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Snowy River Recovery

Snowy flow response monitoring and modelling

Hydrological changes attributed to environmental flow release to the Snowy River, 2002-2005





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Snowy flow response monitoring and modelling:
Hydrological changes attributed to environmental flow release to the Snowy River, 2002-2005

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Summary

The construction of the Snowy Mountains Scheme (the Scheme) between 1955 and 1967 for power generation and to provide water to the Murray and Murrumbidgee irrigation areas diverted approximately 96 per cent of flow from the Snowy River below Jindabyne Dam, as measured at Dalgety. The first environmental flow releases (EFR) to the Snowy River occurred on 28 August 2002 from the Mowamba River aqueduct and occurred until early 2006. The Snowy Environmental Flow Response Monitoring and Modelling Program was established in 2000 to provide a physical, chemical and biological assessment of the river and quantify the changes, if any, caused by the implementation of environmental flows. This report documents:

- The hydrologic impacts on the Snowy River due to construction of the Scheme.
- The hydrologic changes that have occurred as a result of the first stage of the EFR.

The construction of the Scheme has had a large impact on the hydrologic regime of the Snowy River, particularly in the upland reach of the river as measured at Dalgety. Mean daily flows were reduced up to 96 per cent of pre-Scheme. The diversion of flows into Lake Jindabyne has also resulted in a seasonal shift in peak flows from spring to winter, the frequency and magnitude of floods of all recurrence intervals has decreased significantly, and mean summer baseflows in the river have fallen by 70-95 per cent.

The greatest change to flows in the Snowy River as a result of the first stage of environmental releases has occurred in the upland reach of the catchment. By the conclusion of the release period the annual flow at Dalgety had increased from 1.9 per cent to 4.6 per cent of the mean annual natural flow (MANF). These flows were substantially lower than the target release of 15 per cent of the MANF due to the prevailing drought conditions over the catchment during the monitoring period, and the limited water savings in the Murray and Murrumbidgee river systems. The mean daily flow in the midland and lowland macro-reaches declined between 31 and 44 per cent during the period of environmental releases consistent with conditions in the reference rivers, indicating the drought impacts were catchment wide as well as minimising the transfer of the benefits of the releases further down the river to the middle and lower reaches of the Snowy River.

Mean summer baseflows increased from 25 to 45 MLd^{-1} in the upland reach, and flows exceeding 200 MLd^{-1} (considered representative of natural summer baseflow) increased in duration from 1 per cent to 9 per cent of the time during the release period. The hydrograph of daily flows at Dalgety shows that the releases from the Mowamba River greatly increased the daily pattern of variability in the upland reach of the river, and this is reflected in the coefficient of variation at Dalgety which is closer to the pre-scheme variability.

The environmental water releases from the Mowamba River also provided a small snowmelt signal that was within the timing of a snowmelt across the Snowy Mountains rivers, albeit with a small seasonal peak in late September and early October. Although substantially smaller than the natural snowmelt peaks of the Snowy River, a maximum snowmelt peak of 844 MLd^{-1} was recorded during the first stage of the EFR. The Snowy River was previously characterised by these large snowmelt discharges in October and colder water associated with these snowmelt signals should be considered a high priority for future releases considering many of the aquatic biota would have adapted to these predictable cold snowmelt releases.

Abbreviations

The Scheme, SMS Snowy Mountains Scheme

EFR Environmental Flow Releases

FFR First Flow Release (August 2002)

MANF Mean Annual Natural Flow

MLd^{-1} Megalitres per day

GLy^{-1} Gigalitres per year (1 gigalitre = 1000 megalitres)

1. Introduction

Prior to regulation the Snowy River flowed unimpeded from near the summit of Mount Kosciuszko in the south eastern highlands of NSW to the southern Australian coast at Marlo in Victoria. Sixteen large dams and many smaller diversion structures were constructed as part of the Snowy Mountains Scheme (the Scheme) between 1955 and 1967. In addition, flows from the upper tributaries such as the Mowamba River catchment were diverted by aqueducts to Jindabyne Dam. The main purpose of the Scheme was for power generation and to provide water to the Murray River and Murrumbidgee Irrigation areas in the Murray-Darling Basin.

The Scheme diverted approximately 99 per cent of Mean Annual Natural Flow (MANF) from the Snowy River as measured at Jindabyne or 96 per cent as measured at Dalgety (Figure 1). The construction of the Scheme has affected all components of the flow regime in the upper Snowy River, with an increase in flow variability and a fall in baseflows, large spring snowmelt flows and large floods (Pendlebury *et al*., 1996). This change can be represented by the dramatic downward shift on the whole flow duration curve. However, the relative hydrological effects of the construction of the Scheme decrease along the course of the river with reductions in MANF to approximately 65 per cent in the lower Snowy River. This decreasing relative effect is mainly because of the contribution of streamflow from the tributaries downstream of Dalgety. The annual diversion of the Scheme is approximately 1,130 gigalitres (Lyall and Macoun, 1998).

The hydrological impacts of river regulation by large reservoirs are widely published and documented (Magilligan and Nislow 2005). Petts (1994) describes hydrological alteration as first order impacts to riverine ecosystems. Typical changes include a decrease in base flows, a decrease in the magnitude, frequency and duration of events, a change in seasonality of flows and a change in variability and timing of daily flows (Poff *et al*., 1997).

The hydrological regime is regarded to be the key driver of the health of river and floodplain wetland ecosystems (Bunn and Arthington 2002). The changes to the flow regime associated with river regulation have second order impacts resulting in significant declines in river health (Naiman *et al.* 1995; Sparks 1995; Ludquist 1998; Bunn and Arthington 2002). Significant declines in the environmental condition have been associated with the altered hydrological regime of the Snowy River (Pendlebury *et al*., 1996). Bunn and Arthington (2002) list four key principles that link hydrological regimes to aquatic biodiversity:

- River discharge is a major determinate of physical habitat, and thus the composition of biota.
- Aquatic species have evolved life history strategies primarily in response to the flow regime.
- Maintenance of natural patterns of longitudinal and lateral connectivity is essential to maintain viable aquatic populations.
- The invasion and success of introduced species is facilitated by altered flow regimes.

In October 2000 the Victorian, NSW and Federal Governments agreed to release environmental flows to the Snowy River in four stages (SWIOID 2002). An environmental flow allocation of 21 per cent MANF was agreed to be released by year ten, following the first flow release which commenced in August 2002. However, these environmental water allocations are dependent on achieving water savings in the Murray-Darling River Basin (SWIOID 2002).

The objective of the proposed environmental flow regime was to improve the environmental condition of the Snowy River below Jindabyne Dam and to rehabilitate the ecological and physical components of the river as much as possible to pre-regulation conditions. This was to be achieved by ensuring the water releases mimic components of the natural flow regime, by reintroducing the elements of the magnitude, frequency, duration and timing of the natural flow regime. This management approach is often referred to as the natural flow paradigm which postulates that the structure and function of a riverine ecosystem, and the adaptation of aquatic species, are dictated by temporal variations in river flows (Poff *et al.* 1997, Lytle and Poff 2004).

Apart from the volumes being agreed to by the NSW, Victorian and Australian governments (Table 1) the specifics of the releases were not formally defined. The details of the EFR are to be determined by the Snowy Scientific Committee. Previous reviews have recommended the need to provide an annual large flood event (> 20000 MLd^{-1}) to mobilise sediment, increased baseflow volume, more natural daily and seasonal flow variability, and an increased frequency of flushing flows (>1000 MLd^{-1}).

Table 1. Planned staged EFR to the Snowy River downstream of Jindabyne

Stage	Timing of release after Corporatisation (years)	Target volume below Snowy – Mowamba Junction ($GL.y^{-1}$)[1]	Target volume plus base passing[2] flow ($GLyr^{-1}$)[1]	% of MANF[3] at Jindabyne
1	Initial (28/08/02)	38	67	6
2	2-7 (2004-2009)	142	171	15
3	8-10 (2010-2012)	212	241	21
4	> 10 (after 2012)	294	323	28

[1] The period of 12 months commencing 1 May in each year
[2] Base passing flow at Jindabyne Dam (10 GL/yr), Cobbin Creek (0.5 GL/yr), and Mowamba River (18 GL/year)
[3] MANF is 1164 GL/yr based on 55 years of flow data at Jindabyne Dam

Figure 1. Total annual discharge (GLy^{-1}) for the Snowy River at Dalgety for 1. natural and 2. Post Scheme, 1900 to 2001.

The construction of the scheme occurred in the 1950s and 1960s, and only partial diversion of water occurred during this period.

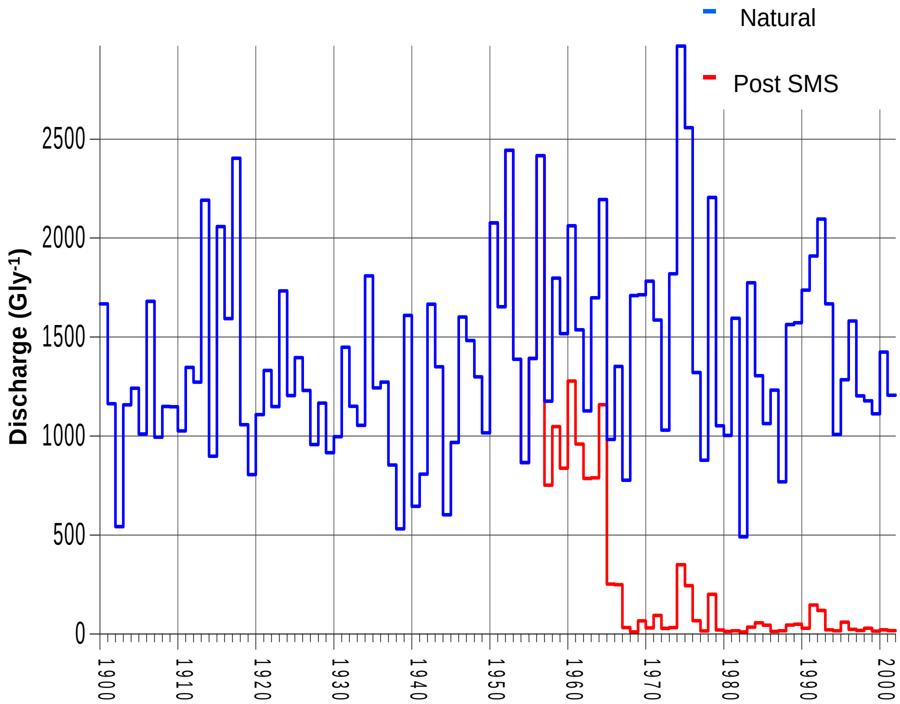
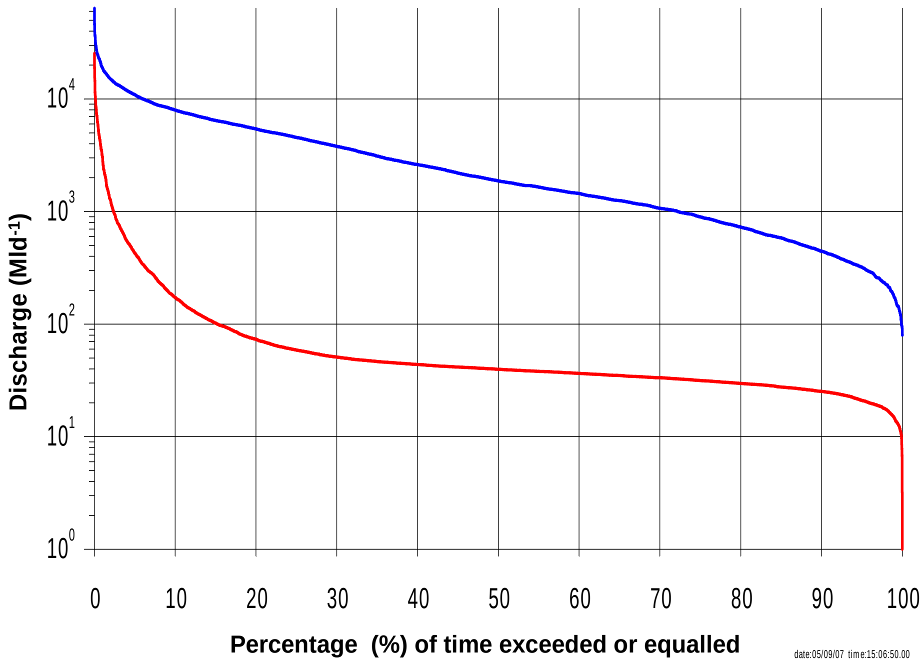


Figure 2. Flow duration curves for the Snowy River at Dalgety for 1. natural and 2. observed for the Post Scheme, 1967 to 2001.

The area between the two lines reflects the volume of water diverted to the Murray-Darling Basin.



1.1 The Snowy River catchment

The Snowy River rises in the Australian Alps and has a catchment area of approximately 24,900 km^2. There are four major dams in the upper catchment of the Snowy River: Guthega, Island Bend, Jindabyne and Eucumbene. The furthest downstream of these is Jindabyne Dam which is capable of storing 689,790 megalitres of water. Below Jindabyne Dam the Snowy River flows for 352 kilometres to its outlet into the Tasman Sea near Orbost.

The general distribution of rainfall over the Snowy River catchment (Figure 3) is controlled to a large extent by the orographic effects. There is a strong rainfall gradient across the catchment. Average annual rainfall ranges from 1,800 millimetres for the alpine areas above 1,500 metres in the north-western corner of the catchment to below 500 millimetres along the rain shadow affected north-eastern parts of the catchment around Dalgety.

The average annual flow of the Snowy River at Jarramond is approximately 1780 GL. High rainfalls in winter and spring combined with the spring snowmelt to produce higher than average stream flows from June to November, with peak mean monthly flows occurring in October.

1.2 Monitoring a response to the environmental flow release

The first stage of the EFR to the Snowy River began in August 2002 and was provided by the Mowamba River aqueduct. This aqueduct previously diverted flows from 3 MLd^{-1} (riparian users) up to 523 MLd^{-1} from Mowamba River to Jindabyne Dam, and flows in excess of the aqueduct capacity of 523 MLd^{-1} spilled over the Mowamba weir to flow into the Snowy River. The EFR resulted in all flows from Mowamba River entering the Snowy River.

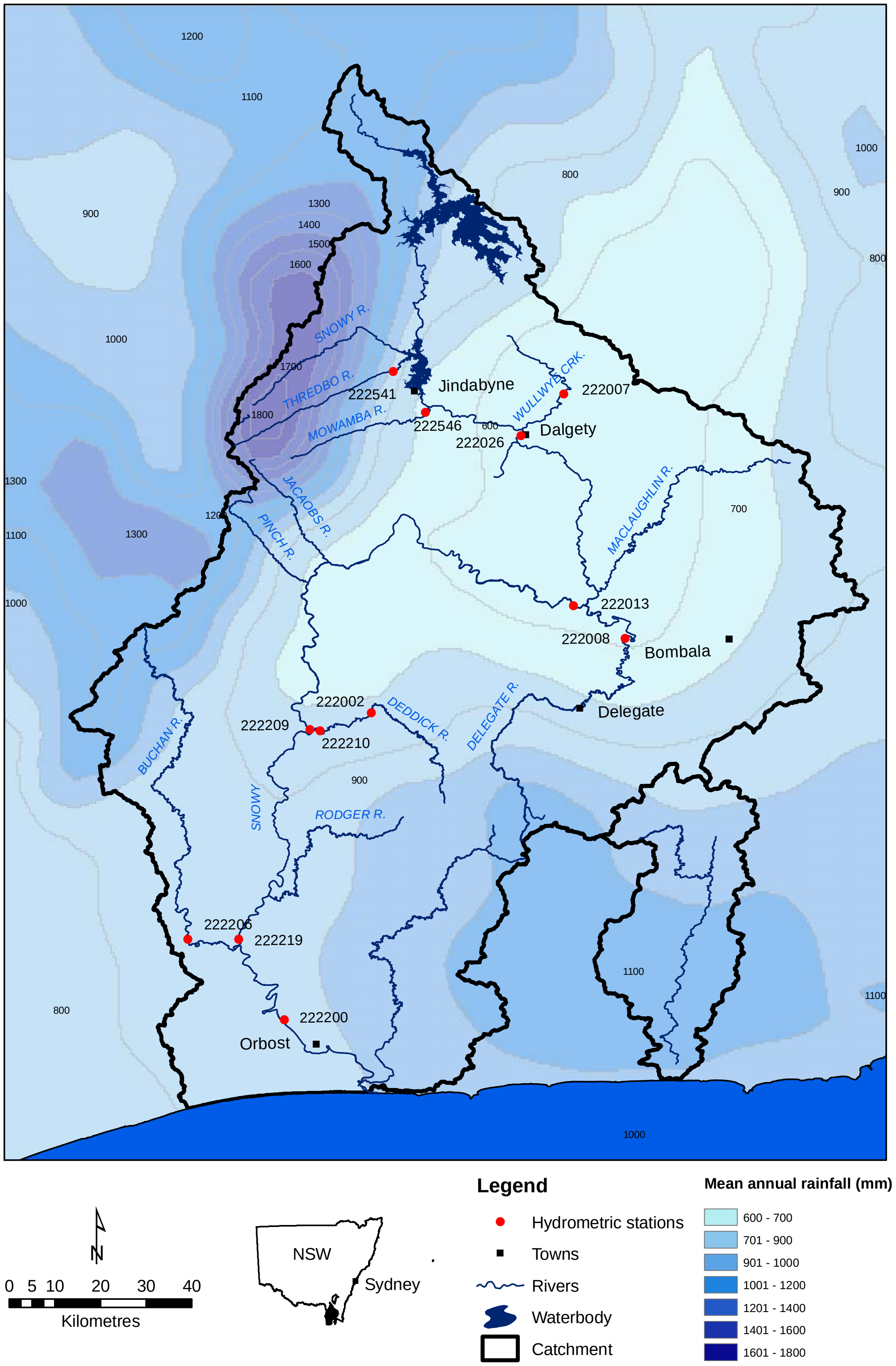
The Snowy Flow Response Monitoring and Modelling program was established to provide a physical, chemical and biological assessment of the river and quantify the changes, if any, caused by the implementation of the EFR, and additionally develop decision support tools for optimising future environmental water releases. The hydrology component of the monitoring program was largely based on the Expert Panel flow assessment (Pendlebury *et al*., 1996), the outcomes of the Snowy Water Inquiry (1998) and adapted as part of the monitoring design. The hydrology monitoring program aims to measure the impact of the first flow release on mean daily flow, mean daily summer baseflow, and flow variability at various Snowy River locations downstream from Jindabyne Dam.

This report documents:

- The hydrologic impacts resulting from the construction of the Scheme (1967-2001).
- The hydrologic changes that have occurred as a result of the EFR to the Snowy River from Mowamba River (2000-2005).

Figure 3. Average annual rainfall (mm) for the Snowy River catchment, 1900-2005.

The Australian Bureau of Meteorology supplied the rainfall data.



2. Methods

2.1 Monitoring design

The 352 kilometre section of the Snowy River downstream of Jindabyne Dam was divided into three large scale 'macro-reaches' based on geographic and hydrological differences. The three macro-reaches are termed upland, midland and lowland, and within each reach exists one or more gauging stations that were used as test sites, i.e. they receive an EFR (Figure 4). A number of gauging stations in other rivers were used as reference sites. Reference sites were chosen from nearby unregulated rivers with hydrological regimes that have not been altered due to regulation. They are intended to represent the hydrological characteristics that the Snowy River is expected to become more similar to with the implementation of the environmental flow regime. The hydrologic regime of the Snowy River test sites was compared to that of the reference sites to determine if any observed hydrologic changes were related to the environmental flows or region-wide influences. The test and reference sites that correspond to each macro reach are listed in Table 2.

The hydrological analysis for this project was divided into four separate analysis periods (

Table 3). These periods correspond to pre and post the Scheme and the environmental flow regime. These periods were used to assess the impact of the construction of the Scheme and the changes associated with the first stage of environmental releases from the Mowamba River (2002-2005) on the hydrology of Snowy River.

Table 2. Macro-reaches for Snowy River test sites and comparative reference sites

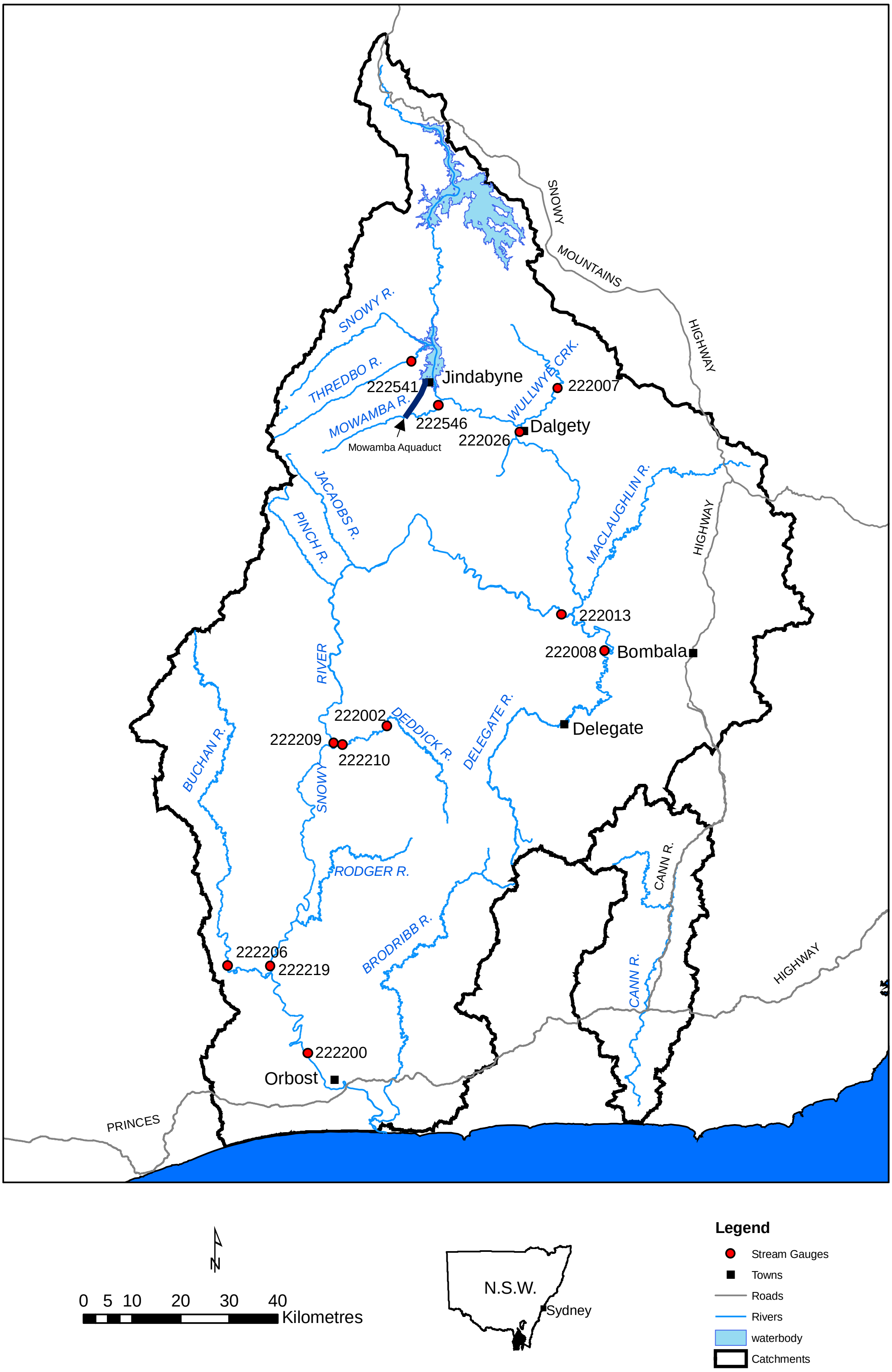
Macro-reach	Description	Snowy River test sites	Tributary sites used as reference sites
Upland	Below Jindabyne Dam to Delegate River	Dalgety (222026)	Thredbo River (222541)
Midland	Delegate to Deddick Rivers	Burnt Hut Crossing (222013)	Delegate River (222008)
Lowland	Deddick River to Orbost	McKillops Bridge (222209)	Deddick River (222210)
		Basin Creek (222219)	
		Jarramond (222000)	Buchan River (222206)

Table 3. Description of analysis periods for hydrological analysis

Description	Period (start)	Period (end)
Pre SMS	May 1942	April 1956
Post SMS	May 1967	April 2001
Pre EFR	May 1998	Aug 2002
Post EFR	Sep 2002	Dec 2005

Figure 4. The hydrological network for the Snowy River catchment.

Refer to Table 2 for gauging station names.



Not all test and reference sites have historical data extending back prior to construction of the Snowy Mountains Scheme. No appropriate reference rivers are available for the upland macro-reach for pre and post SMS periods. Wullwye Creek was considered as a reference site as it has data extending back to 1950. However, flow in Wullwye Creek is highly variable and intermittent and for these reasons it was not considered to be useful as a reference river, as it did not reflect the characteristics of a snowmelt river. The Thredbo River is used as a reference site for the pre and post EFR periods only as it has a short period of record. Similarly the Snowy River test site for the midland reach (Burnt Hut Crossing) only commenced in 1975 and is therefore used only for the pre and post EFR monitoring periods.

2.2 Climate

Rainfall and evaporation data used in this study was obtained from the SILO Patch Point Dataset (Bureau of Meteorology 2008). These long-term datasets extend from 1890 to 2005 and combine interpolated data with Bureau of Meteorology measurements. The rainfall stations were chosen based on data availability, elevation and spatial variability of rainfall over the study area. All rainfall and evaporation stations used in the study are shown in Table 4.

Three rainfall stations were Thiessen weighted and combined to form a long term representative dataset of rainfall over the whole Snowy River catchment from 1890 to 2005. Thiessen weighting assumes that each rainfall gauge will influence the catchment rainfall in proportion to its area of influence within the catchment (determined by bisecting lines between each rainfall station which intersect to form polygons around each station).

Mean annual rainfall was calculated for each of the four analysis periods to determine if there have been any major shifts between flood and drought dominated weather conditions that may influence stream flows.

Table 4. Details of rainfall and evaporation stations used in study

Station No.	Station name	State	Elevation (m AHD)	Period of record	
Rainfall					
071034	Guthega	NSW	1,600	01/01/1952	25/05/2000
071072	Perisher Valley	NSW	1,720	07/06/1976	31/12/2005
070106	Cathcart	NSW	800	01/01/1899	31/12/2005
071021	Jindabyne Dam	NSW	900	01/01/ 1906	31/12/2005
084004	Buchan (Gillingall)	VIC	700	01/01/1891	31/12/1954
Evaporation					
071021	Jindabyne Dam	NSW	900	01/01/ 1970	31/12/2005

2.3 River discharge

Streamflow gauging stations used in the study are detailed in Table 5. Daily flow data for NSW sites was extracted from the NSW Government's Hydsys database while flow data from Victorian gauges was downloaded from the Victorian Water Resources Data Warehouse (Victorian Government 2008). Most of the stations used in the study were extended and/or gap-filled using the IQQM gap fill program (DLWC 1999). Details of the gap filling procedures are discussed in Appendix A

Table 5. Details of key stream flow stations used in study

Station No.	Station name	Period of record		Station used to extend discharge record
222008	Delegate River @ Quidong	01/01/1952	31/12/2005	222003, 222004
222013	Snowy River @ Burnt Hut Crossing	01/01/1975	31/12/2005	-
222026	Snowy River @ Dalgety	01/01/1902	31/12/2005	222501, 222006
222200	Snowy River @ Jarrahmond	01/01/1923	31/12/2005	222219, 222212
222206	Buchan River @ Buchan	01/01/1942	31/12/2005	222210
222209	Snowy River @ McKillop Bridge	01/01/1942	31/12/2005	222219
222210	Deddick River @ Deddick	01/01/1942	31/12/2005	222002, 222208
222219	Snowy River @ Basin Creek	01/01/1933	31/12/2005	222212, 222209
222541	Thredbo River @ Paddys Corner	01/09/1985	31/12/2005	-
222546	Mowamba River @ Pats Patch	01/01/2002	31/12/2005	-

2.4 Data analysis

All hydrologic data within this report were formatted using the Integrated Quality Quantity Model (IQQM) and analysed using Statistica (StatSoft 2008), River Analysis Package (RAP) Primer v6 and Permanova (Clarke and Gorley 2006, Anderson *et al.* 2008) software packages.

IQQM is a hydrological modelling tool that contains a number of modules including data retrieval and utilities, and a graphical output module (DLWC 1999).

RAP is a toolbox of quantitative techniques for environmental flow assessment and also contains a number of modules (Marsh 2004) including a Time Series Analysis module. This module was used to analyse various response variables for each site including:

- basic statistics including mean, median, standard deviation and coefficient of variation of daily flows for test and reference sites
- the flood frequency of small and large floods using a Log-Pearson Type 3 curve
- a flow spell analysis, used for reporting the number, mean duration of high and low flow spells
- the mean daily summer baseflow calculated using a three way digital filter (Grayson *et al*., 1996).

A multivariate analysis was undertaken on daily flow data using Primer v6 and Permanova statistical software (Clarke and Gorley 2006, Anderson *et al.* 2008)). A principle component analysis on the hydrological metrics generated from RAP based on the daily flow data for each site was used to analyse likeness in hydrologic character, and to determine the response variables which most influence the hydrology of the test and reference sites.

The response variables were used to test the following hypotheses (Rose *et al*., unpublished):

$\mathbf{H_1}$ – Annual, monthly, seasonal and daily flow volumes will increase significantly from post SMS conditions and move towards pre SMS conditions at Dalgety. The hydrological response to the EFR will decrease in magnitude with increased distance downstream of Jindabyne dam as measured at McKillops Bridge, Basin Creek and Jarrahmond.

$\mathbf{H_2}$ – Floods with magnitude exceeding mean annual flood of 20,000 MLd^{-1} will increase in frequency and duration annually compared to post SMS flows but will remain less than for pre SMS flows at Dalgety. The hydrological response to the EFR will decrease in magnitude and duration with increased distance downstream of Jindabyne dam as measured at McKillops Bridge, Basin Creek and Jarrahmond.

$\mathbf{H_3}$ – Small floods with magnitude exceeding 1,000 MLd^{-1} will increase in frequency and duration annually compared to post SMS period but will remain less than for small pre SMS floods at Dalgety. The hydrological response will decrease in magnitude and duration with increased distance downstream of Jindabyne dam as measured at McKillops Bridge, Basin Creek and Jarrahmond.

$\mathbf{H_4}$ – Summer baseflows of 200 MLd^{-1} will increase in frequency and duration compared to post SMS baseflows but will remain less than for the pre SMS baseflows at Dalgety. The hydrological response will decrease in frequency and duration with increased distance downstream of Jindabyne dam as measured at McKillops Bridge, Basin Creek and Jarrahmond.

$\mathbf{H_5}$ – Seasonal and daily flow variability will increase significantly from post SMS conditions and move towards pre SMS conditions at Dalgety, McKillops Bridge, Basin Creek and Jarrahmond. Response will become less variable with increased distance downstream of the dam.

$\mathbf{H_6}$ – The environmental water releases from the unregulated Mowamba River will shift the Snowy flow regime to a more natural pattern.

$\mathbf{H_7}$ – Tributaries will contribute most flow to the Snowy River even after the 21 per cent MANF release in 8-10 years.

Not all of the hypotheses can be addressed by the first stage of environmental releases from the Mowamba River, as the Mowamba aqueduct influenced only those flows below 523 MLd [1]. The releases will only re-introduce small magnitude events into the Snowy River. Events larger than the maximum diversion rate flow over the weir and are observed in the Snowy River discharge data.

3. Results

3.1 Rainfall trends

The long-term average annual rainfall for the Snowy River catchment was 1,135 millimetres for the period 1890 to 2005. During this time there were two distinct periods of lower rainfall in the first half of the 1900s and a wetter period in the second half of the 1900s (Figure 5). A distinct reduction in rainfall occurred again in the catchment from around 1978. This pattern is consistent with all rainfall gauges in the catchment (Figure 6).

Calculation of average annual rainfall during the analysis periods (Table 6) shows that over the entire catchment there was only a 2.4 per cent difference in rainfall for the periods before and after construction of the Scheme. In contrast, there has been a substantial decrease (27 per cent) in the average annual rainfall recorded for the period after the release of environmental flows, compared to the pre environmental flow period. This trend has been observed at every gauge across the catchment.

Table 6. Average annual rainfall (mm) in the Snowy River catchment, pre and post the SMS and EFR

Station	Average annual rainfall (mm)					
	Pre SMS	Post SMS	Change (%)	Pre EFR	Post EFR	Change (%)
Snowy River catchment (thiessen weighted)	1,233	1,203	-2.4	1137	830	-27.0
Guthega	1,725	1,723	-0.1	1459	1154	-20.9
Perisher	1,949	1,997	2.5	1861	1383	-25.7
Jindabyne	743	582	-21.7	599	455	-24.0
Buchan	955	855	-10.5	815	640	-21.5
Cathcart	861	837	-2.8	809	516	-36.2

Figure 5. Thiessen weighted total annual rainfall for the Snowy River catchment 1890–2005.

(A) Total annual rainfall (mm) and (B) Difference from long term average rainfall (mm).

Thiessen weighting for rainfall stations in the Snowy River catchment: Cathcart 0.32, Perisher 0.31, and Buchan 0.37. Trend line is a distance weighted least squares regression.

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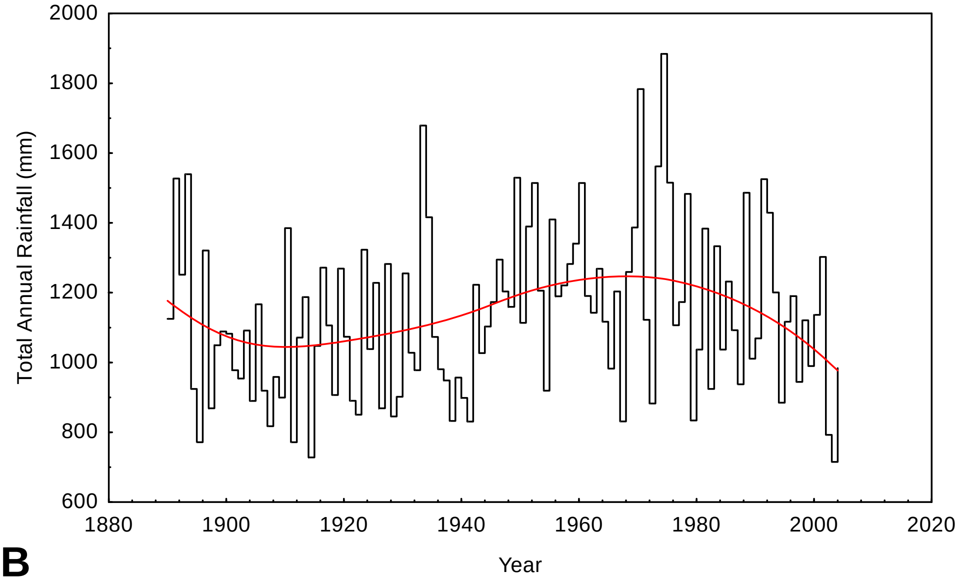

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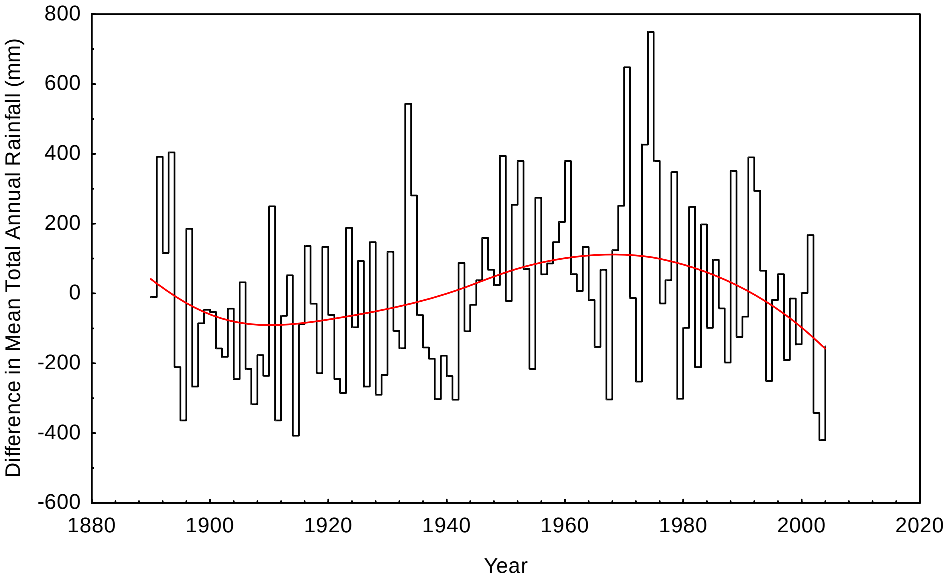
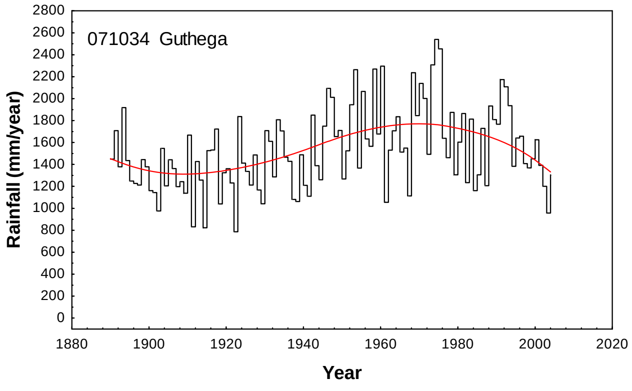


Figure 6. Total annual rainfall for stations in the Snowy River catchment 1890–2005

(A) Guthega, (B) Perisher Valley, (C) Jindabyne, (D) Buchan, and (E) Cathcart.

A



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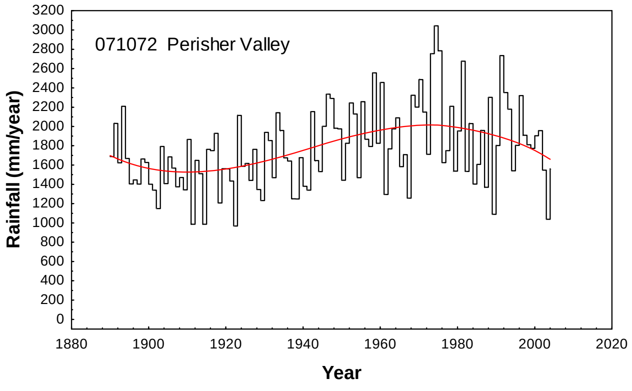

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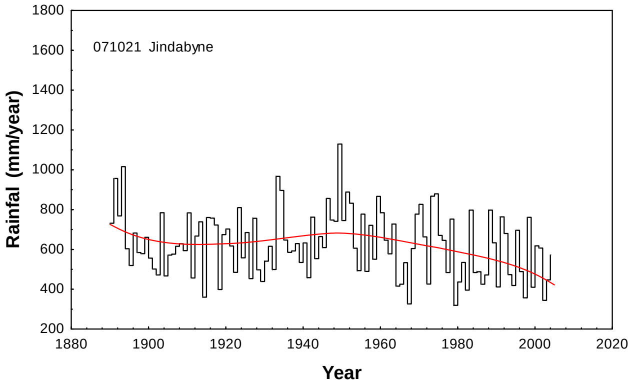

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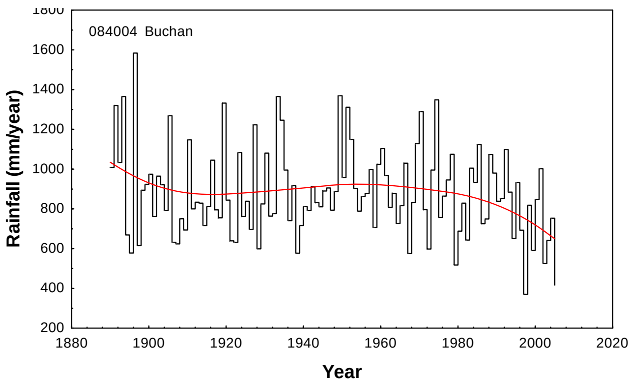

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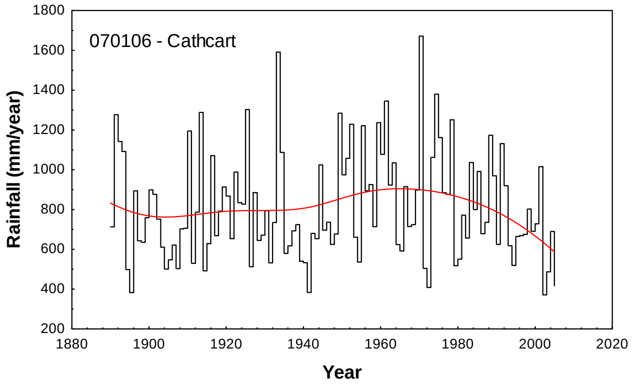


3.2 Flow volumes

H_1 *– Annual, monthly, seasonal and daily flow volumes will increase significantly from post SMS conditions and move towards pre SMS conditions at Dalgety. The hydrological response will decrease in magnitude with increased distance downstream of Jindabyne Dam as measured at McKillops Bridge, Basin Creek and Jarrahmond.*

3.2.1 Annual flow volumes

The Scheme has had a significant effect on discharge along the entire length of the Snowy River. Annual flows at Dalgety declined 96 per cent following construction of the Scheme, while annual flows in the lower reaches of the river declined by between 63 and 65 per cent (Table 7). By comparison annual flows in the reference rivers declined by between 20 and 27 per cent consistent with the lower rainfall that occurred during the post SMS period.

The release from the Mowamba River Weir resulted in increased flows entering the Snowy River throughout the period of the releases. Mean annual flow at Dalgety increased by 81 per cent from 26.1 to 39.2GL. The influence of the environmental release did not extend to the midland or lowland reaches of the river where flows declined by up to 51 per cent during the post EFR period. The period of the environmental releases was extremely dry compared to the pre EFR period with flows in the reference rivers also declining by up to 52 per cent.

Table 7 Mean annual flow (GL) for the Snowy River test and reference sites, pre and post SMS and EFR.

Annual flow (GL)	Pre SMS	Post SMS	Change	Pre EFR	Post EFR	Change
Snowy River test sites						
Dalgety Weir	1,442.3	58.5	-96%	21.6	39.2	+81%
Burnt Hut Crossing				200.3	98.7	-51%
McKillops Bridge	2,102.3	739.5	-65%	395.6	238.1	-40%
Basin Creek	2,386.4	894.4	-63%	549.9	286.3	-48%
Jarrahmond	3,024.0	1,081.4	-64%	752.1	368.5	-51%
Reference rivers						
Thredbo River				172.5	154.5	-10%
Delegate River	181.8	144.6	-20%	89.0	47.2	-47%
Deddick River	89.3	68.3	-23%	44.5	21.3	-52%
Buchan River	184.9	135.5	-27%	104.7	72.0	-31%

3.2.2 Monthly flow volumes and seasonality

Prior to construction of the Scheme the Snowy River displayed two distinct seasonal flow peaks. The primary peak occurred in spring during October, and was associated with the snowmelt tributaries, and a secondary peak occurred in winter during June (Figures 7 and 8). The winter peak was most pronounced in the lowland reach of the river and was typically generated from the surface runoff from tributaries not affected by snowmelt. The lowest monthly flows occurred between January and March for all reaches of the river.

Construction of the Scheme captured much of the spring snowmelt that was previously entering the Snowy River in September to October. At Dalgety this resulted in two seasonal flow peaks of similar magnitude occurring in June and October, although with greatly reduced volumes compared to pre SMS flows. The monthly flow at Dalgety for October fell by 97 per cent from 283,973 ML pre SMS to 8,438 ML post SMS. In the lowland reach of the river, construction of the Scheme resulted in a shift in peak seasonal flow to winter, while the spring peak was significantly reduced.

Monthly flows in the pre EFR period display a bimodal distribution with two distinct peaks in August and November at all sites on the Snowy River. The volume of monthly flows recorded at Dalgety increased during the first stage of environmental releases but as with annual flows, declined at all of the lowland sites on the river. Peak monthly flows occurred in March and September at Dalgety during the post EFR period, but the pattern of the spring snowmelt at Dalgety did not accurately reflect the more distinctive peak that occurred in the corresponding reference river (the Thredbo River) during the same period, where the September/October peak was followed by a dramatic recession in flow volume in November and December (Figure 9).

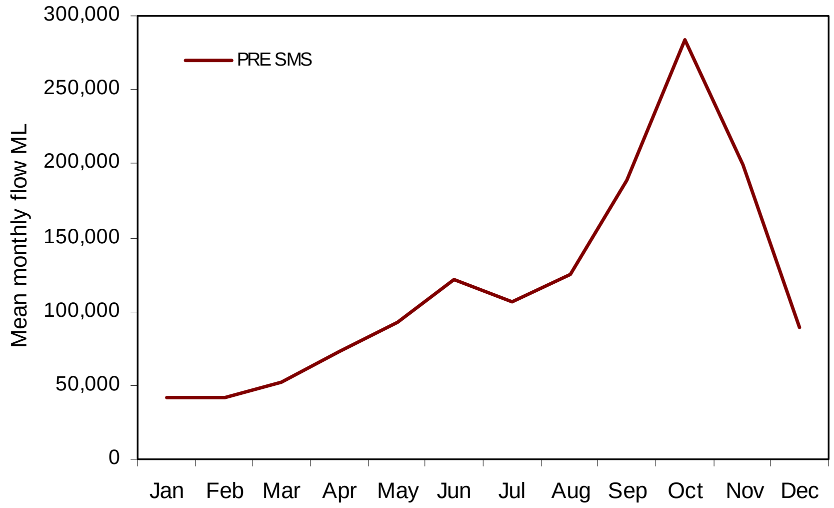
In the lowland reach of the river the dry conditions during the post EFR period resulted in lower monthly flows during the winter and spring with no distinct peak in monthly flows.

Figure 7. Mean monthly flow (ML) in the Snowy River at Dalgety (A) pre SMS and (B) post SMS and pre/post EFR.

Note the loss of the pronounced spring snowmelt signal pre SMS and the shift to smaller bi-modal seasonal peaks post SMS

Note the EFR shifted the monthly bio-model distribution post SMS to single peak in September, one month earlier than recorded in the pre SMS period.

A



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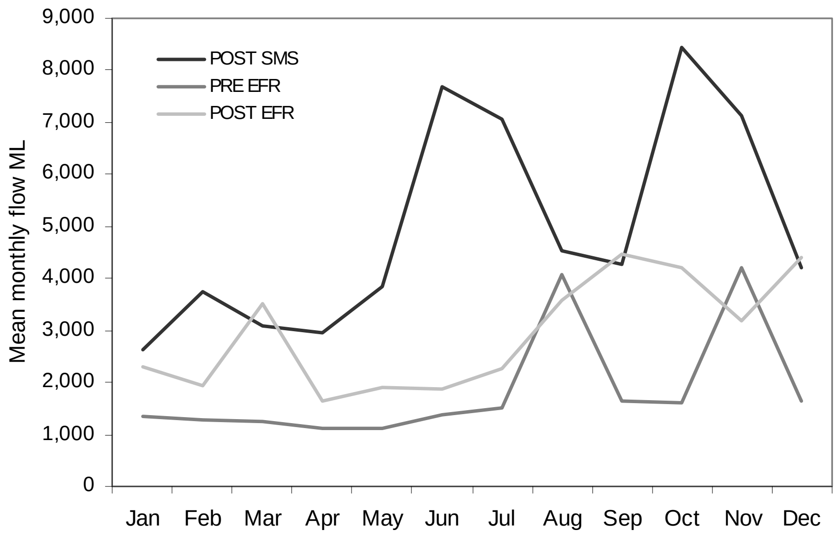


Figure 8. Mean monthly flows in midland and lowland reaches of the Snowy River

Note the loss of the spring snowmelt signal in the mid and lower reaches of the Snowy River post SMS.

Note the lack of a snowmelt response to the EFR in the mid and lower reaches of the Snowy River.

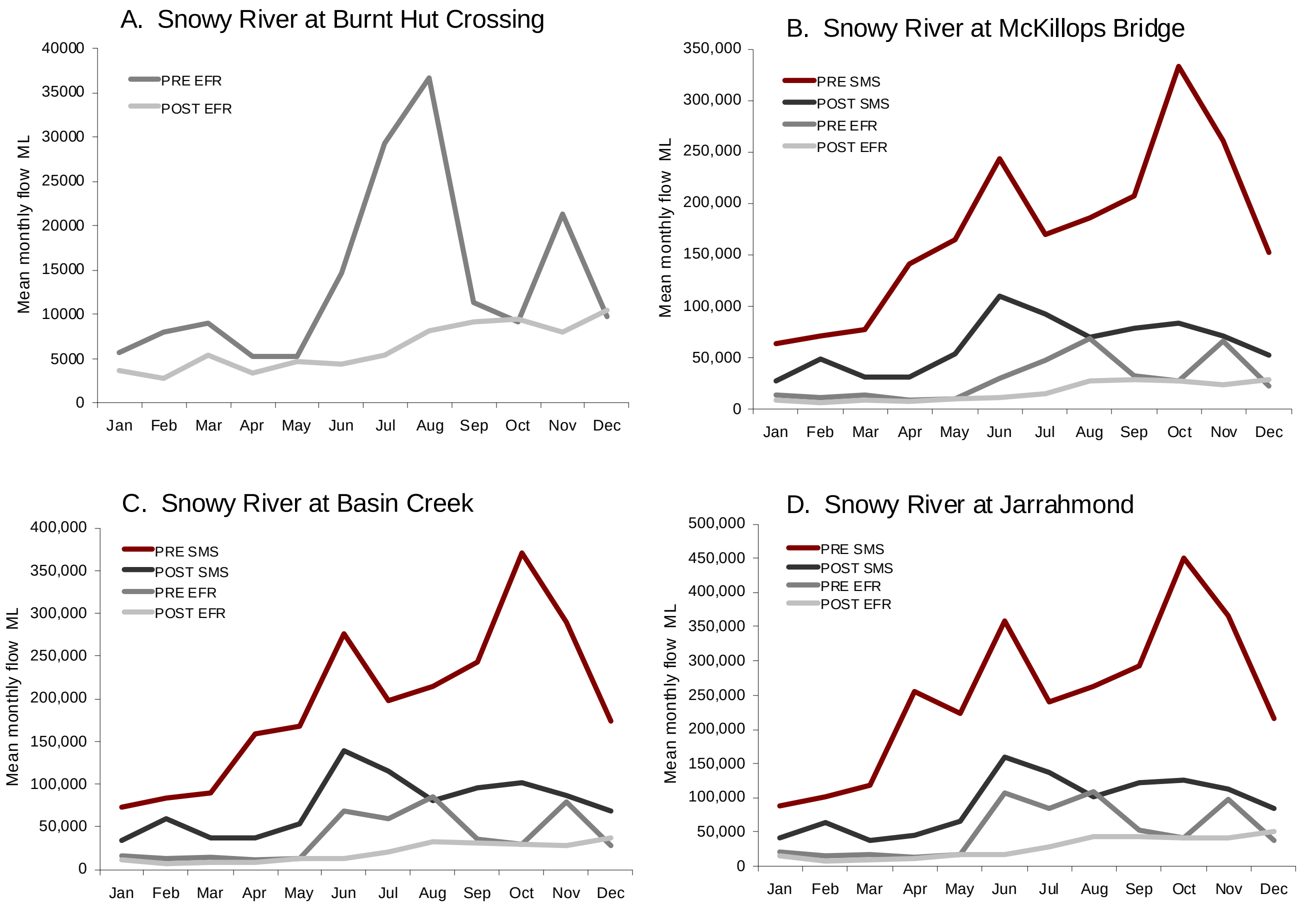
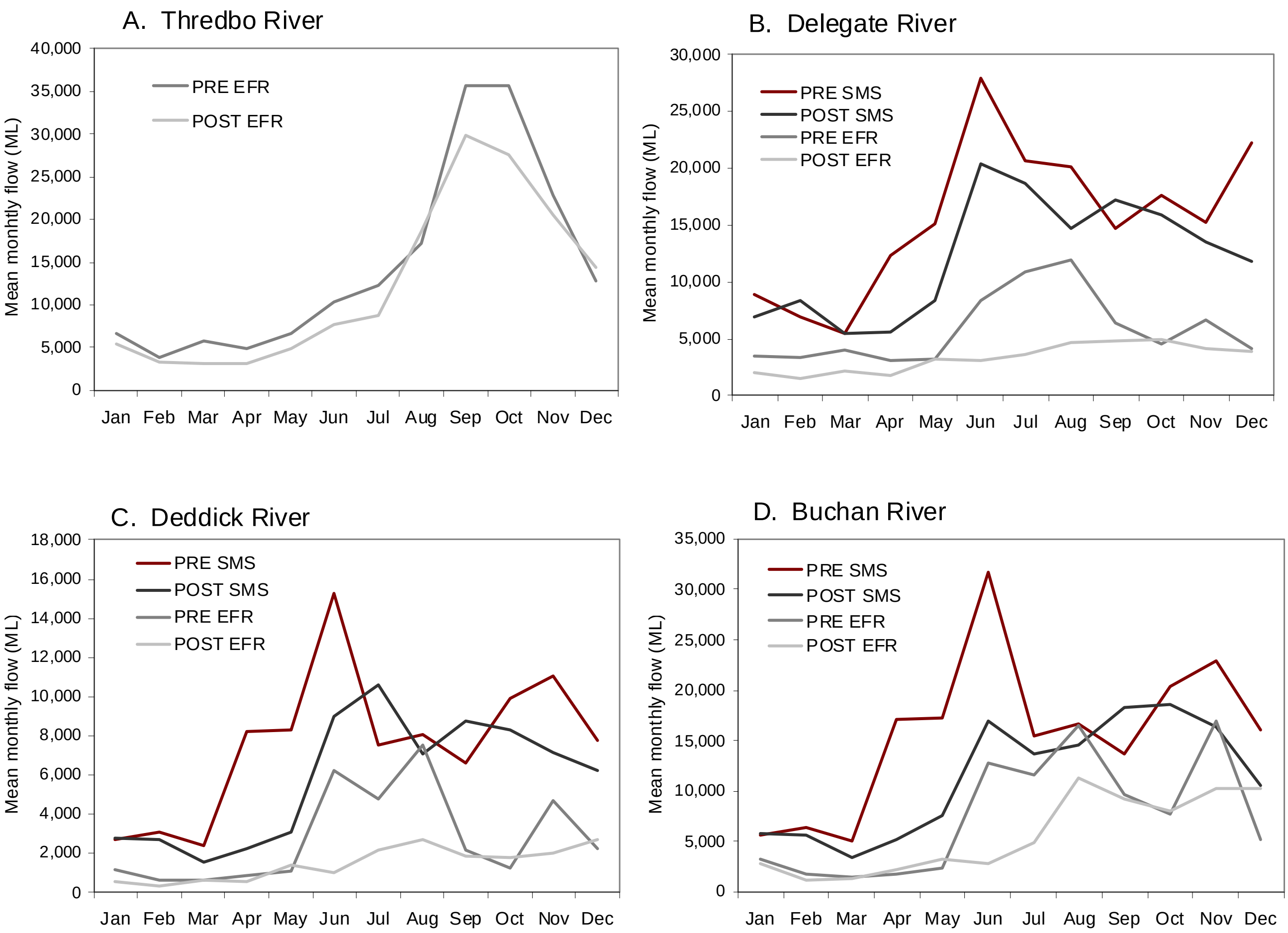


Figure 9. Mean monthly flows in the Snowy River catchment reference rivers

Note the pronounced snowmelt signal in the Thredbo River, with lower tributaries providing a pronounced winter peak in June.



3.2.3 Daily flow volumes

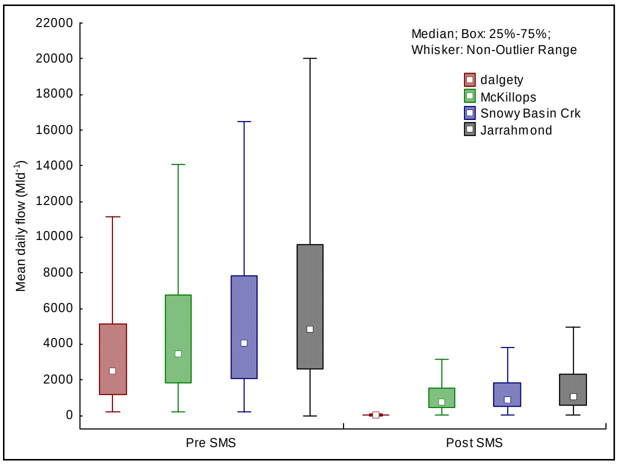
Daily flow statistics pre and post construction of the Scheme show a similar trend to the annual volumes, and are presented in Appendix A. The mean daily flow at Dalgety declined from 3,948 MLd^{-1} to 160 MLd^{-1} following construction of the Scheme.

Large reductions in the median daily flow occurred along the length of the Snowy River with the greatest impact being in the upland reach at Dalgety (Figure 10) where median flow declined from 2,469 $MLd^{-1}$to 40 MLd^{-1}.

Following the environmental releases that commenced in 2002 the median daily flow at Dalgety increased from 42 MLd^{-1} to 90 MLd^{-1} (107 per cent) during the environmental releases while median flow in the midland and lowland reaches declined by between 22 and 25 per cent (Figure 11). A similar pattern of decline appears in the median daily flow of the reference rivers, except for the Thredbo River where the median daily flow remained unchanged.

Figure 10. Comparison of median daily discharge (MLd^{-1}) pre and post the Scheme

A. Snowy River



B. Reference rivers

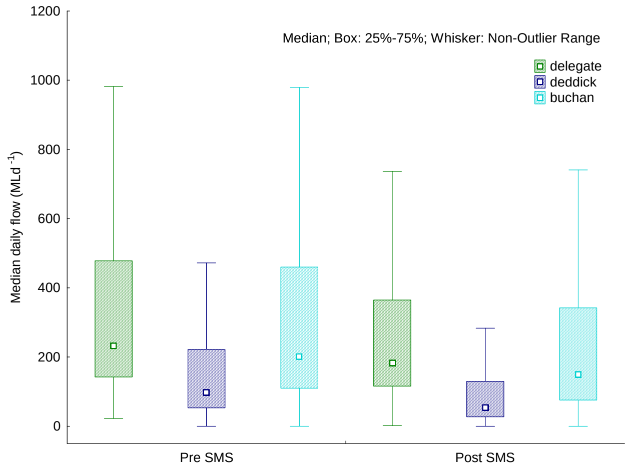
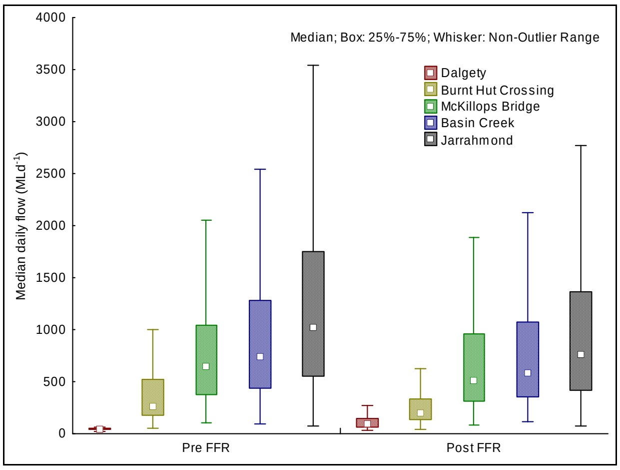
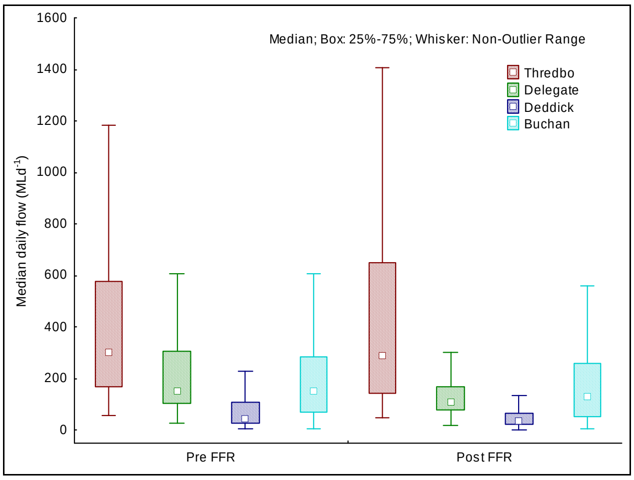


Figure 11. Comparison of median daily discharge (MLd^{-1}) pre (1998-2002) and post (2002-05) the first stage EFR

A. Snowy River



B. Reference rivers



3.3 Floods

***H_2** – Floods with magnitude exceeding mean annual flood of 20,000 MLd^{-1} will increase in frequency and duration annually compared to post SMS flows but will remain less than for pre SMS flows at Dalgety. The hydrological response will decrease in magnitude and duration with increased distance downstream of Jindabyne Dam as measured at McKillops Bridge, Basin Creek and Jarrahmond.*

***H_3** – Small floods with magnitude exceeding 1,000 MLd^{-1} will increase in frequency and duration annually compared to the post SMS period but will remain less than for small pre SMS floods at Dalgety. The hydrological response will decrease in magnitude and duration with increased distance downstream of Jindabyne Dam as measured at McKillops Bridge, Basin Creek and Jarrahmond.*

The first stage of environmental releases will not affect the frequency or duration of flood events in the Snowy River. However an analysis of flood frequency for large and small floods has been undertaken for the periods pre and post the Scheme, to provide a comparison for future monitoring (Appendix B.)

The construction of the Scheme has resulted in a significant reduction in the number of large flood events. Prior to the Scheme large floods greater than 20,000 MLd^{-1} at Dalgety occurred on average 1.2 times per year with an average duration of 3.3 days. There have been no events of this size in the years since the Scheme was constructed.

There has been a similar impact on small sized floods. Small events exceeding 1,000 MLd^{-1} previously occurred several times a year at Dalgety. Since construction of the Scheme these events have occurred on average once every 1.5 years.

3.4 Summer baseflows

***H_4** – Summer baseflows of 200 MLd^{-1} will increase in frequency and duration compared to post SMS baseflows but will remain less than for the pre SMS baseflows at Dalgety. The hydrological response will decrease in frequency and duration with increased distance downstream of Jindabyne Dam as measured at McKillops Bridge, Basin Creek and Jarrahmond.*

A hydrograph can be separated into two main components. Direct runoff is the volume of water resulting from rainfall or snowmelt, while baseflow is the volume of water that represents the groundwater contribution. Groundwater contribution from snowmelt in the higher altitude reaches is a key determinate of the previously stable low flow patterns. Only summer baseflows have been considered as these periods are most likely to place stress on the instream biota due to the limited mixing of low flow habitat refugia.

The Expert Panel (Pendlebury *et al.,* 1996) recommended that a minimum baseflow of 200 MLd^{-1} be restored to the Snowy River immediately downstream of Jindabyne Dam. The panel considered this flow to represent the 95th percentile of natural flows in the driest month prior to construction of the Scheme.

The construction of the Scheme resulted in a significant shift in the duration of baseflows at Dalgety. Prior to the Scheme a baseflow of 200 MLd^{-1} was exceeded 99.9 per cent of the time during the months of December to February. Following construction of the Scheme this flow was exceeded only 5.5 per cent of the time during summer.

The release of water from the Mowamba River aqueduct to create the EFR increased summer baseflows entering the Snowy River. For the Pre EFR period, a baseflow of 200 MLd^{-1} was exceeded 1 per cent of the time, and this increased to 9 per cent of the time during the offer via the Mowamba aqueduct. During this time the mean summer baseflow at Dalgety increased by 80 per cent from 25 MLd^{-1} to 45 MLd^{-1} (Table 8).

A spell analysis was undertaken on flows of less than 200 MLd^{-1} at all Snowy sites. For this analysis, a 'spell' is defined as a flow event of less than 200 MLd^{-1} and having a duration of at least one day. Table 9 summarises the results of this spell analysis.

The construction of the Scheme had a significant impact on the frequency and duration of summer baseflows. Prior to the Scheme, summer baseflows had not fallen below 200 MLd^{-1}. Since its construction, low flow spells less than 200 MLd^{-1} occur at Dalgety on average 4.4 times per year, have a mean flow of 51 MLd^{-1} and last for an average of 76 days (Table 9).

Prior to the EFR, low flow spells had a mean flow of 36 MLd^{-1} with a mean duration of 194 days. During the period of environmental releases, the mean discharge for low flow spells increased to 101 MLd^{-1}. The average duration decreased to 39 days but the events occurred more frequently than the period prior to the releases.

The increase in mean summer baseflow seen at Dalgety following the first stage EFR was not seen in the midland and lowland reaches of the river where the mean baseflow declined (at McKillops Bridge and Jarrahmond) or only increased marginally (at Basin Creek).

Table 8. Mean daily summer baseflow at Snowy River test and reference sites.

Snowy River Test Site	Mean Daily Summer Baseflow (ML/d) [1]					
	Pre SMS	**Post SMS**	**Change (%)**	**Pre EFR**	**Post EFR**	**Change (%)**
Dalgety Weir	810	42	-95	25	45	80
Burnt Hut Crossing				93	88	-5
McKillops Bridge	1,225	351	-71	246	231	-6
Basin Creek	1,396	427	-69	289	280	-3
Jarrahmond	1,729	525	-70	385	367	-5
Reference Rivers						
Thredbo River				115	135	17
Delegate River	144	109	-24	70	44	-37
Deddick River	42	33	-21	17	15	-13
Buchan River	91	70	-23	56	64	14

1 Calculated using the River Analysis Package (Marsh 2004) which separates the baseflow component of the hydrograph using a three way digital filter. In practice it is not possible to describe the baseflow component during storm events. However, the method used in RAP (the Lyn and Holick method) is generally accepted as a suitable approximation (Grayson *et al.,* 1996).

Table 9. Frequency and duration of summer baseflows < 200 MLd^{-1} in the Snowy River.

Snowy River Test Sites		Years of Record	Number of Events	Events per year	Mean Flow (MLd^{-1})	Mean Duration (days)
Dalgety Weir	Pre SMS	15	0	0	>200	0
	Post SMS	34	149	4.4	51	76
	Pre EFR	4.3	8	2	36	194
	Post EFR	3.3	27	8.2	101	39
Burnt Hut Crossing	Pre EFR	4.3	27	6.3	143	24
	Post EFR	3.3	29	8.8	138	18
McKillops Bridge	Pre SMS	15	0	0	>200	0
	Post SMS	34	68	2	137	16
	Pre EFR	4.3	6	1.4	159	12
	Post EFR	3.3	4	1.2	125	32
Basin Creek	Pre SMS	15	0	0	>200	0
	Post SMS	34	41	1.2	124	20
	Pre EFR	4.3	2	0.5	139	21
	Post EFR	3.3	3	0.9	145	28
Jarrahmond	Pre SMS	15	0	0	>200	0
	Post SMS	34	33	1	131	22
	Pre EFR	4.3	0	0	>200	0
	Post EFR	3.3	2	0.6	95	48

3.5 Flow variability

***H_5** – Seasonal and daily flow variability will increase significantly from post SMS conditions and move towards pre SMS conditions at Dalgety, McKillops Bridge, Basin Creek and Jarrahmond. Response will become less variable with increased distance downstream of the dam.*

The coefficient of variation (CV) is a dimensionless measure of variability commonly used to describe variability in river flows (expressed as the ratio of the standard deviation to the mean). It allows comparison of variability within data sets which may have very different means. In hydrology, a high annual or daily CV may be indicative of disturbance or unpredictability in a river's flow regime (Gordon *et al*., 1992). Typically non-snowmelt Australian rivers typically have highly variable river discharge, but snowmelt rivers can be characterised by predictable seasonal patterns and stable baseflows.

The data in Table 10 shows that there has been a very large shift in daily flow variability following the construction of the Scheme. This impact on variability is greatest in the upper macro reach at Dalgety, but also occurs in the lower reaches of the river.

With implementation of the first environmental flows there has been a shift in daily flow variability back towards the pre SMS condition, particularly at Dalgety. In contrast there was no change in flow variability in the upper reference river (Thredbo River).

Changes in the flow variability of midland and lowland macro-reaches pre and post EFR are likely to be related to changes in the coefficient of variation in the reference rivers (in particular the Deddick and Buchan Rivers), which are probably indicative of the drought conditions experienced during this period.

Table 10. Daily flow variability at Snowy River and reference sites.

Snowy River Test Sites	Daily Flow Variability (Coefficient of Variation)			
	Pre SMS	Post SMS	Pre EFR	Post EFR
Dalgety Weir	1.17	5.30	2.12	0.82
Burnt Hut Crossing			1.90	1.90
McKillops Bridge	1.67	3.67	1.59	1.14
Basin Creek	1.63	3.68	2.31	1.29
Jarrahmond	1.80	3.24	2.64	1.28
Reference Rivers				
Thredbo River			1.08	1.06
Delegate River	2.57	2.53	1.27	1.21
Deddick River	2.37	3.09	2.91	2.25
Buchan River	2.37	2.45	2.15	1.24

3.6 Mowamba River flows

***H*$_6$** *– The environmental water releases from the unregulated Mowamba River will shift the Snowy flow regime to a more natural pattern.*

3.6.1 Mowamba River water diversions to Jindabyne Dam

Snowy Hydro Ltd. has been diverting water from the Mowamba River to Jindabyne Dam through the Mowamba River aqueduct since 1968. Between 1968 and 2002 when the environmental releases commenced, the median water diversion was 62.2 MLd^{-1} and the maximum diversion for the period was 523.7 MLd^{-1} (Figure 12). Events larger than the maximum diversion typically flowed over the Mowamba Weir into the Snowy River.

The diversions to Jindabyne Dam showed a strong seasonal pattern. The highest monthly median diversions of between 124 and 127 MLd^{-1} occurred in September and October, and all of the maximum diversion events up to 523.7 MLd^{-1} occurred between June and November. The lowest monthly median diversions of 28.2 and 31 MLd^{-1} were recorded in February and March respectively, and there were very few diversions exceeding 200 MLd^{-1} between January and May (Figure 12).

3.6.2 Mowamba River hydrology

Prior to environmental flows being released from the Mowamba River, discharge at both the Mowamba River and the Snowy River at Dalgety demonstrated very little variability in low flows. Typically events less than 523 MLd^{-1} were captured by the aqueduct and transferred to Jindabyne Reservoir. Much of the low flow variability was removed by these transfers. Flows in the Mowamba River typically displayed small riparian releases of 3 MLd^{-1}, punctuated by occasional events when the flow exceeded the aqueduct capacity of 523 MLd^{-1}.

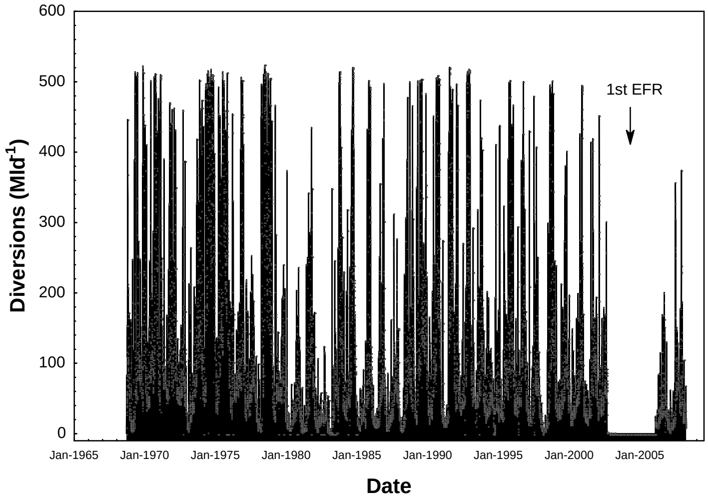
The first stage of environmental water releases to the Snowy River occurred on 28 August, 2002. The majority of these releases came from the Mowamba River as a result of the temporary decommissioning of Mowamba River aqueduct, while minor releases also occurred from Jindabyne Dam (Figure 13) and Cobbin Creek. The temporary decommissioning of the aqueduct was intended to deliver the first phase of environmental flows until outlet works on Jindabyne Dam could be completed.

During the environmental water releases low flow variability in the Snowy River at Dalgety increased significantly (Figure 14). An increase in mean daily flows and seasonal baseflows provided a more natural flow regime within the upland macro reach at Dalgety. The environmental water releases resulted in an increase in mean daily flow from 2.2 MLd^{-1} to 71.8 MLd^{-1} in the Mowamba River, and from 58.6 to 120.4 MLd^{-1} in the Snowy River at Dalgety, although these flows are still significantly smaller than what would have occurred naturally (Figure 15). Similar trends were not observed in the mid to lower macro reaches of the Snowy River, indicating a limited spatial effect of the environmental water releases.

Figure 12. Mowamba River water diversions via Mowamba River Aqueduct, September 1968 to August 2002.

(A) time series of daily water diversions (B) Summary statistics of water diversions, and (C) Median daily water diversions by month 1968 to 2002. Data from Snowy Hydro.

A



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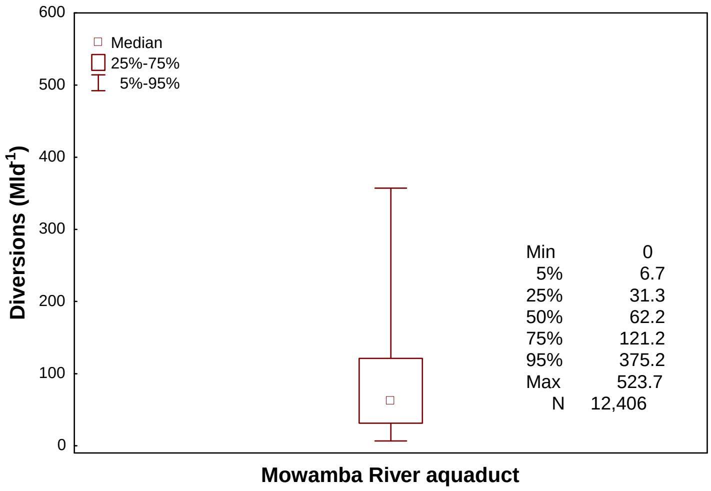

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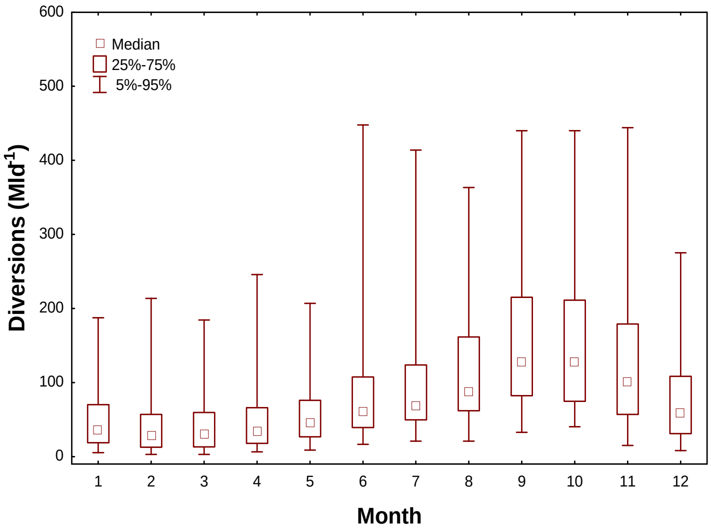


Figure 13. Monthly releases from Mowamba River at Pats Patch and Jindabyne Dam 2002-2006.

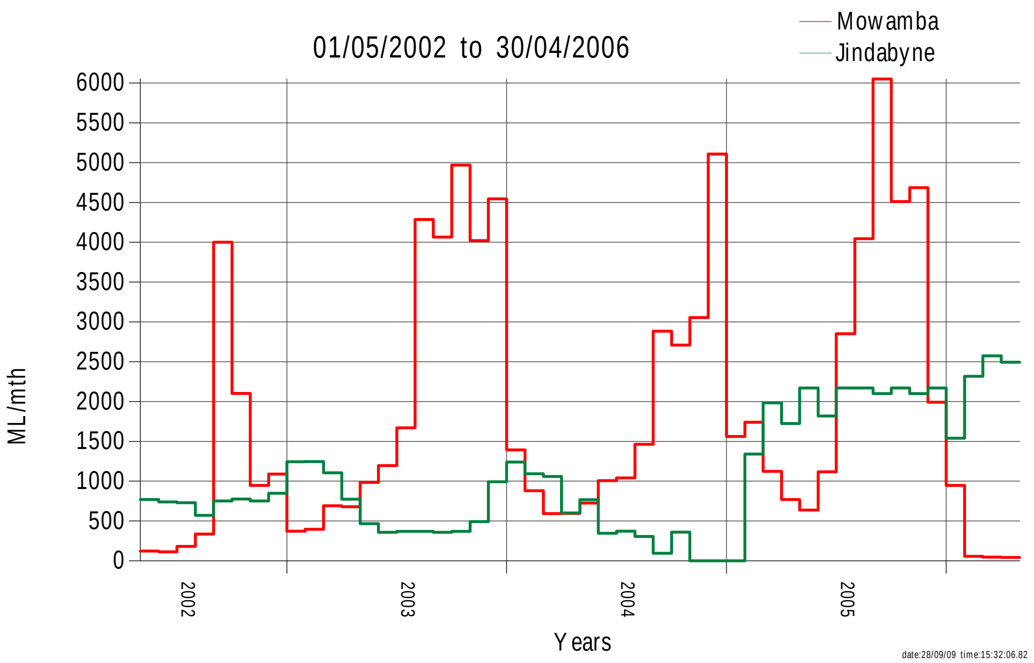


Table 11. Volume of EFR to the Snowy River.

Annual volume is calculated from measured flows in the Mowamba River plus measured releases from Jindabyne Dam plus estimate of 0.5GLy-1 from Cobbin Creek.

Stage	Year [1]	Flow Volume (GLy^{-1})	Flow Volume (% Mean Annual Flow [2])	Target Volume (% Mean Annual Flow)
1	2002	21.8	1.9%	6%
	2003	37.5	3.2%	6%
2	2004	31.0	2.7%	15%
	2005	53.3	4.6%	15%

[1] 12 month period commencing 1 May

[2] MANF at Dalgety is defined as 1,164 ML

The releases from the Mowamba River resulted in an 81 per cent increase in the mean annual discharge at Dalgety from 21.6 GL pre EFR to 39.2 GL post EFR. The mean annual flow achieved via releases from the Mowamba Weir is equivalent to 3.3 per cent of the long term MANF for the Snowy River at Dalgety. This is significantly lower than the planned average of 12 per cent (Table 11). In 2005 releases from Jindabyne Dam increased compared to previous years therefore increasing the released volume for this year to 4.6 per cent of MANF.

Figure 14. Influence of Mowamba River on discharge in the Snowy River at Dalgety 1998-2008.

The period of environmental releases is shown by the black line.

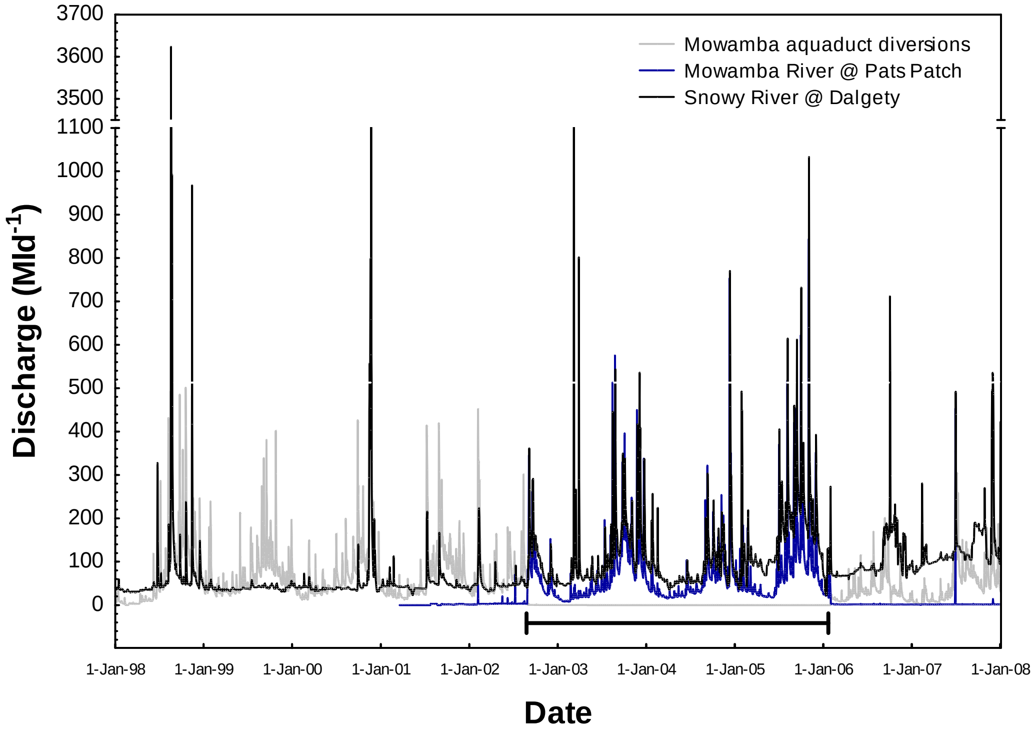
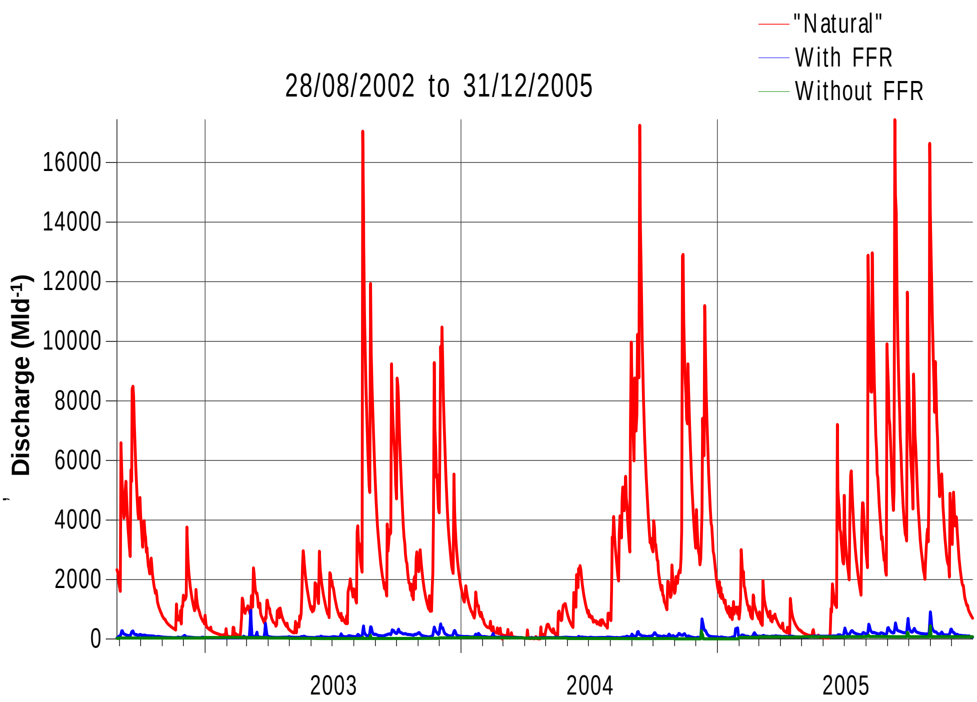


Figure 15. Hydrological changes attributable to the first stage of the EFR at Dalgety.

Natural flows (red), with environmental flow regime (blue) and without environmental flow regime (green).



3.7 Tributary contributions

H_7 *Tributaries will contribute most flow to the Snowy River even after the 21 per cent MANF release in 8-10 years.*

Mean annual flows for the Snowy River at Dalgety and Jarrahmond were used to determine the relative contributions of the Snowy River and its tributaries to end of catchment flows. The difference in flows between these two test sites was assumed to be the tributary contribution.

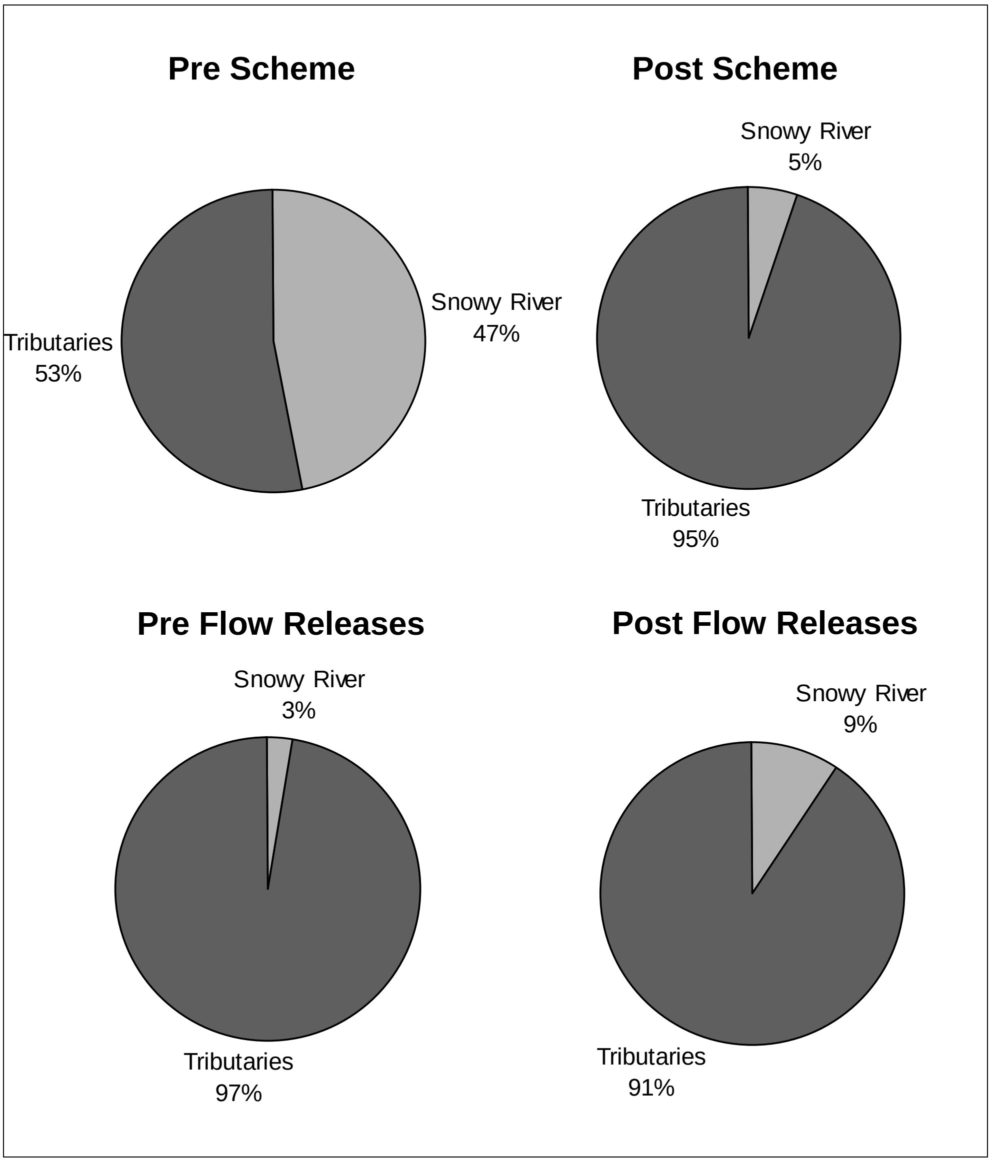
Prior to construction of the Scheme the upper Snowy catchment contributed 47 per cent of end of catchment flows, and this was reduced to just 5 per cent following construction of the Scheme (Table 12 and Figure 16). Following the first stage of environmental releases the relative contribution of the upper Snowy River increased to 9 per cent of flow at Jarrahmond.

Table 12. Tributary contributions to the Snowy River at Jarrahmond.

	Contributing catchment	Mean Annual Flow (GL)	Flow (per cent Jarrahmond)
Pre SMS	Dalgety	1,442	47
	Jarrahmond	3,069	100
	Tributaries	1,627	53
Post SMS	Dalgety	58	5
	Jarrahmond	1,081	100
	Tributaries	1,022	95
Pre EFR	Dalgety	22	3
	Jarrahmond	752	100
	Tributaries	730	97
Post EFR	Dalgety	35	9
	Jarrahmond	372	100
	Tributaries	337	91

Figure 16. Tributary contributions to the Snowy River at Jarrahmond.

The Snowy River contribution represents flows at Dalgety.



3.8 Characterisation of river discharge between the Snowy River and tributaries

The differences in flow characteristics between the Snowy River and the reference rivers account for 68 per cent and 75 per cent of the variation in the hydrology of the upper and mid reaches of the Snowy River (Figure 17 and Figure 18). No single factor could explain these differences, but factors such as, coefficient of variation, mean duration of rises, longest low spell number of rises and falls, periods between high spells and rate of rise each explained between 2.74-3.16 per cent of these differences (Table 13).

Time essentially explains the variation in the hydrological characteristics between the pre and post EFR periods in the Dalgety uplands (23 per cent) and Burnt Hut (18 per cent), showing the influence of the drought predominantly and influence of the EFR at Dalgety only.

Figure 18B shows the increase in median discharge in the Snowy River at Dalgety attributable to the EFR release. Figure 18C shows the decrease in median discharge at Burnt Hut Crossing during the first EFR release, and the smaller median discharge in the reference location of the Delegate River compared to the Snowy River.

Table 13. The main hydrological characteristics showing the differences between Snowy River test sites and the reference sites.

Variable	**Snowy**	**Reference**		
	Av.Value	Av.Value	Contrib%	Cum.%
CV	0.549	-0.549	3.16	3.16
Mean duration of Rises	0.453	-0.453	3.06	6.22
Longest Low Spell	-0.476	0.476	2.94	9.16
Number of Falls	-0.392	0.392	2.81	11.96
Number of Rises	-0.388	0.388	2.79	14.75
Mean period Between High Spells	0.118	-0.118	2.75	17.50
Greatest rate of Rise	0.152	-0.152	2.74	20.24

Figure 17. Principal co-ordinate analysis of RAP flow metrics for the (A) Upper and mid reaches of the Snowy River and reference rivers, (B) Snowy River (Dalgety Uplands) and Thredbo River and the (C) Snowy River at Burnt Hut Crossing and the Delegate River.

The size of the bubble shows the coefficient of variation value for the period pre and post the first EFR. The larger the size the more variability in river discharge.

The closer the symbols are to one another the more similar the flow characteristics, the further apart the symbols the less similar the flow characteristics.

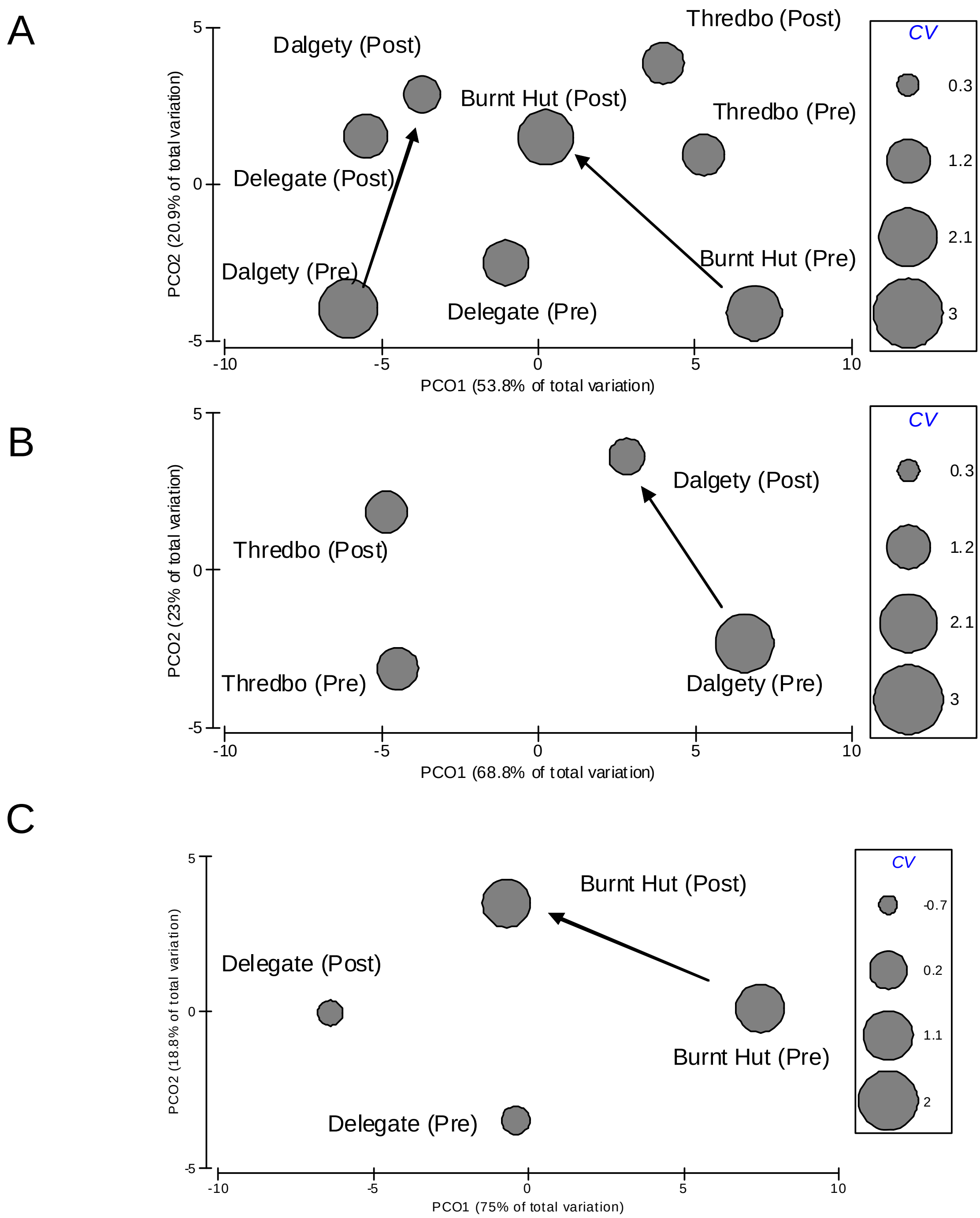
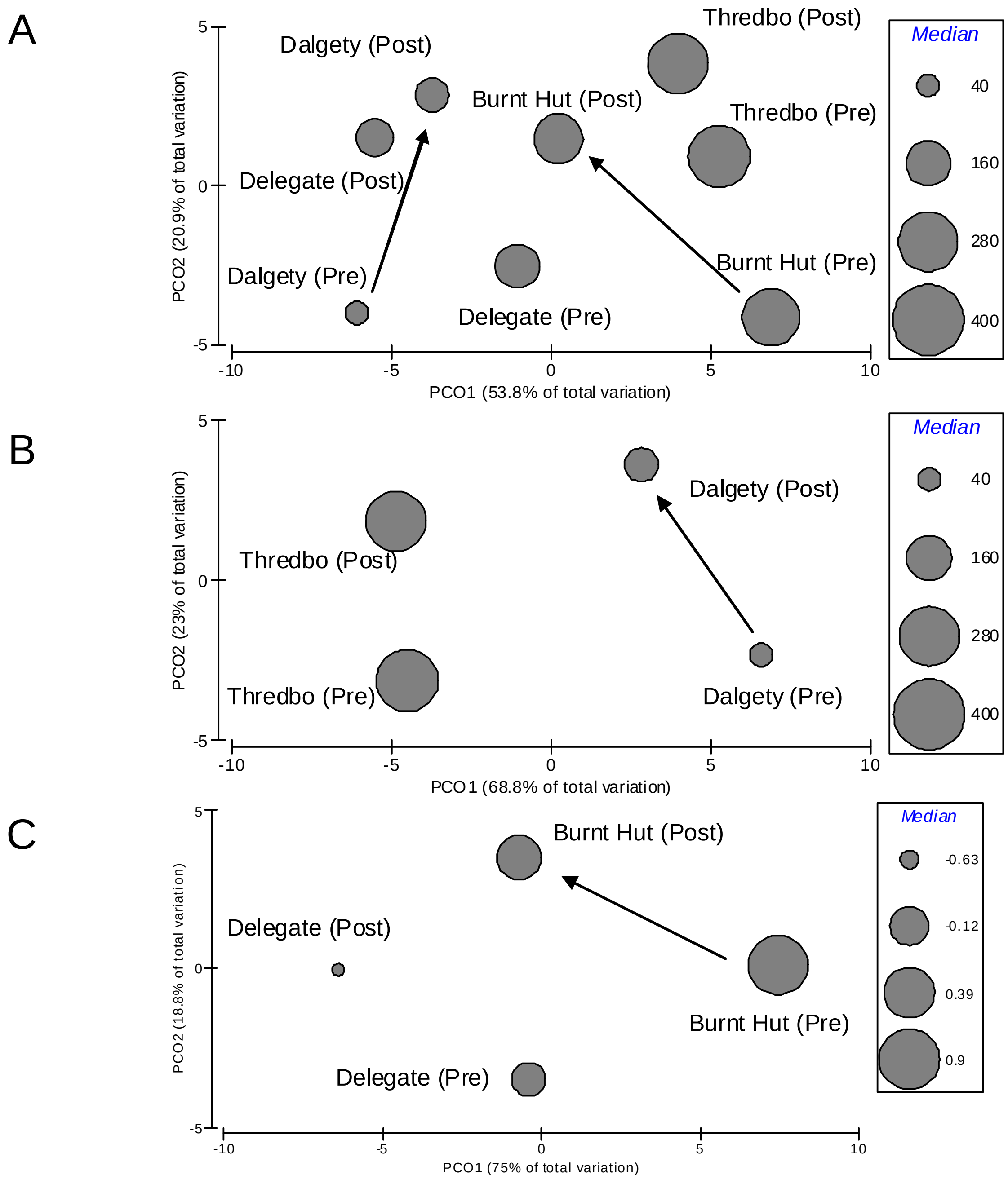


Figure 18. Principal co-ordinate analysis of RAP flow metrics for the (A) Upper and mid reaches of the Snowy River and reference rivers, (B) Snowy River (Dalgety Uplands) and Thredbo River and the (C) Snowy River at Burnt Hut Crossing and the Delegate River.

The size of the bubble shows the median value for the period pre and post the first EFR. The larger the bubble the greater the median daily discharge.

The closer the symbols are to one another the more similar the flow characteristics, the further apart the symbols the less similar the flow characteristics.



4. Discussion

4.1 Changes in flow regime – pre and post the Snowy Mountains Scheme

It is clear that the construction of the Scheme has resulted in significant changes to the natural flow regime of the Snowy River (Pendlebury *et al.* 1996; Erskine *et al.* 1999). Changes in the magnitude of daily flows, monthly and annual flows, the seasonal patterns of flow, and the natural variability of daily flows have occurred. All of these impacts have been most acute in the upper macro reach as recorded by flows at Dalgety, but have also affected the midland and lowland reaches of the river to a lesser degree.

Additional to the reductions in stream flow attributable to the Scheme it is also clear that there have been some regional climatic influences that have affected runoff across the entire Snowy River catchment in the years following construction of the Scheme. Increase in air temperature of +0.2^{o}C per decade since the 1950s in the alpine reaches of the Snowy Mountains has occurred (Hennessy *et al.* 2008, Green and Pickering, 2009). The snow line was historically at 1530m, but has retreated 100m to approximately 1630m (Ken Green personal communication), leading to a potential reduction in the magnitude and shift in the timing of snowmelt runoff. This is typically consistent with other alpine areas, where shifts in rainfall and snowmelt have been recorded (Dettinger and Cayan 1995; Stewart 2009). A change in snowmelt timing has been observed in the mid altitude (1000 to 2000m) western river basins of the USA (Dettinger and Cayan 1995). These changes have resulted in the peak spring snowmelt occurring three weeks earlier, than when compared to the 1940s flow records. However, these types of rainfall changes are not often consistent across the landscape and vary with elevation (Dettinger and Cayan 1995; Hennessy *et al.* 2008).

The results in this analysis show that rainfall has reduced as seen by the data for Jindabyne which was 21 per cent lower in the post SMS period which is likely to have further reduced the amount of runoff to the Snowy River in the upper macro-reach.

In the midland and lowland reaches of the river, mean annual flows in the reference rivers were reduced by between 20 and 27 per cent. Therefore in these reaches it can be concluded that reduced regional rainfall has contributed to the reduced volume of flows observed in the post SMS period.

Changes in the seasonality of peak flows also appear to result from a combination of regulation and climatic influences. The highly seasonal pattern of peak spring flows in October that previously occurred in the upper catchment was almost completely removed at Dalgety following construction of the Scheme. The spring snowmelt pulse and recession dominate the annual discharge of rivers emerging from winter snowpack headwaters (Yanell *et al*. 2010), and often provide the majority of the annual stream flow (i.e. 50-80 per cent) in high elevation river basins (Hauer *et al.* 1997; Stewart 2009; Yanell *et al*. 2010). The spring snowmelt is a key ecological driver for river health in high altitude rivers, and changes to the magnitude, timing and rate are summarised by Yannell *et al*. 2010, (see Table 14). The Scheme has reduced the transfer of these peak spring flows to the midland and lowland reaches of the river. This has resulted in a significant seasonal shift along the whole of the Snowy River from a flow regime dominated by peak flows in spring to one with peak flows in winter following winter rainfall.

The reference rivers for the midland and lowland reaches suggest that the reduced rainfall experienced post SMS resulted in small shifts in the distribution of seasonal flows during this period, best observed in the Deddick and Buchan Rivers where autumn and winter monthly flows were greatly reduced. While this is likely to have contributed to the reduced volume of winter peaks observed in the Snowy River, the elimination of the spring flow peak appears to be mostly due to the impact of regulation. The loss of the magnitude and the predictability of these spring snowmelt events surely have had a significant impact on the aquatic biota that have evolved around these coldwater events. Many of the colder water species are absent from the Snowy River in the Jindabyne Gorge (Brooks *et al.* 2007, Gilligan and Williams 2008).

Table 14. Expected environmental responses to shifts in snowmelt discharge (Modified from Yarnell *et al* 2010).

Shift	Expected response
Decreased magnitude of snowmelt peak	Channel narrowing, loss of backwaters, reduced lateral migration, decreased channel variability.
	Decreased erosion and deposition, reduced lateral migration rates; decreased channel elevation variability
	Increased transport and deposition of fines
	Increased water temperature due to smaller volume snowmelt
	Increased vegetation encroachment, denser vegetation
	Increased growth in early life stages of amphibians
	Decreased diversity of macroinvertebrates and abundance of fish due to loss of habitat
	Shift toward less-specialized riparian arthropod assemblages
	Decreased algal production and increased senescence due to reduced scour and increased deposition of fines
	Reduced supply of terrestrial carbon
Earlier snowmelt peaks	Increased water temperature resulting in changes in timing of macroinvertebrate emergence, maturation age for trout, and fish and macroinvertebrate composition
	Increased growth for warm water fish and amphibians
	Decreased growth for cold water fish
	Decreased riparian seedling recruitment
	Increased low flow duration resulting in decreased arthropod abundance and changes to fish and macroinvertebrate composition
Increased rates of change	Decreased habitat availability and variability due to rapid return to base flow
	Increased water temperatures due to rapid return to base flow Inferred
	Increased stranding of early life stage fish and amphibians
	Increased temperature stress for fish resulting in decreased success
	Increased riparian vegetation encroachment
	Decreased riparian species seedling establishment
	Decelerated riparian leaf breakdown rates
	Decreased arthropod abundance and diversity due to increased substrate embeddedness

4.2 Changes in flow regime – pre and post environmental flow releases

The first stage of environmental releases was never designed to bring about a large change in the flow regime of the Snowy River. It was capable of introducing only the small daily flows that were previously being diverted through the Mowamba aqueduct (flows less than 523 MLd^{-1}). Releases from the Mowamba River did provide a small seasonal snowmelt signal in September-October, a small increase in the daily magnitude of discharge, and the timing of the discharge was synchronised with natural events. Despite the introduction of some smaller natural hydrological cues, the environmental releases achieved significantly less than the volumes that were targeted. The environmental releases commenced in one of the driest years in over 100 years of record at Jindabyne. The following year, 2003, was also very dry, being in the driest 15 per cent of all years at Jindabyne.

These dry climatic conditions were reflected in the rainfall analysis which showed a consistent 20-27 per cent reduction in rainfall across the upper catchment in the years pre and post the environmental releases. The reduced rainfall translated to reduced discharges in the reference rivers of up to 52 per cent when compared to the pre EFR period. The reduced tributary inflows were therefore responsible for declines of between 40 and 50 per cent in discharge seen in the Snowy River test sites for the midland and lowland reaches of the river.

Daily flow variability improved at Dalgety during the period of releases as shown by the daily hydrograph of flows and a reduced coefficient of variation. However, until larger flows are able to be released, this improvement in variability is unable to be transferred down to the midland and lowland test sites.

4.3 Methodology and hypotheses

Further consideration needs to be given to finding suitable reference sites for comparison to the Snowy River, especially in the upper catchment. There is a lack of reference sites from which natural snowmelt conditions can be compared in the current design. The hydrology of the reference rivers in the middle and lower catchment are dominated by winter rainfall patterns, yet it is the loss of the natural snowmelt that has most affected flows in the Snowy River.

Kennard *et al.* (2009) undertook hydrological analysis of the unregulated rivers across Australia and described four regime types in the Snowy Catchment, these being (1) stable base flows, (2) stable winter baseflows, (4) unpredictable base flows and (7) unpredictable intermittent (Table 15). The majority of the current hydrological reference sites typically fall into flow regime type 4 (i.e. unpredictable base flows). These seem to be at odds with the type of flow regime that is typically influenced by snow, large spring snowmelt signal with a stable baseflow generated by groundwater contributions from higher altitudes.

There are a number of existing additional gauging stations operated by Snowy Hydro Ltd within the alpine and montane areas of the Snowy Mountains that need to be further examined for their suitability as reference sites.

Table 15. Classification of natural flow regimes in the Snowy River catchment, (Kennard et al. 2009). Data supplied by Mark Kennard.

State / Territory	Gauge Number	Gauge Name	Flow Regime Class no.	Flow Regime Class Description
NSW	222527	Snowy River Above Guthega Dam	1	Stable baseflow
NSW	222015	Jacobs River at Jacobs Ladder	2	Stable winter baseflow
NSW	222522	Eucumbene River at Providence 2	2	Stable winter baseflow
VIC	222213	Suggan Buggan River at Suggan Buggan	2	Stable winter baseflow
NSW	222004	Little Plains River at Wellesley	4	Unpredictable baseflow
NSW	222008	Delegate River at Quidong	4	Unpredictable baseflow
VIC	222202	Brodribb River at Sardine Creek	4	Unpredictable baseflow
VIC	222206	Buchan River at Buchan	4	Unpredictable baseflow
VIC	222210	Deddick River at Deddick (Caseys)	4	Unpredictable baseflow
VIC	222217	Rodger River at Jacksons Crossing	4	Unpredictable baseflow
NSW	222007	Wullwye Creek at Woolway	7	Unpredictable intermittent
NSW	222010	Bobundara Creek at Dalgety Road	7	Unpredictable intermittent
NSW	222011	Cambalong Creek at Gunning Grach	7	Unpredictable intermittent
NSW	222012	Coolumbooka River Near Bombala	7	Unpredictable intermittent

5. Conclusions

5.1 Long-term changes in climate and hydrology

There have been long term changes in rainfall and hydrology that have influenced the Snowy River catchment independent of the regulatory effects of the Scheme.

- There has been a consistent trend towards declining annual rainfall since about 1979, and an upslope retreat of the snow line over the past 50 years.
- Mean annual rainfall for the upper Snowy River catchment was 27 per cent lower during the period of environmental releases than for the four years prior to the environmental releases, with 2002 being one of the driest years on record in the catchment.
- Annual flows in the midland and lowland reference rivers were up to 27 per cent lower post Scheme.
- Annual flows in the midland and lowland reference rivers were up to 52 per cent lower during the period of environmental releases (compared to pre environmental releases) and 10 per cent lower in the upper catchment reference river.

5.2 Hydrologic changes post Snowy Mountains Scheme

The construction of the Scheme has resulted in extreme changes to the natural flow regime of the Snowy River. While the impacts are most dramatic in the upland macro reach, all reaches of the river have been affected.

- Mean annual flows in the Snowy River have been reduced by 96 per cent in the upland reach and between 63 and 65 per cent in the midland and lowland reaches.
- Mean daily flows at Dalgety declined from 3,948 MLd^{-1} to 160 MLd^{-1} and median daily flows declined from 2,469 MLd^{-1} to 40 MLd^{-1} following construction of the Scheme.
- Peak seasonal flows in most macro reaches have changed from spring to winter due to the diversion of snowmelt.
- The frequency of floods of all recurrence intervals has decreased. Large floods exceeding 20,000 MLd^{-1} at Dalgety have decreased in frequency from an annual occurrence to one in 20 years, while the occurrence of small floods exceeding 1,000 MLd^{-1} at Dalgety has decreased from one in <0.5 years to one in 1.5 years. These reductions will have a significant impact on instream river processes, such as the mixing of water within pools, and the scouring of biofilms from the substrate.
- Mean daily summer baseflows have declined 95 per cent in the upland reach from 810 MLd^{-1} to 42 MLd^{-1}, while mean summer baseflows in the midland and lowland reaches of the river have declined by between 69 and 71 per cent.
- In the upland reach, flows of less than 200 MLd^{-1} (considered to be representative of baseflow) did not previously occur at Dalgety. Post Scheme these low flow spells have occurred on average 4.4 times a year with a mean duration of 76 days.
- There has been an increase in the coefficient of variation (indicating increased disturbance and unnatural patterns of daily flow) at all Snowy River test sites, but most noticeably in the upland macro reach. This possibly indicates the lack of groundwater contribution from the surrounding snowmelt streams, as snowmelt stream typically have a highly stable baseflow.
- Tributaries downstream of Dalgety provide 95 per cent of flows at Jarrahmond, compared to 57 per cent prior to the Scheme.

5.3 Hydrologic changes post environmental flow release

The environmental releases via the Mowamba River resulted in small improvements to the flow regime of the upland reach of the Snowy River as reflected in flows at Dalgety. The impact of the releases was restricted to the upland reach.

- The mean annual flow increased to 39.2 GL during the period of releases compared to a mean of 21.6 for the period prior to the releases. This is equivalent to 3.3 per cent of the MANF at Dalgety.
- The mean daily flow in the upland macro-reach increased 107 per cent from 58 MLd^{-1} to 120 MLd^{-1}. Mean daily flow in the midland and lowland macro-reaches declined between 31-44 per cent during the period of releases consistent with similar changes observed in the reference rivers, indicating the influence of the drought.
- Mean summer baseflows increased from 25 to 45 MLd^{-1} at Dalgety. A flow of 200 MLd^{-1} (considered representative of natural summer baseflow) was exceeded 9 per cent of the time during the releases, compared to 1 per cent of the time prior to the releases.
- The overriding drought conditions during the EFR makes it difficult to determine if there was any shift in the seasonal distribution of flows as a result of the releases.
- Flow variability moved towards a more natural pattern in the upland reach as shown by a reduction in the coefficient of variation at Dalgety from 2.12 to 0.82 during the release period (compared to 1.17 pre Scheme).
- The contribution of the Snowy River to end of catchment flows increased from 3 per cent to 9 per cent of flow at Jarrahmond.
- No large or small floods occurred in the Snowy River since the introduction of first stage of the environmental releases. The largest flow from the Mowamba River was 844 MLd^{-1}, which occurred during the spring snowmelt in 2005.

6. Recommendations

Recommendations regarding the Snowy Flow Response Monitoring and Modelling program include:

- The first stage of the hydrological model (i.e. IQQM) development for the Snowy River system needs to be finalised. Work required includes the calibration of modelled flows against observed flows for Snowy River control sites, and the addition of a snowmelt component for tributaries downstream of Jindabyne Dam (the Mowamba, Jacobs, and Pinch Rivers). The current model does not accurately reflect the strong seasonal variation that should occur in the upper river as a result of snowmelt in these tributaries.
- The second stage of the IQQM should be commissioned to address modelling stream flows in the alpine and montane river reaches above Jindabyne. This will require the incorporation of the Snowy Hydro infrastructure data to better incorporate diversions across the high country.
- Once the model has been finalised a value for the mean annual natural flow (MANF) should be derived for all monitoring control sites on the Snowy River. The current recommendations for MANF were derived for flows at Jindabyne Dam but are being applied to flows at Dalgety. A separate value for MANF needs to be derived for Dalgety, as there is a significant difference in catchment area between the two points.
- Some refinement of the hypotheses is required, in particular H6 which is designed to monitor the baseflow response. A baseflow of 200 MLd^{-1} was previously recommended as a suitable natural baseflow for Dalgety. Appropriate baseflows (representing the 95th percentile flow of the driest month pre SMS) need to be determined for each of the other test sites on the Snowy River.
- Modelled flows for Burnt Hut Crossing are needed to provide the baseline (pre SMS) flow regime for the midland macro-reach of the Snowy River.
- Further assessment of suitable snowmelt alpine/montane reference rivers is needed to better define the desired hydrological characteristics for the Snowy River below Jindabyne. This analysis as a minimum should include the unregulated gauging stations of:
  - Snowy River above Guthega Dam
  - Geehi River above Geehi Dam
  - Tooma River above Tooma Dam
  - Tumut River at Happy Jacks
  - Murrumbidgee River above Tantangara Dam
  - Thredbo River at Paddy’s Corner
  - Eucumbene River above Eucumbene Dam
  - Mowamba River above Mowamba Weir
  - Jacobs River at Jacobs Ladder
  - Snuggan Buggan River at Snuggan Buggan.
- Further assessment of the climate change influence of reduced snow cover and warmer temperature on the snowmelt signals of these unregulated tributaries needs to be investigated, particularly as it will influence the runoff in these systems.
- Investigations into the importance of spring snowmelt are required, and should focus on:
  - water quality characteristics, including water temperature and carbon supply during spring snowmelt
  - life-histories/traits of aquatic flora and fauna during the spring snow.

Recommendations regarding future releases to the Snowy River below Jindabyne include:

- The Snowy River was previously characterised by large snowmelt discharge in October. Releases from the Mowamba River re-introduced a small magnitude spring snowmelt signal in September. On one occasion a peak of 844 MLd^{-1} was observed during spring. Colder water associated with the snowmelt signal was formerly a key feature of the Snowy River, introducing these snowmelt characteristics should be considered a high priority for future releases. The changes to the characteristics of the snowmelt discharge are important, and need to consider three primary components, these being the timing, magnitude and rate of change all of these components have a sustainable influence on the ecological response.
- Experimental snowmelt release/s (i.e. similar magnitude, duration, and timing) should be undertaken to determine the differences in water quality characteristics between water sourced from the Mowamba River Weir and the Jindabyne Dam. This will allow a more direct comparison of the possible ecological benefits from each water source.
- The peak diversion rates that can be achieved from the Mowamba River weir/aqueduct are smaller in magnitude than the peak rates required to mobilise sediment in the Snowy River. Releases from Jindabyne Dam will be required to mobilise bed sediment in the Snowy River.

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Appendices

Appendix A – Gap Filling Methods for Snowy River Flow Data

Data Preparation

Daily data for NSW sites were extracted from the NSW Office of Water Hydsys database while data for Victorian sites were extracted from the Victorian Water Resources Data Warehouse. The following data preparation methods are summarised in Table 16.

Snowy River at Dalgety (222006)

Data for 222006 (Dalgety) and 222026 (Dalgety Weir) were combined to form one continuous record for the Snowy River at Dalgety. Pre SMS data for the Snowy River at Jindabyne (222501) has a very high correlation with Snowy River flows at Dalgety for the overlapping period of 1949-1957 (R=0.94, r^2=0.89 and volume ratio 112.3 per cent). A factor of 1.112 was applied to Jindabyne flows to approximate flows at Dalgety. Comparison of the adjusted data with observed data for the period 1949-1957 showed a volume ratio of 100.9 per cent. The adjusted data was appended to the Dalgety flows for the period 1902-1949.

Delegate River at Quidong (222008)

Records at Quidong commenced in 1951. However, two gauges operated further up in the catchment from 1941. Data for the Delegate River at Meads (222003) and the Little Plains River (222004) were combined for the period 1941-1959. Comparison of the combined data with the overlapping period of record at Quidong showed a volume ratio of 104 per cent. The combined data were adjusted by a factor of 1.04 to approximate flows at Quidong. The adjusted data was appended to Quidong flows for the period 1941 to 1951.

McKillops Bridge (222209)

McKillops Bridge gauge has a large period between 1946-1964 where the gauge was discontinued. The site is well correlated to the Snowy River at Basin Creek (222219) (R=0.92, r^2=0.85, volume ratio=85 per cent). Basin Creek was therefore used to generate modelled flows at McKillops Bridge for the missing period.

Basin Creek (222212)

Data for 222212 (d/s Basin Creek) and 222219 (at Basin Creek) were combined to give one continuous record for the Snowy River at Basin Creek. Catchment areas are within 1 per cent and therefore no adjustment was made to the data. Also, the period of record for 222219 only went to 16/12/2005 so a reasonable correlation was found with 222209 (2002-2005 volume ratio = 120 per cent, CD=0.89, R=0.94, CE=0.69) and flows were extended to 31/12/2005.

Jarrahmond (222200)

Jarrahmond gauge was discontinued between 1951 and 1965. The site is well correlated with the Snowy River at Basin Creek (R=0.88, r^2=0.78, volume ratio=124 per cent). Basin Creek was therefore used to generate modelled flows at Jarrahmond for the missing period.

Deddick River (222210)

There is no continuous gauge that covers both pre and post SMS periods. The current gauge 222210 was installed in 1964 and two earlier gauges (222002 and 222208) operated further up the catchment between 1941 and1949 (222002) and 1959-1964 (222208). Flows at 222208 (not far upstream of the current gauge) were added directly to the record without any adjustment, while flows at 222002 were factored by a catchment area ratio of 1.3 before being added to the current record. The intervening gap from 1949-1958 was generated by correlation with the Buchan River (R=0.81, r2=0.66, volume ratio 48 per cent).

Buchan River (222206)

The Buchan River gauge was discontinued between 1930 and 1948. Correlation with the Deddick River is reasonable (R=0.81, r^2=0.66, volume ratio 203 per cent) and was used to generate modelled flows for the period 1941-1948 for the Buchan River. A short period of overlap (1947-48) allowed comparison of the modelled data with observed data. The correlation statistics were poor (R=0.46, r^2=0.22) however the total volume was within 4 per cent.

Table 16. Summary of gap filling and extension of daily flow data.

Site	Days missing	Site used for correlation	Annual volume ratio	Daily r^2	Comments
222006 / 222026 Snowy River at Dalgety 01/04/49-31/12/05		222501 Snowy at Jindabyne	1.12	0.89	Extended back to 1902 by correlation.
222209 Snowy River at McKillops Bridge 02/03/41 – 31/12/05	6914 29%	222212 Snowy at Basin Creek	0.88	0.84	Large data gap 01/01/46 – 01/01/64 19% missing data Pre SMS 10% missing data Dur SMS
222212 Snowy River at Basin Creek	691 2.5%	222501 Snowy at Jindabyne 222006 Snowy at Dalgety 222200 Snowy at Jarrahmond 222206 Buchan River	1.95 1.18 0.82 8.97	0.30 0.85 0.87 0.54	
222200 Snowy River at Jarrahmond 26/04/22 – 31/12/05	5711 18%	222501 Snowy at Jindabyne 222212 Snowy at Basin Creek 222206 Buchan River	2.04 1.22 9.74	0.16 0.84 0.59	All gaps 1933 onwards filled using Basin Creek. Large data gap 01/01/51 – 18/04/64 10% missing data Pre-SMS 8% missing data Dur-SMS
222008 Delegate River 22/02/51-31/12/05					Extended back to 1941 using discontinued gauges 222003 and 222004.
222210 Deddick River	973 6.4%	222206 Buchan River	0.49	0.64	Includes filling of a 2 year gap 1971-1972
222206 Buchan River 27/03/26 – 31/12/05	7360 25%	222501 Snowy at Jindabyne 222212 Snowy at Basin Creek 222200 Snowy at Jarrahmond 222210 Deddick River	0.16 0.09 0.10 2.04	0.14 0.55 0.59 0.64	Large data gap 01/10/30-08/10/47 filled by correlation with Deddick 23% missing data Pre-SMS 1.5% missing data Dur-SMS 0.1% missing data Post-SMS

Appendix B – Daily Flow Analysis

Table 17. Change in daily flows at Snowy River test sites

Daily Flows	Pre SMS	Post SMS	Pre EFR	Post EFR
Dalgety Weir				
Minimum	190	0	23	36
Maximum	70,583	27,476	3,433	1,140
Mean	3,948	160	58	120
Median	2,469	40	42	90
CV	1.2	5.3	2.1	0.8
Standard Deviation	4,627	850	124	98
Variability	3.4	3.5	0.7	1.9
Burnt Hut Crossing				
Minimum			50	41
Maximum			15,714	11,081
Mean			553	330
Median			260	192
CV			1.9	1.9
Standard Deviation			1,052	627
Variability			3.7	2.5
McKillops Bridge				
Minimum	208	17	105	86
Maximum	267,000	404,000	21,818	15,709
Mean	5,755	2,024	1,081	743
Median	3,478	767	651	509
CV	1.7	3.7	1.6	1.1
Standard Deviation	9,632	7,430	1,722	848
Variability	3.0	4.7	2.3	2.3
Basin Creek				
Minimum	237	10	97	115
Maximum	313,000	426,000	89,679	19,524
Mean	6,533	2,449	1,494	884
Median	4,038	867	742	582
CV	1.6	3.7	2.3	1.3
Standard Deviation	10,694	9,008	3,456	1,143
Variability	3.0	4.9	2.9	2.3
Jarrahmond				
Minimum	0	4	69	70
Maximum	389,000	423,000	160,000	20,567
Mean	8,278	2,960	2,045	1,144
Median	4,859	1,056	1,022	764
CV	1.8	3.2	2.6	1.3
Standard Deviation	14,869	9,590	5,390	1,464
Variability	3.1	5.2	3.0	2.5

Table 18. Change in daily flows at reference sites

	Pre SMS	Post SMS	Pre EFR	Post EFR
Thredbo River				
Minimum			57	50
Maximum			5,516	5,115
Mean			463	460
Median			303	288
CV			1.1	1.1
Standard Deviation			500	490
Variability			2.8	3.1
Delegate River				
Minimum	22	2	28	18
Maximum	51,814	57,285	6,027	3,794
Mean	498	396	255	140
Median	233	183	153	109
CV	2.6	2.5	1.3	1.2
Standard Deviation	1,279	1,003	324	169
Variability	4.1	3.9	2.7	1.5
Deddick River				
Minimum	0	0	7	3
Maximum	10,433	16,609	9,694	3,231
Mean	244	187	122	63
Median	97	54	47	37
CV	2.4	3.1	2.9	2.2
Standard Deviation	579	578	357	142
Variability	4.5	6.5	4.8	3.1
Buchan River				
Minimum	0	0	7	6
Maximum	21,628	17,863	16,124	2,279
Mean	506	371	284	216
Median	201	150	153	128
CV	2.4	2.4	2.1	1.2
Standard Deviation	1,199	908	611	267
Variability	4.5	4.7	3.1	3.7

Appendix C – Assessment of large and small floods

Floods were not expected to be rehabilitated with the first stage of the environmental water releases to the Snowy River via the Mowamba River. The evaluation below forms an assessment of existing hypotheses but has been primarily provided as benchmark for future data analysis.

Large flood analysis

A flood frequency analysis was undertaken on pre and post Scheme flows at Dalgety to ascertain the change in frequency for large floods exceeding 20,000 MLd^{-1}. The magnitude of this event represents the natural one in one year natural flood event (Pendelbury *et al*. 1996). No other sites were analysed because the annual return interval for floods exceeding 20,000 MLd^{-1} during pre SMS periods were less than one year.

Figure 19 shows the pre SMS large flood annual recurrence interval at Dalgety to be approximately one in less than one year while Figure 19 shows the post SMS large flood annual recurrence interval at Dalgety to be approximately one in 20 years.

An event analysis was also undertaken for large floods of 20,000 MLd^{-1}or greater. For this analysis, a 'spell' was defined as a flow event with a flow greater or equal to 20,000 MLd^{-1} and has duration of at least one day. The analysis included total number of spells, mean magnitude and mean duration of spells. Table 19 summarises the results of this spell analysis.

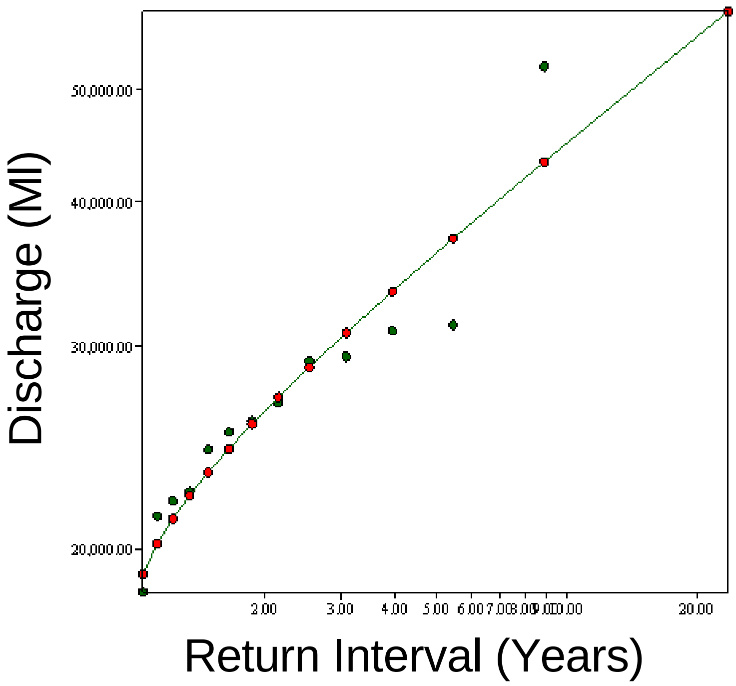
The construction of the Scheme has resulted in a significant reduction in the number of large flood events. At Dalgety prior to the Scheme large floods occurred on average 1.2 times per year, with an average duration of 3.3 days. Since construction of the Scheme no large floods of 20,000 MLd^{-1} or more have occurred at Dalgety.

No large floods occurred at any Snowy River site as a result of releases from Mowamba River. The largest flow from Mowamba River was 844 MLd^{-1} which occurred during the spring snowmelt in 2005.

Figure 19. Annual series large flood frequency curve at Dalgety pre and post the Scheme.

Green symbols are observed data and the red symbols are from the fitted log Pearson curve.

Pre-scheme



Post-scheme

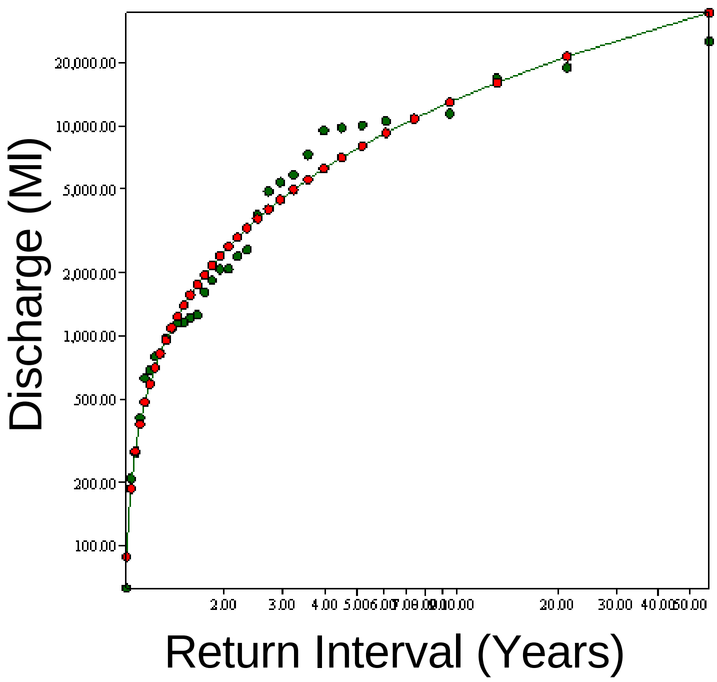


Table 19. Flow spell analysis of large floods of 20,000 MLd^{-1} for the Snowy River.

Gauge number	Snowy River		Record length (years)	Total number	Number per year	Mean flow (MLd^{-1})	Mean duration (days)
222026	Dalgety Weir	Pre SMS	6	7	1.2	33,020	3.3
		Post SMS	34	0	0	0	0
		Pre EFR	4.3	0	0	0	0
		Post EFR	3.3	0	0	0	0
222209	McKillops Bridge	Pre SMS	15	34	2.3	61,959	4.4
		Post SMS	34	33	1.0	77,290	3.3
		Pre EFR	4.3	0	0	0	0
		Post EFR	3.3	0	0	0	0
222219	Basin Creek	Pre SMS	15	39	2.6	61,895	4.5
		Post SMS	34	45	1.3	78,206	3.7
		Pre EFR	4.3	2	0.5	60,320	2.5
		Post EFR	3.3	0	0	0	0
222200	Jarramond	Pre SMS	15	59	3.9	64,313	5.1
		Post SMS	34	52	1.5	79,466	4.3
		Pre EFR	4.3	4	0.9	67,583	2.8
		Post EFR	3.3	0	0	0	0

Small flood analysis

A flood frequency analysis was undertaken on pre and post SMS flows at Dalgety to ascertain the change in frequency for small floods exceeding 1,000 MLd^{-1}. No other sites were analysed because the annual return interval for floods exceeding 1,000 MLd^{-1} during pre SMS periods were significantly less than one year.

Figure 20 shows prior to SMS, the several small floods occurred every year at Dalgety while Figure 20 shows post SMS, small floods have an annual recurrence interval of approximately one in 1.5 years at Dalgety.

A spell analysis was undertaken for flows of 1,000 MLd^{-1} at all Snowy River sites and analysis periods. For this analysis, a ’spell‘ is defined as a flow event with a flow greater or equal to 1,000 ML/d and has duration of at least one day. The analysis included total number of spells, mean magnitude and mean duration of spells. Table 20 summarises the results of this spell analysis.

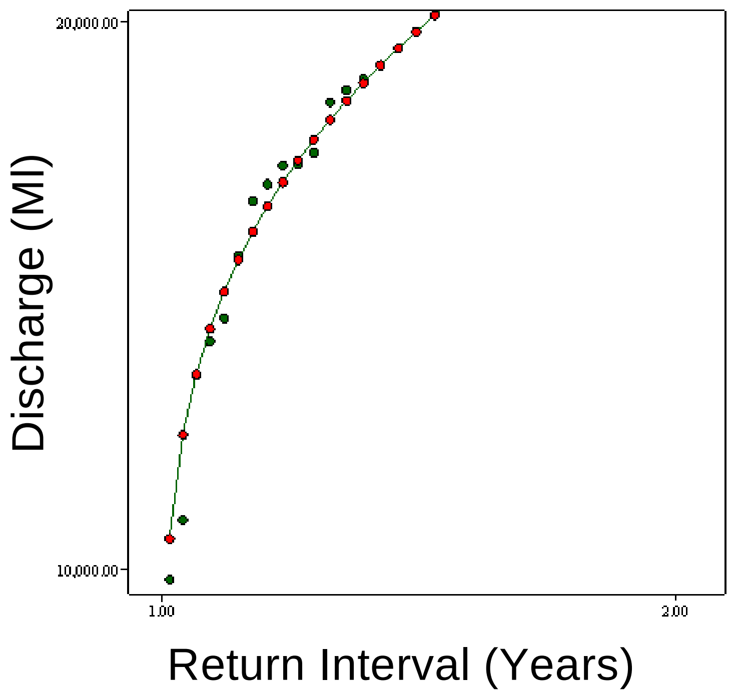
The construction of the Scheme has resulted in a significant reduction in the number of small flood events. Before the dam was constructed, small floods occurred on average 4.3 times per year with a mean magnitude of 11,135 MLd^{-1}. Since construction, small floods occur only 2.2 times per year with a mean magnitude of 134 MLd^{-1} at Dalgety.

No small floods occurred at Dalgety since the EFR from Mowamba River.

Figure 20. Annual series small flood (1,000 MLd^{-1}) frequency for the Snowy River at Dalgety.

Green symbols are observed data and the red symbols are log Pearson curve.

Pre-scheme



Post-scheme

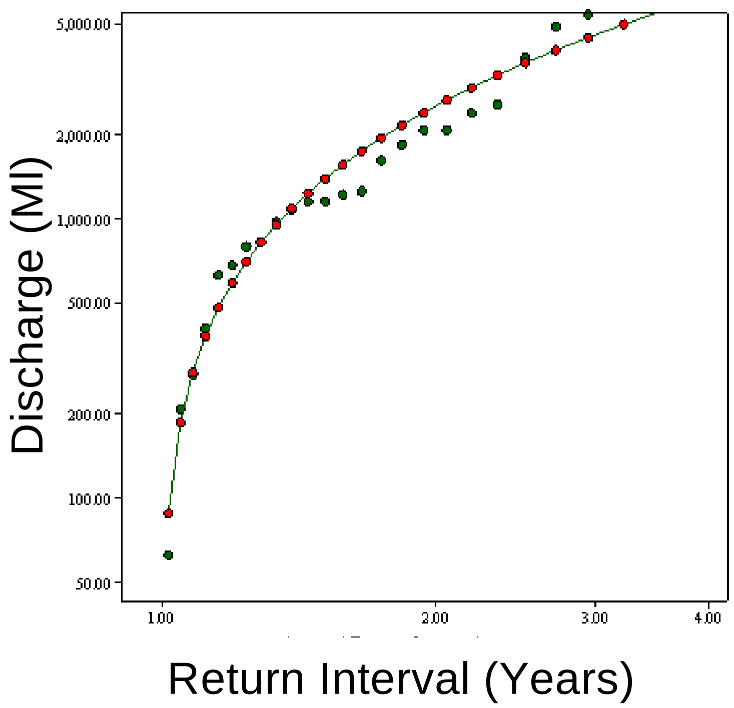


Table 20. Frequency and duration of small floods exceeding 1,000 MLd^{-1}.

Gauge number	Snowy River test sites		Record length (years)	Total number	Number per year	Mean flow (MLd^{-1})	Mean Duration (days)
222026	Dalgety Weir	Pre SMS	6	26	4.3	11,135	69
		Post SMS	34	75	2.2	134	16
		Pre EFR	4.3	1	0.2	2,572	2
		Post EFR	3.3	0	0	0	0
222209	McKillops Bridge	Pre SMS	15	46	3.1	25,698	98
		Post SMS	34	221	6.5	11,146	21
		Pre EFR	4.3	35	8.1	4073	12
		Post EFR	3.3	21	6.4	2,646	13
222219	Basin Creek	Pre SMS	15	34	2.3	34,798	137
		Post SMS	34	212	6.2	13,929	26
		Pre EFR	4.3	27	6.3	9,161	21
		Post EFR	3.3	22	6.7	3,112	15
222200	Jarramond	Pre SMS	15	27	1.8	37,191	177
		Post SMS	34	199	5.9	14,948	32
		Pre EFR	4.3	32	7.4	10,680	25
		Post EFR	3.3	14	4.2	4,500	36