Objectives for flow freshes in the lower Goulburn River 2010/11

Prepared for the Goulburn-Broken CMA and Goulburn Murray Water

by

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Photographs by Peter Cottingham.

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1 INTRODUCTION

Inflows to the Goulburn River have been well below average over the past 10 years. Ongoing drought and low inflows have led to the qualification of rights on the Goulburn system and a reduction in the minimum passing flows in winter/spring. This is assumed to have stressed the ecological health of the river, and the management of environmental water has focused on ensuring ecological survival and minimising ecological damage (e.g. Cottingham et al. 2009, 2010).

However, the purchase of water through Government buy-backs and the delivery of water with Inter-valley Transfers (IVTs) means that there is a potential for delivering more environmental water in the 2010/11 year than was the case in the previous four years. The Goulburn Broken Catchment Management Authority (GB CMA) and Goulburn-Murray Water (G-MW) sought advice from members of the previous environmental flow scientific panel (Cottingham et al. 2003, 2007) on how best to use any additional water to assist the river ecosystem survive the cumulative effects of prolonged drought and/or recover from the recent low flows. The scientific panel, which has considerable experience and knowledge of the Goulburn River and related environmental flow issues, were invited to provide advice on:

- Setting appropriate ecosystem objectives for a fresh or series of freshes along the lower Goulburn River;
- Designing the fresh or freshes to achieve the desired ecosystem objectives; and
- Scoping a monitoring program to test whether or not the designed fresh(es) achieve the stated ecosystem objectives.

The study area is the Goulburn River from Lake Eildon to the Murray River, with particular emphasis on the river below Goulburn Weir (Lake Nagambie). This section of the river is referred to as the Lower Goulburn River and has been described previously as two reaches: Reach 4 (Goulburn Weir to Shepparton) and Reach 5 (Shepparton to the Murray River) (Cottingham et al. 2003, 2007).

Note:
Fortuitously, catchments across the Goulburn-Broken Basin have received good winter rains from mid until late August 2010 (as this report was being prepared). Rainfall and subsequent runoff has increased inflows to storages and along the Goulburn River. This has culminated in a bankfull flow event just below the minor flood warning for the lower Goulburn.

1.1 Current situation

As noted by Cottingham et al. (2010), the current situation of prolonged dry conditions and low inflows, but with the prospect of increased water availability in northern Victoria, is new to managers and scientists alike. This means that the response of rivers such as the Goulburn to the delivery of additional water is difficult to predict. There is also an inherent risk of unforeseen ecological outcomes as water delivery to the various river reaches is varied or increased. In such circumstances, it is important that principles of adaptive management are invoked, whereby clear objectives are set, and events and outcomes are intensively and scientifically monitored and understood. This will help establish how the river has responded and will inform future management under similar conditions.

While catchments across the region are wetter than in the previous year, water availability across the system at the start of the 2010/11 water year is similar to the start of the previous water year (2009/10), even though recent (June-August 2010) rainfall and runoff have increased flow in the Goulburn River and its tributaries, as well as improving the outlook for meeting minimum flow requirements for the rest of the water year (July 2010-June 2011). Should water availability increase, it may be possible to deliver the minimum flows specified in Bulk Entitlements (BE) or recommended in previous advice, as well as deliver events such as a flush or fresh[1]. Important considerations for doing this are:

- There are clear ecosystem objectives for the delivery of such an event;
- The extent to which it is possible to physically deliver the event (i.e. are there constraints on the volume that can be delivered?); and
- The risk of adverse outcomes (e.g. blackwater events, weed distribution, carp breeding events).

As the river has been managed as a refuge in recent years of drought (e.g. maintaining relict populations, avoiding local extinctions where possible) in coming out of drought conditions priority should be given to supporting factors and processes that were not possible under refugial conditions. This includes processes such as recruitment and dispersal. It is important to note, however, that only a subset of ecosystem processes we may wish to promote can be supported by a fresh.

1.2 Project tasks

The project brief specified that the scientific panel would undertake the following tasks:

- Task 1 - Determine objectives for the fresh
  - Before any flows are ‘designed’ an objective for the flow must be determined. In previous advice provided to the GBCMA (Cottingham et al. 2010) objectives have ranged from maintaining fish passage, mobilising sediment to improve habitat for macroinvertebrates, to inundating benches.
  - The task of this project is to consider the current condition of the Goulburn River given the recent prolonged low inflows and presumed stressed ecological condition and determine appropriate objectives for delivering freshes of different magnitudes. The result may be a list of objectives with different volumes of water.

[1] A flush is synonymous with the high flow component defined by DNRE (2002). A flush is a seasonal increase in baseflow that results in persistent wetting of the channel bed and low-lying benches. A fresh is a short duration peak flow event that exceeds baseflow and lasts for several days, often as a result of intensive and localised rainfall.

- Task 2 - Design of a fresh
  - The design of a freshening flow needs to consider many aspects including timing, size of the fresh, number of freshes, duration and rate of rise and fall.
  - Advice previously given to the GB CMA (e.g. Cottingham et al. 2003, 2009) indicates a fresh is best provided in spring. However, in some instances the CMA may not be able to secure enough water for a fresh at this time of year, thus the following questions need to be addressed as part of Task 2:
    - When is the preferred time in winter/spring to send a fresh down the river?
    - If there is not enough water available by December for a fresh, what are the risks of delivering an autumn fresh?
    - Would it be better to not deliver a fresh at all if a spring fresh is not possible for the objectives established in Task 1?
    - Given the objectives established in Task 1 and the current condition of the Goulburn River, what is the volume and duration of the recommended fresh(es) (both in winter/spring and autumn if relevant)? For example, is it better to provide one long fresh over the months of spring, or to separate the water available to two smaller freshes to be delivered in spring and autumn, or is it best to bank the water until an overbank flow can be delivered?

- Task 3 – design of a monitoring program
  - Once Tasks 1 and 2 are complete, the design of a monitoring program is required. The monitoring program will be designed specifically to test whether the objectives in Task 1 are met by the fresh, and/or to test the conceptual ecological response model on which the fresh is based. Where possible the monitoring program should build on existing monitoring programs throughout the catchment. In discussions with the GB CMA, it was agreed that the scientific panel would use the conceptual basis developed in Task 1 as a major input to identifying variables to be monitored and to specify aspects of a monitoring study design (e.g. collection of before-after data). This task will not involve detailed design aspects, such as site selection, power analysis or similar to determine sampling frequency, trial and confirmation of sampling methods and data analysis methods.

1.3 Scope

The project focused on the delivery of freshes along the lower Goulburn River, between Goulburn Weir and the Murray River.

2 ASSESSMENT OF CURRENT ECOSYSTEM CONDITION

A short overview of current condition was considered, based on information supplied by the GB CMA and supplemented by recent information provided by scientific panel members, the latter of which is summarised below.

In the absence of routine condition monitoring, the assessment relied on annual fish surveys from 2003 to 2009 (Koster et al. 2009) and on macroinvertebrate data collected as part of the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP) (Ecowise Environmental 2009), and water quality monitoring conducted by the GB CMA. Annual compliance reports done for VEFMAP were consulted but trends and condition were not readily determined as data have not yet been analysed.

The overview suggested that the ecological condition of the Goulburn River has remained relatively constant over the past decade, although the major bushfires of February 2009 contributed to changed conditions in tributaries and the main stem of the Goulburn River since the spring of 2009. Principal points were:

- Variability but no clear trend in catch per unit effort (CPUE) for native fish populations in the lower Goulburn River between 2003 and 2009 (Figure 1 and Figure 2). This suggests that the abundance and species composition of fish populations have remained reasonably stable between 2003-2009, probably reflecting the maintenance of flows in the river and connection with the Murray River. Murray cod has consistently been the most abundant large-bodied native species and common carp the most abundant large-bodied introduced species. Although adult golden perch are relatively common, very little evidence of spawning by this species has been recorded in the lower Goulburn River. This lack of spawning by golden perch may be due to a lack of large flow events in recent years, or it may be that the lower Goulburn is not a natural spawning area for the species. A study of the movements of adult golden perch during the spawning period is currently underway to address this question (Koster *et al.* 2009). Koster *et al.* (2009) also provide a more detailed analysis and discussion of the status of individual fish species in the lower Goulburn River.
- Relatively benign water quality in terms of EC, pH and turbidity, although there have been instances of high turbidity in fire-affected tributary inflows following the 2009 bushfires (see discussion in Cottingham et al. 2010). There have also been instances where DO concentration (saturation) has not met State Environmental Protection Policy (e.g. see data in EcoWise Environmental 2009, VWQMN results in DSE 2007). Recent monitoring of DO by the GB CMA highlighted the influence of tributary inflows from disturbed (e.g. fire-affected) catchments on water quality. The interaction of flow, DO, turbidity and suspended solids was identified by Cottingham et al. (2010) as an area requiring further investigation.
- Little change in the number of macroinvertebrate taxa from sites along the Goulburn River. Macroinvertebrate sampling is undertaken at four sites along the lower Goulburn River as part of the Victorian Environmental Flow Monitoring & Assessment Program (VEFMAP, Ecowise Environmental 2009).

Recent results indicated that each of four sites complied with EPA (2004) objectives for AUSRIVAS scores, two of the four sites did not comply with Rapid Biological Assessment (RBA) family scores and two sites did not comply with key family scores. The mean number of families per site was 14.5 in spring 2008 and 15.5 in spring 2009. Although there were clear differences in populations within sites between years, there were no consistent patterns (see attached multi-dimensional scaling (mds), Figure 3). Previously (Cottingham et al. 2003) it was noted that whilst the number of families per site remained fairly constant over time, extended low-flow periods resulted in greater similarity between sites in terms of taxonomic composition – i.e. the macroinvertebrates were less diverse on the larger spatial scale. However, although the spring 09 samples appear more scattered than samples from the preceding (drier) year, there is no statistical difference in mean inter-sample similarity (Bray-Curtis) between years. Finally, though the antecedent flow conditions were much drier before spring 08 than before spring 09 any potential differences in macroinvertebrate communities between those years may have been masked by the effects of bushfires in the intervening period.

- There was not sufficient information available to assess if the distribution of aquatic macrophytes, notably ribbon weed (*Vallisneria* sp.) and water primrose (*Ludwigia peploides*), along the lower Goulburn River has changed in recent years. Nor was there information from which to assess if processes such as water column primary production or community respiration has changed over time.

Unlike other rivers across northern Victoria (e.g. Campaspe, Loddon), there has been sufficient water to maintain continuous baseflow along the lower Goulburn River in recent years. This has sustained fish and macroinvertebrate populations during a time of ecological stress (drought) and is likely to have helped reduce the impact of poor quality watering entering the Goulburn from fire-affected tributaries. While there was insufficient information from which to assess aquatic macrophyte condition and primary production, the fact that macroinvertebrate and fish communities remained intact suggests that conditions were sufficient for the survival of each of these important river attributes. Overall, the scientific panel supported the idea of delivering freshes to increase flow variability and achieve additional ecological objectives, consistent with previous environmental flow studies (Cottingham et al. 2003, 2007) as the river recovers from drought.

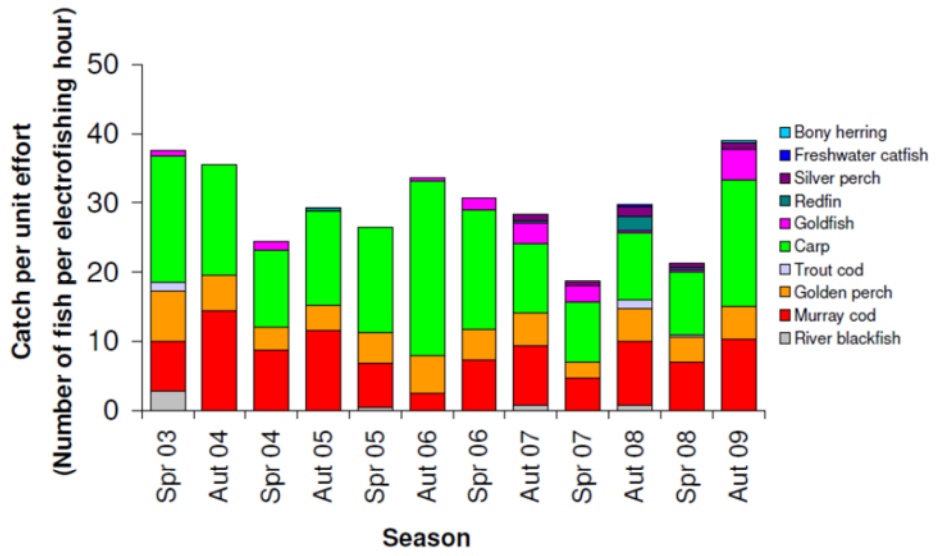


Figure 1: CPUE for large-bodied species captured from the lower Goulburn River 2003-2009 (from Koster et al. 2009).

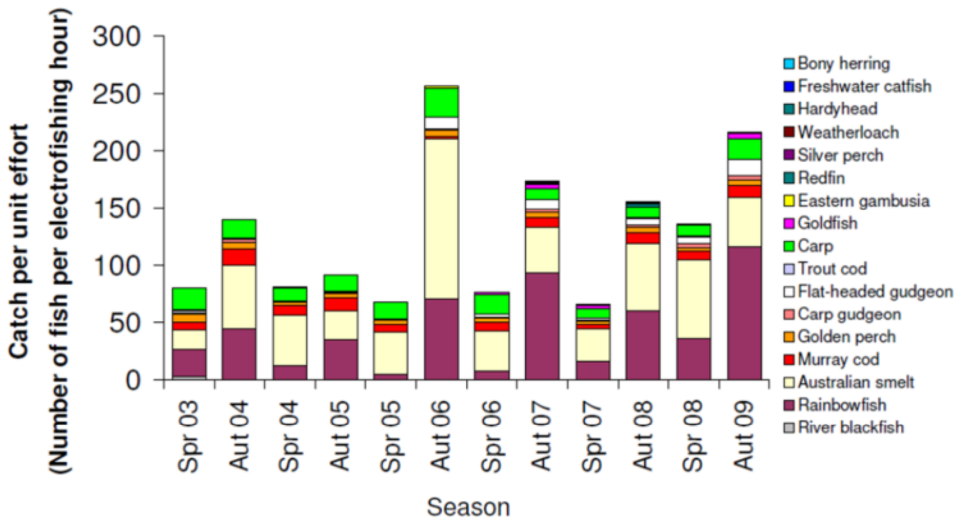


Figure 2: CPUE for all species captured from the lower Goulburn River 2003-2009 (from Koster et al. 2009).

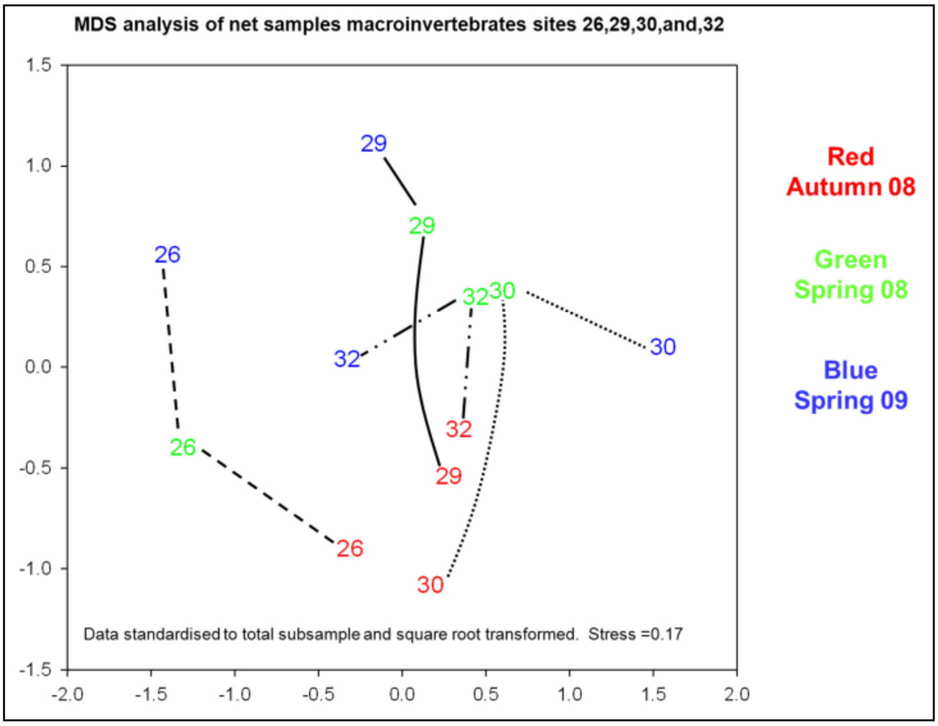


Figure 3: Multi-dimensional scaling plot of macroinvertebrate populations at sites along the lower Goulburn River. Site 26 = Goulburn River at Moss Rd; Site 29 = Goulburn River at Punt Rd; Site 30 = Goulburn River at Bicton Rd; Site 32 = Goulburn River at Darcy track.

3 DEFINITION AND DESIGN OF FRESHES FOR THE LOWER GOULBURN RIVER

3.1 General principles

The following general principles outlined by Cottingham et al. (2010) were adopted when considering the potential ecosystem response to flow freshes and how best to manage the Goulburn River as a refugial system in the current water year:

- Maintain a model-based Adaptive Management approach to learning from experience by developing conceptual models, setting hypotheses, identifying and implementing actions in line with those hypotheses, and evaluating ecosystem responses;
- Avoid critical loss of imperilled species (e.g. critically endangered species and at-risk remnant populations at a catchment or regional scale);
- Maintain viable populations of threatened species within the river system;
- Avoid irretrievable ecosystem damage or catastrophic events (e.g. extensive fish kills);
- Provide refuges for aquatic biota to allow recolonisation and facilitate recovery following drought or other disturbance;
- Continue a long-term perspective to maintain resilience and ecosystem functioning into the future.

The scientific panel kept in mind the principles listed above when considering the benefits and risks of delivering freshes under the three scenarios posed in section 3.2. It sought to ensure that the potential ecosystem benefits had a sound conceptual basis, and was mindful of ecosystem risks that might also occur when delivering freshes.

Given recent rainfall and the potential for increased water availability, the overall management response of delivering freshes represents a shift from ‘survival’ during drought to planning for ecosystem recovery. This means that management should be ready to take watering opportunities as they arise by:

- Identifying trigger levels for watering opportunities,
- Undertaking targeted monitoring to measure ecosystem response to watering events and gain knowledge to inform future management decisions, and
- Understanding the consequences of various alternative management options.

While the potential for increased water availability has improved with recent inflows, there is no guarantee that water availability next year will be better than the current year. The ultimate success of delivering flow freshes this year will be increased if there is sufficient environmental water available in the following year (2011/12) for the desired ecosystem responses to persist.

3.2 Scenarios

The scientific panel considered potential ecosystem benefits from the delivery of environmental water as pulses along the lower Goulburn River under three scenarios:

1. Environmental water delivered as a single, large event (i.e. approaching bankfull or greater in Reach 4: 20,000 – 30,000 ML/d);
2. Environmental water delivered as 2-3 smaller freshes of approximately 2,000-5,000[2] ML/d;
3. Environmental water delivered to increase the variability of baseflows.

It is anticipated that the GB CMA will use the Goulburn environmental water reserve to deliver the desired flow events (in cooperation with G-MW), supplementing natural inflows where possible. It is also possible that the variability desired under scenario 3 could be met by the delivery of Inter-valley Transfers from Lake Eildon to the Murray River.

3.3 What is a fresh?

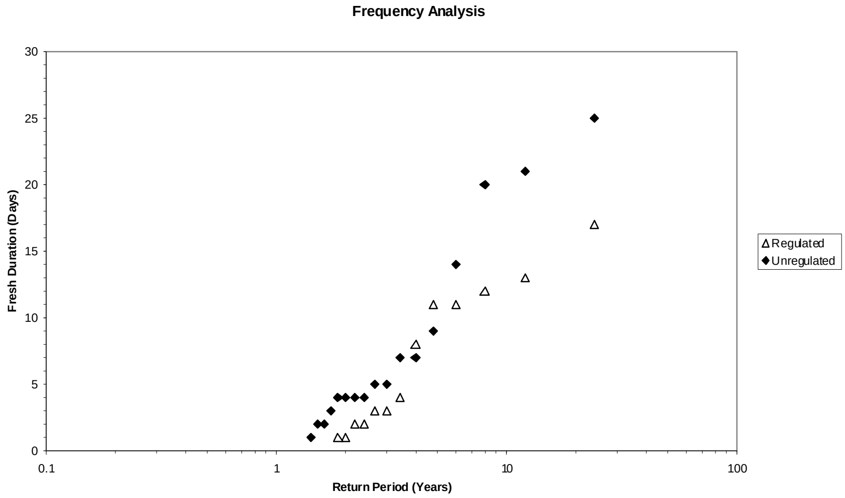
Previous studies on the lower Goulburn River (Cottingham et al. 2003, 2007) have used differing definitions of a fresh. These differences are explained in the following discussion.

The scientific panel developing environmental flow recommendations (Cottingham et al. 2003) defined a fresh in statistical terms, as a short-term flow event that exceeded baseflow by more than 1 standard deviation. Analysis of flow events between 1975 and 2000 indicated that spring freshes tended to be less frequent under regulated (historic) conditions compared with the (modelled) unregulated flow regime (Figure 4). Rain rejection flows (cancelled irrigation orders) still passed Goulburn Weir to the lower Goulburn River, and were considered to serve the same ecological role as freshes would under an unregulated flow regime. No environmental flow recommendations were made for a fresh, as the effects of differences in frequency and duration between the regulated and unregulated flow regimes could not be quantified in terms of ecological outcomes. The scientific panel, did however, state that the historic frequency of freshes should be continued in the future.

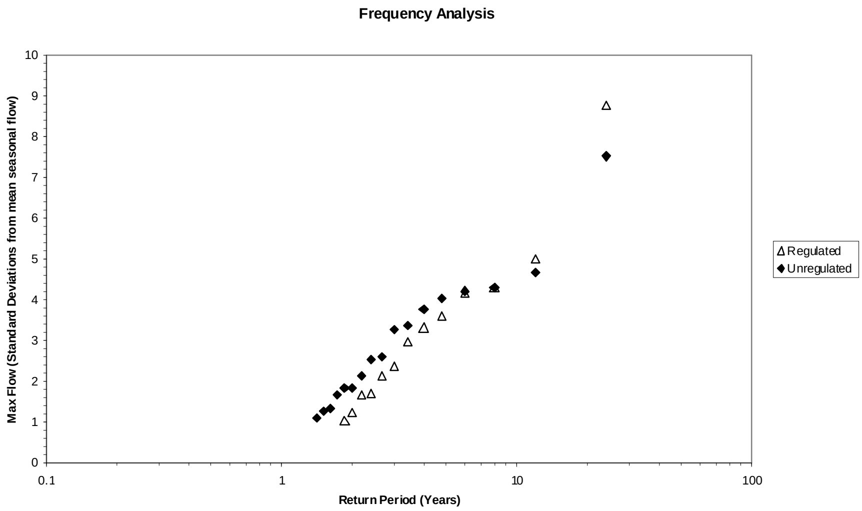
Flow events that inundated low-lying benches in the lower Goulburn River also occurred with a similar frequency under the regulated and unregulated flow regimes (Figure 5a), however their duration was greatly reduced in the regulated flow regime (Figure 5b). Again, no specific recommendation was given for these flow events, as there was insufficient knowledge of the ecological processes that occur following bench inundation, or of the duration of inundation that was required for the completion of such processes. This lack of knowledge was identified as an area requiring further investigation.

[2] Based on hydraulic modelling for a typical stretch of river on Reach 4 and Reach 5, Cottingham et al. (2003) identified that discharge of 2,000 – 5,000 ML/d would inundate in-channel features such as benches and increase the area of slackwater habitat for macrophytes, invertebrates and juvenile fish.

Ecological objectives identified as potentially affected by the delivery of freshes in the 2003 study are outlined in Table 1 to Table 3.

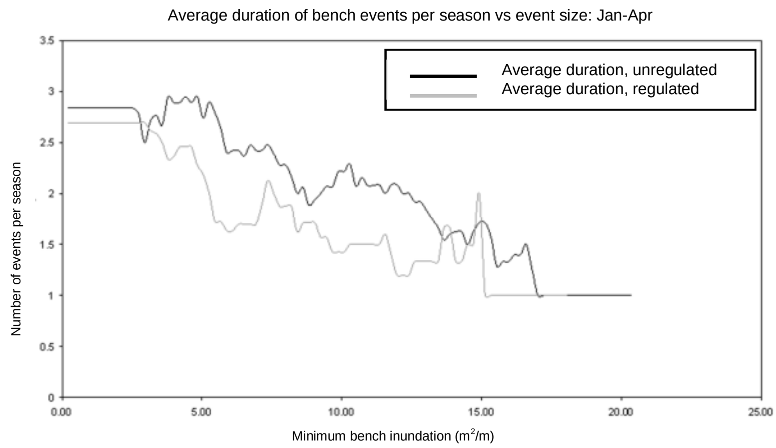


(a)

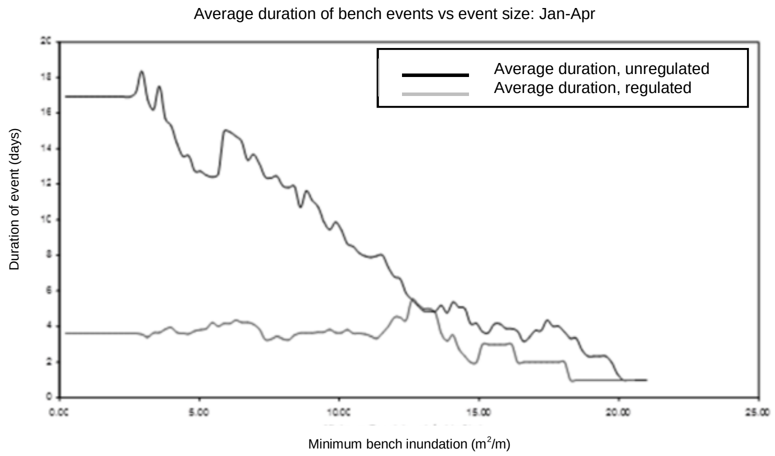


(b)

Figure 4: Comparison of spring (November-December) 'freshes': (a) duration and (b) magnitude for the current (regulated) versus modelled natural regime in Reach 4 (from Cottingham et al. 2003).



(a)



(b)

Figure 5: Frequency (a) and duration (b) of freshes that would inundate benches in the lower Goulburn River (from Cottingham et al. 2003).

Table 1: Ecological features and flow components to be assessed for in-channel vegetation of the lower Goulburn River (adapted from Cottingham et al. 2003).

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow related threats	Flow components to be considered
Vegetation	In-channel	• In –channel macrophyte stands provide habitat for fauna such as fish and invertebrates and contribute to river productivity	• Fair	• Increase the extent and diversity of aquatic vegetation • Increased contribution to processes such as river productivity	√√√	• Sediment accumulation (Reaches 4-5)	• Flushes that initiate the movement of fine sediments

Table 2: Ecological features and flow components to be assessed for macroinvertebrates in the lower Goulburn River (adapted from Cottingham et al. 2003).

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

Table 3: Ecological objectives for native fish populations of the lower Goulburn River (adapted from Cottingham et al 2003).

Ecological Attribute	Feature	Environmental or ecological value	Condition	Ecological objectives	Extent that objectives are flow related	Flow components to be considered
Fish	• Flood spawners • Main channel specialists	• Diversity of native fish • Naturally reproducing and self sustaining populations of native fish • Populations of threatened and icon species	• Poor • Fair-Poor	• Cues for adult migration during spawning season	√√√	• Freshes (Oct-Feb)
	• Flood spawners • Wetland specialists • Freshwater catfish		• Poor • Poor • Fair	• Floodplain and bench inundation for exchange of food and organic material between floodplain and channel	√√√	• Freshes (natural timing and duration) • Overbank flows (natural timing and duration)

When the scientific panel (Cottingham et al. 2007) considered the risks associated with passing Inter-Valley Transfers (IVTs) down the lower Goulburn River to the Murray River, it effectively re-defined freshes in ecological terms. It identified the particular magnitude and duration required to meet specific ecosystem objectives, usually related to the habitat requirements of biota such as macroinvertebrates (e.g. disruption of biofilm, increased wetted area) and geomorphic processes such as the mobilisation of fine sediments (Table 4 and Table 5).

Ecological objectives likely to be influenced by the delivery of freshes were confined to those flow events that occur for less than 50% of the nominated season in a median year (Table 6 to Table 10). Short flow events of between 860 ML/d – 10,700 ML/d are required to meet the stated ecosystem objectives for ‘in-channel’ processes in Reach 4 and Reach 5 of the lower Goulburn River. For example, various macroinvertebrate and geomorphic in-channel objectives for Reach 4 can be achieved by delivering freshes ranging from approximately 1,500 ML/d to 4,500 ML/d in summer (Table 6). Similarly, freshes of approximately 860 ML/d to 6,600 ML/d can be delivered during the main part of the irrigation season (December – April), so long as flows do not exceed 10,700 ML/d for more than 1-2 days (Table 7) and the rate of fall in the flow event is less than 0.15 m per day (based on the 90th percentile rate of fall: Table 8).

Table 4: Previously cited objectives (Cottingham et al. 2007) that are relevant to a fresh. Note: descriptions of the stressor limits are provided in Table 5.

Ecological Value	Attribute/objective code	Ecological Objective	Stressor code(s)	Seasons	Stressor mechanism
Diverse and resilient aquatic macroinvertebrate fauna that are an integral part of food webs	MI1	Provision of conditions suitable for aquatic vegetation, which provides habitat for macroinvertebrates	F007	Su	Slow shallow velocities required for establishment of aquatic vegetation
	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 dependent 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
			F025	Dec-Apr	Reduction in flow result in drying of large woody debris
	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.
	MI4	Entrainment of litter packs available as food/habitat source for macroinvertebrates (MI4)	F004	Su, Au, Sp	Shear stress required to disrupt (refresh) biofilms and entrain organic matter.
Natural Channel Form and Dynamics	Geo1 Geo3	Avoid notching Avoid slumping	F025	Dec-Apr	Long duration of stable flow followed by rapid draw-down. Impact likely to be exacerbated by loss of bank side vegetation.
			F023	Su	Excessive rates of fall in river level.
		Maintain pool depth Maintain natural rates of geomorphic disturbance	F026	Su	Unseasonal events that fill pools with sediment but do not flush them.

Table 5: Description of flow stressor limits for Reach 4 of the Goulburn River (Cottingham et al. 2007).

Flow element code*	Description	Summer	Autumn	Winter	Spring	Dec-Apr	Type
F002b	proportion of time when euphotic depth is less than 0.25 times the mean depth	X	X	X	X		duration
F004c	proportion of time when shear stress is more than 7 N/m2	X	X	X	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
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
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
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
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

*Note: Some stressor/codes presented in Table 4 (e.g. F026) were refined further with additional elements (e.g. F026a, b, c etc.) to explore differences related to inundation at particular levels/heights in the river channel. See Cottingham et al. (2007) for a full description.

Note: The values in the Table 6, Table 7 and Table 9 represent the proportion of time that discharge may exceed a particular bound (e.g. 0.40 = 40%) in the nominated season. Lower bounds represent the minimum sized event required to achieve an ecological objective. 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). Flow element codes are described in Table 5. Lower bounds represent the minimum sized event required to achieve an ecological objective. Upper bounds represent a threshold above which there is increased risk to ecosystem objectives if the flows exceed the upper bound for a prolonged period of time.

Table 6: Upper and lower limits for flow events identified for Reach 4 ecological objectives (adapted from Cottingham et al. 2007).

Ecological Objective	Flow Element Code	Discharge (ML/day)	Minimum	Proportion of time 10th percentile year	Proportion of time 30th percentile year	Proportion of time Median year	Proportion of time 70th percentile year	Proportion of time 90th percentile year	Maximum
Summer Lower Bound									
MI1	F007c	1500		0.10	0.30	0.45	0.75		
MI3	F007c	1500		0.15	0.30	0.40	0.70		
Geo3	F026f	2223		0.11	0.25	0.40	0.60	0.71	1.00
Geo3	F026e	3142		0.01	0.06	0.20	0.43	0.55	0.86
Geo3	F026d	4490				0.05	0.24	0.37	0.64

Table 7: Flow duration bounds identified for Reach 4 ecological objectives (adapted from Cottingham et al. 2007).

Environ. Objective	Flow Element Code	Lower Discharge (ML/day)	Upper Discharge (ML/day)	Minimum	Proportion of time 10th percentile year	Proportion of time 30th percentile year	Proportion of time Median year	Proportion of time 70th percentile year	Proportion of time 90th percentile year	Maximum
Summer Upper Bound										
MI2	F004c	5570	7440		0.01	0.01	0.02	0.30	0.50	
MI4	F004c	5570	7440		0.01	0.01	0.02	0.25	0.45	
Autumn Upper Bound										
MI2	F004c	5570	7440		0.01	0.01	0.02	0.30	0.60	
Dec-Apr Lower Bound										
MI2	F025h	856	1186			0.05	0.08	0.10	0.15	
Dec-Apr Upper Bound										
MI2	F025h	856	1186		0.02	0.20	0.30	0.35	0.45	
Geo1	F025d	3142	4490			0.04	0.10	0.15	0.20	0.33
Geo1	F025c	4490	6590				0.04	0.11	0.16	0.20
Geo1	F025b	6590	10700				0.01	0.05	0.08	0.12

Table 8: Rate of rise and fall required to avoid risk of bank slumping in Reach 4 (from Cottingham et al. 2007).

	Moderate Risk				*Recommended*				
	upper bound 80th daily change	*lower bound 90th daily change*	*upper bound 90th 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/d	*>4000 ML/d*
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

Table 9: Upper and lower limits for flow events identified for Reach 5 ecological objectives (adapted from Cottingham et al. 2007).

Environ. Objective	**Flow Element Code**	**Flow Threshold (ML/day)**	**Minimum**	**Proportion of time 10th percentile year**	**Proportion of time 30th percentile year**	**Proportion of time Median year**	**Proportion of time 70th percentile year**	**Proportion of time 90th percentile year**	**Maximum**
Summer Lower Bound									
Geo3	F026f	2711	0	0.09	0.21	0.35	0.60	0.87	1.00
Geo3	F026e	3800	0	0	0.05	0.20	0.40	0.66	1.00
Geo3	F026d	5240	0	0	0	0.02	0.22	0.43	0.71
Summer Upper Bound									
Geo3	F026f	2711	0	0.09	0.21	0.35	0.60	0.87	1.00
Geo3	F026e	3800	0	0	0.05	0.20	0.40	0.66	1.00
Geo3	F026d	5240	0	0	0	0.02	0.22	0.43	0.71
MI2	F004c	5610		0.01	0.01	0.02	0.30	0.50	
MI4	F004c	5610		0.01	0.01	0.02	0.25	0.45	
MI2	F002b	8910		0.01	0.01	0.01	0.05	0.15	
Autumn Upper Bound									
MI2	F004c	5610		0.01	0.01	0.02	0.30	0.60	
MI4	F004c	5610					0.03	0.10	
MI2	F002b	8910		0.01	0.01	0.01	0.01	0.05	

Table 10: Flow duration bounds identified for Reach 5 ecological objectives (adapted from Cottingham et al. 2007).

Environ. Objective	Flow Element Code	(U)pper or (L)ower bound	Lower Flow Threshold (ML/day)	Upper Flow Threshold (ML/day)	Minimum	Proportion of time 10th percentile year	Proportion of time 30th percentile year	Proportion of time Median year	Proportion of time 70th percentile year	Proportion of time 90th percentile year	Maximum
Summer											
MI1	F007c	L	440	1820			0.10	0.30	0.45	0.75	
MI3	F007c	L	440	1820		0	0.15	0.30	0.40	0.70	
Dec - Apr											
Geo1	F025c	U	5240	7560				0.02	0.09	0.18	0.24
Geo1	F025d	U	3800	5240			0.03	0.06	0.15	0.23	0.39
MI2	F025h	U	1096	1505		0.02	0.2	0.30	0.35	0.45	
MI2	F025h	L	1096	1505		0	0.05	0.08	0.10	0.15	

3.4 Ecosystem objectives for each scenario

This report follows same definition of a fresh as used by Cottingham et al. (2007). As discussed in the previous sections, the scientific panel considered potential ecosystem benefits from the delivery of environmental water as pulses along the lower Goulburn River under three scenarios:

1. Environmental water delivered as a single, large (approaching bankfull or greater: 20,000 ML/d-30,000 ML/d) fresh;
2. Environmental water delivered as 2-3 smaller freshes of approximately 860-6,600 ML/d[3];
3. Environmental water delivered to increase the variability of baseflows.

Note that the magnitude of freshes listed for scenario 2 above are based on the lower flow bounds required to meet objectives listed in Table 4.

3.4.1 Scenario 1 – single large bankfull event

Under this scenario, environmental water would be banked until a sufficient volume was available to deliver a flow event of sufficient magnitude, and duration based on the rates of rise and fall defined in Table 8.

> Examination of flow data indicates that flow event of bankfull or greater has not occurred in Reach 4 or Reach 5 since 1996. The scientific panel therefore concluded that delivery of a bankfull event is a high priority.

[3] Freshes between 860 ML/d – 6,600 ML/d are based on the lower bounds recommended in Tables 6-10. Flow events can exceed these magnitudes for short periods, assuming appropriate rates of rise and fall or water levels.

The features of this event include:

- **Magnitude**: 20,000 ML/d – 30,000 ML/d. Note that different outcomes are likely at 20,000 ML/d compared with 30,000 ML/d. At 20,000 ML/d, water starts leaving the main channel and flows into anabranches and wetlands such as the Wakiti Creek system (Cottingham et al. 2003). Once river levels fall, water will return to the Goulburn River. At 30,000 ML/d, flow inundates more of the lower Goulburn floodplain and enters wetlands and effluent creeks such as the Deep Creek system, which is an area of shedding floodplain that discharges to the Murray River (Moroka Pty Ltd 2005).
- **Timing**: End of May until the end of October (period in which such events would occur in an unregulated flow regime).
- **Duration**: Minimum 2 days at peak discharge, with appropriate rates of rise and fall.
- **Rate of rise and fall**: Rate of rise not to exceed 0.80m per day; rate of fall not to exceed 0.72m per day. Rates are based on preferred 80th percentile values for spring in Table 8.

Figure 6 shows the hydrographs required to comply with target rates of rise and fall, based on rates of rise and fall provided for Reach 4. The total volume of the flow event over its duration is estimated as 210 and 310 GL for peak flows of 20,000 ML/d and 30,000 ML/d, respectively. The hydrographs have been prepared using the rates of rise and fall listed above and stage relationships presented in Figure 7. The stage relationships for Reach 4 and Reach 5 can be used to identify the flow (ML/d) in relationship to river height, which is how rates of rise and fall are expressed above. The total volume for an event of each magnitude could be reduced by adopting the higher risk (moderate) rates of rise and fall listed in Table 8 (e.g. 2.74m rate of rise, 1.15m rate of fall).

It is unlikely that an event of this magnitude would be released from storage. Rather, flows would be released from storage to ‘piggy-back’ on natural rainfall-runoff events.

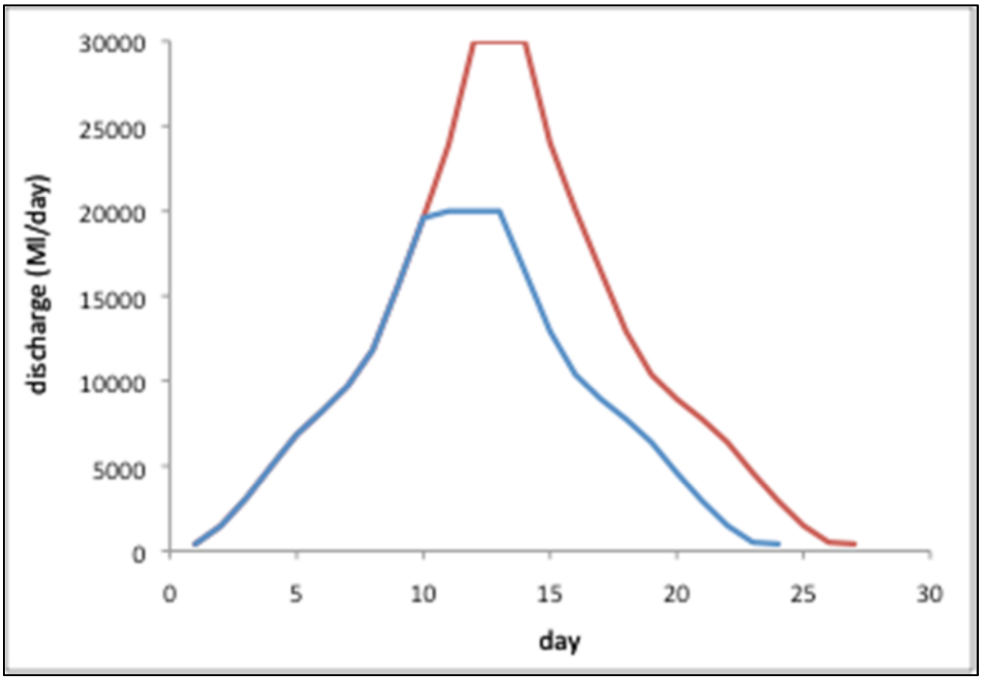


Figure 6: Environmental flow pulses with peaks of 20,000 ML/d and 30,000 ML/d.

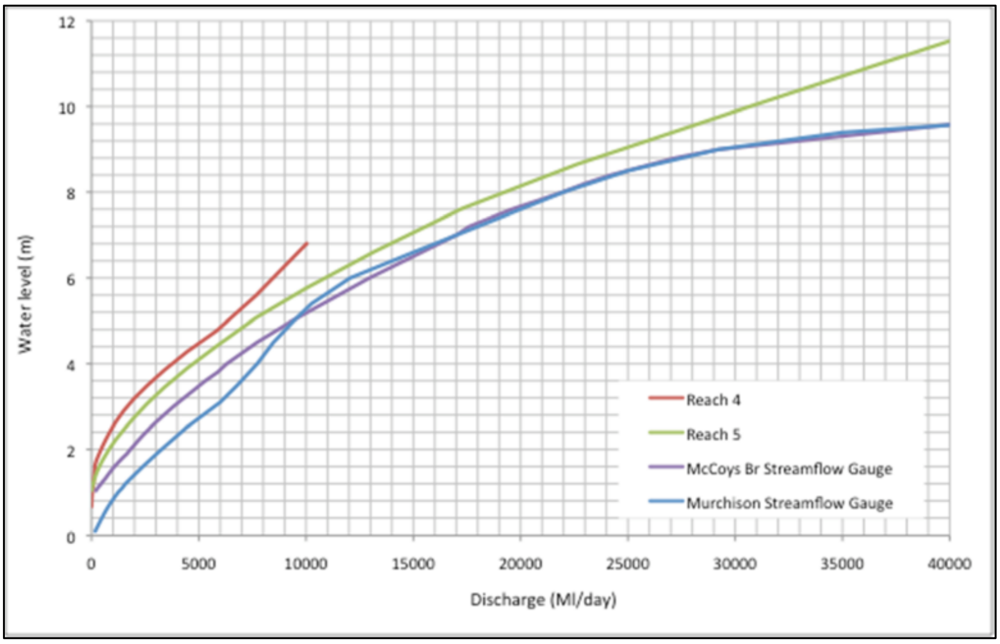


Figure 7: Stage-discharge relationships for the lower Goulburn River.

Geomorphology

It is anticipated that flows approaching bankfull will have sufficient shear stress to mobilise and move fine sediments, as well as to scour sediments from pools. This will maintain the diversity and quality of habitat for aquatic biota (Table 11).

Table 11: Proposed geomorphology-related objectives for Scenario 1.

Objective	Timing of flow event	Hypotheses to be tested
• Maintain pool depth.	• May – October.	• Flow event will mobilise fine sediments. • Flow event will increase or maintain pool depth.
• Maintain natural rates of geomorphic disturbance.	• May – October.	• Flow event will increase or maintain channel geomorphic diversity.
• Avoid notching or slumping of the river bank	• Any event	• Rates of rise and fall below the 90th percentile value will maintain rates of bank erosion within natural limits.

Fish

Monitoring of fish communities along the lower Goulburn River undertaken since 2003 (Koster et al. 2009) indicates that there has been little breeding of native fish that are reliant on high flows to initiate spawning (e.g. Golden perch) since 2003. Acoustic-tracking studies have shown that some individual Golden perch leave the lower Goulburn and enter the Murray River following the arrival of freshes along the lower Goulburn River (e.g. approximately 3,500 ML/d, Koster et al. 2009). It is possible that this movement out of the Goulburn River is pre-spawning migration to breeding sites in the Murray River. While smaller freshes of 2,000-5,000 ML/d do not appear to trigger Golden perch spawning in the lower Goulburn, it is unclear if the same would be true for larger events such as a bankfull discharge.

The scientific panel recommends that the effects of a bankfull flow on native fish populations be monitored by the GB CMA as part of an adaptive management experiment to detect:

- Whether or not Golden perch and other flow-cued species spawn in the lower Goulburn River in response to the larger flow event;
- Whether a bankfull flow initiates migration of native fish into or out of the lower Goulburn River
- Whether recruitment of native fish species is enhanced following the bankfull flow.

If, as hypothesised, mature Golden perch migrate from the lower Goulburn to spawn in the Murray River, then the timing of a bankfull discharge should best coincide with natural and/or environmental flows in the Murray River. Golden perch spawning in the Murray River in the Barmah-Millewa Forest and Murray-Goulburn junction areas has been shown to be enhanced during high flow events at relatively high temperatures from 17-25^{o}C (King et al. 2005; 2009). Coinciding the timing of flows in the Goulburn and Murray rivers would greatly increase the likelihood that fish leaving the Goulburn River will have access to suitable breeding conditions. To achieve the above, the bankfull event should be timed to occur from early October to late December, if possible, or other such time in spring when water temperature exceeds 17^{o}C (King et al. 2009).

As the magnitude of a bankfull event exceeds 20,000 ML/d, water will enter off-channel habitat such as flood-runners, low-lying billabongs and depressions in the landscape. This will provide spawning cues and habitat for wetland-specialist fish species, as well as providing a source of organic carbon into the river that can increase the productivity of food sources for fish.

Table 12: Proposed native fish objectives for Scenario 1.

Objective	Timing of flow event	Hypotheses to be tested
• Initiate spawning, pre-spawning migrations and recruitment of native fish	• Preferably October (as late as possible in spring/early summer to maximize chances of water temperature exceeding 17^{o}C).	• Flow event will trigger spawning by Golden perch in the lower Goulburn • Flow event will trigger pre-spawning migration movement by Golden perch. • Flow event will enhance recruitment of native fish in the lower Goulburn.
• Increase habitat availability for wetland-specialist species.	• Preferably October.	• Flow event will increase area of and access to off-channel habitat for wetland-specialist species. • Wetland-specialist species will breed in larger off-channel habitat features.

In addition to potential ecosystem benefits, a large event such as a bankfull discharge also poses ecosystem risks. Carp are known to spawn in response to large flow events in spring and summer (Stuart and Jones 2002; King et al. 2003; Crook and Gillanders 2006) and it must be assumed that they would also spawn in response to the release of a bankfull flow along the lower Goulburn River. One possible way to limit carp breeding success, whilst still achieving other environmental objectives, may be to quickly reduce water levels once carp have laid their eggs (Figure 8), which are adhesive and are laid amongst vegetation on the floodplain and river bank (Stuart and Jones 2002). By rapidly dropping the water level, it is likely that at least a proportion of the eggs will be stranded before they can hatch (which takes 2-6 days). This is unlikely to disadvantage native fish, as they either spawn pelagic eggs during flow events (e.g. Golden perch) or will not be triggered to spawn by the flow event (e.g. Murray cod).

A rapid reduction in water levels may pose an increased risk of bank slumping. However, the scientific panel considered that risk of widespread bank slumping was relatively low given the short duration of a bankfull event (i.e. the river bank was unlikely to become saturated) and that vegetation was likely to provide some ‘armouring’ of the river bank.

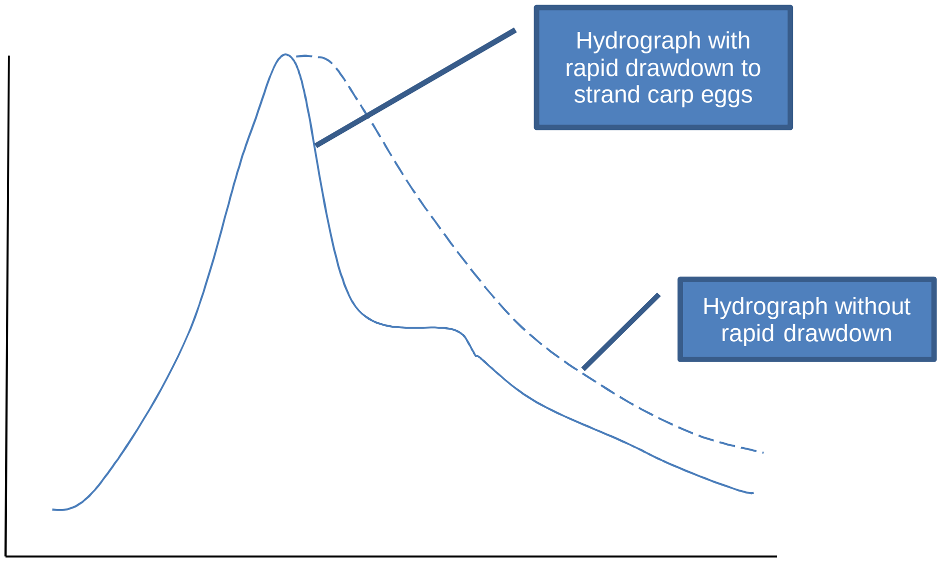


Figure 8: Example hydrograph with rapid drawdown to strand carp eggs.

Invertebrates

Objectives for invertebrates relate to the provision of a diverse range of habitats, which in turn will affect invertebrate diversity and biomass (Table 13). The objectives and hypotheses proposed are consistent with VEFMAP hypotheses (Chee et al. 2006) such as:

- Do implemented environmental flows increase volume of pool habitats?
- Do implemented environmental flows result in temporary inundation of higher-level channel edge macrophytes, tree roots, woody debris, bars, benches, overhanging/undercut banks?
- Do implemented environmental flows improve macroinvertebrate community structure?

Table 13: Proposed macroinvertebrate objectives for Scenario 1.

Objective	Timing of flow event	Hypotheses
• Provision of conditions suitable for aquatic vegetation, which provides habitat for macroinvertebrates	• Any time from late May to October.	• Maintenance of aquatic vegetation will preserve invertebrate diversity and biomass.
• Submersion of snag habitat within the euphotic zone to provide habitat and food source for macroinvertebrates.	• Any time from late May to October.	• Submersion of snags will increase food resource diversity
• Provision of slackwater habitat favourable for planktonic production (food source) and habitat for macroinvertebrates.	• Any time from late May to October.	• Increased slackwater habitat area will lead to a relative increase in planktonic food production. • Slackwater habitat area will initially increase and then decrease as discharge increases and approaches bankfull.

Objective	Timing of flow event	Hypotheses
• Entrainment of litter packs available as food/habitat source for macroinvertebrates.	• Any time from late May to October.	• Increasing discharge will entrain and redeposit course organic matter, reducing burial of the resource and creating concentrations (e.g. leaf-packs against snags) that result in diverse habitats and food supply for invertebrates. • Invertebrate biomass will increase as available organic matter increases. More diverse habitats lead to complex food-webs and biodiversity.
• Biomass equivalent to similar streams elsewhere.	• Any time from late May to October.	• Increased habitat and food resource availability will increase invertebrate biomass to similar of that of other lowland rivers.
• Trophic structure and diversity with a more balanced representation of all functional groups.	• Any time from late May to October.	• Flow event will increase habitat diversity and availability for invertebrates. • Flow event will scour biofilms, resetting them as a food source for invertebrates.

Vegetation

This scenario is a step towards reversing terrestrialisation on banks and benches by favouring diversity in plant functional types (hopefully increase in amphibious plants) at the water-bank interface, which at present makes quite a sudden transition from a terrestrial to aquatic environment with narrow to zero band of amphibious plants (e.g. domination by *Eucalyptus camuldensis*, see VEFMAP raw data). However, without long duration events, vegetation changes are likely to be small, hard to detect and happen progressively through time, assuming that such flow events are released each year.

By allowing low-lying wetlands to fill and then dry naturally, a flow event of 20,000 ML/d – 30,000 ML/d will also give wetland plants the chance to grow and replenish seedbanks. In this case, timing (season) is important because flooding earlier (winter) when evaporation is low means water will persist longer than flooding in spring (high evaporation into summer could mean durations is too short to allow re-growth and complete flowering). Given that the floodplain has not been inundated since 1996, it is likely that floodplain wetlands will already have suffered a severe depletion in terms of seed abundance and species loss.

Although the response may be hard to monitor (e.g. it is difficult to know when an event of this magnitude might occur and so when to collect 'before' data; benefits of increased seedbank diversity may only occur over time) delivery of an event that will inundate low-lying wetlands and other floodplain features is recommended in order to reinvigorate and replenish wetland and riparian plants.

The best outcome in terms of increased extent and diversity of riparian and wetland plants will be achieved if there are similar such events in subsequent years. The VEFMAP model for spring bankfull flows provides the basis for monitoring vegetation responses in the future. Hypotheses to consider in relation to a bankfull event are listed in Table 14.

Table 14: Proposed vegetation objectives for Scenario 1.

Objective	Timing of flow event	Hypotheses
• Increase the extent and diversity of aquatic vegetation.	• Any time from late May to October?	• Bankfull flow will disrupt sediments and increase wetted area for aquatic vegetation (in-channel).
• Increased aquatic macrophyte contribution to in-channel productivity.	• Any time from late May to October?	• Increased aquatic vegetation extent and biomass will increase the relative proportion of macrophyte production to overall in-channel production.
• Replenishment of riparian and wetland vegetation.	• Any time from late May to October.	• Inundation will increase the emergence of seedlings from the riparian and wetland seedbank.
• Maintain existing plants.	• Any time from June - November	• Inundating benches will stimulate a growth pulse in perennial groundcover and terrestrial shrubs and trees, and increase flowering and seed set relative to unflooded areas.
• Maintain vegetation diversity and replenish seedbanks of existing vegetation	• Any time from June - November	• Inundation of lower bank will increase soil moisture and result in vegetative growth and flowering, and also trigger germination, relative to unflooded banks.

3.4.2 Scenario 2 – multiple freshes

Examination of flow data indicated that freshes of 860 – 6,600 ML/d would occur between June and November each year under an unregulated flow regime, often with a duration of many weeks. They can also occur in the summer-autumn period, but with a much shorter duration (e.g. up to 4 days).

Under this scenario, freshes serve to increase the diversity of flows, and hence habitat availability after a prolonged period of (stable) low flow. The scientific panel considered that it would be better to deliver multiple freshes, rather than a single event. Freshes of this magnitude are hypothesised to:

- Increase wetted area, including that of low-lying benches;
- Disrupt biofilms, move fine sediments and entrain organic matter;
- Submerge snags and increase slackwater habitat for fish larvae and juveniles, aquatic macrophytes and invertebrates;
- Increase habitat diversity and food resources for invertebrates;
- Provide cues for spawning and migration by Golden perch if in late spring or early summer;
- Increase native fish recruitment.

Freshes may also serve to improve water quality, assuming the released water is of sufficient quality. For example, freshes might be released to reduce high turbidity due to the discharge of poor quality water from fire-affected tributaries. Freshes might also be released to reduce instances stratification and increase DO concentration (Cottingham et al. 2010).

As it is desirable to test the ecosystem outcomes from freshes of different magnitudes, and given that the lower Goulburn has already experienced freshes this year, it is recommended that at least one fresh at the upper end of the 860 ML/d - 6,600 ML/d range be released in this water year (preferably late spring), as this will provide the strongest ecosystem signal. It is also recommended that if multiple freshes are delivered as managed releases (spring-autumn), then these should be at least 30 days apart.

Fresh(es) should be delivered to coincide with the timing window for Golden perch in order to maximise the chances of detecting an ecosystem response signal. Results can be used to inform the timing of releases in subsequent years.

The features of flow freshes include:

- **Magnitude**: 860 ML/d – 6,600 ML/d. Flows above approximately 860 ML/d – 5,600 ML/d will meet macroinvertebrate objectives (see Tables 6-10), while flows above approximately 2,200 ML/d – 6,600 ML/d would meet geomorphic objectives. Flow can exceed 6,600 ML/d in spring with little risk to ecosystem objectives, assuming appropriate rates for rise and fall. The duration of events exceeding 6,600 ML/d in summer and autumn should be kept to 6 days in order to protect ecosystem objectives for macroinvertebrates.
- **Timing**: June - November.
- **Duration:** Minimum 2 weeks at peak discharge (e.g. for emergence of invertebrates, seed germination), with appropriate rates of rise and fall.
- **Rate of rise and fall:** Rate of rise not to exceed 0.80m per day; rate of fall not to exceed 0.72m per day. Rates are based on the preferred 80th percentile values given in Table 8**.**

Note:
The above scenario of flow freshes was developed prior to the recent rainfall and bankfull flow events, and as an alternative to a bankfull flow winter-spring. Recent (late August 2010) rainfall and flow events means that the emphasis can shift from delivering freshes in winter-spring to their delivery in summer-autumn (see section 3.4.4 and section 5).

Geomorphology
Geomorphology objectives and hypotheses relevant to flow freshes are listed in Table 15. Freshes are unlikely to provide the same stream power and shear stress to achieve the geomorphic objectives as for a for a bankfull discharge. The emphasis here is on the mobilisation of fines sediments in order to improve habitat quality for biota such as macroinvertebrates.

Table 15: Proposed geomorphology-related objectives for Scenario 2.

Objective	Timing of flow event	Hypotheses
• Maintain aquatic macrophyte, invertebrate and fish habitat	• June - November.	• Freshes will mobilise fine sediments. • Freshes will disrupt biofilms on hard substrate.
• Avoid notching or slumping of the river bank	• Any event	• Rates of rise and fall below the 90th percentile value will maintain rates of bank erosion within natural limits.

Fish

As for the bankfull event, the native fish objective for freshes is in the form of an adaptive management experiment to detect if Golden perch respond by undertaking pre-spawning migrations to the Murray River, or detect if freshes are of sufficient magnitude to attract Golden perch from the Murray River (Table 16).

Table 16: Proposed native fish objectives for Scenario 2.

Objective	Timing of flow event	Hypotheses to be tested
• Initiate spawning, pre-spawning migrations and recruitment of native fish	• Preferably October (as late as possible in spring/early summer to maximize chances of water temperature exceeding 17^{o}C).	• Flow event will trigger spawning by Golden perch in the lower Goulburn • Flow event will trigger pre-spawning migration movement by Golden perch. • Flow event will enhance recruitment of native fish in the lower Goulburn.

Invertebrates

As was the case for a bankfull event, invertebrate objectives relate to maintaining or increasing habitat diversity, as well as having a ‘resetting’ or ‘refreshing’ effect on some aspects of macroinvertebrate ecosystems by shifting silt or biofilms (Table 17).

Table 17: Proposed macroinvertebrate objectives for Scenario 2.

Objective	Timing of flow event	Hypotheses
• Provision of conditions suitable for aquatic vegetation, which provides habitat for macroinvertebrates	• Any time from June to November.	• Maintenance of aquatic vegetation will preserve invertebrate diversity and biomass.
• Submersion of snags and temporary shift in the euphotic zone to reset periphytic community structure and production.	• Any time from June to November.	• Re-setting of periphytic diversity and production will improve invertebrate food resource particularly on important snag habitats.
• Replenish slackwater habitat favourable for planktonic production (food source) and habitat for macroinvertebrates.	• Any time.	• Increased slackwater habitat area will lead to a relative increase in planktonic food production. • Some return of macro- and microinvertebrates to the channel on flow decline – food resource and inoculation

Objective	Timing of flow event	Hypotheses
• Resuspension and removal of settled fine sediment from submerged surfaces enhances benthic primary production and invertebrate habitat.	• Any time.	• Increasing discharge will entrain and redeposit course organic matter, reducing burial of the resource and creating concentrations (e.g. leaf-packs against snags) that result in diverse habitats and food supply for invertebrates. • Invertebrate biomass will increase as available organic matter increases. More diverse habitats lead to complex food-webs and biodiversity.
• Biomass equivalent to similar streams elsewhere.	• Any time.	• Increased habitat and food resource availability will increase invertebrate biomass to similar of that of other lowland rivers.
• Foodweb complexity (and trophic diversity) supported through a pulse disturbance	• Any time.	• Flow event will increase habitat diversity and availability for invertebrates. • Flow event will scour biofilms, resetting them as a food source for invertebrates.

Vegetation

Freshes of minimum 2 weeks duration are likely to increase the in-channel wetted area for aquatic macrophytes and inundate low-lying bench areas. This may occur in either the non-growing (winter) or early growth (spring) season, and in turn remove some flood intolerant plants, as well as leaf litter and dead standing (plant) material. A single fresh is unlikely to affect the assemblage of plants on the river bank, as vegetation is unlikely to be out of the euphotic zone for long, if at all.

Irrigating the soil on the benches may, however, result in the germination of both native and non-native species, as well as flushes of new growth in established plants. Thus vegetative cover may be expected to increase and an improvement in vigour may lead to more flowering in both woody and non-woody species. While a detectable change in cover may occur approximately 8-12 weeks after a fresh (e.g. Warwick and Brock 2003), the changes are unlikely to persist if there is only one fresh for one year. However, if there are multiple events and the second or subsequent events occur 2-3 months after the first, then there may be a change in assemblage, as a second event would act as a selective filter on successful recruitment by drowning out young terrestrial species (intolerant of submergence) and causing a shift to amphibious species. Objectives and relevant hypotheses to consider are listed in Table 18.

Table 18: Proposed vegetation objectives for Scenario 2.

Objective	Timing of flow event	Hypotheses
• Increase the extent and diversity of aquatic vegetation.	• Any time from June - November	• Freshes will disrupt sediments and increase wetted area for aquatic vegetation (in-channel).
• Increased aquatic macrophyte contribution to in-channel productivity.	• Any time from June - November	• Increased aquatic vegetation extent and biomass will increase the relative proportion of macrophyte production to overall in-channel production.
• Reinvigoration of riparian and wetland vegetation.	• Any time from June - November	• Inundation will increase the emergence of seedlings from the riparian and wetland seedbank.
• Maintain existing plants.	• Any time from June - November	• Inundating benches will stimulate a growth pulse in perennial groundcover and terrestrial shrubs and trees, and increase flowering and seed set relative to unflooded benches
• Maintain vegetation diversity and replenish seedbanks of existing vegetation	• Any time from June - November	• Inundation of lower bank will increase soil moisture and result in vegetative growth and flowering, and also trigger germination, relative to unflooded banks
• Increase diversity of types of plants	• Any time from June - November	• A repeat inundation(s) of benches and lower banks will affect species composition, and cause a shift towards amphibious species (number, cover) and away from terrestrial species (number, cover) favoring amphibious species.

3.4.3 Scenario 3 – increased variability of winter-spring baseflow

The intention of this scenario is to cycle water levels by ±40 cm (a change in depth and potential ecological response (vegetation, habitat) that could be detected) over the period of a month or so to introduce a pattern of wetting and drying. This fluctuation can be achieved as part of operational management of the river. It is expected that such fluctuation in water levels will contribute to the:

- Disturbance of biofilm on snags and other hard surfaces;
- Area suitable for the growth of littoral emergent vegetation;
- Diversity of littoral vegetation;
- Entrainment of organic matter (primarily from dissolved and fine particulate) from the river bank and increase primary and bacterial production;
- Access to slackwater habitat by invertebrates and fish larvae and juveniles;
- Maintenance of good water quality conditions by increasing DO concentration and reducing the extent of water column stratification.

The scientific panel considered that the use of environmental water reserve (EWR) to fluctuate baseflow did not represent a discrete flow pulse, such as a fresh. No specific recommendations about the magnitude, timing and duration of releases have been prescribed.

Ecological outcomes are anticipated to be a sub-set of those listed for Scenario 2 for macroinvertebrates (Table 21) and vegetation (Table 22), as the change in wetted area and position of shallow water within the channel is most likely to influence these ecosystem attributes.

Table 19: Proposed macroinvertebrate objectives for Scenario 3.

Objective	Timing of flow event	Hypotheses
• Provision of conditions suitable for aquatic vegetation, which provides habitat for macroinvertebrates	• Any time November - April	• Maintenance of aquatic vegetation will preserve invertebrate diversity and biomass.
• Submersion of snags and temporary shift in the euphotic zone to reset periphytic community structure and production.	• Any time November - April	• Re-setting of periphytic diversity and production will improve invertebrate food resource particularly on important snag habitats.
• Replenish slackwater habitat favourable for planktonic production (food source) and habitat for macroinvertebrates.	• Any time November - April	• Increased slackwater habitat area will lead to a relative increase in planktonic food production. • Some return of macro- and microinvertebrates to the channel on flow decline – food resource and inoculation

The panel also considered that VEFMAP was well placed to monitor ecological response to fluctuations in the low-flow regime. For example, VEFMAP already monitors the riverbank vegetation assemblages, with its approach based on changes to vegetation assemblage zones within the river bank. The outcome of increased baseflow variability under this scenario is likely to be a wider fringe of macrophyte cover and an increase in number of amphibious functional groups at the littoral edge. This outcome may not be evident in one growing season and will require careful analysis of VEFMAP data (assigning species to amphibious/terrestrial/aquatic categories) for zones within the river bank. Initially (e.g. in the first year) this will mean germination and establishment of amphibious plants amongst terrestrial species. If repeated over successive years, then the balance between the cover of amphibious and terrestrials will gradually change; this is similar to the VEFMAP conceptual model for effects of seasonal spring freshes.

Table 20: Proposed vegetation objectives for Scenario 3.

Objective	Timing of flow event	Hypotheses
• Increase the extent and diversity of amphibious littoral vegetation.	• Any time November - April	• Variability in water level will increase area of wetted sediments suitable for amphibious vegetation.

3.4.4 Priority for the current water year

Given that recent rainfall-runoff events have delivered freshes to the lower Goulburn River in the lead up to this project, the emphasis for the rest of the water year was to be on delivering a bankfull discharge, if possible. If this was not possible by the end of October, then smaller freshes (2 or more) of 860 ML/d-6,600 ML/d should be delivered over the summer-autumn period (December – April). The recent bankfull event (late August 2010) along the lower Goulburn River means that priority for the use of environmental water can now shift to delivering freshes over summer-autumn. Freshes delivered as managed releases should be separated by no less than 30 days to maximise the benefits expected from meeting ecosystem objectives for invertebrates (disrupting biofilms to refresh them as a food source for macroinvertebrates), or by no less than 60 days in order to favour amphibious plant species over terrestrial species growing on low-lying benches. The preference of the scientific panel is to deliver a fresh with a magnitude at the upper end of the range, as this is likely to provide the largest ecosystem response, which will increase the likelihood of detecting changes when monitoring.

The need for a bankfull event in spring 2011 should be reviewed in light of antecedent conditions in the lead up to the 2011/12 water year.

It should be noted that risks associated with bankfull discharge and freshes have been considered in terms of potential effect on ecosystem assets and processes. Considering socio-economic risks associated with these flows was beyond the scope of the project.

4 MONITORING AND EVALUATION CONSIDERATIONS

The discrete nature of flow pulses such as freshes and the ecosystem response they generate means that monitoring and evaluation forms part of an intervention analysis experiment within an adaptive management framework. The conceptual basis for the ecosystem response to freshes has largely been covered as part of the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP) as it is applied to the Goulburn River (Chee et al. 2006).

In most instances, hypotheses can only be tested with a 'before-after' design, as there will not be suitable controls against which to asses impact under a full BACI design. The exception may be for assessing vegetation responses to the inundation of low-lying benches should there be benches that remain dry (controls) at flows of 860 – 6,600 ML/d.

The monitoring proposed in the following sections is in addition to monitoring already undertaken as part of other GB CMA programs (e.g. DO monitoring, lower Goulburn fish surveys). It highlights hypotheses that may be tested and relevant variables to consider for monitoring. It does not provide detailed information on monitoring design (e.g. number of sites, number of times, costing, logistics), as this was beyond the scope of this project.

4.1 Geomorphology

Hypotheses and variables to monitor (Table 21) are broadly consistent with monitoring recommended for geomorphic Zone 2 as described by Chee et al. (2006).

Table 21: Hypotheses and variables to consider for assessing geomorphic responses.

Objective	Hypotheses	Variables to monitor
• Maintain pool depth.	• Flow event will mobilise (redistribute) fine sediments. • Flow event will increase or maintain pool depth.	• Sediment cores (grain size analysis). • Thalweg depth.
• Maintain natural rates of geomorphic disturbance.	• Flow event will increase or maintain channel geomorphic diversity.	• Rate of bench deposition • Bed complexity • Bench development and variability • Mean channel top width, cross-section area and thalweg depth • Bank erosion on outside of meander bends • Point bar development.
• Avoid notching or slumping of the river bank	• Rates of rise and fall below the 90th percentile value will maintain rates of bank erosion within natural limits.	• Disturbance at the toe of the bank. • River levels.

4.2 Fish

Hypotheses and variables to monitor (Table 22) are broadly consistent with those described for native fish by Chee et al. (2006). The panel concluded that understanding of the responses to the provision of freshes in the lower Goulburn is best addressed by testing specific hypotheses about the behavioural responses of fish, as well as determining population-level effects. To achieve this, larval drift surveys during and immediately after flows are recommended to test if Golden perch are triggered to spawn. Acoustic-tracking studies are also recommended to determine whether the flows initiate pre-spawning migrations by Golden perch. Continuation of the lower Goulburn standardised fish surveys is recommended to allow estimation of juvenile recruitment following the flow (via length frequency analysis). Finally, surveys of wetland habitats and fish assemblages within newly inundated wetlands are recommended to determine whether the objectives for wetland species are met by the flows.

Table 22: Hypotheses and variables to consider for assessing native fish responses.

Objective	Hypotheses to be tested	Variables to monitor
• Initiate spawning, pre-spawning migrations and recruitment of native fish	• Flow event will trigger spawning by Golden perch in the lower Goulburn • Flow event will trigger pre-spawning migration movement by Golden perch. • Flow event will enhance recruitment of native fish in the lower Goulburn.	• Continue program of standardised electrofishing and larval drift surveys conducted by ARI since 2003. • Continue acoustic-tracking of Golden perch between the lower Goulburn and the Murray (upstream and downstream from the Goulburn confluence) to measure migration responses to flows.
• Increased habitat availability for wetland-specialist species.	• Flow event will increase area of and access to off-channel habitat for wetland-specialist species. • Wetland-specialist species will breed in larger off-channel habitat features.	• Measure off-channel habitat availability and persistence. • Conduct netting surveys to determine population structure and relative abundance of wetland-specialist species in newly inundated habitats.
•	•	•

4.3 Invertebrates

Hypotheses and variables to monitor (Table 23Table 22) are broadly consistent with those described for invertebrates by Chee et al. (2006). The conceptual basis linking flow events to macroinvertebrate communities is predominantly a two-step process in which flow drivers affect components of the macroinvertebrate habitat (e.g. food and physical habitat) which, in turn, are reflected in changes to the macroinvertebrate community – such as increased biomass and diversity. As major consumers of detritus, algal growth, and microbiota, as well as providing an essential food source for larger organisms such as fish and birds, macroinvertebrates have a pivotal role in maintaining the biological diversity and health of river ecosystems (Wallace and Webster 1996). Response of algal communities and macroinvertebrate grazing

(Stevenson 1990), slackwater communities (Price 2007), and deposition of fine sediment (Harrison 2010) have been reported elsewhere. In monitoring the responses to freshes in the Goulburn, it will be important to monitor the individual drivers as well as the macroinvertebrate community response if reliable and manageable links between flow and macroinvertebrates are to be established.

Table 23: Hypotheses and variables to consider for assessing macroinvertebrate responses.

Objective	Hypotheses	Variables to monitor
• Provision of conditions suitable for aquatic vegetation, which provides habitat for macroinvertebrates	• Maintenance of aquatic vegetation will preserve invertebrate diversity and biomass.	• Extent of in-channel macrophyte cover. • Diversity and biomass of invertebrates.
• Submersion of snag habitat within the euphotic zone to provide habitat and food source for macroinvertebrates.	• Submersion of snags will increase food resource diversity.	• Biofilms on snags or on artificial substrate such as wood blocks.
• Provision of slackwater habitat favourable for planktonic production (food source) and habitat for macroinvertebrates.	• Increased slackwater habitat area will lead to a relative increase in planktonic food production. • Slackwater habitat area will initially increase and then decrease as discharge increases and approaches bankfull.	• Slackwater availability at increasing discharge. • Zooplankton populations (net samples and/or egg bank samples).
• Entrainment of litter packs available as food/habitat source for macroinvertebrates.	• Increasing discharge will entrain and redeposit course organic matter, reducing burial of the resource and creating concentrations (e.g. leaf-packs against snags) that result in diverse habitats and food supply for invertebrates. • Invertebrate biomass will increase as available organic matter increases. More diverse habitats lead to complex food-webs and biodiversity.	• Leaf packs – littoral and on benches and snags. • Diversity and biomass of invertebrates.
• Biomass equivalent to similar streams elsewhere.	• Increased habitat and food resource availability will increase invertebrate biomass to that of other lowland rivers.	• Invertebrate biomass.
• Trophic structure and diversity with a more balanced representation of all functional groups.	• Flow event will increase habitat diversity and availability for invertebrates. • Flow event will scour biofilms, resetting them as a food source for invertebrates.	• Invertebrate community structure: ➢ Number of invertebrate families index ➢ AUSRIVAS score ➢ SIGNAL biotic index ➢ EPT biotic index ➢ Presence/Absence and number of 'flow-sensitive' taxa • Biofilm structure and succession.

4.4 Vegetation

The conceptual model and hypotheses developed for VEFMAP (Chee et al. 2006) are also applicable to detecting vegetation responses to bankfull discharge and freshes (Table 24).

In some instances (multiple benches at different heights) it may be possible to apply a BACI design (Before-After Control-Impact (multiple freshes and benches)) that would increase the inference that may be drawn over that possible from monitoring before and after the intervention only (i.e. with no control-impact comparison). This would provide valuable information and new knowledge about flow-vegetation ecology relationships for species as well as functional type (Brock and Casanova 1997). Assessment of the duration of inundation that might at different depths would be particularly valuable in detailing conditions that would limit terrestrial encroachment and favour amphibious species. Monitoring vegetation response on benches and banks (even if it is suspected that duration will be too short) would be useful as it would help to define a critical minimum inundation, and specify what duration- depths might not be effective.

Detecting vegetation responses to flow events such as bankfull discharge and freshes will require monitoring over a significant time (months), post-intervention. For example, Nias (1999) found that sedge cover on forest floor near Raftery Lagoon reached a maximum six months after flooding. Within the river red gum forest at the lagoon, wetland vegetation responded but at different rates following an August flooding, with one species reaching max biomass 16 weeks after flood and another at 20 weeks after flood. In an experiment to contrast summer versus autumn inundation, Warwick and Brock (2003) found that season was important in that more species and more functional types emerged with summer flooding compared with autumn flooding over the experimental time of 13 weeks. Monitoring should there occur immediately prior to the intervention (e.g. bankfull discharge), post-intervention and then for a period of months after the intervention.

Table 24: Hypotheses and variables to consider for assessing vegetation responses.

Objective	Hypotheses	Variables to monitor
• Increase the extent and diversity of aquatic vegetation.	• Bankfull flow will disrupt sediments and increase wetted area for aquatic vegetation (in-channel and riparian). • What is the pattern of inundation and drying in Zones B imposed by the implemented environmental flows? • What is the composition of the resultant plant community?	• Wetting of geomorphic features in Zones B & C[4] • Species composition, number of amphibious and terrestrial species in Zones B & C • Proportion of exotic plant species • Germination of seedlings of overstorey and midstorey species • Canopy condition
• Increased aquatic macrophyte contribution to	• Increased aquatic vegetation extent and	• Aquatic primary production: • Phytoplankton production

[4] See Chee et al. (2006) for full explanation. Zone B for this project refers to the Goulburn River between Lake Nagambie and Loch Garry; Zone C refers to the Goulburn River below Loch Garry.

Objective	Hypotheses	Variables to monitor
in-channel productivity.	biomass will increase the relative proportion of macrophyte production to overall in-channel production.	• Benthic production • Aquatic macrophyte production.
• Replenishment of riparian and wetland vegetation.	• Inundation will increase the emergence of seedlings from the riparian and wetland seedbank.	• As for the objective to increase the extent and diversity of aquatic vegetation.

5 SUMMARY AND RECOMMENDATIONS

The scientific panel considered potential ecosystem benefits from the delivery of environmental water as pulses along the lower Goulburn River under three scenarios:

1. Environmental water delivered as a single, large (approaching bankfull or greater: 20,000 ML/d-30,000 ML/d) fresh;
2. Environmental water delivered as 2-3 smaller freshes of approximately 860-6,600 ML/d;
3. Environmental water delivered to increase the variability of baseflows.

Ecosystem objectives and insights from previous investigations have been restated to provide the basis for the magnitude of freshes outlined above.

Prior to this project and preparation of this report, the lower Goulburn River had received smaller freshes following rainfall-runoff events in 2010, but had not experienced a bankfull discharge since 1996. Given these circumstances, the scientific panel recommended that priority be given to delivering a bankfull flow during spring 2010, if possible. This was anticipated to provide numerous ecosystem benefits (geomorphic diversity, fish spawning and migration trigger, provision of habitat and food resources for biota, replenishment of riparian and wetland vegetation) and a bankfull event should be monitored as part of an adaptive management experiment. Ecosystem objectives and associated hypotheses have been summarised and variables for monitoring ecosystem response have been identified for consideration in any future monitoring.

The features of a bankfull event include:

- **Magnitude**: 20,000 ML/d – 30,000 ML/d. Note that different outcomes are likely at 20,000 ML/d compared with 30,000 ML/d. At 20,000 ML/d, water starts leaving the main channel and flows into anabranches and wetlands such as the Wakiti Creek system (Cottingham et al. 2003). Once river levels fall, water will return to the Goulburn River. At 30,000 ML/d, flow inundates more of the lower Goulburn floodplain and enters wetlands and effluent creeks such as the Deep Creek system, which is an area of shedding floodplain that discharges to the Murray River (Moroka Pty Ltd 2005).
- **Timing**: End of May until the end of October (period in which such events would occur in an unregulated flow regime).
- **Duration**: Minimum 2 days at peak discharge, with appropriate rates of rise and fall.
- **Rate of rise and fall**: Rate of rise not to exceed 0.80m per day; rate of fall not to exceed 0.72m per day.

Rainfall across the Goulburn catchment as this report was prepared in late August 2010 has subsequently resulted in a bankfull event along the lower Goulburn River, eliminating the need for a managed release to achieve such an event this spring (2010). Given this recent development, the scientific panel recommends that the focus should shift from delivering a bankfull event in spring, to delivering 2 or more smaller freshes over the December-April irrigation season. Events are to be not less than 30 days apart, and preferably greater than 2 months apart if vegetation responses to flow events are to be evaluated.

The features of a flow fresh include:

- **Magnitude**: 860 ML/d – 6,600 ML/d. Flows above approximately 860 ML/d – 5,600 ML/d will meet macroinvertebrate objectives (see Tables 6-10), while flows above approximately 2,200 ML/d – 6,600 ML/d would meet geomorphic objectives. Flow can exceed 6,600 ML/d for short durations (e.g. up to 4 days) with little risk to ecosystem objectives, assuming appropriate rates for rise and fall.
- **Timing**: December - April.
- **Duration**: Minimum 2 weeks at peak discharge (e.g. for emergence of invertebrates, seed germination), with appropriate rates of rise and fall.
- **Rate of rise and fall**: Rate of rise not to exceed 0.80m per day; rate of fall not to exceed 0.72m per day.

The need for a bankfull event in spring 2011 should be reviewed in light of antecedent conditions in the lead up to the 2011/12 water year.

The delivery of a single event or a number of smaller freshes is an opportunity for the GB CMA to gather new knowledge about the response of the lower Goulburn River to managed releases. This will inform future management decisions on the allocation of the EWR. Monitoring should take the form of an intervention analysis, where before-after data is collected to detect ecosystem responses to the flow events or where specific hypotheses about the responses of biota are tested (e.g. fish spawning and migration triggers). In some instances (bench inundation experiments), it may be possible to implement a BACI design and so increase the inference that can be assigned to monitoring results.

It should be noted that risks associated with bankfull discharge and freshes have been considered in terms of potential effect on ecosystem assets and processes. Considering socio-economic risks associated with these flows was beyond the scope of the project.

The scientific panel considered that the use of environmental water reserve (EWR) to fluctuate baseflow (Scenario 3) did not represent a discrete flow pulse, such as a fresh. No specific recommendations about the magnitude, timing and duration of releases have been prescribed, other than that fluctuations should seek to vary water levels by ±40 cm. The ecological outcomes are anticipated to be a sub-set of those listed for Scenario 2 for macroinvertebrates and vegetation, as the change in wetted area and position of shallow water within the channel is most likely to influence these ecosystem attributes.

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