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Environmental monitoring of variable flow trials conducted at Dartmouth Dam, 2001/02-07/08 - Synthesis of key findings and operational guidelines

Report to the Murray-Darling Basin Authority

Robyn J. Watts, Darren S. Ryder and Catherine Allan

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Executive Summary

During 1997-99 the (then) Murray-Darling Basin Commission (MDBC) undertook a review of the operation of Hume and Dartmouth Dams, establishing an independent stakeholder Reference Panel to assist with this task. Their aim was to consider how the operating rules might be amended to better address the competing objectives of water supply, environmental enhancement and flood mitigation. One of the recommendations of the review was *"Strategies to increase the variability of in-stream flows below Dartmouth should be developed, and should not await solution of the water temperature problem"*.

Between 2001/02-2007/08 four discrete variable flow 'trials' were implemented by River Murray Water (RMW) (the MDBC's operational arm) and Goulburn-Murray Water (GMW); three during the 'releasing' mode of operation (bulk water transfers from Dartmouth to Hume Reservoirs) and one during the 'filling' mode of operation (minimum release from Dartmouth Dam). The aim of the variable flow trials was to evaluate the biophysical response of instream environments to increased flow variability created by varying the release from Dartmouth Reservoir.

Key stakeholders were engaged in the process, including the MDBC, GMW, biophysical scientists and social scientists from Charles Sturt University and the University of New England, Mitta Mitta landholders, and to a lesser extent State Water Corporation, the North-East Catchment Management Authority and AGL Hydro. Collaboration among stakeholders occurred before, during and after trials to capture the learnings.

The monitoring of Trial 1 (2001/02) examined a range of indicators including water quality, water column bacterial activity, benthic metabolism, the structure and composition of biofilms on permanently inundated cobble, and macroinvertebrates. Successive trials (04/05, 05/06, 07/08) (Watts et al. 2005; 2006; 2008b) progressively refined the set of indicators (in conjunction with river managers and stakeholders) to focus on biofilm structure and composition, and water quality indicators (Table 2). These informative indicators respond rapidly (i.e. within hours, days or weeks) to flow changes and are also time and cost efficient, hence are useful for assessment of individual variable flow events.

Key learnings from the four variable flow trials

- In-stream variable flows are ecologically beneficial compared to sustained periods of relatively constant flow of any magnitude during both the filling and releasing modes of operation of Dartmouth Dam. Some environmental dis-benefits (e.g., accumulation of algal biomass) become apparent if flows following the flow peak are relatively constant for more than two to three weeks in warmer months.

- Depending on the ecological indicator, the responses to discrete ("one-off") variable releases can be relatively rapid (1-2 weeks for scouring of algal biofilms) or may become apparent over a longer period of time (>5 weeks for macroinvertebtrates). For sustained whole of river ecosystem benefit, variable flows would need to be incorporated into river operations on an ongoing basis in accordance with the operating guidelines outlined below.

- The positive ecological responses to variable flows were greatest immediately below the dam and declined with increasing distance from the dam. It should be possible to coordinate the timing of variable releases with inflows from Snowy Creek to extend the benefits further downstream.

- Variable flow patterns that are 'regular' in shape &/or frequency may not be as ecologically beneficial as flow patterns that have a more irregular pattern. When operationally possible, the long-term hydrograph (months) should include pulses of different magnitudes and reflect the variability of a more natural flow hydrograph.

- Bulk water transfers from Dartmouth to Hume Reservoir should commence earlier in the season and at less than channel capacity rates whenever possible to provide greater operational flexibility to vary flows within channel capacity.

- Antecedent flow conditions influence the ecological outcomes of discrete variable flow releases. If flow following a variable release has been relatively constant for more than two to three weeks in warmer weather, the amplitude of flow variation (difference between peak and trough) of the variable release should be as large as operationally possible to maximise the potential for ecological benefits (e.g. scouring of mature biofilms).

- Release of colder water from the low level offtake of Dartmouth Dam decreased the temperature of water in the Mitta Mitta River by 3-7ºC (Trial 4 in 2007-08), with a smaller impact on water temperature at downstream sites. Colder water temperatures may limit some ecological responses to variable flows.

Interim operational guidelines for operation of Dartmouth Dam

The following draft objective for variable flows in the Mitta Mitta River has been developed by the Murray-Darling Basin Authority (MDBA): *"To vary in-stream flows in the Mitta Mitta River below Dartmouth Dam for environmental and geomorphic benefits whenever possible, consistent with overall River Murray System operational requirements, and to also complement local social and economic objectives."*

This draft objective, along with the key learnings described above, have guided the development of the following operational guidelines for implementing variable flows during the filling and releasing modes of operation of Dartmouth Dam. These guidelines have been developed in collaboration with River Murray operations staff at the MDBA. They should be regarded as 'interim', that is, they may be refined with increasing knowledge and experience over time.

Interim operational guidelines for filling and releasing modes of operation of Dartmouth Dam*

Whenever possible, and to the extent possible, operations will aim to:

1. ***Pulse flows to avoid relatively constant discharges of any magnitude*** *at Coleman's gauge for longer than a few weeks.*

2. *Pulse flows to mirror a more natural hydrograph in shape; that is,* ***rise steeply, with a steep initial recession, followed by a more gradual recession*** *(within the limits of operating rules for rates of rise and fall).*

3. ***Include pulses of different magnitudes (over a period of months)*** *that reflect the variability of a more natural flow hydrograph.*

4. ***Vary the discharge from the trough to peak of the rising limb of flow pulses to the maximum extent possible*** *within operational constraints and requirements.*

5. ***Coordinate the timing of releases from Dartmouth Dam with Snowy Creek inflows*** *to extend the benefits of flow pulsing in the Mitta Mitta River downstream of the confluence with Snowy Creek.*

Additional guideline for the releasing mode of operation only

6. ***Commence Dartmouth to Hume transfers earlier in the season and at less than channel capacity rates*** *to provide greater operational flexibility to vary within-channel flows.*

**These guidelines may be refined with increasing knowledge and experience over time*

Table of contents

1. Project Background

Dartmouth and Hume Dams are operated as part of the 'River Murray System' by the River Murray Division of the Murray-Darling Basin Authority (MDBA). Hume Dam was built 1919-36 and is the primary regulating storage in that river system. It was enlarged 1950-61 to accommodate additional water from the Snowy Mountains Scheme. Dartmouth Dam was constructed later (between 1973 and 1979) on the Mitta Mitta River, a major tributary entering Hume Reservoir (Figure 1). Dartmouth Reservoir has a larger capacity (3908 GL) than Hume Reservoir (approx 3000 GL) and is primarily used as "drought reserve" to supplement storage in Hume. Dartmouth Reservoir can take several years to fill because of its large storage capacity relative to its catchment size. Hume typically fills and empties more frequently, sometimes annually. Although the primary purpose of Dartmouth and Hume Reservoirs is to increase the security of water supply for irrigation, stock, domestic and town use, dam operations also mitigate flooding in the valleys below them (Hume and Dartmouth Dams Operations Review Panel 1998).

Many components of natural flow regime of the Mitta Mitta River have been altered by the operation of Dartmouth Dam. A comparison of modelled Natural and Current flow at Colemans gauge shows some of the principal changes to flow volume, variability and seasonality (Figure 2). For instance, there has been a reduction in the magnitude and frequency of freshes, high flows and overbank events during winter and spring and a shift in the seasonality of low flows from warmer months to cooler months in some years (Figure 2). Much of the time under Current conditions, flows are managed so as not to exceed channel capacity of 10,000 ML/d at Tallandoon and the operation of Dartmouth tends to reflect longer cycles of wet and dry periods (MDBC 2006) (Figure 2). Dartmouth is generally in either a filling phase of operation (where inflows are being stored, characterised by long periods of relatively constant low flow in the Mitta Mitta) or a releasing phase of operation (where there are bulk water transfers to Hume, characterised by long periods of relatively constant high flow in the Mitta Mitta) (see Appendix 1 for background on the operation of Dartmouth Dam).

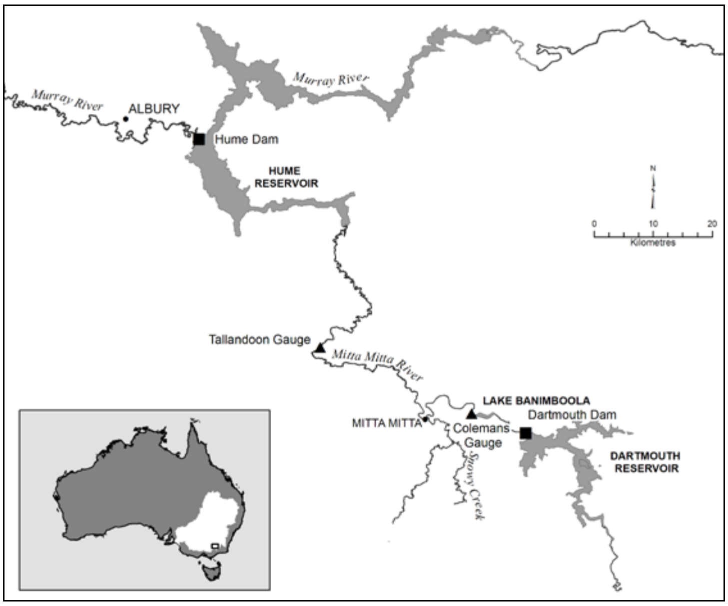

Figure 1. Map of Mitta Mitta catchment in south eastern Australia showing the location of Dartmouth Dam, Hume Dam and Colemans gauge, downstream from Lake Banimboola.

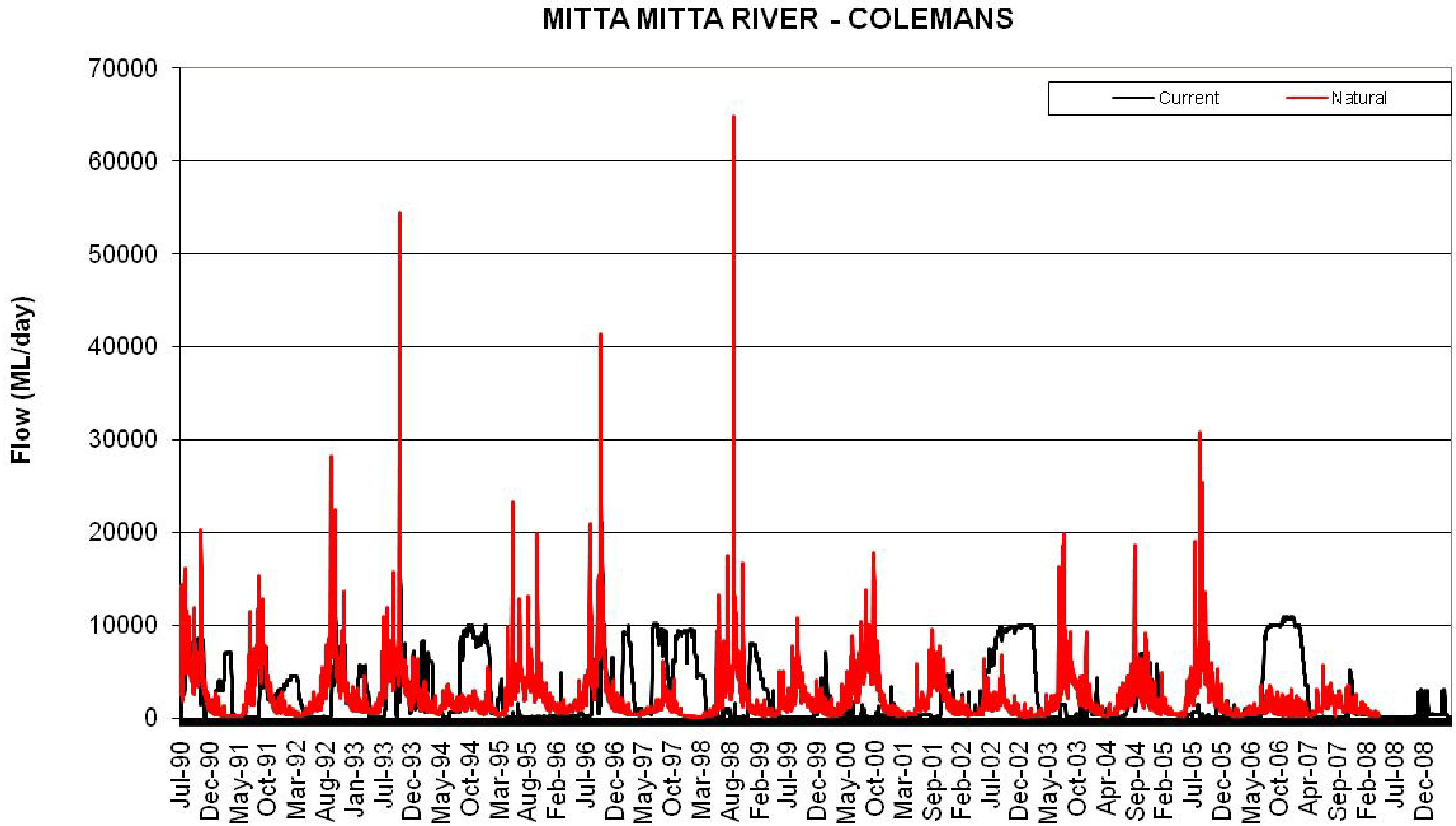

Figure 2. Hydrograph of the Mitta Mitta River (at Colemans Gauge) showing modelled Natural and Current flow conditions for the period 1990 to 2008. Variable flow trials occurred during 2001/02-2007/08 (Source: MDBA).

Mitta Mitta landholders receive benefits from the regulation of the river (e.g. more reliable water supply and flood protection). However, post Dartmouth Dam construction Mitta Mitta Valley landowners reported declining pastures and reduced milk production. This was attributed to reduced floodplain watering resulting from changes to the natural flow regime associated with the operation of Dartmouth Dam (Hume and Dartmouth Dams Operations Review Panel 1999). During 1997-99 the (then) Murray-Darling Basin Commission (MDBC) undertook a review of the operation of Hume and Dartmouth Dams, establishing an independent stakeholder Reference Panel to assist with this task. The aim was to consider how the operating rules might be amended to better address the competing objectives of water supply, environmental enhancement and flood mitigation. The Reference Panel consulted widely with impacted communities and the review gained wide community acceptance (Hume and Dartmouth Dams Operations Review Panel 1999).

One of the issues considered in the Hume/Dartmouth review was the dramatically reduced flow variability in the hydrograph of the Mitta Mitta River post construction of Dartmouth Dam. A recommendation of the Hume and Dartmouth Dams Operations Review provides a mandate for the re-introduction of greater in-stream flow variability in the Mitta Mitta River:

> *"Strategies to increase the variability of in-stream flows below Dartmouth should be developed, and should not await solution of the water temperature problem".*

The Scientific Reference Panel also commented that:

> *"introduction of variability would have some value even if the water temperature issue was not addressed immediately. It will reduce the current level of bed and bank erosion and should create more bank habitat for bank vegetation to re-establish"* (Hume and Dartmouth Dams Operations Review Reference Panel 1999).

Between 2001/02 – 2007/08 four discrete variable flow 'trials' were implemented during both the 'releasing' (bulk water transfers from Dartmouth to Hume Reservoirs at flow rates up to 6,000 ML/d at Colemans gauge) and 'filling' (minimum release from Dartmouth Dam at flow rates up to 900 ML/d at Colemans gauge) modes of operation (see appendix 1 for background on the operation of Dartmouth Dam). Environmental monitoring was undertaken for each trial to evaluate the biophysical response of instream environments to increased flow variability in the Mitta Mitta River that was created by varying the pattern of releases from Dartmouth Reservoir. The learnings from these trials have supported an adaptive management approach, and ultimately, the development of operational guidelines which can be taken forward by the MDBA. The draft objective for variable flows in the Mitta Mitta River that is consistent with these learning's has been developed by the MDBA:

> *"To vary in-stream flows in the Mitta Mitta River below Dartmouth Dam for environmental and geomorphic benefits whenever possible, consistent with overall River Murray System operational requirements, and to also complement local social and economic objectives.*
> *(November, 2008)*

This report is a synthesis of the key environmental learnings from the four variable flow trials, and operational guidelines based on these learning's which were developed collaboratively with the MDBA. This and other information will be integrated to guide future river operations for this dam. Also, the synthesis will integrate with broader efforts as part of the current River Murray System Operations Review to better understand how water management from Dartmouth to Hume Reservoirs could be better managed to optimise social, environmental and economic objectives.

2. Summary of variable flow trials

Aim of variable flow trials

The aim of the variable flow trials was to evaluate the biophysical response of instream environments to increased flow variability created by varying the release from Dartmouth Reservoir. Water quality and biofilm were the primary environmental indicators monitored to gauge the response.

Summary of variable flow trials and instream ecological indicators

Between 2001/02-2007/08 four variable flow trials from Dartmouth Dam were implemented on a trial basis. Three of the trials were during the releasing mode and one during the filling mode of operation of Dartmouth Dam (Table 1, Figure 3).

For each of the four flow trials, sampling was undertaken at four sites in the Mitta Mitta River downstream of Dartmouth Dam, and one 'reference' site (i.e. a 'benchmark' stream with a more natural flow regime) in the unregulated tributary Snowy Creek (Figure 1). A 'control' site (i.e. a comparable stream but with no variable release) in the Buffalo River downstream of Lake Buffalo was included in Trial 2 (2004/05) and Trial 3 (2005/06). For Trial 4 (2007/08) the relationship between discharge and inundation area of representative cobble benches (a common physical habitat feature in the Mitta Mitta River and in Snowy Creek) was monitored visually during the flow pulse using photo points.

The hydrographs of the variable flow trials from Dartmouth Dam (Figure 3) illustrate the difference between the inflows to Dartmouth Dam (flows at Hinnomunjie gauge), the unregulated flows in Snowy Creek (Granite Flat gauge) and the regulated flows in the Mitta Mitta River (Colemans and Tallandoon gauges). Descriptions of the antecedent conditions prior to the flow trials and monitoring design of the flow trials are summarised in Table 1.

Table 1. Summary of the antecedent conditions, hydrology and monitoring design of four variable flow trials from Dartmouth Dam (2001/02-2007/08)

Trial	Antecedent conditions	Summary of the release	Monitoring design
1: 2/12/01 – 11/2/02	Releasing mode of operation - Extended bulk water transfer period of discharge with minimal flow variability.	Trial conducted during the releasing mode of operation. Commencing at 4000 ML/day, each of three pulses rose to a peak of 4800 ML/day, then receded over 12 days to 3200 ML/day at Colemans gauge. This was followed by a period of constant flows of approx 800 ML/day.	Sampling undertaken at 4 sites in the Mitta Mitta River and the reference river, Snowy Creek, on nine sample dates between December 2001 and February 2002. Cobble habitats that were inundated throughout the project and newly inundated cobble that was inundated only during periods of high flow were sampled at each site.
2: 3/12/04 – 10/2/05	Releasing mode of operation - Prior to the trial there was an extended bulk water transfer period (max discharge 7060 ML/day). There was variability in the discharge during this period due to two natural freshes that prompted RMW to briefly reduce the discharge from Dartmouth Dam. For about two weeks before the pulsed release discharge was constant at approx. 2000 ML/d.	Trial conducted during the releasing mode of operation. The variable flow release began on the 4/01/2005 and reached a peak of 6110 ML/day at Colemans gauge on day 3 (6/01/05). The recession occurred until the 22/01/2005, followed by a period of relatively constant flow of approximately 800 ML/day.	Sampling undertaken at 4 sites in the Mitta Mitta River, Snowy Creek and a control site in the Buffalo River on twelve dates; five prior to the release, three during the release, and five after the release during a period of constant discharge.
3: 1/12/05 – 4/5/06	Filling mode of operation – Prior to the flow trial the discharge from Dartmouth Reservoir was at a constant rate of 200 ML/day; there were a number of entitlement releases (for hydro-power generation) in the months preceding the trial which provided some flow variability.	Trial conducted during the filling mode of operation. During the flow trial ten weekly variable releases with a flow range of 200 to 400 ML/d at Colemans gauge, and thirteen larger weekly cycles (range approx 300-900 ML/d at Colemans gauge) were delivered.	Sampling undertaken from 6/4/06 to 4/5/06 at sites 1 and 4 in the Mitta River, site 5 (Snowy Creek) and a control site in the Buffalo River. During the study period four variable flow releases were sampled including two smaller weekly cycles (approx 200-400 ML/d) and two larger weekly cycles (approx 300-900 ML/d).
4: 5/11/07- 17/12/07	Filling mode of operation - In the six months prior to variable flow trial the discharge from Dartmouth Reservoir was at a constant discharge rate of 200 ML/day.	Trial conducted during the releasing mode of operation. During the trial there was a single flow pulse that reached a peak magnitude of 5160 ML/day at Colemans gauge on 20/11/07 and receded slowly (over 3 weeks) to a relatively constant flow of approx 800 ML/d.	Sampling undertaken at sites 1 and 4 in the Mitta River, site 5 (Snowy Creek) on eight sample dates; three before the release, one on the peak of the pulsed event and four during the recession of the flow event.

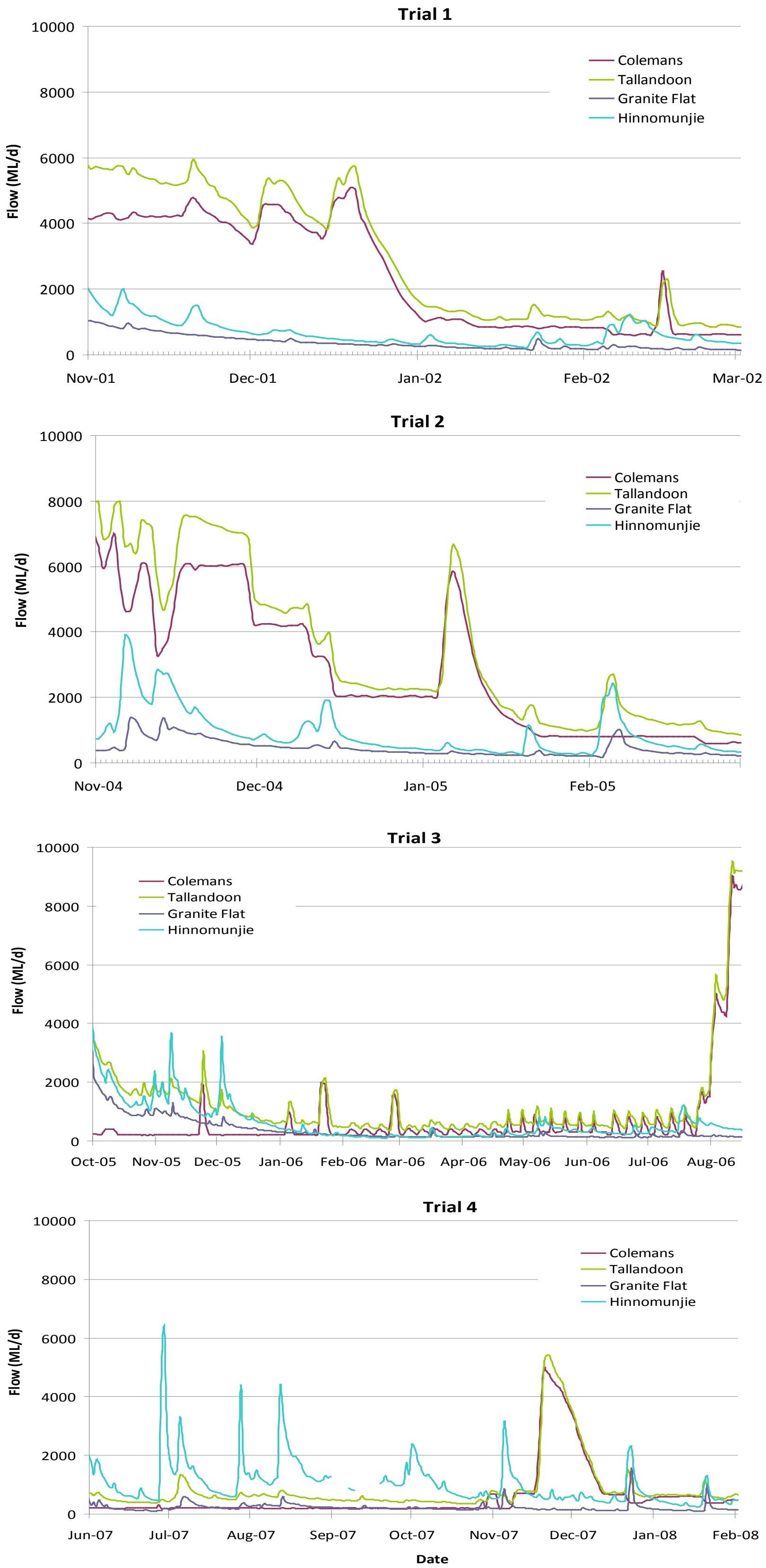

Figure 3. Hydrographs of the four variable flow trials from Dartmouth Dam conducted between 2001/02 – 2007/08 showing flows in the Mitta Mitta River at the Colemans and Tallandoon gauges; and also at the Granite Flat gauge in Snowy Creek, and at the Hinnomunjie gauge on the Mitta Mitta River upstream of Dartmouth Dam for an indication of natural flow characteristics.

The monitoring of Trial 1 (2001/02) (Sutherland *et al.* 2002) was undertaken using a set of indicators including water quality, water column bacterial activity, benthic metabolism, the structure and composition of biofilms on permanently inundated cobble, and macroinvertebrates (Table 2). All of these indicators are capable of detecting changes in the condition of a river in response to variable flows and they respond over different timeframes (Table 3). Successive trials (04/05, 05/06, 07/08) progressively refined the set of indicators (in conjunction with river managers and stakeholders) to focus on biofilm structure and composition, and water quality indicators (Table 2). These informative indicators respond rapidly (i.e. within hours, days to weeks) to flow changes and are also time and cost efficient, hence are useful for assessment of variable flow trials.

The short generation time, sessile nature, responsiveness to environmental conditions and the availability of quantitative methodologies make biofilms ideally suited as indicators of disturbance in aquatic systems. Biofilms are also good functional indicators because they are a major instream source of carbon in river systems and they form the base of food webs supporting zooplankton, grazers (such as crustaceans), insects, molluscs and some fish. Constant flow regimes can lead to the accrual of high biomass of algal biofilms. Flow pulses regulate the accrual of biofilm biomass through scour, substratum loss and by decreasing light levels through higher loads of suspended material. There are two main reasons why it is desirable to scour biofilms from cobbles:

1. To reduce the nuisance factor when biofilm growing on the beds of rivers builds to levels that are unacceptable to the general public or landholders.
2. To promote early successional algal taxa and develop a biofilm that has a higher diversity. A high diversity of biofilms usually indicates good ecosystem health.

The long-term ecological outcomes of variable flows could be assessed using general indicators of river health, such as AusRivAS (Coysh *et al*. 2000) and the Index of Stream Condition (Ladson & White 1999). These methods provide an assessment of overall condition and are used to report the trajectory of change in river condition over time.

Table 2: Summary of indicators sampled during the four variable flow trials implemented in the Mitta Mitta River 2001/02- 2007/08.

		Trial			
	Indicator	**1** (01/02)	**2** (04/05)	**3** (05/06)	**4** (07/08)
Water Quality	Dissolved organic carbon (DOC)	✓	✓		
	Particulate organic matter (POM)	✓	✓		
	Total suspended solids (TSS)	✓	✓	✓	✓
	Water column chlorophyll-*a* (Chl-*a*)	✓	✓		
	Temp, turbidity, conductivity, DO, pH	✓	✓	✓	✓
	Water column nutrients	✓			
Water velocity				✓	✓
River productivity	Total biomass (dry weight)	✓	✓	✓	✓
	Organic biomass (ash free dry weight)	✓	✓	✓	✓
	Algal biomass (chlorophyll *a*)	✓	✓	✓	✓
	Biofilm species composition	✓	✓	✓	✓
	Benthic production/respiration	✓			
	Water column production	✓			
	Water column bacterial activity	✓			
Macro-invertebrates	Number of taxa	✓	✓		
	SIGNAL-2 index	✓	✓		
	Community composition	✓	✓		

Table 3. Response times of a range of indicators to flow change

Indicator(s)	**Response time**
Water quality indicators (e.g. DOC, POM, TSS, Chl-a, Temp, turbidity, conductivity, DO, pH)	Hours
Water column bacterial activity	Hours
Benthic production/respiration	Hours to days
Biofilms (e.g. total biomass, organic biomass, algal biomass, biofilm species composition)	Days to weeks
Macroinvertebrate indicators (e.g. number taxa, SIGNAL index, community composition)	Weeks to months

Hypotheses tested during the flow trials

Water quality

- Concentrations of dissolved organic carbon, particulate organic matter, total suspended solids, water column chlorophyl-*a* and turbidity will increase during variable flow releases as a result of riverbank and floodplain inundation, in-channel re-suspension and scouring of biofilms and will decrease during the flow recession.

Water velocity

- Water velocity will be higher during the peak flow and will be of a sufficient level on cobble bars to scour biofilms from cobbles.

Biofilms

- Algal biomass (chlorophyll *a*) and total biomass (ash free dry weight) on cobbles will decrease on the peak of the variable flow release due to scouring of biofilms from increased velocity.
- The flow peak of the variable flow release will change the community composition of algal biofilm and promote early successional algal taxa on cobble substrate due to scouring from increased velocity.
- During the constant flow period following the variable flow release biofilm biomass will increase and biofilm diversity will decrease.

Benthic metabolism

- Carbon respiration of biofilms on permanently inundated cobble will increase following the peak of the variable flow release due to scouring from increased water velocity and light deprivation from increased water depth.

Bacterial activity

- Peak flows will increase the overall activity of water column bacteria due to increased riverbank and floodplain inundation and in channel re-suspension and there will be increased overall enzyme activity with distance downstream.

Macroinvertebrates

- The number of macroinvertebrate families and SIGNAL scores at sites in the Mitta Mitta River will increase following the variable flow release. The composition of the macroinvertebrate community will become more similar to that in the reference stream following the variable flow release.

3. Key findings of variable flow trials

Trial 1 (2001/02) – Multiple bankfull flows during releasing mode of operation

- Biofilms at all four sites in the Mitta Mitta River were scoured and sloughed during each flow peak (4800 ML/day at Colemans gauge) resulting in a slight reduction in biomass and change in taxonomic composition. There were also rapid changes in net productivity, resulting in a diversity of productivity rates along the study reach.
- The post-release constant low flow period resulted in an increase in biofilm biomass to pre-release levels and an altered composition of biofilm algal species dominated by fewer, late successional taxon such as cyanobacteria (blue-green algae). During this period there was also a rapid decrease in net productivity.
- There was an increase in macroinvertebrate family-level richness and SIGNAL scores at the site closest to Dartmouth Dam following the flow peak. There were also significant changes in the macroinvertebrate community composition at three of the four sites studied in the Mitta Mitta River in response to the three flow pulses.
- The SIGNAL score (response of macroinvertebrates) continued to increase at the site closest to Dartmouth Dam during the post-release constant flows, suggesting that the ecological responses of macroinvertebrates to the variable flows at this site may become apparent over a longer period of time (> 5 weeks) after the flow peak. In contrast, there was an increased abundance of tolerant families and decreased abundance of more sensitive families at the most downstream sites by the end of the constant flow period.
- No data were collected prior to the variable flow release, because the release occurred before approval to sample was given. This limited the ability to fully understand the impacts of the variable flow release.

Trial 2 (2004/05) – Single bankfull release during releasing mode of operation

- Water temperature and conductivity in the Mitta Mitta River decreased on the flow peak and increased during the flow recession. Turbidity, particulate organic matter, total suspended solids and water column chlorophyll-a in the Mitta Mitta River increased during the flow peak and decreased during the flow recession.
- Biofilm biomass in the Mitta Mitta River was scoured and sloughed during the flow peak (6110 ML/day at Colemans gauge) but the biomass rapidly increased during the flow recession. The scouring of biofilms removed filamentous green algae and increased the relative biovolume of early successional species of diatoms, shifting the composition of biofilm in the Mitta Mitta River during the flow release towards that in the reference site.
- The number of benthic macroinvertebrate taxa and the SIGNAL-2 index increased at all sites in the Mitta Mitta following the flow release. The composition of the community at site 1 became more similar to the reference site due to the colonisation of several sensitive taxa that had been absent prior to the flow release. In contrast, there was no change in the SIGNAL-2 index or total number of taxa at site 4 further downstream. However, the macroinvertebrate community composition at site 4 became more similar to the reference condition during the variable flow release, but shifted back towards the original composition at the end of the release.

Trial 3 (2005/06) – Multiple low flow releases during filling mode of operation

- Total suspended solids were similar during the 200-400 ML/day flow cycles and the 300-900 ML/day cycles.
- For this trial biofilm biomass indicators were also assessed using artificial substrates that were deployed at each site at the beginning of the trial (6/4/06) and the beginning of the 300-900 ML/day cycles (20/4/06) to examine rates of colonisation. The 200-400 ML/day cycles did not reduce the total biofilm biomass on permanently inundated cobble or the artificial substrates. The repeated cycling in discharge from 200 to 400 ML/day may have encouraged growth of some filamentous taxa that are tolerant to that range of discharge and are capable of growing fast. However, water velocities of more than 1m/sec during the 900 ML/day flow peak selectively scoured some of the filamentous forms of algae that grew readily in the 200-400 ML/day cycle. These results reiterate that constant flows of any magnitude can lead to an accumulation of filamentous algae, and even low-volume discharge can change algal species composition.

Trial 4 (2007/08) - single pulsed event during releasing mode of operation

- There was a decrease in water temperature of between 3 and 7 degrees during the pulsed release. All other aspects of the water quality (conductivity, level dissolved oxygen, pH) in the Mitta Mitta were within acceptable limits at all sites on all sample dates. There was a short-lived 2- to 4-fold increased in turbidity at sites 3 and 4 on the flow peak and immediately after the pulse event.
- The filamentous algal communities on cobbles in the Mitta Mitta River were mature and stable prior to the flow release. The flow peak (4990 ML/day) resulted in water velocities greater than 1m/sec at the sample sites in the Mitta Mitta River and this scoured the branched filaments of the dominant algal species, resulting in a rapid reduction in biofilm biomass for approximately one to two weeks after the flow peak. However, these water velocities were unable to remove the holdfast and central stem of the filamentous algae attached to cobbles. Consequently, the algal holdfasts remained, and the damaged, but viable, algae grew rapidly during the flow recession. After the flow pulse, the biofilm biomass was the highest recorded in this river from all previous flow trials. The drawdown allowed silt to settle on cobbles at downstream sites providing additional nutrients to algae and facilitating a rapid growth response.

4. Key learnings

Variable flows vs constant flows

The four flow trials demonstrate conclusively that variable flows are ecologically beneficial compared to relatively constant flows. Ecological benefits were observed during the peak of variable release cycles (when biofilm scouring typically occurs) and in the period immediately following the flow peak, when benefits flow through to other ecological indicators. Some environmental dis-benefits were apparent when flows were relatively constant for more than two to three weeks in warm weather. For example, during Trial 2 there was an accumulation of algal biomass within two to three weeks of relatively constant flows following the flow peak.

Key Learning: In-stream variable flows are ecologically beneficial compared to sustained periods of relatively constant flow of any magnitude during both the filling and releasing modes of operation of Dartmouth Dam. Some environmental dis-benefits become apparent if flows are relatively constant for more than two to three weeks in warmer months.

Duration of ecological benefits

Depending on the ecological indicator, the responses to the variable releases may be immediately apparent (one - two weeks for scouring of algal biofilms) or may become apparent over a longer period of time (>5 weeks for macroinvertebrates). For example, during Trial 2 (04/05) several indices had shifted towards the reference condition during the flow peak, whereas within 1 – 2 weeks after the peak they had a trajectory of change back towards the condition prior to the variable flow. In contrast, some of the ecological responses to variable flow may become apparent over a longer time period. For example, during Trial 1 (01/02) the increases in SIGNAL-2 index and number of macroinvertebrate taxa were evident up to 5 weeks after the trial commenced and may have extended beyond this time, however monitoring was discontinued 5 weeks after the end of the trial.

Key Learning: Depending on the ecological indicator, the responses to discrete ("one-off") variable releases can be relatively rapid (1-2 weeks for biofilms) or may become apparent over a longer period of time (>5 weeks for macroinvertebtrates). For sustained whole of river ecosystem benefit, variable flows would need to be incorporated into river operations on an on-going basis and in accordance with the operational guidelines outlined in section 6.

Ecological responses were greatest at upstream sites

The ecological responses to the flow trials were greatest at the site immediately downstream of the dam:

- During Trial 1 (01/02) the positive response of macroinvertebrates to the variable releases was most pronounced at the site closest to Dartmouth Dam. There were an increased number of families and a higher SIGNAL score at this site.
- During Trial 2 (04/05) the algal communities were not scoured to the same extent at site 4 (downstream) as they were at site 1 (upstream). Similarly, changes in macroinvertebrate communities observed at the upstream site were not observed at site 4 further downstream.
- During Trial 3 (05/06) algal biomass on cobbles decreased at site 1 during the last 2.5 weeks of the study but not at site 4 further downstream.

The limited response at downstream sites relative to the upstream site may be due to two mechanisms. Firstly, as the reach of the Mitta Mitta River downstream of Lake Banimboola re-regulating pondage and upstream of the unregulated tributary Snowy Creek has been most impacted by regulated flows, this river reach has the greatest potential to show improvement in ecological condition. Secondly, the ability to deliver a flow pulse from a reservoir to a river reach is influenced by channel morphology; the river geometry affects the rate of dispersion of pulses during downstream transport. When a natural flood moves downstream, inflows from tributaries add to the flood making the peak higher or spreading it out, depending on timing. Even when there are no tributary inflows (as might be the case for a flow pulse from a dam), the flow pulse will undergo attenuation, such that the flood hydrograph becomes broader and less peaked. Consequently, there is likely to be a smaller flood peak and lower velocities at downstream sites as the flow pulse moves downstream.

Key Learning: The positive ecological responses to variable flows were greatest immediately below the dam and declined with increasing distance from the dam. It should be possible to coordinate the timing of variable releases with inflows from Snowy Creek to extend the benefits further downstream.

Frequency of variable releases

According to the intermediate disturbance hypothesis (Connell 1978), biodiversity will be highest when disturbance is neither too rare nor too frequent. When there is a low level of disturbance (e.g. constant discharge levels) dominant species will tend to out-compete others. When there is a high frequency of disturbance (e.g. highly variable discharge or regular discharge patterns) only species that can tolerate the stress of high levels of disturbance can persist.

The results of the variable flow release trials in the Mitta Mitta River follow the pattern predicted by this hypothesis. For example, during periods of constant low discharge or constant high discharge conditions there was reduced algal diversity of biofilms with a dominance of late successional species. Similarly, frequent and, more importantly, regular cyclic flows did not promote higher levels of biodiversity in algal biofilms. Trial 3 (05/06) demonstrated that frequent (i.e. weekly), regular (i.e. same shape) variable flow cycles do not promote high levels of biodiversity. The repeated cycling from 200-400 ML/day may have encouraged growth of some filamentous algal taxa that are capable of growing fast under those conditions.

Key Learning: Variable flow patterns that are ‘regular’ in shape &/or frequency may not be as ecologically beneficial as flow patterns that have a more irregular pattern. When operationally possible, the long-term hydrograph (months) should include pulses of different magnitudes and reflect the variability of a more natural flow hydrograph.

Timing of variable flows

Examination of the hydrographs from years when bulk water transfers were made from Dartmouth to Hume shows that in some years (e.g. 1982/83, 1994/95, 2002/03) the decision to transfer water was delayed as long as possible to minimise the risk of unnecessarily transferring water. However, in these years, once transfers commenced the water had to be delivered at or near bankfull levels to transfer the required volume of water to Hume Reservoir in time. This strategy of delaying the decision to transfer water limited the potential to implement a variable flow pattern, because an operational rule restricts discharge above bankfull.

Key Learning: Bulk water transfers from Dartmouth to Hume Reservoir should commence earlier in the season and at less than channel capacity rates whenever possible to provide greater operational flexibility to vary flows within channel capacity.

Antecedent conditions influence the outcome of variable flow releases

Several of the flow trials demonstrated the importance of assessing and understanding the antecedent conditions prior to the variable flow, as the same discharge volume can have a different ecological outcomes depending on the antecedent flow conditions in the river.

Antecedent condition: extended period of low flows during the filling mode of operation
The extended period of constant low flow prior to Trial 4 (07/08) facilitated the development of mature filamentous algal communities on cobbles. Thus, although the peak water velocity during the trial was capable of scouring the branched filaments of the dominant biofilm algal species, the water velocities were unable to remove the entire mature holdfast and central stem of the filamentous algae attached to cobbles. Consequently, the algal holdfasts remained, and the damaged, but viable, algae grew rapidly during the drawdown period resulting in the highest total biomass of biofilms recorded in this river from all previous variable flow trials (Figure 4).

Antecedent conditions: variable discharge
In the three months prior to Trial 3 (05/06) there was variability in the discharge pattern. Consequently, the ecological response to the variable release was not substantial, as there had already been considerable variability in the discharge pattern.

Figure 4. Mitta Mitta River at site 3 on the 17th December 2007 showing the presence of filamentous green algae following the flow peak.

Key Learning: Antecedent flow conditions influence the ecological outcomes of discrete variable flow releases. If flow has been relatively constant for greater than two to three weeks in warmer weather, the amplitude of flow variation (difference between peak and trough) of the variable release should be as large as operationally possible to maximise the potential for ecological benefits (e.g. scouring of mature biofilms).

Thermal pollution and pulsed flows

Thermal pollution can be caused by the release of cold water from the base of reservoirs into warmer rivers. The water temperature in the Mitta Mitta River downstream of Dartmouth Dam is affected by the storage level of Dartmouth Reservoir (which affects whether a high level or low level outlet is used) and the prevailing weather conditions. The water within the impoundment has been shown to stratify, with the thermocline generally occurring at depths of between 5 to 10m below the surface from October to January, and up to 40m in August/September (Ebsary 1990).

Colder water released from Dartmouth Reservoir during the variable flow trials had an impact on the water temperature in the Mitta Mitta River. For example, during Trial 2 (04/05) the water temperature of the flow peak was approximately 3°C lower than the water temperature during the constant flow period prior to the flow release. Similarly, during Trial 4 (07/08) there was a decrease in water temperature of between 3 and 7°C during the flow peak compared to the constant flow period prior to the release (Figure 5). On each sample date the water temperature in the Mitta Mitta River was coldest upstream at site 1 and warmest downstream at site 4 because the water is warmed during transport down the river. In contrast, at the same time the water temperature in the unregulated reference stream Snowy Creek was increasing due to higher ambient temperatures in November (Figure 5).

Key Learning: Release of colder water from the low level offtake of Dartmouth Dam decreased the temperature of water in the Mitta Mitta River (by 3-7ºC during Trials 2 and 4), with a smaller impact on water temperature at downstream sites. Colder water temperatures may limit some ecological responses to variable flows.

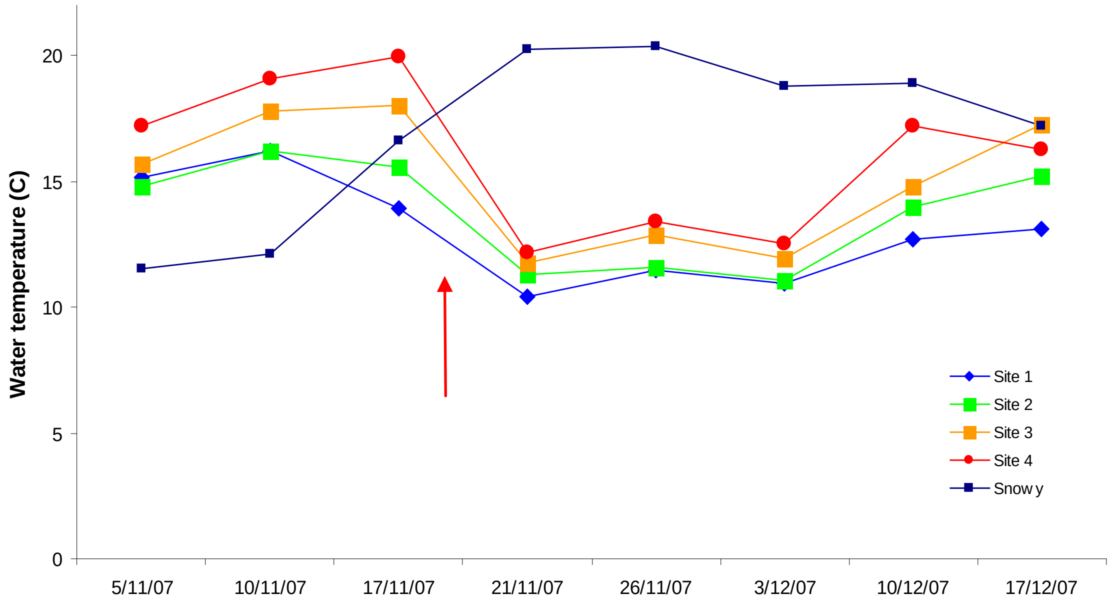

Figure 5: Water temperature (°C) at sites 1 to 4 on the Mitta Mitta River and in Snowy Creek during the 07/08 flow trial. Arrow indicates the time of peak discharge in the Mitta Mitta River.

5. Adaptive management process

The Mitta Mitta flow trials provide an example of active adaptive management with a cycle of learning from a series of monitored and evaluated variable releases. Adaptive management requires multi and trans-disciplinary participation. This was achieved in these trials by including all key stakeholders including the Murray-Darling Basin Commission (MDBC) including River Murray Water (RMW), Goulburn-Murray Water (GMW), biophysical scientists and social scientists from Charles Sturt University and the University of New England, Mitta Mitta landholders, and to a lesser extent State Water Corporation, the North-East Catchment Management Authority and AGL Hydro.

Collaboration among stakeholders occurred at all key stages – before, during and after the trials. During the flow trials the researchers and MDBC discussed, informally, the emerging results and possible implications. The close contact between the research team and the dam operators also enabled the researchers to be informed of changes to proposed discharge patterns, allowing better organisation of field sampling. Mitta Mitta landholders were regularly informed during trials through "Flow Advices' sent by fax or email from MDBC. Informative articles, written jointly by MDBC and CSU, were published in a local newsletter, the "Bush and Bulldust", to provide context for the trials. Following each trial the CSU researchers presented their results at seminars for MDBC, and formal meetings were held to discuss findings and future directions and potential activities.

Details of the adaptive management process are presented in a chapter of a book that was developed to guide potential adaptive managers (Allan and Stankey 2009). In that chapter we suggest that three key ingredients fostered adaptive management in this particular case; aspects of the operational context, the roles of individuals involved in these trials and their institutional arrangements, and the trusting relationships that developed between individuals and organisations (Allan, Watts, Commens and Ryder 2009).

6. Interim operational guidelines for future river operations

The following draft objective for variable flows in the Mitta Mitta River has been developed by MDBA:

> *"To vary in-stream flows in the Mitta Mitta River below Dartmouth Dam for environmental and geomorphic benefits whenever possible, consistent with overall River Murray System operational requirements, and to also complement local social and economic objectives."*

This draft objective, along with the key learnings described above, have guided the development of the following operational guidelines for implementing variable within-channel flows during the filling and releasing modes of operation of Dartmouth Dam. These guidelines have been developed in collaboration with River Murray operations staff at the MDBA. They should be regarded as 'interim', that is, they may be refined with increasing knowledge and experience over time. These guidelines should be read in conjunction with the full synthesis report that provides specific examples of findings to date that underpin the guidelines.

Operational guidelines for the filling mode of operation (minimum release)

The filling mode of operation of Dartmouth Dam has reduced several key elements of the natural flow regime, particularly the frequency of freshes, higher flows and overbank events during winter and spring. Since Dartmouth is an important water storage in the Murray-Darling Basin and is primarily used as "drought reserve" to supplement storage in Hume Reservoir, it is unlikely that all of the key flow elements in this river that have been altered due to dam operations can be restored. However, the environmental outcomes of within-channel flow management during the filling mode of operation can be improved by implementing the operating guidelines outlined below.

Implementing variable flows during the filling mode in winter and spring would serve to restore some elements of the natural flow regime, particularly the frequency of within-channel freshes. Biofilms are rarely a nuisance in the cooler months as they are temperature and possibly light limited. Thus, biofilm response to flow variability, as an indicator, may be more limited during the cooler months. However, broader ecological benefits of within-channel flow pulsing during the cooler months could include sustaining littoral vegetation, inundation of in-stream benches, and connectivity of wetlands as discussed in Watts *et al.* (2008a).

Implementing variable flows in the filling mode of operation during warmer months would minimise the potential for development and maturation of biofilm (particularly the holdfast and central stem of filamentous algae) which may be more difficult to scour subsequently.

There is a need to examine the case for increasing (or temporarily operating below) the minimum flow of 200 ML/d, and also to move toward calculating a minimum flow that is based on an average over several weeks, rather than the current daily flow target. This would allow more operational flexibility in the delivery of variable flows during the filling mode of operation.

Operational guidelines for the releasing mode of operation (water transfers)

Implementing variable flows during the releasing mode of operation of Dartmouth Dam would serve to restore some elements of the natural flow regime, particularly the frequency of freshes and higher flows in spring. In addition, it would serve to lessen then negative ecological effects of extended periods of constant higher discharge over warmer months, such as the undesirable accumulation of biofilm. The introduction of flow variability, particularly at higher flow rates, is also expected to have geomorphic benefits (irrespective of water temperature) such as reducing bed and bank erosion and creating more bank habitat for riverbank vegetation to re-establish (Hume and Dartmouth Dams Operations Review Reference Panel, 1999).

One of the key operating guidelines (guideline 6) that should be implemented whenever possible during the planning process is to *commence Dartmouth to Hume transfers earlier in the season and at less than channel capacity rates to provide greater scope for in-stream flow variability*. Examination of hydrographs from years when bulk water transfers were made from Dartmouth to Hume shows that in some years (e.g. 1982/83, 1994/95, 2002/03) the decision to transfer water was delayed as long as possible to minimise the risk of unnecessarily transferring water. However, in these years, once transfers commenced the water had to be delivered at bankfull levels to transfer the required volume of water to Hume Reservoir in time. In contrast, in 2004/05 the decision to transfer water was taken earlier and this meant that the volume of required water could be transferred over a longer period of time, providing the opportunity to include some variability in the discharge pattern.

Interim Operating Guidelines for filling and releasing modes of operation of Dartmouth Dam*

Whenever possible, and to the extent possible, operations will aim to:

1. ***Pulse flows to avoid relatively constant discharges of any magnitude*** *at Coleman's gauge for longer than a few weeks.*

2. *Pulse flows to mirror a more natural hydrograph in shape; that is,* **rise steeply, with a steep initial recession, followed by a more gradual recession** *(within the limits of operating rules for rates of rise and fall).*

3. **Include pulses of different magnitudes (over a period of months)** *that reflect the variability of a more natural flow hydrograph.*

4. ***Vary the discharge from the trough to peak of the rising limb of flow pulses to the maximum extent possible*** *within operational constraints and requirements.*

5. ***Coordinate the timing of releases from Dartmouth Dam with Snowy Creek inflows*** *to extend the benefits of flow pulsing in the Mitta Mitta River downstream of the confluence with Snowy Creek.*

Additional guideline for the releasing mode of operation only

6. ***Commence Dartmouth to Hume transfers earlier in the season and at less than channel capacity rates*** *to provide greater operational flexibility to vary within-channel flows.*

**These guidelines may be refined with increasing knowledge and experience over time*

7. Where to now?

The crucial next step is to move toward incorporating variable flow releases into river operations on an on-ongoing basis in accordance with the operating guidelines outlined in section 6, whenever possible and to the extent possible.

There may be opportunities for further ecological and other studies in the future that will refine the interim operational guidelines and ultimately improve the management and outcomes of variable flows in the Mitta Mitta River. Some of the key areas for future research include:

- An examination of any practical operational issues associated with implementing the operational guidelines.

- Exploration of ways to meet social, economic and environmental outcomes simultaneously with variable flows. There is a need to better understand community perceptions of variable flow releases and work collaboratively with communities to tailor variable flow releases to meet multiple needs where possible.

- Modelling of the potential outcomes of implementing the operational guidelines. For example, to quantify and assess the impact on system water resources of commencing bulk water transfers earlier in the season (and at less than channel capacity rates), to permit flow variation.

- Undertake a closer examination of historical events (or water transfers) and future events to obtain better estimates of potential additional losses from adopting variable flows practice.

- Explore the feasibility of operating below 200 ML/d for brief periods (in terms of its operational feasibility, potential impacts on landowners and ecological effectiveness) in order to permit variation whilst releasing 'minimum flows'.

- An examination of the ecosystem wide benefits of variable flows. For example, future studies could extend the current monitoring of instream health to the response of low-lying wetlands along the Mitta Mitta River to variable flows. There is also a need to better understand longer-term responses, and the trajectory of change, in river ecosystem condition in response to a more variable flow regime.

- Studies of factors that will help optimise the river health outcomes of variable releases including:
  - Duration of flow events
  - Frequency of flow pulses
  - Rates of rise and fall
  - Length of inter-flood period
  - Antecedent conditions

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9. Appendix 1

Background on the operation of Dartmouth Dam

The main modes of operation of Dartmouth Dam are summarised below (see also MDBC, 2006):

- *Filling* - During the filling mode of operation, a minimum flow of at least 200 ML/d is maintained at Colemans gauge. This may be increased (to a maximum of 500 ML/d, depending on storage volume) if required to meet community water quality or environmental objectives as follows:

  60% < Dartmouth level < 70%, Minimum release = 300 ML/d
  70% < Dartmouth level < 80%, Minimum release = 400 ML/d
  Dartmouth level >80%, Minimum release = 500 ML/d.

  Dartmouth is operated in filling mode typically during the cooler and wetter months from May to September when inflows to the reservoir are being stored. But depending on operational requirements and seasonal conditions Dartmouth can be 'on minimums' at other times of the year and for more extended periods (see Figure 1).

- *Release* - Releases are made primarily to supplement storage in Hume Reservoir when required to meet downstream needs. These releases (or 'bulk water transfers') may be made at flow rates up to regulated channel capacity (3.4m at Tallandoon, or about 10,000 ML/d). These releases are not required every season, and the volume of transfer that is required varies between seasons. When required they usually commence in spring or summer, and may continue as late in the season as April or May. In some years (e.g 1982/83) the transfer of water continued over an extended period of time from July 1982 to April 1983. In addition to releases for downstream requirements, 'harmony' transfers of water from Dartmouth to Hume Reservoirs may be made for the complimentary management of both storages (MDBC 2006). These transfers are usually made in summer and autumn of years when Dartmouth storage level is high. Variations in release rates are frequently required during the operation of Dartmouth Reservoir and power station in response to changing downstream requirements. Limits to the rates of rise and fall of the river downstream of the dam have been adopted to provide adequate warning of river level changes, and to minimise river bank slumping.

- *Pre-release and Spill* - When the storage approaches full, pre-releases may be made to maintain airspace to assist with flood mitigation. Pre-releases are determined so that the storage will subsequently fill without affecting the security of supplies. When the *s*torage exceeds full supply level, flow over the spillway commences.