the warmer months (December to April inclusive) that are 50 cm deep and last a minimum of 15 days can be expected to cause mortality in 50% of terrestrial plants. The plot shows occurrence of such events under regulated flows (Above) and non-regulated flows (Below) at 0.6m, 1 m, 1.8m and 4 m on gauge at Murchison, equivalent to 90th, 75th, 50th and 25th percentile of natural flows.

Four ecological objectives were considered for river bank vegetation with the intention of returning the vertical diversity and distribution of vegetation (terrestrial, amphibious, aquatic) towards that presumed for pre-regulated conditions:

1. Maintain persistent cover over part of upper part of bank (equivalent to natural flow percentiles where bank inundation has same/similar duration under natural as historic – i.e. protect those areas of the bank unaffected by regulation).
2. Reduce cover, ie move towards assumed natural, for those parts of bank falling below threshold (threshold is flow percentile where natural duration of inundation is approximately equal to historic).
3. Maintain composition that is mainly native species (notionally at least 75% by cover)
4. Avoid conditions that favour significant riparian and aquatic weeds known to occur in the area.

However, it is acknowledged that factors outside the study reaches (e.g. weed propagule delivery) or flow components other than summer-autumn low flow will affect the latter two objectives (objectives 3 and 4 above). The implications for IVTs on bank vegetation are therefore based on the first two objectives listed above. The flow stressors relevant to these objectives are:

- Maximum spell duration (days) at the stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime (*assess conditions favourable for terrestrial vegetation at the top of the river bank*);
- Maximum spell duration (days) at the stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime (*assess conditions favourable for terrestrial vegetation at the top of the river bank*);
- Maximum spell duration (days) at the stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime (*assess conditions favourable for terrestrial vegetation at the top of the river bank*);
- Maximum spell duration (days) at the stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime (*assess conditions suitable for a dynamic mix of amphibious and terrestrial species*);
- Maximum spell duration (days) at the stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime (*assess conditions suitable for a dynamic mix of amphibious and terrestrial species*);
- Maximum spell duration (days) at the stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime (*assess conditions favourable for amphibious species at the bottom of the river bank)*;
- Maximum spell duration (days) at the stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime (*assess conditions favourable for amphibious species at the bottom of the river bank)*;
- Maximum spell duration (days) at the stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime (*assess conditions favourable for aquatic and amphibious species at the bottom of the river bank*);
- Maximum spell duration (days) at the stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime (*assess conditions favourable for aquatic and amphibious species at the bottom of the river bank*).

4.2.4 Macroinvertebrates

Macroinvertebrate communities are often used as indicators of stream condition. Reasons for this include:

- Macroinvertebrates occupy a range of positions in aquatic food webs - grazers, predators, detritivores, and food resources for other macroinvertebrates, fish, and birds. They are therefore involved in a wide array of ecosystem processes and respond to changes in any of those processes.

- Individual macroinvertebrate taxa occupy particular habitat niches - in/on sediments, aquatic plants, biofilms, and snags and subject to a wide variety of flow regimes. The make-up of the macroinvertebrate community (taxonomic composition and biomass) is likely to reflect changes in these habitat components over a range of time-scales.
- Well-tested and repeatable techniques are available to sample and identify macroinvertebrates and to analyse and interpret community data.

The macroinvertebrates present at any point in a river represent the outcomes of interactions within the macroinvertebrate community and between members of the community and numerous components and processes in their environment. A conceptual model of flow-habitat interactions for a regulated lowland river reach is presented in Figure 32. It should be noted, however, that there has been little or no research on macroinvertebrate response specific to increased summer flows. Despite this, the conceptual model does provide links with a range of flow-dependent biophysical components of the ecosystem that, in turn, impinge on the macroinvertebrate community.

The macroinvertebrates present at any point in a river represent the outcomes of interactions within the macroinvertebrate community, and between members of the community and numerous components and processes in their environment. Macroinvertebrate communities are likely to contain a mixture of ‘generalists’ and taxa that have quite specialist requirements regarding food supply, structural habitat and/or interactions with other organisms (e.g. avoidance of predation). Whilst there is a long history of sampling and analysing macroinvertebrate communities, there is relatively little detail available on the specific environmental requirements for the range of macroinvertebrate taxa found in Australian lowland rivers (and therefore to describe in detail the drivers for macroinvertebrate diversity or biomass). Prescription of specific flow management actions to create particular macroinvertebrate communities is currently not possible. In such circumstances, it is reasonable to seek management outcomes such as maximising habitat heterogeneity in time and space or mimicking, where practical, ‘undisturbed’ conditions. Hydraulic and hydrological modelling can then be used to refine flow recommendations at least in terms of predicting the space/time distribution of macroinvertebrate *habitat* – and thereby an estimate whether various flow management regimes are likely to be favourable to the macroinvertebrate community of the Goulburn River. This approach also allows the use of ‘undisturbed’ flow regimes – the regime under which the macroinvertebrate community evolved and persisted in the past - as a reference condition against which to compare a suite of managed flows. However, this does ***not*** imply that ‘undisturbed’ condition is a ***target*** for future management regimes.

The composition of macroinvertebrate communities varies between **substrates** found in lowland rivers. Thus snags, emergent plants, and bare sediment/bank material all support some macroinvertebrate taxa specifically adapted to them, as well as a suite of more widely distributed taxa that may be favoured by one or other substrate to a greater or lesser extent. Likewise, **flow velocity** at any point influences the macroinvertebrate taxa present in lowland rivers, though possibly not at the fine scale seen in upland streams. None-the-less backwaters, slackwater areas, and zones with significant flow velocity are likely to support different macroinvertebrate communities. The availability, nature, and quality of **food** sources obviously influence the composition and biomass of macroinvertebrate communities. Grazers, dependant on primary production, are likely to be limited mainly to zones in which the light climate is sufficient to support photosynthesis. Invertebrates involved in the breakdown of litter may well be distributed differently in the river. Thus substrate type, flow velocity, food source together with other factors such as water quality and intra-community interactions constitute a multi-dimensional matrix of drivers that in total determine the make-up and biomass of the macroinvertebrate community. River regulation influences the macroinvertebrate community through its impact on these drivers. The aim of environmental flow regimes is to minimise negative outcomes of this impact.

An additional complication arises from the time/space pattern of change amongst these flow-related drivers. The Intermediate Disturbance Hypothesis (Sousa 1979) leads to the view that either relatively unchanging (e.g. a weir-pool or invariant regulated flow) or persistently and rapidly changing conditions are likely to support a less diverse macroinvertebrate community than an environmental dynamic somewhere between these extremes. ‘Unnatural’ trends toward either extreme in a managed flow regime represent a potential threat to macroinvertebrate diversity. This has particular relevance to the operation of regulatory infrastructure and the management of IVTs.

Taking habitat and other resources as surrogates for macroinvertebrate diversity and abundance it is possible to assess the likely outcomes for macroinvertebrate communities of high summer flows in the Goulburn resulting from proposed IVTs.

In-channel wood (snags). Observations of the Panel indicate that the quantity of submerged course wood (snags) will increase with increase in flow, though the rate of snag habitat accretion may not be linear. Field observations near Wyuna indicate that the majority of snag material is above the water surface at flows of about 400ML/day, and almost all snags are submerged at flows of 4,000 ML/d. The response of macroinvertebrate taxa depends on their individual autecology. Taxa limited by the availability of woody material will be favoured. Taxa dependent on non-photosynthesing biofilm may also respond to the increase in submerged surface area. Grazing macroinvertebrates will remain restricted to the euphotic zone and will therefore respond to a combination of the availability of surfaces and light penetration (see discussion on riverine production in Section 4.3.2). Depending on ambient light penetration, flows significantly higher than 4,000ML/day are likely to reduce the amount of snag surface able to support photosynthesis and therefore those macroinvertebrates dependant on biofilm primary production.

As well as providing substrate, snags also act as collection points for decomposing organic material, particularly floodplain litter, carried by the stream. A significant number of macroinvertebrate taxa, specialised in ‘processing’ this material, are favoured by the accumulation of litter around snags.

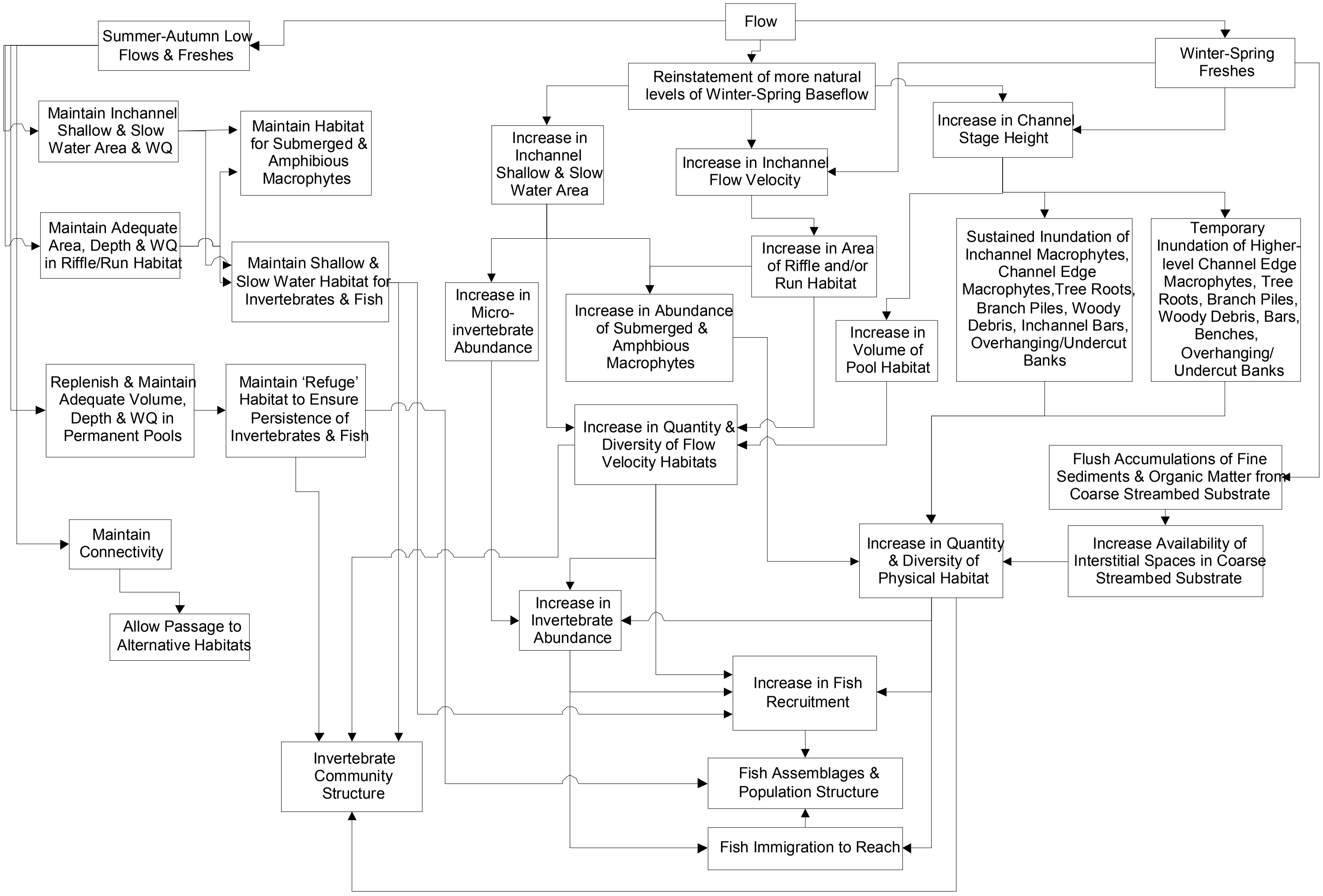


Figure 32: Conceptualisation of macroinvertebrate, vegetation and fish habitat responses to flow components (from Chee et al. 2006).

Aquatic Vegetation. Aquatic plants provide a complex resource for macroinvertebrates. A few invertebrate taxa feed directly on the plants themselves but many more benefit from the provision of a physical substrate for biofilm, protection from predation, and from the plants' modifying effect on flow and water quality. Many species lay eggs on (or even into in the case of some odonates) the plants and emergent plant species provide a relatively safe platform for the transition from aquatic nymph to terrestrial adult for a number of aquatic insects. Increased stability through the enhancement of low-flow areas and concomitant reduction of the resuspension of bank sediment through surface turbulence also enhance macroinvertebrate habitat. During their breeding cycle, atyid prawns congregate amongst river edge vegetation. The first developmental instar of atyids is pelagic and presumably the sheltered environment is important to their survival and further development. The effects of IVT flows on aquatic vegetation (see Section 4.2.3) will also be expressed in changes to macroinvertebrate communities.

Backwaters. Backwaters (shallow temporary waterbodies attached to the river channel but without current) are becoming recognised as important components of the lowland river ecosystem. They are highly productive, supporting high densities of micro-organisms (including many zooplankton species) that cannot persist in areas of significant flow velocity. They also support dense macroinvertebrate communities including a number of taxa rare in the main stream and provide food and shelter for fish larvae.

Water Quality. It is difficult to disentangle any potential influence on macroinvertebrate communities of water quality parameters in the Goulburn River downstream of Goulburn Weir from other environmental factors. However, in assessing the likely affects of IVTs it is probably sufficient to concentrate on changes that these might bring to significant water quality parameters. There is no indication of the likelihood of substantial change in those solutes commonly measured and known to influence macroinvertebrate communities (Cottingham et al. 2003). These include salinity, pH, major ionic balance, and nutrients (which influence macroinvertebrates via modification of primary production). Risk from pollutants in returning drainage water is likely to be reduced by dilution.

In recent field visits a substantial deposit of inorganic fine sediment has been observed overlaying submerged surfaces (and presumably the biofilm). During the EPA macroinvertebrate sampling in 2005-06 at McLelland's Road and McCoy's Bridge it was noted that 'loose silt' occupied 65-90% of the reach. At two other sites, 2-Chain Road and at Shepparton, the cover was 10-35%. Similar measurements were not made in 1992-94 so comparisons cannot be made. However it is reasonable to assume the following:

- Such deposits suppress primary productivity in aquatic plants and biofilm by reducing light penetration;
- It probably has a direct adverse affect on many organisms that make up the biofilm (and are food resources for some macroinvertebrate taxa);
- Premature burying of leaf packs may reduce access for detritivores;
- Extended periods of low flow will permit the deposit to persist.

Analysis of recent macroinvertebrate data suggests that increased fine sediment deposits might have contributed to the disappearance of *Micronecta* sp. (associated with biofilms) and *Cloeon* sp. (a detritivore which also bears external gills) from the 2005-06 samples (see Appendix 2 for details). Research in upland streams (Zweig and Rabeni 2001, Hogg and Norris 1991) indicates changes in taxonomic composition and numbers in response to sediment loads. Hogg and Norris (1991) studied the fauna of pools (in riffle-pool sequences) and their findings of significantly reduced biomass and loss of taxa are probably applicable to the lowland river conditions existing in the Goulburn River. Fine sediment deposition has been observed in several Victorian rivers and investigation of its biological effect and the role of high summer flows would be valuable. Monitoring of fine sediment dynamics should also be included as part of the IVT program.

Seven ecological objectives have been identified to maintain or improve the species diversity and biomass of macroinvertebrates:

1. Provision of conditions suitable for aquatic vegetation, which provides habitat for macroinvertebrates;
2. Submersion of snag habitat within the euphotic zone to provide habitat and food source for macroinvertebrates;
3. Provision of slackwater habitat favourable for planktonic production (food source) and habitat for macroinvertebrates;
4. Entrainment of litter packs to provide food source for macroinvertebrates;
5. Maintenance of habitat heterogeneity over time;
6. Maintenance of water quality suitable for macrophytes;
7. Maintenance of the quality of food and habitat.

Of the ecological objectives for macroinvertebrates listed above, flow elements related to Objectives 1-4 are expected to provide the conditions necessary to fulfil Objective 5, while elements associated with objectives for Primary Production (section 4.2.2) would provide conditions suitable for achieving Objective 7. Thus, flow recommendations for macroinvertebrates (see Chapter 5) were based on the assessment of the stressor elements listed below.

Stressors related to Macroinvertebrate Objective 1:

- water level fluctuation - amphibious habitat index for 4.85 m stage corresponding to euphotic depth at the 20% exceedence flow in the natural regime (*to assess the diversity of macrophyte assemblages*);
- water level fluctuation - amphibious habitat index for 1.54 m stage corresponding to euphotic depth at the 50% exceedence flow in the natural regime(*to assess macrophyte assemblages*);
- Proportion of time when there is less than 1 m^2/m slow shallow habitat (depth < 0.5 m, velocity < 0.05 m/s) (*to assess minimum levels of slow, shallow habitat availability*);
- Proportion of time when there is less than 3 m^2/m slow shallow habitat (depth < 0.5 m, velocity < 0.05 m/s) (*to assess minimum levels of slow, shallow habitat availability*);
- 10th percentile daily change in stage (m) (*to assess maximum rates of change in wetted area*);

- 90th percentile daily change in stage (m) (*to assess minimum rates of change in wetted area*).

Stressors related to Macroinvertebrate Objective 2:

- Proportion of time when shear stress is more than 7 N/m2 (*to assess shear stress required to renew biofilm sources of food for macroinvertebrates*);
- Proportion of time when there is less than 10 m^2/m deep water habitat defined as d>1.5 m (*to assess periods of snag inundation*);
- Proportion of time when there is less than 15 m^2/m deep water habitat defined as d>1.5 m (*to assess periods of snag inundation)*;
- Proportion of time when there is less than 20 m^2/m deep water habitat defined as d>1.5 m (*to assess periods of snag inundation)*;
- Proportion of time water level is within the range 2.71 to 2.98 m above bed corresponding to the 80% to 70 % exceedence flows in the natural regime (*to assess periods of snag inundation)*;
- Proportion of time water level is within the range 2.46 to 2.71 m above bed corresponding to the 90% to 80 % exceedence flows in the natural regime (*to assess periods of snag inundation)*.

Stressors related to Macroinvertebrate Objective 3:

- Proportion of time when there is less than 1 m^2/m slow shallow habitat (depth < 0.5 m, velocity < 0.05 m/s) (*to assess minimum levels of slow, shallow habitat*);
- Proportion of time when there is less than 3 m^2/m slow shallow habitat (depth < 0.5 m, velocity < 0.05 m/s) (*to assess minimum levels of slow, shallow habitat*);
- 80th percentile daily fall in stage (m) (*to assess rates of slow, shallow habitat loss*);
- 10th percentile daily fall in stage (m) for flows less than 4000 ML/day) (*to assess rates of slow, shallow habitat loss*);
- 50th percentile daily fall in stage (m) for flows less than 4000 ML/day) (*to assess rates of slow, shallow habitat loss*);
- 90th percentile daily fall in stage (m) for flows less than 4000 ML/day) (*to assess rates of slow, shallow habitat loss*).

Stressors related to Macroinvertebrate Objective 4:

- Proportion of time when shear stress is less than 2 N/m^2 (*to assess conditions suitable for leaf pack formation and biofilm production as habitat and food for macroinvertebrates*);
- Proportion of time when shear stress is more than 7 N/m^2 (*to assess conditions suitable for the disturbance and renewal of biofilm as a food source for macroinvertebrates*);
- number of floods exceeding 32,700 ML/day, corresponding to minor flood warning level in Reach 4 *(to assess the frequency of external organic matter inputs*);
- number of floods exceeding 55,000 ML/day, corresponding to commence to flow at Loch Garry *(to assess the frequency of external organic matter inputs).*

Stressors related to Macroinvertebrate Objective 6:

- Proportion of time when shear stress is less than 2 N/m^2 (*to assess conditions suitable for leaf pack formation and biofilm production as habitat and food for macroinvertebrates*).

4.2.5 Native Fish

Current condition

Recent surveys have shown that the fish assemblages of the lower Goulburn River have high recreational angling and conservation value (Koster and Crook 2006). However, as discussed by Cottingham et al (2003), it is clear that conditions within the lower Goulburn, including alterations to the natural flow regime, are negatively impacting on fish populations and limiting achievement of increases in the ecological condition of the fish assemblages. Of the recreational angling species present in the lower Goulburn River, Murray cod and golden perch are currently the most widespread and abundant. Murray cod breed each year over a wide spatial extent in the lower Goulburn, whereas there is little evidence of natural recruitment by golden perch. Given the apparent lack of natural recruitment, populations of golden perch in the lower Goulburn appear to be maintained either by artificial stocking or via migrating adult fish entering the system from the Murray River. Several species of fish that were once considered angling species in the Goulburn River, most notably trout cod, silver perch, Macquarie perch, river blackfish and freshwater catfish are now recognised more for their conservation value than for their value to anglers. Trout cod, silver perch and river blackfish are currently present in very low numbers and are patchily distributed, whilst Macquarie perch and freshwater catfish appear to be locally extinct in the Goulburn River below Lake Nagambie.

Several small native species are currently abundant and widespread in the lower Goulburn River, including Australian smelt, rainbowfish, carp gudgeon and flatheaded gudgeon (Koster and Crook 2006). Other small native fish species that have previously been recorded in the lower Goulburn River were not recorded in the 2003-06 surveys, including the flat-headed galaxias, Murray hardyhead, non-specked hardyhead, bony bream and short-headed lamprey.

A number of introduced fish species are currently widespread and abundant throughout the lower Goulburn River, although the proportion of introduced species within the assemblages has declined substantially since the 1980's (Crook and Koster 2006). In surveys conducted in 1982-83 (Brumley et al. 1987), introduced species comprised 96% respectively of all large bodied fish collected compared to 49% in 2003-06. Despite their apparent decline in dominance, carp continue to breed each year in the lower Goulburn River and remain very abundant, particularly in the lower reaches below Shepparton. The once common redfin perch, however, is now rare in the main river channel below Lake Nagambie. Other introduced fish present in the lower Goulburn River include goldfish and Gambusia.

Ecological objectives

The ecological objectives (see Appendix 1) set for fish in the previous environmental flow study for the Goulburn River (Cottingham et al. 2003) were considered to remain relevant to the present study. Each objective is discussed in turn, and the potential for IVTs to affect the flow components are discussed with regards to the ecological requirements of native fish. Potential ways of mitigating any risks associated with IVTs have also been discussed.

Suitable in-channel habitat

The availability of suitable habitat within the main channel is critical to the viability of native fish populations in the lower Goulburn River (Figure 32). Based on scientific literature, the previous environmental flow study (Cottingham et al. 2003) recommended minimum flows to ensure the availability of adequate deep water habitat (defined as >1.5 m depth) for large native fish as the primary factor to be considered with regards to in-channel habitat (Gorman and Karr 1978; Harvey and Stewart 1991; Crook et al. 2001). The availability of shallow, slow flowing habitat for small fish (see King 2004, Humphries et al. 2006) was not considered under this objective, as it was addressed under an objective relating to low flows for spawning and recruitment (see below). Cottingham et al. (2003) conducted hydrologic modelling to examine the effects of discharge on the availability of deep-water habitat in the lower Goulburn. This analysis showed that the area of deep water was drastically reduced under current management in all months of the year compared with modelled natural conditions, and that the area of deep-water habitat always increased with increasing discharge. A minimum flow of 610 ML/d or natural (increased from 350 ML/d) was recommended for the lower Goulburn to provide increased deep-water habitat for large fish, which corresponds to slightly more than 10 m^2/m of deep water habitat for reach 4. The flow element examined in the current analysis to address this ecological objective, therefore, relates to the proportion of time that <10 m^2/m of deep water habitat is available throughout the year.

Suitable off-channel habitat/floodplain inundation

Off-channel habitats such as floodplain wetlands are commonly used as habitat by a number of native fish species in south-eastern Australia (Geddes and Puckridge 1989; King et al. 2003), and connection between the river channel and its floodplain provides an important source of carbon to the main channel (Robertson et al. 1999). The environmental flows report recommended an annual floodplain inundation event for the lower Goulburn ranging from 15,000 to 65,000 ML/d to provide for connection between the river and its floodplain. The proportion of time with discharges exceeding the onset of out-of-channel flow during spring was used as a variable (ie. flow stressor) to analyse the potential effect of IVT releases on the degree of connectivity between the main channel and the floodplain during the critical period leading up to the spawning season.

Fish passage

The migration and movement of fish between habitats appears to be a critical aspect of the life histories of at least several native fish species that occur in the Goulburn River (Mallen-Cooper et al. 1995; O'Connor et al. 2005). Loss of habitat connectivity due to man-made barriers in rivers has contributed to the decline of several native fish species in Australia (Bunn and Arthington 2002). Cottingham et al. (2003) examined the depths of cross-sections at Murchison and Wyuna and found that a large proportion of the river channel was suitable for fish passage based on depth criterion of 20 cm (Tunbridge 1988) under the Bulk Entitlement minimum flow. On this basis, no recommendation was made in relation to fish passage. As IVT releases will not reduce discharge to below the BE minimum flow, it was considered that sufficient depth for fish passage will remain and that IVT releases posed no potential risk to the achievement of this objective.

Spawning and migration cues

Within-channel rises in water level during spring and summer appear to play an important role as cues for fish migration and spawning (Mallen-Cooper and Stuart 2003; O'Connor et al. 2005). Cottingham et al. (2003) examined the frequency and duration of spring and summer freshes under modelled natural and current conditions and found that the differences in the lower Goulburn were not sufficient to warrant specific flow recommendations. It was suggested that the retention of spring and summer freshes in the lower Goulburn under current conditions was due largely to rain rejection flows. Although no specific flow recommendations were made regarding spring/summer freshes, the Panel recognised the importance of freshes and recommended that they be retained should management of irrigation releases change. The introduction of IVT releases during summer has the potential to greatly affect the frequency and duration of freshes in the lower Goulburn.

Recent studies have found that golden perch and silver perch can spawned in large numbers in the Murray River during periods of high, within-channel irrigation flows (King et al. 2005, Koster and Crook 2006), whereas spawning by these species was not detected under the low summer flow regime in the nearby lower Goulburn. Mallen-Cooper and Stuart (2003) also found that strong golden perch recruitment occurred in years where were flow pulses of 1-2 m in stage height within the main channel of the Murray River. Smaller increases in stage height of >15 cm were sufficient to initiate migration of large numbers of juvenile golden perch and silver perch (Mallen-Cooper et al. 1995). From these studies, it appears that increases in flow associated with IVT releases during spring and early summer may increase the likelihood of migration and spawning by golden perch and silver perch in the lower Goulburn. It is also possible that increased flows in the Goulburn would act as an attractant to fish migrating from the Murray River, which may have a beneficial effect on fish populations in the Goulburn River.

Although increased flows have potential benefits to at least some native fish species, retention of variability in the flow regime is considered critical to mitigating any risks associated with the IVT releases. If IVT releases were managed as stable flows over extended periods, it is likely that there will be detrimental effects on native fish populations. However, if appropriate patterns of variability were introduced to mimic natural within-channel rises and falls in stage height, it is likely that there will be a strong beneficial effect for at least several native species. It should also be noted that the IVTs might also provide benefits as migration and spawning cues and attractant flows to non-native fish, in particular carp. Variables that measure the potential effects of IVT releases on the rates of rise and fall in stage height during spring and summer have been used to assess the potential effects of IVT scenarios on this objective.

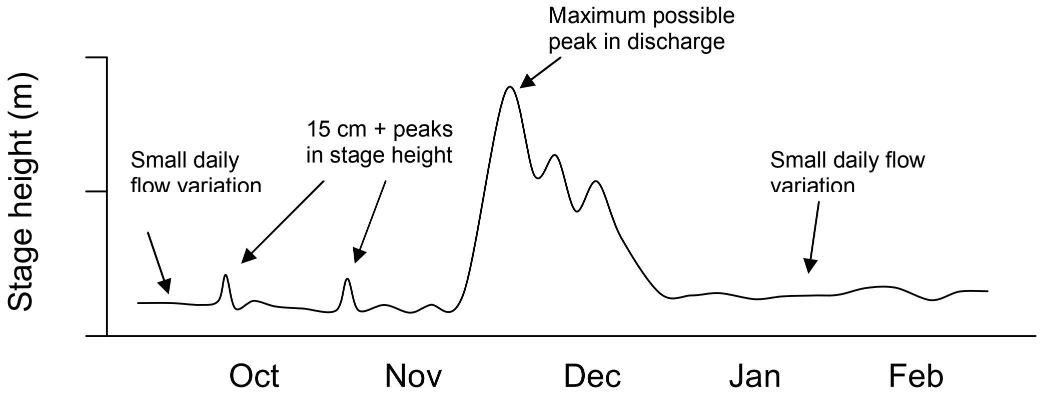


Figure 33: Idealised flow pattern likely to promote spawning and migration cues for native fish.

Low flows for spawning and recruitment

Recent research has suggested that periods of low flow during the summer months are critical for successful spawning and recruitment of some native fish species (Humphries et al. 1999). The "low flow recruitment hypothesis" is based on the idea that there will be sufficient food resources available within the river channel and that an abundance of shallow, slow velocity habitat exists during low flows periods to serve as nursery habitat for larval and juvenile fish (Humphries et al. 1999; King 2004 and 2005). No recommendations for low flow periods were made for the lower Goulburn by Cottingham et al. (2003) because the regulated flow regime had lower flows than would occur in an unregulated environment. However, IVTs have the potential to exceed natural low flows during summer, and so reduce the availability of shallow, slow velocity habitat at a time critical for the recruitment of fish. The availability of shallow, slow flowing habitat suitable for the settlement and recruitment of larval and juvenile fish throughout the year was used to assess the potential effects of IVT releases on this objective. Based on the findings of King (2004), habitat criteria for larval and juvenile fish were defined as areas with depths less than 0.5 m and velocities of less than 0.05 m/sec.

In summary, five ecological objectives for native fish have been identified as providing:

1. Suitable in-channel habitat for all life stages;
2. Suitable off-channel habitat/floodplain inundation for exchange of food and organic material between floodplain and channel;
3. Passage for all life stages;
4. Cues for spawning and migration;
5. Low flows for spawning and recruitment;

However, current conditions already meet the requirements of Objective 3 above, so further analysis for this objective is not required. The flow stressors analysed to provide flow recommendations for the above objectives include:

- Objective 1:Proportion of time throughout the year when there is less than 10 m^2/m deep water habitat defined as d>1.5 m (*to assess changes to the availability of deep-water habitat for large bodied fish*);

- Objective 2: Proportion of discharge exceeding 24000 ML/day during spring, corresponding to anecdotal onset of out of channel flow (*to assess changes to connection between in-channel and floodplain habitats and inputs of food materials in Reach 4*);
- Objective 3: 90th percentile daily rise in stage (m) during spring and summer (*to assess changes in the rates of rise in stage as spawning/migration cues*).
- Objective 4: 90th percentile daily fall in stage (m) during spring and summer (*to assess changes in the rates of fall in stage as spawning/migration cues).*
- Objective 5: Proportion of time throughout the year when there is less than 2 m^2/m slow, shallow habitat (d<0.5 m, v<0.05 m/s) (*to assess changes in availability of critical habitat for small bodied fish and the recruitment of larvae and juveniles*);

4.3 Summary of flow stressors

The various flow stressors identified in the previous sections are summarised in Table 4. The relationship between flow objectives and flow stressors is summarised in Table 5.

Table 4: Flow stressors and their components

Code	Description	Elements
F001	Mean hydraulic residence time (hours/km)	-
F002	Proportion of time when euphotic depth is less than *n* times the mean depth	*n* = 0.2, 0.25, 0.3
F003	Proportion of time when mean shear stress is less than *n* N/m^2 - leading to deposition of fine sediments	*n* = 1, 2, 3
F004	Proportion of time when mean shear stress is more than *n* N/m^2 – leading to possibly biofilm instability	*n* = 5, 6, 7
F005	Water level fluctuation characterised by the amphibious habitat index calculated at euphotic depth for the *n*% exceedence flows (in the pre-regulation regime)	*n* = 10, 20, 30, …, 90
F006	Maximum inundation duration at heights up the bank corresponding to the water surface levels for the *n*% exceedence flows (in the pre-regulation regime)	*n* = 10, 20, 30, …, 90
F007	Proportion of time when there is less than *n* m^2/m slow shallow habitat (d<0.5 m, v<0.05 m/s).	*n* = 1, 2, 3, …, 5
F008	Proportion of time when there is less than *n* m^2/m deep water habitat defined as d>1.5 m	*n* = 5, 10, 15, 20
F009	Maximum continuous rise in stage (m)	-
F010	The distribution of daily change in stage characterised by the nth percentile values (m)	*n* = 10, 90
F011	mean illuminated volume of water (m^3 per m length of channel)	-
F012	mean ratio of euphotic depth to mean water depth	-
F013	mean ratio of fall velocity (*n* m/s) to mean water depth	*n* = 0.2, 0.4 and 0.94
F014	mean illuminated area of benthos (m^2 per m length of channel)	-
F015	mean illuminated area of benthos with velocity less than *n* m/s (m^2 per m length of channel)	*n* = 0.2, 0.3, 0.4 and 0.9
F016	proportion of time when benthos has been in euphotic zone for at least *n* days, calculated for water surface levels corresponding to the *m*% exceedence flows (in the pre-regulation regime)	*n* = 14 and 42 *m* = 10, 20, 30, …, 90
F017	Number of independent events when benthos has been in euphotic zone for at least *n* days, calculated for water surface levels corresponding to the *m*% exceedence flows (in the pre-regulation regime)	*n* = 14 and 42 *m* = 10, 20, 30, …, 90

Code	Description	Elements
F018	Mean water depth (m) during periods when benthos is in euphotic zone for at least *n* days calculated for water surface levels corresponding to the *m*% exceedence flows (in the pre-regulation regime)	*n* = 14 and 42 *m* = 10, 20, 30, …, 90
F019	proportion of time benthos is in the euphotic zone, calculated for water surface levels corresponding to the *m*% exceedence flows (in the pre-regulation regime)	*m* = 10, 20, 30, …, 90
F020	Proportion of time benthos is below the euphotic zone, calculated for water surface levels corresponding to the *m*% exceedence flows (in the pre-regulation regime)	*m* = 10, 20, 30, …, 90
F021	number of overbank events	
F022	The distribution of daily rises in stage characterised by the n^{th} percentile values (m)	*n* = 10, 90
F023	The distribution of daily falls in stage characterised by the n^{th} percentile values (m)	*n* = 10, 90
F024	The distribution of daily falls in stage characterised by the n^{th} percentile values (m) for flow bands defined by the flows Q_i ML/day	*n* = 10, 50, 90 = 0, 4000, 100000
F025	Proportion of time water level is within a range defined by water surface levels corresponding to the *m*% exceedence flows (in the pre-regulation regime)	*m* = 10, 20, 30, …, 90
F026	Proportion of time water level is above a specified depth above bed corresponding to the *m*% exceedence flows (in the pre-regulation regime)	*m* = 10, 20, 30, …, 90
F027	Proportion of time flow exceeds 24000 Ml/day	

Table 5: Summary of relationships between flow-related objectives and flow stressors (see Appendix 1 and 2 for further details of flow objectives)

Ecological Value	Code	Ecological Objective	Stressor code(s)	Seasons	Stressor mechanism
Source of food for fish and invertebrates and influence on river nutrient and chemical conditions	Planktonic algae	Production rates, biomass levels and community composition more resembling un-impacted sites and dynamic diverse food webs	F001	Su, Sp	Increased channel retention due to reduced water velocity and/or hydraulic retention zones allows accumulation of biomass if growth rates exceed loss rates.
			F002	Su, Sp	Proportion of time planktonic algae spend in the euphotic zone determines whether net production is possible or not
			F012	Sp	Proportion of time planktonic algae spend in the euphotic zone multiplied by mean surface irradiance determines the relative level of production
			F013	Su, Sp	Water depth influences the rate of depostion of planktonic algae (It takes longer for settling in deeper water)
Source of food for fish and invertebrates, habitat, and influence on river nutrient and chemical conditions	Periphytic algae	Production rates, biomass levels and community composition more resembling un-impacted sites and dynamic diverse food webs	F014	Su, Sp	Bethic production is restreicted to wetted perimeter within the euphotic zone (i.e. where light penetrates to the channel bed and banks)
			F015	Su, Sp	High velocities influencing biofilm stability. Area of colonization determined by extent of light zone - use euphotic depth, but limited by velocity.
			F016	Sp	Establishment of biofilms requires that the wetted surface remains wet and within the euphotic depth for a period of some time. Drying and submersion below the euphotic depth will advsersely affect biofilms
Contributes to primary production, habitat for macroinvertebrates and native fish	Macrophytes	Production rates, biomass levels and community composition more resembling un-impacted sites and dynamic diverse food webs	F014	Su, Au, Wi, Sp	Bethic production is restreicted to wetted perimeter within the euphotic zone (i.e. where light penetrates to the channel bed and banks)
			F015	Su, Au, Sp	High velocities influencing biofilm stability. Area of colonization determined by extent of light zone - use euphotic depth, but limited by velocity.
			F016	Su, Au, Sp	Establishment of aquatic macrophytes requires that the wetted surface remains wet and within the euphotic depth for a period of some time. Drying and submersion below the euphotic depth will advsersely affect macrophytes
Natural gradient of native terrestrial vegetation up the river banks	Terrestrial bank vegetation	Maintain native terrestrial cover at top of banks and reduce cover of terrestrial vegetation in areas of the bank influenced by flow regulation	F006	Dec-Apr	Duration of submergence (inundation) has potential to drown out terrestrial vegetation, due to carbon and oxygen starvation; critical values for duration tolerance expected to vary between seasons, being much longer in cool (autumn-winter) than in warm growing (spring-summer) season.
Diverse and resiliant aquatic macroinvertebrate fauna	MI1	Provision of conditions suitable for aquatic vegetation, which provides habitat for macroinvertebrates	F007	Su	Slow shallow velocities required for establishment of aquatic vegetation
			F010	Wi	Short-term flow fluctions can adversely effect aquatic vegetation growing along the channel margins
			F022	Su, Au, Wi, Sp	Short-term flow fluctions can adversely effect aquatic vegetation growing along the channel margins

Ecological Value	Code	Ecological Objective	Stressor code(s)	Seasons	Stressor mechanism
			F023	Su, Au, Wi, Sp	Short-term flow fluctions can adversely effect aquatic vegetation growing along the channel margins
	MI2	Submersion of snag habitat within the euphotic zone to provide habitat and food source for macroinvertebrates	F002	Su, Au, Wi, Sp	Quantity and variety of snags dependant on volume (possibly modified by biodiversity and productivity of snag biofilm - depth and variability of light climate).
			F004	Su, Au	High shear stresses can lead to biofilm instability
			F008	Su, Au, Wi, Sp	Loss of pools
			F025	Dec-Apr	Reduction in flpw result in drying of large woody denris
	MI3	Provision of slackwater habitat favourable for planktonic production (food source) and habitat for macroinvertebrates (MI3)	F007	Su	Increased flow velocity and rapid rates of rise and fall affect availability of shallow, slackwater habitat for macroinvertebrates.
			F023	Su, Au, Wi, Sp	daily fall in stage
			F024	Dec-Apr	daily fall in stage
	MI4	Entrainment of litter packs available as food/habitat source for macroinvertebrates (MI4)	F003	Su, Au, Wi, Sp	Shear stress required to disrupt (refresh) biofilms and entrain organic matter.
			F004	Su, Au, Sp	Shear stress required to disrupt (refresh) biofilms and entrain organic matter.
			F021	Su, Au, Wi, Sp	Overbank events may entrain organic matter
	MI6	Maintenance of water quality suitable for macroinvertebrates	F003	Su, Au, Wi, Sp	Temperature, nutrients and salinity assumed not significant, pollution effects (toxicants) not known. Sediment deposition noted and known to remove susceptible taxa.
Diversity of native species, naturally self-reporducing populations of native fish, threatened and iconic native species.	Native Fish	Suitable in-channel habitat for all life stages	F007	Su, Aut, Wi, Sp	Slow shallow habitat required for larvae/juvenile recruitment and adult habitat for small bodied fish
			F008	Su, Au, Wi, Sp	Deep water habitat for large bodied fish
		Cues for adult migration during spawning season	F022	Su, Sp	Flow variation required as a cue for migration and spawning
			F023	Su, Sp	Flow variation required as a cue for migration and spawning
		Suitable off-channel habitat for all life stages	F027	Sp	Inundation of floodplain required by some species and for transport of nutrients and organic matter to drive food webs
Natural Channel Form and Dynamics	Geo1	Avoid notching	F025	Dec-Apr	Long duration of stable flow followed by rapid draw-down. Impact likely to be exacerbated by loss of bank side vegetation.
	Geo2	Avoid slumping	F023	Su	Excessive rates of fall in river level.
	Geo3	Maintain pool depth	F026	Su	Unseasonal events that fill pools with sediment but do not flush them.
	Geo6	Maintain natural rates of geomorphic disturbance	F006	Dec-Apr	High velocity discharge increases disturbance of sand substrates and aquatic macrophytes.

5 SUMMER IVT REGIME FOR THE LOWER GOULBURN RIVER

5.1 General approach

Environmental flow recommendations are designed to achieve ecological objectives related to a desired future state. Flow recommendations may be designed either to affect ecosystem responses directly, or to ensure that flow stress will not be a factor preventing achievement of ecological objectives if flow recommendations are met (if some other factor limits the achievement of objectives, then other complementary works will be required).

The environment flow method used in this project is a development of earlier FLOWS studies. The three main improvements are as follows.

- Previous studies using the FLOWS method have recommended a single flow component to achieve multiple environmental objectives. Although this has been a pragmatic approach, there is often little transparency around the specification of these flow components and how they relate to each objective. To overcome this shortcoming, this study recommends flows for each individual environmental objective.
- Previous studies recommended static environmental flows that allowed for little variation between years. Recommendations in this study explicitly deal with inter-annual variability, allowing more flexible operation of the water resource and the protection of important inter-annual variation in flows.
- Previous studies have provided a single recommendation. In this project we provide two levels of environmental flow (i) the recommended environmental flow to achieve the environmental flow objective with a high degree of confidence (low risk) and (ii) the "moderate risk" environmental flow which has a moderate chance of achieving the environmental flow objective. These two levels are provided in recognition of the inherent uncertainty in flow-ecology linkages and the need to trade off environmental risks with consumptive water use.

As a direct consequence of these developments there are an increased number of flow recommendations for each reach. These recommendations are expressed in tables in this report and are also provided in an accompanying decision support tool, which can be used to evaluate the compliance. The task of complying with this increased number of recommendations may at first seem daunting. In particular, there may be a concern that the environmental flows leave too little "room to move" for water use. However, it should be remembered that in all cases we have used the natural flow regime as our reference point. All recommendations represent a deviation from natural conditions. There remains a wide envelope around the natural flow regime within which water authorities can operate the river whilst meeting many of the Scientific Panel’s environmental flow objectives.

The Panel has identified a number of **flow stressors** (Table 4) that were assessed in terms of their potential to either contribute, or adversely affect ecosystem response and thus achieving ecological objectives in the lower Goulburn River. An ecosystem objective can be affected by a single or multiple flow stressors, which are identified by a code number (e.g. F001, F002, F003 etc.).

Each flow stressor is characterised by one or more **elements**. For example F003 is the "proportion of time when mean bed shear stress is low, leading to deposition of fine sediment". This flow stressor has three flow elements corresponding to three different shear stress thresholds below which sedimentation might occur (1, 2 and 3 N/m^2). The elements are identified by a letter placed after the flow stressor code (e.g. F003a, F003b, F003c). Flow elements can be calculated for one or more **seasons** (Table 6). In most cases flow stressors/elements are calculated for the calendar seasons (some are calculated for periods such as the summer-autumn irrigation season – December to April).

The flow stressors are calculated for each year of the flow record with daily flow data (1975-2000). This provides an **annual series** of the flow stressors/elements. For example, F003a, is the proportion of time when the mean shear stress is less than 3 N/m^2. This element is calculated for each year of record using (i) the modelled pre-regulation condition and (ii) the actual recorded flows. The **10th, 30th, 50th, 70th, 90th percentile values** in addition to the minimum and maximum values from this annual series are used to characterise the inter-annual variability in this flow element. This provides information over a range of years from dry to wet years and is consistent with the approach used by Richter et al. (1996) in the Range of Variability Approach (RVA) and Indicators of Hydrological Alteration (IHA), although they use discharge statistics rather than hydraulic metrics.

In summary:

- For each ecological objective, relevant flow stressors (characterised by one or more flow elements) were identified and analysed for one or more seasons; and
- Inter-annual variability in these flow stressors/elements was characterised by five percentiles of the annual series plus the minimum and maximum values and these percentiles are calculated for the pre- and post-regulation series.

Many of the flow elements relate to the duration and/or frequency of spells above particular hydrologically-defined flow thresholds. In most cases, several flow elements are presented, each using a different threshold. While it is common to use single flow thresholds when analysing flow variability for environmental flow studies, optimising river operation to meet environmental flow recommendations based on single threshold flows can lead to unintended outcomes. The most obvious example is a minimum flow recommendation, which may lead to constant base flow releases.

5.2 Decision Support Tool

A Microsoft Excel spreadsheet Decision Support Tool (DST) accompanies this report and has been developed to assist the Goulburn Broken CMA and DSE assess the implication of various IVT scenarios. **A separate DST has been established for each of the study reaches** that contains the ecological objectives identified in Appendix 1, the flow elements identified in Chapter 4, and bounds for individual stressors representing a preferred range to be achieved during the relevant season. The bounds also describe flow stressor levels indicative of moderate and high risk to achieving stated ecological objectives. The bounds for moderate and high risk are based on best-available scientific information and the opinion of Scientific Panel members.

5.2.1 Assessing Compliance against Panel Recommendations

Example outputs from the DST are presented in Figure 34 and Figure 35. The DST worksheet labelled “Env Obj” summarises the performance of each flow scenario against the Panel’s flow recommendations. To view this, select the “Sci Panel” button in cell D1. The results for other scenarios can be viewed by scrolling with the use of the left and right arrow button in Cell B1.

Column B lists all the flow elements for which environmental flow recommendations have been made. Column D divides these into upper and lower bounds. Row 1 lists all the environmental objective codes and Row 5 divides these into seasons.

The colours indicate compliance against the flow recommendations of the panel:

- Green indicates compliance against the recommended bounds;
- Yellow indicates compliance against the moderate risk bounds; and
- Red indicates the flow scenario does not comply with the moderate risk bounds.

Individual cells in this matrix show the performance against Panel recommendations for a particular flow element, upper and lower bounds, season and flow objective. Note that grey cells indicate that no recommendations were made in these cases.

The cells in Column D indicate the performance of the flow scenario for each flow element against upper or lower bounds. Likewise, the cells in Row 5 indicate the performance for each environmental objective and season.

Row 2 gives the proportion of recommended bounds that are met for each environmental objective. Row 3 gives the proportion of moderate risk bounds that are satisfied for each environmental objective.

Table 6: List of flow stressors and elements considered by the Scientific Panel

Flow element code	Description	Summer	Autumn	Winter	Spring	Dec-Apr	Type
F001	mean residence time (hours/km)	X	X	X	X		magnitude
F002a	proportion of time when euphotic depth is less than 0.2 times the mean depth	X	X	X	X		duration
F002b	proportion of time when euphotic depth is less than 0.25 times the mean depth	X	X	X	X		duration
F002c	proportion of time when euphotic depth is less than 0.3 times the mean depth	X	X	X	X		duration
F003a	proportion of time when shear stress is less than 1 N/m2	X	X	X	X		duration
F003b	proportion of time when shear stress is less than 2 N/m2	X	X	X	X		duration
F003c	proportion of time when shear stress is less than 3 N/m2	X	X	X	X		duration
F004a	proportion of time when shear stress is more than 5 N/m2	X	X	X	X		duration
F004b	proportion of time when shear stress is more than 6 N/m2	X	X	X	X		duration
F004c	proportion of time when shear stress is more than 7 N/m2	X	X	X	X		duration
F005a	water level fluctuation - amphibious habitat index for 7.66 m stage corresponding to euphotic depth at the 10% exceedence flow in the natural regime	X	X	X	X		stability
F005b	water level fluctuation - amphibious habitat index for 5.51 m stage corresponding to euphotic depth at the 20% exceedence flow in the natural regime	X	X	X	X		stability
F005c	water level fluctuation - amphibious habitat index for 4.06 m stage corresponding to euphotic depth at the 30% exceedence flow in the natural regime	X	X	X	X		stability
F005d	water level fluctuation - amphibious habitat index for 3.26 m stage corresponding to euphotic depth at the 40% exceedence flow in the natural regime	X	X	X	X		stability
F005e	water level fluctuation - amphibious habitat index for 2.67 m stage corresponding to euphotic depth at the 50% exceedence flow in the natural regime	X	X	X	X		stability
F005f	water level fluctuation - amphibious habitat index for 2.13 m stage corresponding to euphotic depth at the 60% exceedence flow in the natural regime	X	X	X	X		stability
F005g	water level fluctuation - amphibious habitat index for 1.76 m stage corresponding to euphotic depth at the 70% exceedence flow in the natural regime	X	X	X	X		stability
F005h	water level fluctuation - amphibious habitat index for 1.52 m stage corresponding to euphotic depth at the 80% exceedence flow in the natural regime	X	X	X	X		stability
F005i	water level fluctuation - amphibious habitat index for 1.27 m stage corresponding to euphotic depth at the 90% exceedence flow in the natural regime	X	X	X	X		stability
F006a	max spell duration (days) at the stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime					X	spell duration
F006b	max spell duration (days) at the stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime					X	spell duration
F006c	max spell duration (days) at the stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime					X	spell duration
F006d	max spell duration (days) at the stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime					X	spell duration
F006e	max spell duration (days) at the stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime					X	spell duration
F006f	max spell duration (days) at the stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime					X	spell duration
F006g	max spell duration (days) at the stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime					X	spell duration
F006h	max spell duration (days) at the stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime					X	spell duration
F006i	max spell duration (days) at the stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime					X	spell duration
F007a	Proportion of time when there is less than 1 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)	X					duration
F007b	Proportion of time when there is less than 2 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)	X					duration
F007c	Proportion of time when there is less than 3 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)	X					duration

Flow element code	Description	Summer	Autumn	Winter	Spring	Dec-Apr	Type
F007d	Proportion of time when there is less than 4 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)	X					duration
F007e	Proportion of time when there is less than 5 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)	X					duration
F008a	Proportion of time when there is less than 5 m2/m deep water habitat defined as d>1.5 m	X	X	X	X		duration
F008b	Proportion of time when there is less than 10 m2/m deep water habitat defined as d>1.5 m	X	X	X	X		duration
F008c	Proportion of time when there is less than 15 m2/m deep water habitat defined as d>1.5 m	X	X	X	X		duration
F008d	Proportion of time when there is less than 20 m2/m deep water habitat defined as d>1.5 m	X	X	X	X		duration
F009	Maximum continuous rise in stage (m)						spell variability
F010a	10th percentile daily change in stage (m)	X	X	X	X		daily change
F010b	90th percentile daily change in stage (m)	X	X	X	X		daily change
F011	mean illuminated volume of water (m3 per m lenth of channel	X	X	X	X		magnitude
F012	mean ratio of euphotic depth to mean water depth	X	X	X	X		magnitude
F013a	mean ratio of fall velocity (.2 m/s) to mean water depth	X	X	X	X		magnitude
F013b	mean ratio of fall velocity (.4 m/s) to mean water depth	X	X	X	X		magnitude
F013c	mean ratio of fall velocity (.95 m/s) to mean water depth	X	X	X	X		magnitude
F014	mean illuminated area of benthos (m2 per m length of channel)	X	X	X	X		magnitude
F015a	mean illuminated area of benthos with velocity less than .2 m/s (m2 per m length of channel)	X	X	X	X		magnitude
F015b	mean illuminated area of benthos with velocity less than .3 m/s (m2 per m length of channel)	X	X	X	X		magnitude
F015c	mean illuminated area of benthos with velocity less than .4 m/s (m2 per m length of channel)	X	X	X	X		magnitude
F015d	mean illuminated area of benthos with velocity less than .9 m/s (m2 per m length of channel)	X	X	X	X		magnitude
F016a	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime	X	X	X	X		stability
F016b	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime	X	X	X	X		stability
F016c	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime	X	X	X	X		stability
F016d	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime	X	X	X	X		stability
F016e	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime	X	X	X	X		stability
F016f	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime	X	X	X	X		stability
F016g	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime	X	X	X	X		stability
F016h	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime	X	X	X	X		stability
F016i	proportion of time the bank has been within euphotic zone for at least 14 days: at stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime	X	X	X	X		stability

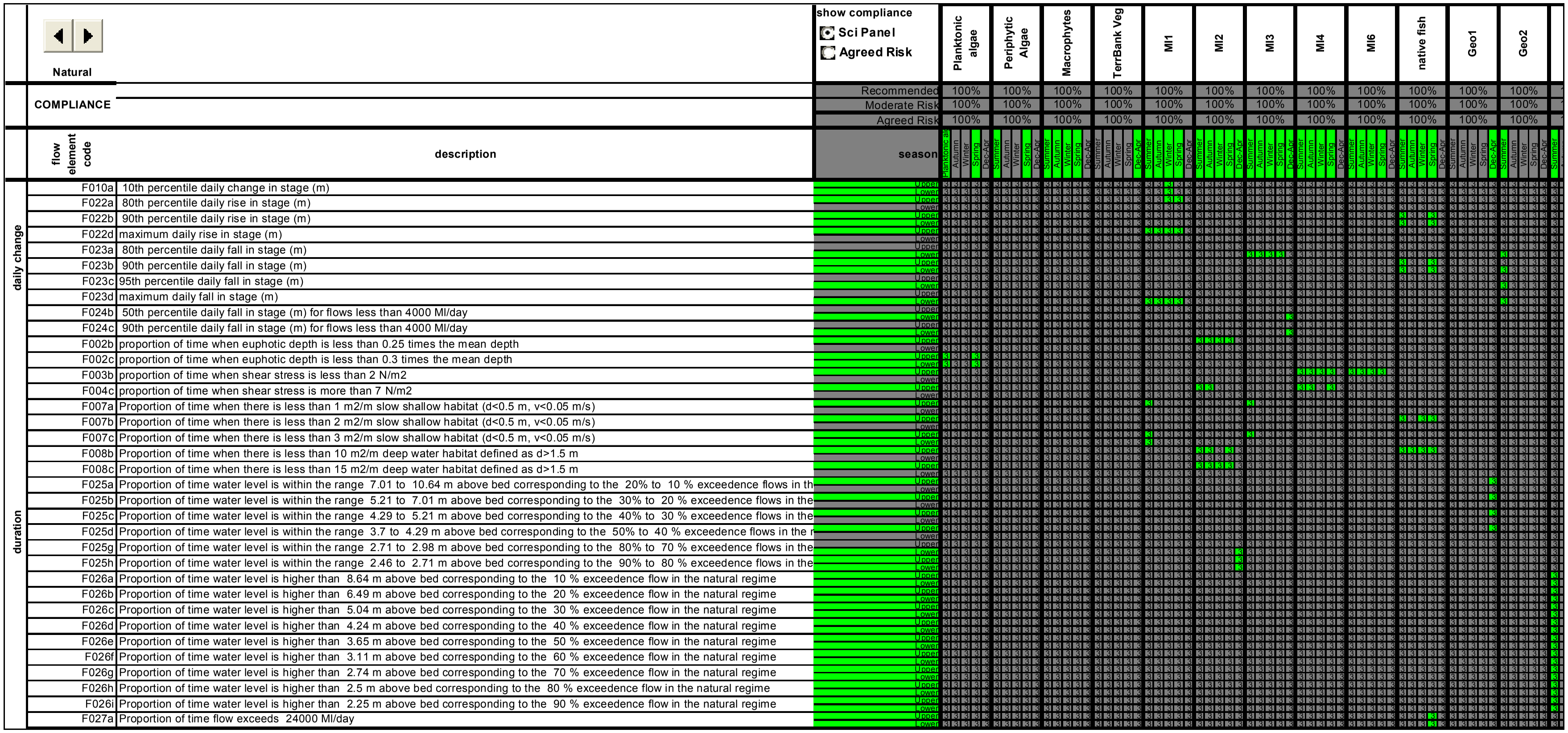
Flow element code	Description	Summer	Autumn	Winter	Spring	Dec-Apr	Type
F016j	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime	X	X	X	X		stability
F016k	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime	X	X	X	X		stability
F016l	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime	X	X	X	X		stability
F016m	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime	X	X	X	X		stability
F016n	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime	X	X	X	X		stability
F016o	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime	X	X	X	X		stability
F016p	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime	X	X	X	X		stability
F016q	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime	X	X	X	X		stability
F016r	proportion of time the bank has been within euphotic zone for at least 42 days: at stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime	X	X	X	X		stability
F017a	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime	X	X	X	X		stability
F017b	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime	X	X	X	X		stability
F017c	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime	X	X	X	X		stability
F017d	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime	X	X	X	X		stability
F017e	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime	X	X	X	X		stability
F017f	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime	X	X	X	X		stability
F017g	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime	X	X	X	X		stability
F017h	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime	X	X	X	X		stability
F017i	Number of independent events when benthos has been in euphotic zone for at least 14 days: at stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime	X	X	X	X		stability
F017j	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime	X	X	X	X		stability
F017k	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime	X	X	X	X		stability
F017l	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 5.04 m above bed corresponding to the 30%	X	X	X	X		stability

Flow element code	Description	Summer	Autumn	Winter	Spring	Dec-Apr	Type
	exceedence flow in the natural regime						
F017m	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime	X	X	X	X		stability
F017n	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime	X	X	X	X		stability
F017o	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime	X	X	X	X		stability
F017p	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime	X	X	X	X		stability
F017q	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime	X	X	X	X		stability
F017r	Number of independent events when benthos has been in euphotic zone for at least 42 days: at stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime	X	X	X	X		stability
F018a	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime	X	X	X	X		magnitude
F018b	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime	X	X	X	X		magnitude
F018c	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime	X	X	X	X		magnitude
F018d	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime	X	X	X	X		magnitude
F018e	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime	X	X	X	X		magnitude
F018f	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime	X	X	X	X		magnitude
F018g	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime	X	X	X	X		magnitude
F018h	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime	X	X	X	X		magnitude
F018i	mean water depth during periods when the bank has been within euphotic zone for at least 14 days: at stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime	X	X	X	X		magnitude
F018j	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime	X	X	X	X		magnitude
F018k	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime	X	X	X	X		magnitude
F018l	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime	X	X	X	X		magnitude
F018m	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime	X	X	X	X		magnitude
F018n	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime	X	X	X	X		magnitude

Flow element code	Description	Summer	Autumn	Winter	Spring	Dec-Apr	Type
F018o	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime	X	X	X	X		magnitude
F018p	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime	X	X	X	X		magnitude
F018q	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime	X	X	X	X		magnitude
F018r	mean water depth during periods when the bank has been within euphotic zone for at least 42 days: at stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime	X	X	X	X		magnitude
F019a	Proportion of time benthos is in the euphotic zone at stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime	X	X	X	X		duration
F019b	Proportion of time benthos is in the euphotic zone at stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime	X	X	X	X		duration
F019c	Proportion of time benthos is in the euphotic zone at stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime	X	X	X	X		duration
F019d	Proportion of time benthos is in the euphotic zone at stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime	X	X	X	X		duration
F019e	Proportion of time benthos is in the euphotic zone at stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime	X	X	X	X		duration
F019f	Proportion of time benthos is in the euphotic zone at stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime	X	X	X	X		duration
F019g	Proportion of time benthos is in the euphotic zone at stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime	X	X	X	X		duration
F019h	Proportion of time benthos is in the euphotic zone at stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime	X	X	X	X		duration
F019i	Proportion of time benthos is in the euphotic zone at stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime	X	X	X	X		duration
F020a	Proportion of time benthos is in below euphotic zone at stage 8.64 m above bed corresponding to the 10% exceedence flow in the natural regime	X	X	X	X		duration
F020b	Proportion of time benthos is in below euphotic zone at stage 6.49 m above bed corresponding to the 20% exceedence flow in the natural regime	X	X	X	X		duration
F020c	Proportion of time benthos is in below euphotic zone at stage 5.04 m above bed corresponding to the 30% exceedence flow in the natural regime	X	X	X	X		duration
F020d	Proportion of time benthos is in below euphotic zone at stage 4.24 m above bed corresponding to the 40% exceedence flow in the natural regime	X	X	X	X		duration
F020e	Proportion of time benthos is in below euphotic zone at stage 3.65 m above bed corresponding to the 50% exceedence flow in the natural regime	X	X	X	X		duration
F020f	Proportion of time benthos is in below euphotic zone at stage 3.11 m above bed corresponding to the 60% exceedence flow in the natural regime	X	X	X	X		duration
F020g	Proportion of time benthos is in below euphotic zone at stage 2.74 m above bed corresponding to the 70% exceedence flow in the natural regime	X	X	X	X		duration
F020h	Proportion of time benthos is in below euphotic zone at stage 2.5 m above bed corresponding to the 80% exceedence flow in the natural regime	X	X	X	X		duration
F020i	Proportion of time benthos is in below euphotic zone at stage 2.25 m above bed corresponding to the 90% exceedence flow in the natural regime	X	X	X	X		duration
F021a	number of floods exceeding 24000 ML/day, corresponding to anecdotal onset of out of channel flow	X	X	X	X		spell frequency
F021b	number of floods exceeding 32700 ML/day, corresponding to minor flood warning level	X	X	X	X		spell frequency
F021c	number of floods exceeding 58700 ML/day, corresponding to moderate flood warning level	X	X	X	X		spell frequency
F021d	number of floods exceeding 55000 ML/day, corresponding to commence to flow at Loch Garry	X	X	X	X		spell frequency
F021e	number of floods exceeding 26000 ML/day, corresponding to commence to flow at Deep Creek	X	X	X	X		spell frequency
F021f	number of floods exceeding 21000 ML/day, corresponding to commence to flow at Wakiti Creek	X	X	X	X		spell frequency

Flow element code	Description	Summer	Autumn	Winter	Spring	Dec-Apr	Type
F021g	number of floods exceeding 23000 ML/day, corresponding to commence to flow at Hancocks Creek	X	X	X	X		spell frequency
F021h	number of floods exceeding 19500 ML/day, corresponding to commence to flow at Raftery Forest	X	X	X	X		spell frequency
F022a	80th percentile daily rise in stage (m)	X	X	X	X		daily change
F022b	90th percentile daily rise in stage (m)	X	X	X	X		daily change
F022c	95th percentile daily rise in stage (m)	X	X	X	X		daily change
F022d	maximum daily rise in stage (m)	X	X	X	X		daily change
F023a	80th percentile daily fall in stage (m)	X	X	X	X		daily change
F023b	90th percentile daily fall in stage (m)	X	X	X	X		daily change
F023c	95th percentile daily fall in stage (m)	X	X	X	X		daily change
F023d	maximum daily fall in stage (m)	X	X	X	X		daily change
F024a	0th percentile daily fall in stage (m) for flows less than 4000 ML/day	X	X	X	X		daily change
F024b	50th percentile daily fall in stage (m) for flows less than 4000 ML/day	X	X	X	X		daily change
F024c	100th percentile daily fall in stage (m) for flows less than 4000 ML/day	X	X	X	X		daily change
F024d	0th percentile daily fall in stage (m) for flows greater than 4000 ML/day	X	X	X	X		daily change
F024e	50th percentile daily fall in stage (m) for flows greater than 4000 ML/day	X	X	X	X		daily change
F024f	100th percentile daily fall in stage (m) for flows greater than 4000 ML/day	X	X	X	X		daily change
F025a	Proportion of time water level is within the range 6.49 to 8.64 m above bed corresponding to the 20% to 10 % exceedence flows in the natural regime					X	duration
F025b	Proportion of time water level is within the range 5.04 to 6.49 m above bed corresponding to the 30% to 20 % exceedence flows in the natural regime					X	duration
F025c	Proportion of time water level is within the range 4.24 to 5.04 m above bed corresponding to the 40% to 30 % exceedence flows in the natural regime					X	duration
F025d	Proportion of time water level is within the range 3.65 to 4.24 m above bed corresponding to the 50% to 40 % exceedence flows in the natural regime					X	duration
F025e	Proportion of time water level is within the range 3.11 to 3.65 m above bed corresponding to the 60% to 50 % exceedence flows in the natural regime					X	duration
F025f	Proportion of time water level is within the range 2.74 to 3.11 m above bed corresponding to the 70% to 60 % exceedence flows in the natural regime					X	duration
F025g	Proportion of time water level is within the range 2.5 to 2.74 m above bed corresponding to the 80% to 70 % exceedence flows in the natural regime					X	duration
F025h	Proportion of time water level is within the range 2.25 to 2.5 m above bed corresponding to the 90% to 80 % exceedence flows in the natural regime					X	duration
F026a	Proportion of time water level is higher than 8.64 m above bed corresponding to the 10 % exceedence flow in the natural regime	X	X	X	X		duration
F026b	Proportion of time water level is higher than 6.49 m above bed corresponding to the 20 % exceedence flow in the natural regime	X	X	X	X		duration
F026c	Proportion of time water level is higher than 5.04 m above bed corresponding to the 30 % exceedence flow in the natural regime	X	X	X	X		duration
F026d	Proportion of time water level is higher than 4.24 m above bed corresponding to the 40 % exceedence flow in the natural regime	X	X	X	X		duration
F026e	Proportion of time water level is higher than 3.65 m above bed corresponding to the 50 % exceedence flow in the natural regime	X	X	X	X		duration

Flow element code	Description	Summer	Autumn	Winter	Spring	Dec-Apr	Type
F026f	Proportion of time water level is higher than 3.11 m above bed corresponding to the 60 % exceedence flow in the natural regime	X	X	X	X		duration
F026g	Proportion of time water level is higher than 2.74 m above bed corresponding to the 70 % exceedence flow in the natural regime	X	X	X	X		duration
F026h	Proportion of time water level is higher than 2.5 m above bed corresponding to the 80 % exceedence flow in the natural regime	X	X	X	X		duration
F026i	Proportion of time water level is higher than 2.25 m above bed corresponding to the 90 % exceedence flow in the natural regime	X	X	X	X		duration
F027a	Proportion of time flow exceeds 24000 ML/day	X	X	X	X		duration
F027b	Proportion of time flow exceeds 32700 ML/day	X	X	X	X		duration
F027c	Proportion of time flow exceeds 58700 ML/day	X	X	X	X		duration
F027d	Proportion of time flow exceeds 55000 ML/day	X	X	X	X		duration
F027e	Proportion of time flow exceeds 26000 ML/day	X	X	X	X		duration
F027f	Proportion of time flow exceeds 21000 ML/day	X	X	X	X		duration
F027g	Proportion of time flow exceeds 23000 ML/day	X	X	X	X		duration
F027h	Proportion of time flow exceeds 19500 ML/day	X	X	X	X		duration



Natural

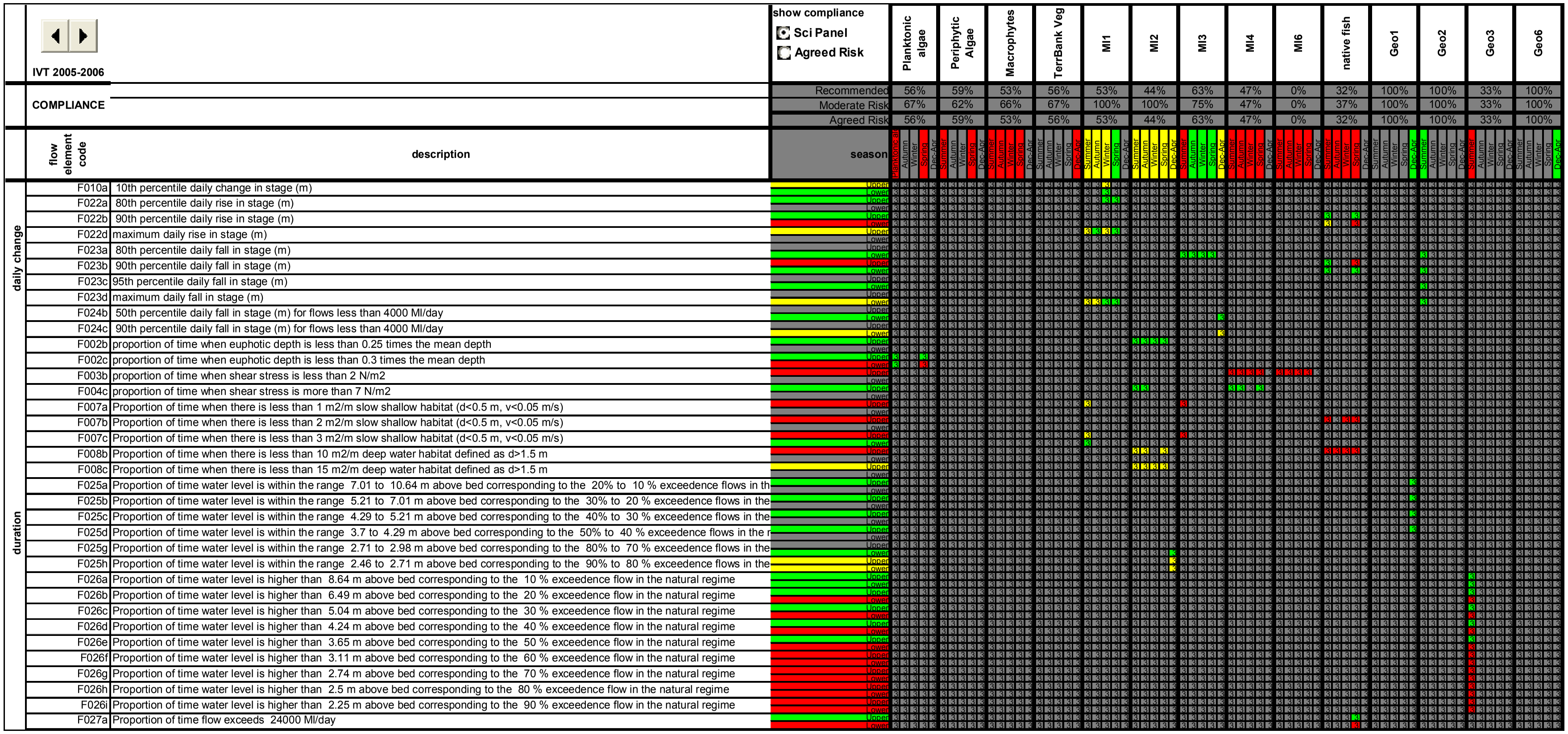
show compliance
● Sci Panel
○ Agreed Risk

	Planktonic algae	Periphytic Algae	Macrophytes	TerrBank Veg	MI1	MI2	MI3	MI4	MI6	native fish	Geo1	Geo2
Recommended	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Moderate Risk	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Agreed Risk	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

COMPLIANCE

	flow element code	description
daily change	F010a	10th percentile daily change in stage (m)
	F022a	80th percentile daily rise in stage (m)
	F022b	90th percentile daily rise in stage (m)
	F022d	maximum daily rise in stage (m)
	F023a	80th percentile daily fall in stage (m)
	F023b	90th percentile daily fall in stage (m)
	F023c	95th percentile daily fall in stage (m)
	F023d	maximum daily fall in stage (m)
	F024b	50th percentile daily fall in stage (m) for flows less than 4000 Ml/day
	F024c	90th percentile daily fall in stage (m) for flows less than 4000 Ml/day
	F002b	proportion of time when euphotic depth is less than 0.25 times the mean depth
	F002c	proportion of time when euphotic depth is less than 0.3 times the mean depth
	F003b	proportion of time when shear stress is less than 2 N/m2
	F004c	proportion of time when shear stress is more than 7 N/m2
duration	F007a	Proportion of time when there is less than 1 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)
	F007b	Proportion of time when there is less than 2 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)
	F007c	Proportion of time when there is less than 3 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)
	F008b	Proportion of time when there is less than 10 m2/m deep water habitat defined as d>1.5 m
	F008c	Proportion of time when there is less than 15 m2/m deep water habitat defined as d>1.5 m
	F025a	Proportion of time water level is within the range 7.01 to 10.64 m above bed corresponding to the 20% to 10 % exceedence flows in th
	F025b	Proportion of time water level is within the range 5.21 to 7.01 m above bed corresponding to the 30% to 20 % exceedence flows in the
	F025c	Proportion of time water level is within the range 4.29 to 5.21 m above bed corresponding to the 40% to 30 % exceedence flows in the
	F025d	Proportion of time water level is within the range 3.7 to 4.29 m above bed corresponding to the 50% to 40 % exceedence flows in the r
	F025g	Proportion of time water level is within the range 2.71 to 2.98 m above bed corresponding to the 80% to 70 % exceedence flows in the
	F025h	Proportion of time water level is within the range 2.46 to 2.71 m above bed corresponding to the 90% to 80 % exceedence flows in the
	F026a	Proportion of time water level is higher than 8.64 m above bed corresponding to the 10 % exceedence flow in the natural regime
	F026b	Proportion of time water level is higher than 6.49 m above bed corresponding to the 20 % exceedence flow in the natural regime
	F026c	Proportion of time water level is higher than 5.04 m above bed corresponding to the 30 % exceedence flow in the natural regime
	F026d	Proportion of time water level is higher than 4.24 m above bed corresponding to the 40 % exceedence flow in the natural regime
	F026e	Proportion of time water level is higher than 3.65 m above bed corresponding to the 50 % exceedence flow in the natural regime
	F026f	Proportion of time water level is higher than 3.11 m above bed corresponding to the 60 % exceedence flow in the natural regime
	F026g	Proportion of time water level is higher than 2.74 m above bed corresponding to the 70 % exceedence flow in the natural regime
	F026h	Proportion of time water level is higher than 2.5 m above bed corresponding to the 80 % exceedence flow in the natural regime
	F026i	Proportion of time water level is higher than 2.25 m above bed corresponding to the 90 % exceedence flow in the natural regime
	F027a	Proportion of time flow exceeds 24000 Ml/day

Figure 34: Example output of the DST for Reach 4 under an unregulated flow regime, identifying the relevant ecological objectives, flow components, flow stressors and risk levels (green = low risk to objectives, yellow = moderate risk to objectives, red = high risk to objectives).



IVT 2005-2006

show compliance

● Sci Panel

○ Agreed Risk

COMPLIANCE	Planktonic algae	Periphytic Algae	Macrophytes	TerrBank Veg	MI1	MI2	MI3	MI4	MI6	native fish	Geo1	Geo2	Geo3	Geo6
Recommended	56%	59%	53%	56%	53%	44%	63%	47%	0%	32%	100%	100%	33%	100%
Moderate Risk	67%	62%	66%	67%	100%	100%	75%	47%	0%	37%	100%	100%	33%	100%
Agreed Risk	56%	59%	53%	56%	53%	44%	63%	47%	0%	32%	100%	100%	33%	100%

	flow element code	description
daily change	F010a	10th percentile daily change in stage (m)
	F022a	80th percentile daily rise in stage (m)
	F022b	90th percentile daily rise in stage (m)
	F022d	maximum daily rise in stage (m)
	F023a	80th percentile daily fall in stage (m)
	F023b	90th percentile daily fall in stage (m)
	F023c	95th percentile daily fall in stage (m)
	F023d	maximum daily fall in stage (m)
	F024b	50th percentile daily fall in stage (m) for flows less than 4000 Ml/day
	F024c	90th percentile daily fall in stage (m) for flows less than 4000 Ml/day
duration	F002b	proportion of time when euphotic depth is less than 0.25 times the mean depth
	F002c	proportion of time when euphotic depth is less than 0.3 times the mean depth
	F003b	proportion of time when shear stress is less than 2 N/m2
	F004c	proportion of time when shear stress is more than 7 N/m2
	F007a	Proportion of time when there is less than 1 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)
	F007b	Proportion of time when there is less than 2 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)
	F007c	Proportion of time when there is less than 3 m2/m slow shallow habitat (d<0.5 m, v<0.05 m/s)
	F008b	Proportion of time when there is less than 10 m2/m deep water habitat defined as d>1.5 m
	F008c	Proportion of time when there is less than 15 m2/m deep water habitat defined as d>1.5 m
	F025a	Proportion of time water level is within the range 7.01 to 10.64 m above bed corresponding to the 20% to 10 % exceedence flows in th
	F025b	Proportion of time water level is within the range 5.21 to 7.01 m above bed corresponding to the 30% to 20 % exceedence flows in the
	F025c	Proportion of time water level is within the range 4.29 to 5.21 m above bed corresponding to the 40% to 30 % exceedence flows in the
	F025d	Proportion of time water level is within the range 3.7 to 4.29 m above bed corresponding to the 50% to 40 % exceedence flows in the r
	F025g	Proportion of time water level is within the range 2.71 to 2.98 m above bed corresponding to the 80% to 70 % exceedence flows in the
	F025h	Proportion of time water level is within the range 2.46 to 2.71 m above bed corresponding to the 90% to 80 % exceedence flows in the
	F026a	Proportion of time water level is higher than 8.64 m above bed corresponding to the 10 % exceedence flow in the natural regime
	F026b	Proportion of time water level is higher than 6.49 m above bed corresponding to the 20 % exceedence flow in the natural regime
	F026c	Proportion of time water level is higher than 5.04 m above bed corresponding to the 30 % exceedence flow in the natural regime
	F026d	Proportion of time water level is higher than 4.24 m above bed corresponding to the 40 % exceedence flow in the natural regime
	F026e	Proportion of time water level is higher than 3.65 m above bed corresponding to the 50 % exceedence flow in the natural regime
	F026f	Proportion of time water level is higher than 3.11 m above bed corresponding to the 60 % exceedence flow in the natural regime
	F026g	Proportion of time water level is higher than 2.74 m above bed corresponding to the 70 % exceedence flow in the natural regime
	F026h	Proportion of time water level is higher than 2.5 m above bed corresponding to the 80 % exceedence flow in the natural regime
	F026i	Proportion of time water level is higher than 2.25 m above bed corresponding to the 90 % exceedence flow in the natural regime
	F027a	Proportion of time flow exceeds 24000 Ml/day

Figure 35: Example output of the DST for Reach 4 under the most recent IVT regime, 2005-2006 (green = low risk to objectives, yellow = moderate risk to objectives, red = high risk to objectives).

Environmental flow recommendations made by the Panel apply to three different aspects of the flow regime:

- the frequency distribution of flows;
- flow spells; and
- the rates of rise and fall in stage.

In some cases it is possible to simplify the recommendations in the following sections, from the form in which they are expressed in the DST. For example some of the rates of rise and fall recommendations were redundant and these have been eliminated in this summary (although retained in the DST). In others, simplification has not been possible and the full set of recommendations is provided in a table. The DST provides the full set of recommendations as they were agreed by the Panel and should be used for assessing compliance of a proposed flow regime rather than the information provided in this chapter. The purpose of this document is to collate and organise these recommendations in a form that is meaningful to water resource managers.

Recommendations can be summarised as a colour coded table that makes it easy to quickly identify which of the recommendations relating to river health could be affected by current or proposed river operations. The table also can guide flow operation decisions to achieve compliance.

In many cases inter-annual variation is incorporated in some of the upper and lower bounds set by the Panel. This means that in some years a higher flow may be possible for a longer duration although this is offset by a requirement for lower magnitudes and shorter duration in other years. Allowing for such inter-annual variability increases the complexity of the recommendations. However the advantage is an increased flexibility of river operation with the possibility of greater resource use in some years than would be possible if rigid or fixed recommendations were made. In some cases it is only conditions in extreme years which are constrained.

In applying the DST, it is suggested that attention is paid firstly to recommendations for the median year as a means of considering conditions for a typical year (although recognising the potential for year to year variability). Recommendations are not always expressed in terms of the magnitude of a discharge. In some cases recommendations are expressed in terms of the duration of a particular flow event, while in others it is the magnitude of a habitat metric (which might have an inverse relation with flow). The magnitude refers to the flow element in question, which have been defined previously in section 5.2. The median year relates to the median year for the particular flow element of concern, not necessarily a median flow year.

After considering results for median years, examination of absolute maximum and minimum recommendations (the maximum and minimum values for the metric over the period of record, 1975-2000) identifies the full range of values possible under the Panel's recommendations. The recommendations for other "percentile years" simply provide more detail on the inter-annual distribution for the particular flow element.

5.3 IVT bounds to achieve environmental flow objectives

In summary, the Panel has assigned upper and lower limits based on best available understanding of the natural range, and level of departure from, elements such as ecologically important flow events. This is demonstrated, for example, in the identification of flow events capable of controlling the encroachment of terrestrial vegetation (Section 4.2.3, Figure 26).

The environmental flow recommendations place constraints on the frequency distribution of flows for each season (i.e. the flow duration curve). These constraints are expressed in one of three forms, each of which refers to a particular set of objectives:

- duration of flow exceedence;
- duration within a flow range; or
- mean value of habitat metric which has a simple functional relation to discharge.

Upper and lower bounds have been considered in all three cases. Recommendations have also been developed for rates of rise and fall in river level.

5.3.1 Duration of flow exceedence

Upper and lower bounds for various flow durations relevant to ecological objectives for Reach 4 are listed in Table 7. Interesting observations on the recommendations for a median year are that:

- Recommended lower limits to achieve macroinvertebrate and native fish objectives are that discharge in the range 310 - 830 ML/d should be exceeded for between 95% and 100% of the time all year round. This is consistent with the previous Panel recommendation of a minimum flow of 610 ML/d or natural (see also Chapter 6). Exceedence of the above range in flows for between 80% and 90% of the time represents a moderate risk.
- Summer flows can exceed 1,500 ML/d for 90% of the time with little risk to ecological objectives, but should only exceed 1,660 ML/d for 63% of the time, 2,220 ML/d for 40% of the time, and 3,140 ML/d for 20% of the time.
- Short duration peak flows of approximately 4,500 ML/d (for 5% of the time) over summer are also considered to pose little risk to ecological objectives, subject to other constraints such as appropriate rates of rise and fall in river levels.
- Flow events above approximately 6,500 ML/d in summer would not be expected to occur in a median year but are considered to pose little risk to ecological objectives in wet years.
- Short duration events exceeding 24,000 ML/d in spring are considered to pose little risk to ecological objectives and are likely to be beneficial (e.g. for native fish).

A similar pattern to that described above is evident for Reach 5 (Table 8).

Given the low flows that prevail under the current regime, increases in discharge with IVTs up to approximately 1,500 ML/d are likely to be of benefit to ecological processes in the lower Goulburn River. It should be noted that the discharges and associated duration stated in the points above are indicative of how IVTs can be managed. The information in Table 7 provides a large degree of flexibility and better accounts for climatic variability than does a relatively static expression of a flow recommendation (e.g. a single upper or lower limit).

Table 7: Flow duration bounds identified for Reach 4 ecological objectives. The values in the table represent the proportion of time that discharge may exceed a particular bound (e.g. 0.85 = 85%). The various percentile years provide opportunities for inter-annual variability, providing different exceedence levels for dry (min, 10th and 30th percentile years) median and wet years (70th, 90th and max years).

			Moderate Risk							Recommended						
Ecological Objective	**Flow Element Code**	**Discharge (ML/day)**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**
Summer - Lower Bound																
MI4	F003b	540		0.80	0.85	0.9	0.96	0.98			0.90	0.95	0.95	0.98	0.99	
MI1	F007a	310								0.70	0.80	1.00	1.00			
MI3	F007a	310		0.85	0.90	0.93	0.95	0.95		0.99	0.99	0.99	0.99	0.99		
MI2	F008b	400		0.75	0.80	0.85	0.90	0.90		0.90	0.93	0.95	0.98	0.98		
n. fish	F008b	400		0.55	0.76	0.80	0.80	0.80		0.74	0.95	0.99	0.99	0.99		
n. fish	F007b	500		0.80	0.80	0.80	0.80	0.80		0.97	0.98	0.99	0.99	0.99		
MI6	F003b	540		0.60	0.80	0.90	0.98	0.98			0.80	0.90	0.95	0.99	0.99	
MI2	F008c	830	0.55	0.70	0.90	0.95	0.95	0.95		0.70	0.93	0.95	0.98	0.98		
Geo3	F026i	856	0.32	0.64	0.85	0.90	0.90	0.90	0.90	0.36	0.71	0.94	1.00	1.00	1.0	1.00
Geo3	F026h	1186	0.09	0.45	0.60	0.71	0.77	0.80	0.80	0.11	0.57	0.75	0.88	0.96	1.0	1.00
MI1	F007c	1500									0.10	0.30	0.45	0.75		
MI3	F007c	1500				0.15	0.25	0.50			0.15	0.30	0.40	0.70		
Geo3	F026g	1660		0.21	0.33	0.44	0.52	0.66	0.70		0.30	0.47	0.63	0.74	0.94	1.00
Geo3	F026f	2223		0.07	0.15	0.24	0.36	0.43	0.60		0.11	0.25	0.40	0.60	0.71	1.00
Geo3	F026e	3142		0.00	0.03	0.10	0.21	0.27	0.43		0.01	0.06	0.20	0.43	0.55	0.86
Geo3	F026d	4490				0.03	0.15	0.22	0.39				0.05	0.24	0.37	0.64
Geo3	F026c	6590					0.06	0.11	0.30					0.08	0.16	0.42
Geo3	F026b	10700						0.04	0.21						0.04	0.27
Geo3	F026a	19000							0.06							
Summer Upper Bound																
Geo3	F026i	856	0.39	0.78						0.36	0.71	0.94				
Geo3	F026h	1186	0.13	0.68	0.90	1.00				0.11	0.57	0.75	0.88	0.96		
MI1	F007c	1500			0.55	0.70	0.75					0.70	0.90	0.90		
Geo3	F026g	1660	0	0.39	0.62	0.82	0.96			0	0.30	0.47	0.63	0.74	0.94	
Geo3	F026f	2223	0	0.15	0.35	0.56	0.84			0	0.11	0.25	0.40	0.60	0.71	
Geo3	F026e	3142	0	0.01	0.08	0.31	0.64	0.82		0	0.01	0.06	0.20	0.43	0.55	0.86
Geo3	F026d	4490	0	0	0	0.07	0.34	0.52	0.90	0	0	0	0.05	0.24	0.37	0.64
Geo3	F026c	6590	0	0	0	0	0.10	0.20	0.55	0	0	0	0	0.08	0.16	0.42
Geo3	F026b	10700	0	0	0	0	0	0.05	0.32	0	0	0	0	0	0.04	0.27
Geo3	F026a	19000	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0.07
Autumn Lower Bound																
MI2	F008b	400		0.70	0.75	0.75	0.80	0.80			0.90	0.93	0.95	0.98	0.98	
n. fish	F008b	400		0.80	0.80	0.80	0.08	0.80			0.99	0.99	0.99	0.99	0.99	
MI4	F003b	540		0.60	0.85	0.90	0.96	0.98			0.70	0.90	0.95	0.98	0.99	
MI6	F003b	540		0.60	0.80	0.90	0.98	0.98			0.70	0.90	0.95	0.99	0.99	
MI2	F008c	830									0.50	0.65	0.80	0.95	0.98	

			Moderate Risk							Recommended						
Ecological Objective	Flow Element Code	Discharge (ML/day)	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum
Winter Lower Bound																
n. fish	F008b	400		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
n. fish	F007b	500		0.61	0.67	0.69	0.71	0.77			0.80	0.86	0.88	0.90	0.96	
MI4	F003b	540		0.80	0.85	0.90	0.96	0.98			0.85	0.90	0.95	0.98	0.99	
MI6	F003b	540		0.60	0.80	0.90	0.98	0.98			0.80	0.90	0.95	0.99	0.99	
MI2	F008c	830									0.90	0.93	0.95	0.98	0.98	
Spring Lower Bound																
n. fish	F008b	400		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
MI2	F008b	400		0.70	0.75	0.75	0.80	0.80			0.90	0.93	0.95	0.98	0.98	
n. fish	F008b	400		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
n. fish	F007b	500		0.62	0.66	0.72	0.76	0.80			0.81	0.85	0.91	0.95	0.99	
MI4	F003b	540		0.60	0.85	0.90	0.96	0.98			0.70	0.90	0.95	0.98	0.99	
MI6	F003b	540		0.60	0.80	0.90	0.98	0.98			0.70	0.90	0.95	0.99	0.99	
MI2	F008c	830									0.90	0.93	0.95	0.98	0.98	
n. fish	F027a	24000		0	0	0.03	0.08	0.20					0.05	0.13	0.31	
Spring Upper Bound																
n. fish	F027a	24000		0	0	0.10	0.24	0.59			0	0	0.08	0.19	0.47	

Table 8: Flow duration bounds identified for Reach 5 ecological objectives. The values represent the proportion of time that discharge may exceed a particular bound (e.g. 0.85 = 85%). The various percentile years provide opportunities for inter-annual variability, providing different exceedence levels for dry (min, 10th and 30th percentile years) median and wet years (70th, 90th and max years).

			Moderate risk							Recommended						
Environ. Objective	Flow Element Code	Flow Threshold (Ml/day)	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum
Summer - Lower Bound																
MI1	F007a	240									0.70	0.80	1.00	1		
MI3	F007a	240		0.85	0.90	0.93	0.95	0.95			0.99	0.99	0.99	0.99	0.99	
n. fish	F007b	320		0.80	0.80	0.80	0.80	0.80			0.90	0.90	0.99	0.99	0.99	
MI2	F008b	540		0.70	0.75	0.75	0.80	0.80			0.90	0.92	0.95	0.98	0.98	
n. fish	F008b	540		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
MI4	F003b	770		0.80	0.85	0.90	0.96	0.98			0.90	0.95	0.95	0.98	0.99	
MI6	F003b	770		0.60	0.80	0.90	0.98	0.98			0.80	0.90	0.95	0.99	0.99	
MI2	F008c	940		0.40	0.50	0.55	0.60	0.70			0.70	0.92	0.95	0.98	0.98	
Geo3	F026i	1096	0.34	0.67	0.79	0.86	0.90	0.90	0.90	0.38	0.75	0.88	0.96	1.00	1.00	1.00
Geo3	F026h	1505	0.13	0.42	0.51	0.66	0.75	0.80	0.80	0.17	0.53	0.64	0.82	0.94	1.00	1.00
Geo3	F026g	1993	0.02	0.12	0.28	0.42	0.51	0.68	0.70	0.02	0.17	0.40	0.60	0.73	0.97	1.00

			Moderate risk							Recommended						
Environ. Objective	Flow Element Code	Flow Threshold (Ml/day)	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum
Geo3	F026f	2711	0	0.05	0.13	0.21	0.36	0.52	0.60	0	0.09	0.21	0.35	0.60	0.87	1.00
Geo3	F026e	3800	0	0	0.03	0.10	0.2	0.33	0.50	0	0	0.05	0.20	0.40	0.66	1.00
Geo3	F026d	5240	0	0	0	0.01	0.13	0.26	0.43	0	0	0	0.02	0.22	0.43	0.71
Plankt. Algae	F002c	6060				0	0.17						0	0.17		
Geo3	F026c	7560	0	0	0	0	0.05	0.13	0.33	0	0	0	0	0.08	0.18	0.47
Geo3	F026b	13000	0	0	0	0	0	0.02	0.3	0	0	0	0	0	0.03	0.38
Geo3	F026a	23900	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0.09
Summer - Upper Bound																
Geo3	F026i	1096	0.42	0.82	0.97	1.00	1.00	1.00	1.00	0.38	0.75	0.88	0.96	1.00	1.00	1.00
Geo3	F026h	1505	0.20	0.64	0.77	0.99	1.00	1.00	1.00	0.17	0.53	0.64	0.82	0.94	1.00	1.00
Geo3	F026g	1993	0.03	0.23	0.52	0.78	0.95	1.00	1.00	0.02	0.17	0.4	0.60	0.73	0.97	1.00
Geo3	F026f	2711	0	0.13	0.29	0.49	0.84	1.00	1.00	0	0.09	0.21	0.35	0.60	0.87	1.00
Geo3	F026e	3800	0	0	0.08	0.3	0.6	1.00	1.00	0	0	0.05	0.20	0.40	0.66	1.00
Geo3	F026d	5240	0	0	0	0.03	0.31	0.6	1.00	0	0	0	0.02	0.22	0.43	0.71
MI2	F004c	5610		0.05	0.05	0.10	0.40	0.55			0.01	0.01	0.02	0.30	0.50	
MI4	F004c	5610									0.01	0.01	0.02	0.25	0.45	
Plankt. algae	F002c	6060					0.23	0.36						0.19	0.30	
Geo3	F026c	7560	0	0	0	0	0.10	0.24	0.61	0	0	0	0	0.08	0.18	0.47
MI2	F002b	8910		0.02	0.02	0.03	0.10	0.20			0.01	0.01	0.01	0.05	0.15	
Geo3	F026b	13000	0	0	0	0	0	0.03	0.45	0	0	0	0	0	0.03	0.38
Geo3	F026a	23900	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0.09
Autumn - Lower Bound																
n. fish	F007b	320		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
MI2	F008b	540		0.70	0.75	0.75	0.80	0.80			0.90	0.92	0.95	0.98	0.98	
n. fish	F008b	540		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
MI4	F003b	770		0.60	0.85	0.90	0.96	0.98			0.70	0.90	0.95	0.98	0.99	
MI6	F003b	770		0.60	0.80	0.90	0.98	0.98			0.70	0.90	0.95	0.99	0.99	
MI2	F008c	940		0.40	0.50	0.55	0.60	0.70			0.50	0.65	0.80	0.95	0.98	
Autumn - Upper Bound																
MI2	F004c	5610		0.05	0.05	0.1	0.4	0.55			0.01	0.01	0.02	0.30	0.60	
MI4	F004c	5610		0.05	0.05	0.1	0.4	0.55						0.03	0.10	
MI2	F002b	8910		0.02	0.02	0.03	0.1	0.2			0.01	0.01	0.01	0.01	0.05	
Winter - Lower Bound																
n. fish	F007b	320		0.8	0.8	0.8	0.8	0.8			0.99	0.99	0.99	0.99	0.99	
n. fish	F008b	540		0.8	0.8	0.8	0.8	0.8			0.99	0.99	0.99	0.99	0.99	
MI4	F003b	770		0.8	0.85	0.9	0.96	0.98			0.85	0.9	0.95	0.98	0.99	
MI6	F003b	770		0.60	0.80	0.90	0.98	0.98			0.8	0.9	0.95	0.99	0.99	
MI2	F008c	940		0.60	0.70	0.80	0.85	0.85			0.9	0.92	0.95	0.98	0.98	
Winter - Upper Bound																
MI2	F002b	8910		0.30	0.40	0.75	0.85	0.95			0.2	0.3	0.65	0.8	0.9	
Spring - Lower Bound																
n. fish	F007b	320		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
MI2	F008b	540		0.70	0.75	0.75	0.80	0.80			0.9	0.92	0.95	0.98	0.98	
n. fish	F008b	540		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
n. fish	F008b	540		0.80	0.80	0.80	0.80	0.80			0.99	0.99	0.99	0.99	0.99	
MI4	F003b	770		0.60	0.85	0.90	0.96	0.98			0.70	0.90	0.95	0.98	0.99	

			Moderate risk							Recommended						
Environ. Objective	**Flow Element Code**	**Flow Threshold (Ml/day)**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**
MI6	F003b	770		0.60	0.80	0.90	0.98	0.98			0.70	0.90	0.95	0.99	0.99	
MI2	F008c	940		0.60	0.70	0.80	0.85	0.85			0.90	0.92	0.95	0.98	0.98	
Plankt. algae	F002c	6060														
Spring - Upper Bound																
MI4	F004c	5610		0.55	0.80	0.95					0.42	0.70	0.85	0.95	1.00	
Plankt. algae	F002c	6060		0.42	0.83	0.87	1.00	1.00			0.35	0.66	0.73	0.86	1.00	
MI2	F002b	8910		0.15	0.55	0.70	0.95				0.10	0.40	0.65	0.80	1.00	
n. fish	F027a	24000		0.01	0.06	0.16	0.33	0.67			0	0.05	0.13	0.26	0.54	

5.3.2 Duration within a flow range

The duration within a flow range refers to the total duration of flows (as a proportion of the total duration of the season) regardless of whether or not it is a continuous spell. Recommendations for Reach 4 (Table 9) indicate that:

- Discharge in excess of approximately 5,000 ML/d and up to approximately 7,400 ML/d is acceptable for short periods (e.g. 2% of the time) in summer but can persist (85% of the time) in spring with little risk to ecological objectives.
- Discharge above or below the range of approximately 850 ML/d to 1,200 ML/d for 30% of time during the summer-autumn irrigation season is likely to pose little risk to ecological objectives.

A similar pattern is evident for Reach 5 (Table 10). For example, results indicate that to achieve objectives for macroinvertebrates, flows should be within the range 440 ML/d to 1820 ML/d for a minimum of 30% of the time and a maximum of 90% of the time.

Table 9: Upper and lower bounds for the duration of ecologically significant flow events for Reach 4

				Moderate Risk							Recommended						
Environ. Objective	**Flow Element Code**	**Lower Discharge (Ml/day)**	**Upper Discharge (Ml/day)**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**
Summer Upper Bound																	
MI2	F004c	5570	7440		0.05	0.05	0.10	0.40	0.55			0.01	0.01	0.02	0.30	0.50	

				Moderate Risk							Recommended						
Environ. Objective	Flow Element Code	Lower Discharge (Ml/day)	Upper Discharge (Ml/day)	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum
MI4	F004c	5570	7440		0.05	0.05	0.10	0.40	0.55			0.01	0.01	0.02	0.25	0.45	
Autumn Upper Bound																	
MI2	F004c	5570	7440		0.02	0.02	0.03	0.05	0.15			0.01	0.01	0.02	0.30	0.60	
MI4	F004c	5570	7440		0.02	0.02	0.03	0.05	0.15						0.03	0.10	
Spring Upper Bound																	
MI4	F004c	5570	7440		0.55	0.85	0.95					0.35	0.70	0.85	0.95		
Dec_Apr Lower Bound																	
MI2	F025h	856	1186			0.03	0.05	0.08	0.10				0.05	0.08	0.10	0.15	
MI2	F025g	1186	1660			0.02						0.01	0.05				
Dec_Apr Upper Bound																	
MI2	F025h	856	1186		0.03	0.30	0.40	0.50	0.55			0.02	0.20	0.30	0.35	0.45	
Geo1	F025d	3142	4490		0.01	0.05	0.13	0.18	0.25	0.42			0.04	0.10	0.15	0.20	0.33
Geo1	F025c	4490	6590				0.05	0.13	0.19	0.23				0.04	0.11	0.16	0.20
Geo1	F025b	6590	10700				0.01	0.06	0.09	0.14				0.01	0.05	0.08	0.12
Geo1	F025a	10700	19000						0.03	0.14						0.03	0.14

Table 10: Upper and lower bounds for the duration of ecologically significant flow events for Reach 5

					Moderate Risk							Recommended						
Environ. Objective	Flow Element Code	(U)pper or (L)ower bound	Lower Flow Threshold (Ml/day)	Upper Flow Threshold (Ml/day)	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum
Summer																		
MI1	F007c	L	440	1820										0.10	0.30	0.45	0.75	
MI1	F007c	U	440	1820			0.50	0.70	0.80	0.95				0.70	0.90	0.90	1.00	
MI3	F007c	L	440	1820		0	0	0.15	0.25	0.50			0	0.15	0.30	0.40	0.70	
Dec_Apr																		
Geo1	F025a	U	13000	23900						0.02	0.21						0.02	0.20
Geo1	F025b	U	7560	13000				0	0.06	0.12	0.15				0	0.05	0.10	0.14

Geo1	F025c	U	5240	7560				0.03	0.10	0.21	0.29				0.02	0.09	0.18	0.24
Geo1	F025d	U	3800	5240		0	0.04	0.08	0.18	0.29	0.48			0.03	0.06	0.15	0.23	0.39
MI2	F025g	L	1505	1993			0.03	0.06	0.10	0.20			0.01	0.05				
MI2	F025h	U	1096	1505		0.03	0.30	0.40	0.50	0.60			0.02	0.2	0.30	0.35	0.45	
MI2	F025h	L	1096	1505			0.03	0.05	0.06	0.10			0	0.05	0.08	0.10	0.15	

5.3.3 Habitat Conditions – mean habitat availability over a season

In many cases the mean habitat conditions recommendations will be met if the duration recommendations (in the sections above) are satisfied. In order to check compliance against these recommendations it is necessary to first transform the flow series to a time-series of the relevant habitat metric (Table 11 and Table 12). Units for individual metrics, such as F005 etc. can be found in Table 6 (section 5.2.1).

Table 11: Upper and lower bounds for habitat metrics relevant to Reach 4. See Table 5 for the units associated with each metric.

			Moderate Risk							Recommended						
Environmental Objective	Flow Element Code	(U)pper or (L)ower bound	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum
Summer																
Plankt. algae	F001	L		0.73							0.80					
Plankt. algae	F001	U		1.00		1.20		1.40			0.86		1.02		1.30	
Plankt. algae	F013b	L		0.14							0.18					
Plankt. algae	F013b	U						0.30							0.25	
Plankt. algae	F013c	L		0.36							0.44					
Plankt. algae	F013c	U						0.70							0.59	
Periph. Algae	F014	L		24.5							25.3					
Macrophytes	F014	L		24.5							25.3					
Periph. Algae	F014	U						28.2							27.5	
Macrophytes	F014	U						28.2							27.5	
Periph. Algae	F015a	L		0.30				4.0			0.39					
Periph. Algae	F015a	U						6.0							5.0	
Periph. Algae	F015b	L		2.0				8.0			2.5					
Periph. algae	F015b	U						12.0							10.0	
Periph. algae	F015c	L		5.0				12.0			6.0					
Macrophytes	F015c	L		5.0				12.0			6.0					
Periph. algae	F015c	U						18.0							15.0	
Macrophytes	F015c	U						18.0							15.0	
Macrophytes	F015D	L		24.2				25.5								
Macrophytes	F015D	U		26.2				27.4			25.2				26.6	
Autumn																

			Moderate Risk							Recommended						
Environmental Objective	Flow Element Code	(U)pper or (L)ower bound	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum
Macrophytes	F014	U	23.0			24.0		26.0		25.1			25.8		27.3	
Macrophytes	F015c	L						14.4			9.5					
Macrophytes	F015c	U						21.6							18.0	
Macrophytes	F015d	L		24.6				25.4								
Macrophytes	F015d	U		25.7				27.0			24.7				26.4	
Winter																
Macrophytes	F014	U		10.1			23.0	27.5			10.1			24.4	25.3	
Spring																
Plankt. algae	F001	L		0.30							0.40					
Plankt. algae	F001	U						1.1							0.90	
Plankt. algae	F012	L		0.21		0.48					0.27		0.60			
Plankt. algae	F012	U				0.73		1.1					0.61		0.95	
Plankt. algae	F013b	L		0.05							0.05					
Plankt. algae	F013b	U						0.35							0.18	
Plankt. algae	F013c	L		0.12		0.20					0.12		0.25			
Plankt. algae	F013c	U				0.32		0.46					0.27		0.42	
Periph. algae	F014	L		7.2							9.2					
Macrophytes	F014	L		7.6		18.0					9.3					
Periphytic Algae	F014	U						30.0							28.3	
Macrophytes	F014	U				25.0		30.0					20.5		28.3	
Periph. algae	F015a	L					0							0		
Periph. algae	F015a	U						1.0							0.06	
Periph. algae	F015b	L		0							0					
Periph. algae	F015b	U				0.04		1.0					0.03		0.80	
Periph. algae	F015c	L		0.03				3.5			0.05					
Macrophytes	F015c	L		0.03				3.5			0.05					
Periph. algae	F015c	U						5.3							4.4	
Macrophytes	F015c	U						5.3							4.4	

Table 12: Upper and lower bounds for habitat metrics relevant to Reach 5. See Table 5 for the units associated with each metric

			Moderate Risk							Recommended					
Environ. Objective	Flow Element Code	(U)pper or (L)ower bound	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	Maximum	Minimum	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year
Summer															
Planktonic algae	F001	U						1.70							1.40
Planktonic algae	F001	L		0.56							0.70				
Planktonic algae	F012	U						0.45							0.60
Planktonic algae	F012	L		0.30							0.35				
Planktonic algae	F013b	U						0.30							0.24
Planktonic algae	F013b	L		0.14							0.14				
Planktonic algae	F013c	U						0.66							0.55
Planktonic algae	F013c	L		0.30							0.30				
Periphytic Algae	F014	U						10.0							8.20
Periphytic Algae	F014	L		5.60							5.60				
Macrophytes	F014	U						9.90							8.20
Macrophytes	F014	L		5.60	5.60			6.60			5.60	5.65			
Periphytic Algae	F015a	U						6.00							5.60
Periphytic Algae	F015a	L		0.30							0.38				
Periphytic Algae	F015b	U						6.00							5.70
Periphytic Algae	F015b	L		3.90							4.90				
Periphytic Algae	F015c	U						5.00							6.30
Periphytic Algae	F015c	L		4.00							5.20				
Macrophytes	F015c	U		6.23		6.60		7.28			5.29		5.60		6.28
Macrophytes	F015c	L		5.23		4.60		5.00			5.23		5.59		6.27
Macrophytes	F015D	U						9.90							8.20
Macrophytes	F015D	L		5.60	5.06			6.60			5.60	5.65			
Autumn															
Macrophytes	F014	U						15.0							12.50
Macrophytes	F014	L		5.60	6.00						5.60	7.58			
Macrophytes	F015c	U		6.40		7.40		9.40			5.40		6.43		8.43
Macrophytes	F015c	L		5.09		5.40		7.40							
Macrophytes	F015d	U						14.5							12.10
Macrophytes	F015d	L		5.60	6.00			9.70			5.60	7.50	9.00		
Winter															
Macrophytes	F014	U					5.60	7.20						5.61	6.00
Spring															
Planktonic algae	F001	U						1.10			0.40				
Planktonic algae	F001	L		0.30									0.24		0.33
Planktonic algae	F012	U				0.29		0.40			0.15		0.23		
Planktonic algae	F012	L		0.12		0.20									0.18
Planktonic algae	F013b	U						0.35			0.05				
Planktonic algae	F013b	L		0.05									0.23		0.32
Planktonic algae	F013c	U				0.27		0.46			0.12		0.22		
Planktonic algae	F013c	L		0.12		0.18									5.70
Periphytic Algae	F014	U						6.00			5.60				
Periphytic Algae	F014	L		5.60						5.61					5.61

			Moderate Risk							**Recommended**					
Environ. Objective	**Flow Element Code**	**(U)pper or (L)ower bound**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**
Macrophytes	F014	U	5.50					5.50							
Macrophytes	F014	L													5.70
Periphytic Algae	F015a	U						6.00		5.40					
Periphytic Algae	F015a	L	4.30												5.70
Periphytic Algae	F015b	U						5.70			5.50				
Periphytic Algae	F015b	L		4.00											5.70
Periphytic Algae	F015c	U						6.00			5.55				
Periphytic Algae	F015c	L		4.00				4.60		5.56					5.61
Macrophytes	F015c	U	5.50					5.50							
Macrophytes	F015c	L													
Periphytic Algae	F018h	U													
Periphytic Algae	F018h	L													
Periphytic Algae	F018i	U													
Periphytic Algae	F018i	L											2.00	2.00	4.00

5.3.4 Flow Spells – flood frequency

The timing of floods is an important factor in achieving ecological objectives for the Goulburn River. Floods in winter and spring provide important cues in the life-cycle of riverine and floodplain organisms and the Panel recommended more frequent winter-spring flood events in its previous deliberations (Cottingham et al. 2003). However, floods in summer-autumn period are a relatively rare occurrence under natural conditions. Although their ecological significance is not fully understood, it is likely that they will result in some kind of ecological changes, either to riverine biota or ecological processes, and this could be interpreted as a type of risk. For example, the entrainment of decomposing organic matter (with a high tannin content) during summer can lead to ‘blackwater’ events (particularly if a flood follows and extended dry period) that affect water quality and can harm aquatic organisms (e.g. Baldwin et al. 2001, MDBC 2002). The Panel recommends a maximum frequency of one ‘moderate’ sized flood along the lower Goulburn every 2 years for a median year (Table 13 and Table 14). Up to 2 moderate sized floods each year in winter and spring pose little risk to ecological objectives for the river.

Table 13: Return frequency of floods along Reach 4. Values represent upper limits of flood frequency per year.

Environmental Objective	Flow Element Code	(U)pper or (L)ower bound on frequency	Flood Threshold discharge	Moderate Risk Number of floods			Recommended Number of floods		
				median year	70th percentile year	90th percentile year	median year	70th percentile year	90th percentile year
Summer									
MI4	F021b	U	32700	0.80	1.30	1.30	0.50	1.00	1.00
MI4	F021d	U	55000		0.05	0.10		0.02	0.05
Autumn									
MI4	F021b	U	32700	0.80	1.30	1.30	0.50	1.00	1.00
MI4	F021d	U	55000		0.05	0.10		0.02	0.05
Winter									
MI4	F021b	L	32700	1.20	3.00	3.00	2.00	4.00	4.00
MI4	F021d	L	55000			1.00			2.00
Spring									
MI4	F021b	L	32700	1.50	2.00	2.50	2.00	3.00	4.00
MI4	F021d	L	55000		0	1.00		0	2.00

Table 14: Return frequency of floods along Reach 5

				Moderate Risk			Recommended		
Environ. Objective	Flow Element Code	(U)pper or (L)ower bound	Flood Threshold (ML/d)	median year	70th percentile year	90th percentile year	median year	70th percentile year	90th percentile year
Summer									
MI4	F021b	U	32700				0.50	1.00	1.00
MI4	F021d	U	55000		0.05	0.10		0.02	0.05
Autumn									
MI4	F021b	U	32700				0.50	1.00	1.00
MI4	F021d	U	55000		0.05	0.10		0.02	0.05
Winter									
MI4	F021b	L	32700	0.75	2.00	2.00	1.50	3.00	3.00
MI4	F021d	L	55000			0.90			0.18
Spring									
MI4	F021b	L	32700	1.00	1.00	3.00		2.00	3.40
MI4	F021d	L	55000		1.00	2.00			

5.3.5 Duration of the Longest Spell

Managing encroachment of terrestrial vegetation

The environmental flow regime recommended to achieve the objective for non-woody terrestrial bank vegetation (“TerrBank Veg”) applies to the period December to April.

The recommendation (see section 4.3) has two parts, one for the upper and one for the lower banks (Table 15):

- Upper bank: the longest duration spell in excess of 6,600 ML/d should be less than 15 days in nine out of every ten years (30 days for the moderate risk bound).
- Lower bank: the longest duration spell in excess of 4,500 ML/d should be at least 40 days in at least one out of every 10 years (20 days for the moderate risk bound).

Spells must be separated by at least 5 days to be considered independent. Spells may start prior to the December-April period in which case the total duration is counted including the period prior to December.

Table 15: Spell duration to achieve vegetation objectives for the lower and upper section of the river bank

				Moderate risk							Recommended						
Environ. Objective	**Flow Element Code**	**(U)pper or (L)ower bound**	**Flow threshold (ML/d)**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**	**Minimum**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**Maximum**
TerrBank Veg	f006i	L	1096						20							40	
TerrBank Veg	f006h	L	1505						20							40	
TerrBank Veg	f006g	L	1993						20							40	
TerrBank Veg	f006f	L	2711						20							40	
TerrBank Veg	f006e	L	3800						20							40	
TerrBank Veg	f006d	L	5240						20							40	
TerrBank Veg	f006c	L	7560						20							40	
TerrBank Veg	f006b	U	13000						15							30	
TerrBank Veg	f006a	U	23900						15							30	

5.3.6 Persistent Spells of Stable Flow

Persistent spells have been defined as spells exceeding a certain number of days. Spells must be separated by a period of more than 5 days to be considered as separate spells. Separate Panel recommendations address spells exceeding two weeks (for periphytic algae growth) and spells exceeding six weeks (for macrophyte growth). A spell is defined by continuous flow within a specified flow band. If flow persists within this band for more than two (or six) weeks it is considered to be a persistent spell and represents a period of stable flow. When the flow has been stable for two (or six) weeks, additional days of stable flow are counted (counting commences when the threshold is reached and does not include the initial 2 or six weeks). The number of such stable flow days is expressed as a proportion of the total number of days in the season (Table 16 and Table 17).

Table 16: Persistent stable flows exceeding six weeks to achieve the macrophytes objective

				Moderate Risk					Recommended				
Flow Element Code	(U)pper or (L)ower bound	Lower threshold discharge (ML/d)	Upper threshold discharge (ML/d)	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year
Summer													
F016n	U	3142	8080				0.03	0.18				0.04	0.22
F016o	U	2223	7150		0		0.11	0.20		0		0.14	0.25
F016p	U	1660	6440		0.09		0.22	0.36		0.12		0.28	0.46
F016q	L	1186	5820	0.09		0.27		0.44	0.11		0.34		
F016q	U	1186	5820					0.84					0.73
F016r	L	856	5250	0.15		0.43		0.62	0.18		0.53		
F016r	U	856	5250			0.64		0.93					0.78
Autumn													
F016p	U	1660	6440				0	0.42				0	0.53
F016q	U	1186	5820			0	0.05	0.7			0.01	0.07	0.88
F016r	U	856	5250			0.28	0.67	0.8	0		0.35	0.85	1.00
Spring													
F016n	L	3142	8080	0			0.05	0.23	0			0.05	
F016n	U	3142	8080					0.34					0.29
F016o	L	2223	7150	0			0.02	0.21	0			0.02	
F016o	U	2223	7150					0.31					0.27
F016p	L	1660	6440	0			0.01	0.22	0			0.01	
F016p	U	1660	6440					0.33					0.28

Table 17: Persistent stable flows exceeding 2 weeks to achieve the periphytic algae objective

				Moderate Risk					Recommended				
Flow Element Code	(U)pper or (L)ower bound	Lower threshold discharge (ML/d)	Upper threshold discharge (ML/d)	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year	10th percentile year	30th percentile year	median year	70th percentile year	90th percentile year
Spring													
F016a	L	19000	23930	0					0				
F016a	U	19000	23930					0.05					0
F016b	L	10700	15640					0.05				0	
F016b	U	10700	15640					0.07					0.06
F016c	L	6590	11530	0			0.05	0.14	0			0.06	
F016c	U	6590	11530					0.20					0.18
F016d	L	4490	9430	0		0.08	0.16	0.30	0		0.13	0.2	
F016d	U	4490	9430					0.43					0.37
F016e	L	3142	8080	0		0.20	0.30	0.47	0	0.12	0.22	0.39	
F016e	U	3142	8080					0.70					0.60

				Moderate Risk					Recommended				
Flow Element Code	**(U)pper or (L)ower bound**	**Lower threshold discharge (ML/d)**	**Upper threshold discharge (ML/d)**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**	**10th percentile year**	**30th percentile year**	**median year**	**70th percentile year**	**90th percentile year**
F016f	L	2223	7150	0		0.20	0.30	0.47	0	0.13	0.24	0.39	
F016f	U	2223	7150					0.70					0.58
F016g	L	1660	6440	0	0.07	0.13	0.26	0.47	0	0.08	0.16	0.32	
F016g	U	1660	6440				0.38	0.70					0.59
F016h	L	1186	5820	0		0.08		0.32	0		0.10		
F016h	U	1186	5820					0.48					0.40
F016i	L	856	5250	0		0.03		0.30	0		0.03		
F016i	U	856	5250					0.43					0.36

5.3.7 Rates of Rise and Fall

Managing rates of rise and fall in river levels is important to avoid outcomes such as excessive bank slumping and erosion or stranding for organisms such as macroinvertebrates or fish. Rates of rise and fall are (Table 18) based on the 80th and 90th percentile level in daily change for each season.

Table 18: Operational boundaries on the distribution of daily rise and fall in Reach 4 stage (m) to comply with Panel recommendations. The table provides upper limits for the various percentiles on the distribution of daily changes. Lower limits are shown in brackets.

	Moderate Risk				*Recommended*				
	upper bound 80th daily change	*lower bound 90th daily change*	*upper bound 90h daily change*	*upper bound all daily changes*	*upper bound 80th daily change*	*lower bound 90th daily change*	*upper bound 90th daily change*	*upper bound all daily changes*	
								<4000 Ml/day	*>4000 Ml/day*
Daily Rise in Stage (m)									
Summer	-	(0.16)	0.48	0.77	-	(0.26)	0.38	0.52	
Autumn	-	-	-	0.86	-	-	-	0.57	
Winter	-	-	-	5.40	1.20	-	-	3.60	
Spring	-	(0.91)	2.74	4.00	0.80	(1.50)	2.20	2.70	
Daily Fall in Stage (m)									
Summer	0.12	(0.06)	0.18	0.51	0.09	(0.10)	0.15	0.25	0.34
Autumn	0.13	-	-	0.43	0.09	-	-	0.25	0.29
Winter	1.20	-	-	2.60	0.78	-	-	-	1.75
Spring	0.72	(0.38)	1.15	3.70	0.72	(0.38)	1.15	-	3.70

5.4 Summary pattern of recommended releases

The upper and lower bounds of flow recommendations have been summarised in Figure 36. As a **general guide**, the results indicate that for a **median** year, summer discharge within the range of approximately 500 ML/d and 2,000 ML/d for 70% of the time poses little risk to ecological objectives, and indeed is likely to be more beneficial to riverine biota and ecological processes than the current flow regime. Flows above approximately 2000 ML/d can still be delivered, but for increasingly shorter duration as discharge increases. For example, the release of IVTs at discharge exceeding 4,000 – 6,000 ML/d pose little risk to ecological objectives so long as they are delivered as short events (e.g. 10% - 3% exceedence), with appropriate rates of rise and fall. Climatic variability can be accounted for by adopting a similar release pattern for the median year, but with higher or lower discharges for wet and dry years, respectively.

It is reiterated that the approach adopted for this project, while initially complex, provides far greater operational flexibility and will make it easier to define and reinstate elements of natural variability in the flow regime than would be the case if flow recommendations were presented as single (static) discharges.

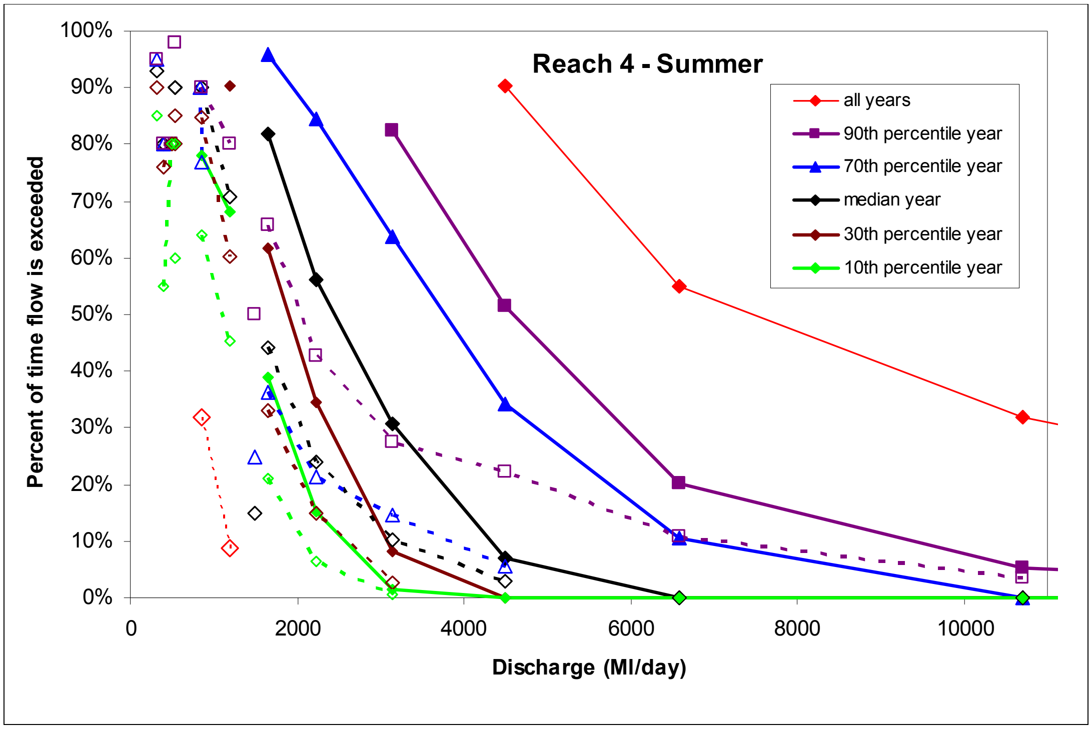


Figure 36: Upper and lower bounds and exceedence levels for flow duration for 10th, 30th, median, 70th, 90th percentile years and all years (1975-2000) for the pre-regulated flow regime. Solid shapes and solid lines represent upper bounds for each percentile year, while open shapes and broken lines represent lower bounds.

5.5 Other considerations

5.5.1 Operational considerations – formation of an advisory group

River managers would prefer to have a clear set of rules from which to operate, free from the need to consult with outside bodies. The set of rules would provide the bounds within which the river should be managed. While it is possible that rules can be developed that will guard against damage to environmental assets and values, managers are likely to require additional advice on risk of alternative flow scenarios that represent different levels of risk. One way of achieving this is to establish an ecosystem advisory group, similar to that established for delivering the Barmah Environmental Water Allocation. Such an advisory group could comment on annual water delivery plans and identify adjustments that might be required, for example in light of prevailing climatic conditions or precedent hydrology. Such a group, working in conjunction with the river managers, could add value to an adaptive management process.

5.5.2 Unseasonal flow regime (inversion of the seasonal flow regime)

Increased IVTs have implications for an emerging pattern of summer flow inversion – as IVT flows increase in magnitude and duration, the flow regime of the lower Goulburn will increasingly be dominated by high flows in summer. The current regime of low flows in winter will presumably be maintained. The intent of the Panel is to return desirable elements of the summer flow regime lost under the historic regulated flow regime, given that we expect management of winter flows to remain unchanged. The proposed decommissioning of Lake Mokoan and delivery of water to meet Living Murray objectives may increase winter flows along the lower Goulburn in the future, adding to variability in discharge. Potential risks associated with seasonal inversion of the flow regime would be reduced even further by implementing the recommendations for wetland watering events in winter-spring outlined in the previous environmental flow study (Cottingham et al. 2003a).

5.5.3 Potential cold water issues

With regards to native fish, depression of water temperatures is probably the most detrimental effect of elevated summer flows below major impoundments in Australian rivers. Depressed water temperatures can decrease the metabolic and growth rates of fish, result in failure of fish to spawn, reduce the survival of eggs and larvae if spawning does occur, and reduce the ability of fish to avoid predators and swim against strong currents (Ryan et al. 2001; Todd et al. 2005). In addition to the direct effects on fish, depressed water temperatures can drastically reduce rates of primary productivity and bacterial activity in river systems (which form the basis of the food chain), thus reducing the carrying capacity of the affected river.

It has been estimated that water temperature in the Goulburn River below Lake Eildon is often depressed by 5-7°C during summer (Gippel and Finlayson 1993; Ryan et al. 2001). Such levels of temperature depression have had detrimental effects upon native fish populations in a wide range of rivers in south-eastern Australia, including the Goulburn (Gippel and Finlayson 1993; Koehn et al. 1995; Lugg 1999; Ryan et al. 2001). Strong temperature depression has not been noted in the Goulburn River below Goulburn Weir under the current flow management regime (Ryan et al. 2001). However, the Scientific Panel is concerned that once storage in

Lake Eildon returns to high levels there will be increased potential for cold water to reach further downstream to the lower Goulburn River under IVT scenarios.

Additional temperature modelling by the CSIRO (Sherman 2007, Appendix 3) was commissioned to inform the Scientific Panel on potential temperature-related issues resulting from IVTs. Results suggest that temperature downstream of Goulburn Weir is likely to be relatively insensitive to changes in discharge and water depth as a result of increasing IVTs.

5.5.4 Social and economic considerations

The scope of this project has been to provide an environmental perspective. It is acknowledged that outcomes that may prove beneficial from an ecosystem perspective may come at some social and economic cost. For example, increased summer flows may preclude access to low-lying benches and 'beaches' favoured for recreation by the local community.

5.5.5 Implications of the Goulburn Interceptor project

DSE is currently considering the feasibility of constructing a diversion channel (the Goulburn Interceptor) from Yarrawonga to the Shepparton Irrigation Area (SIA) to overcome constraints in delivery from the Murray River caused by the Barmah Choke (see the Prime Minister's *National Plan for Water Security*). The Goulburn Interceptor would supply the SIA with water from the Murray River. Thus water that would normally be delivered to the SIA from the Goulburn River would be released to the Murray River as a 'substitution'. Commissioning of the Goulburn Interceptor would increase the volume of releases to the lower Goulburn River from Goulburn Weir, over and above that currently being considered for IVTs.

A number of additional considerations, beyond the scope of this project, should be considered when evaluating the feasibility of the Goulburn Interceptor project:

- Substitution flows increase the likelihood, and therefore risk, associated with increased summer-autumn flows along the lower Goulburn River;
- Increased summer releases of cold water from Hume Dam (Sherman 2006) increases the risk that colder-than natural water would be released from Yarrawonga to the SIA and potentially Broken Creek and the Broken River (should the Interceptor outfall to the Broken River). It is recommended that temperature modelling be undertaken to investigate the risk of cold water releases to Broken Creek and the Broken River.
- Higher summer-autumn water levels increase the risk of unseasonal flooding along the lower Goulburn River. More frequent unseasonal flooding increases the risk of 'blackwater' events, can affect the dynamics of riverine production, bankside erosion and vegetation dynamics, and can affect the availability of shallow, low velocity habitat favoured by aquatic macrophytes, macroinvertebrates and fish. This last risk is exacerbated by the lack of cross-sectional complexity in the lower Goulburn channel.
- Outfall of the Interceptor canal to the Broken Creek and Broken River has the potential to increase summer-autumn flows, potentially posing similar issues to that posed by high IVTs along the lower Goulburn River. It is recommended that high summer-autumn flow scenarios be evaluated for the lower Broken Creek and

lower Broken River using the methodology developed during this project for the Goulburn River.

6 CLARIFICATION OF PREVIOUS ENVIRONMENTAL FLOW RECOMMENDATIONS

DSE has requested that two flow recommendations recommended by Cottingham et al. (2003) be presented in a format consistent with subsequent environmental flow studies for other rivers. This will also allow DSE to include these recommendations in demand models for the Goulburn River. The daily flow data used in the original study (for the period 1975-2000) were used to assess or describe:

- Compliance with a minimum flow recommendation of 610 ML/d (year round) in each study reach (Reach 4 and 5), and
- Summer flow pulses, the frequency, magnitude and duration of which had to be preserved (i.e. the Scientific Panel recommended that these flow attributes were to be maintained in the future).

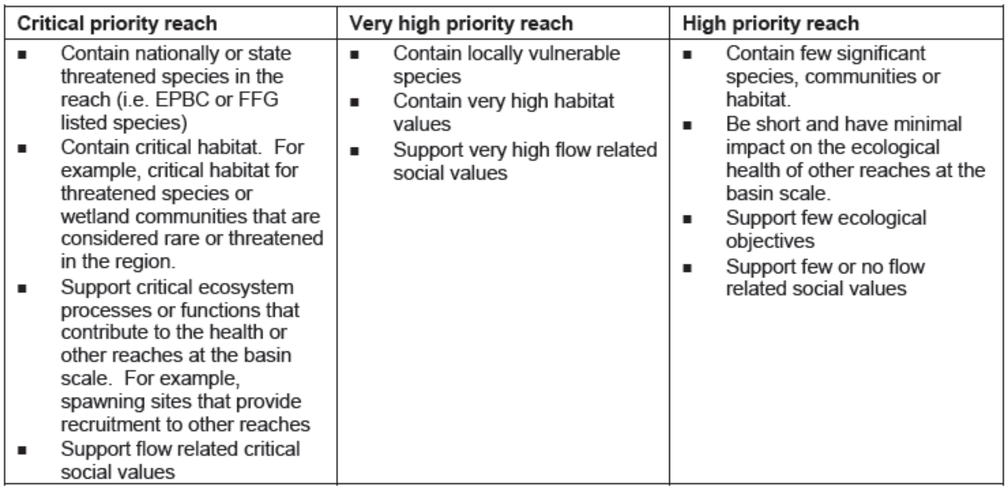
Minimum flow recommendation
Examination of the data indicated that under an unregulated flow regime, flow above 610 ML/d would have occurred 97% and 99% of the time in the Murchison and Wyuna reaches (Reach 4 and 5), respectively. Under the regulated flow regime, flow above 610 ML/d would only have occurred less than 70% of the time in both reaches (Table 19).

Table 19: Compliance of the regulated flow regime in the lower Goulburn with a minimum flow recommendation of 610 ML/d.

Component	Time	Flow Rec	Reach 4		Reach 5	
			Rec	% Comp	Rec	% Comp
Low flow	All year	Volume	610 ML/d	30	610 ML/d	69

Based on the draft priority criteria proposed by SKM (2005), the low flow recommendation of 610 ML/d (or natural) would be classified as a Very High Priority flow component in Critical Priority Reach (Table 20). With compliance levels below 70%, the current low flow regime poses a critical risk (Table 21) to achieving ecological objectives related to the maintenance of native fish populations.

Table 20: Draft criteria for determining priority reaches (from SKM 2005)



Critical priority reach	Very high priority reach	High priority reach
▪ Contain nationally or state threatened species in the reach (i.e. EPBC or FFG listed species) ▪ Contain critical habitat. For example, critical habitat for threatened species or wetland communities that are considered rare or threatened in the region. ▪ Support critical ecosystem processes or functions that contribute to the health or other reaches at the basin scale. For example, spawning sites that provide recruitment to other reaches ▪ Support flow related critical social values	▪ Contain locally vulnerable species ▪ Contain very high habitat values ▪ Support very high flow related social values	▪ Contain few significant species, communities or habitat. ▪ Be short and have minimal impact on the ecological health of other reaches at the basin scale. ▪ Support few ecological objectives ▪ Support few or no flow related social values

Table 21: Draft risk categories (SKM 2005)

	Risk category		
Flow component priority	**High**	**Very high**	**Critical**
Critical	95-99% compliance	85-94% compliance	<85% compliance
Very high	90-99% compliance	70-89% compliance	<70% compliance
High	80-99% compliance	50-79% compliance	<50% compliance

The lower bounds of flow recommendations identified in Chapter 5 complement the previous recommendation of a minimum flow of 610 ML/d (or natural), which aims to provide minimum levels of deep-water (pool) habitat for native fish. Meeting the objectives for minimum levels of macroinvertebrate, macrophyte and fish (larvae and juvenile) habitat adds to the variability of low flows that are important for maintaining diverse and resilient populations of riverine biota.

Summer flow pulses

Flow freshes recommended in the previous environmental flow study were intended to inundate benches, particularly in Reach 4. Bench inundation commences at 1000 ML/day and all benches are inundated by 5000 ML/day (Figure 37). The recommendation in the previous study was to preserve the historic (i.e. regulated for the period 1975 to 2000) frequency of freshes in the range of magnitudes 2000 ML/day to 5000 ML/day. Figure 38 shows the frequency-magnitude relation for this range of discharges (using the partial duration series) for the period December to May. An equation is included which represents the recommended frequency-magnitude relation for freshes at this site. Figure 39 shows the natural variation in fresh duration for spell thresholds in the range of 1000 ML/day to 5000 ML/day. The previous study recommended maintaining this relation in the environmental flow regime.

However, these recommendations become redundant if the recommendations in this current environmental flow study are adopted.

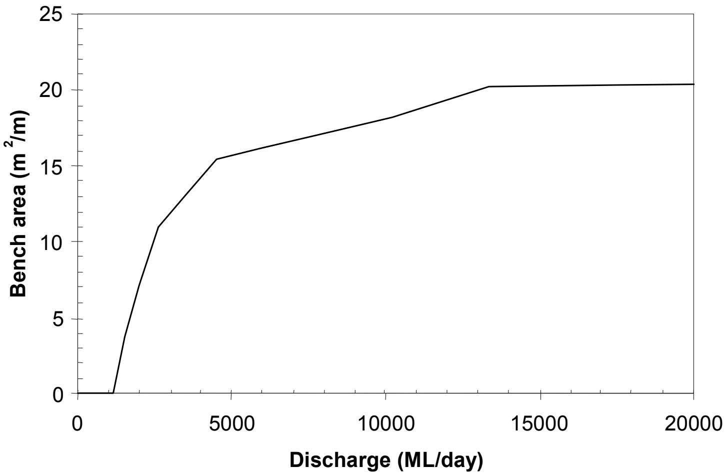


Figure 37: Bench area at Murchison (using model results from the 2003 environmental flow study)

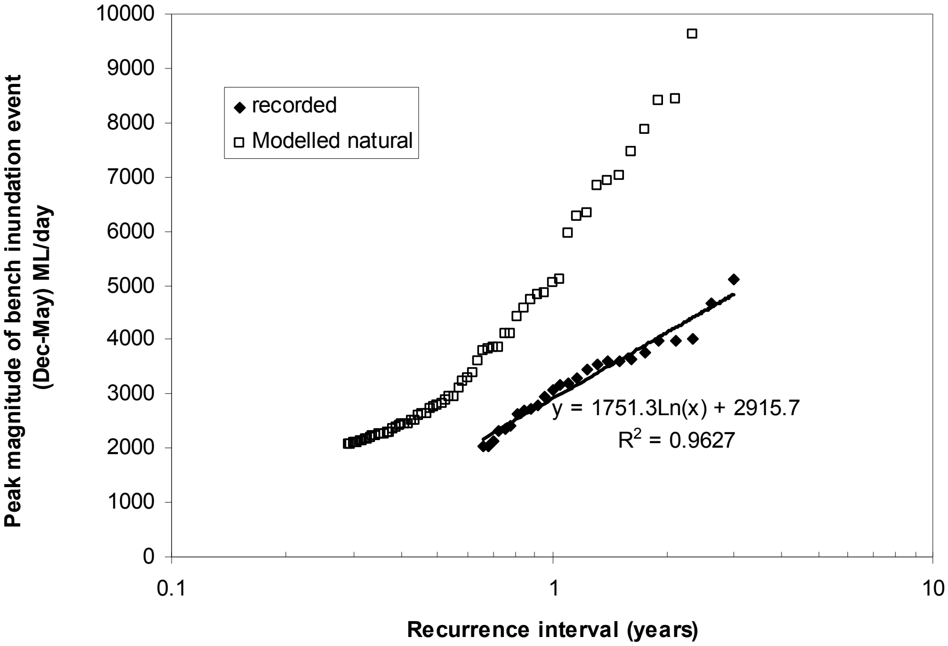


Figure 38: Regulated and modelled natural (partial duration) flood frequency plots for Murchison

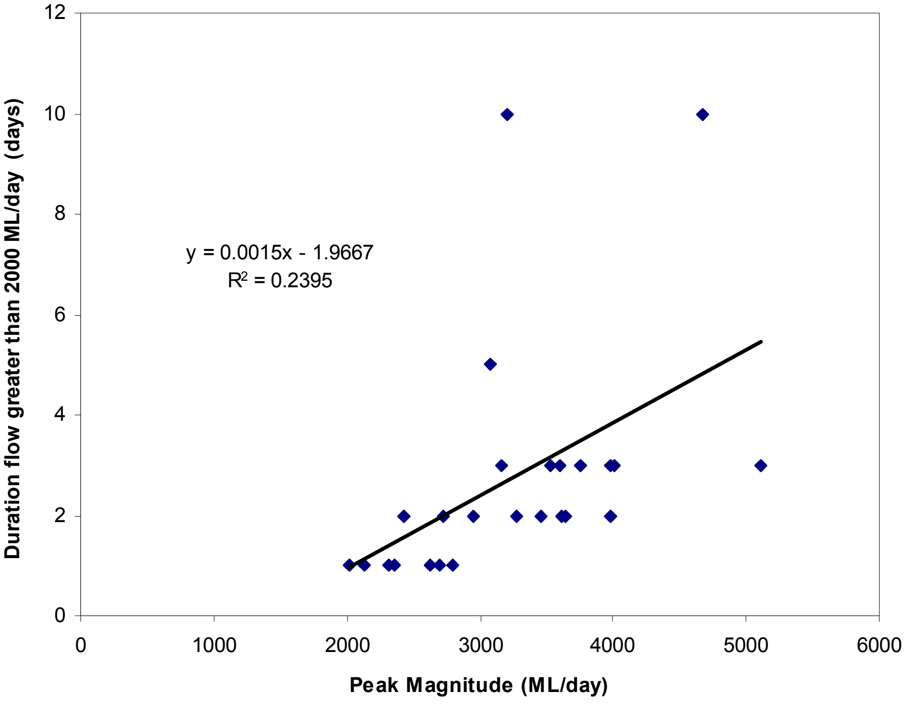


Figure 39: Relation between fresh peak magnitude and duration above a threshold of 2,000 ML/day.

7 MONITORING AND EVALUATION REQUIREMENTS

Field programs, variable definitions and the timing, frequency and protocols for sampling variables relevant to environmental flow recommendations for the Goulburn River have been considered in detail by Chee et al. (2006). However, this, as well as the previous environmental flow study for the Goulburn River on which it was based, did not consider upper limits on summer flows as IVTs were not then prominent. The Panel therefore recommends that the following be added to the list of variables considered for monitoring and evaluation of any environmental flow regime for the Goulburn River.

Riverine Productivity:

- Light penetration measurements added to water quality parameters to develop an improved relationship with turbidity. Using underwater light sensors, record light intensity just below surface and then measure depth of 10% or 1% penetration under stable light conditions. Another option is to mount a series of 4-5 recording light sensors at known intervals on a solid rod and place the top sensor just below the water surface and record irradiances for several minutes.
- Planktonic chlorophyll concentrations should also be added to the water quality parameters. If the river is well mixed then bottle sampling is acceptable, but preferably representative samples are taken with an integrating tube at stations across the river, combined and sub-sampled. If blooms occur then sampling needs to be modified as required to provide specific information on bloom characteristics.
- Identification of major phytoplankton genera (eg. Genera comprising 90% of biomass) with species identification if required. Sub-sampled from chlorophyll sample.
- Measures of periphyton cover and its distribution within the euphotic zone. Direct sediment sampling and chlorophyll analyses is a difficult method and chlorophyll fluorescence measurements are likely to be more tenable, but this requires suitable instrumentation and calibration and testing will be required. Matched with water velocity measurements, substrate measurements and light penetration measurements.
- River metabolism measurements based on diel fluctuations in dissolved oxygen concentrations. With the newer style oxygen sensors it should now be possible to do this routinely and provides valuable information on energy sources within the river and how energy supplies alter in response to changes in seasonal flow conditions.

Terrestrial bank vegetation:

- Vegetation cover by the following combinations:
  - ➢ growth form (tree, shrub, herb, grass and graminoid, sedges) with herbs, grasses and sedges and graminoids sub-divided according to form (tussock form, prostrate or stoloniferous or rhizomatous form, simple erect), and tree and shrub noted according to a height class;
  - ➢ life-span (perennial, annual meaning regenerating from seed);
  - ➢ origin (Australian, introduced).

Native Fish:

- Fish movement studies (radio-tracking or acoustic surveys) to evaluate whether IVTs encourage the exchange of fish such as Murray cod and golden perch between the Goulburn River and the Murray River.

8 REFERENCES

Baldwin D., Howitt J. and Edwards, M. (2001). Blackwater event. *Austasia Aquaculture*, April/May, 21.

Basu B. K. and Pick F. R. (1996) Factors regulating phytoplankton and zooplankton biomass in temperate rivers. *Limnology and Oceanography*, 41, pp. 1572-1577.

Bennett J., Sanders N., Moulton D., Phillips N., Lukacs G., Walker K. and Redfern F. (2002). Guidelines for Protecting Australian Waterways. Land & Water Australia, Canberra.

Berkamp G., McCartney M., Dugan P., McNeely J., Acreman M. (2000). Dams, Ecosystem Functions and Environmental Restoration Thematic Review II.1 prepared as an input to the World Commission on Dams, Cape Town, www.dams.org.

Blom C.W., Voesenek L.A., Banga M., Engelaar W.M., Rijinders J.H., van de Steeg H.M. and Visser E.J.W. (1994). Physiological ecology of riverside species; adaptive responses of plants to submergence. *Annals of Botany,* 74, pp. 253-263.

Bond N. R. and Lake P. S. (2003). Characterizing fish-habitat associations in streams as the first step in ecological restoration. *Austral Ecology*, 28, pp. 611-621.

Bowler J. M. (1978). Quaternary climate and tectonics in the evolution of the Riverine Plain, south eastern Australia. In: M.A.J. Williams. (editor) Landform Evolution in Australasia, Canberra. A.N.U. Press, pp. 70-112.

Casanova M.T. and Brock M.A. (2000). How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? *Plant Ecology,* 147, pp. 237-250.

Chee Y.E., Webb A., Stewardson M. and Cottingham P. (2006). Victorian environmental flows monitoring and assessment program. Monitoring and evaluation of environmental flows releases in the Goulburn River. Report prepared for the Goulburn Broken Catchment Management Authority and the Department of Sustainability and Environment. e-Water CRC, Melbourne.

Cottingham P., Stewardson M., Crook D., Hillman T., Roberts J. and Rutherfurd I. (2003). Environmental flow recommendations for the Goulburn River below Lake Eildon. CRC Freshwater Ecology and CRC Catchment Hydrology report to DSE Victoria and the MDBC.

Crowder L. B. and Cooper W. E. (1982). Habitat structural complexity and the interaction between bluegills and their prey. *Ecology*, 63, pp.1802-1813.

Crook D., Robertson A., King A. and Humphries P. (2001). The influence of spatial scale and habitat arrangement on diel patterns of habitat use by two lowland river fishes. *Oecologia*, 129(4), pp. 525-533.

DNRE (2002). The FLOWS method: a method for determining environmental water requirements in Victoria. SKM, CRC Freshwater Ecology, Freshwater Ecology (NRE), and Lloyd Environmental Consultants report to the Department of Natural Resources and Environment, Victoria. Environment and Natural Resources Committee (2001). Inquiry into the allocation of water resources – Report ENRC, Parliament of Victoria.

DSE (2003). Irrigation Development in Sunraysia and Associated Murray Channel Capacity Issues. Discussion Draft, Department of Sustainability and Environment, Victoria.

Ferrari I., Farabegoli A. and Mazzoni R. (1989). Abundance and diversity of planktonic rotifers in the Po river. *Hydrobiologia*, 186/187, pp. 201-208.

GBCMA (2005a). Regional River Health Strategy 2005-2015. Goulburn Broken Catchment Management Authority, Shepparton.

GBCMA (2005b). Regional River Health Strategy 2005: status of the riverine system - waterways in focus. Goulburn Broken Catchment Management Authority, Shepparton.

Gorman O. and Karr J. (1978). Habitat structure and stream fish communities. *Ecology*, 59(3), pp. 507-515.

Harvey B. and Stewart A. (1991). Fish size and habitat depth relationships in headwater streams. *Oecologia*, 87(3), pp. 336-342.

Hoenderdos M. (2006). Spatial and temporal variation in the macroinvertebrate community of the lower Murray Darling Basin, Australia, between 1980 and 2000. Honours Thesis, Dept. Environmental Management and Ecology, La Trobe University.

Hogg I.B. and Norris R.H. (1991). Effects of runoff from land clearing and urban development on the distribution and abundance of macroinvertebrates in pool areas of a river. *Aust. J. Mar. Freshw. Res.,* 43, pp. 507-518.

Humphries P., Cook R. A., Richardson A. J. and Sarafini L. G. (2006). Creating a disturbance: manipulating slackwaters in a lowland river. *River Research and Applications*, 22(5), pp. 525 – 542.

.

King A.J. (2004). Ontogenetic patterns of habitat use by fishes within the main channel of an Australian floodplain river. *Journal of Fish Biology*, 65, pp. 1582-1603.

King, A. J. (2004). Density and distribution of potential prey for larval fish in the main channel of a floodplain river: pelagic versus epibenthic meiofauna. *River Research and Applications*, 20, pp. 883-897.

LCC (1991). Rivers and streams special investigation: final recommendations. Land Conservation Council, Melbourne.

Lowe B. (2002). Impacts of altered flow regime on riverbank vegetation in a lowland floodplain river. PhD Thesis, Charles Sturt University.

McAllister D., Craig J., Davidson N., Delany S. and Seddon M. (2001). Biodiversity impacts of large dams. Background Paper Nr. 1. Prepared for IUCN / UNEP / WCD.

MDBC (2005). Environmental watering plan for 2005/2006. Murray Darling Basin Commission, Canberra.

MDBC (2004). The Living Murray business plan. Murray Darling Basin Commission, Canberra.

MDBC (2002). Barmah-Millewa Forest Fish Research and Monitoring Strategy. Murray-Darling Basin Commission on behalf of the Barmah-Millewa Forum.

Minshall G. W. (1984). Aquatic insect-substratum relationships. In *The Ecology of Aquatic Insects*. Resh, V. H. and Rosenberg, D. M., (Ed.). Praeger,New York, pp. 358-400.

Mommer L., de Kroon H., Pierik R., Bogerman G.M. and Visser E.J.W. (2005). A functional comparison of acclimation to shade and submergence in two terrestrial plant species. *New Phytologist,* 167, pp. 197-206.

Newman R. M. (1991). Herbivory and detrivory on freshwater macrophytes by invertebrates: a review. *Journal of North American Benthological Society*, 10, pp. 89-114.

O'Connor N. A. (1991). The effects of habitat complexity on macroinvertebrates colonising stream substrates in a lowland stream. *Oecologia,* 85, pp. 504-512.

Oliver R., Hart B., Olley J., Grace M., Rees G. and Caitcheon G. (1999). The Darling River: algal growth and the cycling and sources of nutrients. CRCFE and CSIRO report to the Murray Darling Basin Commission.

Pace M. L., Findlay S. E. and Lints D. (1992). Zooplankton in advective environments: the Hudson River community and a comparative analysis*. Canadian Journal of Fisheries and Aquatic Sciences*, 49, pp. 1060-1069.

Phillips N., Bennett J. and Moulton D. (2001). Principles and tools for protecting Australian rivers. Land & Water Australia, Canberra.

Poff L., Allan J., Bain M., Karr J., Prestegaard K and Richter B. (1996). The natural flow regime: a paradigm for river conservation and restoration. *Bioscience*, 47(11), pp. 769-784.

Pusey, B. J., Kennard, M. J. and Arthington, A. H. (2004). Freshwater Fishes of North-eastern Australia. CSIRO Publishing, Melbourne.

Pusey, B. J., Kennard, M. J. and Arthington, A. H. (2000). Discharge variability and the development of predictive models relating stream fish assemblage to habitat in north-eastern Australia. *Ecology of Freshwater Fish*, 9, pp. 30-50.

Pusey, B. J., Arthington, A. H. and Read, M. G. (1998). Freshwater fishes of the Burdekin River, Australia: biogeography, history and spatial variation in community structure. *Environmental Biology of Fishes*, 53, pp. 303-318.

Pusey, B. J. and Kennard, M. J. (1996). Species richness and geographical variation in assemblage structure of the freshwater fish fauna of the Wet Tropics Region of northern Queensland. *Marine and Freshwater Research*, 47, pp. 563-573.

Pusey, B. J., Arthington, A. H. and Read, M. G. (1995). Species richness and spatial variation in fish assemblage structure in two rivers of the Wet Tropics of northern Queensland, Australia. *Environmental Biology of Fishes*, 42, pp. 181-199.

Pusey, B. J., Arthington, A. H. and Read, M. G. (1993). Spatial and temporal variation in fish assemblage structure in the Mary River, south-east Queensland: the influence of habitat structure. *Environmental Biology of Fishes*, 37, pp. 355-380.

Pusey, B. J. and Arthington, A. H. (2003). Importance of the riparian zone to conservation and management of freshwater fish: a review*. Marine and Freshwater Research*, 54, pp. 1-16.

Richter B. Baumgartner J., Wiggington R. and Braun D. (1997). How much water does a river need? *Freshwater Biology*, 37, pp. 231-249.

Richter B.D., Baumgartner J.V., Powell J. and Braun D.P. (1996). A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* ,10, pp. 163-1174.

Robertson A. I., Bacon P. and Heagney G. (2001). The responses of floodplain primary production to flood frequency and timing. *Journal of Applied Ecology.* 38, pp. 126-136.

SKM (2006). Assessment of Victorian demands in the River Murray and future supply options. Report to the Department of Sustainability and Environment, Melbourne.

SKM (2005). Environmental flows compliance and ecological risk assessment methods. Draft report to the Department of Sustainability and Environment.

Sousa, M.E. (1979). Disturbance in marine intertidal boulder fields: the nonequalibrium maintenance of species diversity. *Ecology,* 60, pp. 225-1239.

van der Sman A. J., Blom C.W.P.M. and Barendse G.W.M. (1993). Flooding resistance and shoot elongation in relation to developmental stage and environmental conditions in *Rumex maritimus* L. and *Rumex palustris* Sm. *New Phytologist* ,125, pp. 73-84.

van Eck WH.M., van de Steeg H.M., Blom C.W.P.M. and de Kroon H. (2004). Is tolerance to summer flooding correlated with distribution patterns in river floodplains? A comparative study of 20 terrestrial grassland species. *Oikos*, 107, pp. 393-405.

van Eck W.H.J.M., van de Steeg H.M., Blom C.W.P.M. and de Kroon H. (2005a). Recruitment limitation along disturbance gradients in river floodplains. *Journal of Vegetation Science,* 16, pp. 103-110.

van Eck W.H.J.M., Lenssen J.P.M., Rengelink R.H.J., Blom C.W.P.M. and de Kroon H. (2005b). Water temperature instead of acclimation stage and oxygen concentration determines responses to winter floods. *Aquatic Botany,* 81, pp. 253-264.

van Eck W.H.J.M., Lenssen J.P.M., van de Steeg H.M., Blom C.W.P.M. and de Kroon H. (2006). Seasonal dependent effects of flooding on plant species survival and zonation: a comparative study of 10 terrestrial grassland species. *Hydrobiologia,* 565, pp. 59-69.

Vervuren P.J.A., Blom C.W. P.M., and de Kroon H. (2003). Extreme flooding events on the Rhine and the survival and distribution of riparian plant species. *Journal of Ecology,* 91, pp. 135-146.

Voesenek L.A.C., Colmer T.D., Pierik R., Millenaar F.F. and Peeters A.J.M. (2006). How plants cope with submergence. *New Phytologist,* 170, pp. 213-226.

Weatherhead M. A. and James M. R. (2001). Distribution of macroinvertebrates in relation to physical and biological variables in the littoral zone of New Zealand lakes. *Hydrobiologia*, 462, pp. 115-129.

Zweig L.D. and Rabeni C.F. (2001). Biomonitoring for deposited sediment using benthic invertebrates: a test on 4 Missouri streams. *Journal of North American Benthological Society,* 20, pp. 643-657.

9 APPENDIX 1: FLOW-RELATED ECOSYSTEM OBJECTIVES

Note: the following tables include a restatement of previous environmental flow objectives, and additional considerations and objectives based on new insights on ecosystem responses gained since 2003. The information presented is that applying to the current study reaches (Reach 4 and 5 of the original study).

Table 22: Flow related issues and ecosystem objectives related to river geomorphology

Ecological Attribute	Issue	Environmental or Ecological Values	Current Condition	Ecological Objectives (code)	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
Geomorphic diversity	Increased bank erosion (notching) due to long-duration summer flows	As on Murray analog - makes it difficult for plants to colonise the bank face	Presently only observed in the Wyuna reach	Avoid notching (Geo 1)	100% along with loss of grass		F025a	Dec-Apr	Flow stays within one flow band for twice the natural duration, but the higher the flow gets, the more undesirable long -duration still stands become because the velocity is higher. Also depends on the effect of the flow on bank grasses.
	Rapid draw down leading to mass failure of banks	Reduced habitat value of banks + increased turbidity	Rare process at present	Avoid slumping (Geo 2)	100%	revegetation	F023	Dec-Apr	Rate of fall is double the natural rate with twice the frequency (this too could be scaled up the bank) - i.e. falls twice as fast, twice as often.
	Filling of pools by redistribution of sand at regulated flows	Reduced fish habitat?	Uncertain, probably changed little since regulation began.	Maintain pool depth (Geo 3)	Also controlled by sediment supply		FO04a-c	Dec-Apr	Perhaps best expressed in terms of shear stress magnitude and duration as for F004a-c. The key is to reduce the 'moderate' sized events that fill the pools but do not flush them.
	Potential loss of low flow habitat (channel margin and LWD) because of deposition or lack of erosion			N/A				Dec-Apr	

Ecological Attribute	Issue	Environmental or Ecological Values	Current Condition	Ecological Objectives (code)	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
	Bench formation: reduction in rate of vertical accretion of concave benches, increase in erosion of bench margins (restricted to upper third of target reach)	Unique terrestrial habitat, consistent back-water area	Rate of accretion already compromised by sediment starvation	Maintain bench accretion and erosion as for natural (covered by Geo 1 and Geo 6)	Sediment supply also a factor	revegetation		Dec-Apr	Avoid flows that always sit at the top of the present bench level = 1.5m on gauge or 1000 ML/d. Mechanism is that flows that are big enough to cover the benches quickly exhaust them of sediment because of the low yield to the river. Avoid flows that are twice as long on average.
	Scour of aquatic macrophytes (especially *Vallisnaria*)	Key aquatic plant	Good. Abundant *Vallisnaria* in the reach	Natural rate of disturbance (Geo 6)			F004a-c	Dec-Apr	Some literature suggests that flows above 0.75m/s are starting to erode the Vallisnaria in sand bed channels and 1m/s is severely stressing them.

Table 23: Ecological features and flow components to be assessed for riverine production in the Goulburn River.

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
Planktonic algae	Biomass	Source of food for macro-/micro invertebrates and fish	Unknown	Biomass levels resembling sites unaffected by flow regulation	Increased channel retention due to reduced water velocity and/or increased hydraulic retention zones allows accumulation of biomass if growth rates exceed loss rates. Other factors impinge eg. sedimentation, nutrients, grazing	Management of in-stream structure including shape and woody debris, nutrient management,	F001	Spring-Summer	Increases in phytoplantkon biomass occur at average flow velocities <0.2-0.3 m/s in Murray and similar rates observed elsewhere so could use mean duration when average velocity<0.3 m/s. Mike has estimated retention as cross sectional area/flow. Inverse is average velocity.Critical average flow in same units is 0.3 m/s=0.93 h/km, 0.25=1.1, 0.2=1.38, 0.15=1.85, 0.1=2.8, 0.05=5.6
					Depending on sinking rate of phytoplankton, turbulent mixing and depth of water resulting sedimentation will reduce phytoplankton biomass. Other factors impinge eg. nutrients, grazing, light availability	Management of in-stream structure including shape and woody debris, nutrient management,	F013	Spring-Summer	In a well mixed column with a non-mixed bottom surface the population loss by sinking is: Nt=Noe(-vt/z) therefore In(No/Nt)*1/t=v/z where v sinking velocity and z is average depth. This is the rate of change in population due to losses by sedimentation expressed in a form equivalent to a growth rate. Look at mean population loss rate for seasons assuming phytos have sinking rates of 0.95 and 0.4 and 0.2 m/day

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
	Productivity	Population growth providing source of food for macro-/micro invertebrates and fish	Unknown	Productivity consistent with supporting foodwebs comparable with sites unaffected by flow regulation	Reduced light penetration as a result of poor light penetration, deep well mixed conditions, if zeu/zave is <0.3 then light starvation likely and production is not possible	Management of sediment loads, colour	F002	Spring-Summer	Approximately delimits zero growth periods. Calculate for seasons proportion of time when euphotic depth less than 0.3 times the average depth
					As zeu/zave declines towards ca. 0.3 phytoplankton production decines with the falling light availability	Management of sediment loads, colour	F012	Spring-Summer	Follows conditions found in Murray R by Oliver/Merrick. When euphotic depth<average depth, NPP and GPP proportional to mean irradiance which is given by I*zeu/4.6*zave where I is the average daily incident irradiance. Assuming an average I for a season, growth is proportional to zeu/zave. Could use actual I but didn't. This is an indicator of growth rates but only for zeu/zave<1. Based on Murray work and assuming average summer incident irradiance of 900 µE m-2 s-1, NP growth rate is zero at ratio 0.5 (need to re-visit this as high?) and 0.3 d-1 (maxm growth rate) at ratio 0.97
	Biomass	Source of food and habitat for macro-/micro invertebrates and fish	Unknown	Biomass levels resembling sites unaffected by flow regulation	Area of colonization determined by extent of light zone (use euphotic depth) which is influenced by water level on bank and also sediment type	Management of sediment loads and colour for light conditions, channel shape and in-stream structures such as woody debris for surface	F014	Spring-Summer	Calculate mean euphotic area of benthos for seasons

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
					Area of colonization determined by extent of light zone but delineated by velocities influencing biofilm stability	Substrate condition, channel structures	F015	Spring-Summer	Literature suggests that filamentous biofilms have maximum biomass at near bed velocities of <0.2m/s and decline exponentially above these velocities to very low values above 0.4 m/s. Mucilaginous forms had maximum biomass at near bed velocities of 0.2 m/s. Calculate mean euphotic area of benthos with velocity <0.3 m/s for seasons or <0.2 and <0.4
Periphytic algae/biofilm	Productivity	Productivity consistent with supporting a comparable foodweb to unregulated conditions	Unknown	Productivity resembling sites unaffected by flow regulation	I. Increased water level fluctuation, stranding periphyton above water line or to a depth greater than eupotic depth for extended periods	As above	F016	Spring-Summer	Problem with above measures is that euphotic area may be moving rapidly up and down bank so that periphyton cannot establish. Even with rapid growth rates and good propagule delivery establishing biofilms will take minimum of 2 weeks. Investigate the proportion of time that particular points within representative flow bands on the bank are within the euphotic zone for minimum of 2 weeks over the seasons
					II. Increased water level fluctuation, stranding periphyton above water line or to a depth greater than eupotic depth for extended periods	As above	F017	Spring-Summer	Another way of looking at the previoius component is rather than proportion of time look at number of times within seasons that particular points within representative flow bands are within the euphotic zone for periods exceeding 2 weeks

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
					Light requirement for productivity	As above	F018	Spring-Summer	Difficult because of water level variation, but could estimate average light in areas within representative flow bands that are within the euphotic zone for periods lasting 2 weeks over seasons ie. average depth of each occurrence in F017. Average light at a given point is estimated as Iz= Iexp^(-kd*z). As I and kd are considered to be constant, then the average light is a function of zave. At Murchison kd ~ 2 while at Wyuna kd~4.7. Assuming summer light ca. 900 and taking light limited region as 20, 100, 200 we have corresponding zave values at Murchison of 1.9, 1.1 and 0.75 and at Wyuna of 0.81, 0.47 and 0.32.
	Diversity	Suitable food items to support reliant trophic levels (grazers, microbes, detritivores) and an appropriate mix for driving biogeochemical cycles comparable to unregulated conditions. Suitable habitat structuring	Unknown	Community composition resembling sites unaffected by flow regulation	Fluctuating flow conditions influence biofilm diversity by moving it in and out of the euphotic zone. If more time is spent below euphotic then biofilm tends to be more heterotrophic, if more time in euphotic then more autotrophic and green filamentous (although velocity influences this) while being stranded re-sets biofilm development such that may start again more heterotrophic but shifts to autotrophic.				Diversity is influenced by the time in and out of euphotic. Similar to above biomass considerations but within each month the mean ratio of time in euphotic/time out of euphotic. Perhaps improve by using two ratios, time in euphotic/time below euphotic and time in euphotic/time above euphotic

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
	Biomass	Source of food and habitat for macro-/micro invertebrates and fish	Unknown	Biomass levels resembling sites unaffected by flow regulation	Area of colonization determined by extent of light zone:use euphotic depth	Management of sediment loads and colour for light conditions, channel shape and in-stream structures such as woody debris for flow modification	F014	Spring, Summer, Autumn	Calculate mean euphotic area of benthos for seasons as done for periphyton as the euphotic zone limits appear similar
					Area of colonization determined by extent of light zone:use euphotic depth, but delineated by velocity, high velocities influencing macrophyte stability.		F015	Spring, Summer, Autumn	Critical near bed velocities appear similar to those of periphyton ie 0.2 m/s maximum biomass with few macrophytes after 0.9 m/s. Compared to periphyton, submerged macrophytes require more depth to grow in. Calculate mean euphotic area of benthos with velocity <0.3 m/s for seasons as for periphyton
					I. Increased water level fluctuation, stranding periphyton above water line or to a depth greater than eupotic depth for extended periods. Assume stable period of 6 weeks required for plant establishment		F016	Spring, Summer, Autumn	The euphotic area may move rapidly up and down the bank so that macrophytes cannot establish. Even with rapid growth rates and good propagule delivery establishing will take minimum of 6 weeks. Investigate the proportion of time that particular points within representative flow bands on the bank are within the euphotic zone for minimum of 6 weeks over the seasons.

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
Submerged macrophytes					II. Increased water level fluctuation, stranding macrophytes above water line or to a depth greater than eupotic depth for extended periods	As above	F017	Spring, Summer, Autumn	Another way of looking at the previoius component is rather than proportion of time look at number of times within seasons that particular points within representative flow bands are within the euphotic zone for periods exceeding 6 weeks
	Productivity	Productivity consistent with supporting a comparable foodweb to unregulated conditions	Unknown	Productivity resembling un-impacted sites	Light requirement for productivity influenced by water depth, light penetration, channel shape. Seeking zones with sufficient light for long enough with an acceptable depth (assumed >0.2m)		F018	Spring, Summer, Autumn	Difficult because of water level variation, but average light intensity within euphotic zone, or add to above ie. average light in euphotic zones lasting 6 weeks. Estimate average light in areas within representative flow bands that are within the euphotic zone for periods lasting 6 weeks over seasons ie. average depth of each occurrence. Average light at a given point is estimated as Iz= Iexp^(-kd*z). As we are considering I and kd to be constant, then the average light is a function of zave. At Murchison kd ~ 2 while at Wyuna kd~4.7. Assuming summer light ca. 900 and taking light limited region as 20, we have corresponding zave value at Murchison of 1.9 and at Wyuna of 0.81.

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons	Notes
	Diversity	Suitable food items to support reliant trophic levels (grazers, microbes, detritivores) and an appropriate mix for driving biogeochemical cycles comparable to unregulated conditions	Unknown	Community composition resembling un-impacted sites	Fluctuating flow conditions influence macrophyte survival and diversity by moving plants in and out of the euphotic zone.				Diversity is influenced by the time in and out of euphotic. Similar to above biomass considerations but within each month the mean ratio of time in euphotic/time out of euphotic. Perhaps improve by using two ratios, time in euphotic/time below euphotic and time in euphotic/time above euphotic
	Energy/Food supply, nutrients	Supply of terrestrial organic carbon suitable to support foodwebs along with sediments and nutrients to drive biogeochemcial cycles comparable with unregulated conditions	Unkknown	Floodplain Connectivity	Considerd principal form of supply of allochthonous organic carbon although also aeolian delivery and flying insect deposition.	Land use	F021	Spring, Summer, Autumn	Aim to retain connectivity.

Table 24: Ecological features and flow components to be assessed for bankside vegetation along the Goulburn River.

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons
[1] Terrestrial tussock GRASSES on riverbank			**General:** Unquantified, little known, no benchmark information; ecological studies very few, most studies have been on hydrology, hydraulics; no mapping. **Goulburn**: Knowledge of Goulburn is qualitative, from field vists					
	ABUNDANCE (cover)	Bank stability through root systems binding sparse soil	Probably greater vertical range now, extending further down bank under regulated than under non-regulated conditions	[1] Minimise likelihood of extensive bank erosion			**not attempted**	
		Habitat under dry and flooded conditions *(see below)*		[2a] Maintain persistent cover over part of upper part of bank (equivalent to natrual flow percentiles where bank inundation has same/similar duration under natrual as historic). .	Flow critical: Duration of submergence (inundation) has potential to drown out terresgtrial vegetation; critical values for duration expected to vary with season, whether cool (autumn-winter) or growing (spring-summer)	Land management practices that could degrade soils and vegetation on bank, especially upper part, should be avoided, such as: stock access, extensive recreational usage, burning off.	F006	Dec April

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons
				[2b] Reduce cover, ie move towards assumed natural, for those parts of bank falling below threshold (threshold is flow percentile where natrual duration of inundaiton is approximately equal to historic).	Flow and Water levels are the principal driver here.		F006	Dec April
	HEIGHT	Contributes to channel roughness		[3] Maintain some cover and flow refuge habitat across a flow range and across seasons.			**not attempted**	
	HEIGHT and ABUNDANCE	Provides a temporary velocity refuge for aquatic small & micro-fauna if inundated in winter-spring floods						
	Composition	Biodiversity: specific suites of plant species and/or functional types	Native perennials, mostly (field observations). No evidence of species change.	[4] Maintain composition that is mainly native species (notionally at least 75% by cover)	Flow, along with water levels and time of year, is highly relevant but is not sole determinant. State of knowledge is currently insufficient to assign a relative importance to flow versus other hydrological factors (levels, time of year, durations) or other ecological factors (species pool, season, other disturbances) in determining nativeness. Equally, is not possible select a flow component that is uniquely and unambiguously linked to nativeness		Insufficient knowledge to forge a flow component that describes this. **Not attempted**	

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons
				[5] Avoid conditions that favour significant riparian and aquatic weeds known to occur in the area.	Flow critical, even if imperfectly understood at species level.	Upstream and catchment control of known outbreaks essential.	**not attempted**	
[2] Terrestrial woody (SHRUBS and TREES) on riverbank and within channel			**General:** Unquantified, little known, no benchmark information. **Goulburn**: Knowledge is qualitative, from field vists.					
	Abundance (Cover; number of patches)	Contribute to habitat diversity within channel, for terrestrial fauna and for aquatic fauna (eg as velocity refuge in high flows).	Abundance in some parts of the river channel is considered to be greater now than under natural conditions.	[6] Prevent further encroachment of terrestrial shrubs and trees.	Success of processes such as germination and establishment from propagules such as seeds or plant parts is strongly dependent on flow regime.		**not attempted**	
		Aesthetic value	Evidence of encroachment, down bank and into channel (where these species are colonising bars and benches).	[7] Reverse enroachment	Uses flow as agent so dependent on flow. Re-instating wetter conditions (ie increasing duration of bank inundation) is expected to create anaerobic conditions in substrate which if repeated annually will result in stress, loss of vigour, root weakening, and eventual death or toppling. **TARGET** would be discharges from 400 ML to approx 0.35 m deeper, ie up to 750 ML from a perspective of **REHABILITATION**.		**NEEDS A NEW FLOW COMPONENT: duration inundated per season, and total annual**	

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons
		Biodiversity: specific suites of plant species.	Presence of woodland and shrubland patches on higher in-channel features. Condition of understorey often poor due to introduced and or annual grasses and herbs.	[8] Protect vigour of trees in existing River Red Gum woodland established on inset benches	Tree vigour can be negatively affected by many factors, ranging from fire to insect attack, to vandalism, to localised pollution. This objective is concerned with the risk of soil saturation through sustained or persistent inundation of wooded inset benches, resulting in water logging, through high summer flows. **TARGET** would be 1 m above when visited or approx 1.3 m on gauge, and would consider durations in the range 1000 to 2000 ML, from perspective of potential **RISK**.		**NEEDS A NEW FLOW COMPONENT (same as above): duration inundated per season, and total annual**	
		Locally modify micro-climate through shading. Minor role in carbon contribution through direct contribution of leaf litter.						

Table 25: Ecological features and flow components to be assessed for macroinvertebrate populations along the Goulburn River.

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons
Macroinvertebrates	DIVERSITY - Biodiversity over space and time	Resillience to change. All potentially successful taxa represented	Variable but mostly poor (EPA data)	Full range of habitat types present and 'functional'.				
				1. Aquatic Veg (especially emergent) on banks and bars variable over years but similar (in sum) to natural.	Flow is a limiting factor (ie necessary but not sufficient)	# Riparian land-use (Grazing) # High turbidity reduces 'flexibility' of flow components	F005	all
							F007	All (esp spr/summ)
							F010	spring-summer
				2. Range of snag habitats (Natural Inter- and Intra-year distribution not significantly diminished)	Quantity and variety of snags dependant on volume (inter alia) [possibly modified by biodiversity and productivity of snag biofilm - depth and variability of light climate]	Snag management	F002	all
							F004	
							F008	
							F025	Dec-Apr
				3. Low-flow & slackwater zones maintained (similar to sites unaffected by flow regulation)	Highly	Riparian land-use and management	F007	all
							F010	

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons
							F023/F024	
				4. Litter packs available, augmented and free of excess sediment	moderate-high	Appropriate riverine terrestrial vegetation maintained and floodplain not alienated from high flows	F003	
							F004	any
							F021	all
				Habitat heterogeneity over time	high		interannual variability	Perhaps 'multi-annual'
				Water quality appropriate to supporting range of MI taxa as per 'natural'	Moderate. [In lower Goulburn temperature assumed not significant, pollution effects (salt nutrients toxins) not known. Sediment deposition noted and known to 'knock out' susceptible taxa]	Catchment land management. Indirect effects of river management including temperature, interaction with groundwater (salinity) and bank erosion	F003	all
	BIOMASS	Sufficient quantity of organisms to support higher trophic levels and sufficient numbers in each functional feeding group to maintain reasonable ecological balance (e.g. break down litter, graze on primary producers)	Not reported (some estimates in recent EPA observations). Believed to be poor	1. Provide sufficient range and quantity of habitat and food resources to support macroinvertebrates				
				2. Maintain **quality** of food and habitat resources	Moderate - high. Probably closely associated with supporting aquatic primary production to some extent	Catchment and riparian land management especially generation of fine sediment and grazing	F003	all

Ecological Attribute	Features	Environmental or Ecological Values	Current Condition	Ecological Objectives	Extent to which objective is flow related	Complementary management required	Flow component codes	Seasons
Native fish assemblages		Diversity of native species, naturally self-reporducing populations of native fish, threatened and iconic native species.	Poor to moderate	Suitable thermal regime for spawning, growth and survival of all life stages	Not directly related, but increased flows may decrease warming of water downstream of Eildon	Mitigation of cold water releases may be required	NA	Summer
				Suitable in-channel habitat for all life stages	High	Protection of existing habitat and habitat restoration. Management of introduced species	F007, F008	Summer (F007), all year (F008)
				Suitable off-channel habitat for all life stages	Moderate to high	Riparian and floodplain wetland management. Removal of unnecessary levees and blockbanks	F021	all year
				Passage for all life stages	High	Removal of instream barriers and/or installation of fish ladders	Not required	
				Cues for adult migration during spawning season	High	Removal of instream barriers	F022	Spring, summer
				Low flows for spawning and recruitment	High	Protection of existing habitat and habitat restoration. Management of introduced species	F007	Summer

10 APPENDIX 2: MACROINVERTEBRATE RESPONSE TO WET AND DRY CONDITIONS

EPA Victoria carry out regular macroinvertebrate monitoring along the Goulburn. The following analysis is based on data (L Metzling, pers. Com) from macroinvertebrate samples taken in the Goulburn near Shepparton and McCoy's bridge using two sampling methods – hand-net sweeps at the edge of the river and artificial substrate samples (bundles of sticks providing habitat similar to course woody debris) – during the period 1992-94 and again in 2005-06 using hand-net sweeps alone. These sets of samples are designated ASS, HN19, and HN20 respectively for the following discussion. The taxonomic resolution of the data is mixed with identifications to family level or finer.

The mean numbers of taxa captured per sample were quite similar for each group of samples – 17.79 taxa per ASS sample (14 samples), 16.56 for HN19 (9 samples), and 14.33 for HN20 (12 samples). However, the total number of taxa observed through either sampling method in the 'wet' period 1992-94 (73 taxa in ASS, 79 taxa in HN19) was notably higher than in the hand-net samples taken during the drought period 2005-06 (36 taxa in HN20). Of these latter 36 taxa, only 11 had been observed in any HN19 samples. These results imply that, whilst the taxonomic richness at any point in the river remained fairly constant in wet and dry periods, the diversity or heterogeneity of macroinvertebrates was considerably greater during the wet period (regardless of sampling technique). Unfortunately, the sampling methods used preclude any reliable estimate of biomass from these data and temporal differences in this aspect of macroinvertebrate communities cannot be assessed.

More-detailed analysis supports the above assessment of taxonomic composition, however. Figure X is an ordination plot resulting from a NMDS analysis based on Bray-Curtis similarity indices calculated using fourth root transformation of counts from live-picked samples. The analysis indicates notable differences in the composition of macroinvertebrate communities sampled by the two methods during 1992-94 (average dissimilarity 94%) and also between communities in 1992-94 versus those in 2005-06 both sampled using hand-nets (average dissimilarity 92%). SIMPER analysis (ref) ranks taxa according to their contribution to the observed dissimilarities between groups of samples. The results are summarised in table Y.

Differences between sampling methods – increased representation of oligochaetes (associated with organic material and sediment) and the mayfly, *Cloeon* sp. (detritivore), in the stick bundles (ASS) and *Miconecta* sp. (omnivorous bug associated with biofilm in low-flow zones and wetlands) in the edge net samples (HN19) – support the suggestion that habitat diversity contributes to the biodiversity of macroinvertebrate communities.

The analyses also showed a clear difference between sweep-net samples taken in 1992-94 and similar samples in 2005-06 (92%). Again the relative numbers of *Micronecta* sp. contribute substantially to this difference as does the ephemeropteran, *Cloeon* sp. – both being absent from the 2005-06 samples. Unidentified corixids (predacious bugs associated with open water) occurred in significant numbers in 2005-06 but were not found in 1992-94.

The substantial dissimilarity between edge samples in 1992-94 (HN19) versus those in 2005-06 (HN20) is a little more difficult to explain partly because information regarding habitat conditions (extent of vegetation, flow conditions etc.) is limited for the 1992-94 samples. There is also no information about the relative biomass present as the data are sub-samples of an unspecified proportion of the total catch. There is therefore no way of determining if the samples come from dense or sparsely distributed communities.

These are significant factors that should be bourn in mind through the following assessment.

A recent study of 20 years of macroinvertebrate sampling in the Murray (Hoenderdos 2006) indicated long periods of stable community composition broken up by two 'sudden' shifts to new, stable, assemblages (interestingly, one of these occurred in 1994. Hoenderdos (2006) observed that the sudden shifts in macroinvertebrate community composition at Murray sites in 1985 and 1994 occurred during dry periods that, in turn, followed significant periods of higher than average flow. No causal explanations are provided but it is clear that macroinvertebrate communities in the Murray were responding to factors operating on a greater temporal scale than seasonal or annual. Some hydrological factor seems a likely explanation. It is also evident that the period 1992-94 was considerably 'wetter' than 2005-06 (see some figure in the report somewhere).

The possibility that the relative dryness of conditions might be estimated from precedent hydrological conditions was tested by assessing the macroinvertebrate data against the following hydrological variables:

- Flow (ML/day) on the day of sampling ('flow on day of sampling')
- Days since flow exceeded 500 ML/day
- Days since flow exceeded 1000 ML/day
- Days since flow exceeded 2000 ML/day
- Days since flow exceeded 5000 ML/day
- Days since flow exceeded 1000 ML/day
- Flow on day of sampling as %age of maximum flow during preceding 30 days
- Flow on day of sampling as %age of maximum flow during preceding 60 days
- Flow on day of sampling as %age of mean flow during preceding 30 days
- Flow on day of sampling as %age of mean flow during preceding 60 days
- CV of flow for preceding 30 days
- CV of flow for preceding 60 days
- CV of flow for preceding 90 days

These data were normalised (to compensate for differences in numerical scale) and a dissimilarity matrix (Euclidian distance) calculated. The BIO-ENV procedure (Clarke and Warwick 1994) was applied seeking to identify maximum rank correlation between this matrix and one describing dissimilarities between the macroinvertebrate samples. The flow variable that groups the sites in a pattern most similar to the macroinvertebrate data 'flow on day of sampling as % of mean flow during the past 60 days'. The best-fitting pair of hydrological variables was this one plus 'days since flows exceeded 2000 ML/day'. It should be noted, however, that in both cases the weighted Spearman Rank Correlation is only a little over 0.3, indicating that other factors are also linked to the observed biotic dissimilarity.

11 APPENDIX 3: TEMPERATURE MODELLING

GB IVT thermal calculations
Bradford Sherman
CSIRO Land and Water

Summary

Two methods were used to predict the effect of intervalley transfers on water temperature in the Goulburn River downstream of Goulburn Weir. The first method ('assumed heat flux') employed a simple heat budget model has been used to calculate changes in monthly mean water temperature along the Goulburn River using historical, minimum and proposed IVT discharge scenarios. Channel hydraulic characteristics were computed using Manning's equation. A net heat flux based on observations at Hume Dam and Chaffey Dam was assumed to apply to the Goulburn River as well. The second method employed the 'Equilibrium Temperature Method' to determine the expected equilibrium temperature (ETM) predicted using SILO historical meteorological values for the region near Reach 4 and wind speed at Tatura.

The ETM approach matched observed temperature trends much better than the 'assumed heat flux' method and its predictions have higher confidence. However, there remain unresolved issues regarding the reconciliation of observed river temperatures at McCoys Bridge with the ETM predictions which are beyond the scope of this report to predict.

The ETM method predicts that changes in water depth arising from IVTs are expected to have little impact on water temperature compared to the existing conditions. The expected temperature varied by approximately 0.4 °C between the current conditions (1.3 m assumed depth) and the maximum anticipated IVT (350 GL, 5 m depth).

The observed temperature at Murchison was 0.5-1 °C warmer than ETM predictions during spring-early summer but generally tracked the ETM predictions well. Observations clearly show that the river temperature increases downstream of Goulburn Weir and this implies that the ETM predictions underpredict the true equilibrium temperature although the error at Murchison is small and the seasonal patterns are reproduced well.

The time scale for water temperature to adjust to short-term fluctuations in meteorological forcing ranged from about 1.5 d for the current conditions to slightly more than 6 days for an IVT of 350 GL. This adjustment time scale is likely to be characteristic of adjustment to any temperature difference between Lake Nagambie discharge temperature and the predicted equilibrium temperature as well. The ETM method suggests that the Lake Nagambie discharge temperature is already close to the equlibrium value for the geographic region and it is not possible to predict a 'recovery' distance as a consequence because little change in temperature downstream of Goulburn Weir is predicted to occur.

Comparison of the 'assumed heat flux' model predictions with observed temperature data for the Goulburn River between Lake Eildon and Trawool were satisfactory during spring but lower than observed during Jan-Apr suggesting that either discharge temperatures from Eildon Dam were warmer than assumed (i.e. lower water level) or that the assumed net heat flux was in error. Performance of the model downstream of Goulburn Weir has not been accurately assessed (beyond the scope of this report) as both discharge and temperature are expected to be impacted by tributary flows from drains and the Broken River. A preliminary comparison of predicted and observed temperatures at Murchison under current flow conditions was poor and casts doubt on the usefulness of this approach to estimating river temperature in the lower Goulburn River.

Background

CSIRO Land and Water was hired to use a simple heat budget method to predict the impact of proposed intervalley water transfers (IVTs) on the temperature of the Goulburn River downstream of Goulburn Weir. IVTs introduce a significant change in the discharge and this has consequences for the river temperature (Figure 40). The simple estimates presented here provide an indication of the extent of the likely impact of IVTs on river temperature.

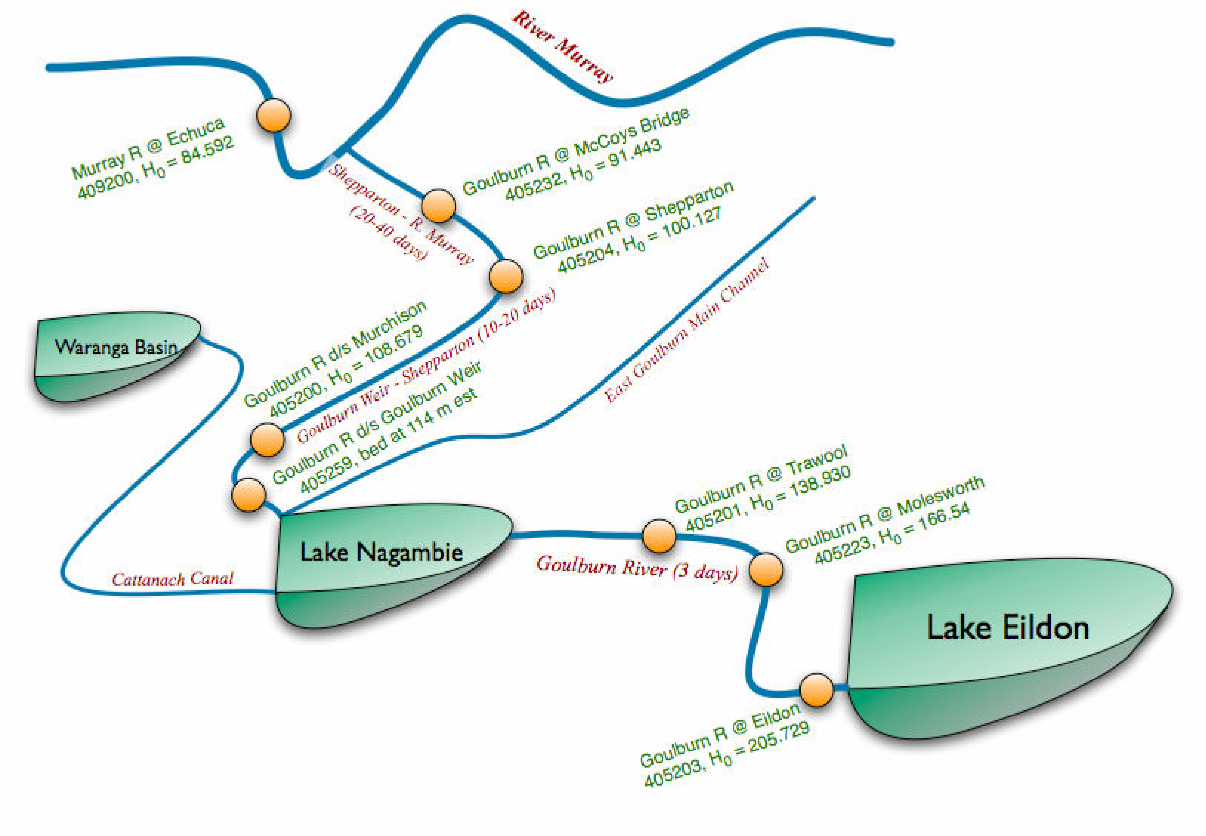


Figure 40: Schematic of Goulburn River system. Yellow circles denote stream flow gaging stations. H_0 denotes channel bed elevation at gaging station. Also shown are typical travel times along various reaches.

Method of calculation

The impact of IVTs on the temperature of the Goulburn River downstream of Goulburn Weir was estimated on a monthly basis for the Oct-Apr period using a simple heat budget approach proposed by Sherman (2001). In this approach, the change in water temperature is estimated by specifying a net heat flux, channel width, water depth, and water travel time. The net heat flux across the air-water interface was assumed to be comparable to that measured at Hume Dam (Sherman 2005) and Chaffey Dam (Sherman et al. 2001). The channel was assumed to have a rectangular cross-section and the width was assumed equal to the bankfull width provided by P. Cottingham (pers. comm.). Water depth and travel time were derived from specified flows and the application of Manning's equation for the reaches considered.

For a given net heat flux, H, the change in temperature, ΔT, experienced along a reach with depth h, during time Δt is given by,

$$\Delta T = \frac{H \Delta t}{\rho C_p h}$$

where ρ and C_p are the density and heat capacity of water.

The travel time through a reach is given by

$$\Delta t = \frac{L}{v}$$

where L is the reach length (m) and v (m s^{-1}) is the mean velocity in the reach.

The velocity is estimated from Manning's equation,

$$v = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where n is a roughness coefficient typically in the range 0.03 - 0.035 for natural streams, S is the channel gradient (m/m) determined as the difference in elevation between gauge zero elevations (the elevation corresponding to no flow and assumed to be equivalent to the bed level) divided by the reach length between the gauges, and R is the hydraulic radius,

$$R = \frac{A}{P}$$

A and P are the cross-sectional area and wetted perimeter which for a rectangular channel of depth h and width b are given by,

$$P = 2h + b$$
$$A = b h$$

Manning's equation can be rearranged as:

$$n = \frac{b \left(\frac{b\,h}{2\,h + b} \right)^{\frac{2}{3}} h \,\sqrt{S}}{Q}$$

where Q is the flow ($m^3\ s^{-1}$).

The flowing depth, *h*, was derived by solving Manning's equation graphically for the depth by taking value of depth corresponding to Manning's n provided by Melbourne University 1D hydraulic model results (Stewardson, pers. comm.).

Assumptions

Discharge scenarios

Calculations were performed using the following assumed discharges for the Goulburn River upstream and downstream of Goulburn Weir. The five reaches considered in previous work and corresponding streamflow gauging station details are given in Table 26. Discharge and temperature data referred to throughout this report correspond to the stations listed in Table 26 unless otherwise noted.

Table 26: Goulburn River study reaches. Reach length was derived from 1:250000 contour map. Gauge zero depth for Lake Nagambie (Goulburn Weir) is the full supply level (FSL). Reach ID indicates the downstream end of a reach. Shaded rows denote stations within a reach. Reach 4a is measured from 405259 to 405200 and reach 5a is measured from 405204 to 405232.

Reach ID	Gauging Station	Bankfull Flow ($m^3\ s^{-1}$)	Bankfull Flow ($ML\ d^{-1}$)	Bankfull Width (m)	Reach length (km)	Gauge zero elevation (m AHD)	Bed slope (m/m)	Bankfull Depth (m)
	Eildon (405203)					205.729		
1	Molesworth (405223)	163	14083	54	57.5	166.540	6.82E-04	2.7
2	Trawool (405201)	327	28253	68	52.5	138.930	5.26E-04	3.5
3	Lake Nagambie	417	36029	73	71.5	124.240	2.05E-04	4.7
	Goulburn Weir (405259)				181.50	114. (estimate)		
4	Shepparton (405204)	825	71280	86	75	100.127	1.85E-04	5.9
5	Murray @ Echuca (409200)	578	49939	74	144.4	84.592	1.08E-04	6.3
4a	Murchison (405200)				20.9	108.679		
5a	McCoys Bridge (405232)				85.7	91.443		

The discharge was assumed to be the same in reaches 1-3 and was based on daily historical flow data (P. Cottingham, pers comm.) compiled for the three reaches between Lake Eildon and Lake Nagambie. Although October exhibits appreciable tributary inflows between Eildon Dam and Goulburn Weir, this assumption was quite good for Nov-Apr (Figure 41).

Mean monthly discharge below Goulburn Weir is shown in Figure 42. There is substantial additional inflow to the Goulburn River downstream of Shepparton (Reach 5) where the flow increases by 40-100% compared to Reach 4. Consideration of the impact of this additional flow on the thermal regime of Reach 5 is beyond the scope of this work.

The proposed IVTs, which assume a 'monthly crop factor pattern', are compared with the historical (1995-2000) mean flows in Table 27. The range of flows contemplated represent increases in flow in Reach 4 by a factor of roughly 3 to 9. There is a significant difference between the historical Oct flows and the minimum required flow. More recently, the drought has caused a reduction in Oct flows to close to the minimum value (P. Cottingham, pers. comm.).

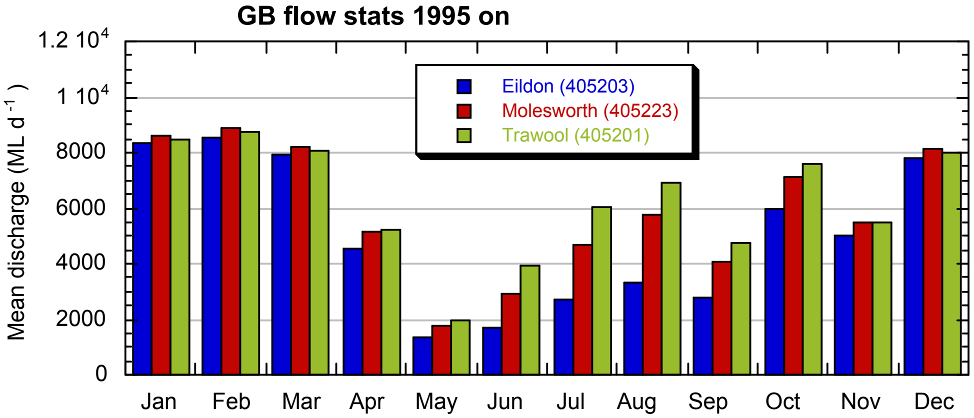


Figure 41: Mean monthly flows during 1 Jan 1995 - 30 June 2000 below Eildon Dam (blue) and at Molesworth (red) and Trawool (green).

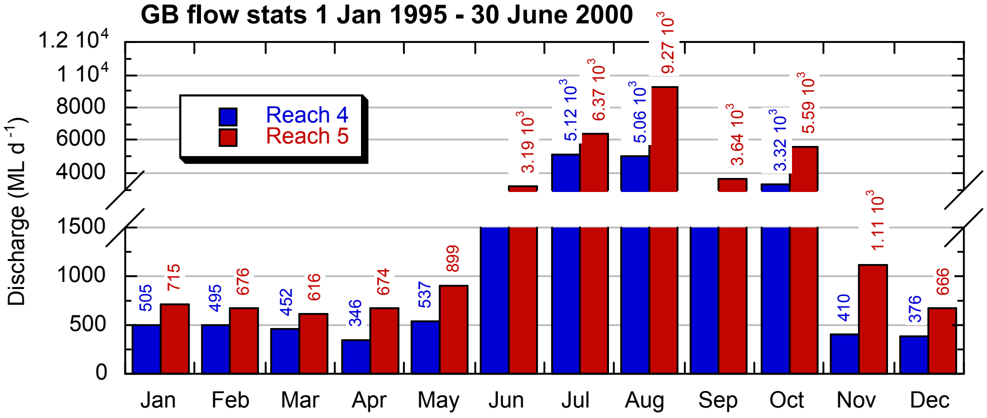


Figure 42: Mean monthly flows during 1 Jan 1995 - 30 June 2000 between Goulburn Weir and Shepparton (Reach 4, blue) and Shepparton to the River Murray (Reach 5, red).

Table 27: Discharge scenarios for Goulburn River below Goulburn Weir. Intervalley transfer (IVT) scenarios are adjusted to reflect a crop demand factor.

	Current (ML d^{-1})	Minimum (ML d^{-1})	200 GL IVT (ML d^{-1})	300 GL IVT (ML d^{-1})	350 GL IVT (ML d^{-1})	Current (m^3 s^{-1})	Minimum (m^3 s^{-1})	200 GL IVT (m^3 s^{-1})	300 GL IVT (m^3 s^{-1})	350 GL IVT (m^3 s^{-1})
Oct	3321	400	650	750	800	38.44	4.63	7.5	8.7	9.3
Nov	410	350	1150	1500	1700	4.75	4.05	13.3	17.4	19.7
Dec	376	350	1700	2350	2700	4.35	4.05	19.7	27.2	31.3
Jan	505	350	1900	2700	3050	5.84	4.05	22.0	31.3	35.3
Feb	495	350	1650	2250	2600	5.73	4.05	19.1	26.0	30.1
Mar	452	350	1300	1800	2100	5.23	4.05	15.1	20.8	24.3
Apr	346	350	800	1000	1150	4.00	4.05	9.3	11.6	13.3

Net air-water heat flux

The net heat air-water flux was assumed to be similar to that measured at Chaffey Dam and Hume Dam. Monthly net fluxes are shown in Figure 43 and illustrate both the natural interannual variability of the flux as well as the seasonal trends in flux. Calculations were limited to the Oct - Apr period and the heat flux values used are given in

Table 28. Although the shortwave radiation compares well, wind speed does not (Figure 44) and this could lead to errors in the assumed heat flux.

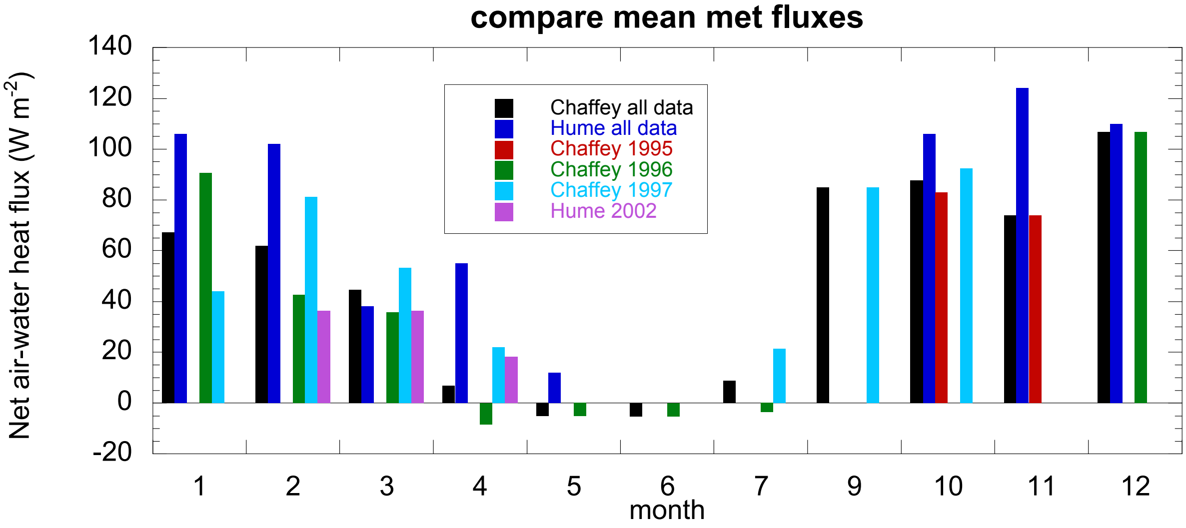


Figure 43: Mean monthly net heat fluxes computed from on-site high resolution meteorological measurements at Chaffey Dam and Hume Dam.

Table 28: Assumed mean monthly net heat flux experienced by Goulburn River.

Month	Flux (W m^{-2})	Max Flux (W m^{-2})
Oct	90	106
Nov	100	124
Dec	105	110
Jan	85	106
Feb	50	102
Mar	35	38
Apr	20	55

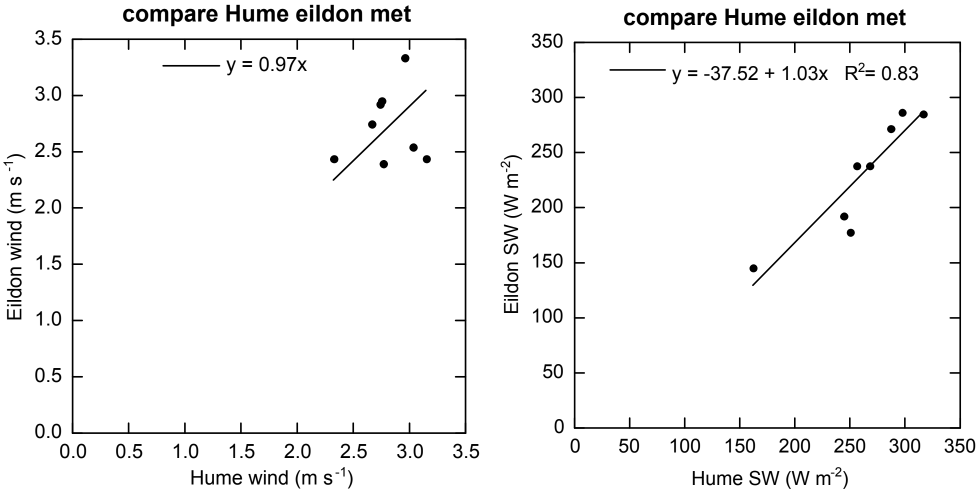


Figure 44: Comparison between Eildon Dam and Hume Dam shortwave radiation and wind speed observations.

Eildon discharge temperature

Discharge temperature from Eildon dam is very consistently cold under all but the most extreme drought conditions. For 85% of the time the Eildon offtake will be at least 25 m below the water surface during Oct - Apr (Figure 45). The temperature at this depth is expected to be between 11 and 12 °C based on Eildon thermistor chain data for the first half of 2003.

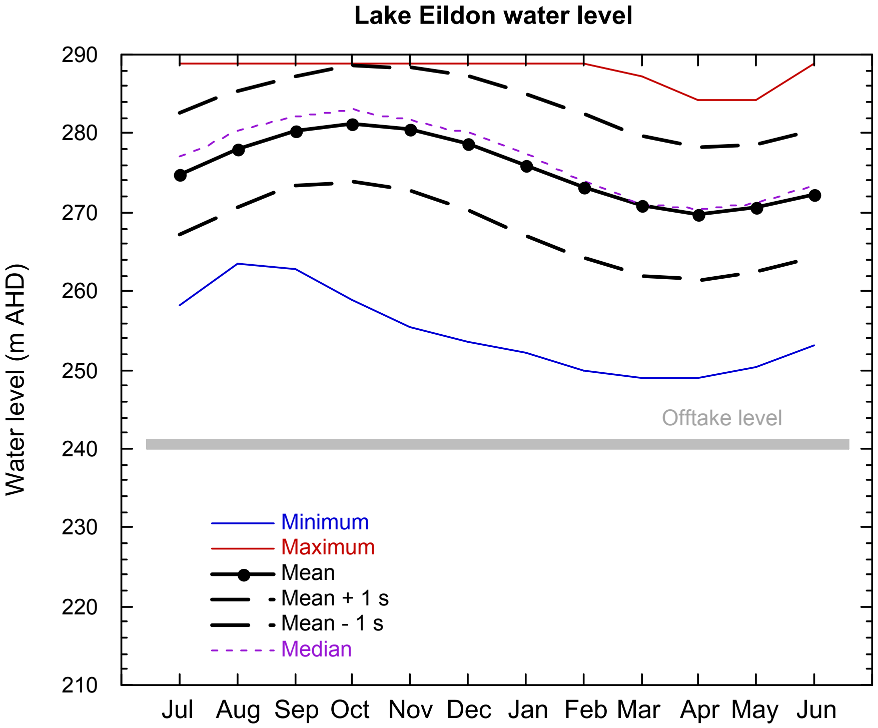


Figure 45: Monthly water levels in Lake Eildon. Grey bar denotes offtake level. Dashed lines denote ± 1 standard deviation from the mean monthly water levels.

Sources of uncertainty

Intrinsic uncertainties in heat flux estimates arise from natural variability in the net meterological heat fluxes (about ± 10-20 W m^{-2}) as well as differences in the water temperature between Eildon discharge (11-12 °C) and the Chaffey and Hume reservoir surface temperatures corresponding to the heat fluxes in Figure 43. For example, a difference in water temperature of 5 °C would introduce an offset of > 25 W m^{-2} in the net heat flux equivalent to roughly 0.5 °C d^{-1} for a 1 m deep water column.

There are also uncertainties regarding the hydraulic components of the calculation. Anything that alters the travel time (i.e. velocity) or the depth in a reach will alter the predicted temperature change. The channel is not rectangular and the width, depth and slope will vary along each reach. Furthermore, tributary inflows may add substantial amounts of heat to the river and could not be accounted for within the scope of this work.

Finally, it must be borne in mind that the calculations presented here assume both a constant monthly heat flux and a constant water temperature to predict a potential temperature change along a reach. *This is not the same as predicting the temperature.* The important feedback between increasing temperature and the loss of heat from a water body is not included in the calculations. In reality, this feedback strongly damps temperature increases such that for all practical purposes there is little chance of the water temperature ever exceeding an equilibrium temperature of

25-26 °C in the Goulburn River. Nor are any heat transfers between the water and the earth considered. Where very large potential temperature changes are predicted they should be interpreted as indicating that the river approaches equilibrium early in the reach and then maintains an equilibrium temperature along the remainder of the river.

Results

Eildon Dam to Lake Nagambie - validation

Little change in the release patterns from Eildon dam are expected and a single calculation was performed for the upper 3 reaches as a test of the model. Results for the Goulburn River upstream of Lake Nagambie are presented in Table 4 (hydraulic parameters) and Table 30 (predicted temperature increases).

Between Eildon Dam and Lake Nagambie, the temperature is predicted to increase by 3-4 °C during Oct-Dec. Assuming the release temperature is 11-12 °C the prediction is that the river will warm to within the range 14-16 °C during this period. Data collected at Trawool confirm the prediction very well (Figure 46). During Jan - Apr smaller temperature increases (1-2 °C) are predicted which, given the observed temperature range at Trawool of 16-19 °C imply a warmer discharge temperature from Eildon Dam or a significant error in the assumed net heat flux. Water levels during 1995-2000 fell nearly midway between the mean and mean -1 std dev lines in Figure 45, consistent with the requirement for warmer discharge water but probably not enough to account for the entire discrepancy. The relevant reservoir temperature data were not available to confirm this hypothesis at the time of writing. Such confirmation would provide useful insight into the accuracy of the simple modelling approach used here.

Table 29: Characteristic depth, velocity and travel time for reaches 1-3 and Lake Nagambie for the assumed monthly mean daily discharge for Eildon - Lake Nagambie and corresponding (Vol = 25000 ML, mean depth = 2.2 m).

			Reach 1			Reach 2			Reach 3			Nagambie
	Eildon-Nagambie mean discharge (ML d^{-1})	Eildon-Nagambie mean discharge (m^3 s^{-1})	Depth (m)	Velocity (m s^{-1})	Δt (days)	Depth (m)	Velocity (m s^{-1})	Δt (days)	Depth (m)	Velocity (m s^{-1})	Δt (days)	Residence time (days)
Oct	6915	80	1.5	1.0	0.7	1.4	0.8	0.7	1.8	0.6	1.4	3.6
Nov	5276	61	1.3	0.9	0.8	1.2	0.7	0.8	1.6	0.5	1.5	4.7
Dec	7989	92	1.7	1.0	0.7	1.6	0.9	0.7	2.0	0.6	1.3	3.1
Jan	8469	98	1.8	1.0	0.6	1.6	0.9	0.7	2.1	0.6	1.3	3.0
Feb	8720	101	1.8	1.0	0.6	1.7	0.9	0.7	2.1	0.7	1.3	2.9
Mar	8085	94	1.7	1.0	0.7	1.6	0.9	0.7	2.0	0.6	1.3	3.1
Apr	4985	58	1.3	0.8	0.8	1.2	0.7	0.8	1.5	0.5	1.6	5.0

Table 30: Predicted temperature changes along reaches 1-3 and during passage through Lake Nagambie. Observed change was computed from 15-minute temperature data at Tawool (405201) and downstream of the Goulburn Weir (405259).

	ΔT Reach 1 (°C)	ΔT Reach 2 (°C)	ΔT Reach 3 (°C)	ΔT Eildon - Nagambie (°C)	Observed ΔT Nagambie (°C)	Predicted ΔT reach 3 + Nagambie	Observed ΔT reach 3 + Nagambie
Oct	0.8	1.0	1.4	3.2	3.1	4.5	2.3
Nov	1.0	1.1	1.6	3.7	3.6	5.2	2.1
Dec	0.8	1.0	1.4	3.2	3.1	4.5	3.5
Jan	0.6	0.7	1.0	2.2	2.1	3.0	3.4
Feb	0.4	0.4	0.6	1.4	1.3	2.0	3.2
Mar	0.3	0.3	0.5	1.1	1.0	1.5	2.4
Apr	0.3	0.3	0.4	1.0	0.9	1.4	1.6

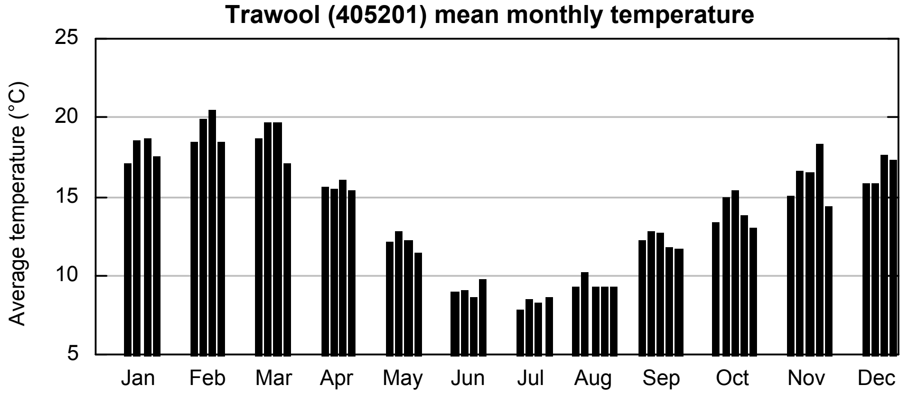


Figure 46: Mean monthly temperature for Goulburn River at Trawool during 1995 - 2001.

Goulburn Weir to River Murray

The river temperatures at Murchison and at McCoys Bridge were estimated as

$T_{\mathrm{Murchison}} = T_{\mathrm{Nagambie}} + dT/dt_{\mathrm{reach\ 4}} * L_{\mathrm{reach\ 4a}} / v_{\mathrm{reach\ 4}}$

$T_{\mathrm{McCoys}} = T_{\mathrm{Shepparton}} + dT/dt_{\mathrm{reach\ 5}} * L_{\mathrm{reach\ 5a}} / v_{\mathrm{reach\ 5}}$

where *dT/dt* is the predicted daily temperature change (Table 39), *L* is the distance from the start of the reach (Table 26) and *v* is the predicted water velocity (Table 37). Temperature was not allowed to exceed 26 °C. Results are shown in Table 31 and Table 32.

Table 31: Predicted temperatures at Murchison. Observed temperatures at Lake Nagambie and Murchison (405200).

	Nagambie Temp (°C)	Observed (°C)	Current (°C)	Minimum (°C)	200 GL trade (°C)	300 GL trade (°C)	350 GL trade (°C)
Oct	16.4	16.7	17.4	24.8	21.6	20.9	20.6
Nov	18.5	19.5	26.0	26.0	21.7	21.0	20.7
Dec	21.0	22.0	26.0	26.0	23.3	22.7	22.4
Jan	21.5	23.0	26.0	26.0	23.2	22.7	22.5
Feb	22.6	22.6	26.0	26.0	23.7	23.4	23.3
Mar	20.8	20.0	23.7	24.5	21.8	21.5	21.4
Apr	17.4	15.6	19.6	19.5	18.3	18.1	18.0

Table 32: Predicted temperature at McCoys Bridge

	Observed (°C)	Current (°C)	Minimum (°C)	200 GL trade (°C)	300 GL trade (°C)	350 GL trade (°C)
Oct	18	23.6	26.0	26.0	26.0	26.0
Nov	20	26.0	26.0	26.0	26.0	26.0
Dec	22.8	26.0	26.0	26.0	26.0	26.0
Jan	26.4	26.0	26.0	26.0	26.0	26.0
Feb	25.9	26.0	26.0	26.0	26.0	26.0
Mar	22.1	26.0	26.0	26.0	26.0	25.2
Apr	16.4	26.0	26.0	24.0	22.7	22.0

The model predicts that the river should attain a near-equilibrium temperature (26 °C) by the time it reaches Murchison under the current and minimum flow scenarios. By increasing the flow the IVTs increase water column depth, decrease travel time and thereby are predicted to decrease the temperature at Murchison by 2-4 °C.

However, when compared with observations of temperature the calculations for current conditions consistently overestimated the temperature at Murchison. This suggests either a significant error in the assumed net heat flux or in the estimated travel time for the system. Observed temperatures show a surprisingly small increase from Lake Nagambie to Murchison given the estimated 5-day travel time from Goulburn Weir and the assumed water column depth of about 1.2 m. The implication is that the assumed net heat flux is much too high (e.g. by a factor of 10 in Nov-Dec) or that the assumed hydraulic conditions contain a large error. It seems unlikely that the assumed heat flux could contain an error of this magnitude.

Results of the calculation are expressed in Table 33 in terms of the distance downstream of Goulburn Weir at which the water temperature is predicted to increase to 25 °C, which is in the range of maximum achievable temperatures based on thermodynamic considerations. The calculations are based on the observed monthly mean discharge temperature from Goulburn Weir during 1999-2001 (Figure 47) because no change in discharge characteristics from Eildon Dam is anticipated and the heating characteristics of Lake Nagambie are difficult to predict accurately due to variable bathymetry and preferred flow paths through the tortuous storage.

Historically, October discharge from Goulburn Weir (‘current’ in Table 33) has been much greater than the minimum required flow and the temperature is not expected to increase to 25 °C for 195 km, roughly 35 km downstream of McCoy’s Bridge. Observed temperatures at McCoy’s Bridge (Figure 48) are smaller than predicted here which suggests that either the heat flux is smaller than assumed or that tributary inflows from the Broken River, agricultural drains, etc have supplemented the discharge with colder water. Confirmation of this hypothesis is beyond the scope of this report but the satisfactory predictions for the upper reaches of the Goulburn during spring suggest the assumed heat flux is approximately correct.

Recently, flows below Goulburn Weir have more closely followed the minimum flow requirement and under these conditions the river is predicted to warm to 25 °C within 20 km of the weir. The introduction of inter-valley transfers (IVTs) extend the distance for the river to recover to 25 °C to roughly 45, 55 and 65 km for the 200, 300 and 350 GL IVT scenarios, respectively. In April, the observed temperature decreases slightly between Goulburn Weir and McCoy’s Bridge and IVTs are not expected to have a material impact on temperature although they may be expected to attenuate the temperature decrease slightly.

Table 33: Predicted distance downstream of Goulburn Weir for river temperature to reach 25°C. Observed temperature at McCoy's Bridge (1995-2001) may be considered an upper limit for an achievable temperature during summer. Note that observations show a decrease in temperature between Goulburn Weir and McCoy's Bridge during April.

	Goulburn Weir Temp (°C)	McCoy's Bridge Temp (°C)	Reach 4 & 5 distance to 25 °C from Goulburn Weir				
			Current (km)	Minimum (km)	200 GL IVT (km)	300 GL IVT (km)	350 GL IVT (km)
Oct	16.4	18.0	194.9	21.5	34.9	40.2	42.9
Nov	18.5	20.0	15.0	12.8	42.0	54.7	62.0
Dec	21.0	22.8	8.0	7.5	36.4	50.3	57.7
Jan	21.5	26.4	11.7	8.1	43.9	62.4	70.5
Feb	22.6	25.9	13.3	9.4	44.5	60.6	70.1
Mar	20.8	22.1	30.5	23.6	89.6	128.8	152.3
Apr	17.4	16.4	73.8	74.7	186.2	235.8	273.0

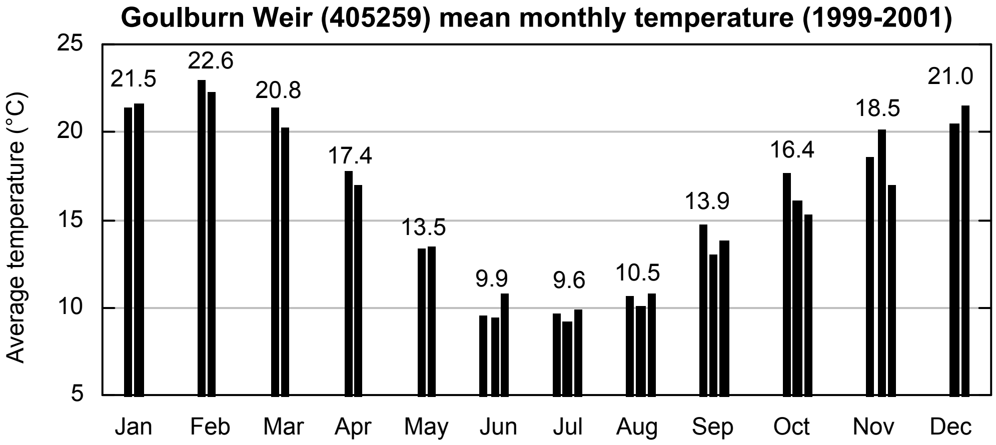


Figure 47: Observed monthly mean temperatures in the Goulburn River downstream of Goulburn Weir (site 405259).

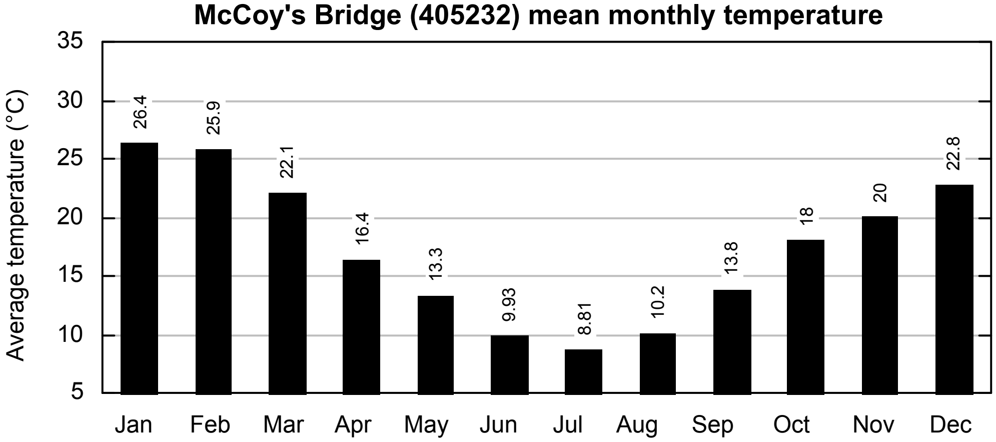


Figure 48: Observed monthly mean temperatures in the Goulburn River at McCoy's Bridge (site 405232).

Temperature estimates using the "Equilibrium Temperature Method" (ETM)

CSIRO Land and Water has recently developed a calculation to estimate water temperature and evaporation rate for any location in the Murray Darling Basin. These calculations are based on the work of are driven by local estimates of meteorological parameters provided from the Bureau of Meteorology's SILO interpolated data set. The Equilibrium Temperature Method is expected to be more accurate than the 'assumed net heat flux' method used in sections 1-6 above because it employs meteorological data that are more representative of local conditions and the method more explicitly incorporates the feedback of changing water temperature on the net heat flux at the air-water interface. The equilibrium temperature method (ETM) computes an 'equilibrium temperature' and a response time based on the work of de Bruin (1982). The equilibrium temperature is the temperature that the water would assume given constant meteorological conditions. In other words, at the equilibrium temperature the net heat flux into the water column is zero. In reality the meteorological forcing is never constant for a sufficient period to allow the water temperature to reach the equilibrium temperature. The true water temperature, Tw, will differ from the equilibrium temperature, Teq, by some amount, ΔT, and is assumed to approach the equilibrium temperature exponentially over a time interval, Δt, with a characteristic time scale, τ.

$$Tw = Teq + \Delta T \exp(-\Delta t / \tau)$$

The following data were used to perform the equilibrium temperature calculations: Temperature, vapour pressure and solar radiation and wind speed data were taken by interrogating the Bureau of Meteorology SILO database using the latitude and longiutude for the river channel midway between Lake Nagambie and Shepparton. Wind speed data were taken from the nearest met station at Tatura. Days without wind speed data have been filled with the average of the complete data set.

The river channel width was set at 45 m and calculations performed for water depths of 3 and 5 m. This depth range spans the predicted range in water depths for the different IVT scenarios.

Results

Results of the equilibrium temperature method calculations are given in Table 34. The observed temperature downstream of Goulburn Weir is well predicted by the ETM calculations for Oct through February and is slightly warmer during March and April (Figure 49). This suggests that Lake Nagambie is at approximate equilibrium during spring and early summer and observed temperatures here are a reasonable intital condition for determining downstream temperatures in the Goulburn River.

Direct comparison of ETM predicted temperature with observed temperatures in the Goulburn River reveal some bias in the predictions. During Oct-Dec the observed temperature at Murchison is about 1 °C warmer than predicted and roughly 0.5 °C warmer during Jan - Apr. At McCoys Bridge the difference is 1.5 -2 °C.

The curves in Figure 50 show the predicted monthly mean temperatures for Reach 4 assuming water column depths of 1.3 m (current conditions), 3 m (200 GL IVT), and 5 m (350 GL IVT). Predicted temperatures all fall within a range of 0.5 °C regardless of the IVT scenario. This indicates that the temperature in the river is not likely to be very sensitive to the flow scenario, i.e. the assumed water column depth.

The characteristic time scale for the water column to approach the equilibrium temperature ranges from 1.5 to 6 days as the depth varies from 1.3 m to 5 m. This time scale represents the time required for the water column temperature to respond to short term variations in meteorological forcing, but it can also be thought of, approximately, as a time scale for water discharged from Goulburn Weir to approach the equilibrium temperature downstream. With the travel time for Reach 4 predicted to range from 9 - 13 days under most circumstances the difference in ETM-predicted response times is equivalent to a 15-20 km longer distance required for the water column to reach equilibrium.

Because the flow regime for Lake Nagambie is unlikely to change substantially and the water column temperature is close to that predicted by the ETM, this calculation method suggests there is not much scope for further warming in the river downstream of Lake Nagambie. The observed temperature at McCoy’s Bridge (Figure 49) implies that the ETM is under-predicting the equilibrium temperature by a significant margin. It is not possible to reconcile this discrepancy within the scope of this report as a much more detailed heat budget calculation would be required.

The root-mean-square difference in predicted temperatures between the 1.3 and 5 m-deep water columns is about 0.4 °C with the 5 m scenario being colder in spring and warmer in autumn. During summer the predicted difference in temperature is just 0.2 °C. The ETM predictions indicate that the temperature of the river downstream of Goulburn Weir should not be very sensitive to changes in discharge.

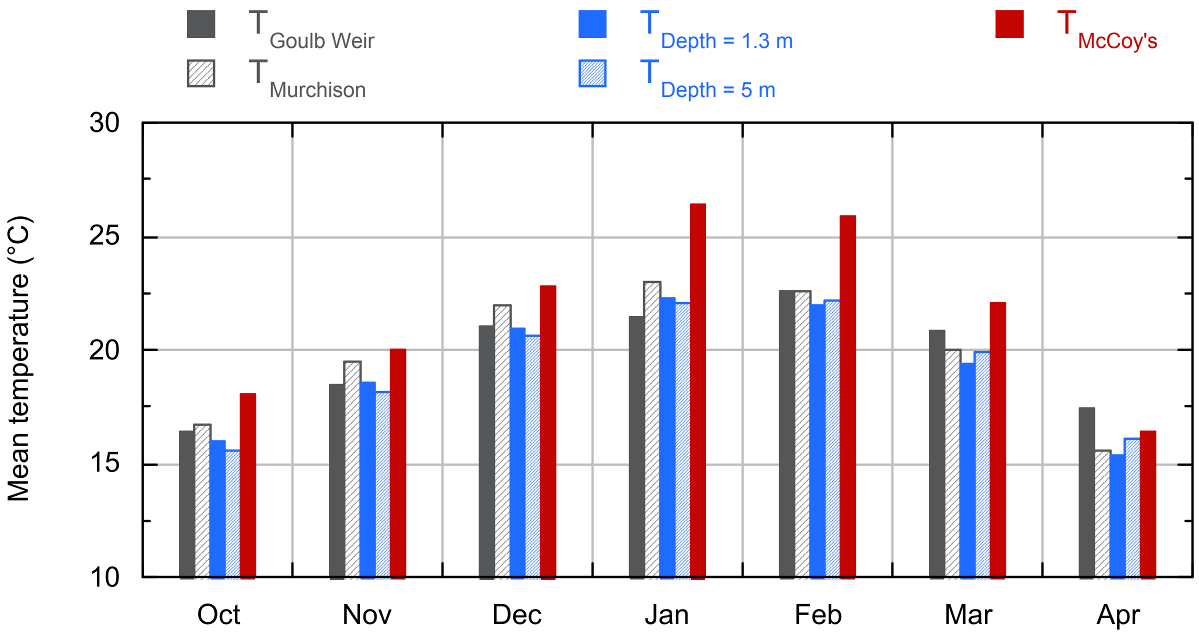


Figure 49: **Observed temperatures downstream of Goulburn Weir (405259), at Murchison (405200), and at McCoy's Bridge (405232) compared to ETM-predicted temperatures for Reach 4 (Goulburn Weir - Shepparton) for water depths of 1.3 m (current conditions) and 5 m (350 GL IVT scenario).**

Table 34: Water temperature predictions using equilibrium temperature method. Average temperature at Murchison and McCoys Bridge (1995-2001). Average temperature downstream of Goulburn Weir (2000-2001). Equilibrium temperature calculations were performed for the period 1 Jan 1990 - 3 Apr 2006.

	Tatura Mean air Temp (°C)	Goulburn Weir Temp (405259) (°C)	Murchison Temp (405200) (°C)	McCoy's Bridge Temp (405232) (°C)	Equilibrium temperature (°C)	ETM response time (d) Depth = 1.3 m	ETM temperature (°C) Depth = 1.3 m	ETM response time (d) Depth = 5 m	ETM temperature (°C) Depth = 5 m	ETM response time (d) Depth = 3 m	ETM temperature (°C) Depth = 3 m
Oct	14.1	16.4	16.7	18.0	16.4	1.9	16.0	7.1	15.6	4.3	15.8
Nov	17.1	18.5	19.5	20.0	18.9	1.7	18.6	6.6	18.2	3.9	18.4
Dec	20.0	21.0	22.0	22.8	21.2	1.7	20.9	6.4	20.6	3.8	20.8
Jan	22.2	21.5	23.0	26.4	22.6	1.5	22.3	5.9	22.1	3.6	22.2
Feb	21.9	22.6	22.6	25.9	22.1	1.6	22.0	6.2	22.1	3.7	22.1
Mar	19.1	20.8	20.0	22.1	19.4	1.8	19.4	6.8	19.9	4.1	19.6
Apr	15.0	17.4	15.6	16.4	15.4	2.0	15.4	7.7	16.1	4.6	15.7

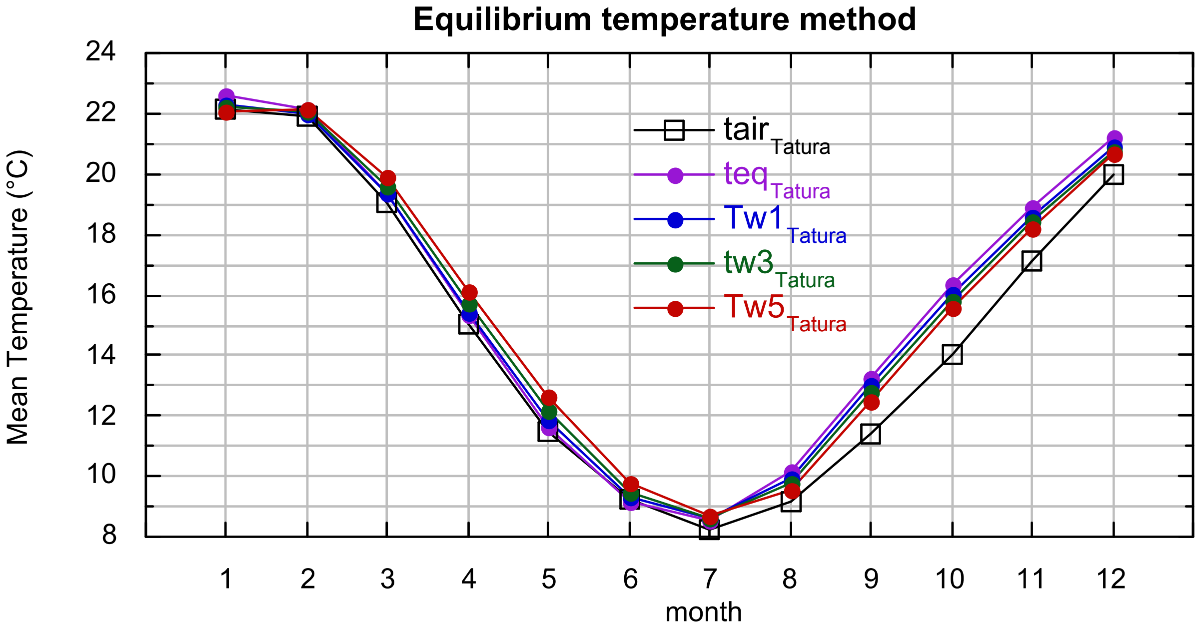


Figure 50: Mean air temperature at Tatura (from SILO data) and predicted equilibrium (violet) and water temperatures for mean water column depths of 1.3 m (blue), 3 m (green) and 5 m (red) in Reach 4 (Lake Nagambie - Shepparton).

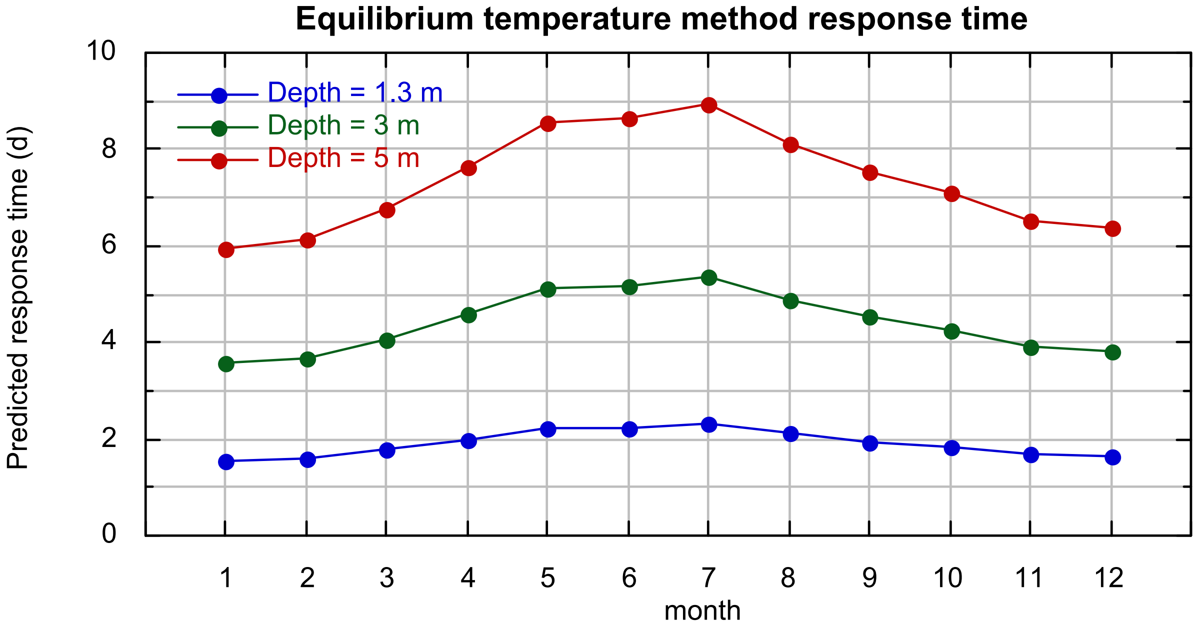


Figure 51: Predicted time for water temperature to reach equilibrium temperature.

References

de Bruin, H.A.R. "Temperature and Energy Balance of a Water Reservoir Determined From Standard Weather Data of a Land Station." Journal of Hydrology 59 (1982): 261 - 274.

Sherman, Bradford S. 2001 "Scoping Options for Mitigating Cold Water Discharges From Dams." In Thermal Pollution of the Murray-Darling Basin Waterways: Workshop Held At Lake Hume 18-19 June 2001: Statement and Recommendations Plus Supporting Papers, edited by Bill Phillips, 12-28. Sydney: Inland Rivers Network, World Wide Fund for Nature Australia.

Sherman, Bradford S. 2005 Hume Reservoir Thermal Monitoring and Modelling - Final Report. Canberra: CSIRO Land and Water.

Sherman, Bradford S., Phillip Ford, Patrick Hatton, John Whittington, Damian Green, Darren Baldwin, Roderick L. Oliver, Russ Shiel, Berkel van, Jason, Ron Beckett, Leigh Grey, and Bill Maher. 2001 *The Chaffey Dam Story*. *Final Report for Crcfe Projects B.202 and B.203*. Canberra: CRC for Freshwater Ecology.

Appendix A - Supporting data and calculations

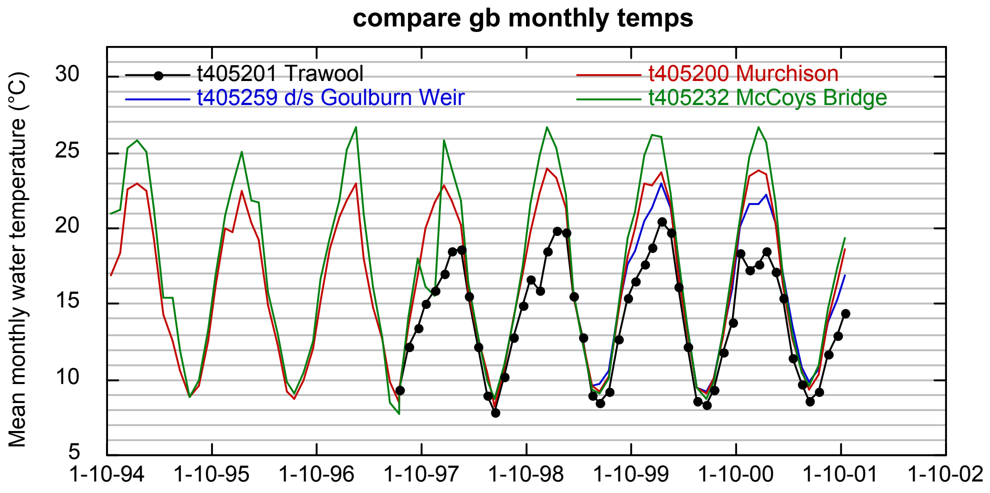


Figure 52: Observed monthly mean temperatures along the Goulburn River.

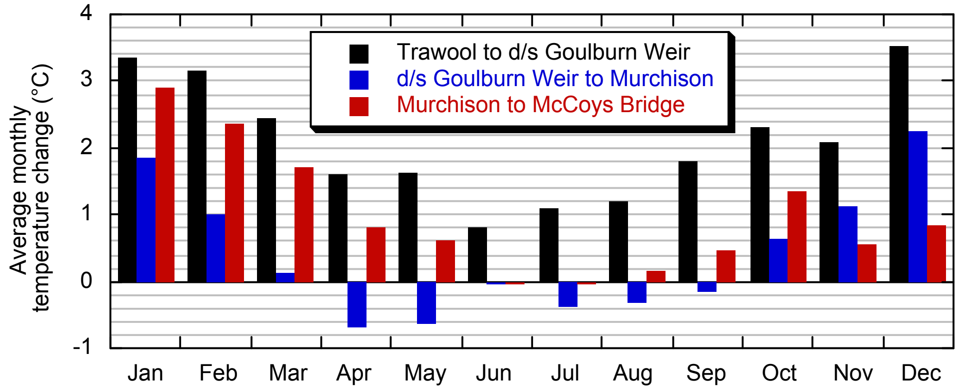


Figure 53: Observed temperature increases in the Goulburn River between Trawool and McCoy's Bridge.

Table 35: Discharge scenarios for Oct-Apr include a crop factor.

	Current (m^3 s^{-1})	Minimum (m^3 s^{-1})	200 GL IVT (m^3 s^{-1})	300 GL IVT (m^3 s^{-1})	350 GL IVT (m^3 s^{-1})	Current (m^3 s^{-1})	Minimum (m^3 s^{-1})	200 GL IVT (m^3 s^{-1})	300 GL IVT (m^3 s^{-1})	350 GL IVT (m^3 s^{-1})
Oct	38.44	4.63	7.5	8.7	9.3	38.44	4.63	7.5	8.7	9.3
Nov	4.75	4.05	13.3	17.4	19.7	4.75	4.05	13.3	17.4	19.7
Dec	4.35	4.05	19.7	27.2	31.3	4.35	4.05	19.7	27.2	31.3
Jan	5.84	4.05	22.0	31.3	35.3	5.84	4.05	22.0	31.3	35.3
Feb	5.73	4.05	19.1	26.0	30.1	5.73	4.05	19.1	26.0	30.1
Mar	5.23	4.05	15.1	20.8	24.3	5.23	4.05	15.1	20.8	24.3
Apr	4.00	4.05	9.3	11.6	13.3	4.00	4.05	9.3	11.6	13.3

Table 36: Predicted flowing depth for reaches 4 and 5 determined from Manning's equation.

	Reach 4 flowing depth					Reach 5 flowing depth				
	Current (m)	Minimum (m)	200 GL IVT (m)	300 GL IVT (m)	350 GL IVT (m)	Current (m)	Minimum (m)	200 GL IVT (m)	300 GL IVT (m)	350 GL IVT (m)
Oct	4.34	1.19	1.59	1.74	1.81	5.36	1.45	1.95	2.13	2.21
Nov	1.21	1.09	2.26	2.66	2.87	1.47	1.33	2.77	3.26	3.52
Dec	1.14	1.09	2.87	3.50	3.82	1.39	1.33	3.52	4.31	4.70
Jan	1.37	1.09	3.07	3.82	4.12	1.67	1.33	3.78	4.70	5.08
Feb	1.35	1.09	2.82	3.41	3.73	1.65	1.33	3.46	4.20	4.59
Mar	1.28	1.09	2.43	2.97	3.27	1.56	1.33	2.98	3.65	4.02
Apr	1.09	1.09	1.81	2.07	2.26	1.32	1.33	2.21	2.54	2.77

Table 37: Predicted mean velocities in reaches 4 and 5.

	Reach 4 velocity					Reach 5 velocity				
	Current (m s^{-1})	Minimum (m s^{-1})	200 GL IVT (m s^{-1})	300 GL IVT (m s^{-1})	350 GL IVT (m s^{-1})	Current (m s^{-1})	Minimum (m s^{-1})	200 GL IVT (m s^{-1})	300 GL IVT (m s^{-1})	350 GL IVT (m s^{-1})
Oct	0.10	0.05	0.06	0.06	0.06	0.10	0.04	0.05	0.06	0.06
Nov	0.05	0.04	0.07	0.08	0.08	0.04	0.04	0.06	0.07	0.08
Dec	0.04	0.04	0.08	0.09	0.10	0.04	0.04	0.08	0.09	0.09
Jan	0.05	0.04	0.08	0.10	0.10	0.05	0.04	0.08	0.09	0.09
Feb	0.05	0.04	0.08	0.09	0.09	0.05	0.04	0.07	0.08	0.09
Mar	0.05	0.04	0.07	0.08	0.09	0.05	0.04	0.07	0.08	0.08
Apr	0.04	0.04	0.06	0.07	0.07	0.04	0.04	0.06	0.06	0.06

Table 38: Predicted travel times for reaches 4 and 5.

	Reach 4 travel time					Reach 5 travel time				
	Current (d)	Minimum (d)	200 GL IVT (d)	300 GL IVT (d)	350 GL IVT (d)	Current (d)	Minimum (d)	200 GL IVT (d)	300 GL IVT (d)	350 GL IVT (d)
Oct	8.4	19.2	15.8	15.0	14.6	17.2	38.7	32.1	30.3	29.5
Nov	19.0	20.1	12.7	11.4	10.9	38.3	40.6	25.7	23.2	22.1
Dec	19.6	20.1	10.9	9.6	9.1	39.5	40.6	22.1	19.6	18.6
Jan	17.5	20.1	10.4	9.1	8.7	35.3	40.6	21.3	18.6	17.8
Feb	17.6	20.1	11.0	9.8	9.3	35.6	40.6	22.4	19.9	18.9
Mar	18.3	20.1	12.1	10.6	10.0	36.9	40.6	24.5	21.7	20.5
Apr	20.3	20.1	14.6	13.4	12.7	40.8	40.6	29.5	27.1	25.7

Table 39: Predicted daily temperature change in reaches 4 and 5.

	Reach 4 daily temperature change					Reach 5 daily temperature change				
	Current (°C d^{-1})	Minimum (°C d^{-1})	200 GL IVT (°C d^{-1})	300 GL IVT (°C d^{-1})	350 GL IVT (°C d^{-1})	Current (°C d^{-1})	Minimum (°C d^{-1})	200 GL IVT (°C d^{-1})	300 GL IVT (°C d^{-1})	350 GL IVT (°C d^{-1})
Oct	0.4	1.6	1.2	1.1	1.0	0.3	1.3	1.0	0.9	0.8
Nov	1.7	1.9	0.9	0.8	0.7	1.4	1.6	0.7	0.6	0.6
Dec	1.9	2.0	0.8	0.6	0.6	1.6	1.6	0.6	0.5	0.5
Jan	1.3	1.6	0.6	0.5	0.4	1.1	1.3	0.5	0.4	0.3
Feb	0.8	1.0	0.4	0.3	0.3	0.6	0.8	0.3	0.2	0.2
Mar	0.6	0.7	0.3	0.2	0.2	0.5	0.5	0.2	0.2	0.2
Apr	0.4	0.4	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.1