Department of Infrastructure,
Planning and Natural Resources

Environmental Flows Initiative Technical Report

SNOWY RIVER BENCHMARKING AND ENVIRONMENTAL FLOW RESPONSE MONITORING PROJECT: SUMMARY PROGRESS REPORT ON AVAILABLE DATA FROM 1999-2001.

April 2003

Environment Australia
Natural Heritage Trust
Helping Communities Helping Australia
Natural Resources and Environment
East Gippsland Catchment Management Authority

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Report to Environment Australia

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edited by Teresa Rose and Robyn Bevitt

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Cover photo:
The Snowy River near Dalgety (Site 4: downstream of Blackburn Creek) *Photo: Robyn Bevitt*

i EXECUTIVE SUMMARY

The Federal, Victorian and NSW state governments agreed in October 2000 to release environmental flows of 21% mean annual natural flow (MANF) in the first ten years after corporatisation of the Snowy Mountains Hydro-Electric Authority. A further environmental flow release of 7% MANF will be reliant on cost savings by irrigators west of the great-dividing range. The environmental flow releases will be delivered to the Snowy River downstream of Jindabyne Dam to improve the physical and ecological integrity of the river. The first environmental flow was released from the Mowamba Weir on 28 August 2002.

The Snowy River Benchmarking and Environmental Flow Response Monitoring Project was developed to benchmark, then measure and monitor changes in the physical, chemical and biological features of the Snowy River as a result of environmental flow releases. The project's design and methods have been rigorously developed under the guidance of a Technical Steering Committee, and based on the first few years of sampling, considered capable of measuring changes after environmental flow releases. A summary of preliminary results for hydrology, geomorphology, water quality, aquatic macrophytes, macro-algae, macroinvertebrate and fish sampling are presented in this progress report for pre-flow release baseline data up to June 2001. Interpretation includes some of the effects of flow regulation from the Snowy Mountains Scheme and exploratory analyses into the adequacy of sampling design and methods.

Records from the Dalgety gauging station show that all aspects of the flow regime have been modified since the commissioning of the Snowy Mountains Scheme. Significant reductions have occurred in flow volume, magnitude and frequency of floods for all recurrence intervals, flow durations for all annual exceedance probabilities, and a complete loss of seasonal flow variability particularly the spring snowmelt.

Three geomorphic assessments are reported. First, post June 1998 sampling in the lower Snowy River at Sandy Point and Bete Bolong showed that floods with a peak discharge four times greater than the mean annual flood are important in mobilising sediment and hence, re-forming the channel boundary. Second, hydraulic modelling conducted in the upper Snowy River downstream Mowamba and Rockwell indicate that flows of 1,000 MLd^{-1} are theoretically capable of flushing unconsolidated fine-grained sediment laminae deposits in pools and unconsolidated very coarse sand in pools, and cobbles in riffles. This response is important because it is the size of the proposed flushing flow for the Snowy River, and therefore the model predicts channel change and sediment movement. A notable result from the hydraulic modelling is the development of a velocity reversal effect at the downstream Mowamba and McKillops Bridge sites under pre- Jindabyne Dam discharges of about 1 in 2 years on the annual maximum series. This is important because velocity reversals develop structural pools in bedrock riverbeds over geologic time, and prevent the deposition of bed load sediment in pools. Third, a maximum of 30,000 MLd^{-1} capacity outlet structure will provide both an adequate margin to manipulate the hydrograph shape and duration, and will satisfy the annual minimum peak flow recommendations of 20,000 MLd^{-1} developed by the Expert Panel to re-form the channel boundary.

Temperature and electrical conductivity (EC) were measured at Dalgety and Willis gauging stations, and as part of a pool stratification pilot study in summer 2000. Temperature exhibited

strong seasonal patterns at Dalgety and Willis, with summer water temperatures high at Willis. EC levels generally correspond with discharge, increasing with flow events arising from local rainfall below Jindabyne Dam. Temperature and oxygen stratification was not prevalent in the Snowy River during the pilot study period but did occur at the sites nearest to the dam. Stratification was not present in the Thredbo or Deddick River reference sites, but strong thermal gradients occurred in the Delegate River reference site. Limited data indicate that there may be a combined effect of discharge, pool depth and pool size on stratification in the Snowy River sites nearer to the dam.

Four vegetation assessments are reported. First, the reach scale assessment allows seasonal and annual variation to be measured. It is important to have a measure of natural variability in vegetation communities to separate it from the effects of the flow releases. Native species data indicate a high component of macro-reach distribution in explaining the observed variation, and the weed flora, a strong seasonal component in explaining the observed variation. Second, emergent vegetation data support macro-reach classification and the adequacy of reference sites for comparing with test sites. Third, submerged vegetation data also support macro-reach classification and usefulness of the reference sites. Fourth, limited analyses indicate that the sampling design for macro-algae will enable the prediction of species groups that are expected to be flow-response indicators.

The macorinvertebrate fauna of pools and riffles in the Snowy River below Jindabyne Dam were very different to those sampled from reference rivers. Taxa found in the reference rivers reflected unregulated conditions, whereas the Snowy River taxa in the upland sites were more characteristic of still and slow flowing assemblages, thus reflecting the altered hydrology and habitat conditions below Jindabyne Dam.

Results of the fish assessment indicate that spatial, rather than annual variation explains the distribution of fish communities in the Snowy River. In particular, there was a clear spatial separation in the fish communities above and below Snowy Falls, in both the Snowy River test sites and reference rivers. Barriers to fish passage are detrimental to fish species in the Snowy catchment that require large -scale migration to complete their life cycle. Further studies are advised into the significance of natural barriers in the Snowy River under the reduced flows from Jindabyne Dam. Of concern is the stocking of trout and Australian bass for recreational fishing because of the potential to confound future results to the fish assessment unless specifically built into the design.

These preliminary results show that the sampling designs are adequate for detecting responses to environmental flow releases. The next progress report will include all analyses for pre-flow release data to the 28 August 2002 and will focus on the effects of Jindabyne Dam on all of the components measured, and compare these findings with the results from other scientific studies.

ii ACKNOWLEDGMENTS

The Snowy River Benchmarking and Environmental Flow Response Project (Snowy River Benchmarking Project) was initiated and implemented in 1997 by the Department of Infrastructure, Planning and Natural Resources (DIPNR), formerly the Department of Land and Water Conservation (DLWC). A peer review was undertaken by independent scientists in 1998, and the Snowy River Benchmarking Project was upgraded in 1999.

Funding for the project upgrade and for the 1999/2000 and 2000/2001 financial years was provided by Environment Australia (EA), with additional contributions from DIPNR, the Department of Sustainability and the Environment (DSE) and the East Gippsland Catchment Management Authority (EGCMA).

Two committees established to oversee the project are:

The Interstate Steering Committee who provide project management support. Members consist of Mr. Chris Barry, East Gippsland Catchment Management Authority; Ms. Robyn Bevitt, DIPNR; Ms. Pam Green, South East Catchment Management Board; Mr. Brett Miners, DIPNR, Mr. Derek Rutherford, NSW Environment Protection Authority; Mr. Tony Roper, DIPNR; Ms. Teresa Rose, DIPNR; Mr. Simon Williams, DIPNR, and Mr. Paul Wilson, DSE.

The Technical Steering Committee who provide scientific advice. Members consist of Dr. Peter Davies, Freshwater Systems; Mr. Hugh Jones, DIPNR; Dr. Amrit Kathuria, DIPNR; Prof. Sam Lake, Monash University, and Dr. Jane Roberts, formerly of CSIRO.

Scientists who undertook significant work for this project period are:

Data analysis and design
Mr. Hugh Jones, DIPNR and Dr. Amrit Kathuria, DIPNR.

Fish
Dr. Peter Gehrke, formerly of NSW Fisheries; Dr. John Harris, formerly of NSW Fisheries; Mr. John Johnstone, via EGCMA; Mr. Bryan Matthews, via EGCMA, and Dr Tarmo Raadik, Arthur Rylah Institute for Environmental Research.

Macroinvertebrates
Ms. Robyn Bevitt, DIPNR; Mr. Andrew Brooks, DIPNR; Mr. Matthew Dasey, DIPNR; Mr. Matthew Russell, DIPNR; Mr. Simon Williams, DIPNR, and the Cooperative Research Centre for Freshwater Ecology.

Vegetation
Ms. Mia Dalby-Ball, Acacia Consulting; Dr. Surrey Jacobs, Royal Botanic Gardens Sydney; Mr. Geoff Sainty, Sainty and Associates, and Mr. Jason Sonneman, "Ecological".

Geomorphology

Dr. Wayne Erskine, NSW State Forests; Dr. Ivars Reinfelds (DIPNR); Ms. Lisa Turner, University of NSW, and Dr. Ashley Webb, NSW State Forests.

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Mr. Paul Corbett, DIPNR; Mr. Chris Ribbons, DIPNR, and Mr. Adam Wiggins, DIPNR.

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Simon Williams, DIPNR Sydney/South Coast Resource Analysis Manager, reviewed this report.

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1. INTRODUCTION

The construction of dams and subsequent downstream changes to both flow and sediment regime is one of the most profound anthropogenic impacts upon river ecology. Changes to the hydrologic regime include a decrease in flow volume, decrease in the magnitude, frequency and duration of flood discharges, a reduction and/or attenuation in seasonality of flows and change in the variability and predictability of flows (Poff *et al*., 1997; Rose 1999). The volume of sediment trapped by the dam can reach sediment trap efficiencies of 95 to 100% (Erskine, 1985; Benn and Erskine, 1994). This is important because the interaction of sediment and water determines river channel morphology, hence morphological adjustments are expected. Such adjustments may be channel widening and infilling through aggradation (Church, 1995), or channel contraction represented by in-channel bar and bench formation encroached by vegetation (Benn and Erskine, 1994). Accommodation adjustment may also occur. This is evidenced by a reduction in the competency of discharges to modify the pre-regulation channel boundary, and vegetation growing to a new water level (Petts, 1979; Petts, 1984). These physical changes impact on the quality and availability of aquatic habitats for flora and fauna. For example, habitats become homogeneous, fine sediments fill interstitial spaces in gravels, and flow depth is reduced increasing summer water temperatures. Thus, changes in the flow regime and its consequent physical outcomes impact on ecological functions. Vegetation becomes established in regulated rivers because of a reduction in disturbance frequency (Cremer *et al*., 1995), and invariably traps sediment that acts as a feedback mechanism in the natural processes of river adjustment (Howard and Dolan 1981; Petts 1984; Benn and Erskine 1994; McKenny *et al*., 1995). Macroinvertebrates may decrease or increase in species richness (Harding, 1992; Petts and Castella, 1993), reduce in species diversity (Stevens *et al*., 1997), or sediment deposition may favour a particular species (Doeg *et al*., 1987). Similarly, flow regulation conditions will favour higher numbers of introduced, rather than native fish species. Before the first environmental flow release on the 28 August 2002, the Snowy River downstream of Jindabyne Dam received 1% of MANF (mean annual natural flow) and this has severely impacted on its ecology.

The re-introduction of components of the pre-Snowy Mountains Scheme flow regime has the potential to recover the Snowy River's ecology to some extent. The Federal, Victorian and NSW state governments have agreed to release the recommended minimum flow of 28% of MANF (Pendlebury *et al*., 1996) to the Snowy River downstream of Jindabyne Dam. Flows of 21% MANF are to be released in the first ten years after corporatisation of the Snowy Mountains Hydro-Electric Authority and a further 7% MANF commensurate with cost savings by irrigators west of the great dividing range. Corporatisation is the trigger for the Snowy Water Inquiry Implementation deed that establishes environmental flows under the *Snowy Corporatisation Act 1999*. The recommended minimum annual environmental flow will bring an increase in the frequency and duration of floods and flushing flows, and an increase in base-flow and flow variability to the Snowy River, and with it, ecological benefit.

1.1 The project

The Snowy River Benchmarking and Environmental Flow Response Monitoring Project (Snowy River Benchmarking Project) is a multi-disciplinary study whereby hydrology, water quality, geomorphology, aquatic macrophytes, macro-algae, macroinvertebrates and fish are sampled. These components are being measured to benchmark river condition before environmental flows are released, and monitored for at least a further seven years to determine river condition after environmental flows are released. In this way the ecological benefit of the releases can be measured. Results will guide the adaptive management of further environmental flow releases to the Snowy River and provide a multi-disciplinary model for benchmarking and monitoring environmental flows in other Australian rivers. How the Snowy River Benchmarking Project developed and how the project relates to river management is shown in (Figure 1). Stakeholder involvement and technology transfer is summarised in Appendix 1.

1.2 Project aim and objectives

The broad aims and objectives of this project are as follows:

Aim 1 is to achieve the maximum possible return of ecological and physical elements that characterised the river before flow regulation.

The objectives are to provide information to inform:
- The rehabilitation of the basic components of the flow regime that occurred pre-regulation.
- The management of the annual flow allocation to maximise ecological response.

Aim 2 is to develop a scientifically rigorous monitoring project to measure the physical, chemical and biological effects of flow releases.
The objectives are to:
- Provide baseline data of pre-flow release river condition and measure the magnitude and direction of change in a number of ecosystem components following the implementation of environmental flows.
- Differentiate between changes brought about by environmental flows and those influenced by the catchment.
- Identify the drivers of change (other than flows) by analysing important physical, chemical and biological interactions.
- Describe pre- and post- flow release river condition.
- Determine the aspects of the flow regime that give greatest ecological benefit and where these occur, and report on, and adaptively manage the flow regime to the five-year review.

1.3 Scope of the report

This report is a final funding progress report to Environment Australia. It presents summary results on available pre- environmental flow release data from 1999-2001. At the time of writing this report, data was not available for all sites, or for all spatial scales. Some analyses were directed at answering study objectives while others, like the vegetation component, were purely exploratory. As a result, there are gaps and inconsistencies in reporting, and limited comparison with the literature. Comprehensive reporting will be conducted when all pre- flow release data are analysed.

A detailed document of the project's design, methods, objectives, hypotheses and analyses is currently being drafted. When completed, future progress reports will reference this document instead of summarising the design and methods like in this report.

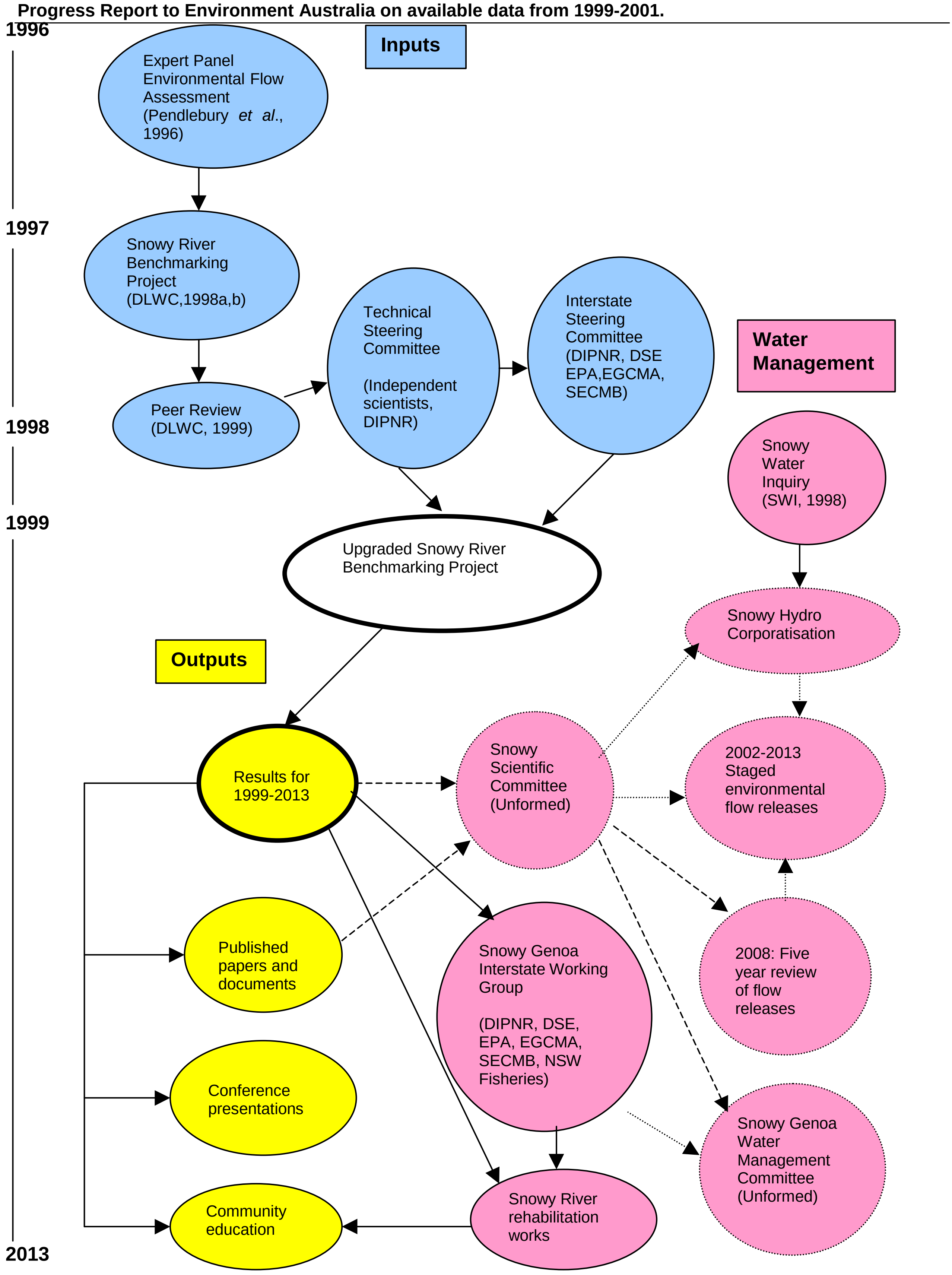


Figure 1. River management and benchmarking in the Snowy River. ----arrangements in progress

2. PROJECT DESIGN

The focus of the Snowy River Benchmarking Project is to measure the effect of environmental flow releases on the ecology of the Snowy River downstream of Jindabyne Dam. The focus of pre-flow release data collection is to benchmark pre- flow release river condition and to determine the natural variability in the system. The following information provides a background of the project's design and is presented to give this report context.

2.1 Sampling design development

The design framework of Maher, Cullen and Norris (1994) was used to develop the project objectives and set testable hypotheses for sampling. The main question is concerned with how the ecology of the Snowy River will respond to the cumulative effects of the recommended minimum annual environmental flow release regime of Pendlebury *et al*., (1996).

Conceptual models of the river's response to different parts of the flow regime were developed for each project component. Ecologically important components that are expected to respond strongly to different parts of the flow regime were chosen. These are water quality, geomorphology (channel morphology, sediment and habitat), vegetation (including riparian, emergent macrophytes and macro-algae), macroinvertebrates and fish (broad-scale and recruitment). Covariables that may influence change in the project components (other than flows) are also measured. Response variables and covariables for each component are measured repeatedly at representative Snowy River test, reference and control sites (see 2.3). This approach enables the measurement of changes in the selected variables and their relationship with specific covariables, and the testing of hypotheses over time. The project measures both immediate, short (< 5 years) and long term (>5 years) response variables for each project component to enable reporting on the effect of the flow regime which is separated into four essential components (Pendlebury *et al*., 1996):

1. At least one flood event of 20,000 MLd^{-1} and of sufficient duration (3 to 5 days) to restore and maintain channel morphology and to exceed the threshold of motion for stabilised sediments;

2. An increase in base-flow between 150 MLd^{-1} to 300 MLd^{-1} to provide adequate wet habitat area and reduce summer water temperature;

3. Re-introduction of flow variability that mimics the natural hydrograph based on the importance of seasonality of base-flow patterns in preserving habitat and water quality for healthy aquatic biota; and,

4. Two flushing flow events of 1,000 MLd^{-1} to remove the accumulation of bio-clastic and fine sediment from the interstitial spaces of the substrate that are important habitat for aquatic fauna.

2.2 Statistical design

There are a number of environmental flow variables that are expected to respond at different spatial and temporal scales. It is not possible to have one common design for all response variables. The study is a modified Before-After, Control-Impact (BACI) design (Keough and

Mapstone 1995; Underwood, 1991) because there is not a control for each site. Where there are no controls, reference sites are used.

Control sites are sites on rivers that currently have a dam and are not expected to receive an environmental flow during the study period. Control sites were selected as an environmental condition to move away from, as it would be expected that control sites would also vary over time. There are only two control sites for this project and these were selected along the Eucumbene River to be used primarily for comparison with the Jindabyne Gorge and Dalgety Uplands geomorphic reaches. Selection of more control sites was not achievable in the Snowy River catchment.

Reference sites are sites on rivers that do not have a modified flow regime (ie. a dam) and have similar geography, elevation and flow as test sites. Reference sites were selected to provide an environmental condition for the Snowy River test sites to move towards. They were selected by monitoring scientists over a three-day field trip based on their knowledge of what the Snowy River might look like following environmental flows, therefore, the environmental condition, and hence specific reference river to move towards, do vary between components. The vegetation component does not use reference rivers as a condition to move towards because there are no suitable sites. It will use selected reference sites to determine natural variability in the system.

Multistage sampling is used for most of the components in this project and involves two or more hierarchically arranged levels of replication allowing the estimation of variability at different scales. Simple random, stratified or systematic sampling was used at each stage of sampling.

The river is divided into geomorphic reaches (Erskine, 1996; Erskine *et al*., 1999; Webb and Erskine, 2000). Two or more performance reaches (sites) are selected from each geomorphic reach and habitats within each performance reach are sampled on a number of occasions over several years. For some components, geomorphic reaches are combined to form macro-reaches, so reporting is simplified. Combinations of geomorphic reaches vary depending on what is perceived to drive change (other than flows). How geomorphic reaches are combined is tabled in the introduction of each component in section 3. The general hypothesis is that with the introduction of environmental flow releases, the difference between the Snowy River geomorphic reaches and the reference rivers will become smaller over time. Similarly, the difference between the Snowy River geomorphic reaches and the control sites will become larger over time. Where elements of a BACI design are missing, inference that environmental flows have caused change becomes uncertain. In this situation a levels-of-evidence approach is adopted by correlating covariables with particular components to establish the strength, consistency and specificity of association (Downes *et. al*., 2002). Correlative evidence using long data sets may build a sufficiently strong case to infer/not infer causality.

Time is partitioned into blocks of time nested within each other such as before-after periods, years and season.

2.3 Study sites

All study sites are shown in (Table 1, Figure 2 and Figure 3). Snowy River test sites were chosen within the hierarchical framework developed by Erskine (1996), Erskine *et al*., (1999) and Webb and Erskine (2000). Site selection also incorporated personal judgement using pragmatic decisions of accessibility and safety.

Table 1. Geomorphic reaches, test, reference and control sites.

Snowy River geomorphic reach	Site No.	Site (performance reach)	State
		Snowv River test sites	
Jindabyne Gorge	*(1)*	*Downstream of Cobbin Creek, now discontinued*	NSW
	1	Downstream of the Mowamba River	NSW
	2	Upstream of Sugarloaf Creek	NSW
Dalgety Uplands	3	Rockwell	NSW
	4	Downstream of Blackburn Creek	NSW
Burnt Hut Gorge	5	Burnt Hut Crossing	NSW
Willis Sand zone	6	Willis	NSW
	7	McKillops Bridge	Vic.
Lucas Point Reach	16	Jacksons Crossing	Vic.
	8	Wests Track	Vic.
	(8)	*Sandy Point, now discontinued*	Vic.
Long Point Reach	9	Long Point	Vic.
Orbost Alluvial	10	Bete Bolong	Vic.
		Reference sites	
	11	Delegate River at Quidong	NSW
	12	Mowamba River on the Barry Way	NSW
	13	Thredbo River at Paddys Corner	NSW
	14	Deddick River upstream of Bulls Flat gauge	Vic.
	15	Buchan River downstream of Tara Creek	Vic.
	17	Delegate River at Delegate	NSW
	18	Deddick River at Ambyne Road	Vic.
	19	Buchan River at Buchan Station	Vic.
	20	MacLaughlin River at Sherwood	NSW
	21	MacLaughlin River at Boco	NSW
	24	Cann River upstream of the Broome Track	Vic.
	25	Cann River near Silverwood	Vic.
	26	Buchan River upstream of the Snowy River confluence	Vic.
	(10)	*Pinch River*, *now discontinued*	NSW
		Control sites	
	22	Eucumbene River upstream of Nimmo Bridge	NSW
	23	Eucumbene River near Montana	NSW

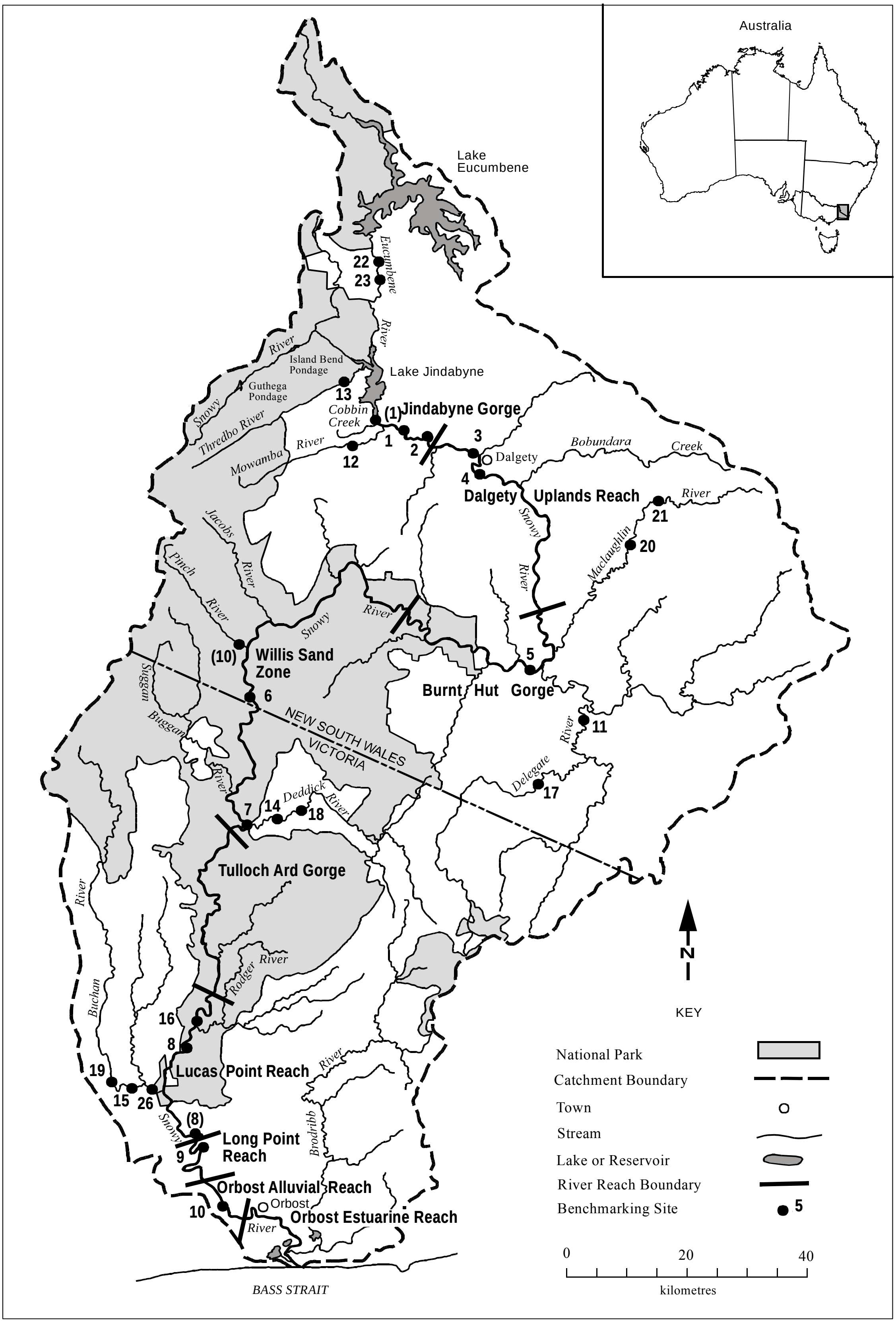


Figure 2. Snowy test, reference and control river sites (Webb and Erskine, 2000).

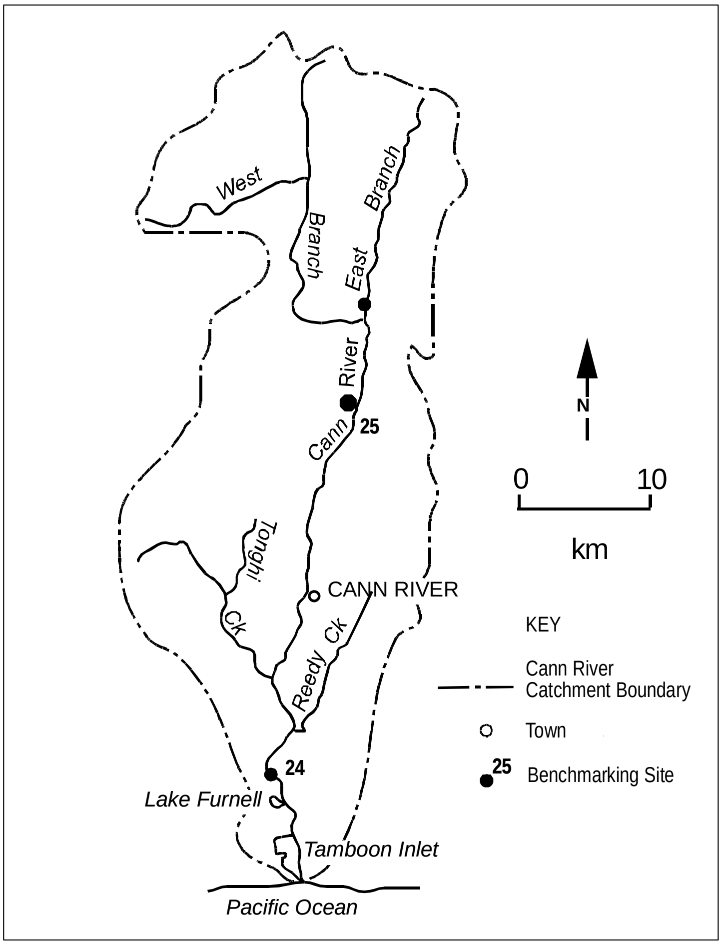


Figure 3. The Cann River reference sites (Webb, 2002).

2.4 Sampling

The Snowy River has been spatially stratified to control for varying spatial scales for the different project components under study (Table 2). All sampling is conducted within the limits of the performance reach to integrate benchmarking effort, and habitat maps produced to direct sampling location, however not all components are sampled at each site (Table 3).

2.4.1 Habitat based sampling

Sampling is conducted at two spatial scales these are, the performance reach and the bedform. Hydrology, water quality, geomorphology, habitat quantity, diversity and quality, riparian vegetation and fish are measured at the performance reach level. At this scale the occurrence of biota are determined by overall features such as topography, altitude and fluvial processes (Maddock, 1999). Substratum, aquatic macrophytes, macro-algae and macroinvertebrates are measured at the bedform scale. At this scale the occurrence of biota are influenced by morphological units (eg., riffles, pools and runs) dominant substrate, average flow velocity and flow depth (Maddock, 1999).

Table 2. Spatial and temporal organisation of river habitat classification for the Snowy River Benchmarking Project. Adapted from Webb and Erskine (2000), with sensitivity scales of Frissell *et al*., (1986) and Petts (1984).

Spatial classification level	Linear spatial scale (m)	Essential features	Response time	Sensitivity to change
Catchment	$>10^5$	Snowy River	Long	Low
Macro reach	10^4	Flow release coupled with tributary influences (eg., hydrology), or combinations of geomorphic reaches (eg., vegetation, macroinvertebrates and fish)	↓	↓
Geomorphic reach *(see Fig. 2 and Table 1)*	10^4	Relatively homogeneous associations of topographic features and habitat types which distinguish them from adjoining reaches	↓	↓
Performance Reach, or site	10^2-10^3	A stretch of river 10-15 times longer than the channel width, including two riffle pool sequences	↓	↓
Bedforms	10	Areas of relatively homogeneous flow & depth eg. rapids, riffles, runs, pools	Short	High

2.4.2 Sampling frequency

The project hypotheses and associated response variables are diverse, incorporating wide time scales for an effect to be detected. Some responses will be immediate (eg., scouring of algal biofilms), some responses will be detected in < 5 years (eg., lateral movement of fine sediment), and other responses detected in > 5 years (eg., changes in gross channel morphology) while others may respond variably. Table 3 describes the sampling frequency of the project's components.

2.5 Analysis

The overall objective of analysis in this project is to determine that environmental flows have had an effect on the Snowy River and its biota downstream of Jindabyne Dam. Uni-variate analysis, time series, intervention analysis and randomised intervention analysis and multivariate methods are used for hypothesis testing. Regression analysis, gradient and indirect analysis, correspondence analysis and canonical correspondence analysis are used for relating biological and environmental data.

The objective of the analysis for the first few years of pre-flow release data collection is to explore the data using graphical representation of data and/or multivariate methods. Specific analytical methods are described under each project component in this report.

Table 3. Sampling frequency.

Project component	Response variable	Sampling frequency	Sites
Hydrology	Gauge heights	Continuous	222501 Snowy River at Jindabyne 222541 Thredbo Paddys Cnr 222006 Snowy River at Dalgety 222026 Snowy River, Dalgety Weir 222007 Wullwye Creek at Woolway 222008 Delegate River at Quidong 222013 Snowy River at Burnt Hut Crossing (site 5) 222023 Snowy River at Willis (site 6) 222209 McKillops Bridge (site 7) 222219 Snowy River downstream of Basin Creek 222200 Snowy river at Jarrahmond 222210 Deddick River 222217 Rodger River 222206 Buchan River
Water quality	EC and temperature	Continuous and/or every two months	Dalgety Weir, 5, 6, 7
Geomorphology	Channel morphology sediments, habitat	Once before flows, once immediately after flows then every 2-3 years, and/or after a >1 in 5 year flood.	1-10, 11-13, 22, 24
Vegetation	Riparian (boundaries and reach census)	Once before flows, once immediately after flows then every five years.	1-4, 6, 7, 11-13, 22
	Transects (boundaries and quadrats[1]), emergent macrophytes and macroalgae (random quadrats)	Biannually (in autumn and spring)	1-4, 6, 7, 11-13, 22
Macroinvertebrates	Composition and abundance	Biannually (in autumn and spring	1-8, 11-13, 22, 23, 25, 26
Fish	Composition and abundance	Annually (summer)	1, 4, 5-7, 11, 14-21
Fish recruitment	Composition and abundance	Single event: spring-summer	Lochend, site 9

3. PROJECT COMPONENTS

This section provides a summary of major findings to date in an attempt to simplify the reporting to Environment Australia. Results are from scientific reports cited in each of the project studies.

3.1 Hydrology

3.1.1 Introduction

Typical changes to the hydrologic regime in rivers downstream of dams, following dam closure, include a decrease in flow volume, decrease in the magnitude, frequency and duration of flood discharges, a reduction and/or attenuation in seasonality of flows and change in the variability and predictability of flows (Poff *et al*., 1997; Rose 1999).

Environmental flows are designed to shift the hydrology of the Snowy River towards flows more typical of pre- Jindabyne dam hydrological conditions. For example at the Dalgety gauging station a 20,000 MLd^{-1} flood event occurred 80% of the time; flushing flows of 1,000 MLd^{-1} occurred over 99% of the time; baseflows of between 150-300 MLd^{-1} occurred 99 and 98% of the time respectively, and there was a spring snow melt (Rose, 1999). The pre-flow release objective therefore is to provide baseline information on the pre- and post-dam hydrological conditions relevant to the four essential hydrological components described in section 2.1. This will enable the magnitude and direction of change towards pre- dam hydrological conditions, and the proposed flow regime, to be assessed following environmental flow releases.

The hydrology design and analyses for the Snowy River Benchmarking Project differs from that conducted by Pendlebury *et al*., 1996; SWI, 1998 and Erskine *et al*., 1999 because they have been developed within a sampling design framework that includes objectives and hypotheses. The design includes:

- Whether there are changes in the regional rainfall regime. If so, it will influence the discharge of water in the Snowy River;
- The calculation of annual, seasonal and daily flow variability and flow height and velocity to determine if there is an association with the project components measured; and
- The standardisation of rainfall and discharge against reference conditions.

3.1.2 Design and methods

The hydrological design of the Snowy River Benchmarking Project is partitioned into macro reaches that are determined by major tributaries. There are four macro reaches:

1. Mowamba River to the Delegate River;
2. Delegate River to the Deddick River;
3. Deddick River to the Buchan River; and
4. Buchan River to the Tasman sea.

Table 4. Gauging station details on Snowy and reference rivers.

Gauge No.	Test sites	Macro-reach	Gauge No.	Reference sites
222006	Dalgety	1	222541	Thredbo, Paddys Corner
			222007	Wullwye, Woolway
222013	Burnt Hut Crossing	2	222008	Delegate River, Quidong
222209	McKillops Bridge	2	222210	Deddick River
222219	Basin Creek	3	222217	Rodger River
222200	Jarrahmond	4	222206	Buchan River

There is at least one gauging station within each macro reach providing continuous height and flow data. Data from gauging stations on reference rivers are used to standardise Snowy River flows. Standardisation accounts for change in the rainfall runoff relationship caused by altered catchment surface or detectable rainfall variations (Erskine, 1985). Table 4 shows the reference sites that are used to standardise flows at Snowy River tests sites.

3.1.3 Analysis

Flow volume, magnitude and frequency of floods, flow durations and flow variability were analysed. The Dalgety record was extended back to 1903 with an ordinary least squares regression between the flow records at Dalgety (1949-56) and Jindabyne (1903-56). Following is a summary of the analytical methods used.

Median daily discharge data for the gauging stations listed in (Table 4) were used to investigate pre- and post-dam discharge magnitudes in the Snowy River and to characterise flow volumes in the reference rivers. A Mann-Whitney U Test was performed on median daily flow by year, median daily flow by season, median daily flow by month and median daily Snowy River flow data to give a relative measure of impact between the pre- and post-dam periods. Population variances were compared with an *F* test.

Mean daily discharge data were used to compare the yearly, seasonal and monthly variability for the pre- and post- dam periods in the Snowy River. Annual discharge variability was calculated using discharge deviations from the pre- dam long term mean using a Wilcoxin Rank-Sum Test (Georges, 1997). Monthly discharge variability was determined by calculating the percentage change in the range of monthly discharge, and the difference in variance using an *F* test. It may however be a good descriptor for between site comparisons. Daily flow variability has not been analysed yet.

Flood frequency analysis for the pre- and post-dam periods was undertaken to determine if there was any significant change in magnitude and frequency of flood events, particularly >20,000 MLd^{-1}. A Mann-Whitney U Test was performed on the transformed ($\log_{10}$) annual maximum flood discharge data and a Log Pearson III (LP3) analytical distribution fitted by the method of moments (Pilgrim and Doran, 1987). Reference rivers are used to compare flood peaks over the same period using the standardised percentage change in flood discharges for various recurrence intervals (Erskine, 1985).

Median daily discharge data for the pre- and post- dam periods were used to determine if there was any significant change in flow durations, particularly baseflows of 150-300 MLd^{-1} and flushing flows of 1,000 MLd^{-1}. A Mann-Whitney U Test was performed on these data and flow duration curves (Vogel and Fennessey, 1995) constructed for each gauging station. Reference rivers are used to compare flow durations over the same period using the standardised percentage change in flow for various annual exceedance probabilities (Erskine, 1985).

3.1.4 Results

Preliminary results from the Dalgety gauge are presented because they are the most complete. The pre-dam period is from 1949 to 1966, and the post- dam period is from 1967 to 1996. Results are from calculations and previous investigations of Rose (1999).

Flow volume

There was a significant difference between the pre- and post- dam periods in median daily flows by year, median daily flows by season and median daily flows by month ($p < 0.01$: Mann-Whitney U Test). Pre- and post-Jindabyne Dam annual and monthly flow volumes are shown in Figure 4 and Figure 5 respectively. The magnitude of median monthly discharges and seasonal variability has been appreciably attenuated following flow regulation.

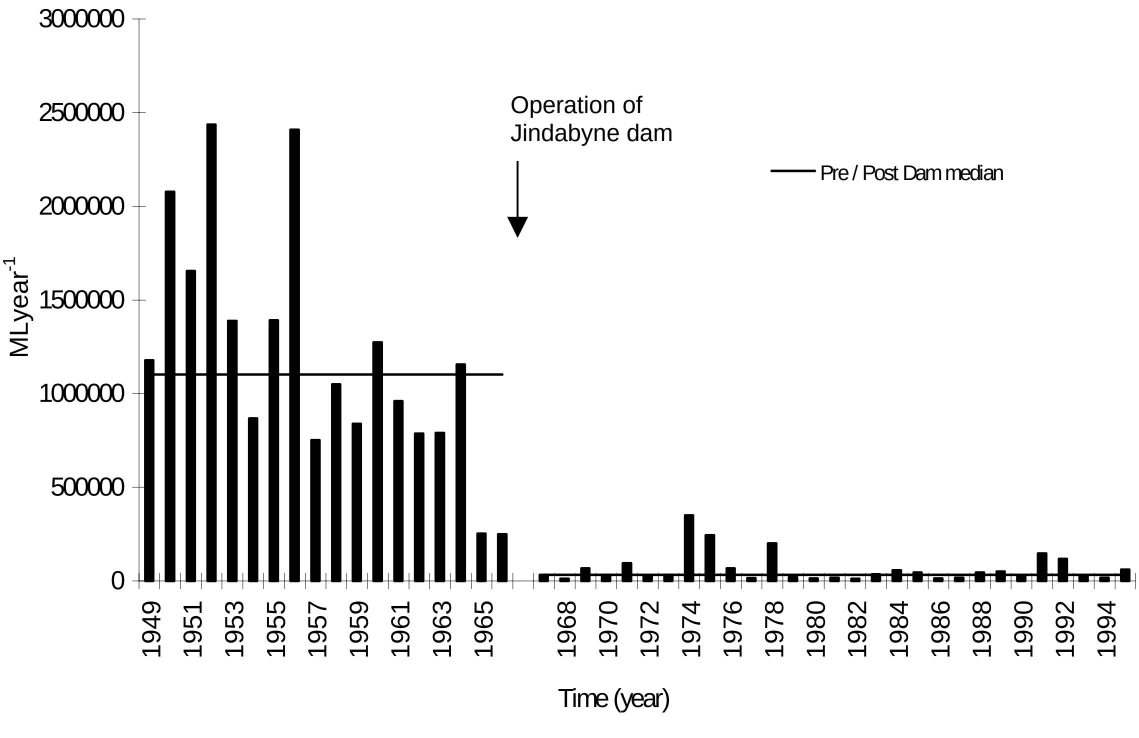


Figure 4. Pre-and post- Jindabyne Dam annual flow volumes at Dalgety (Rose, 1999).

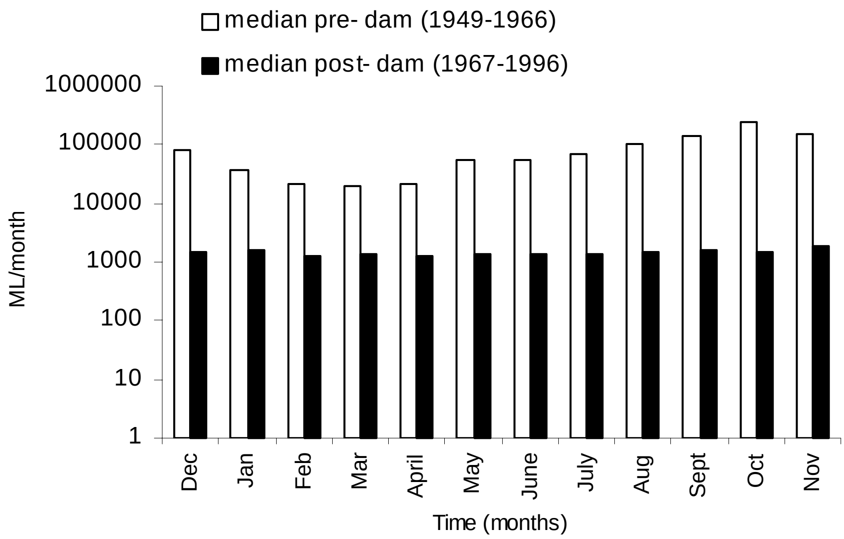


Figure 5. Pre-and post - Jindabyne Dam median monthly flow volumes at Dalgety (Rose, 1999).

Flow variability

Annual discharge deviations from the pre- dam long term mean show a significant reduction ($Z=5.70$, $p<0.0005$: Wilcoxin Rank-Sum Test; Figure 6) in inter-annual flow variability between the pre- and post- dam periods. The range in discharge has been reduced across all months particularly in March, April and September (Table 5.). The variance in monthly discharge between the pre- and post- dam periods has been significantly reduced for all months at Dalgety (Table 6).

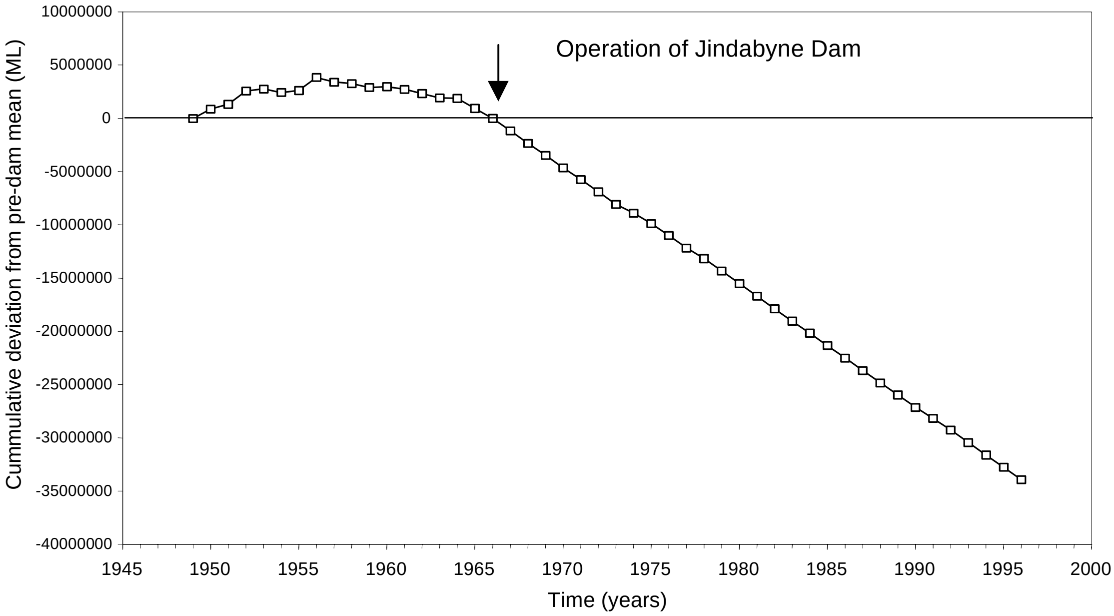


Figure 6. Annual discharge deviations from the pre- dam long term mean for the period 1949 to 1996, at Dalgety (Rose, 1999).

Table 5. Per cent reduction in the range of monthly discharge for the pre- and post- dam periods at Dalgety (Rose, 1999).

Month	Range in discharge (ML)		% Reduction
	Pre-dam period 1949 to 1966, N=17	Post-dam period 1967 to 1996, N=30	
December	6,228	2,006	68
January	1,927	453	76
February	4,381	2,228	49
March	9,944	769	92
April	13,782	646	95
May	7,864	2,132	73
June	19,523	2,680	86
July	6,871	2,469	64
August	6,671	1,874	72
September	9,415	855	91
October	10,974	3,666	67
November	8,884	2,474	72

Table 6. Difference in variance of monthly discharge for the pre- and post- dam periods at Dalgety (Rose, 1999).

Month	Variance		% reduction	F-statistic	Significance
	pre- dam period 1949 to 1966 N=17	post- dam period 1967 to 1996 N=30			
December	2,347,024	138,384	94	17	p<0.005
January	268,324	13,456	95	20	p<0.005
February	1,113,025	165,649	85	6.7	p<0.005
March	5,900,041	28,561	99.5	206.6	p<0.005
April	13,793,796	24,964	99.8	554.8	p<0.005
May	4,060,225	149,769	96	27.2	p<0.005
June	22,448,644	349,281	98	64.3	p<0.005
July	4,343,056	269,361	94	16.1	p<0.005
August	4,112,784	117,649	97	35	p<0.005
September	7,513,081	49,284	99.3	152	p<0.005
October	11,744,329	512,656	22.9	96	p<0.005

November	5,442,889	256,036	95	21.3	p<0.005

Flood frequency

Significant differences occurred in flood magnitude between the pre- and post- dam periods for all recurrence intervals ($p < 0.01$: Mann-Whitney U Test; Table 7). Before regulation floods of 20,000 MLd^{-1} magnitude occurred every 1.25 years on the annual maximum series (80% annual exceedance probability), whereas post- regulation the same discharge has an annual recurrence interval of 4.47 years (25.3% annual exceedance probability). A 95% reduction in discharge was calculated for floods of this magnitude after standardising against the Delegate River gauge, suggesting that the dam was responsible for the reduction in magnitude.

Table 7. Log Pearson 3 analyses of annual floods at Dalgety for the pre- and post- dam periods.

Recurrence interval (years)	Exceedance probability	Pre- dam period 1949 to 1966 (MLd^{-1})	Post-dam period 1967 to 1996 (MLd^{-1})
1.001	99.9	7,050	15
1.01	99	10,100	110
1.1	90	16,245	1,010
1.25	80	20,600	2,475
1.5	67	25,130	4,775
2	50	30,985	8,730
5	20	46,785	22,420
10	10	58,120	32,785
20	5	69,575	42,570

Flow duration

There has been a complete downward shift in the flow duration curve between the pre- and post-dam periods (Figure 7). Marked change occurred in baseflow conditions for flows of 100 MLd^{-1} to 300 MLd^{-1}, and flushing flows of 1,000 MLd^{-1} (Table 8). No tests of significance have yet been performed but the percentage change in flow durations for each of these flows was marked when standardised against the Delegate River gauge. Again, this suggests that natural effects were not the cause of such reductions.

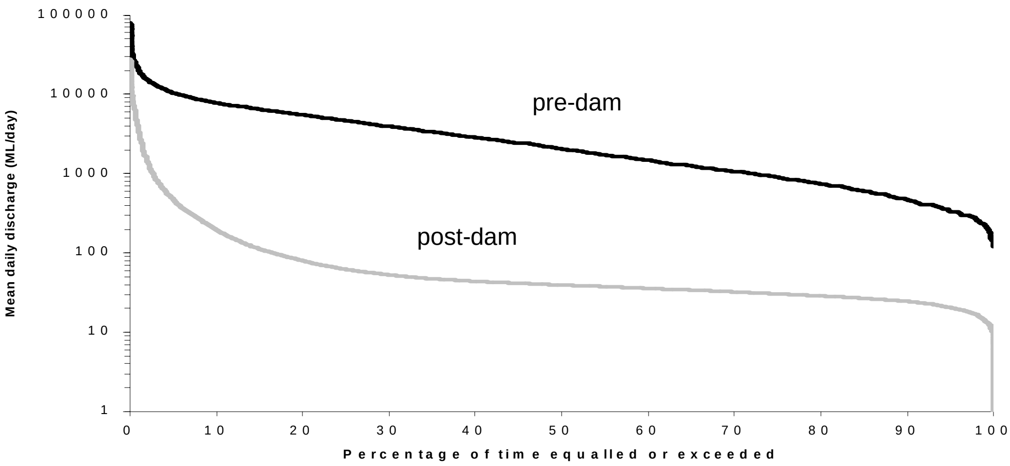


Figure 7. Jindabyne Dam daily flow duration curves at Dalgety for the pre- (1949 to 1966) and post- (1967 to 1996) dam periods.

Table 8. Percentage of time proposed base flows and flushing flows were equalled or exceeded for the pre- and post- Jindabyne Dam periods at Dalgety.

Flow (MLd^{-1})	% of time equalled or exceeded		Standardised % change using the Delegate River gauge
	pre- dam period 1949 to 1966	post- dam period 1967 to 1996	
100	100	17	71
200	99	10	71
300	97	8	85
1000	73	3	95

3.1.5 Discussion

The magnitude and frequency of floods, base flows (particularly summer), flow variability (seasonal and daily) and flushing flows (regular) have been altered. These components are critical in regulating physical and biological processes in rivers (Hynes, 1970: Poff and Ward, 1989; Walker *et al*., 1995; Richter *et al*., 1996; Poff *et al*., 1997; Puckeridge *et al*., 1998). While the components of the flow regime are treated separately, in reality, they interact in complex ways to regulate geomorphic and ecological processes (Poff *et. al*., 1997).

Before commissioning of the Snowy Mountains Scheme the Snowy River was characterised by 99% greater volume and a greater range in discharge than it has currently at Dalgety (Rose, 1999). The channel was wide and active and was shaped by a powerful spring snowmelt flow regime apparent at all gauging stations between Jindabyne and Jarrahmond (Erskine *et al*., 1999; Reinfelds and Erskine, 2000; Reinfelds, 2000). The occurrence of baseflows between 100-300 MLd^{-1} were equalled or exceeded almost 100% percent of the time, and flushing flows of 1,000

MLd^{-1} about 73% of the time. Since Jindabyne Dam there has been significant reductions in flow volume, flow durations, flow variability and a large loss of the seasonal spring snow melt (Figure 4, Figure 5, Figure 6, Figure 7 and Table 5, Table 6, Table 7, Table 8). Similar, but less pronounced outcomes, are likely to occur at gauging stations downstream of Dalgety. It is yet to be determined however, whether these reductions have been influenced by any change in catchment rainfall but the largest influence on flows is undoubtedly the Snowy Mountains Scheme.

Clearly, the pre- Jindabyne Dam flow regime cannot be achieved unless the dam is decommissioned. This is unlikely, so the pre- regulation flow regime is used as a condition for the Snowy River hydrology to move towards. The flow regime proposed by the Expert Panel (Pendlebury *et al*., 1996) is the target end point. Current methods are capable of measuring the magnitude, direction and significance of hydrological change, however ten years post-environmental flow data should be collected before drawing firm conclusions.

3.1.6 Key hydrological findings

- All aspects of the flow regime have been modified at the Dalgety gauging station since the commissioning of the Snowy Mountains Scheme. Significant reductions have occurred in flow volume, magnitude and frequency of floods for all recurrence intervals, flow durations for all annual exceedance probabilities, and a complete loss of seasonal flow variability particularly the spring snowmelt; and

- The current methods are capable of measuring hydrological change.

3.2 Geomorphology

3.2.1 Introduction

The interaction of water and sediment discharge determines river channel morphology. Flow regulation alters this interaction with consequent changes in river channel morphology and substratum (river bed sediments) downstream of dams (Rose, 1999). One of the most profound responses is aggradation, where the discharge released from the dam is below the threshold for mobilization of sediment (Kellerhals, 1982; Petts, 1984; Carling, 1988). Consequent outcomes may be bar and bench formation, destruction of aquatic fauna habitat, and vegetation invasion caused by immobile substrate. In order to rehabilitate channel morphology, hydraulic modelling of the interaction of water and sediment must be determined under a range of environmental flow release scenarios, in a range of geomorphic environments (eg., pools and riffles) down the river. This will determine the threshold of motion for sediment movement.

Three aspects of the geomorphology of the Snowy River will be reported. The first, is a baseline reach scale assessment of geomorphic condition at three sites after the post June 1998 flood reported by Erskine and Turner (2002). The second, is a geomorphic investigation into thresholds of sediment movement (Reinfelds, 2000). The third, is a study into channel maintenance flow requirements and the sizing of an outlet structure for Jindabyne Dam (Reinfelds and Erskine, 2000).

The objective of the reach scale assessment of geomorphic condition is the characterisation of channel morphology, river channel sediments and physical habitat diversity and quantity.

The objectives of the investigation into threshold of sediment movement were to:

1. Determine geomorphically significant flows under pre- regulation, post- regulation and environmental flow release conditions;

2. Hydraulically model these discharges at selected sites; and,

3. Investigate thresholds of sediment movement using results from hydraulic modelling.

The objectives of the investigation into channel maintenance flow requirements and the sizing of an outlet structure were to:

1. Briefly describe downstream hydrological and geomorphic impacts of Jindabyne Dam that have been detailed by Erskine *et al*., (1999);

2. Investigate threshold discharges needed to initiate transport of a range of sediment sizes and channel maintenance flow requirements; and,

3. Discuss the implications of the above with regard to the design of flow release outlet structures for Jindabyne Dam.

3.2.2 Design and methods

Reach scale assessment of geomorphic condition

The Snowy River is partitioned into nine geomorphically homogeneous reaches (Erskine 1996; Erskine and Turner, 1998; Webb and Erskine, 2000), 10 performance reaches (sites), then by habitat type. Snowy River test sites and corresponding reference and control river sites are shown in Table 9). Sampling of the channel morphology, sediments and habitats is conducted once before flows are released, once immediately flows are released then every two years and/or after the occurrence of a 1 in 5 year or larger flood event.

Table 9. Geomorphological sampling sites for the Snowy Benchmarking project.

Geomorphic reach	Test sites	Reference site	Control site
Jindabyne Gorge	Site 1 Snowy River d/s Mowamba	None	Site 22 Eucumbene River u/s Nimmo Bridge
	Site 2 Snowy River u/s Sugarloaf Creek	None	
Dalgety Uplands	Site 3 Snowy River at Rockwell	Site 13 Thredbo River at Paddys Corner; Site 11 Delegate River at Quidong; Site 12 Mowamba River on the Barry Way.	None
	Site 4 Snowy River d/s Blackburn Creek		
Burnt Hut Gorge	Site 5 Snowy River at Burnt Hut Crossing	None	Site 22 Eucumbene River u/s Nimmo Bridge
Willis Sand Zone	Site 6 Snowy River at Willis	Site 13 Thredbo River at Paddys Corner; Site 12 Mowamba River on the Barry Way	None
	Site 7 Snowy River at McKillops Bridge	None	None
Canoe Gorge	None	None	None
Lucas Point Reach	Site 8 Snowy River at Wests Track	Site 11 Delegate River at Quidong	None
	Site (8) Snowy River at Sandy Point (site now discontinued)	None	None
Long Point Reach	Site 9 Snowy River at Long Point	None	None
Orbost Alluvial	Site 10 Snowy River at Bete Bolong	Site 24 Cann River u/s of the Broome Track	None
Orbost Estuarine	None	None	None

Following is a summary of the methods for sampling channel morphology, sediments and physical habitat.

Channel width, maximum depth and width-depth ratio is determined for each major bench (benchfull) and the flooplain (bankfull) where present at each cross section. Cross sectional areas and 'benchfull/bankfull' discharge are determined across the channel, regardless of multiple channel separation by bedrock risers or benches. Bed slope is calculated from survey data. The reach survey consists of 8-10 cross sections permanently located in areas where maximum geomorphic change is expected, and a longitudinal section of the thalweg. A total station theodolite and hand held GPS were used to conduct the survey. From these data scaled cross sections, long sections and survey plans were produced.

Bulk samples were collected from riverbed, and bank and from specific depositional or geomorphic environments (bar, bench tec.) and analysed by bulk sieve analysis as described by Kellerhals and Bray (1971). Bulk samples are collected by trowel from at least eight points on the cross section and combined as the bed sample. A scoop sample is used out of a boat to sample sub-aqueous bulk samples. Bank sediments are collected at 0.25, 0.5 and 0.75 the height of each bank up to the floodplain/main valley flat level following the method of Pickup (1976), and pooled. Surface sediments were collected using the grid-by-numbers surface (gravel count method) sampling technique of Wolman (1954) across the surveyed cross sections, and the b axis diameter of at least 100 gravel clasts measured.

Fine grained sediment laminae (Droppo and Stone, 1994) are bulk sampled for grain size analysis. Samples of 100 g were collected from the riverbed, cobble and boulder clasts or pieces of woody debris.

All bulk sediment samples are air dried before being analysed. The gravel fraction of samples are manually sieved through a set of brass sieves. The sand fraction is coned and quartered until approximately 50 g sub-sample is obtained. This sub-sample is then dry sieved through a nest of stainless steel sieves at $\phi/2$ intervals using a 15 minutes shake time. Gravel counts are obtained by measurements in the field and are not subject to sieving unless 5% or more of the sample is finer than 8 mm. The fine earth fraction (< 2 mm) of samples containing significant amounts of mud are processed using methods described in Erskine and Turner (2002).

Grain size data are plotted as cumulative percent coarser distributions (Folk, 1974). Graphic grain size statistics (i.e., median size, graphic mean size, inclusive graphic standard deviation, inclusive graphic skewness, inclusive graphic kurtosis and normalised kurtosis) are calculated using the relevant percentiles from the grain size distributions and the equations of Folk and Ward (1957) and Folk (1974).

Investigation into thresholds of sediment movement and channel maintenance flow requirements

Pre- and post- Jindabyne Dam discharges for the three monitoring sites are provided from the Jindabyne (222501), McKillops Bridge (222209) and Jarrahmond (222200) gauging stations. Data from the Burnt Hut gauge is also used for post-regulation calculations (see Reinfelds, 2000).

Hydraulic modelling was undertaken using pre- determined geomorphically significant flows under pre- and post- Jindabyne Dam, and the proposed environmental flow releases. The models hydraulic capabilities include calculation of steady flow water surface profiles and output of associated parameters (HEC-RAS 2.2 hydraulics manual, 1998). Input data needed for the modelling includes cross sections, identified channel and overbank zones, specified discharges, a schematic diagram of channel planform and estimates of channel floodplain roughness.

The Neill (1968) dimensionless shear stress (SS) criterion is used to investigate thresholds of critical shear stress required to initiate sediment movement. Dimensionless SS of 0.03 is used to estimate entrainable d_{50} particle sizes in pools, and 0.06 for riffles.

3.2.3 Analysis

Reach scale assessment of geomorphic condition

Change in each benchfull/bankfull geometric and hydraulic parameters, and change in each grain size statistic, was compared using the *F* test to assess changes in the variance and a *t*-test to assess the mean.

Investigation into thresholds of sediment movement and channel maintenance flow requirements

The geomorphically significant flows selected for HEC-RAS 2.2 modelling were:

- Daily mean and daily median snowmelt discharges for pre- and post- regulation and 15% environmental flow regime flow (EFR) conditions at Mowamba, Rockwell and McKillops Bridge;
- The Mowamba and Rockwell monitoring sites upstream of the Delegate River, EFR flushing flows of 1,000 MLd^{-1} and 3,000 MLd^{-1}, and an annual maximum EFR event of 12,000 MLd^{-1}; and,
- The 50% and 90% annual exceedance probability floods as determined by Log Pearson 3 analysis of annual maximum daily discharges for the pre- and post- dam flow conditions at McKillops Bridge.

3.2.4 Results

Reach scale assessment of geomorphic condition

Investigations into the cumulative effects of three floods were carried out at three test sites (McKillops Bridge, Sandy Point and Bete Bolong) between 1997-1998. Flood peaks measured at the Jarrahmond gauging station were 44,000 MLd^{-1} in June 1997, 228,000 MLd^{-1} in June 1998 and 27,600 MLd^{-1} in August 1998. The largest was the June 1998 flood. The results summarised below are from Erskine and Turner (2002).

Site 7 McKillops Bridge

There was no change in the variance and mean of benchfull and bankfull channel morphologic and hydraulic parameters (width, area, mean depth, maximum depth, width-maximum depth ration, mean flow velocity, discharge and specific stream power).

Few significant changes in channel boundary sediment occurred. There was no significant difference in either average median (d_{50}) or average graphic mean (M_z) ($0.34 < \rho < 0.8$). The bed material mean inclusive graphic standard deviation increased significantly (sorting decreased) because of an influx of sand (σ_1 changed from 1.15 to 1.82 ϕ; $\rho = 0.02$). The bank sediment variance of the inclusive graphic standard deviation increased ($\rho = 0.021$), while the mean inclusive graphic skewness changed from fine ($Sk_1 = 0.20$) to coarse skewed ($Sk_1 = -0.103$; $\rho = 0.0029$).

Site (8) Sandy Point (site now discontinued)

There was no significant change in the variance and mean of benchfull parameters. There was no change in the variance of bankfull parameters but significant change in mean bankfull depth, velocity, discharge and specific stream power and a decrease in mean width-to maximum depth ratio.

There were no significant changes in the variance and mean of the grain size statistics for both bed material and bank sediment, except for an increase in the variance of median and graphic mean size of the bank sediment ($\rho > 0.0049$). This change represents a significant reworking of the bed material.

Site 10 Bete Bolong

Benchfull mean depth, area, velocity, discharge and specific stream power increased significantly because of bed degradation from the flood. Mean bankfull width and area also increased significantly and the weighted mean percent clay in the channel boundary decreased significantly.

There were many significant changes in the grain size statistics of both bed material and bank sediment. There was a highly significant increase (0.0047 to 0.099) in the bed material variance of graphic kurtosis ($\rho = 0.00066$). Average median bed material size increased significantly from 0.74 to 0.58 ϕ ($\rho = 0.014$) and, as expected, average graphic mean bed material size exhibited the same trend (M_z decreased from 0.73 to 0.59 ϕ; $\rho = 0.045$). Nevertheless, median and graphic mean bed material size is still coarse sand. The sorting of the bed material improved significantly with the mean inclusive graphic standard deviation decreasing from 0.55 to 0.48 ϕ ($\rho = 0.024$). The mean graphic skewness significantly increased, the change was only from -0.04 to 0.05 ($\rho = 0.036$). There was a decrease in the bank sediment variance of the median size, graphic mean, inclusive graphic standard deviation and graphic kurtosis ($0.029 > \rho > 0.0002$). The average median size increased (2.32 to 1.63 ϕ; $\rho = 0.028$), graphic mean decreased (M_z 2.78 to 1.68 ϕ; $\rho = 0.008$) and mean inclusive graphic standard deviation decreased significantly form 1.87 to 0.91 ϕ ($\rho = 0.00232$). Clearly, there was a major reworking of the bed material and the deposition of sand on the banks by the flood.

Investigation into thresholds of sediment movement

Table 10 and Table 11 summarise the results of modelled outputs for three test sites, downstream of Mowamba, Rockwell and McKillops Bridge. Table 10 shows the changes in geomorphology under various flow scenarios. Table 11 shows the average shear stress in pools and riffles and the maximum particle sizes that can be entrained under various flow scenarios.

Investigation into channel maintenance flow requirements

Hydraulic modelling by Reinfelds (2000) suggested that discharges between the EFR flushing flow of 12,000 MLd^{-1} and the pre- regulation 1 in 2 year event of 29,000 MLd^{-1} are needed to induce entrainment of cobble size material (> 54 mm b-axis). These discharges are also required to generate velocity reversals in pools at the downstream Mowamba site in Jindabyne Gorge (Figure 8 and Table 10). Before commissioning of the Snowy Mountains Scheme flows, the pre-Jindabyne Dam 1 in 2 year event (on the annual series) was important in some gorge reaches of the Snowy River because velocity and competence reversals were generated in some pools (Reinfleds, 2000). The majority of such events were generated by snowmelt flows in the upper catchment now captured by the Snowy Mountains Scheme. The importance of the upper catchment on snowmelt flows is demonstrated by a comparison of instantaneous annual maximum pre- Jindabyne Dam flow records for Dalgety and Jindabyne. A 75-86% of the instantaneous maximum discharge of the 1 in 2 year event (50% annual exceedance probability flood) at Dalgety within a catchment area of 3,160 km^2 was generated from the catchment upstream of Jindabyne with a catchment area of 1,160 km^2. Similarly the catchment above Jindabyne accounts for 77% and 86% of mean and median daily snowmelt flows at Dalgety and 68% and 63% respectively, of these flows at Jarrahmond (13,421 km^2). Clearly the catchment upstream of Jindabyne was central to both the magnitude and frequency of high flows along the length of the Snowy River before Jindabyne Dam.

Table 10. Summary results of HEC-RAS 2.2 model outputs for three test sites. Compiled from Reinfelds (2000).

Geomorphically significant flow	Downstream Mowamba	Rockwell	McKillops Bridge
Median and mean daily snowmelt flows under pre-regulation conditions	Inundate low to medium height benches, bars and platforms and associated chute channels.	Inundate low to medium height benches, bars and platforms and associated chute channels.	Too low to inundate bench levels identified in DLWC (1998).
50% annual exceedance probability flood under pre-regulation conditions	Inundate low to medium height benches, bar and platforms and associated chute channels by up to 4 m.	Inundate low to medium height benches, bar and platforms and associated chute channels by up to 4 m.	Inundate upper level benches. Bankfull levels not inundated.
90% annual exceedance probability flood under pre-regulation conditions	Filled high level chute channel on the right bank .	Inundated low to medium height benches, bar and platforms and associated chute channels by 1-2 m.	Inner channel identified by DLWC (1998) was filled. Bankfull levels not inundated.
Current post-regulation mean and median daily snowmelt discharge	Only spread onto a single low level bar surface on the right bank	Only spread onto a single low level bar surface on the right bank	missing data
Median daily snowmelt flows under (EFR)	Fills active channel and provides minor inundation of the lowest sedimentological surfaces.	Do not fill the active channel and inundate only the lowest level sedimentological surface	missing data
Mean daily snowmelt flows under EFR	Fills active channel but provides more extensive inundation of low level surfaces.	Fills the active channel and inundates low level surfaces but are insufficient to inundate chute channels	missing data
EFR flushing flows of 1,000 MLd^{-1}	Fill the active channel with little inundation of low lying surfaces.	missing data	missing data

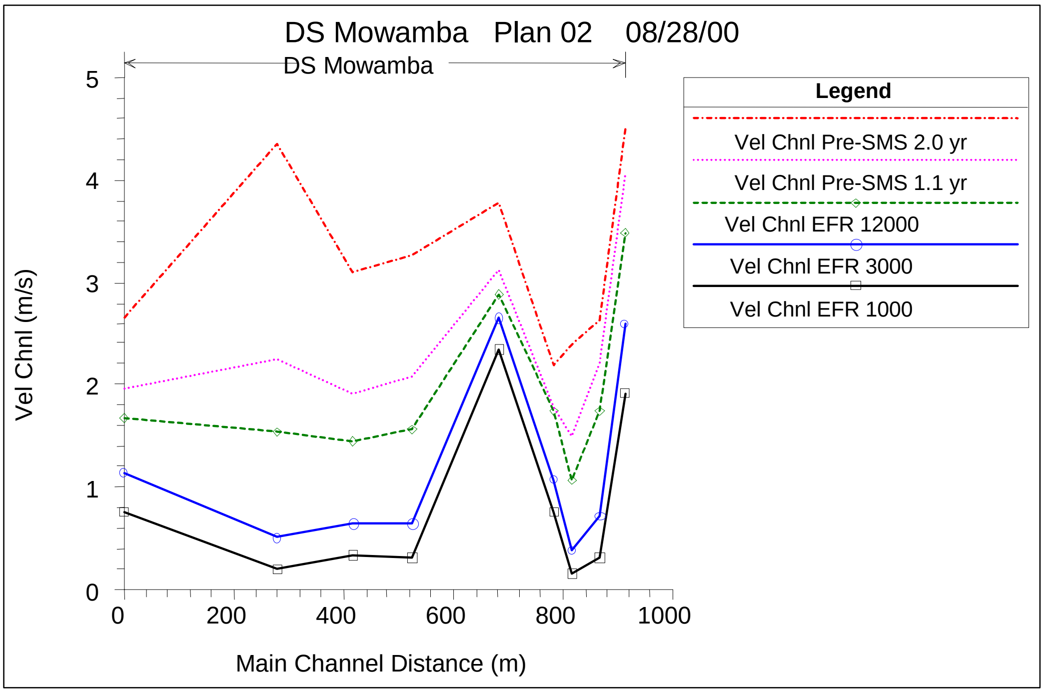
Table 10 (cont.). Summary results of HEC-RAS 2.2 model outputs for three test sites. Compiled from Reinfelds (2000) data.

Geomorphically significant flow	Downstream Mowamba	Rockwell	McKillops Bridge
EFR flushing flows of 3,000 MLd^{-1}	Overtop low level surfaces and generally rise to just below or lap onto mid-level surfaces.	Insufficient to inundate chute channels	missing data
EFR flushing flows of 12,000 MLd^{-1}	Inundate all mid-level features at all cross sections.	Inundate chute channels	missing data
Water surface profiles for flows below 12,000 MLd^{-1}	Steepest water surface profile occurs at cross section 4 producing the highest channel shear stress and mean velocity in the reach.	Steepest water surface profile at cross section 4 producing the highest channel shear stress and mean velocity in the reach.	Steepest water surfaces profile occurs at cross section 2 producing the highest channel shear stress and mean velocity at low flows in the reach.
Water surface profiles for flows above 12,000 MLd^{-1}	Velocity reversal effect occurs at cross section 8, where higher higher channel velocities and shear stress occur in pools instead of riffles.	Local steep gradients at riffles are drowned out and shear stress and velocity profiles through the reach become less variable.	Strong velocity reversal effect occurs at cross sections 6 and 8 similar to downstream Mowamba site.

Table 11. Summary of average shear stress (SS) in pools and riffles and maximum entrainable particle sizes for environmental flushing flows, mean snowmelt discharge and pre- regulation 90% and 50% annual exceedance probability floods (Reinfelds, 2000).

Habitat	Site	Discharge in MLd^{-1}					
		1,000	1,595	3,000	12,000	16,388	28,646
		SS, d_{50}	SS, d_{50}	SS, d_{50}	SS, d_{50}	SS, d_{50}	SS, d_{50}
Pools	Downstream Mowamba (N=4)	0.9 Nm^2	1.7 Nm^2	3.7 Nm^2	20.6 Nm^2	36.9 Nm^2	97.0 Nm^2
		1.9 mm	3.5 mm	7.6 mm	42.5 mm	76.1 mm	199.9 mm
	Rockwell (N=3)	0.6 Nm^2	1.0 Nm^2	2.2 Nm^2	9.1 Nm^2	12.2 Nm^2	19.1 Nm^2
		1.2 mm	2.1 mm	4.5 mm	18.8 mm	25.2 mm	39.4 mm
Riffles	Downstream Mowamba (N=1)	106.0 Nm^2	96.8 Nm^2	106.2 Nm^2	97.8 Nm^2	103.3 Nm^2	127.4 Nm^2
		109.3 mm	99.8 mm	109.5 mm	100.8 mm	106.5 mm	131.3 mm
	Rockwell (N=1)	67.5 Nm^2	95.2 Nm^2	80.9 Nm^2	32.8 Nm^2	30.2 Nm^2	33.5 Nm^2
		69.6 mm	98.1 mm	83.4 mm	33.8 mm	31.1 mm	34.5 mm

Downstream Mowamba mean channel velocity under EFR and pre-regulation 90% and 50% annual exceedence floods



Downstream Mowamba channel shear stress under EFR and pre-regulation 90% and 50% annual exceedence floods

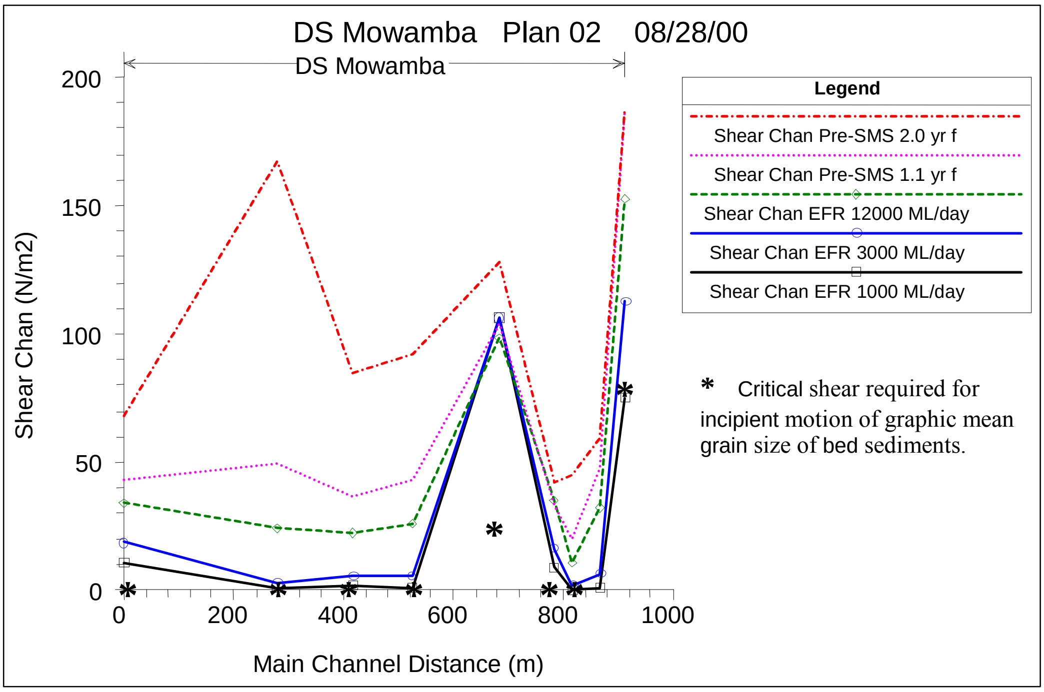


Figure 8. Velocity (a) and shear stress (b) results downstream Mowamba site under flows of 1,000 MLd^{-1}, 1,595 MLd^{-1}, 3,000 MLd^{-1}, 16,500 MLd^{-1} and 29,000 MLd^{-1}. Upstream and downstream is from right to left. Note that development of a pronounced velocity and competence reversal at a pool cross section occurs under flows of 29,000 MLd^{-1} (pre-SMS 2.0 year flood) (Reinfelds and Erskine, 2000).

3.2.5 Discussion

The effect of three floods on river channel morphology and sediment distribution was measured in the lower Snowy River in Victoria in the 14 months between June 1997 and August 1998 (Erskine and Turner, 2002). At the Jarrahmond gauging station the June 1998 flood event had a return period of about 1 in 10 years on the annual maximum series. The combined effect however, of the three floods, was greatest at Sandy Point and Bete Bolong downstream of the Rodger River junction. Few significant changes in channel boundary grain size statistics were found at McKillops Bridge despite the mobilisation of the bed material (Erskine and Turner, 2002). The Sandy Point site showed a change in the variance of median and graphic mean size of the bed material. This change represents a significant re-working of the bed material. The Bete Bolong site showed significant changes in grain size statistics indicating reworking of the bed material and the deposition of sand on the banks by the June 1998 flood. The channel morphology did not change at McKillops Bridge however at Sandy Point and Bete Bolong there were significant post-flood changes (Erskine and Turner, 2002). Post flood sampling is important for validating hydraulic models. Such models endeavour to estimate how the river channel responds under a range of flow conditions and can therefore be used to advise river managers on the potential effect of flow releases on channel morphology and sediment distribution.

Hydraulic modelling conducted at the downstream Mowamba River and Rockwell sites (Reinfelds, 2000) indicate that flows of 1,000 MLd^{-1} are theoretically capable of mobilising unconsolidated very coarse sand in the pools, and cobbles in the riffles (Table 11). These flows are also sufficient to initiate flushing of unconsolidated fine-grained sediment laminae deposits in pools at these sites. A notable result from the hydraulic modelling is the development of a velocity reversal effect at the downstream Mowamba and McKillops Bridge sites under pre-Jindabyne Dam discharges of about 1 in 2 years on the annual maximum series (Figure 8, Table 10). This is important because velocity reversals develop structural pools in bedrock riverbeds over geologic time, and prevent the deposition of bed load sediment in pools. Reconstructed snowmelt discharges under a 15% Environmental Flow Regime (EFR) will be more variable than the steady high discharges experience before Jindabyne Dam, but it was suggested that a 28% EFR might somewhat redress this issue (Reinfelds, 2000). Upstream sites exhibit sedimentological features that are inundated and formed by pre- Jindabyne Dam flows (Reinfelds, 2000). Downstream sedimentological features exhibit a better relationship to higher discharges. This hydraulic modelling shows how river channel morphology can change and how sediments can be mobilised under a range of flows, particularly those flows recommended by the Expert Panel (Table 10, Table 11, Figure 8, Pendlebury *et al*., 1996; Reinfelds, 2000).

The capacity of any environmental flow outlet structure in Jindabyne Dam is crucial in meeting the Expert Panel (Pendlebury *et al*., 1996) requirements and recommendations and other studies (Reinfelds, 2000; Reinfelds and Erskine, 2000). A maximum of 30,000 MLd^{-1} will provide both an adequate margin of safety to manipulate hydrograph shape and duration, and will satisfy the annual minimum peak flow recommendations of 20,000 MLd^{-1} developed by the Expert Panel (Pendlebury *et al*., 1996; Reinfelds and Erskine, 2000).

3.2.6 Key geomorphological findings

- Current methods are capable of measuring flood induced channel changes;

- Floods with a peak discharge size at least four times greater than the mean annual flood are important in mobilising sediment and hence channel morphology at some sites;
- Repeat sampling is required after floods with a peak discharge having a return period of about 10 years on the annual maximum series;
- Expert Panel recommended flows are required to entrain sediment, scour pools, address velocity reversals; and,
- The desirable maximum size outlet capacity structure for Jindabyne Dam is 30,000 MLd^{-1}.

3.3 Water quality

3.3.1 Introduction

The focus of this section is on the:

1. Water temperature and electrical conductivity data; and,

2. Pool stratification pilot study.

Impoundments such as Jindabyne Dam can have major effects on the water quality of a river, particularly water temperature. Changes in water temperature downstream may be loss of diurnal and seasonal variability, and decreased or increased summer (Ward and Stanford, 1979). Constant low flows in rivers due to regulation, such as the Snowy River, can eliminate mixing whereby deeper pools downstream of the dam become thermally stratified (Allan, 1995). Absence of mixing due to constant low flows can also cause oxygen stratification. This can cause anoxic conditions to develop, which is detrimental to aquatic biota.

The pre-flow release objective of the water quality studies of the Snowy River Benchmarking Project is to establish baseline information on water temperature and electrical conductivity (EC) in the Snowy River below Jindabyne Dam. Monitoring of other water quality variables as shown in (Table 12) is conducted by other agencies for other projects and will be reported on a later date. The ongoing water quality program is based on a small number of sites and a limited number of variables, because of data quality issues with some variables and the difficulty of installing and/or maintaining equipment at most of the sites. The effect of Jindabyne Dam on water temperature and electrical conductivity in the Snowy River in general cannot be determined because there are no data available before the commissioning of the Snowy Mountains Scheme.

A pilot study into pool stratification was conducted in the summer 2000 (Bevitt, 2003). The objectives of this pre-flow release pilot study were to:

1. Determine the location and extent of thermal and oxygen stratification in pools in the Snowy River downstream of Jindabyne Dam; and,

2. Test whether stratification is more developed in the Snowy River test sites than the reference sites.

3.3.2 Design and methods

The design of the water quality monitoring program is shown in (Table 12). All water quality measurements are taken with multiprobes, either in situ at sites that are continuously monitored, or hand held multiprobes used in gauge pool edges for spot sampling at all other sites.

Sites and sampling frequencies for the pool stratification pilot study are shown in (Table 12). Sampling was undertaken more frequently at Snowy River test sites closest to Jindabyne Dam than at test sites further downstream as the former were expected to show a greater impact of reduced flows and bottom releases from Jindabyne Dam. The pilot study was undertaken using a “Datasonde DS-4” multiprobe from a kayak. On each sampling occasion, four depth profiles at

0.25m intervals were taken in each of two pools at each site, measuring water temperature, dissolved oxygen, redox (ORP) and electrical conductivity (Bevitt, 2003.).

3.3.3 Analysis

The temperature and EC data have not been analysed to date. The analysis technique used will depend on exploratory analysis of the data. The design for this component will allow the use of Randomised Intervention Analysis, periodic regression or time series. Intervention analyses will enable conclusions to be drawn about the effect of environmental flows on water quality in the Snowy River. Qualitative conclusions will be made on the relationships between changes to biota and water quality following environmental flows.

The pool stratification data were examined in Excel and graphed to show changes in temperature or oxygen with increasing depth.

Table 12. Sites and water quality variables monitored to June 2001 for the Snowy River Benchmarking Project.

Site and sample location	Variables	Term	Sampling Frequency or number of observations	Agency/ Consultant
For Sites 3&4: Snowy River at Dalgety Weir (222026)	Temperature, EC pH	4 years 4 years	Continuous 6 per year	DLWC
For Sites 3&4: Snowy River at Dalgety (222006)	Temperature EC pH	28 years 27 years 21 Years	6 per year	DLWC
Site 5: Snowy River at Burnt Hut Crossing (222013)	Temperature, EC	25 years	6 per year	DLWC
Site 6: Snowy River at Willis (222023)	Temperature, EC pH	2 years 2 years	Continuous 6 per year	DLWC
Site 7: Snowy River at McKillops Bridge	Temperature, DO, EC, pH, turbidity React. Phos., Suspended solids, Nitrates & Nitrites Total Kjeldahl Nitrogen, Total Phos.,	26 years 11 years 11 years 11 years	281-301 (monthly) 126 (monthly) 126 (monthly) 126 (monthly)	DNRE, VIC EPA
For Site 13: Thredbo River at Gaden Trout Hatchery (3 locations: upstream of discharge, @ discharge, and 100m downstream)	BOD, NFR, NH3, Nox, TP, TN Temperature	Several years	Monthly Daily	NSW Fisheries
Sites 1 - 7: Snowy River test sites; Site 12: Mowamba R @ Barry Way; Site 13: Thredbo R @ Gaden Trout Hatchery; Site 11: Delegate R @ Quidong; Site 14: Deddick R u/s McKillops Br.	DO, Temp., TP, TN, Turbidity, TSS, EC, BOD. (Depth profiles taken over a 5 week period for pool stratification study)	Jan-Feb 2000	160-480 data points per site. 2-6 sampling events per site.	DLWC

3.3.4 Results

Water temperature at Dalgety and Willis showed marked seasonal variation (Figure 9 and Figure 10), with summer temperature ranges of 16-27 °C and 16-30 °C, and winter temperature ranges of

3-8^{o}C and 4-12 ^{o}C respectively over the reporting period of July 1999 to June 2001. Mean monthly temperatures for both sites for the reporting period are shown in Table 13.

Continuous data for EC for both sites usually corresponded with discharge, so most of the time EC increased with flow events (Figure 9 and Figure 10). EC ranged from 40-240 µs/cm at Dalgety and 45-210 µs/cm at Willis.

Table 13. Mean monthly water temperature (^{o}C) at Dalgety and Willis from July 1999 to June 2001. - signifies no data available due to instrument failure.

Site	Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Dalgety	99/00	5	8	13	16	18	21	20	23	20	14	10	5
Dalgety	00/01	5	7	11	16	19	22	23	23	19	14	10	6
Willis	99/00	7	9	13	16	18	21	18	23	26	20	15	-
Willis	00/01	-	-	-	14	17	19	21	22	-	-	-	-

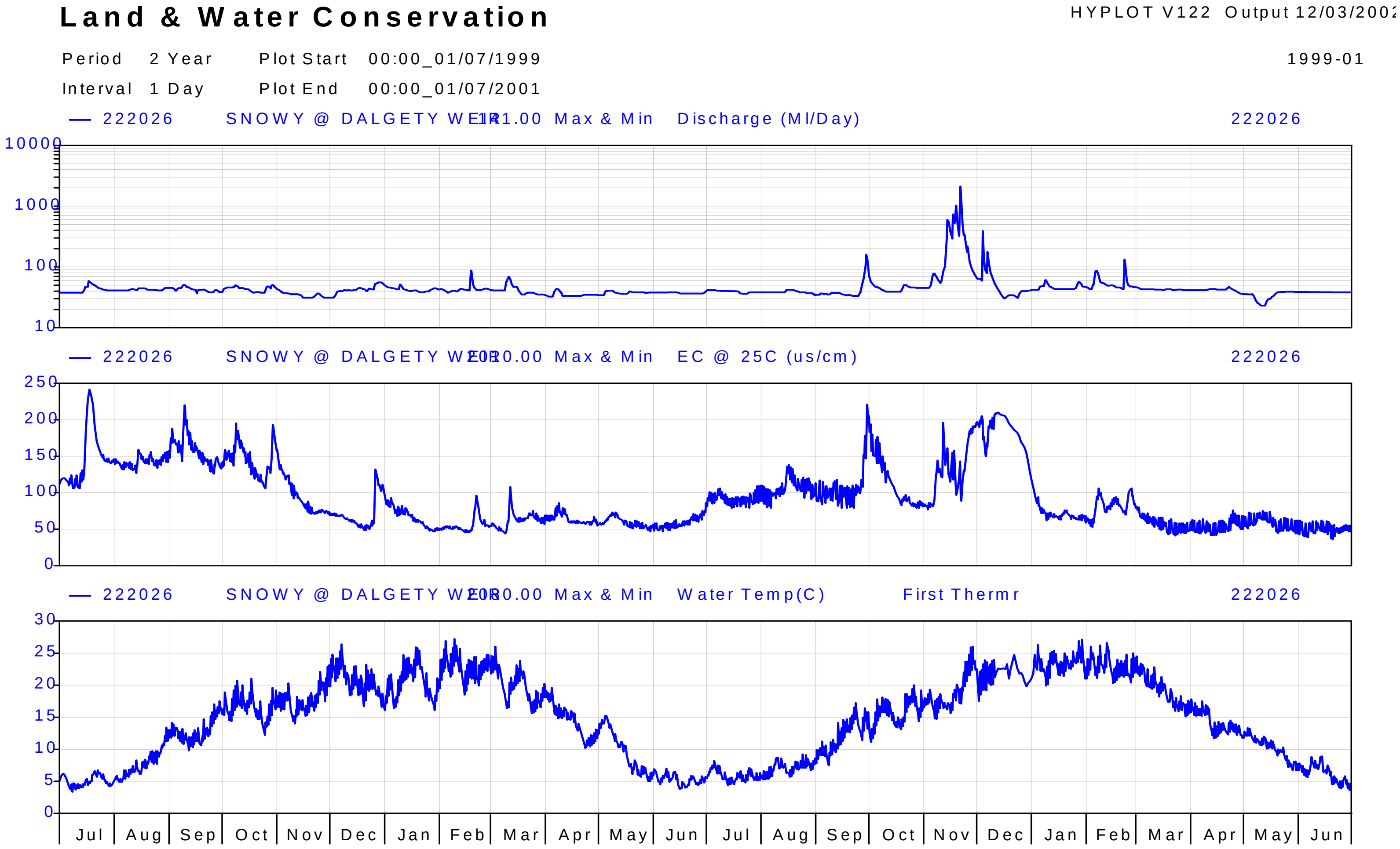

Land & Water Conservation
HYPLOT V122 Output 12/03/2002
Period 2 Year Plot Start 00:00_01/07/1999
1999-01
Interval 1 Day Plot End 00:00_01/07/2001
222026 SNOWY @ DALGETY WEIR 141.00 Max & Min Discharge (Ml/Day)
222026
10000
1000
100
10
222026 SNOWY @ DALGETY WEIR 2080.00 Max & Min EC @ 25C (us/cm)
222026
250
200
150
100
50
0
222026 SNOWY @ DALGETY WEIR 2080.00 Max & Min Water Temp(C) First Thermr
222026
30
25
20
15
10
5
0
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

Figure 9. Continuous discharge (MLd^{-1}), electrical conductivity (µs/cm) and temperature (°C) data for the Snowy River at Dalgety weir from July 1999 to June 2001.

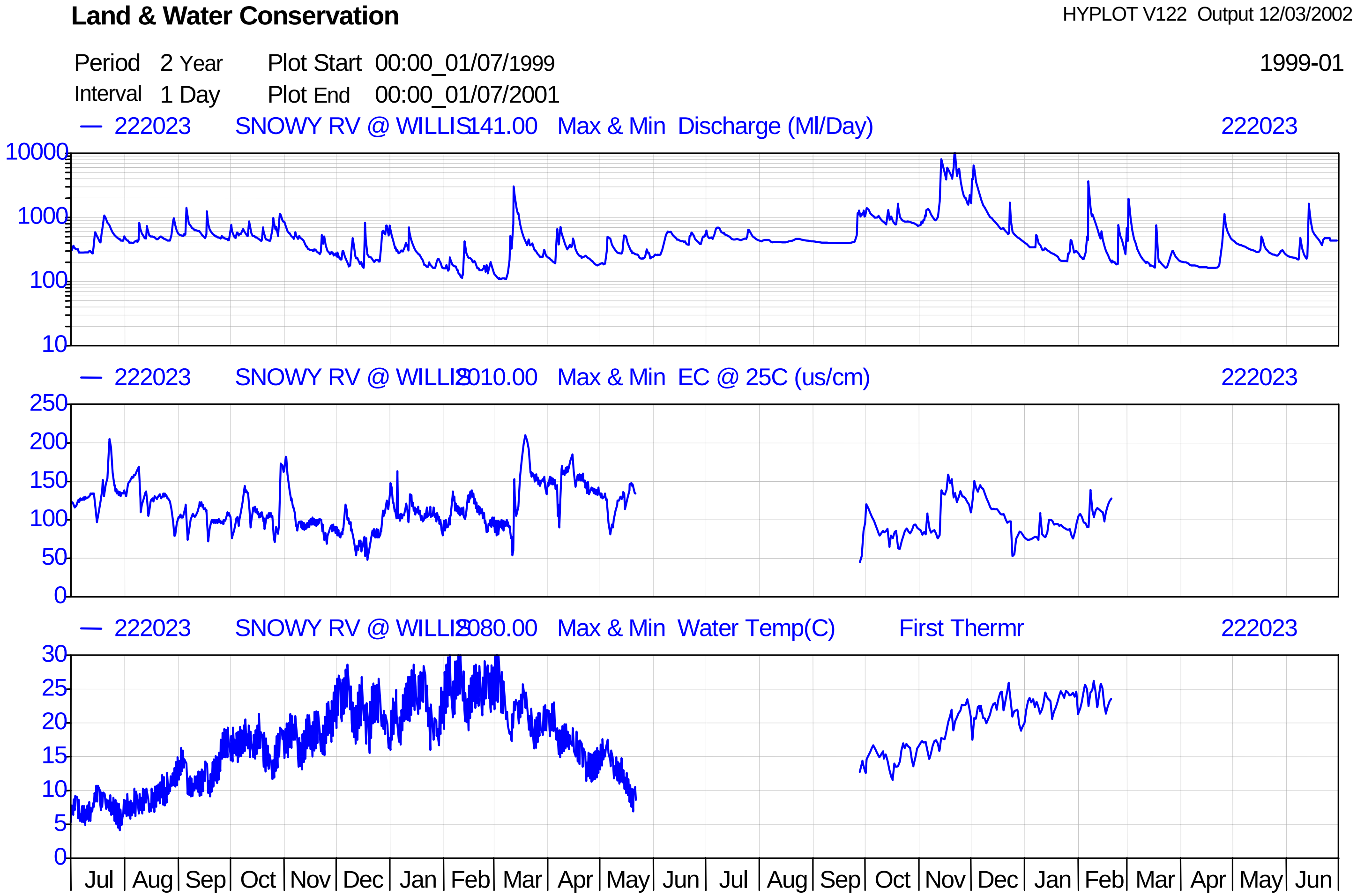


Figure 10. Continuous discharge (MLd^{-1}), electrical conductivity (µs/cm) and temperature (°C) data for the Snowy River at Willis from July 1999 to June 2001.

The pool stratification study found that temperature and dissolved oxygen stratification were most prevalent at site 1 (Snowy River downstream or Mowamba River) and the Delegate River reference site (site 11), with limited stratification occuring at Snowy River Sites 2, 3 and 5. Temperature and dissolved oxygen stratification occurred at site 1 in at least one of eight profiles on most sampling occasions (eg., Figure 11), under constant low flow conditions but irrespective of varying climatic conditions. The thermocline was 1-2°C at depths of between 2 and 3 metres and usually occurred in a small number of profiles in one of the two pools sampled. Dissolved oxygen was usually below the 90% saturation level recommended as the minimum for ecological health (ANZECC, 2000), with an oxycline of between 5 and 25% saturation occurring in the deeper profiles at 3 to 4 metres (Bevitt, 2003).

No stratification was found at the Thredbo or Deddick River reference sites (sites 13 and 14). Thermal stratification occurred at both pools in the Delegate River reference site (site 11) on all sampling occasions (eg., Figure 12a), and there were strong oxygen gradients on most occasions (eg., Figure 12b) (Bevitt, 2003.).

(a) **(b)**

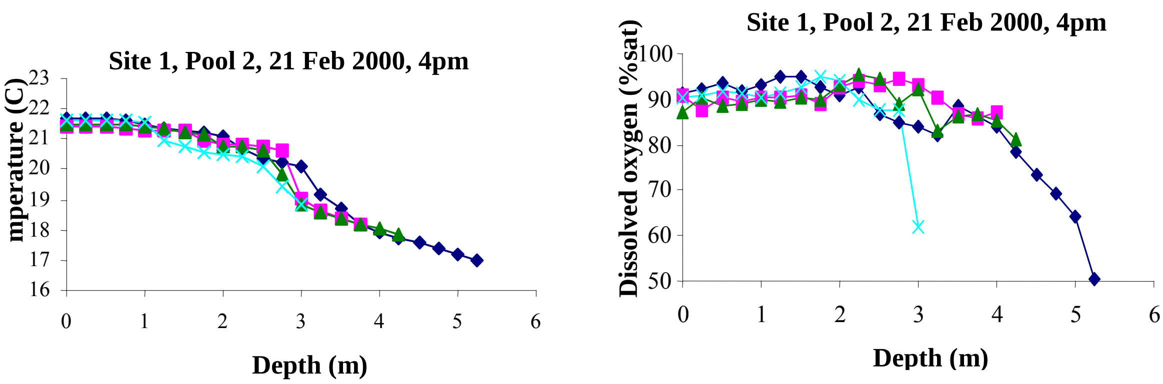


Figure 11. Temperature (a) and dissolved oxygen (b) gradients in four depth profiles at site 2 (Snowy River downstream of Sugarloaf Creek) on 1 February 2000.

(a) **(b)**

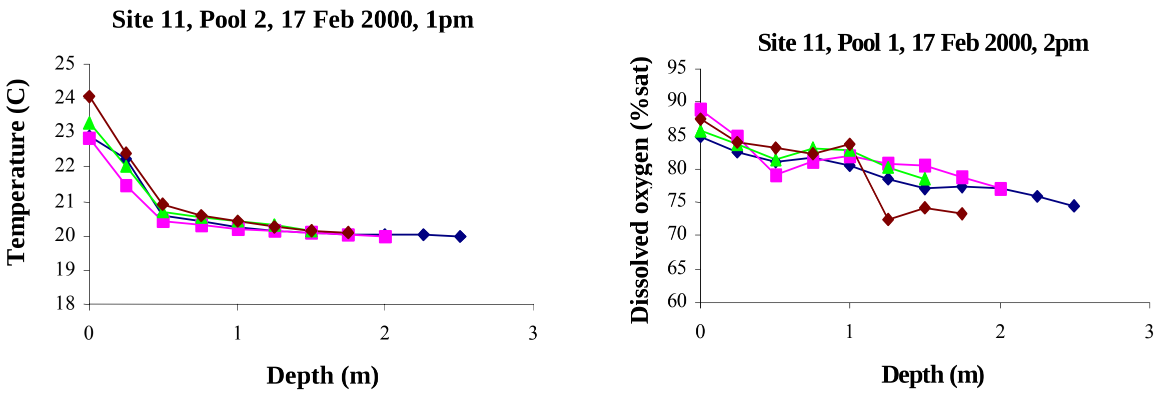


Figure 12. Temperature (a) and dissolved oxygen (b) gradients in four profiles within a pool at site 11 (the Delegate River), on 17 February 2000.

At all sites exhibiting stratification, this occurred in pools with a depth equal to or greater than 2.5m, with the exception of pool 2 at Burnt Hut which did not exhibit stratification. The latter indicates, however, that pool size may also influence stratification, as pool 2 is much smaller than pool 1 at this site. The deepest pools experienced the lowest discharge relative to their size, and the lowest velocities (*pers. obs*.), so stratification is likely to be a due to a combination of pool depth and discharge (Bevitt, 2003).

3.3.5 Discussion

Seasonal water temperatures in the Snowy River are similar at Dalgety Weir and Willis, although water temperatures tend to be 3-4°C higher at Willis (Figure 9 and Figure 10). This is probably due to a combination of the warmer climate at Willis and the reduced flows over a much wider channel. Summer water temperatures at Willis frequently reach 30°C (Figure 10) and this may impact some species of fish and other biota.

The EC data for Dalgety and Willis are also similar, and are within the range recommended for slightly disturbed ecosystems in south eastern Australia (ANZECC, 2000). EC is much higher, however, than the very low concentrations in Lake Jindabyne (eg. Bowling *et al*., 1993; Kinross and Acaba, 1996; Maini *et al*., 1997), and is influenced by runoff from the catchment below Jindabyne Dam (Figure 9 and Figure 10). Environmental flows from Jindabyne Dam would dilute EC concentrations in the upland reaches of the Snowy River.

Temperature and oxygen stratification was not found to be well-developed or frequent in the Snowy River test sites during the pilot study period of summer 2000, nor were strong thermal gradients developed. Some stratification did occur at the Snowy River test sites 1, 2 and 3 that are closest to the dam, and the Delegate River reference site. Similarly, opportunistic monitoring of the upland test sites by Erskine *et al*. (in prep.) found that temperature and oxygen stratification were not prevalent, although strong thermal gradients and oxygen stratification did occur at site 2 on occasions. Stratification in summer 2000 was not influenced by climatic conditions but a relationship with discharge, pool depth and pool size was apparent (Bevitt, 2003).

3.3.6 Key water quality findings

- Water temperatures at Dalgety and Willis exhibit strong seasonal patterns, and summer water temperatures are high at Willis;

- Electrical conductivity levels generally correspond with discharge, increasing with flow events arising from local rainfall below Jindabyne Dam; and, temperature and oxygen stratification was not prevalent in the Snowy River during the pilot study period but did occur at sites 1, 2, 3 and 5, decreasing in development with increasing discharge. Stratification was not present in the Thredbo and Deddick Rivers, but strong thermal gradients occurred in the Delegate River reference site.

- There may be a combined effect of discharge, pool depth and pool size on the development of stratification in some of the upland Snowy River sites and Delegate River reference site. Further investigation of this relationship in the Snowy River Site 1 would be beneficial, utilising both telemetered thermistor chains and manual dissolved oxygen measurements, however a cost benefit analysis of this would be required.

3.4 Vegetation

3.4.1 Introduction

The composition and rate of colonization of aquatic and riparian vegetation depends on substratum stability (disturbance frequency), availability of moisture (water quantity), rate of dispersal (Petts, 1984) and water quality (Rose, 1999). Species composition often become weedy (not native to the catchment), monoculture in nature, and indicative of still water environments because of changed flow and water temperature conditions downstream of dams.

Accelerated sedimentation rates because of flow incompetence, and stabilization of the channel boundary because of reduced flow variability, lead to vegetation invasion of the banks and instream after dam closure. This is important, because vegetation plays a significant role as a feedback mechanism in regulated rivers (McKenny *et al*., 1995). Local roughness and bank strength are increased sedimentation sites that create obstructions to flow. Ultimately, the extent of vegetation encroachment will markedly influence the magnitude of floods required to induce significant changes in channel morphology (Petts, 1984).

Four studies, covering a range of spatial scales were developed to benchmark, then detect and monitor change in species cover and composition following environmental flow releases. Sampling at a range of spatial scales provides an opportunity to explain variability and therefore corroborate results. Starting from the largest scale the four studies are:

1. Reach scale species assessment;

2. Emergent (edge) macrophyte and littoral assessment;

3. Submerged macrophyte assessment; and,

4. Macro-algae assessment.

This report looks at baseline data at Snowy River test and reference sites from 1997 to 2000 (Table 14). Subsequent years data have not been analysed to date and so could not be incorporated into this report.

The pre-flow release objectives are to:

- Benchmark plant species composition (native and weedy) and abundance; and,

- Measure seasonal and inter-annual changes.

In this report only exploratory analyses were conducted as a prelude to answering the study objectives. Exploratory analyses were required to determine the level of variability in the system, and to provide information on how best to group data to detect and measure impact following flow releases.

3.4.2 Design and methods

The Snowy River is divided into three macro-reaches based on the effect of tributaries on vegetation community differences in five upland, two midland and two lowland sites (Table 14). Corresponding reference rivers are used to assess the types and magnitude of change with respect to background variation. If change in the Snowy River is greater than change that occurs in reference rivers then it can be said that environmental flows have had some effect.

Sampling of emergent and submerged macrophytes, and macro-algae is undertaken twice annually in autumn and spring because there will be major differences in flow characteristics in spring (large floods) and in autumn (long period of baseflow when plants are growing). Sampling is conducted in pool, riffle or run habitats within a performance reach to determine if physical habitat, or change in post-flow habitat affects the composition, cover and abundance of plant assemblages. Reach scale sampling has been conducted seven times, and will be conducted once immediately flows are released, then every five years thereafter.

Table 14. Snowy Benchmarking project vegetation sampling sites.

Macro-reach	Test sites	Reference sites	Control sites
Upland *(Jindabyne Gorge and Dalgety Uplands)*	*Site (1) Snowy River d/s Cobbin Creek (site now discontinued)*	Site 11 Delegate River at Quidong	None during this sampling period
	Site 1 Snowy River d/s Mowamba River Site 2 Snowy River u/s Sugarloaf Creek Site 3 Snowy River at Rockwell Site 4 Snowy River d/s Blackburn Creek	Site 12 Mowamba River on the Barry Way Site 13 Thredbo River at Paddys Corner	
Midland (*Burnt Hut Gorge, Willis Sand Reach and Lucas Point Reach)*	Site 5 Snowy River at Burnt Hut Crossing	*Site (10) Pinch River (site now discontinued)*	None
	Site 6 Snowy River at Willis Site 7 Snowy River at McKillops Bridge *Site (8) Snowy River at Sandy Point (site now discontinued)*		
Lowland *(Orbost Reach)*	Site 10 Snowy River at Jarrahmond	None	None

Reach scale species assessment

Relative abundance for riparian, emergent and submerged macrophytes is estimated using symbols based on a four point rating scale (Gates, 1949; Tansely, 1954; Grieg-Smith, 1983):

Blank or 0 Indicates that a species is not recorded;

+ or 1 Rare, is for species where few (1-2) plants are recorded;

++ or 2 Uncommon, where a few plants are observed but species are not always in view; and,

+++ or 3 Common, where plants are seen and always in view.

Relative abundance for macro-algae is estimated using frequency symbols based on a rating scale used by Entwisle (1990):

Blank Indicates that a species is not recorded;

+ Present (isolated filaments or fragments were found);

++ Common (one or a few clumps were found but not always immediately obvious); and,

+++ Abundant, substantial and immediately obvious clumps were found.

Emergent (edge) and submerged macrophytes, and macro-algae

Data are recorded for emergent and submerged macrophytes, and macro-algae. Designs for each are multistage with four levels of stratification (Table 15).

Table 15. Levels of stratification.

Level of stratification	Comment
Macro-reach	Upland, midland and lowland
Performance reach	Sites within macro-reaches
Habitat	Emergent plants: pools and runs. Submerged macrophytes: vegetated areas of pools and runs. Macro-algae: riffles, pool edges and runs. Select 2 of each habitat type in each performance reach
Replicate	Randomly place 10 quadrats in each habitat type (= 40 per site)

Emergent edge and submerged macrophytes, and macro-algae cover (%) was recorded in each quadrat along with a record of species using five uneven cover classes. Submerged aquatic macrophytes and macro-algae are sampled from the same quadrat in pool edges and runs but from independent quadrats in riffles. The class that best describes each species in the quadrat is recorded alongside that species name. Cover classes are:

Class 1 0-1%

Class 2 1-9%

Class 3 10-29%

Class 4 30-59%

Class 5 60-100%

The field procedures for sampling macro-algae are based on protocols described in the ANZECC (1999), US EPA (1997) - Rapid Assessment Protocols for use in streams and rivers, and US geological Survey (1993). Macro-algal samples were prepared and identified using laboratory procedures described in Sainty *et al*., (2000).

3.4.3 Analysis

Relationships among samples, sites, reaches, habitats and seasons were explored using non-metric mutli-dimensional scaling (NMDS). Points on the scatterplots of ordination results are colour-coded by reach or other appropriate factor levels (e.g., season, habitat) to aid interpretation of the plots.

3.4.4 Results

Following is a summary of the results, discussion and recommendations from a report by Sainty *et al*., (2000).

Reach scale species assessment

Data from the autumn 1997, 1998 and 2000 and spring 1997, 1998 and 1999 sampling periods were used in the analyses. No data was collected in autumn 1999 because sampling methods were being reviewed.

Riparian, emergent and submerged species

NMDS analysis indicate a strong grouping both by season and by year (Figure 13).

Superimposed on this is a pattern related to the macro reach grouping of sites: upland sites (0) 1, 2, 3 and 4; midland sites 5 -7 and (8); and the lowland site 10 (Figure 14).

Reference sites also group separately from test sites demonstrating that they should be able to provide reasonable comparisons after flows are released.

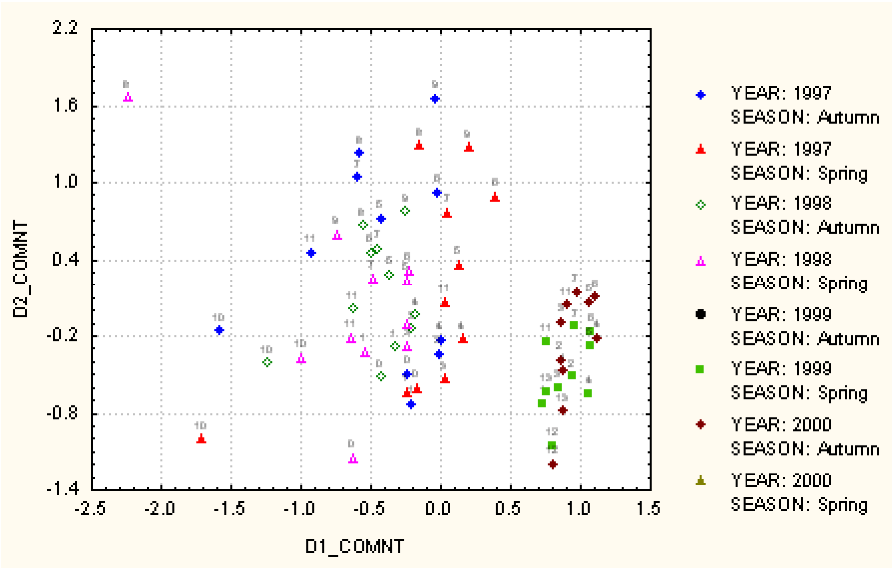


Figure 13. Two-dimensional NMDS of the species similarity matrix, for the complete reach scale non-transformed data (stress=0.18).

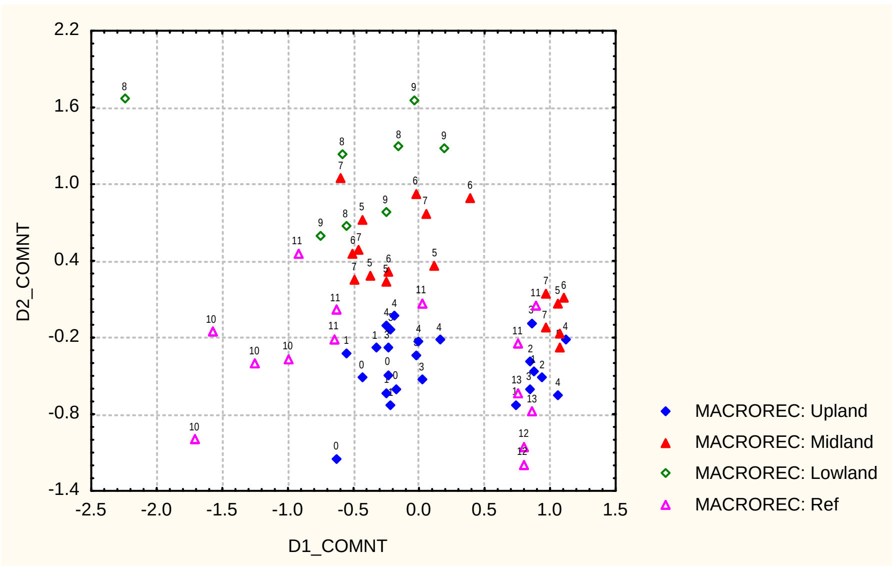


Figure 14. Two-dimensional NMDS of the species similarity matrix, for the complete reach scale non-transformed data by macro-reach (stress=0.18).

NMDS analysis of native species indicate that the geographical distribution across macro-reaches is important in explaining their distribution (Figure 15). Seasonality is also important but less so.

NMDS analysis of introduced (weedy) species indicate that season is important in explaining a large amount of the observed variation (Figure 16). It is possible that this seasonality may be due more to annual weeds. There is less of an indication of the importance of distribution by macro-reach.

Across all data, the distribution of the reference sites throughout the NMDS diagrams indicate that they are appropriate for inclusion in the sampling program.

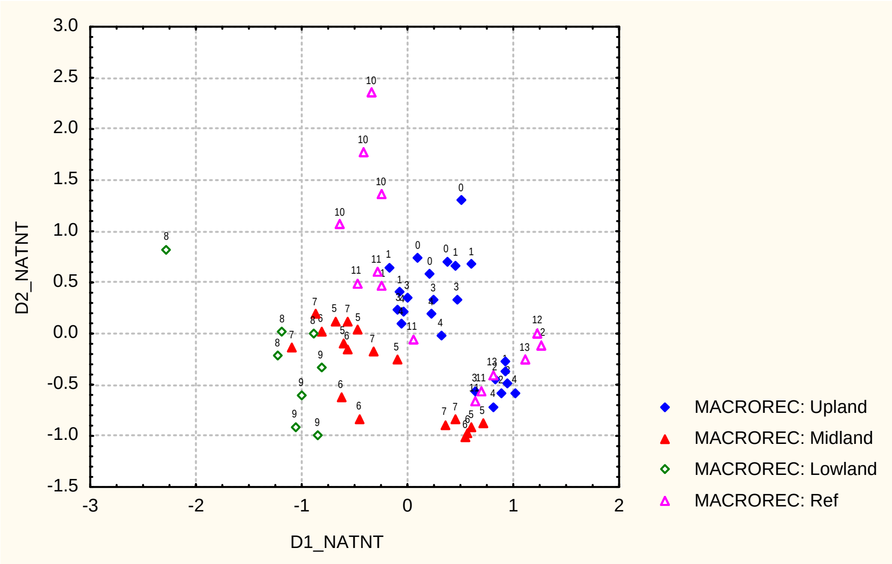


Figure 15. Two-dimensional NMDS of the species similarity matrix, for the complete reach scale native species by macro-reach (stress=0.18).

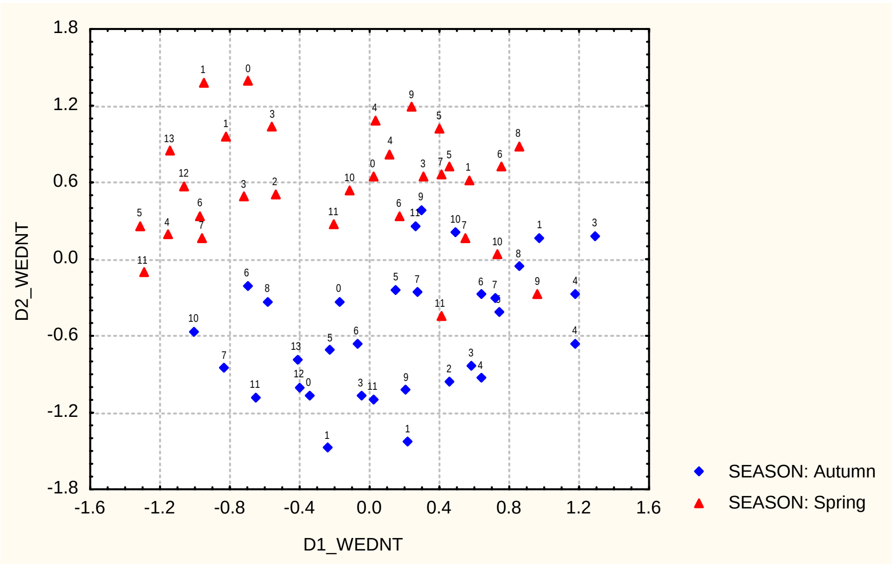


Figure 16. Two-dimensional NMDS of the species similarity matrix, for the complete reach scale weed species by season (stress=0.30).

Macro-algae

NMDS analysis using presence/absence data indicates a general seasonal separation at most sites (Figure 17). Analysis using both seasonal and yearly classifications indicates stronger grouping of macro-algal communities in 1999 and 2000 compared to 1997 and 1998 (Figure 18).

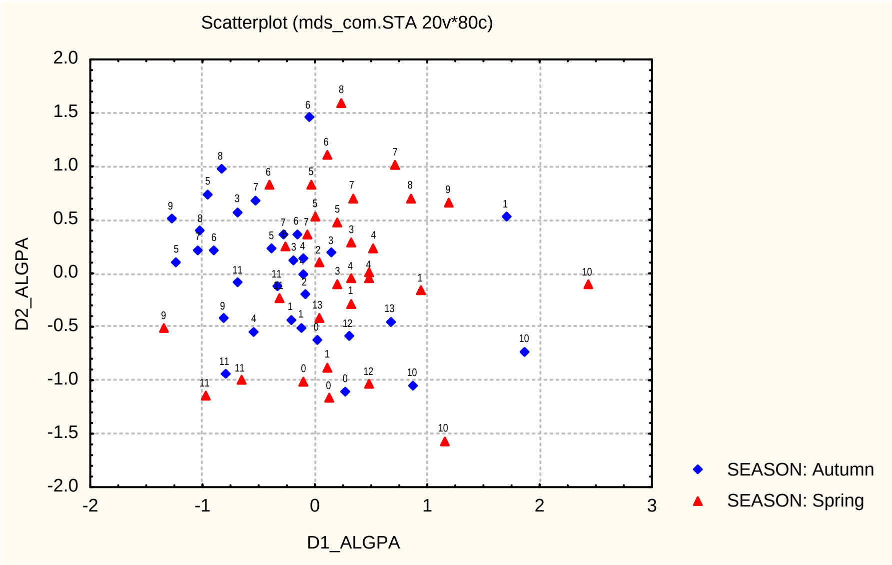


Figure 17. Two-dimensional NMDS ordination of reach scale macro-algal presence/absence data, showing seasonal classification of performance reaches (stress=0.27).

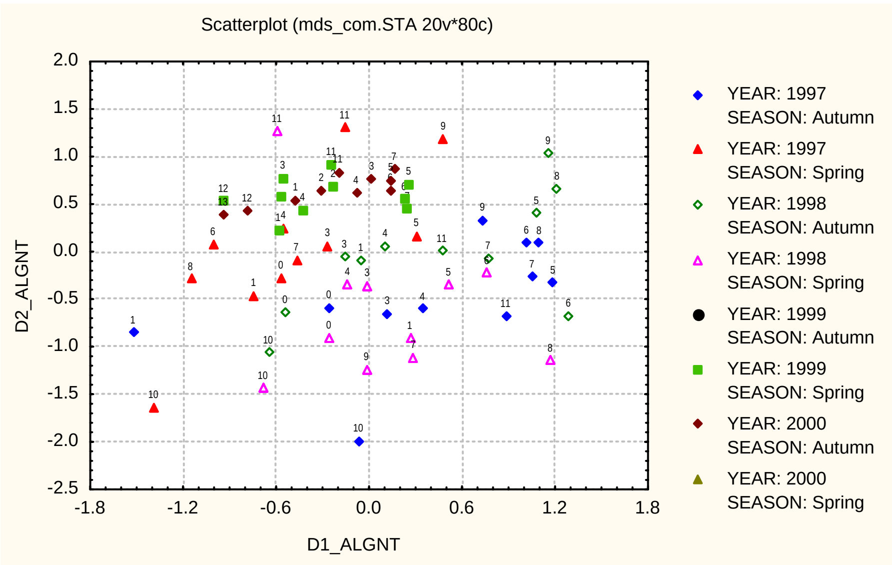


Figure 18. Two-dimensional NMDS ordination of reach scale untransformed macro-algal abundance data, showing seasonal and yearly classification of performance reaches (stress=0.27).

Random quadrats

Only data for the spring 1999 and autumn 2000 sampling periods were available for analyses, therefore the following are very preliminary results only.

Emergent (edge) macrophytes

NMDS analysis indicates a separation of the data by season (Figure 19). Cluster and NMDS analyses do however, provide support for the macro reach classification (Figure 20 and Figure 21). NMDS analyses of native species indicate support for the macro reach concept (Figure 22 and Figure 23). There does not appear to be any interpretable pattern in the weed data other than a seasonal pattern. The distribution of reference sites in all analyses suggests that they provide an adequate sample for comparing with the test sites.

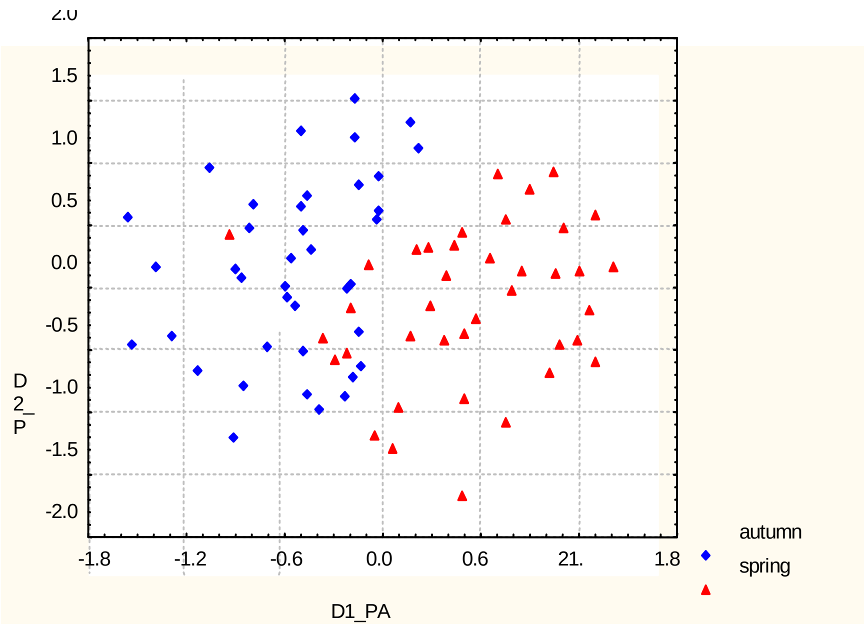


Figure 19. Two-dimensional NMDS plot of all the emergent species by season (stress=0.29).

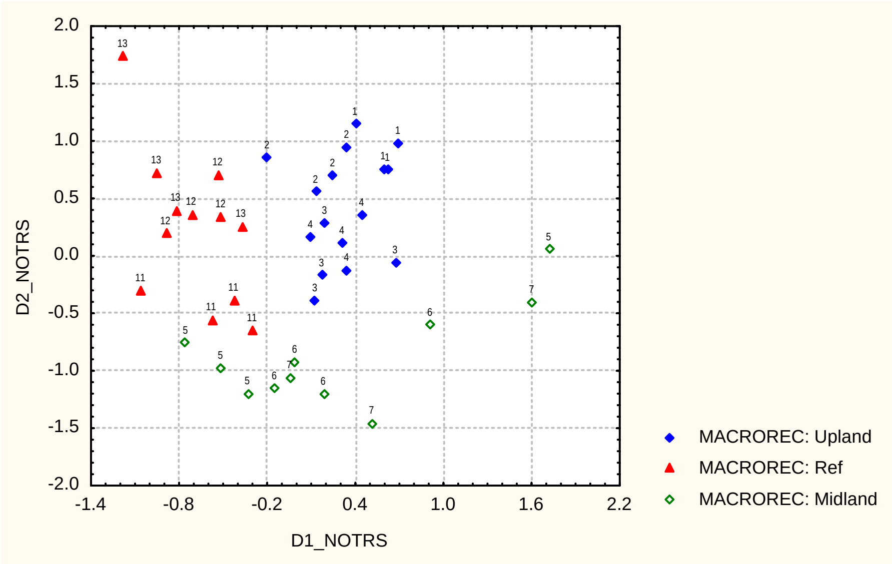


Figure 20. Two-dimensional NMDS plot of emergent species for the spring 1999 data, by macro-reach, upland (1-4), midland (5-7) and reference (11-13) (stress=0.20).

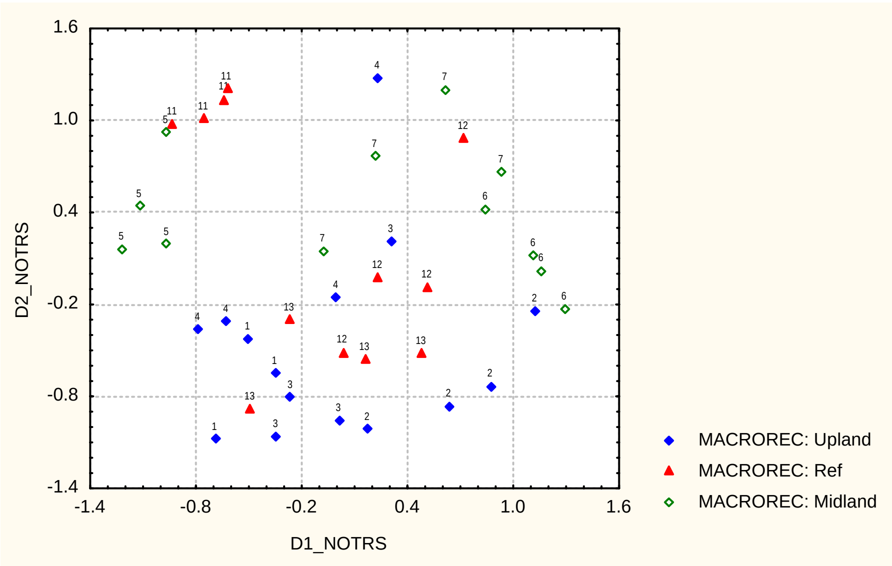


Figure 21. Two-dimensional NMDS plot of emergent species for the autumn 2000 data, by macro-reach, upland (1-4), midland (5-7) and reference (11-13) (stress=0.17).

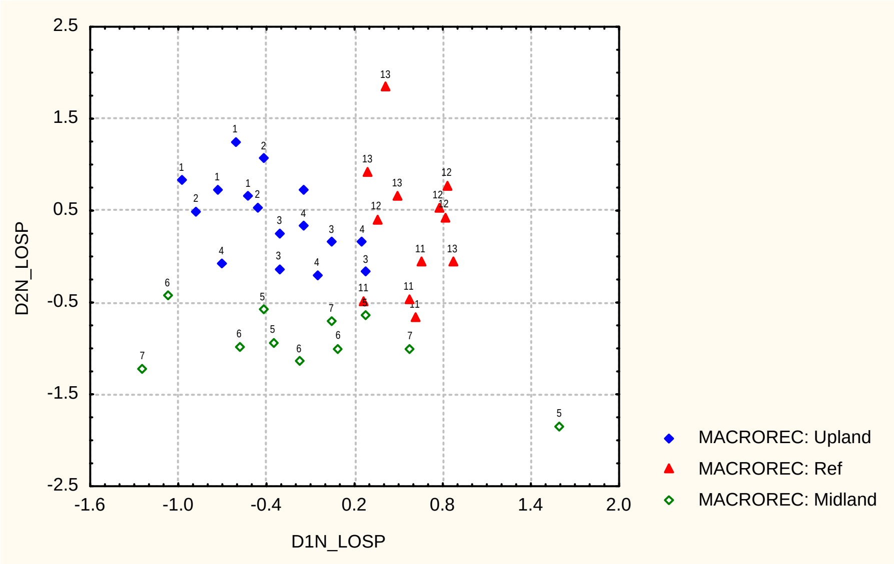


Figure 22. Two-dimensional NMDS plot of emergent native species for the spring 1999 data, by macro-reach, upland (1-4), midland (5-7) and reference (11-13) (stress=0.24).

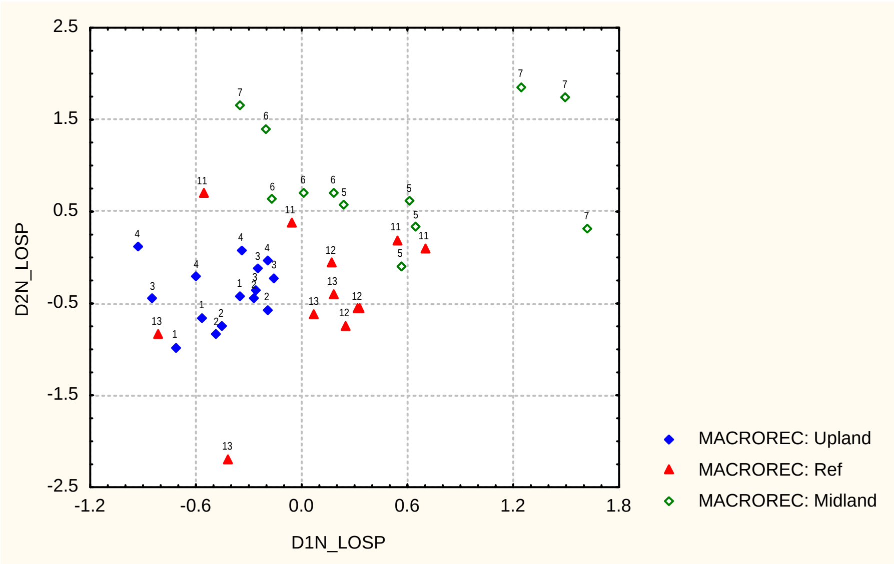


Figure 23. Two-dimensional NMDS plot of emergent native species for the autumn 2000 data, by macro-reach, upland (1-4), midland (5-7) and reference (11-13) (stress=0.17).

Submerged macrophytes

For the autumn 2000 NMDS analysis there is some suggestion of sorting into upland and midland, with the reference sites scattered between the two. In all analyses the reference sites are well distributed in the NMDS analysis indicating a good selection of such sites. The complete data set indicates that there be a seasonal pattern in vegetation communities. The variation between these two sampling periods is too great at the moment for any strong pattern to emerge. NMDS diagrams were not available while writing this report.

The spring 1999 data results indicate that a similar number of submerged macrophyte species occur in pools and runs. Species composition in pools was variable and species composition less similar to the Snowy than most sites within the Snowy River. Introduced plants occur at all sites and in all habitats. The most common aquatic weed was *Elodea canadensis*, being more common in pools than in runs. This species is marginally more common in the runs of reference rivers. *Cyperus erragrostis*, *Gnaphalium* sp., *Juncus articulatus*, *Myosotis* sp. and *Veronica anagallis-aquatica* also grew at almost all sites and in all habitats. The number of native species varied across sites with no definite trends.

Macro-algae

Macro-algal data were collected from riffles, runs and pool edges. NMDS analysis of all habitats (using untransformed abundance data) for both seasons sampled produced a separation of sites consistent with the macro-reach classification (Figure 24). Reference sites were associated with both upland and midland test sites. NMDS also illustrate high variability of macro-algal communities within pool edge habitats. When pools were removed from further analyses, the NMDS analysis showed that the separation of riffle and run habitats for both seasons remained consistent with the macro-reach classification (Figure 25). The NMDS analysis of riffles and runs produced a distinct separation of reference sites from the test sites (Figure 26).

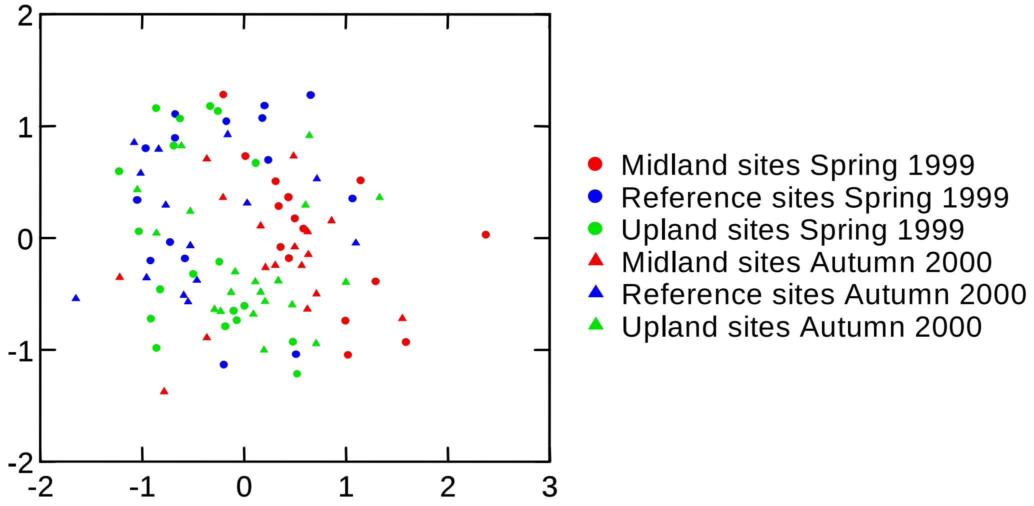


Figure 24. Two-dimensional NMDS ordination of all habitats (riffles, runs and pools) for both seasons using untransformed macro-algal abundance data, showing seasonal and yearly classification of sites (stress=0.27).

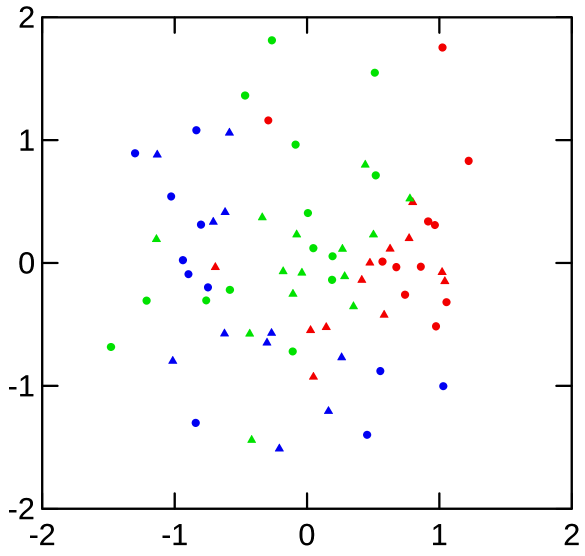


Figure 25. Two-dimensional NMDS ordination of riffle and run habitats (no pools) for both seasons using untransformed macro-algal abundance data, showing seasonal, yearly and macro-reach classification of sites (stress=0.25). Legend same as previous figure.

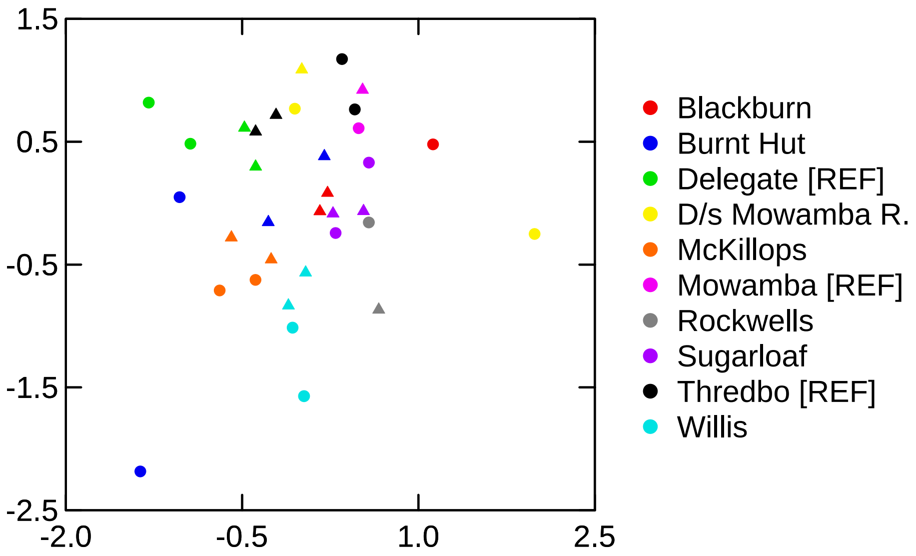


Figure 26. Two-dimensional NMDS ordination of riffles for both seasons using untransformed macro-algal abundance data. [circles - spring 1999 samples, triangles - autumn 2000 samples (stress=0.21)].

3.4.5 Discussion

The reach scale species assessment provides a measure of seasonal and annual variation and indicates a complex relationship between season, year and macro reach (Figure 13, Figure 14, Figure 15, Figure 16). In particular, the high variation observed in macro-algal community composition along the Snowy River demonstrates the need for seasonal sampling (Figure 17, Figure 18). Currently, reach scale macro-algae data is insufficient to accurately determine the key macro-algal species differentiating test and reference sites because there are only two season's data for the Mowamba and Thredbo reference rivers.

The random quadrat data for the emergent edge and submerged plant species are too few and too definitive about their interpretation yet (Figure 19, Figure 20, Figure 21, Figure 22, Figure 23). The random quadrat data for macro-algae clearly supports the macro reach classification, also that variability in pool macro-algal communities is too high to provide interpretable patterns (Figure 24). This may be attributable to the low number of species recorded and limited substrate availability from this habitat. Most species recorded are either epiphytic on submerged macrophytes or free-floating. It is not appropriate therefore to continue sampling pool edge habitats. Patterns exhibited by both riffle and run habitats are similar but differences in community composition between these two habitats at most sites support the separate classification and analysis of these habitats (Figure 25, Figure 26).

3.4.6 Key vegetation findings

- Present limited analyses indicate that the sampling design should detect changes due to any significant flow releases and enable the prediction of macro-algal species groups that are expected to be flow-response indicators;

- Strong seasonal patterns between spring and autumn were reported for all analyses;

- The reach scale species assessment enables seasonal and annual variation to be measured;

- The analyses of native species data indicate a high component of macro reach distribution in explaining the observed variation, and the weed flora (especially annual weeds) a strong seasonal component in explaining the observed variation;

- The species composition of submerged macrophytes in different habitats is similar; and,

- Discontinue sampling macro-algae in pool edges because of high variability.

3.5 Macroinvertebrates

3.5.1 Introduction

This progress report establishes baseline information on the composition of macroinvertebrate assemblages, relative abundance and density in the Snowy River test sites and control and reference sites for the reporting period of June 1999 to June 2001, which encompasses four sampling events. The effect of Jindabyne Dam on macroinvertberate communities will be determined with the analysis of data collected following the release of significant environmental flows. Typical impacts on macroinvertberate communities below dams include loss of species diversity and reduced abundance (eg., Rader and Belish, 1999; Growns and Growns, 2001).

3.5.2 Design and methods

The Snowy River is divided into two macro-reaches based on geographic differences in the eight upland and lowland sites that are sampled for macroinvertebrates (Table 16). Corresponding reference and control sites sampled for macroinvertebrates are also shown in Table 16 (as discussed in Section 2, there are no lowland control sites available). Surveys are conducted biannually in autumn and spring. Sampling is undertaken in riffles (cobble habitats in fast flowing water) and pools (sandy edges).

Three random samples in each of two riffles and two pools were taken at each site. Riffles were cobble habitats, and pool habitats were sandy edges. A suction sampler modified from that of Brooks (1994) was placed over the substrate and operated for one minute at each sampling location. Material in the jar was washed thoroughly over a 2 mm mesh sieve nested above a 0.5 mm mesh sieve. Matter retained on the 2 mm sieve was placed in a large white tray and all invertebrates present were picked out on site into a jar of 70% ethanol. All trays were checked by a second field officer to ensure all invertebrates were removed, and five percent of live-picked sample residues were randomly selected and preserved for laboratory QA/QC. Material retained on the 0.5 mm sieve was preserved in 70% ethanol for laboratory sorting.

Macroinvertebrates were identified to the family level using dissecting and compound microscopes and published keys and descriptions. All samples were stored for possible future identification to lower taxonomic levels. In the larger fraction all invertebrates were identified, however in the small fraction sub-sampling is undertaken where there is a high abundance of dominant taxa (>1000 estimated during sorting). Typically, these taxa were Oligochaeta, Chironomidae, and/or Caenidae. A 25% sub-sample of the particular taxa that is >1000 in abundance is taken.

3.5.3 Analysis

Differences in macroinvertebrate community composition was compared through time between reference sites, control sites (where present) and Snowy River test sites (Table 16) for both riffle and pool habitats.

Ordination plots were produced by non-metric multidimensional scaling (NMDS) of logarithmically ($\log_{10}$+1) transformed community data expressed as a rank similarity

Table 16. Snowy River test sites and corresponding reference and control sites for macroinvertebrates.

Macro-reach	Test sites	Reference sites	Control sites
Upland *(Jindabyne Gorge and Dalgety Uplands)*	Site 1 - Snowy River d/s Mowamba	12. Mowamba River at the Barry Way 13. Thredbo River downstream of the Gaden Trout Hatchery	22. Eucumbene R. u/s of Nimmo Bridge 23. Eucumbene R. near Montana
	Site 2 - Snowy River u/s Sugarloaf		
	Site 3 - Snowy River @ Rockwell		
	Site 4 - Snowy River d/s Blackburn		
Midland *(Burnt Hut Gorge)*	Site 5 - Snowy River @ Burnt Hut Crossing	11. Delegate River at Quidong	
Lowland *(Willis Sand Reach and Lucas Point Reach)*	Site 6 - Snowy River @ Willis	25. Cann R. near Silverwood 26. Buchan River upstream of Snowy confluence	
	Site 7 - Snowy River @ McKillops	Cann and Buchan	
	Site 8 - Snowy River @ Wests Track	Cann and Buchan Rivers	

matrix using the Bray-Curtis similarity measure as outlined by Clarke (1993). Differences between reference sites, control sites and Snowy River test sites were tested by MRPP (Multi-Response Permutation Procedures). The taxa that best discriminated these groups were determined by Indicator Species Analysis (Dufrêne & Legendre 1997). Alpha was set at 0.1 for all analyses to minimise the probability of Type II errors.

3.5.4 Results

Riffles

The analysis showed that macroinvertebrate communities of the Snowy River test sites in the upland and lowland macro-reaches were distinct from those of their corresponding reference and control sites for both riffle and pool habitats. Riffles in the Snowy River test sites 1 and 2 were distinguished from the reference and control sites primarily by higher abundances of Tipulidae, Caenidae, Gomphidae, Hydroptilidae, and Corydalidae (Figure 27). Sites 3 and 4 were characterised by higher abundances of Tipulidae, Caenidae, Gomphidae, Atyidae and Pyralidae (Figure 28). The reference sites for these areas (sites 12 and 13) contained assemblages that differed from each other, and were clearly different from the impacted Snowy River test sites. Site 12 (Mowamba River) was distinguished by the mayflies Leptophlebidae and Coloburiscidae, adult and larval Elmidae beetles, Hydrophilidae (beetle larvae), Psephenidae (beetle larvae) and Conoesucidae cadisflies. Site 13 (Thredbo River) was dominated mainly by Athericidae, Glossomatidae and Helicopsychidae. The assemblages sampled from the control site 22 (Eucumbene River) were dominated by the amphipod Paramelitidae, Glossiphoniidae, Leptoceridae, Planorbidae and Calamoceridae.

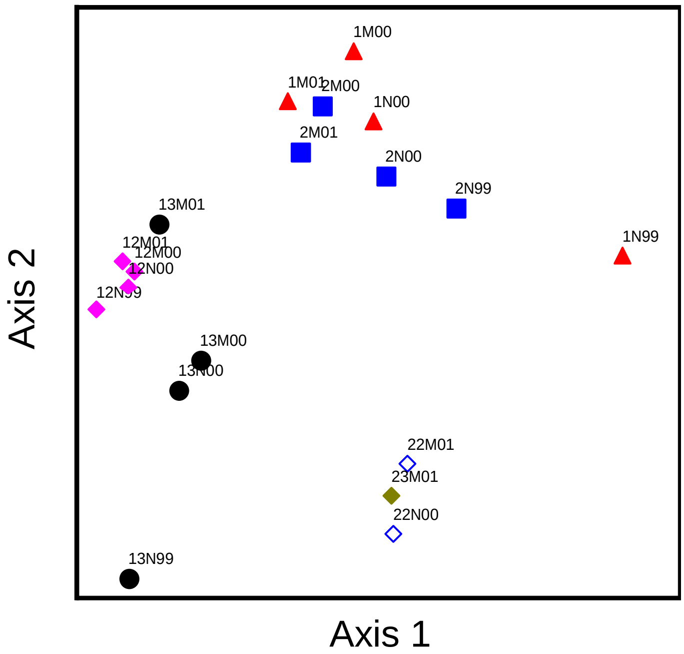


Figure 27. Two-dimensional NMDS ordination of macroinvertebrate communities sampled from riffle habitats at Snowy River test sites 1 & 2, reference sites 12 & 13 and control sites 22 & 23 (stress=0.11).

Symbols and preceding numbers distinguish each site, letters distinguish each sampling occasion, eg. ▲ 1N99 signifies "Site 1, November 1999", i.e. M=May (autumn), N=November (spring), 99=1999, 00=2000, 01=2001.

The macroinvertebrate communities sampled from site 5 (Burnt Hut Crossing) remained distinct from the reference site at Delegate River (site 11) for all times of sampling (Figure 29). Burnt Hut Crossing communities were dominated by Baetidae (mayfly), Corydalidae (alderfly) and Pyralidae (moth), and Delegate River was characterised by the cadisflies Leptoceridae and Conoesucidae, Empididae (dance fly), Gripopterygidae (stonefly) and Ancylidae (freshwater limpet).

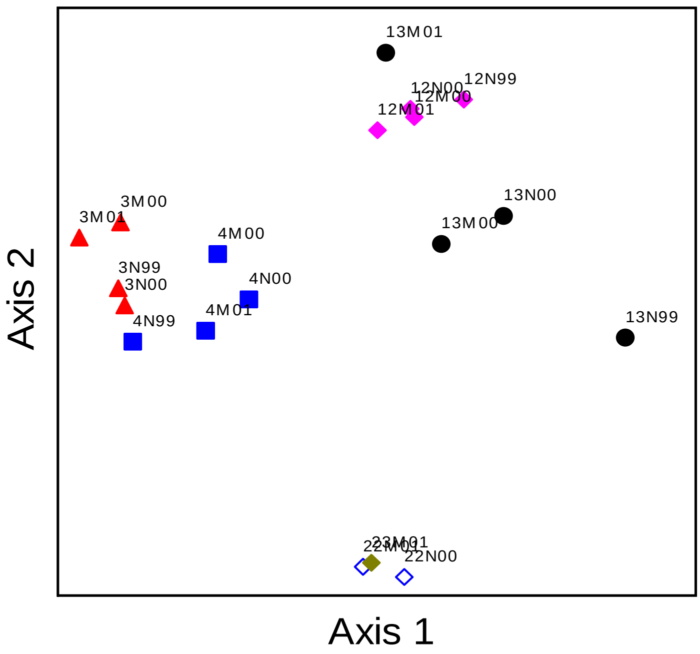


Figure 28. Two-dimensional NMDS ordination of macroinvertebrate communities sampled from riffle habitats at Snowy River test sites 3 & 4, reference sites 12 & 13 and control sites 22 & 23 (stress=0.20).

Symbols and preceding numbers distinguish each site, letters distinguish each sampling occasion, eg ▲ 3M00 signifies "Site 3, May 2000", i.e. M= May (autumn), N= November (spring), 99=1999, 00=2000, 01=2001

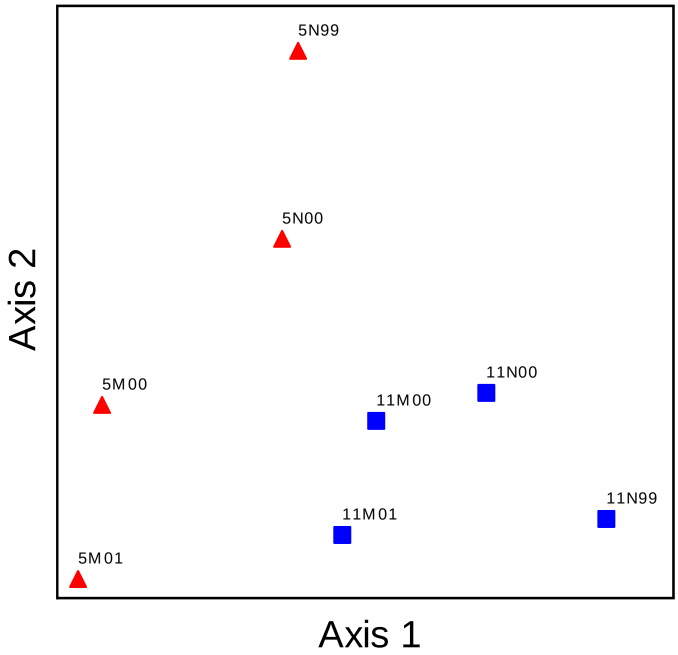


Figure 29. Two-dimensional NMDS ordination of macroinvertebrate communities sampled from riffle habitats at Snowy River site 5 and reference site 11 (stress=0.02).

Symbols and preceding numbers distinguish each site, letters distinguish each sampling occasion, eg. ▲ 5M01 signifies "Site 5, May 2001", i.e. M=M ay (autumn), N= November (spring), 99=1999, 00=2000, 01=2001.

The riffle habitats in the lowland test sites (6, 7 & 8) showed distinct temporal patterns with site groups reflecting time of sampling (Figure 30). The autumn samples from 2000 and 2001 contained very similar assemblages dominated by baetid and caenid mayflies (Baetidae and Caenidae), dragonfly larvae (Telephlebidae and Libellulidae), larval elmid beetles (Elmidae), fly larvae (Chironomidae and Simulidae) and leeches (Glossiphoniidae). However the macroinvertebrates collected in samples from spring 1999 and 2000 were clearly different from each other and from the autumn samples. The spring 1999 assemblages were characterised by high abundances of the freshwater limpet Ancylidae and Dyticidae beetle larvae, and spring 2000 by cadisfly larvae (Glossosomatidae).

The macroinvertebrate assemblages sampled from riffles in the Cann River reference site were different to all other sites during both times of collection (spring 2000 and autumn 2001). This difference in community structure was attributable to higher abundances of Synthemistidae (dragonfly larvae), Psephenidae (water pennies) and ceratopogonidae (biting midge larvae). The assemblages sampled from the Buchan River riffles during spring 2000 and autumn 2001 were very similar to those from the Snowy River test sites sampled in autumn 2000 and 2001. The taxa that were the best indicators of this site are Hydrobiidae (freshwater snail), Physidae (introduced freshwater snail), Corydalidae (alderfly/dobsonfly) Tipulidae (crane fly), Ecnomidae (beetle larvae) and Pyralidae (moth larvae).

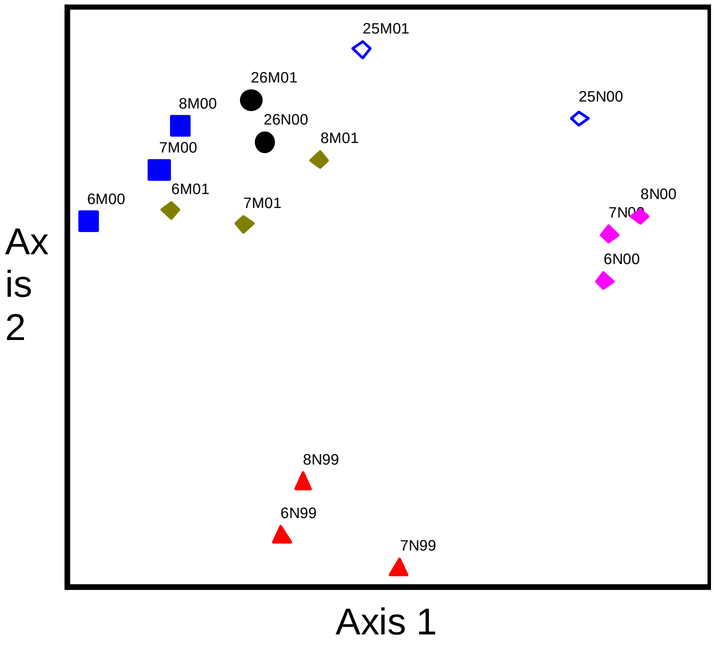


Figure 30. Two-dimensional NMDS ordination of macroinvertebrate communities sampled from riffle habitats at Snowy River test sites 6, 7 & 8, reference sites 25 & 26 (stress=0.14).

Symbols and preceding numbers distinguish each site, letters distinguish each sampling occasion, eg. ▲ 8N99 signifies "Site 8, November 1999", i.e. M= May (autumn), N= November (spring), 99=1999, 00=2000, 01=2001.

Pools

Pool samples for the lowland reference sites and control sites are currently being analysed at date of writing. Results from analysis of sampling in November 1999 are reported.

There were a total of 28 taxa collected from the upland reference sites (12 and 13) and 41 taxa from the Snowy River test sites (1-4). In the reference sites Oniscigastridae (mayfly) and Ceratopoginidae (fly larvae) were the most abundant families, and Chironomidae (fly larvae) and Lumbriculidae (worm) numerically dominated the Snowy River test sites.

There were a total of 26 taxa collected from the Delegate River reference site (11), Chironomidae, Lumbriculidae, Veneroida and Hydroptilidae being the most abundant groups. There were 33 taxa collected from the test site at Burnt Hut Crossing (site 5) and Physidae, Lumbriculidae, Caenidae and Heterodonta numerically dominated these samples.

The lowland Snowy River test sites (6-8) were characterised by Chironomidae (fly larvae, Caenidae (mayfly), Lumbriculidae (worm) and Heterodonta (freshwater bivalve).

3.5.5 Discussion

The riffles of the Snowy River upland test sites (sites 1-4) were characterised by higher abundances of Tipulidae, Caenidae, Gompidae, Hydroptidae, Corydalidae, Atyidae and Pyralidae (Figure 27 and Figure 28). The habitat preferences of Tipulidae, Pyralidae and Gomphidae are generally thought to be slow flowing or still waters. The presence of these taxa in riffle habitats in the Snowy River suggests that the alterations to the flow regime have increased their abundance in these usually lotic habitats. The reference site provides an indication of the range of fauna that may have been found in the Snowy River prior to Jindabyne Dam being built. The distinguishing macroinvertebrates in the reference sites may also become more abundant in the Snowy River following the implementation of environmental flows. The macroinvertebrate assemblages from the Eucumbene River control site (site 22) also reflect the impact of Eucumbene Dam, but were quite distinct from the communities immediately below Jindabyne Dam. This is likely to be caused by the greater reduction in flows below Eucumbene where no water is released, compared to Jindabyne Dam where 1% of mean annual natural flow is released.

3.5.6 Key macroinvertebrate findings

- The macroinvertebrate fauna of pools and riffles in the Snowy River below Jindabyne Dam were very different to those sampled from rivers without regulated flows in the region, and reflect the altered hydrology and habitat caused by the Snowy Mountains Scheme; and,

- The altered flow and habitat conditions in the Snowy River have favoured still water macroinvertebrate fauna in the upland sites.

3.6 Fish

3.6.1 Introduction

Ecological effects of flow regulation on fish communities include a change in population structure (Cadwallader and Lawrence, 1990), and a decline in species diversity (Gehrke *et al*., 1996). Moreover, flow regulation has been shown to reduce the resilience of New South Wales rivers and native fish communities by the invasion of alien fish species (Harris and Gehrke, 1997).

Two separate aspects of the fish component of the Snowy River Benchmarking Project are reported:

1. The Broad-scale fish study is an annual survey in summer to establish baseline information on fish communities and to assess changes over time; and,

2. The native fish recruitment study was a pilot study conducted in the lower Snowy River in the peak fish migration period between September 2000 and January 2001. Intensive monitoring and assessment was undertaken of native fish recruitment and passage over the sand barrier extending from the Snowy River at Lochend to Long Point. The sand barrier is essentially the deposition of sand in the main river channel from erosion in the upper catchment and may be a potential barrier to fish migration.

The pre-environmental flow release objective of the Broad-scale study reported in this document is to establish baseline information on fish population size structures, species richness, relative abundance and composition of fish communities, in the Snowy River test and reference sites.

The objectives of the native fish recruitment study were:

1. To establish the abundance and species of juvenile native fish which move from the estuary into the sand slug; and,

2. To establish the abundance and species of juvenile native fish which successfully travel past the sand barrier at Lochend to Long Point.

3.6.2 Design and methods

The Snowy River for fish is divided into three macro-reaches defined by barriers to fish passage, shown in Table 17. The first two macro-reaches contain performance reaches and corresponding reference sites that are surveyed annually for the broad-scale fish study. Not all Snowy River test sites are surveyed because of resource limitations and boat access difficulty at some sites. The third macro-reach (Table 17) was surveyed for native fish recruitment over the sand barrier, and is not incorporated into the broad-scale fish survey**.**

Table 17. Spatial stratification of the Snowy River for the broad-scale fish study.

Macro-reach	Performance reach	Reference reach
Above Snowy Falls *(Jindabyne Gorge, Dalgety Uplands and Burnt Hut Gorge)*	Snowy R. d/s Mowamba R.	Delegate R. at Quidong
	Snowy R. d/s Blackburn Ck.	Delegate R. at Delegate
	Snowy R. at Burnt Hut Crossing	Maclaughlin R. at Boco
		Maclaughlin R. at Sherwood
Below Snowy Falls *(Willis Sand Zone and Lucas Point Reach)*	Snowy R. at Willis	Buchan R. d/s Tara Ck.
	Snowy R. at McKillops Bridge	Buchan R. at Buchan Station
	Snowy R. at Jacksons Crossing	Deddick R. at Bulls Flat gauge
		Deddick R. at Ambyne Rd.
Long Point Reach and Orbost Alluvial Reach to Lochend	Snowy R. at Long Point	
	Snowy River at Lochend	

The broad-scale fish sampling methods utilised in the Snowy River Benchmarking Project are based on the NSW Rivers Survey electro-fishing method (Harris and Gehrke, 1997). Fish are sampled at a broader scale than other components of the Snowy River Benchmarking Project, because fish communities tend to be relatively evenly distributed within a given reach. Patchy distributions are only apparent at the habitat scale, therefore a larger sample is collected from many habitats within a single pool. This provides a more reliable estimate of community composition than a smaller sample from a few habitats within a defined performance reach. Boat electro-fishing is conducted at all sites in Table 17 except McKillops Bridge where lack of boat access necessitates backpack electrofishing.

The fish recruitment study entailed intensive sampling (on average, twice per week at each site) utilising the overnight use of fyke nets. Details on sampling, water quality measurements, catch processing and larval fish identification are provided in Freshwater Ecology (2000) and Raadik *et al*. (2001).

3.6.3 Analysis

Limited temporal analysis was conducted on the broad-scale fish survey data because there are only two sampling occasions to report at present. Ordination and classification identified spatial patterns in fish samples, Analysis of Similarities (ANOSIM) then detected community-level differences between macro-reaches, and between Snowy River and reference sites. Similarity Percentages (Simper) analysis was conducted to identify species contributing strongly to differences detected by ANOSIM.

For the fish recruitment study, abundance data were obtained for migratory species (separated from non-migratory life-phases of individual species), and migration peaks were presented as catch-per-unit-effort for pooled key migratory species as well as individual species (Raadik *et al*., 2001).

3.6.4 Results

The following is a summary of the results and discussion from Gehrke (2001) and Raadik *et al*. (2001).

Twenty-four fish species are known or expected to occur in the Snowy River (Table 18). A total of 16 fish species were recorded during the broad-scale fish survey, with many species requiring large scale migrations to complete their lifecycles.

The broad-scale fish data for the 2000 and 2001 surveys (Table 19 and Table 20) shows a significant separation between fish communities upstream and downstream of Snowy Falls (ANOSIM $p \leq 0.001$). A significant differencebetween reference and performance reaches within reaches either upstream ($p \leq 0.001$) or downstream ($p \leq 0.018$) of Snowy Falls was also observed. Differences in fish communities across all samples between the two years sampled were not significant (Figure 31).

The species contributing to the spatial differences were predominantly short-finned eels and goldfish which were more abundant upstream of Snowy Falls, whilst Australian smelt, gambusia, long-finned eels, congolli and short-headed lampreys were more abundant downstream of Snowy Falls.

Significant differences were also shown between Snowy River and reference sites, in either macro-reach. Above Snowy Falls, the most abundant species in the Snowy River test sites were long-finned eels, goldfish and mountain galaxias, whilst short-finned eels, redfin perch and brown trout were characteristic of the reference reaches. The most abundant species in the Snowy River test sites downstream of Snowy Falls were gambusia, long-finned eels and congolli, with the reference sites being characterised by Australian smelt, short-headed lampreys and common Galaxias.

In the native fish recruitment study, ten migratory species and three non-migratory species were collected. The key migratory species, based on true diadromy and abundance, were short-finned eels, long-finned eels, broad-finned galaxias, spotted galaxias, common galaxias, tupong and short-headed lamprey. Pooled migratory data for these key species, corrected for migratory phase only, showed two main peaks in migration at both sites (expressed as catch-per-unit-effort – CPUE) (Figure 32). However, overall CPUE for key migratory species was relatively low and the data suggest that peak migration may have occurred prior to the sampling start date.

The abundance of migratory species was generally lower at Long Point than Lochend. Four migratory species present in the Snowy River were not recorded in the recruitment study, these being Australian bass, Australian grayling, cox's gudgeon and striped gudgeon.

Table 18. Fish species recorded in the Snowy River catchment.

Scientific Name	Common name	Migratory classification	Abbreviation
*Anguilla australis**	*short-finned eel	Catadromous	Ang aus
*Anguilla reinhardtii**	*long-finned eel	Catadromous	Ang rei
Arenigobius bifrenatus	bridled goby		Are bif
Atherinosoma microstoma	small-mouthed hardy-head	Unknown	Ath mic
(Carassius auratus)	(goldfish)		Car aur
Gadopsis marmoratus	river blackfish	Potamodromous (local)	Gad mar
*Galaxias brevipinnis**	*climbing galaxias	Amphidromous	Gal bre
*Galaxias maculatus**	*common galaxias	Catadromous	Gal mac
Galaxias olidus	mountain galaxias	Potamodromous (local)	Gal oli
*Galaxias truttaceus**	*spotted galaxias	Diadromous	Gal tru
(Gambusia holbrooki)	(gambusia)		Gam hol
*Geotria australis**	*pouched lamprey	Anadromous	Goe aus
Gobiomorphus australis	striped gudgeon	Amphidromous	Gob aus
Gobiomorphus coxii	Cox's gudgeon	Potomadromous	Gob cox
Herklotsichthys castelnaui	sprat		Her cas
Maquaria novemaculeata	Australian bass	Catadromous	Maq nov
*Mordacia mordax**	*short-headed lamprey	Anadromous	Mor mor
Nannoperca australis	southern pygmy perch	Potamodromous (local)	Nan aus
(Oncorhynchus mykiss)	(rainbow trout)		Onc myk
(Perca fluviatilis)	(redfin perch)		Per flu
Philypnodon grandiceps	flatheaded gudgeon	Unknown	Phi gra
Philypnodon sp1	dwarf flathead gudgeon	Unknown	Phisp1
Prototroctes maraena	Australian grayling	Amphidromous	Pro mar
*Pseudaphritis urvilli**	*tupong or congolli	Amphidromous	Pse urv
*Retropinna semoni**	*Australian smelt	Potadromous	Ret sem
(Salmo trutta)	(brown trout)		Sal tru

* = actively recruiting into the lower Snowy River in 2000/01 (Raadik *et al*., 2001).
( ) = introduced species.
Potamodromous = fish that migrate wholly within freshwater;
Diadromous = fish that migrate between freshwater and the sea;
Anadromous = fish spend most of their life in the sea and migrate to freshwater to breed;
Catadromous = fish spend most of their life in freshwater and migrate to the sea to breed;
Amphidromous = fish migration between the sea and freshwater is not for breeding;
(local) = requires passage in immediate environment only (Thorncroft and Harris, 2000).
Other Sources: Raadik, 1992, 1995b; Raadik and O'Connor, 1997; DLWC, 1998a; Gehrke, 2000, 2001).

Table 19. Mean length (mm) of fish collected at each site in 2000 and 2001 (Source: Gehrke, 2001). See Table 18 for key to species abbreviations

ID	Site Name	Species														
	2000	ang aus	ang rei	car aur	gad mar	gal mac	gal oli	gam hol	gob aus	mac nov	mor mor	nan aus	per flu	pse urv	ret sem	sal tru
1	Mowamba River		509													
4	Blackburn Creek		437	48												
5	Burnt Hut		725	80			47									
6	Willis		655								120			167	43	
7	McKillops Bridge		467					19						166	37	
11	Quidong	180	650										108			
14	Deddick Park		510											196	62	
15	Buchan 2	405	400			85					119	38		104	45	
16	Jacksons Crossing	485	527			89		20	177	480	97			101	38	
17	Bill Jeffreys Park	452			183								195			250
18	Ambyne		625											166	46	
19	Buchan Station		825			99					112	42		121	37	
20	Sherwood	560														528
21	Boco	612														
	Annual Total	**514**	**546**	**77**	**183**	**90**	**47**	**19**	**177**	**480**	**110**	**41**	**142**	**135**	**44**	**342**
	2001															
1	Mowamba River	532	736													194
4	Blackburn Creek	563		96												
5	Burnt Hut		443	89									139		39	
6	Willis		615											189		
7	McKillops Bridge	115	264	175				18						123	48	
11	Quidong	475	700													295
14	Deddick Park		700											146	55	
15	Buchan 2	1000	383			93						27		118	52	
16	Jacksons Crossing	560	542	39		75		27		357	140			103	37	
17	Bill Jeffreys Park	484														201
18	Ambyne		433											138	61	
19	Buchan Station	550	413			68						39		139	43	
20	Sherwood	53														544
21	Boco	577														
	Annual Total	**533**	**498**	**81**		**75**		**27**		**357**	**140**	**33**	**139**	**133**	**52**	**286**

Table 20. Number of fish collected at each site in 2000 and 2001 (Source: Gehrke, 2001). See Table 18 for key to species abbreviations.

Site ID	Site Name	Species															1.1.1.1	No. Species
		ang aus	ang rei	car aur	gad mar	gal mac	gal oli	gam hol	Gob Aus	mac nov	mor mor	nan aus	per flu	pse urv	ret sem	sal tru		
2000																		
1	d/s Mowamba River		22					2									24	2
4	d/s Blackburn Creek		18	2													20	2
5	Burnt Hut		6	10			21										37	3
11	Quidong	2	2										21				25	3
17	Bill Jeffreys Park	18			2								12			4	36	4
20	Sherwood	15														2	17	2
21	Boco	13															13	1
6	Willis		11								2			18	26		57	4
7	McKillops Bridge		3					3						6	15		27	4
16	Jacksons Crossing	2	24			9		1	4	1	15			36	3		95	9
14	Deddick Park		5											8	2		15	3
18	Ambyne		2											8	71		81	3
15	Buchan 2	2	1			7					25	1		6	23		65	7
19	Buchan Station		4			4					12	4		5	10		39	6
	Annual total	**52**	**98**	**12**	**2**	**20**	**21**	**6**	**4**	**1**	**54**	**5**	**33**	**87**	**150**	**6**	**551**	**15**
	No. Sites	**6**	**11**	**2**	**1**	**3**	**1**	**3**	**1**	**1**	**4**	**2**	**2**	**7**	**7**	**2**		
2001																		
1	d/s Mowamba River	11	9					2								5	25	3
4	d/s Blackburn Creek	4		70													74	2
5	Burnt Hut		14	6									4		1		25	4
11	Quidong	2	1													1	4	3
17	Bill Jeffreys Park	20														9	29	2
20	Sherwood	28														5	33	2
21	Boco	29															29	1
6	Willis		14					100						7	1		122	4
7	McKillops Bridge	4	14	2				123						2	9		154	6
16	Jacksons Crossing	2	21	10		3		2		1	4			14	13		70	9
14	Deddick Park		3											9	121		133	3
18	Ambyne		3											10	9		22	3
15	Buchan 2	1	3			2						1		9	49		56	6
19	Buchan Station	1	4			35						1		7	38		86	6
	Annual total	**102**	**86**	**88**		**40**		**225**		**1**	**4**	**2**	**4**	**58**	**232**	**20**	**862**	**12**
	No. Sites	**10**	**10**	**4**		**3**		**4**		**1**	**1**	**2**	**1**	**7**	**8**	**4**		

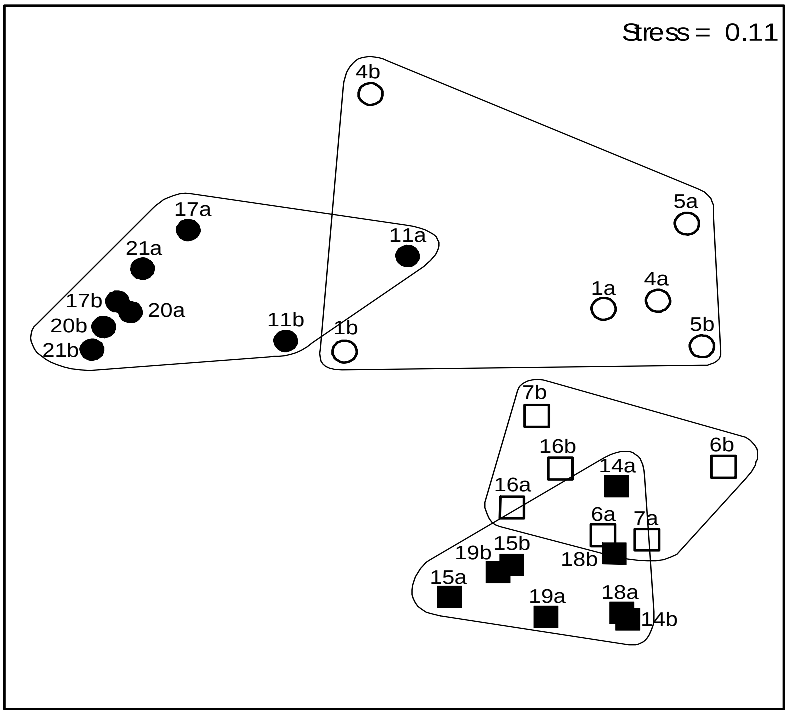


Figure 31. MDS ordination of fish samples from the Snowy River system in 2000 and 2001 (Source: Gherke, 2001).

Open symbols represent sites in performance reaches, solid symbols depict reference reaches in tributaries. Circles show sites upstream of Snowy Falls, squares show sites downstream of Snowy Falls. Letters *a* and *b* after site numbers represent samples collected in 2000 and 2001.

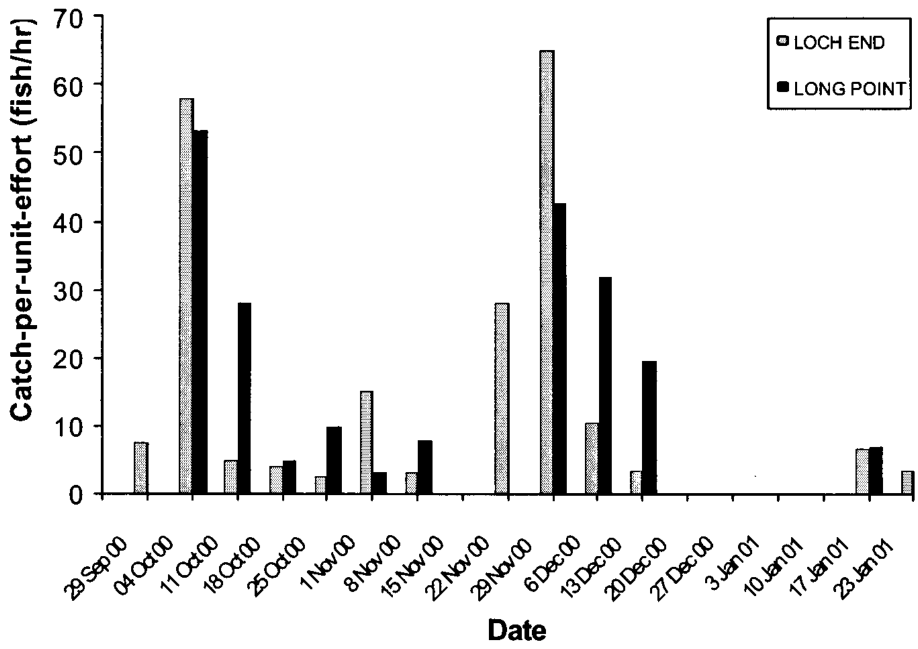


Figure 32. Pooled catch-per-unit-effort of key migratory fish species per week per site, for the period 25 September 2000 to 23 January 2001 (Source: Raadik *et al.*, 2001).

3.6.5 Discussion

The results to date indicate that spatial variation may explain the distribution of fish communities in the Snowy River rather than annual variation, and therefore continued annual sampling should be sufficient to detect changes resulting from environmental flows (Gehrke, 2001).

A clear spatial separation in the fish communities above and below Snowy-Falls was recorded (Figure 31). The reasons for the differences in the fish assemblages are unclear at this stage, but the interaction of natural barriers and reduced river discharge need to be further investigated to determine if it is a significant factor in determining the composition of fish within the Snowy River. This is an important factor for fish recruitment in the Snowy River as many of the fish species require large-scale migration to complete their life cycle.

Further investigations into fish recruitment in the lower Snowy River should begin in early August to capture peak migration data for the key species collected, and later into summer for Australian bass (Raadik *et al*, 2001). Also, further investigation is required to determine the causes of low recruitment in Australian bass and other absent migratory species. Time series data is required for migratory species, as well as comparison with migration rates in reference and control streams.

A potential issue for the Snowy Benchmarking project will be the need to better co-ordinate fish management in the Snowy River. Uncontrolled stocking of fish into the Snowy River may confound the results of the Benchmarking project to assess the impact of the environmental flow releases on the fish communities of the Snowy River. Similarly, stocking of trout in reference rivers will confound the project's design.

3.6.6 Key fish findings

- Further investigation into fish communities, recruitment and barriers are required to determine the causal factors in fish species distribution and abundance; and,

- The stocking of trout and Australian bass for recreational fishing will likely confound the results of fish surveys. It will be difficult to determine the effect of environmental flows on fish communities in the Snowy River without increased funding and coordination of fish research and management.

4. DISCUSSION

The hydrology of the Snowy River below Jindabyne Dam has been significantly altered by flow regulation. Flow volumes at Dalgety have been reduced to 1% of the flow volume before the dam, with the magnitude of median monthly discharges and seasonal variability appreciably attenuated. Flow variability has also been reduced, with variance in monthly discharge between the pre- and post- dam periods significantly reduced for all months. Flow duration and flood magnitude and frequency have also been reduced. Similar hydrological responses are expected when data are analysed from other gauging stations along the river, however the magnitude of impact is expected to decrease with distance downstream because of tributary inflows.

These hydrological changes in the Snowy River have impacted on river channel morphology. The channel has contracted markedly at the upland Snowy River test sites (DLWC, 1998a). Elsewhere, the river has infilled with sand, and attached side bars at Bete Bolong have been replaced by longitudinal bars due to the absence of large magnitude long duration floods, and reduced frequency of flushing flows (DLWC, 1998a). Even the post-June 1998 flood had little effect on sediment mobilisation at McKillops Bridge, however there was significant re-distribution of sand at Sandy Point and Bete Bolong because of tributary contributions (Erskine and Turner, 2002). These changes combined with catchment impacts have degraded physical habitats making them homogeneous at most sites. Riparian and aquatic vegetation invade the channel boundary, peat has formed in wetland margins, and thick veneers of biogenic sediment are common over the substrate.

Hydraulic modelling showed that flows considerably higher than 12,000 MLd^{-1} were required to induce entrainment of cobble size material and generate velocity reversals in pools in the Jindabyne gorge. This is important because velocity reversals develop structural pools in bedrock riverbeds over geologic time, and prevent the deposition of bed load sediment in pools. Flushing flows of 1,000 MLd^{-1} however, were theoretically, sufficient to remove very coarse sand from the pools, and cobbles from riffles in the gorge (Reinfelds, 2000). A 30,000 MLd^{-1} outlet on Jindabyne Dam is required to re-form the channel boundary and would provide the flexibility to manipulate the regime to specific recovery of the river's ecology (Reinfelds and Erskine, 2000).

The water temperature of the Snowy River exhibits strong seasonal variation and high summer temperatures. Electrical conductivity concentrations correspond with discharge, increasing with flow events from local rainfall below Jindabyne Dam. Analysis of long term water quality data is required. The Snowy River sites 1, 2 and 3 below Jindabyne Dam exhibited some temperature and oxygen stratification in summer 2000, as did the Delegate River reference sites. Further investigation of a possible combined influence between discharge, pool depth and pool length on stratification in the Snowy River at site 1 would be a useful addition to the project, however a cost benefit analysis of collecting this information would be required for the considerable cost involved.

Plants introduced to the Snowy River occurred at all sites. The most common aquatic weed species in the river is *Elodea canadensis*. The weed flora indicated a strong seasonal component in explaining observed variation whereas native flora indicated a high component of macro reach distribution in explaining the observed variation. Strong seasonal patterns were shown for all analyses indicating the importance of seasonal sampling in determining natural variability of vegetation and macro-algae along the river. In order to detect changes due to any significant flow releases, groups of flow response indicator plants and macro-algae must be determined for future analyses.

The reduced flows and increased sedimentation significantly impact macroinvertebrate communities in the Snowy River. For example, the riffle habitats of the upland Snowy River sites contain significant abundances of Tipulidae, Pyralidae and Gomphidae, taxa that are generally thought to prefer slow flowing or still waters. The presence of these taxa in riffles reflects the changes to hydrology and habitat caused by Jindabyne Dam. The fauna of the Eucumbene River, whilst distinct from the nearby Snowy River sites below Jindabyne Dam, also reflect the impact of flow regulation. The reference site assemblages are thought to represent those of the Snowy River before flow regulation, which may become more similar after the release of significant environmental flows such as the flow recommendations of Pendlebury *et al*., (1996).

There were distinct spatial variations in the fish communities, with differences between the Snowy River and reference sites, and above and below Snowy Falls. Further investigation of a possible interaction between reduced discharge and natural barriers such as Snowy Falls is required. Low recruitment success of Australian bass and other migratory species was recorded during the native fish recruitment study in the lower Snowy River and needs further investigation.

Continued monitoring of these physical and biological components of the Snowy River is required to determine the effect of environmental flows that will be released from Jindabyne Dam and the Mowamba River. The results of the Snowy River Benchmarking Project will provide essential data to the Snowy Scientific Committee (SSC) to be formed as part of Snowy Corporatisation, in order for the SSC to perform its legislative duties. These results will form the basis of the Five-Year Review to be completed following the release of environmental flows. The information on the Snowy River's response to environmental flows will guide adaptive management of releases from Jindabyne Dam to improve the physical and biological integrity of the Snowy River. To effectively implement adaptive management it will be necessary to continue monitoring the effect of environmental flow releases for at least the next ten years.

5. RECOMMENDATIONS

1. Further investigation is required on the degree of association between the river's biota and the environment to provide correlative evidence at sites where there is no control;

2. Complete hydrologic assessment for remaining gauging stations;

3. Conduct rainfall/runoff analysis so that changes in the river's ecology can be attributed to flow releases and not natural climatic variability;

4. Extend hydraulic modelling to predict changes in the channel boundary, in pools and riffles, for other sites down the river;

5. Extend hydraulic modelling to define sediment mobility to discharge thresholds, for other sites down the river;

6. Conduct hydraulic modelling at flows lower than 1,000 MLd^{-1} to investigate threshold discharges below which the average velocity in deep pools decreases to < 0.15 ms-1 (a situation conducive to deposition of fine-grained sediment);

7. Once (3) and (6) are accomplished, investigate pre- and post- Jindabyne Dam, and environmental flow release flow durations above which flows are sufficient to prevent silt deposition;

8. Investigate whether velocity reversals in pools can be generated under lower flows than previously modelled by increasing floodplain roughness coefficients;

9. Before flows are released 'tag' rocks of various size grades at several sites to undertake validation of sediment mobility thresholds;

10. After flows are released survey-in flood marks at cross section sites to enable calibration of observed water surface profiles to model water surface profiles;

11. In-channel benches and bars are sensitive to flow-induced channel changes and need to be investigated in more detail;

12. Determine indicator species for vegetation and macro-algae to focus on the effect of flow regulation and environmental flow releases;

13. Discontinue sampling macro-algae in pools because of high variability;

14. Whilst the macroinvertebrate results are significant at the family level, the Technical Steering Committee suggested that the identification of macroinvertebrates to genus or species level may provide more information on the current effects of Jindabyne Dam and future response to environmental flows. All samples are retained so this can take place at a future date if required;

15. Further investigation into the causes of fish species distribution and abundance are required. This includes investigation of native fish recruitment, the effect of

barriers to fish passage and research focussed on management target species such as Australian Bass;

16. The confounding effects of fish stocking on the results of environmental flow response monitoring for the Snowy River Benchmarking Project need to be addressed;

17. Conduct water quality analyses for all relevant gauging stations throughout the catchment;

18. Conduct a cost benefit analysis of further investigation of pool stratification and any relationship to discharge, pool depth and pool size at Snowy River site 1 (eg., the cost of installing and maintaining telemetered thermistors and undertaking field measurements of dissolved oxygen;

19. Compare each component measured with reference and control rivers and with distance downstream of Jindabyne Dam; and,

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APPENDIX 1. STAKEHOLDER INVOLVEMENT AND TECHNOLOGY TRANSFER

Stakeholder involvement

The main stakeholders in the Snowy River Benchmarking project at present are the NSW and Victorian State governments, namely the Department of Sustainable Natural Resources (formerly the Department of Land and Water Conservation), Department of Natural Resources and Environment, and East Gippsland Catchment Management Authority. Additional involvement in the project is from the South East Catchment Management Board, the Environment Protection Authority, and independent scientists (Figure 1). In the near future, when the Snowy Scientific Committee is established under Snowy Corporatisation, there will be additional stakeholder agencies. These will be the Federal Government, Snowy Hydro, The Snowy River Alliance, tourism operators, anglers, and landholders along the Snowy river who are interested in the project.

Technology transfer

An overview of the project's design and methods was presented at the *Snowy Rivers Forum* during the Australian Society for Limnology (ASL) conference in Darwin July 2000. This and other technical presentations provided focus for the members at the annual general meeting to draft a position paper on Snowy River issues (http://www.asl.org.au/asl_snowy_poldoc.htm).

The designs for this project have evolved through research, discussion with monitoring scientists and peer review by the project's Technical Steering Committee. The designs are somewhat unique, and as a result, many requests from within, and outside the Department of Sustainable Natural Resources (DSNR) have been made for guidance on particular projects and assistance in solving specific sampling design problems in river's expecting to receive environmental flows. Some recent examples:

River	Requesting scientist/body	Purpose of request
Hawksebury-Nepean	H-N R ⇒ IEP	Developing performance assessment monitoring programs for environmental flows
rivers in general	Arthur Rylah Institute	Review of current methodologies on environmental flow assessment
Goodradigbee	DLWC, Murrumbidgee Region	Methodology of environmental flow assessment
Hawksebury-Nepean	DLWC, Penrith	Choosing environmental indicators
Consumnes	Michigan State University	Methodology of environmental flow assessment
Cox's	DLWC, Penrith	Methods of vegetation assessment
Snowy	CSIRO Land and Water	Case study to the World Bank Water Form 2002
Cudgegong	DLWC, Central West region	Methods of assessment for channel change, sediment movement and vegetation

APPENDIX 2. INDEX TO ELECTRONIC META-DATABASES FOR THE SNOWY BENCHMARKING PROJECT

Databases are currently being developed for Snowy River Benchmarking data, therefore it is considered more effective to supply data to Environment Australia when they have been finalised. Following are meta-data files for each project component prepared in accordance with ANZLIC standard format.

Hydrology meta-data for the Snowy Benchmarking project

Category	Element	Comment
Data-set	Title	DLWC
	Custodian	DLWC
	Jurisdiction	Bega, NSW
Description	Abstract	Instantaneous flow data recorded at gauging stations in the Snowy River catchment and some surrounding gauges. **See example of output below.**
	Search Word(s)	Set list
	Geographic Extent Name(s)	Hydsys database
	Geographic Extent Polygon(s)	TBA
Data Currency	Beginning date	Period of record differs for each gauging station
	Ending date	Current
Data-set Status	Progress	In progress
	Maintenance and Update Frequency	Data is downloaded at two monthly intervals
Access	Stored Data Format	Hydsys database
	Available Format Type	Digital form
	Access Constraints	None known
Data Quality	Lineage	Continuous hydrological monitoring stations are equipped with a height measuring sensor, automatic recorder and data logger that provide a continuous digital record of stage. Telemetred stations allow the data to be accessed remotely and in real time.
	Positional Accuracy	Lat/long coordinates are available for all records. Data points have been identified using the best available topographic maps.
	Attribute Accuracy	Not known
	Logical Consistency	Linked
	Completeness	Edited and quality coded archive
Contact Information	Contact Organisation	DLWC, Bega
	Contact Position	Paul Corbett (hydrographer)
	Mail Address 1	P.O. Box 118
	Mail Address 2	N/A
	Suburb or Place or Locality	Bega
	State or Locality	NSW
	Country	Australia
	Postcode	2550
	Telephone	(02) 6492 3439
	Facsimile	(02) 6492 3439
	Electronic Mail Address	pcorbett@dlwc.nsw.gov.au
Metadata Date	Metadata Date	Extracted from Hydsys when required
Additional Meta-data	Additional Metadata	N/A

Geomorphology meta-data for the Snowy Benchmarking project

Category	Element	Comment
Dataset	Title	DLWC
	Custodian	DLWC
	Jurisdiction	Sydney South Coast, Cooma, NSW
Description	Abstract	Land survey, sediment grain size and habitat mapping data are collected every 2-3 years or after a > 1 in 5 year flood in the Snowy River, reference and control rivers.
	Search Word(s)	Set list
	Geographic Extent Name(s)	Snowy River - Sydney South Coast Region, Cooma, NSW
	Geographic Extent Polygon(s)	TBA
Data Currency	Beginning date	1996
	Ending date	Current
Dataset Status	Progress	In progress
	Maintenance and Update Frequency	Continual
Access	Stored Data Format	Land survey and habitat mapping data are stored electronically in Foresight and sediment data in Mircosoft Excel/Word
	Available Format Type	Digital text and charts, digital text.
	Access Constraints	Permission required
Data Quality	Lineage	All data is collected using standard repeatable procedures by trained observers
	Positional Accuracy	Sites are connected to AHD and the coordinate system is AMG 66
	Attribute Accuracy	Land survey data is accurate to ± 0.005m, habitat data to 1 m and sediment data is limited by the sampling methods used (these are well documented)
	Logical Consistency	Guided by algorithms
	Completeness	All data is verified by survey closure
Contact Information	Contact Organisation	DLWC, Goulburn (land survey and habitat data) DLWC, Cooma (sediment data)
	Contact Position	Land survey and habitat data (Kevin Brown), sediment data (Teresa Rose)
	Mail Address 1	P.O. Box 390, Goulburn, NSW 2580
	Mail Address 2	P.O. Box 26, Cooma, NSW 2630
	Suburb or Place or Locality	as above
	State or Locality	NSW
	Country	Australia
	Postcode	as above
	Telephone	Kevin Brown (02) 4828 6713 Teresa Rose (02) 6452 1455
	Facsimile	Kevin Brown (02) 4821 9413 Teresa Rose (02) 6452 2080
	Electronic Mail Address	kjbrown@dlwc.nsw.gov.au troce@dlwc.nsw.gov.au.
Metadata Date	Metadata Date	1996
Additional Metadata	Additional Metadata	N/A

Water quality meta-data for the Snowy Benchmarking project

Category	Element	Comment
Data-set	Title	DLWC
	Custodian	DLWC
	Jurisdiction	Sydney South Coast, NSW
Description	Abstract	Instantaneous water quality recorded at two gauging stations. See example of output below.
	Search Word(s)	Set list
	Geographic Extent Name(s)	Snowy River – Sydney South Coast Region
	Geographic Extent Polygon(s)	TBA
Data Currency	Beginning date	1972
	Ending date	Current
Data-set Status	Progress	In progress
	Maintenance and Update Frequency	Two monthly intervals
Access	Stored Data Format	**Digital** data set is stored electronically in HYDSYS, the computer system DLWC uses for is hydrographic and water quality data. Non-digital data is stored as text in Microsoft Excel or field notes.
	Available Format Type	**Digital** Text and charts, **Non-Digital** Text
	Access Constraints	None known
Data Quality	Lineage	Continuous monitoring stations are equipped with temperature and electrical conductivity probes and data logger that provide a continuous digital record. Telemetred stations allow the data to be accessed remotely and in real time.
	Positional Accuracy	Lat/long coordinates are available for all records. Data points have been identified using the best available topographic maps
	Attribute Accuracy	Not known
	Logical Consistency	Not known
	Completeness	Edited and quality coded archive
Contact Information	Contact Organisation	Resource Information Unit, Sydney/South Coast Region, DLWC, Bega
	Contact Position	Paul Corbett, Hydrographer
	Mail Address 1	P.O. Box 118
	Mail Address 2	N/A
	Suburb or Place or Locality	Bega
	State or Locality	NSW
	Country	Australia
	Postcode	2550
	Telephone	(02) 6492 3439
	Facsimile	(02) 6492 3439
	Electronic Mail Address	pcorbett@dlwc.nsw.gov.au
Metadata Date	Metadata Date	Extracted from Hydsys when required
Additional Metadata	Additional Metadata	N/A

Vegetation meta-data for the Snowy Benchmarking project

Category	Element	Comment
Data-set	Title	DLWC
	Custodian	DLWC
	Jurisdiction	Sydney South Coast, Cooma, NSW
Description	Abstract	Plant composition, present/absence and abundance data are collected at the species level from sites in the Snowy River catchment and selected reference and control sites.
	Search Word(s)	Set list
	Geographic Extent Name(s)	Snowy River - Sydney South Coast Region, Cooma
	Geographic Extent Polygon(s)	TBA
Data Currency	Beginning date	1996
	Ending date	Current
Data-set Status	Progress	In progress
	Maintenance and Update Frequency	Continual
Access	Stored Data Format	Data is stored electronically in Access database. The system is currently being further developed.
	Available Format Type	Digital and non-digital text and charts
	Access Constraints	Permission required
Data Quality	Lineage	Data are collected using standardised methods by trained consultants and provided on CD.
	Positional Accuracy	Lat/long coordinates are available for all records. Data points have been identified using the best available topographic maps.
	Attribute Accuracy	Not known
	Logical Consistency	Linked
	Completeness	Edited and quality coded archive
Contact Information	Contact Organisation	DLWC, Cooma.
	Contact Position	Teresa Rose
	Mail Address 1	P.O. Box 26
	Mail Address 2	N/A
	Suburb or Place or Locality	Cooma
	State or Locality	NSW
	Country	Australia
	Postcode	2630
	Telephone	(02) 6452 1455
	Facsimile	(02) 6452 2080
	Electronic Mail Address	trose@dlwc.nsw.gov.au
Meta-data Date	Metadata Date	1996
Additional Meta-data	Additional Metadata	Will be linked with GIS in the future

Macroinvertebrate meta-data for the Snowy Benchmarking project

Category	Element	Comment
Data-set	Title	DLWC
	Custodian	DLWC
	Jurisdiction	Sydney South Coast, NSW
Description	Abstract	Macroinvertebrate abundance and community composition data at taxonomic level of family, collected at Snowy River benchmarking and reference and control sites on biannual basis in spring and autumn
	Search Word(s)	Set list
	Geographic Extent Name(s)	Snowy River – Sydney South Coast Region
	Geographic Extent Polygon(s)	TBA
Data Currency	Beginning date	Nov 1999
	Ending date	Current
Data-set Status	Progress	In progress
	Maintenance and Update Frequency	Continual
Access	Stored Data Format	Data is stored electronically in Microsoft excel, to be transferred to Microsoft Access.
	Available Format Type	**Non-Digital** Text
	Access Constraints	None known
Data Quality	Lineage	Data are collected using standardised sampling methods by trained staff
	Positional Accuracy	Lat/long coordinates are available for all records. Data points have been identified using the best available topographic maps
	Attribute Accuracy	Not known
	Logical Consistency	Not known
	Completeness	Nov 1999-May 2001. Later samples being identified in laboratory
Contact Information	Contact Organisation	Resource Analysis Unit, Sydney South Coast Branch, DLWC, Wollongong
	Contact Position	Robyn Bevitt, Resource Officer Snowy River
	Mail Address 1	P.O. Box 867
	Mail Address 2	N/A
	Suburb or Place or Locality	Wollongong
	State or Locality	NSW
	Country	Australia
	Postcode	2520
	Telephone	(02) 4224 9688
	Facsimile	(02) 4224 9689
	Electronic Mail Address	Rbevitt@dlwc.nsw.gov.au
Meta-data Date	Meta-data Date	March 2002
Additional Meta-data	Additional Meta-data	N/A

Fish meta-data for the Snowy Benchmarking project

Category	Element	Comment
Data-set	Title	DLWC
	Custodian	DLWC
	Jurisdiction	Sydney South Coast, NSW
Description	Abstract	Fish abundance and community composition data at taxonomic level of species, collected at Snowy River benchmarking and reference and control sites on biannual basis in spring and autumn
	Search Word(s)	Set list
	Geographic Extent Name(s)	Snowy River – Sydney South Coast Region
	Geographic Extent Polygon(s)	TBA
Data Currency	Beginning date	March 1998
	Ending date	Current
Data-set Status	Progress	In progress
	Maintenance and Update Frequency	Continual
Access	Stored Data Format	Data is stored electronically in Microsoft Excel and Word
	Available Format Type	**Non-Digital** Text
	Access Constraints	None known
Data Quality	Lineage	Data are collected using standardised sampling methods by trained staff
	Positional Accuracy	Lat/long coordinates are available for all records. Data points have been identified using the best available topographic maps
	Attribute Accuracy	Not known
	Logical Consistency	Not known
	Completeness	March 1999-Feb 2001
Contact Information	Contact Organisation	Resource Analysis Unit, Sydney/South Coast Branch, DLWC, Wollongong
	Contact Position	Robyn Bevitt, Resource Officer Snowy River
	Mail Address 1	P.O. Box 867
	Mail Address 2	N/A
	Suburb or Place or Locality	Wollongong
	State or Locality	NSW
	Country	Australia
	Postcode	2520
	Telephone	(02) 4224 9688
	Facsimile	(02) 4224 9689
	Electronic Mail Address	Rbevitt@dlwc.nsw.gov.au
Meta-data Date	Metadata Date	March 2002
Additional Meta-data	Additional Metadata	N/A