Adequacy of environmental releases to the Snowy River

Snowy Scientific Committee

October 2008

Canberra

Report No. 1

Prepared for the

Water Ministerial Administration Corporation

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EXECUTIVE SUMMARY

[1] This report assesses the adequacy of environmental releases to the Snowy River downstream of Jindabyne Dam. These environmental releases are part of a long-term restoration program for the Snowy River. No analyses were specially commissioned: information and data comes from existing documents. The internationally-recognised four flow response principles of Bunn and Arthington (2002) were used as a framework for ecological responses.

[2] Adequacy was evaluated by considering it in four ways: the flow regime itself, because flow is the principal driver of riverine ecology; responses to flow releases, particularly water quality; the monitoring program; and institutional arrangements that affect the delivery of the volumes that are available. The report accepts the findings of the Snowy Water Inquiry and does not consider the adequacy of 21% MANF.

[3] The flow regime since 2002 was considered focussing on volume, seasonality and variability, and all three were found to be inadequate to meet the intended ecological objectives. The actual volumes released have not increased since the first year following corporatisation. The seasonal signal has been muted and barely noticeable except in the years when the Mowamba Aqueduct was decommissioned. Variability was low and flat-lined for long periods.

[4] In terms of the four flow response principles, flows down the Snowy River from the dam have not been adequate for habitat and channel maintenance, have not provided normal stream conditions for stream fauna, and have not delivered any discernible lateral connectivity; they have maintained a reduced longitudinal connectivity and have provided conditions for the maintenance of some exotic fish species, for example Eastern Gambusia, goldfish.

[5] The current monitoring program is not adequate to detect changes in water quality down the Snowy River resulting from releases; and it does not include water quality of Jindabyne Dam or releases from Jindabyne Dam.

[6] Institutional arrangements for delivering water appear fixed and inadequate to provide the kind of flexibility needed when working with small volumes.

[7] A number of recommendations are made on specific details of flow releases, institutional processes. Releases to flush deep pools are urgently needed.

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Section 1: Introduction

PURPOSE AND SCOPE OF THIS REPORT

This report addresses the first task specified for the Snowy Scientific Committee in its Terms of Reference, which is "*to provide advice on the adequacy of releases of water for environmental reasons following assessment of available information*."

Theoretically adequacy can be evaluated by considering either the drivers of the environmental condition of rivers (in this case, the flow regime) or the responses to environmental flows (in this case, habitat, biota, and water quality), but ideally both. Here we focus on both, emphasising the drivers in Section 2 and the responses in Section 3. Note that concentrating on the responses only would be premature for the following reasons: first, the reporting to date considers only the initial three years following Corporatisation (for a restoration project with a 10-year time-frame); second, the hypotheses that are built into the flow response monitoring program (Rose and Bevitt 2005a, 2005b) are structured towards the responses anticipated for flows equivalent to 21% MANF, which, due to recent drought, will not be achieved for some time.

Thus the term *adequacy* is interpreted here broadly to refer to the key components of the flow regime; to water quality; and to the ecological responses. Streamflow is a "master variable" that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing water systems (Poff *et al.* 1997). Hence adequacy should also consider in what way the effectiveness of the flow regime and certain flow thresholds have changed with increased environmental flows. Restoration to a pre-regulation state is not expected but recovery of a proportion of lost capacity to sustain native biodiversity and bioproduction certainly is (Stanford *et al.* 1996).

NATURAL FLOW REGIME AND THE CONSEQUENCES OF CHANGING IT

There is widespread agreement that there are five key components of natural flow regimes in flowing waters (Poff *et al.* 1997, Bunn and Arthington 2002). These are (1) the volume of flow, (2) the frequency of occurrence of flow events, (3) the duration of flow events, (4) the predictability of flow events, and (5) the rate of change or flashiness of flows (Poff *et al.* 1997). The flow regime of a river can thus be characterized by the nature of these components, and it is to the combination of these components in natural rivers to which flora and fauna have adapted (Lytle & Poff 2004). Arising from the natural flow components and the adaptations of the biota, there are four major principles that emerge when considering flow and river ecosystems (Bunn and Arthington 2002). Specifically, in terms of biodiversity and ecological processes these principles are:

> Principle 1: Flow is a major determinant of the physical habitat in streams, which in turn is a major determinant of biotic composition.
>
> Principle 2: Aquatic species have evolved life history strategies primarily in direct response to the natural flow regime.
>
> Principle 3: Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of many riverine species.
>
> Principle 4: The invasion and success of exotic and introduced species is facilitated by the alteration of flow regimes.

Altering the flow regime of a river by changing any one or any combination of the five key components of the flow regime greatly increases the potential to degrade the river ecosystem. This degradation is due to significant alteration of any, some or all of the four principles listed above. All five key components of the flow regime, and all four principles apply to the Snowy River.

Since 1967 when the Jindabyne Dam closed the Snowy River, flow at Jindabyne has been reduced to an annual mean flow of about 1% of its original mean annual flow. As clearly revealed by the ongoing monitoring, such a reduction in volume, in the seasonality and predictability of flows, and a great increase in the duration of low flows have had major degrading effects on the biota of the Snowy River below Jindabyne. The changes in flow have given rise to significant changes in water quality.

River regulation and diversion change the flow regime and so at least disrupt or, at worst, sever these relationships. The purpose of flow restoration, such as on the Snowy River, is to re-establish or strengthen the inter-dependencies summarised by the four principles. The challenge in attempting to restore the Snowy River to a less degraded state lies in providing environmental flows. This means attempting to most effectively provide flow regimes that meet the key flow components outlined above so that the four ecological principles (Bunn and Arthington 2002, Arthington *et al*. 2006) become manifest. Meeting this challenge will depend on the volumes of water available. Effective management of the project of providing environmental flows is very dependent on the ongoing assessment of the physical and biotic condition of the Snowy River below Jindabyne Dam. As streamflows are only partly restored, the challenge is to ensure the flows that are returned are used as effectively as possible (Erskine *et al.*, 1999a).

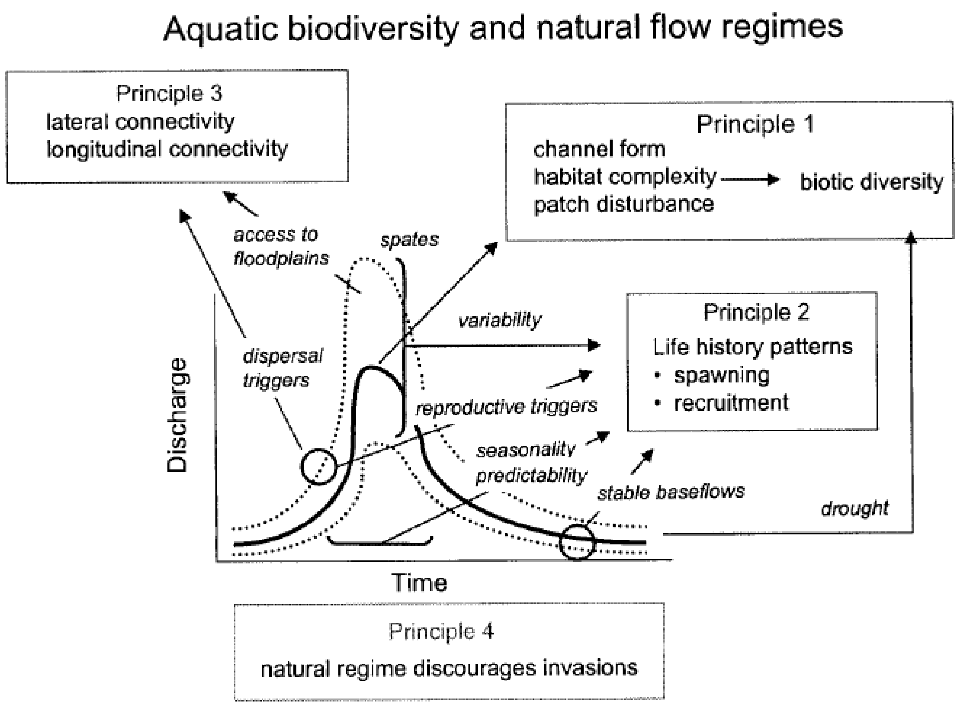

Figure 1: *Aquatic biodiversity and natural flow regimes*

The natural flow regime of a river influences aquatic biodiversity via several interrelated mechanisms that operate over different spatial and temporal scales. From Bunn and Arthington (2002).

This report considers the four principles, but considers only flow components for which information was readily available, i.e. volume, seasonality and variability.

INFORMATION SOURCES

Information sources used in preparing this paper are the international and local scientific literature, published and in press reports on the Snowy River, submissions to the Snowy Licence Review, and presentations made to the Snowy Scientific Committee. The Snowy Scientific Committee would like to acknowledge the assistance of the following persons and organisations:

- Simon Williams and Andrew Brooks, DWE; Andrew Nolan, Snowy Hydro Limited; Neville Smith, Water for Rivers.
- Andrew Brooks, DWE, provided flow data for Dalgety.

All sources have been used in good faith that the information therein is reliable.

Section 2: Drivers of Environmental Condition

THE EXPECTED FLOW REGIME: A CONTEXT

The objective of sending increased flows down the Snowy River, as set out in Annexure One to the Snowy Water Inquiry Outcomes Implementation Deed (SWIOID (2002), is "*to improve the habitat for a diverse range of plant and animal species through a combination of:*

- *[1] improving the temperature regime of the river water*
- *[2] achieving channel maintenance and flushing flows within rivers*
- *[3] restoring connectivity within rivers for migratory species and their dispersion*
- *[4] improving triggers for fish spawning; and*
- *[5] improving the aesthetics of currently degraded riverine environments".*

The broad outline of the flow regime for the Snowy River is given in the Implementation Deed (SWIOID 2002). This advises on achieving target volumes and delivering a seasonal pattern. It does not advise on other aspects of the flow regime for the Snowy River such as inter-annual variability or critical intervals between specific flow events, variability at short temporal scales such as weekly or daily, or on delivering channel maintenance and flushing flows.

The annual target volumes are specified in the Implementation Deed (SWIOID 2002) for each year following Corporatisation (Table 1).

Table 1: 10-year staged releases scheduled for the Snowy River

Schedule taken from the 'Agreed Snowy Water Inquiry Outcomes" as given in Part Two of the Implementation Deed (SWOID 2002). The Deed does not specify actual years.

Stage	When	Annual Target Volume
1	12 months from the date of Corporatisation to its first anniversary	38 GL From either or both Mowamba River and Cobbin Creek
2	From first to seventh anniversary of Corporatisation	142 GL (annual average per Water Year) Note: 38 GL is to come from either or both Mowamba River or Cobbin Creek, up to the third anniversary 15% of MANF (142 + 9 GL Base Passing Flow)
3	From seventh to tenth anniversary of Corporatisation	212 GL (annual average per Water Year) 21% of MANF(212 + 9 GL Base Passing Flow)
4	From tenth anniversary of Corporatisation	28% MANF

These are scheduled to increase in three stages over ten years (Table 1): thirty eight GL in Stage 1, 142 GL in Stage 2, 212 GL in Stage 3. The fourth stage after 10 years is not so strongly prescribed. The SWIOID clarifies that the annual target volumes for Stages 2, 3 and 4 plus the Base Passing Flow of 9 GL are to be considered as 15%, 21% and 28% MANF respectively.

The seasonal pattern for these releases is specified in advice to Snowy Hydro Limited by the Water Administration Ministerial Corporation, with the option of covering all months of the year. If this advice is not received by 13th February in a given water year, then Snowy Hydro Limited must release the available volume according to a default condition in the following water year. This default condition is specified in the Deed (SWIOID 2002, Section 11.4) and is known as the Monthly Default Release Volumes. The annual hydrograph provided by the Monthly Default Volumes is a slow increase through winter, a strong peak in spring (September-October) corresponding to snow-melt, with lowest flows in summer-autumn (Table 2).

Table 2: Monthly Default Release Volumes (as a water year)

Given as a % of total available volume for a given water year, starting in May, and designed to give a seasonal signal equivalent to spring snow melt with peak in September-October.

May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
3.8	6.5	7.7	9.2	20.4	24.5	11.8	5.5	2.6	3.3	1.9	2.8

Actual Flow Regime

The first flow releases[1] began on 28 August 2002, with the decommissioning (temporarily) of the Mowamba Aqueduct (SHL 2008a).

Decommissioning the Aqueduct allowed the Mowamba River, the first significant tributary into the Snowy River downstream of Jindabyne Dam, to flow directly into the Snowy River. This lasted for about three years, until the Mowamba Aqueduct diversion was re-commissioned on 30 January 2006 (SHL 2008a). For a brief period, 1 May 2005 to 30 January 2006, Snowy River Increased Flows (SRIF) were made from Mowamba and Cobbin Creek Weirs, and from Jindabyne Dam, via the existing siphon outlet. The pattern of releases between 1 September 2006 and January 2007 was partly dictated by the requirement to test the outlet works.

[1] **Release history and actual flow regime:** This history of Snowy River Increased Flows (SRIF) is taken from the submission by SHL (2008a) to the 5 year licence review, there being no other sources readily available.

The recent historical flow regime is considered here from three aspects relevant to river health: volume, seasonality and variability. Volume or magnitude relates to fluvial disturbance by channel maintenance and flushing flows, as set out in Principle 1 above.

Volume: The current situation is that the amount of water flowing down the Snowy River appears to be less than expected (Figure 2).

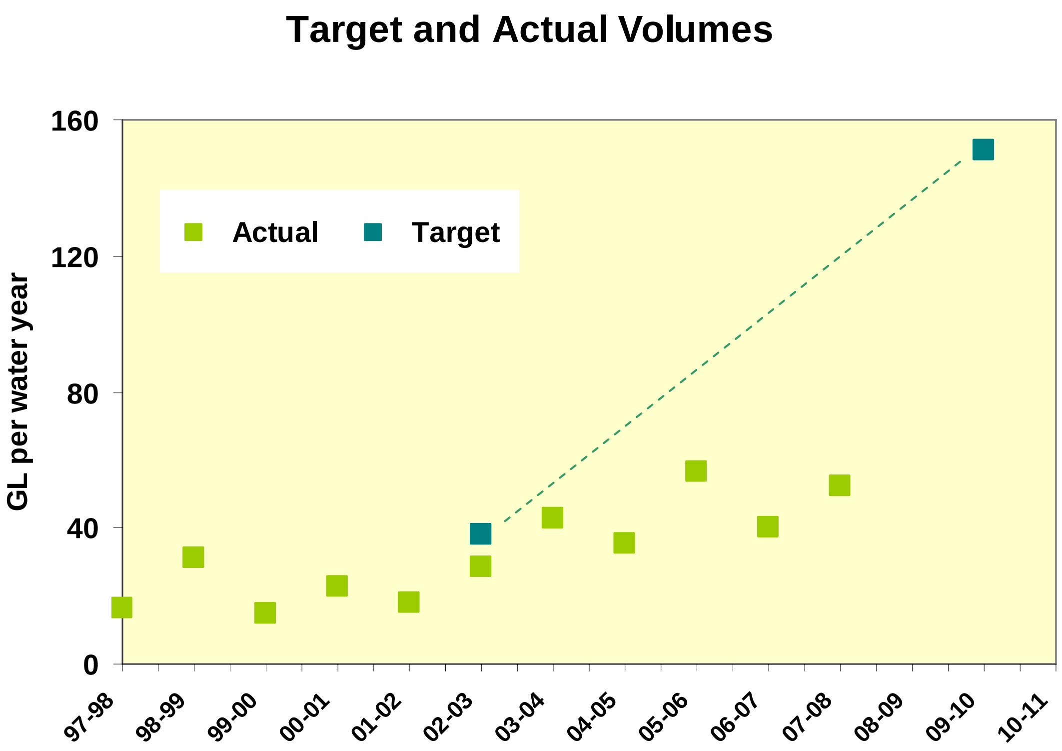

Figure 2: Comparison of Target versus Actual Volumes in the Snowy River

Comparison between Target and Actual annual flows. GS 222026 (Dalgety) is the indicator of actual flows, and is the sum of daily flows from 1 May to 30 April. Target is the Target volume specified in the Implementation Deed (SWIOID 2002) for the seventh anniversary of Corporatisation plus 9 GL released from Jindabyne Dam for Base Passing Flow but not including the unregulated flow component of Base Passing Flow.

This is evident when comparing the target volumes per water year, indicated by assuming a steady linear increase from volumes scheduled for first (38 GL) to seventh (151 GL) anniversary of Corporatisation, with the annual volumes passing Dalgety (the closest gauging station to Jindabyne Dam and one with a record preceding the SWIOID). Target and actual volumes were close in the first year following corporatisation (Figure 2), when the target was 38 GL and the actual annual flow[2] at Dalgety was 28.5 GL. Target volume for the seventh anniversary of corporatisation (2009) is 151 GL, nearly three times actual flows in 2007-2008. The target volume of 151 GL is calculated as the sum of 142 GL plus Base Passing Flow, conservatively estimated as 9 GL released from Jindabyne Dam but not including the unregulated flow past the relevant works on the Mowamba River and Cobbin Creek prior to the Corporatisation.[3]

The Snowy Scientific Committee notes that:

- flows down the Snowy River will need to increase dramatically over the next two years if the target volume of 151 GL is to be met by the seventh anniversary of Corporatisation.

Seasonality: Graphical analysis of time series at Dalgety (Appendix 2) shows only a few years where there are normal seasonal contrasts, i.e. years where winter-spring flows are considerably higher than in summer-autumn. However, even in those years, the seasonal signal is not strong.

To date, only very limited directions[4] have been provided to Snowy Hydro Limited by the Water Administration Ministerial Corporation (WAMC) via the Water Corporatisation Liaison Committee (WCLC) (SHL 2008b), and these were that the monthly distribution for the 2006-07 water year should follow the Default Monthly Release Volumes "*modified to ensure a floor of 95 ML day release from Jindabyne Dam across the entire year so that the Dalgety supply system could continue to access water in the Snowy River*" (SHL 2008b). The volume required to meet this is 34,675 ML (95 ML/d for 365 days), which is turn is equivalent to the SRIF for 2007-2008. Because this advice was not rescinded or modified in any way, it has remained operational since then, and hence made applicable to 2007-2008 and 2008-2009 (SHL 2008b).

The result is an almost undetectable seasonal pattern for these years. Opportunities for introducing a seasonal signal have been lost due to the needs of domestic water supply. However, as these needs no longer apply (Southern Rivers CMA, pers. comm.), seasonality can now be reintroduced, although the size of the signal will depend on the volumes available.

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[2] **Actual Volume**: calculated as the sum of all mean daily flows from 1 May to 30 April.

[3] **Unregulated flow past works on Mowamba River and Cobbin Creek:** no reliable estimates were located.

[4] **History and Nature of Advice from WAMC to SHL:** This paragraph is based on information given in Snowy Hydro's supplementary submission to the 5-year Licence Review (SHL 2008 b), the only public information on history and nature of this advice, and is not necessarily complete.

The Snowy Scientific Committee notes that:

- none of the years since 2002, or indeed since 1997, show the strong spring snow-melt signal necessary for river health that was intended to be delivered through the Default Monthly Release Volumes
- opportunities for introducing a seasonal signal over the last three water years have been lost due to domestic water supply requirements equivalent to the SRIF for 2007-2008
- the water supply issue is now resolved.

Variability: Flow variability over a range of temporal scales occurs naturally and is integral to maintaining the ecological condition of a river (e.g. Giller and Malmqvist 1998, Poff *et al*. 2006). Graphical and statistical analyses of flows passing Dalgety since 1998 (Appendix 1, Table 3) show that flow variability has been generally very low since 1997 but was higher in the years 2002-03 to 2005-06. Standard measures of variability (Table 3) are all higher for this period.

Table 3: *Characterising recent flows*

Basic statistical characteristics of river flow at GS 222026 (Dalgety) over the last ten years. Variability = range/median where range refers 20% and 80%. All calculations done using River Analysis Package V2.0.4 (eWater).

	BEFORE De-commissioning	AFTER De-commissioning	AFTER Re-commissioning
Data Analysis Period	6 June 1997 to 27 August 2002	28 August 2002 to 4 February 2006	5 February 2006 to 2 June 2008
Daily Flow			
Mean (ML day)	57.0	120.4	119.9
Median (ML day)	41.8	92.1	101.9
Variability			
P10 (ML day)	64.1	224.5	175.4
P90 (ML day)	34.0	50.3	71.9
Variability	0.35	1.16	0.58
Total volume (GL)	108.8	151.3	101.8

This higher variability was particularly evident in 2005-2006 (Appendix 1), at different temporal scales, from monthly to weekly and less, and included a weak seasonal signal from July to January with an overlay of small peaks. This period of higher variability coincides with when the Mowamba Aqueduct was decommissioned, and is sandwiched between years with very little flow variability, with several instances[5] of 2+ months of essentially constant flow.

To date, only very limited directions[6] have been provided to Snowy Hydro Limited by the Water Administration Ministerial Corporation regarding departures from the prescribed Monthly Default Release Volume, and these were for September-October 2006 (SHL 2008b).

The current flow regime in the Snowy River below the Jindabyne Dam is now flat-lining at Dalgety at flows below natural base flows, with occasional small events of positive flow variability due to precipitation events in the catchments of tributaries (Appendix 1). The current variability is biased in that it is created by positive spikes from the flat-lined flow. Thus, in comparison to natural levels of flow variability or the variability present when the Mowamba Aqueduct was decommissioned, the flow variability is currently quite unnatural and has been greatly dampened. Furthermore, the current low volumes serve to increase the range in water temperatures, both diurnally and seasonally, with the current flows being colder in winter and warmer in summer than those of the pre-dam flows, due to lack of thermal buffering (Bevitt and Jones 2008).

The effects of reducing variability without any strong high flow events, or even variability in velocities, is to allow, among other things, sediments from sand to silt to build up in the stream bed, to create clogging of the hyporheic zone (colmation), to encourage the growth of filamentous algae and aquatic macrophytes (both submerged and emergent), to greatly reduce habitat variety and availability, and to reduce the variability of the shoreline inundation and exposure --the important "toiche" habitat. By reducing habitat variety and habitat changes with high flows and low flows, the current flow regime with minimal variability is reducing both the diversity and the seasonal succession of the biota and is certainly not allowing the river to be a rapid flowing, highly variable, montane river.

The Snowy Scientific Committee notes that:

- since the Mowamba Aqueduct was re-commissioned, flows in the Snowy River at Dalgety have been characterised by reduced variability

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[5] **Periods of near constant flow**: January 1999-October 2000; most of the period from January 2001 to September 2002; March 2006 to September 2006; most of March 2007 to September 2007; March-April 2008.

[6] **History and Nature of Advice from WAMC to SHL:** This paragraph is based on information given in Snowy Hydro's supplementary submission to the 5-year Licence Review (SHL 2008 b), the only public information on history and nature of this advice, and not necessarily complete.

- the opportunities for introducing flow variability were apparently compromised by the same water supply requirement that has been constraining the seasonal pattern
- as this water supply constraint no longer applies, there is now opportunity to increase flow variability, for example on a weekly time-step
- even under low flow conditions, two types of variability need to be built into the pattern of flow releases: short-term variability over days and weeks, and seasonal variability over months
- part of the necessary flow variability can be achieved by decommissioning the Mowamba Aqueduct.

HISTORY OF SNOWY RIVER INCREASED FLOWS (SRIF)

In 2002, the Joint Government Enterprise, now known as Water for Rivers, began identifying projects where water efficiencies could be made, and entitlements purchased. By winter 2008, it had identified a total of 165 GL[7]. Based on the 2:1 formula, this translates into 110 GL for the Snowy River and 55 GL for the Murray River.

The volume identified as water savings is not immediately available to the Snowy River but must go through auditing and legal scrutiny, eventually becoming known as Verified Water Savings. Based on this, a volume of water is allocated to the Snowy River, known as the Environmental Entitlement. In line with progress made by Water for Rivers, the Environmental Entitlement has been increasing steadily[8] in the years since 2005-2006 water year, at the rate of 4-6 GL per year, from 57 GL to 67 GL (SHL 2008a). This is a little over half of the volume identified by Water for Rivers.

The volume of water actually released to the Snowy River is the Snowy River Increased Flows (SRIF). In any one water year, this is the Environmental Entitlement subject to various adjustments: these adjustments are part pay-back for the Mowamba Borrow, for seasonal availability, and for any over or under-spills in the previous year. Over the first three years, the combined effect of these adjustments has gradually become bigger, with the result that the SRIF has progressively decreased from 2005-06 when it was 38 GL to 2007-08 when it was 32.6 GL (SHL 2008 a). The increasing divergence between Releases and Entitlements, and the

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[7] **Water for Rivers and 165 GL**: Stated in a presentation by Neville Smith, Water for Rivers, on 31 August 2008 at Dalgety for Snowy Day.

[8] **Environmental Entitlements and SRIF:** Data taken from Annexure Two in the submission by Snowy Hydro Limited to the 5-year Licence Review (SHL 2008 a), being the only public source of this information.

overall size of both of these relative to identified water savings (approximately half and approximately one third respectively) is shown below (Figure 3).

Note that reliable estimates of Environmental Entitlements and of SRIF for the 2008-2009 water year were not located in time for inclusion in this report.

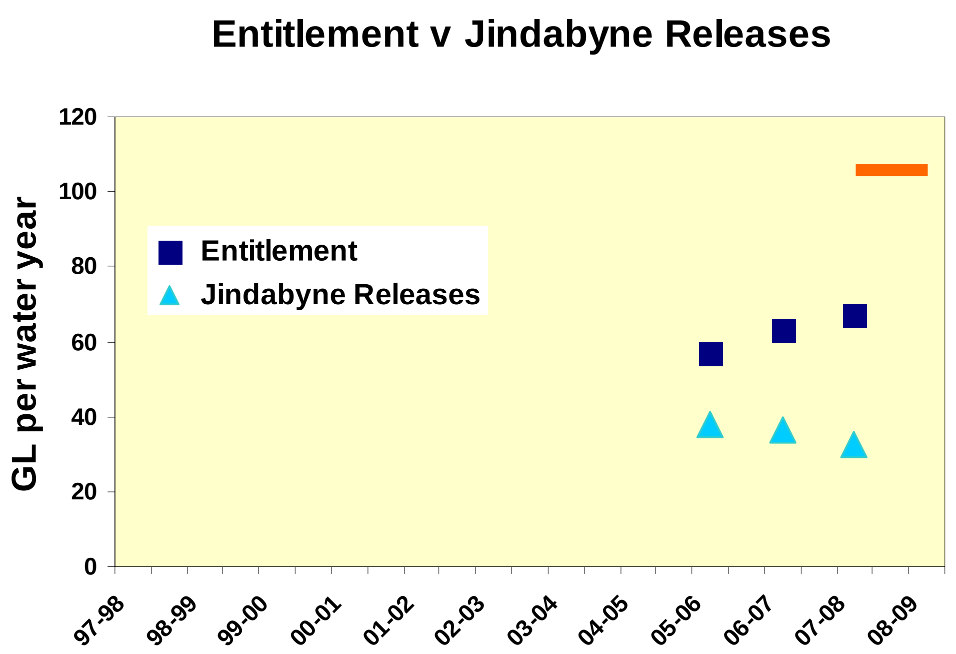

Figure 3: Entitlement and Releases from Jindabyne Dam

Environmental Entitlement apportioned to the Snowy River is the volume theoretically available to the Snowy River, after partitioning the total Verified Water Savings to date between the Snowy and the Murray Rivers. Releases are the actual volumes released by Snowy Hydro Limited from Jindabyne Dam, on advice from Department of Water and Energy, after the Entitlement volume has been debited for the Mowamba Borrow, adjusted for seasonal conditions, and/or debited for over-releases in the previous Water Year. The orange line marks 110 GL, the volume identified through water efficiency projects for the Snowy River by Water for Rivers, as of August 2008. Data taken from Annexure Two (SHL 2008a).

The Snowy Scientific Committee notes that:

- the volume released into the Snowy River decreased in the two years following the first releases made in 2005-2006 water year, from 38 to 32.6 GL; over the same period, Environmental Entitlements increased, from 57 to 67 GL.

- there appears to be a delay in converting savings identified by Water for Rivers into an Environmental Entitlement.

Section 3: Responses to Environmental Flows

RESPONSES RELATED TO FLOW VOLUME

Since environmental releases began, they have not exceeded 38 GL in any year, and the total flows passing Dalgety have not exceeded 58 GL. Thus, in terms of the four general flow response principles (Bunn and Arthington 2002) outlined earlier in the report, flows down the Snowy River from the dam have not been adequate for habitat and channel maintenance, have not provided normal stream conditions for stream fauna, and have not delivered any discernible lateral connectivity. They have maintained a reduced longitudinal connectivity and have provided conditions for the maintenance of some exotic fish species, for example Eastern Gambusia (*Gambusia holbrooki*) and goldfish (*Carassius auratus*) (Gilligan and Williams in press). This inadequacy is particularly evident in relation to flow as the major determinant of physical habitat, as stated in Principle 1, such as Deep Pools. Fluvial or hydraulic disturbance of the Snowy River channel downstream of Jindabyne Dam is required to remove invading vegetation, rework bars and benches, flush and remove accumulating silt and organic matter from pools and to de-stratify pools during summer. Vegetation and silt removal are discussed below (Channel Forming flows).

DEEP POOLS

In a study of the development, persistence and breakdown of stratification in pools of the Snowy River, Turner and Erskine (2005) demonstrated that pools greater than 4 m deep upstream of Dalgety oxygen stratify during summer low flows with both hypolimnetic hypoxia and anoxia having been recorded at different times. Although thermal stratification has not been measured, strong thermal gradients were often present during summer when temperature differences of up to 6.5ºC occurred between surface and bottom waters. Hypolimnetic hypoxia and anoxia limit the amount of habitat for fish and would have been unlikely to have formed before the closure of Jindabyne Dam. Flushing flows are required to completely mix epi- and hypolimnetic waters, thus improving water quality. Hydrodynamic modelling by Erskine (unpublished) shows that flows of 864 ML/d are required to mix these pools by intense interfacial entrainment. Such flows should persist for at least a week. Erskine *et al.* (1999b) and Turner and Erskine (2005) also reported thermal, oxygen and salt stratification in the upper estuary which was mixed by large floods. Most releases from Jindabyne Dam are too small to destratify the estuary.

If the SRIF do not increase, to at least 21% MANF, the deep pools in the two highest reaches, Jindabyne Gorge and Dalgety Uplands, will be under threat of permanent or near-permanent change, and the fauna living there will experience repeated adverse conditions.

The Snowy Scientific Committee notes that:

- flows of about 850 ML/d and lasting about a week are required during hot spells in summer to breakdown oxygen stratification in deep remnant pools in the Jindabyne Gorge
- flows greater than 850 ML/d have occurred three times at Dalgety since 2002 but never lasted more than 2 days (Appendix 1).

The Snowy Scientific Committee recommends:

- as a matter of urgency, that every effort be made to generate sustained high flows lasting several days within the next 1-2 years (i.e. before the end of 2010).
- institutional arrangements, that permit Environmental Entitlements to be stored and accumulated in order to achieve a critical volume, need to be worked out.

CHANNEL MAINTENANCE FLOWS

Channel maintenance flows of 12000 ML/d were recommended by the Expert Panel (Anon. 1996). Erskine *et al.* (1999a) noted that the smallest annual flood ever recorded at Jindabyne before the closure of Jindabyne Dam was 10600 ML/d and that flows of at least 8000 ML/d are required to entrain loosely packed 256 mm diameter gravel. However, as gravels are now tightly embedded, even higher flows are required as the critical shear stress for movement is much greater than for loosely packed material (Downes *et al.* 1997). Reinfelds and Williams (in press) used HEC-RAS to show that at a discharge of 28646 ML/d velocity reversal between pools and riffles occurs at the monitoring site downstream of the Mowamba River junction. This means that higher velocities and shear stresses are recorded in pools than on riffles at this discharge. This is very important because pools are scoured and riffles are filled, maintaining the pool-riffle sequence.

Ideally, and as a rule of thumb, therefore, channel maintenance flows of about 12000 ML/d should occur every year, and last for about 1 week during the spring snow melt period. Such flows would ensure all of the following functions:

- Gravels are overturned and stripped of biofilms;
- Substrate sediments are moved and interstitial fines and organic matter are removed so hyporheic flow is not blocked;

- Pool, riffle and run margins (bed and banks) are trimmed of encroaching sediment and vegetation so that channel shrinkage is reversed and so that aquatic habitat is maintained;
- Fine sediment infilling pools (see below) is totally stripped and replaced with coarser sediment;
- Pools are scoured and riffles are filled, so maintaining the pool-riffle sequence,
- Pools are fully mixed by turbulent flows; and
- Marginal bars and benches are inundated and their surficial sediment reworked to reverse recent terrestrialization of the riparian corridor.

The Snowy Scientific Committee notes that:

- the value of channel maintenance flows is not restricted to channel maintenance, they also have significant ecological functions such as fish passage, maintenance of connectivity between the uplands and lowlands, maintenance of natural biological cues based on streamflow, and dispersal of invertebrates, seeds and propagules.

CHANNEL-FORMING FLOWS

Since 1967, spatially variable channel shrinkage has occurred on the Snowy River in the Jindabyne Gorge by a combination of bio-geomorphic processes (Erskine *et al.,* 1999a). These processes included:

- formation of tributary-mouth bars where incised channels and gullies join the main stream;
- side bar and marginal bench formation, and slackwater deposition by the downstream reworking of tributary-mouth deposits;
- infilling of pools with bio-clastic sediment; and
- native and exotic vegetation invasion and consequent stabilisation of recent deposits.

Bioclastic sediment is a combination of clastics (fine-grained mineral suspended sediment) and organic material (dead microalgae, leaf litter, living and dead macrophytes). Both the mineral and organic fractions settle in the still water of remnant pools during long periods without floods. Bioclastic sediment in the Snowy River has a high organic matter content with a loss-on-ignition of between 20 and 45%, but is clearly dominated by the clastic fraction which has a mean size in the silt fraction of the Wentworth grain size scale (Erskine and Turner 1998, Erskine 2007).

It is only loosely consolidated and forms well-defined but low density flocs or pellets when disturbed (Wayne Erskine, pers. obs., over several years 1997 to 2006).

The 2002-2003 wildfires in the Snowy catchment burnt a large area, especially downstream of Jindabyne Dam (Rose and Henderson 2003, Russell *et al.* in press). The consequences of this for the in-channel environment and biota are only beginning to be understood.

Rose and Henderson (2003) documented significant influxes of charcoal, organic matter, sand, silt and clay into the Snowy River immediately after these fires. A storm which produced up to 64.2 mm of rainfall (Dalgety) in March 2003 immediately followed these wildfires and generated a flashy flood with a peak discharge of 9239 ML/d at Dalgety (Russell *et al.* in press). Intense storms immediately following wildfires cause severe soil erosion and supply large amounts of sediment to rivers (e.g. Good 1973), with as much as three orders of magnitude increase in suspended sediment concentrations documented for the Yarrangobilly catchment (Brown 1972). These increased suspended sediment concentrations are a major source of the fine-grained sediment laminae in the Snowy River.

However, it takes a long time for the deposited flocs in the fine-grained sediment laminae to consolidate on the river bed. Observations of farm dams near Sydney following the 1994 wildfires (Erskine *et al.* 2003) found that the deposited sediment initially formed a thick gel which slowly consolidated by progressive dewatering over the following 1-2 years. A similar process of consolidation has been observed in the Snowy River. Erskine (2007) noted that the fine-grained sediment laminae in the Snowy River downstream of Jindabyne Dam were much thicker in 2006 than in 1997 when they were originally sampled (Erskine and Turner 1998). He further noted that the sediments had consolidated after the 2002-2003 wildfires. Further consolidation is likely over time unless the fine-grained sediment laminae are disturbed by discharges large enough to scour the bed of pools. Such high discharges conform to the habitat maintenance and channel maintenance discharges recommended by the Expert Panel (Anon, 1996) and Erskine *et al.* (1999a).

To avoid consolidation, scouring flows are needed. Specifics of what is needed can be identified through hydrodynamic modelling with HEC-RAS or similar program. Modelling completed to date (Reinfelds and Williams in press) shows that discharges of 1000 ML/d generate mean flow velocities of 0.21-0.29 m/s which exceed the threshold of about 0.15 m/s thought to be required to entrain fine-grained sediment laminae in the Jindabyne Gorge and Dalgety Uplands Reach. Ideally, such flushing flows should be released every year, irrespective of droughts, to prevent continual accumulation and consolidation of fine-grained sediment laminae.

As a rule of thumb, high releases corresponding to habitat maintenance and channel maintenance flows should be a priority during the first 1-2 years after a wildfire followed by an intense storm that produces significant post-fire soil erosion. As entrainment is a duration dependent process, these flows should be maintained for as long as possible, with a minimum proposed duration of 1 week.

The present contracted channel which Professor Seddon metaphorically called "*a cot-sized river in a king sized bed*" in his submission to the Snowy Water Inquiry needs large-scale fluvial disturbance (discharges of 12000-20000 ML/d) to remove invading vegetation, to rework encroaching bars and benches and to scour pools (Erskine *et al.* 1999b).

The Snowy Scientific Committee notes that:

- the Snowy River Increased Flows since 2002 are inadequate to prevent pool infilling with fine-grained sediment laminae.
- the window of opportunity to achieve effective entrainment of fine-grained sediment laminae in the Jindabyne Gorge and Dalgety Uplands Reach is relatively short, in the order of 1-3 years following a major wildfire.
- channel maintenance flows should be scheduled to follow as soon as possible after a major wildfire.
- flushing flows of 1000 ML/d should be released every year.

WATER QUALITY

Reservoirs are large lakes and thus as lentic ecosystems they process nutrients and other inputs. As a result of this processing, the water leaving a reservoir may be quite different from that entering it, and may also be quite different from natural river water (Wetzel 2001). This is exemplified by changes in phosphorus, nitrate, dissolved silica and organic carbon. Dissolved silica is exported from eroding sections of river – i.e. by montane rivers. Silicon is an essential element for the growth of diatoms, both benthic and limnetic. Diatoms are a major source of food for the fauna of both streams and lakes. It has been reported in North America and Europe that water leaving reservoirs is deficient in dissolved silica (e.g. Humborg *et al.* 2000, Ahearn *et al.* 2005). This deficiency may inhibit the growth of stream benthic diatoms, thus depriving the fauna of a high quality trophic resource.

Water in natural streams contains both dissolved and particulate organic carbon, which constitutes a key trophic resource for stream biota ranging from bacteria, fungi to invertebrates. Water leaving a reservoir can be low in organic carbon, due to processing within the reservoir. Thus, below the reservoir the development of a fully functional stream ecosystem may be impeded. It is not known whether this is true for the Snowy River, as currently there is no relevant water quality monitoring of the water column in Jindabyne Dam or of releases from the dam.

The Snowy Scientific Committee notes that:

- due to impoundment effects, there is a risk that the quality of environmental releases from Jindabyne Dam will be altered in ways that could constrain in-stream productivity.
- currently there is no water quality monitoring program in place at Jindabyne Dam, other than temperature.
- the Mowamba River could be a natural supplier of nutrients (nitrogen and phosphorus), silica and organic carbon as well as providing colonising flora and fauna to the Snowy River.

Section 4: Flow Response Monitoring

Monitoring ecological and geomorphic responses is the most robust and reliable means of determining the effectiveness of increased environmental flows on the Snowy River from 2002 onwards. Monitoring should ensure accountability, as the analysis and interpretation of monitoring data gives feedback to management and so creates opportunities for better management of flows down the Snowy (adaptive management). Scientific understanding improves the amount and reliability of knowledge, a value that extends beyond the catchment boundary.

The Snowy River Recovery project is significant because it is one of the most extensive and most ambitious river restoration projects in Australia today. Further, in a worldwide context, it is one of the very few environmental flow projects with a rigorous design framework, a comprehensive set of before-implementation data, a long-term and ongoing monitoring program, and a set of unambiguous hypotheses for the abiotic and biotic responses. Specific features of the Snowy River Flow Response monitoring program include:

- use of a replicated BACI (Before-After Control-Impact) design that allows temporal and spatial inferences to be made
- good temporal resolution in that it has up to three years of pre-intervention data for some but not all disciplines
- a set of testable hypotheses, making it possible to formally test results for assessing restoration progress
- anticipated responses to increased flows, the principal responses selected for monitoring being geomorphology, water quality, macro-invertebrates, fish and vegetation.

The basis for the monitoring program, its design and rationale have been documented in a timely series of reports (Rose *et al.* 2005, Rose and Bevitt 2005a, Rose and Bevitt 2005b). The effects of the environmental releases, at least for the first three years following Corporatisation (i.e. up to 2005) have been analysed and are now reported on for nearly all the disciplines: fish, macro-invertebrates, water quality (Gilligan and Williams, in press, Brooks *et al.* 2007, Bevitt and Jones 2008). In addition, special studies have been completed that complement the monitoring such as the effects of 2003 bushfires (Russell *et al*. in press), and using hydraulic modelling to determine what flows are required for improving upstream fish movement past barriers or for entraining sediment (Haeusler and Bevitt 2007, Reinfelds and Williams, in press).

Achieving recovery through returning flow volumes to the Snowy River is a long-term project and hence reporting of monitoring results at frequent intervals is essential if monitoring is to maintain its role as a feedback to management and to provide accountability. Monitoring is a critical aspect of management and cannot be divorced from it.

The Snowy Scientific Committee notes that:

- the Snowy River Flow Response Monitoring Program is a high quality and well-founded monitoring program which satisfies contemporary expectations of a well-founded monitoring program, despite having been initiated ten years ago.
- considerable effort from the Snowy Flow Response team has resulted in a high level of documentation and reporting.
- reporting the results of the annual monitoring at periodic intervals is especially important in long-term river restoration
- results and publications from the Snowy River Flow Response Monitoring Program have been primary sources of information used by the Snowy Scientific Committee in its deliberations.

WATER QUALITY MONITORING

As foreshadowed above, interim and periodic reporting in a long-term monitoring program is important for several reasons: it gives an indication of early trends, it informs year to year decisions on flow delivery, and it tests the rigour of the design. The report entitled[9] "*Snowy River Flow Response Monitoring. Water Quality in the Snowy River Before and After the First Environmental Flow Regime*" (Bevitt and Jones 2008) is an excellent example of this.

The report provides some very useful and salient information and shows that considerable progress has been made in the development of modelling procedures and in the appropriate statistical design to test all three hypotheses on which the flow response monitoring is based. The above report analyzes the available data to detect changes (however minor) in temperature, in mean water temperatures, in the variability of temperature and in electrical conductivity before and after the decommissioning of the Mowamba Aqueduct. In spite of an unbalanced design, the analysis did detect minor changes in diurnal water temperatures at Dalgety and a decrease in conductivity. This decrease was probably not due to the effect of the

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[9] **Title:** The report title is a bit misleading as it is actually reporting on the first environmental flow regime, rather than after it.

environmental flows, but to greatly decreased inputs from the catchment downstream of Jindabyne Dam because of the prevailing drought.

The report also addresses the question of the appropriate study design required to fully test the effects of the projected environmental flow releases down the Snowy River on water temperatures and conductivity. Finally, it makes eight recommendations, several of which relate to the future releases from Jindabyne Dam.

The Snowy Scientific Committee notes and agrees with the following recommendations that:

- the requirement to aim for a natural water regime, in terms of temperature, when releasing from Jindabyne Dam, and to avoid releases from the hypolimnion.
- current system of water quality monitoring stations is inadequate to track changes in turbidity and nutrients down the Snowy River. The report calls for new stations to be established, as a matter of urgency.
- the report calls for continuous depth profile monitoring for temperature and dissolved oxygen, and frequent monitoring of nutrients (nitrogen and phosphorus) in Lake Jindabyne and near the outlet.
- current set of meteorological stations is inadequate to provide a history of air temperature.
- there is a requirement for greater flows to prevent pool stratification, and this is consistent with the need to prevent consolidation of clastic materials.
- the condition of deep pools, particularly in the most upstream reaches of Jindabyne Gorge and Dalgety Uplands, is declining.
- fluvial disturbance by flows of between 12000 and 20000 ML/d should be planned for all years in which water is available.

FUNDING ARRANGEMENTS

The Snowy River Flow Response Monitoring program is an essential part of the Snowy River Recovery project. As pointed out above, continuity is essential. However, continuity is not assured, as there is no long-term financial guaranteed commitment.

This lack of financial security has the potential to compromise the quality of the monitoring program and hence the integrity of the restoration project. There are some gaps in the datasets and in the baseline data. Nonetheless, the analysis of the data will allow determination of trends which is important both in planning and executing environmental flow regimes and evaluating the outcomes of environmental flow delivery. At present, the only guaranteed long-term funding for the Flow Response Monitoring program comes from the Victorian Government that has committed to maintaining a constant level of financial support until 2012.

The Snowy Scientific Committee notes that:

- lack of financial security can have a negative effect on staff morale and then on work quality
- in a long-term project, retaining corporate knowledge in the form of a core of valued staff is critical to the delivery of government commitments.
- there has been no program and no operational budget for monitoring montane rivers.

Section 5: Institutional Adequacy

When release volumes are small, it is important to avoid anything that can diminish their ecological value. Conversely, it is essential to maximise their ecological value. The delivery of high flows can be particularly challenging.

DELIVERING CRITICAL FLOWS

Jindabyne Dam was commissioned in 1967, which is the beginning of when the effects of major diversions and flow abstraction began to impact on the Snowy River downstream of Jindabyne. The resulting flow regime, estimated as 1.9% MANF, was to be partly restored as a result of the Snowy Water Inquiry but despite the Heads of government agreement in 2000 to re-instate up to 21% MANF by 2010, there has been very little change in the flow regime. Forty years with flows continuously less than 5% MANF is a very severe stress for a riverine ecosystem. There is a real risk that if channel-forming flows are not received or delivered within the next few years, then their effectiveness when delivered will be diminished. If habitat replenishing and channel-forming flows are delivered, there still remains the problem of where do the new stream invertebrate species and their populations come from. They will not be supplied from Lake Jindabyne. Some species may recruit downstream by flying from the Thredbo and Mowamba Rivers and some may recruit upstream from the Bombala River. However, there are many invertebrates (e.g. annelids, crustaceans, molluscs) that do not fly and for them recolonization may be impossible in ecological time. One solution to this problem is de-commissioning Mowamba aqueduct as the flow thus provided should deliver eggs, larvae and adults of these taxa to the Snowy River below Jindabyne Dam.

Under the current system, which is based on an annual allocation and release, there is very little potential for delivering volumes equivalent to a high flow event. And, under the current dry conditions that result in downwards adjustments to Environmental Entitlements, there is little likelihood that SRIF will increase substantially in the next 2-4 years. Even when Environmental Entitlements do increase to over 100 GL, the actual releases will continue to be much less as long as drought conditions prevail. What is needed is a revision to the current annual-based accounting and operating system that would allow volumes to be accumulated over a few years in Lake Jindabyne so that a high flow could be eventually released. Equally, under current arrangements with the SHL license, there are no obvious means for making a natural flow event even larger by deliberate releases to “piggy-back” onto flows from the catchment downstream of Jindabyne Dam.

The Snowy Scientific Committee therefore advocates:

- exploring the potential under existing arrangements for volume banking and for piggy-backing environmental releases onto natural floods
- convening a feasibility workshop of stakeholders, hydrologists and WCLC to develop institutional flexibility for delivering environmental releases
- tapping in to the experience of those that developed the joint storage option in Hume Dam that can be released to deliberately increase magnitude or duration of flooding in the Barmah-Millewa Forest.

Section 6: Findings and Recommendations

ADEQUACY OF ENVIRONMENTAL RELEASES

The Snowy Scientific Committee has considered 'adequacy' from different perspectives and finds that environmental releases to date have not been adequate.

In terms of volumes released, these have been less than one third of what was agreed. Restoration of flow-related processes summarised by the four general flow principles is not being achieved*; flows down the Snowy River from the dam have not been adequate for habitat and channel maintenance, have not provided normal stream conditions for stream fauna, and have not delivered any discernible lateral connectivity. They have maintained a reduced longitudinal connectivity and have provided conditions for the maintenance of some exotic fish species, for example Eastern Gambusia and goldfish*. Finally, the flow pattern has been compromised by the need to meet water supply requirements, and the delivery of large releases will continue to be compromised unless some institutional flexibility can be developed.

The principal points made through this report were:

Volume

- Releases down the Snowy River will need to increase dramatically over the next two years if the target volume of 151 GL is to be met by the seventh anniversary of Corporatisation.

Seasonality

- None of the years since 2002, or indeed since 1997, show the strong spring snow-melt signal necessary for river health that was intended to be delivered through the Default Monthly Release Volumes.
- Opportunities for introducing a seasonal signal over the last three water years have been lost due to domestic water supply requirements equivalent to the SRIF for 2007-2008.

Variability

- Since the Mowamba Aqueduct was re-commissioned, flows in the Snowy River at Dalgety have been characterised by reduced variability.
- The opportunities for introducing flow variability were apparently compromised by the same water supply requirement that has been constraining the seasonal pattern.
- As this water supply constraint no longer applies, there is now opportunity to increase flow variability, for example by scheduling releases from Jindabyne Dam on a weekly time-step.

Adequacy of Releases

SRIF history

- The volume released into the Snowy River decreased in the two years following the first releases made in 2005-2006 water year, from 38 to 32.6 GL; over the same period, Environmental Entitlements increased from 57 to 67 GL.

Deep Pools

- Flows of about 850 ML/d and ideally lasting a week are required during hot spells in summer to breakdown oxygen stratification in deep remnant pools in the Jindabyne Gorge.
- Flows greater than 850 ML/d have occurred three times at Dalgety since 2002 but never lasted more than 2 days (Appendix 1).
- The condition of deep pools, particularly in the most upstream reaches of Jindabyne Gorge and Dalgety Uplands, is declining.

Channel Maintenance and Channel Forming Flows

- The Snowy River Increased Flows since 2002 are inadequate to prevent pools infilling with fine-grained sediment laminae.
- The window of opportunity to achieve effective entrainment of fine-grained sediment laminae in the Jindabyne Gorge and Dalgety Uplands Reach is relatively short, in the order of 1-3 years following a major wildfire.
- The value of channel maintenance flows is not restricted to channel maintenance; these have significant ecological functions such as fish passage, maintenance of connectivity between the uplands and lowlands, maintenance of natural biological cues based on streamflow, and dispersal of invertebrates, seeds and propagules.

Water Quality

- Due to impoundment effects, there is a risk that the water quality of environmental releases from Jindabyne Dam will be altered in ways that could constrain in-stream productivity.
- Currently there is no water quality monitoring program in place at Jindabyne Dam, other than temperature.
- The Mowamba River could be a natural supplier of nutrients (nitrogen and phosphorus), silica and organic carbon to the Snowy River as well as of propagules and colonising micro-fauna.

Flow Response Monitoring

- The Snowy River Flow Response Monitoring Program is a high quality and well-founded monitoring program that satisfies contemporary expectations, despite having been initiated ten years ago.

- Considerable effort from the Snowy Flow Response team has resulted in a high level of documentation and reporting.
- Reporting at 3-4 year intervals is especially important in long-term river restoration projects.
- Results and publications from the Snowy River Flow Response Monitoring Program have been primary sources of information used by the Snowy Scientific Committee in its deliberations.

Funding

- Lack of financial security can have a negative effect on staff morale and then on work quality
- In a long-term project, retaining corporate knowledge in the form of a core of valued staff is critical to the delivery of government commitments.
- There has been no program or operational budget for monitoring montane rivers.

RECOMMENDATIONS

Whilst recognising that the current resources are limited (water, finances), the Snowy Scientific Committee makes the recommendations below in the interests of the long-term health of the Snowy River. It asks that all concerned parties and stakeholders take an open and flexible approach to implementing these or to finding solutions.

Flows need to be made more variable.

- As a rule of thumb, even under low flow conditions, two types of variability need to be built into the pattern of flow releases: short-term variability over days and weeks, and seasonal variability over months.

In-flows from the Mowamba River are recognised as a potentially significant in restoring the uppermost reaches of the regulated Snowy River, through contributing colonising micro-fauna and propagules, water of suitable quality and temperature, and adding flow variability. The role of Mowamba River needs to be more precisely understood, and to be documented, so as to better inform restoration of the Snowy River. Opportunities for doing this are good, being either through the routine Flow Response Monitoring or through an externally-funded specific project, both using a well-planned adaptive management approach with temporary de-commissioning.

- A targeted investigation is needed to determine the importance of in-flows from the Mowamba River to the restoration of the uppermost reaches of the Snowy River, using a well-planned, hypothesis-driven adaptive management approach.

Flows volumes could be larger than at present if the process of converting identified savings into Environmental Entitlements could be accelerated.

- The procedures for converting savings identified by Water for Rivers into an Environmental Entitlement need to be accelerated.

The Deep Pool habitat needs to be improved.

- As a matter of urgency, every effort should be made to generate sustained high flushing flows lasting several days within the next 1-2 years (ie before the end of 2010).

In relation to Channel Maintenance and Channel Forming Flows:

- Channel maintenance flows should be scheduled to follow as soon as possible after a major wildfire.
- Flushing flows of 1000 ML/d should be released every year.
- Fluvial disturbance by flows of between 12000 and 20000 ML/d should be planned for all years in which water is available.

In order to ensure appropriate water quality downstream of Jindabyne Dam, the releases should be structured as follows.

- The target for a release from Jindabyne Dam should be to aim for a natural water regime, in terms of temperature, and to avoid releases from the hypolimnion.
- There is a requirement for greater flows to prevent pool stratification, and this is consistent with the need to prevent consolidation of clastic materials.

As reported by Bevitt and Jones (2008), the water quality monitoring program is currently inadequate to detect changes resulting from environmental releases.

- New water quality monitoring stations need to be established down the Snowy River, as a matter of urgency.
- The number of meteorological stations needs to be increased in order to provide an adequate history of air temperature.
- Water quality of releases from Jindabyne Dam and within Jindabyne Dam should be monitored by continuous depth profile monitoring for temperature and dissolved oxygen, and frequent monitoring of nutrients (nitrogen and phosphorus).

Greater flexibility is needed in institutional arrangements in order to improve the flow regime down the Snowy River so that the volumes that are available can be used more effectively.

- The potential must be explored under existing arrangements for volume banking and for piggy-backing environmental releases onto natural floods.

- If necessary, new institutional arrangements, permitting Environmental Entitlements to be stored and accumulated in order to achieve a critical volume, need to be worked out.

- A workshop should be convened, of stakeholders, hydrologists and WCLC, to explore the feasibility of greater institutional flexibility, particularly in relation to banking volumes and piggy-backing releases.

- The experience of those that developed the joint storage option in Hume Dam that improves the flooding in the Barmah-Millewa Forest is a resource that should be accessed.

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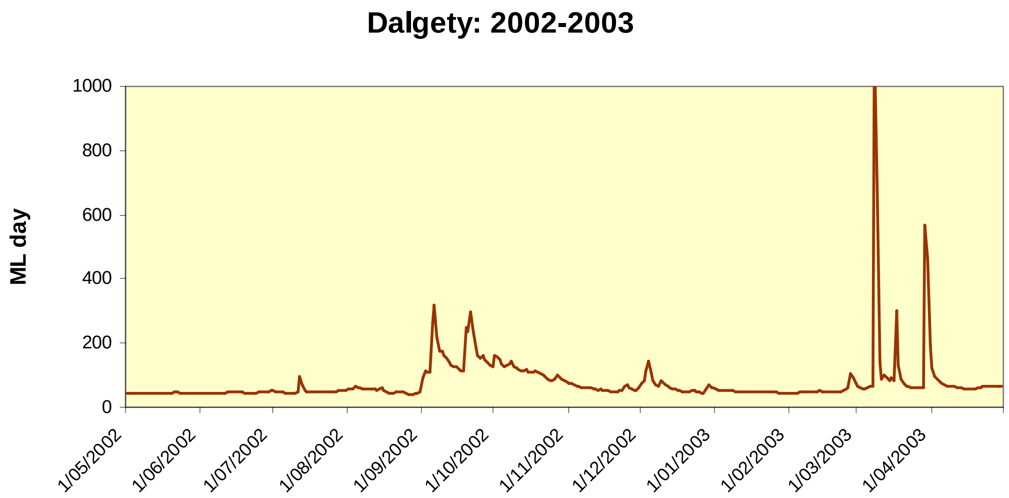
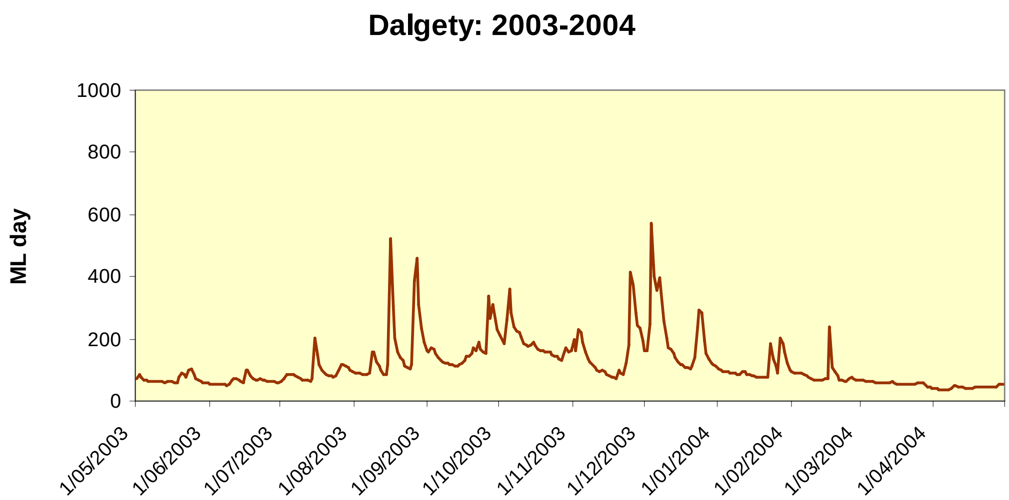
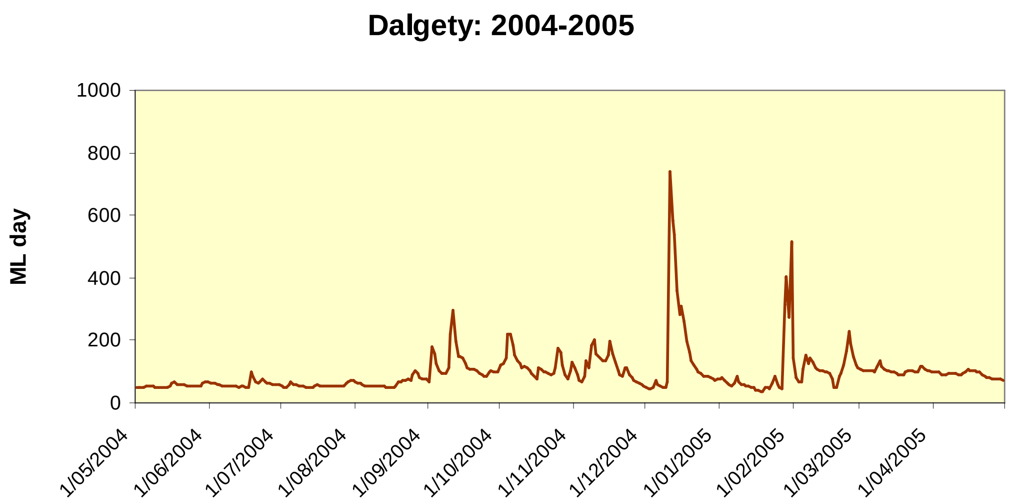
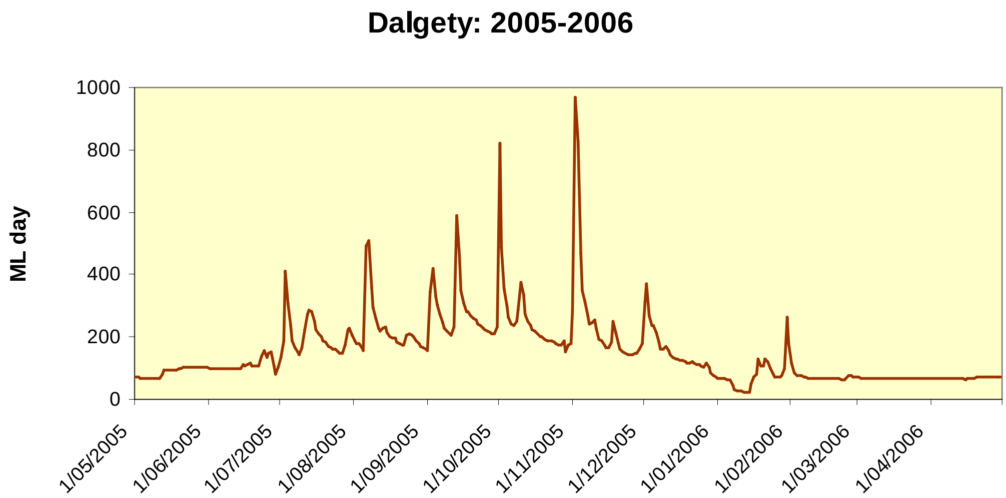
Appendix 1: Flow time series at GS 222026








Dalgety: 2005-2006
ML day
1000
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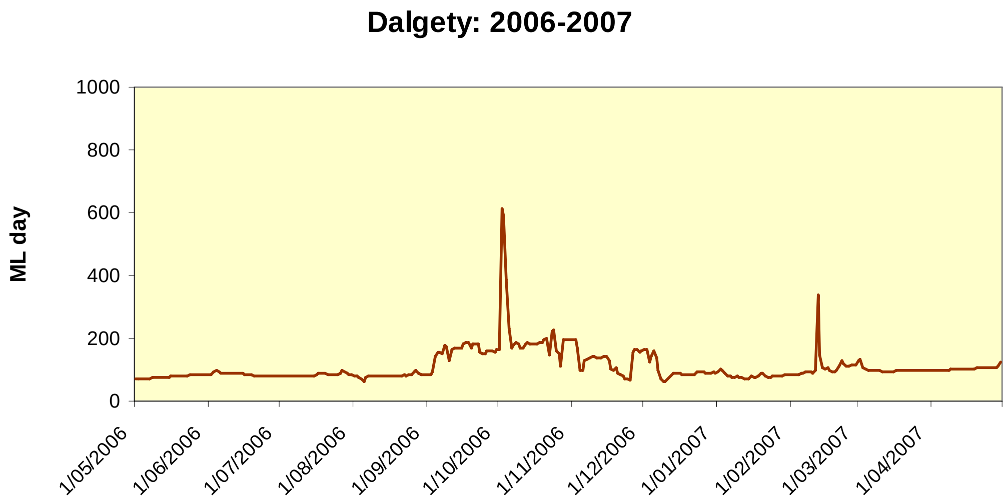
1/11/2005
1/12/2005
1/01/2006
1/02/2006
1/03/2006
1/04/2006


Dalgety: 2006-2007
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1000
800
600
400
200
0
1/05/2006
1/06/2006
1/07/2006
1/08/2006
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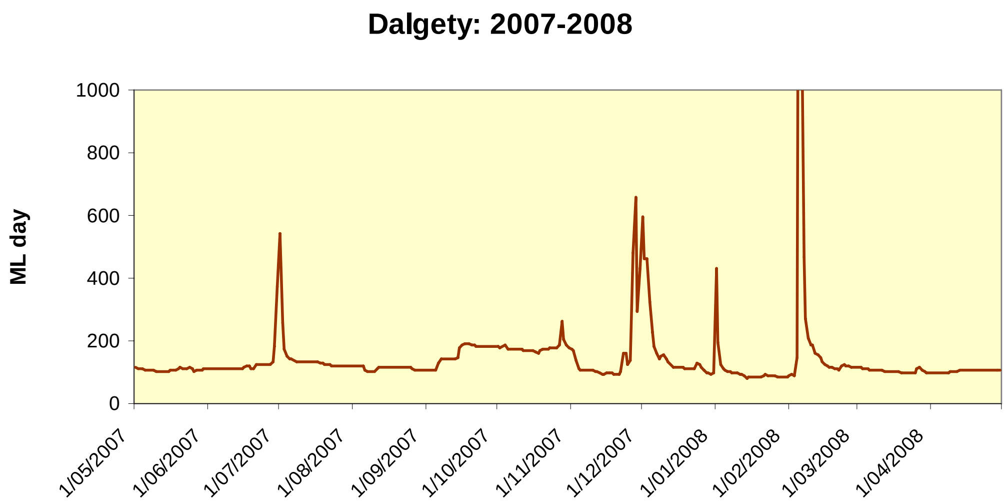
1/10/2006
1/11/2006
1/12/2006
1/01/2007
1/02/2007
1/03/2007
1/04/2007


Dalgety: 2007-2008
ML day
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600
400
200
0
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1/08/2007
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1/10/2007
1/11/2007
1/12/2007
1/01/2008
1/02/2008
1/03/2008
1/04/2008