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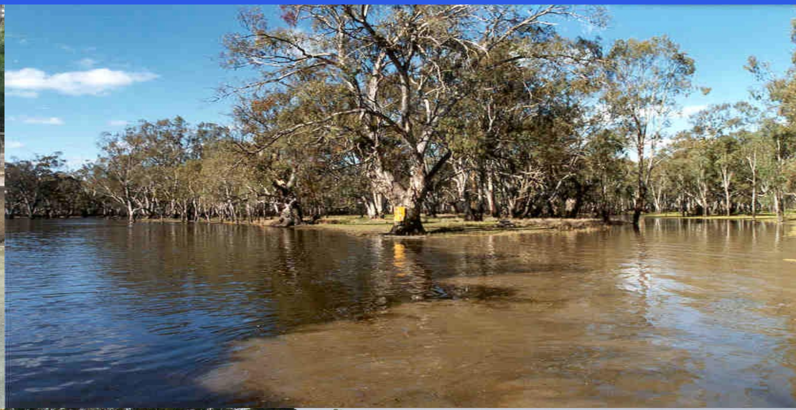

Monitoring Programs for Environmental Flows in Australia – A Literature Review

Alison King, Jacqui Brooks, Gerry Quinn, Andrew Sharpe and Shanaugh McKay

Victoria The Place To Be

Cooperative Research Centre for Freshwater Ecology

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MONITORING PROGRAMS FOR ENVIRONMENTAL FLOWS IN AUSTRALIA– A LITERATURE REVIEW

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Cover photographs (left to right from top): **Gulpa Creek regulator, Millewa Forest, New South Wales.** Photo: Matthew Jones, DSE; **Broken Creek in 2000 after a flood, Victoria.** Photo: Ivor Stuart, DSE; **Kalatha Creek, Yea River Catchment, Victoria.** Photo: Shanaugh McKay, DSE; **Goulburn River Weir, Victoria.** Photo: Justin O'Mahony, DSE.

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Introduction

Human induced degradation of land, floodplain, riparian and riverine areas is recognised as a major problem within Australia and throughout the world. Streams and rivers have experienced some of the most severe forms of habitat destruction and simplification (Allan & Flecker 1993; Stanford *et al.* 1996). The economic and ecological importance of streams and rivers has led to significant restoration and rehabilitation effort, in an attempt to return these systems towards a more natural and "healthy" condition (Karr & Chu 1999). The results of many of these restoration programs have been frequently reported in the international scientific literature, particularly from North America. The nature of these restoration activities is diverse and includes simple habitat improvement processes, such as the reintroduction of woody debris to improve fish habitat, the replanting of riparian vegetation, the implementation of environmental flows, hydrological experimentation, and channel engineering (reviewed by Palmer *et al.* 1997; Rutherfurd *et al.* 1998; Smokorowski *et al.* 1998).

There is an extensive terminology associated with restoration and rehabilitation and the definition of these terms has been strongly debated in the literature. As stated by Schreiber & Cottingham (2000) "the clear separation of these terms is necessary, as they imply different outcomes, and the use of appropriate terminology is important so that project objectives are clear". For the purpose of this report, the following definitions have been adopted. *Conservation* includes the total group of actions undertaken to protect, maintain, restore, rehabilitate or remediate a system so as to retain or restore its natural significance (Phillips *et al.* 2001). *Restoration* is defined as the act of restoring a system to a "close approximation of its condition prior to disturbance, with both the structure and function of the system recreated" (National Research Council 1992). *Rehabilitation* involves "the act of restoring a system to a previous condition or status". In contrast to restoration there is no underlying implication of a return to a state without any human disturbance. *Remediation* implies an attempt to improve a system in some way, but not necessarily to the full extent required by restoration or rehabilitation projects.

The term "Environmental Flows" has been broadly applied and refers generally to the component of water flowing down a river that is reserved solely for the purpose of improving the ecological environment of rivers and their floodplains. In many regulated river systems, Environmental Water Allocations (EWAs) provide an important component of the environmental flows within the system. In regulated rivers, the term EWA refers to a volume of water that is held in storage and released to the river environment at times designed to benefit natural ecosystem processes (Reid *et al.* 2001). In unregulated streams, the primary source of environmental flows is derived from water savings that result from reduced water extraction, generally increasing summer low flow level.

Within Australia, the need for environmental flows and water allocations has arisen from the high degree of flow regulation and/or water extraction from rivers. Analysis of historic and current hydrologic data have revealed that the effects of regulation and/or flow extraction have had two major impacts on the natural hydrographs of many Australian rivers. First, there has been a general decrease in the median annual flow of the rivers. For example, at the mouth of the Murray River in South Australia, cumulative effects of water extraction along the length of the River has resulted in a present-day median flow that is only 21% of the natural median flow (Crabb 1997). Reduction in total flow volume can also occur downstream of major extraction regulating structures, decreasing the frequency, magnitude and duration of flood events. Second, regulation has resulted in dramatic changes to the timing and magnitude of high and low flows close to the major impoundments and storage structures. Historically, lowest flows occurred in summer in southern Australia. However, summer is the period of peak irrigation demand, which necessitates water being released from storage. Accordingly, the hydrographs of rivers immediately below large storages are effectively seasonally reversed. Within these regulated systems, summer water releases have the added effect of reducing the frequency of very low flows. These effects decrease with distance downstream away from the storage, but are apparent at some level throughout the entire length of the river. Large impoundments also have a flood mitigating capacity, such that while very large floods still occur at around the same frequency, mid-sized floods are considerably less frequent within regulated rivers (Maheshwari *et al.* 1995, Thoms *et al*. 2002). Conversely, in unregulated rivers, the extraction of water over summer tends to increase the frequency of very low to cease-to-flow events.

It is generally accepted that any alteration of a natural river hydrograph has the potential for significant ecological impacts on instream and riparian river ecosystems (Poff *et al*. 1997, Richter *et al*. 2003). Changes to river flow conditions also have direct consequences on the timing, magnitude and duration of floodwaters received by river floodplains, which can result in significant lasting changes to the ecology and health of associated wetlands (Reid & Brooks 2000, Thoms *et al*. 2002). In recognition of the potential for ecological degradation of river and floodplain ecosystems, management agencies in many parts of the world are planning and implementing environmental flows and water allocations in a wide range of river systems (Richter *et al*. 2003). At present, the planning and implementation of these programs is most prevalent in Australia and South Africa (see review by Tharme in press). Although the range of methods for planning and implementing environmental flows is enormous (Arthington & Zalucki 1998, Tharme in press), two very broad strategies can be adopted. First, flows can be provided for specific biota or habitats, such as a flow pulse to promote fish spawning or to maintain connectivity or water quality during low-flow periods. Second, components of the natural flow regime, including the natural variability in low and high flows, can be reinstated (Poff *et al*. 1997). There are many versions of this latter approach based on the natural flow paradigm, termed holistic by Arthington & Zalucki (1998), and these are being used to determine environmental flows in both Australia and South Africa.

Essential to the long-term success of any environmental flow and/or water allocation, is the development of measurable objectives and well designed, scientifically rigorous, cost-effective and easily implemented monitoring programs. Results from these programs will provide evidence of the level of success of the designated environmental flow, and allow an "adaptive management" approach to be applied. Clearly specified objectives leading to hypotheses that can be addressed by targeted monitoring programs should become an integral part of all restoration and rehabilitation projects (Block *et al*. 2001), including those involving environmental flows. Information gained from monitoring the outcomes of these projects will ensure that future management programs can include the knowledge gained from past management activities for future improvements.

Our aim is to review recent developments toward rigorous, scientifically valid monitoring of rehabilitation in aquatic systems, focusing on the monitoring of environmental flows within Australia. We will examine the designs of monitoring programs for some key environmental flows projects in Australia and report how these match the general recommendations for monitoring the rehabilitation of aquatic ecosystems. The information gained from this review will be important for the development of guidelines for designing monitoring programs for environmental flow restoration programs.

Monitoring Ecological Impacts and Restoration Activities

Approaches for monitoring ecological responses to human interventions have received much recent attention from ecologists, especially those working in aquatic ecosystems (Schmitt & Osenberg 1996, Downes *et al*. 2002). The focus of this work has been on assessments of degrading interventions, such as pollution events. Current interest in the restoration of land and water ecosystems has prompted the timely investigation of methods appropriate for the assessment and validation of restoration and rehabilitation efforts (Downes *et al*. 2002, Michener 1997, Block *et al*. 2001). Michener (1997) recognised that most restoration efforts might not always be amenable to traditional designs and analyses because, like degrading interventions, they are often unplanned and unreplicated. He argued that a broad range of techniques should be considered when evaluating restoration experiments, including long-term studies and space-for-time substitution, the latter being when sites are sampled that represent different periods post-restoration (see also Pickett 1989).

Schreiber & Cottingham (2000) reviewed the literature to identify currently acceptable approaches to validating the effectiveness of habitat rehabilitation in rivers. In their review of the Australian unrefereed literature from the past eight years, Schreiber & Cottingham (2000) located only seven reports that were directly related to the rehabilitation of stream habitat. The majority of reports were related to land rehabilitation, and a relatively small number of the reports were related to wetland rehabilitation. Schreiber & Cottingham (2000) concluded that the majority of rehabilitation projects lacked adequate attempts at validating their success. In response to this review, Stewardson *et al*. (2002) presented three possible approaches to evaluating the success of river restoration attempts. The first approach involved evaluation only after a project has been completed. Post-project evaluation would generally only be considered where habitat reconstruction work was completed some time in the past. This type of analysis may take two forms: a) an analysis of trends in the response to restoration, based on a comparison of the condition of sites that were restored at different times in the past (space-for-time substitution; see Pickett 1989); and b) a one-off comparison of restored sites with sites that have not been restored (this method does not consider temporal trends in response). The second approach involved a combination of management and evaluation, applying either an adaptive management approach or a more conventional monitoring approach to a planned management-initiated restoration effort. Adaptive management specifically includes a modelling component to simulate and compare alternate management options and one (passive management) or multiple (active management) options are initiated as management experiments (Walters 1986, Schreiber *et al*. submitted). Conventional monitoring evaluates a management-initiated rehabilitation activity, but without the simulation phase and without formal consideration of alternative management actions. The third approach involved the design of an experiment that is dedicated to revealing the effects of the restoration attempt and incorporates sampling before and after the restoration and using spatial controls and reference systems. The main distinction between approaches two and three is that the design of the former may be constrained by political and pragmatic issues that may also restrict the analysis options, and therefore may limit the conclusions. In the latter approach, the researchers have control over the restoration experiment and can ensure an appropriate design and analysis.

A full evaluation of each of these approaches led Stewardson *et al.* (2002) to conclude that the third approach, the development of a dedicated experiment, was likely to provide the most appropriate method for evaluating the effectiveness of stream habitat reconstruction. However, the scope of habitat degradation and rehabilitation projects that were considered in the Stewardson *et al.* (2002) review was relatively narrow, and included only those projects that involved the clearing/rehabilitation of native riparian vegetation and the access of stock along stream banks. The rehabilitation of flow regimes through the instigation of environmental flows and water allocations was not considered in their review. This form of restoration/rehabilitation is known to be fraught with a range of social, economic and political issues that compromise the practicalities of water delivery. Uncertainty surrounding water delivery will undoubtedly influence which of the three proposed evaluation approaches is most likely to be successful for evaluating the success of environmental flows. Indeed, a dedicated experiment may be far less practical in a situation where the amount of water delivered is likely to be too small to produce a detectable ecological response at a single restored site or the timing of water delivery is subject to last-minute changes by management authorities. In this situation, an approach that rigorously monitors a management activity, such as a changed flow regime, may be more appropriate.

Stewardson *et al.* (2002) proposed that in situations where targeted management (e.g. restoration of a particular reach of river) is the over-riding objective, decisions regarding site selection, project timing and the choice of rehabilitation methods are determined by management priorities rather than the needs of an appropriate monitoring program. While monitoring may be actively supported by the management agency, constraints imposed by management priorities can lead to inadequate program planning, and highly complex or unique projects that have little generality. In such situations, Stewardson *et al.* (2002) questioned the ability of conventional monitoring of a management-initiated rehabilitation activity to provide useful information to guide the planning of future habitat restoration efforts. Stewardson *et al.* (2002) recommended that conventional monitoring of management activities will be most informative in situations where:

1) there is sound project planning, including the development of clear ecological and management objectives;
2) sites used for rehabilitation are representative of the ecosystem more generally and of sites that may be considered for restoration in the future; and

3) there is sufficient time for the collection of data before rehabilitation works are implemented.

Generally speaking, current management and restoration principles rely on an incomplete knowledge of river ecosystems, which contributes in considerable uncertainty in how we expect an ecosystem to respond to management intervention. It is important, therefore, that management processes can incorporate new information and management techniques as they become available. Management must also be able to respond to temporal and spatial changes in important environmental/habitat variables. Similarly, changes in objectives that result from the changing expectations of stakeholders need to be considered. The challenge is to design monitoring programs that are flexible and can incorporate new information without compromising the fundamental hypotheses and data analyses.

Information gained from rigorously designed monitoring of management activities, or from evaluation of management experiments, will ensure that future rehabilitation efforts can include the knowledge gained from past management activities and also include new scientific insights. However, stakeholders must accept that management decisions will not be made solely for the purpose of achieving local management goals, but also to improve our understanding of the links between management actions and ecosystem responses (Stewardson *et al.* 2002). This increased understanding may require a more strategic approach to investment in river restoration, emphasising coordinated rehabilitation activities across space and time, particularly focusing on management experiments that can evaluate alternative actions and identify causal links with ecosystem responses.

Downes *et al.* (2002) outline a series of steps to be followed during the design and implementation of monitoring programs to detect human impacts. Michener (1997) and Block *et al*. (2001) also provide recommendations for monitoring but in the context of restoration. In summary, the method promoted by Downes *et al.* (2002) involves aspects of the following approach:

1. Define key objectives and management priorities.
2. Develop a conceptual model for the study region (see Michener 1997 for a restoration context).
3. Assess information on study sites and determine the availability of pre-existing data.
4. Decide on program design.
5. Determine the availability of control and/or reference sites.
6. Determine whether a “levels of evidence" approach is required.
7. Select variables and indicators for measuring responses.
8. Define specific objectives and propose hypotheses regarding expected changes in variables or indicators.
9. Decide on acceptable levels of environmental change in the response variables and indicators.
10. Collect pilot data, analyse pre-existing data, and adjust the final design/analytical model as necessary.
11. Optimise the monitoring design, given the money and resources available, to achieve the desired ratio of risks of errors.
12. Consider and decide on the type of management action to be taken in the event of an unacceptable change occurring.

The information presented in Downes *et al*. (2002) provides a thorough compilation of knowledge on conventional monitoring of ecological impacts and restoration efforts. There is little doubt that the information presented in this book will provide a firm foundation for many ecological monitoring programs, including those that might detect effects of environmental flows. Indeed, we envisage that the protocol outlined by Downes *et al*. (2002) would make a major contribution to general recommendations for monitoring ecological responses to environmental flows. However, monitoring environmental flows has particular challenges, such as lack of control sites and replication and on-going changes to nature of flow regime, that mean that a straightforward application of the protocol of Downes et al. (2002) will often not be possible.

Grayson *et al*. (1999) and Chapman & Underwood (2000) outline designs for monitoring restoration in urban and coastal wetlands. Their approach emphasises restoration as an experiment and uses the logic of a falsificationist test to determine whether restoration has been successful. While having much in common with the protocol described by Downes *et al*. (2002), they highlight some statistical procedures that will be particularly useful for restoration monitoring, including tests for bio-equivalence (McDonald & Erickson 1994) and application of before-after-control-impact designs.

Quinn *et al.* (2003) provide a framework for use in the development of a monitoring program to assess changes in the ecological condition of a large wetland ecosystem (Narran Lakes), which is located at the bottom end of the Narran River, a distributary of the flow-impacted Condamine-Balonne system on the NSW-Queensland border. This monitoring framework was designed to detect changes in wetland condition in response to 1) negative human impacts (e.g. land clearing and water resource development), and 2) restoration efforts that will result in increased flows down the river and into the terminal wetlands (e.g. altered land management practices or reduced water abstraction). The information presented by Quinn *et al.* (2003) is especially relevant to the current review because it focuses on detecting changes in ecological condition in response to environmental flows, in an ecosystem where control and reference comparisons are difficult and replication impossible. While neither Quinn *et al*. (2003) nor Downes *et al*. (2002) provide any simple solutions to the difficulties of monitoring ecosystem effects of human interventions at large scales (e.g. environmental flows), both stress the importance of clear objectives and a statement of our understanding of the system through a conceptual model. Both also suggest that a "lines-of-evidence" approach will be required when trying to assign causality in unreplicated interventions. The lines-of-evidence (or multiple levels-of-evidence) approach as described by Downes *et al*. (2002) uses various criteria (often correlative) to infer causality in the absence of the critical, well designed, monitoring program incorporating before data and appropriate controls.

Recent funding by the National Centre for Ecological Analysis and Synthesis (NCEAS) in the United States has promoted the establishment of the National River Restoration Synthesis Working Group (NRRSWG). The mission of the NRRSWG is to assess the quality of the science underlying ecological restoration activities, using stream ecosystems as model restoration systems. Research and investigations by the NRRSWG have led to the conclusion that monitoring of stream restoration projects, in general, is limited. Programs that are in place are often poorly planned and frequently were not developed specifically to monitor the effects of restoration activities, but were part of a previous, more general, monitoring program. Bash & Ryan (2002) also pointed out that even for those stream restoration projects being monitored, the nature of the data is very variable, making broader assessments difficult, and within Washington State (USA), most monitoring was voluntary.

It is clear from this brief overview that monitoring programs for restoration projects, including environmental flows projects, must be carefully designed and targeted specifically for the restoration project being assessed. The objectives must be clear, based around a conceptual model of how the ecosystem functions and how it is likely to respond to both the degrading influences and also the restoration effort. The design should match the fundamental criteria that have been identified as necessary for assigning causal links between responses and the restoration effort, and be flexible enough to incorporate new learning in an adaptive framework. The design options for meeting these requirements will be considered below with respect to current monitoring programs for environmental flows.

Current environmental flow monitoring programs

The development of a monitoring program for any restoration activity is a complex and time-consuming process that should be well considered and planned. We have reviewed eight Australian environmental flow monitoring programs in detail and examined their design and methodological features for similarities/consistencies, differences, successes and failures (see Table 1 for summary and Appendix for detailed review). We have structured the review around three basic themes in any monitoring program:

1. Initial development phase, including defining objectives, constructing conceptual models that summarise our understanding of how the ecosystem functions and developing predictions and hypotheses about how the system will respond to the environmental flow.
2. Choice of response variables or indicators, including how to select appropriate indicators and a discussion of the indicators that have been used in environmental flow monitoring programs.
3. Design considerations, including analytical and statistical design, use of controls or reference conditions, issues of scaling (both temporal and spatial), use of formal target setting, and use of multiple lines of evidence (Downes *et al*. 2002).

Table 1: Summary of environmental flow assessment programs conducted in Australia

Name of program	Chief researchers	Location	Aim of environmental flow	Indicators used	Spatial and temporal sampling details	Status
Campaspe Flow Manipulation Project (Partners: CRC for Freshwater Ecology, Marine and Freshwater Research Institute, Goulburn-Murray Water, CRC for Catchment Hydrology)	Dr. Paul Humphries, Prof. Sam Lake, Dr. Jane Growns	Campaspe River, Northeast, Victoria. Broken River as reference river.	Restore aspects of natural hydrology (translucent dam approach) outside irrigation season downstream of Lake Eppalock.	Fish larvae as indicators of spawning success Macroinvertebrate community composition on woody debris Adult fish community composition	Each river divided into 3 sections. See Table X for details of sampling protocol as spatial and temporal sampling differed between variables.	Project began July 1996 and will finish in 2004 due to lack of water available for environmental flows.
NSW Integrated Monitoring of Environmental Flows	Dr. Bruce Chessman headed the project, but there were numerous other contributors.	Barwon-Darling, Gwydir, Hunter, Lachlan, Macquarie, Murrumbidgee and Namoi River Valleys (NSW).	Environmental flows address 12 broad flow objectives that aimed to protect or restore flow levels and variability to natural ranges.	Hydrology, phytoplankton, biofilms, terrestrial organic matter inputs, river fish, and plants, macroinvertebrates, birds, fish and amphibians in wetlands.	Separate studies were conducted within each river valley. Different indicators were tested across sites within and between tributaries and main river channels and between replicate wetlands within in each valley. Sampling was conducted weekly in some cases (phytoplankton, but other variables were only measured once during the reported period).	Project design commenced in 1997. The first report (2003 – draft) presents data from 1998-2000. IMEF is intended to be a long term monitoring program and is ongoing.
Assessment of environmental flows for the Murrumbidgee River: developing biological indicators for assessing river flow management.	Dr. Robyn Watts, Dr. Darren Ryder, Ms. Laurie Chisholm, Ms. Bronwyn Lowe	Murrumbidgee River catchment	Environmental flow is based on four flow rules, (1) to protect low flows, (2) protect end of system flow (3) protect winter flow variability (April to October) and (4) provide water for contingencies. The project aim however was to develop and assess biological indicators for assessing river flow management	A variety of attributes of: Macroinvertebrates (inc. abundance richness and diversity of mayfly larvae, gastropods, *Paratya* sp.), Biofilms (inc. total, algal and organic biomass) Riverbank plants (inc. diversity, distribution, abundance, survival and growth rates). Floodplain trees (inc. Chlorophyll fluorescence)	The Murrumbidgee River was divided into 3 geomorphic zones (upper, middle and lower catchment). Various indicators were trialled across temporal scales ranging from days to several months.	Project complete. Conducted from December 1997 – July 2001.
Snowy River Benchmarking and Environmental Flow Response Monitoring	Teresa Rose, Robyn Bevitt (and subconsultants)	Upper and Lower Snowy River and tributaries downstream of	Achieve the maximum possible return of ecological and physical elements that	Hydrology, geomorphology, water quality, aquatic macrophytes, macro-algae, macroinvertebrates, fish.	11 test sites on the Snowy River, 13 reference sites on 8 tributary rivers, 2 control sites on the Eucumbene River and 3 former sites (now discontinued).	Project began 1997 -upgraded in 1999. Results available for pre flow release data up to June 2001. Pre flow release data to

Project		Jindabyne Dam.	characterised the river before flow regulation.			August 2002 in prep.
Ecological assessment of cyclic release patterns (CRP) from Dartmouth Dam to the Mitta Mitta River, Victoria	Lachlan Sutherland, Dr. Darren Ryder, Dr. Robyn Watts	Mitta Mitta River downstream of Dartmouth dam, Northeast Victoria	Introduce flow variability to water transfers from Dartmouth Dam to Hume weir to mimic minor natural flood events	Water quality parameters, river productivity parameters (inc. biofilm composition, benthic production/respiration, water column bacterial activity) and macroinvertebrates	Four sampling sites on the Mitta Mitta River downstream of Dartmouth Dam and one reference site in Snowy Creek. Nine sampling events spread throughout the three variable flow releases and during the constant flow period.	December 2001 – February 2002. Final report with recommendations for future monitoring completed.
Ecological monitoring of the Barmah-Millewa Forest Environmental Water Allocation	A variety of researchers. Administered by Barmah-Millewa Forum.	Barmah-Millewa Forest, Murray River	Extend natural flooding events in Barmah-Millewa Forest	Aerial photography of flood extent Waterbirds Frogs Fish (opportunistic surveys) Tree health (observations)	Variable (see text)	EWA also monitored during spring/summer 1998 & 2000. Intensive monitoring opportunistic depending on use of EWA. Monthly waterbird and frog surveys ongoing.
Measuring the effectiveness of environmental water allocations – Barmah-Millewa	Drs Michael Reid, Gerry Quinn and Terry Hillman	Barmah-Millewa Forest, Murray River	Extend natural flooding cycle in Barmah-Millewa Forest	Water depth (or soil moisture), turbidity, electrical conductivity, water temperature, dissolved oxygen concentrations, pH, aquatic macrophytes, aquatic macroinvertebrates, zooplankton (emergence)	Nine wetlands, five receiving environmental water allocations and four not. Eight situated within the Barmah-Millewa Forest, and one situated within Bruce's Bend Forest. Wetlands surveyed twice yearly, during late spring and in autumn.	Results available for the nine wetlands surveyed on four occasions from spring 1998 until autumn 2000. Recommended that monitoring continue for the pilot study.
Mersey River Aquatic Fauna Monitoring Program	Dr. Martin Read, Dr. Peter Davies, Mr Stuart Chilcott	Mersey River and its tributaries, Tasmania	Restore summer minimum flow levels and peak flows during winter and spring spates.	Fish abundance and species diversity, juvenile trout abundance Macroinvertebrate using AusRivAS Filamentous algal abundance	Variable (see text)	Commenced in 1996, flow change occurred 1999, monitoring is still ongoing.

Initial development phase

The first step in any monitoring program should be to clearly state and understand the objectives of the environmental flows and also the monitoring program itself. Whilst this seems an obvious statement, the explicit consideration of the management objectives and questions ensures that the outcomes are directly interpretable and useful, rather than an exercise in just generating data (Boulton *et al.* 2002). Overall, most of the programs reviewed clearly stated the objectives of the environmental flow for the systems. Often the objective of the environmental flow was broad and simply stated, for example the aim of the Snowy River environmental flow project is "to achieve the maximum possible return of ecological and physical elements that characterised the river before flow regulation" (Rose & Bevitt 2003). In most cases, the objectives of the monitoring program itself were also clearly stated and were obviously important in the consideration of the final design of the program. The NSW Integrated Monitoring for Environmental Flow (IMEF) program was established to provide additional understanding of the flow responses of river and wetland ecosystems, and to evaluate the environmental performance of the environmental flow rules across seven river valleys in NSW (Chessman & Jones 2001). The objectives of the IMEF program are clearly stated and go beyond the scope of most monitoring program objectives in that they aim not only to understand the responses of hydrology, habitat, biota and ecological processes associated with specific flow events, but also to estimate the likely long-term effects of the environmental flows (Chessman & Jones 2001). The aims of a monitoring program, however, should not necessarily be limited to demonstrating the environmental benefits of the new flow regime. An additional objective of the monitoring program for the Mersey River environmental flow program, for example, was to involve the local community in the monitoring, since there was substantial community and political concerns regarding the environmental flow releases (MRWG 1998).

All ecological monitoring programs should be based around a multidisciplinary conceptual model of how the system would naturally function and how it might change with human disturbance and any subsequent restoration activities (Michener 1997, Quinn *et al.* 2003). Conceptual models provide a descriptive summary of the ecosystem and the connections between its different components, important for representing and communicating our understanding of an ecosystem and how it might respond to flow change. Conceptual models are developed from a broad knowledge base of the study region including biological, chemical, hydrological, geological and geomorphological attributes. It is also important to consider any ecological assets in the study region, and any potential threats to these assets. The knowledge required to generate a specific conceptual model for the test system is often based on extrapolations from similar systems, general hypotheses and models relevant to that type of ecological system, for example the Flood Pulse Concept (Junk *et al.* 1989), and considerations from qualified experts, often from an appointed 'expert panel' (Cottingham *et al*. 2002). The conceptual model must be used cautiously, however. The different components and links in the model will be based on varying levels of uncertainty, sometime just intelligent guesses, and it is important that this uncertainty is identified (Ruckelhauss *et al*. 2002).

While most of the reviewed programs did develop conceptual models of their systems, few presented the evidence and justification for the components of the models. An understanding of the strengths and weaknesses of the conceptual model is necessary to constrain the use of the model within realistic bounds and allow modifications to the model when recognised deficiencies and weaknesses are resolved (Boulton *et al.* 2002). The Campaspe Flow Manipulation Project (CFMP) was one of the first large-scale, long term environmental flow experiments attempted, and as such the conceptual models developed in the initial phases of the project were based on the available knowledge at that time on how flows would affect lowland river biota. However, our understanding of the relationships between riverine biota and the flow regime, and their underlying mechanisms, have been greatly enhanced since then, and subsequent reviews of the CFMP have revised the basic conceptual model and added to the general understanding of predicted ecological responses for the development of other similar programs (Humphries, pers. comm.).

Conceptual models of the ecosystem under consideration can serve a few purposes in the design of a monitoring program. First, they identify which variables are likely to be key responses to assess changes in the ecosystem, and will therefore aid in the selection of appropriate indicators and generation of hypotheses (Quinn *et al.* 2003). A conceptual model also allows us to explicitly consider the spatial and temporal scales at which ecological processes and biota might respond to changing flow regimes, and is therefore crucial in the design of the sampling regime of the monitoring program. Generally, the main stated purpose of the conceptual models developed in the reviewed environmental flow monitoring programs was to aid in the selection of appropriate indicators. Little reference was made as to whether the models were also used to decide on the appropriate spatial and temporal scales for sampling.

Second, conceptual models may also partly address the problem of a lack of appropriate reference sites. Boulton *et al.* (2002) discusses the potential use of a conceptual model based on the expectations of an expert panel of the predicted ecological responses in the Nymboida River to the absence of an extended low flow period, and suggest that this model could then be used as a form of reference or 'target' condition for the system. However, conceptual models are not as useful as good reference locations, and Boulton *et al.* (2002) suggest that having reference rivers for at least some indicators to 'ground truth' the conceptual model is critical.

Third, the main purpose of a conceptual model for environmental flow monitoring programs should be to develop and articulate the ecology and functioning of the ecosystem, incorporating the predicted spatial and temporal extent of the effect of the environmental flow. To do this, their needs to be a clear understanding of what the environmental flow will consist of, ie. what components of the present hydrological regime will be changed, and also how, if it all, these changes may influence the ecology of the system. In general the environmental flow monitoring programs reviewed all used conceptual models to develop hypotheses to predict what ecological responses were expected to their specific environmental flow regime. Most of the reviewed monitoring programs stated clear scientific hypotheses that were being tested (see Appendix). These hypotheses varied between each program, as they reflected both the special ecological considerations of each ecosystem and the type and objectives of the environmental flow regime for that ecosystem. As an example, the IMEF program design is based on testing specific hypotheses incorporating the likely effects of environmental flow rules (Chessman & Jones 2001). At first they developed 40 potential hypotheses, these were then reduced to 16 generic and valley specific response hypotheses after considering the views of scientific experts and the following criteria (DLWC 2003):

- Relevance to intended environmental benefits of the NSW river flow objectives,
- strength of a priori support for the hypotheses from previous scientific studies and expert opinion,
- practicality of testing the hypothesis (including cost),
- temporal and spatial applicability of the hypothesis (giving preferences to hypotheses that apply widely rather than at particular times and locations),
- strength of the expected response to flow rule implementation,
- sensitivity to confounding factors,
- community perception of the importance of the hypothesis, and
- availability of relevant historical data.

A strong and well developed monitoring program needs to clearly define the objectives of the environmental flow and the monitoring program, create a defensible conceptual model which is then used to understand the predicted responses of the system to the environmental flow and create an initial list of testable hypotheses. This will then assist in the selection of appropriate dependent variables and indicators for monitoring and the choice of a robust statistical design.

Choice of response variables or indicators

Indicators used for monitoring in freshwater systems can be based on physical variables (flow, hydraulics and geomorphology), chemical variables (water quality), biological variables (groups of plants and animals) and/or ecological variables (ecosystem process measurements such as primary productivity) (Chessman & Jones 2001). Because it is not practical to measure all of these variables, we need to identify and select which variables are the most appropriate for the monitoring program. The choice of response variables or indicators to be measured in any monitoring program is an extremely important decision, and should not be made arbitrarily or be based on standard variables that may have been used elsewhere (Downes *et al.* 2002). Briefly, variables chosen for any monitoring program should be relevant to the questions asked, strongly associated with the putative impact (Keough & Quinn 1991), represent a range of temporal and spatial scales of response (Reid & Brooks 2000), ecologically and/or socially significant, and efficient and practical to measure (Downes *et al.* 2002).

Environmental flow monitoring programs need to consider how the new flow regime may influence the ecosystem, which variables might respond in a predictable manner to flows, and importantly at what spatial and temporal scales these responses will occur. Therefore, standardised monitoring programs and variables designed to indicate the overall "health" of the riverine ecosystem may not be particularly useful for assessing responses to environmental flows, unless there is additional evidence that demonstrates a causal relationship between the health indicator and flow change. The development of a rigorous conceptual model of how the ecosystem functions, with and without the impact of concern, should aid in determining which variables should be further considered for inclusion in the monitoring program. Most of the environmental flow monitoring studies reviewed did use conceptual models to aid in their selection of indicators. The reasons behind the selection of indicators were commonly related to a likely scientific causal link between the chosen variables and flows, although other criteria were also used, including:

- Budgetary considerations,
- easily interpreted and communicated variables (for example flagship species such as waterbirds and recreational fishing species), and
- the existence of historical data sets for some variables (for example Monitoring River Health Initiative data).

Watts *et al.* (2001) used an extensive range of criteria to select which variables were considered for their study on effectiveness as indicators for environmental flows, including:

- Responsiveness to changes in flow at spatial and temporal scales relevant to river management,
- responsiveness within the timeframe of the project,
- scientific justification,
- represent important structural and/or functional component of the riverine ecosystem,
- easily measured and quantitative,
- easy to interpret responses,
- can determine and measure directions of change,
- respond differently to background variability,
- cost effectiveness,
- relevant to policy and management needs, and
- that overall the indicators should cover a range of habitats, trophic levels, several measures of biodiversity, range of organisational levels and a range of spatial and temporal scales.

There is an enormous amount of literature on potential indicators of a wide range of different stressors in flowing water systems (see for example summary table by Downes *et al.* (2002), and special issues of *Freshwater Biology* 41 (2), *Hydrobiologia* 422/423 and *Australian Journal of Ecology* 20 (1)). As there is such a tremendous diversity of potential indicators, careful consideration needs to be given regarding the indicators efficacy, indeed indicators should not be chosen purely because of convention, familiarity to researcher or social pressure (Downes *et al.* 2002). Table 2 illustrates the diversity of indicators that have currently been selected for use in environmental flow monitoring programs. As this arena of research is in its infancy, at this stage only some of these indicators have been causally linked to flows and respond in a predictable manner (see Table 2). New indicators, with direct and predictable responses to flows, will no doubt emerge in time and monitoring programs currently being implemented must be flexible so that new variables can be incorporated as our understanding of relationships between flow change and ecological responses improves.

Table 2: Indicators currently used in environmental flows monitoring programs.

Indicators measured	Attributes	Programs used by	Comments
Hydrology		Snowy, IMEF	
Geomorphology	Channel morphology, sediments and habitat	Snowy, Campaspe #	
	Standard MRHI habitat assessments	Mersey	
Water quality	Various measures	Snowy, Mitta Mitta, Campaspe, Barmah-Millewa wetlands	Often these were used as additional explanatory variables.
River productivity	Benthic production/respiration, water column production, bacterial activity	Mitta Mitta	Short term responses to specific flow events as predicted
	Terrestrial organic matter (DOC, zooplankton)	IMEF	Trial only, in one river, to determine whether rewetting stimulates food webs, also sampled DOC and zooplankton
Biofilm	Total/algal/organic biomass, productivity	Murrumbidgee, IMEF, Mitta Mitta	Consistently responded as predicted to flow events in the Murrumbidgee and Mitta Mitta studies.
	Composition	Mitta Mitta	Structural and functional responses of biofilm were evident immediately following peak flows.
Macroalgae	Filamentous algal abundance	Mersey, Snowy	Preliminary results suggest show good response to flow events in Mersey study
Phytoplankton	Density of cyanobacteria	IMEF	
Zooplankton	Emergence from wetland sediments	Barmah-Millewa wetlands	Weak correlations with flow
Macroinvertebrates	Community structure and abundance	Snowy, Mitta Mitta, Mersey	Several attributes measured in cobble habitats responded rapidly to variable flow releases in Mitta Mitta study. Preliminary results in Mersey study suggest good response to flow regime change
	Number of families, SIGNAL scores	Mitta Mitta	Responded rapidly to variable flow releases
	Community structure, relative abundance and species occurrence on snags	Campaspe	Preliminary results suggest good response to flow stress
	Mayfly larvae (abundance, species richness and diversity)	Murrumbidgee	Responded predictably to flow events in upper reaches
	Gastropoda (abundance, species richness and diversity, proportion of introduced taxa, no. of egg masses, weight)	Murrumbidgee	Murrumbidgee study suggested responses less predictable over a range of spatial and temporal scales
	Paratya australiensis (abundance, weight, berried	Murrumbidgee	Murrumbidgee study suggested responses less predictable

	females)		over a range of spatial and temporal scales
	Abundance and composition of shrimp fauna	Campaspe	Preliminary results suggest good response to flow stress
	Wetland macroinvertebrates, community structure and abundance	IMEF, Barmah-Millewa wetlands	Some evidence that show good responses to flow events from Barmah-Millewa program.
Vegetation	Riverbank understorey vegetation (species composition, distribution, abundance, survival, growth, reproduction)	Murrumbidgee	Survival and total biomass responded predictably to flow events in lower reaches
	River red gum (leaf chlorophyll fluorescence, leaf relative chlorophyll, spectral reflectance, leaf xylem water potential)	Murrumbidgee	Health measured using remotely sensed data, experimental assessment only needs to be assessed in the field
	Riparian vegetation	Snowy	
	Macrophytes - emergent	Snowy	
	submerged	Campaspe #	
	Wetland vegetation	IMEF, Barmah-Millewa wetlands	Successful for Barmah-Millewa project
Fish	Adult fish (community composition)	Campaspe, Snowy, Mersey, IMEF	
	Larval fish (occurrence, relative abundance, community composition)	Campaspe	Preliminary results suggest good response to flow stress
	Recruitment (composition and abundance)	Snowy, Mersey (trout only)	Preliminary results suggest potentially good response to flow stress for Mersey study
	Trout angler surveys	Mersey	
Waterbirds	Abundance, diversity and breeding occurrence in wetlands	Barmah-Millewa	Easily communicated and can assess effect of watering quickly
Frogs	Abundance, diversity and breeding occurrence in wetlands	Barmah-Millewa	Easily communicated and can assess effect of watering quickly
Aesthetics	Community attitude surveys, photo points	Mersey	

Initial surveys conducted; variable either removed from program due to technical difficulties or no follow-up surveys been conducted

A number of environmental flow monitoring programs also selected indicators that were principally aimed at easily communicating the results of the environmental flows to the general public. For example, observations of numbers, species diversity and breeding success of waterbirds in the Barmah-Millewa Forest during the use of the environmental water allocation are easily reportable stories for media. However, surveys of waterbird breeding are also very useful for management of the water, as surveys can be conducted relatively quickly and easily, and real-time management decisions about the use and operation of the water can be made at a site specific scale (Leslie & Ward in press). The Mersey River Aquatic Fauna Monitoring Program has also included some variables principally aimed at engaging the local community in the program (MRWG 1998). Trout angler surveys, for example, will be conducted annually before and after the use of the environmental flow to gauge whether fisherman are noticing any differences in the health of the stream and catches.

Design considerations

There are two broad strategies for monitoring effects of human activities on the environment and both have been advocated for freshwater ecosystems. The first strategy is to use some type of predictive modelling, such as the reference condition approach to assessing river health (Norris & Thoms 1999) as exemplified in Australia by the AusRivAS protocol for macroinvertebrates. This strategy uses a measure of reference condition (i.e. the condition of the ecosystem without human disturbance) based on sampling comparable rivers that are in a condition that is judged to be 'near pristine' by the person selecting them or at least with less obvious human impacts. The reference condition allows a prediction of what (e.g. families of macroinvertebrates) should be at a particular river site and this is compared to what is observed, the difference being a measure of river health. These methods are undergoing continued development and refinement, now incorporating habitat-specific predictions and alternative ways of defining the reference condition.

The predictive modelling strategy was not designed to necessarily detect responses to specific interventions nor does it easily establish causal links between river "health" and a particular human activity. Therefore its role in monitoring responses to restoration and environmental flows is not yet clear. Nonetheless, river health monitoring based on reference condition predictions is well established in Australia and must be considered when designing restoration-specific monitoring, even if only in the context of choice of indicator variables. The measures of river health may be one component of a lines-of-evidence approach to assessing ecological responses to changes in flow regime and we expect this to be an active area of future research.

The second strategy for monitoring human activities is to use the fundamental principles of experimental design to assess responses to a human intervention on the environment. The best known, and arguably the most scientifically defensible and sensitive, approach is the "before-after-control-impact (BACI) designs". The design involves sampling 'before' and 'after' the change of interest, at both the 'control' and 'impact' sites (Green 1979). Control sites are ones that have similar characteristics to the 'impact' sites but without the intervention. Impact sites are those affected by the intervention, although the term 'impact' is probably inappropriate when the intervention is a restoration effort designed to result in ecosystem improvement. The original BACI design used a single impact site with a matching control site and the hypothesis of interest is whether the control-impact differences change from before to after. If such a change does occur, it is evidence that the observed response is likely to be a result of the human activity. Recognition of difficulties caused by only having single control and impact sites resulted in the development of MBACI (Multiple Before After Control Impact) designs, that provide much more confidence that the observed response is caused by the human intervention. While multiple 'impact' (i.e. restored) sites might not be possible, the asymmetrical 'beyond-BACI' designs developed by Underwood (1994) allow the comparison of a single impact site with multiple control sites. Downes et al. (2002) provide a thorough summary and comparison of the different versions of BACI designs.

For a BACI design to be implemented for an environmental flow monitoring program, the intervention would be the application of the environmental flow regime, the 'before' would be the situation prior to the implementation of the modified flow regime and 'after' would be the situation post environmental flow implementation, 'impact' sites would be on rivers with flow rules, and 'control' sites would be on similarly flow-modified rivers but without environmental flow regime implemented (Chessman & Jones 2001, Rose & Bevitt 2003). Therefore, when selecting a monitoring design for any environmental flows monitoring program, two issues need to be considered:

- the timing of the proposed changes to the current water management strategy so that, where possible, monitoring data can be collected before the changes occur; and
- the availability of control sites to be used as a comparison for the effects observed at the study site.

The timing issue can be a problem, especially if the environmental flow regime is gradually implemented as water becomes available and then allocated to the environment. Results from BACI monitoring designs will be more difficult to interpret in situations where the type and magnitude of the intervention changes through time.

Most of the reviewed environmental flow monitoring programs are indeed based on modifications to the general BACI design. For example, the Mersey River aquatic fauna monitoring program is based on a BACIP design (MRWG 1998). In this approach sampling is conducted 'before' and 'after', at 'control' and 'impact' locations with samples 'paired' in time, and focuses on any changes at the 'impact' location, relative to the control, and the variable that is analysed is the difference between 'control' and 'impact' values (Downes *et al.* 2002).

An additional consideration in the application of BACI-style monitoring to restoration projects is the issue of targets. The control-impact comparison indicates whether our restored ecosystem is moving away from the control ecosystem and, if the monitoring is well designed and interpreted in the context of the conceptual model, also provides good evidence for causal links. However, Downes *et al*. (2002), Grayson *et al*. (1999), Henry & Amoros (1995) and Quinn *et al*. (2003) have argued that restoration monitoring designs should also include reference sites, to indicate whether our restored site is moving towards a more 'pristine' condition and to allow a decision about whether restoration has been successful. Reference sites are chosen to be as close as possible to the state of the environment undisturbed by human activity (Downes *et al.* 2002), and represent a target or direction of restoration for the test system to be compared against. For environmental flows, a reference site would be a river that has not been flow-modified and represents a hydrological and ecological target. Unfortunately, for environmental flows on regulated lowland rivers, there are few unregulated rivers that could be used as reference ecosystems. There is also the difficulty of incorporating the reference-impact comparison into the statistical analysis of the monitoring design, although bio-equivalence methods are discussed by Chapman & Underwood (2000) and Downes *et al*. (2002). The inclusion of reference sites in restoration monitoring designs may also provide a bridge between intervention-specific monitoring using BACI techniques and the reference condition approach used in river health assessments. We know of no published example of river restoration monitoring, including for environmental flows, which used a control-impact-reference design.

Establishing adequate control and/or reference systems was difficult or impossible for most of the reviewed monitoring programs, mainly due to the widespread degradation of floodplain ecosystems and the large natural spatial and temporal variability of lowland Australian rivers (Quinn *et al.* 2003). Although all of the reviewed monitoring programs were principally conducted in regulated lowland rivers, finding appropriate ‘control’ and ‘reference’ rivers may be easier in upland areas where there are many more tributaries to act as possible sites. To be able to separate the effects of impacts from natural variations requires that we know the characteristics of natural variation in both ‘before’ (unimpacted baseline) and ‘after’ periods (Stewart-Oaten *et al.* 1986; Stewart-Oaten 1996). Unfortunately a major limitation of the Mitta Mitta River study was the inability to collect before data to describe ecological condition prior to the cyclic release patterns (Sutherland *et al.* 2002). As acknowledged by the authors, this placed major constraints on statistical analysis and the strength of their conclusions. Fortunately, other programs such as the CFMP, the Snowy River project and the Mersey River project have been able to successfully negotiate with river managers to allow a delay in the instigation of the environmental flow to allow for the collection of ‘before’ data. Ideally the duration of sampling within each of the ‘before’ and ‘after’ phases should span several occurrences of the major sources of natural variation that might be expected within the system (Keough & Mapstone 1995). For example sampling in streams should cover all seasons and should span at least two, perhaps three years (Downes *et al.* 2002). The Mersey River monitoring program (MRWG 1998) is the only program reviewed that has successfully been able to collect at least three years of data ‘before’ and ‘after’ the commencement of flow releases. Indeed, the Mersey River Monitoring program is now demonstrating a number of significant ecological responses (including increased macroinvertebrate density and juvenile trout abundance) that have occurred as a result of the flow change (Davies, pers. comm.).

The Campaspe Flow Manipulation project has only one reference system, the Broken River. Even though the Broken River is far from an undisturbed catchment, it was chosen as it represented the most ecologically intact river in the region of a similar size, morphology and climate to the Campaspe river (Humphries 2001). The Snowy River Environmental Flow Response Monitoring project however, was able to select one control site, the Eucumbene River, and numerous reference sites in both tributaries and nearby rivers (Rose & Bevitt 2003). Suitable reference locations for some indicators were unlikely to be available for the Nymboida River monitoring program

(Boulton *et al.* 2002), due to both a lack of similar rivers in the region to act as a suitable target and the recognised differences between the ecological condition upstream and downstream of the weir. As discussed, Boulton *et al.* (2002) suggested that this lack of reference sites could be partly addressed by the use of a well designed conceptual model.

The NSW IMEF program originally considered using a routine BACI type monitoring program, however this approach was abandoned because:

- most of the study rivers had environmental flow rules in operation at the start of the project, and therefore there was limited opportunity to obtain 'before' data, and
- it was very difficult to find appropriate control or reference rivers. While some of the larger impounded rivers did not have environmental flow rules, they were physically different and had different regulated flow regimes than the test rivers (Chessman & Jones 2001).

They therefore decided to use a predictive modelling approach, whereby hydrological and ecological modelling was combined to deduce the likely ecological consequences of different hydrological regimes. The hydrological modelling enables actual flow regimes under the new flow rules to be compared with modelled regimes without the rules and with simulated natural flows. The ecological response model is based on specific hypotheses incorporating the likely effects of environmental flows, and requires that a range of flow regimes are studies in order for the final model to have broad predictive capability. To date, the IMEF program has produced one major summary report (DLWC 2003) which presents preliminary findings for each river valley for a number of parameters for the first two years of investigation. The IMEF summary report however does not analyse these results using the predictive modelling approach, rather it presents the results of each parameter individually and does not ascribe any environmental benefits to the operation of environmental flows. As such at this stage, the use of predictive modelling as a successful analysis tool for demonstrating responses to environmental flows has not been demonstrated.

The overriding message from the above discussion is that the ideal control and reference systems required for classical monitoring designs are unlikely to occur when dealing with large-scale restoration activities such as environmental flows. Boulton *et al.* (2002) suggested that in situations where the full (M)BACI design is not possible because only one of the design elements (e.g. after data from the impact site) is possible, the final design will only provide weak inference about the causes of change at the impact location. Having appropriate and replicated control sites will obviously provide the strongest inference linking ecological change to human induced changes, a combination of individually weaker forms of evidence may help in situations where real controls are not possible (Quinn *et al.* 2003). This approach relies on multiple lines of evidence, using causal criteria to select appropriate hypotheses which need to be tested in the monitoring program (Downes *et al.* 2002). The Snowy River Program is the only reviewed program which mentions that it may use a levels-of-evidence approach to correlate co-variables with particular components to establish the strength, consistency and specificity of association. Rose & Bevitt (2003) suggest that this correlative evidence using long-term data sets may build a sufficiently strong case to infer/not infer causality.

Downes *et al*. (2002) recommend conducting a pilot study prior to the selection of the final statistical model, to assess the level of variation among replicates and to optimise the final monitoring program. Often these data has to be collected separately in a pilot study, however relevant pre-existing data from other studies may be useful in some circumstances. From our review, none of the monitoring programs discussed collecting any pilot study data or optimising the design through a statistical power analysis prior to the selection of the final monitoring design. It should be noted that power calculations can be difficult for some of the complex interaction terms tested as part of linear models analyses of (M)BACI designs.

We finish this consideration of design issues by acknowledging that we have focused on BACI-style designs. We have also highlighted some potential limitations of these designs for monitoring responses to environmental flows, especially the probable absence of control rivers, the likelihood that flow implementation will be gradual and changing, and the absence of replication at the appropriate spatial scales. Additionally, these designs are almost always analysed using linear statistical models and frequentist inferential techniques (see Downes *et al*. 2002). Other analytical approaches that better handle uncertainty and provide conclusions more appropriate for decision-making (e.g. Bayesian methods) should also be considered.

Conclusion

Environmental flows are a form of ecosystem restoration, and therefore monitoring designs for environmental flows in Australian rivers should follow the same principles as designs for assessing any ecosystem restoration project. The objectives of the environmental flows and the hypotheses being addressed by the monitoring program should be clearly defined. A conceptual model that summarises our understanding of the river ecosystem under consideration and how different components of that system have responded to flow modification and might respond to environmental flows should be developed. Along with an evaluation of any available data, this model should be used to guide the selection of response variables and spatial and temporal extent of sampling. The collection of before and after data should be possible for assessing most environmental flows in Australia, as the re-allocation of water to the environment is a relatively new strategy and has not been applied in most rivers. Ideally, a monitoring design for environmental flows should have control and reference sites, although for many rivers, especially lowland rivers in southeastern Australia, both will be difficult to find and replication at an appropriate scale will not be possible. Alternative methods, including using a “lines-of-evidence” approach, will need to be considered to be able to assign a causal link between the responses observed and the implementation of environmental flows. Also, less traditional statistical methods (e.g. Bayesian modelling) should be explored as they might better handle the difficulties associated with monitoring designs for environmental flows.

The few monitoring designs for assessing ecological effects of environmental flow regimes in Australia have taken a variety of approaches, especially in how they have dealt with lack of controls and reference rivers. Most of these environmental flow monitoring programs are at an early stage, so it is not possible to judge which approach and methods are most applicable to Australian river systems. However, a consistent and rigorous approach to the design of monitoring would result in greater confidence about links between ecological response and flow change. It could also improve future environmental flow decisions and monitoring by identifying the components of the flow regime that are ecologically important. The information gained from this review will be used to develop guidelines for designing monitoring programs for environmental flow restoration programs.

Yea River, Devlins Bridge gauge, Victoria.
Photo: Shanaugh McKay, DSE.

Appendix: Summary of Environmental Flow Monitoring Programs

In the process of conducting this literature review, several Australian environmental flow monitoring programs were critically reviewed and summarised. These are included below to provide more detailed information on individual projects. At the time of writing three other environmental flow monitoring projects were known to exist; Fitzroy Basin study, Gordon River Basslink project and CRC FE's Cotter River project; but were unable to be included in this review as reports detailing the programs were unavailable.

Campaspe Flow Manipulation Project

Lake Eppalock, the major storage on the Campaspe River, northeast Victoria, captures winter and early spring rains and then releases the water downstream during summer and autumn where it is diverted to irrigation channels. Operation of Lake Eppalock has resulted in a significant change in the flow regime (Humphries & Lake 1996), including:

- Reduced duration of high winter flows through the entire river downstream to its mouth,
- Significantly enhanced magnitude, duration and stability of bank-full flows in the upper and middle reaches, and
- Only minor increased summer flows in the lower reach.

The Campaspe Flow Manipulation Project (CFMP) was one of the first ecosystem-scale long term environmental flow experiments in Australia. The project aims to assess the effectiveness of a 'translucent dam' approach to environmental flow allocation (Humphries & Lake 1996; Smith & Humphries 1997; Growns 1998; Humphries 2001), where 25% of input flows are passed downstream of the storage once a dam trigger level of 64% is reached outside the normal irrigation season (Humphries 2001). Therefore, the environmental flow change imposed on the operation of Lake Eppalock was principally to increase flows between May and October.

The basic design of the monitoring program was structured around a BACI (before-after-control-impact) design, where response variables (or biological indicators) are monitored "before" and "after" the flow manipulation in the "impacted" river (Campaspe) and are compared to a "control" or "reference" river, the nearby Broken River. Early modelling of the likelihood of receiving environmental flow releases suggested that the releases would occur in 9 out of 10 years. The original design of the project was for pre-flow data to be collected before May 1998, when the flow change would be implemented and monitored for three years. The actual trigger level for providing an environmental flow to the Campaspe River was reached a week before the end of October 2000, and therefore only one week of the environmental flow occurred (P. Humphries. pers. comm.). Additionally, between May and October 2001 very little in the way of environmental flows again occurred due to low water level in Lake Eppalock. While this technically means that there were environmental flow events in these two years, the flows are believed to be too small to warrant a true before/after comparison (P. Humphries pers. comm.).

Early development of the project included establishing conceptual models and determining hypotheses to test short and long term variables and their response to the flow change (P. Humphries, pers. comm.) (Table A.1). Pilot studies were conducted in the early stages of the project, principally to develop appropriate methods for sampling larval fish (P. Humphries pers. comm.) and macroinvertebrates (Humphries *et al.* 1998; Growns *et al.* 1999) in lowland rivers, rather than to test the applicability of these indicators to detecting any response to environmental flow regimes.

Table A.1: Predicted responses to Campaspe River environmental flow change, response variables measured and sampling design employed.

Prediction after flow change	Variable measured	Sampling design
Greater abundance of adult fish in upper reaches of each section	Adult fish abundance	Bimonthly sampling (Oct 1995 – June 2001) Campaspe only: 2 randomly chosen run sites and one pool site in each section (except no pool site in lower reach)
Reproductive development and maturation and subsequent spawning of fish enhanced	Larval fish species occurrence and relative abundance	Sampled monthly between Oct 1995 and June 2002, except May and July, then 4 times a year until June 2003. Campaspe: 2 randomly chosen run sites and 1 pool site in each section (except no pool site in lower section) Broken: 4 randomly chosen run sites (1 upper, 1 middle, 2 lower) and 2 fixed pool sites in upper and middle sections
Increase in the abundance and number of fish larvae of native species	Larval fish species occurrence and relative abundance	
Reduction in the abundance and number of fish larvae of introduced species	Larval fish species occurrence and relative abundance	
Alteration of macroinvertebrate community on snags in Campaspe River to a more natural reference (Broken River) community.	Macroinvertebrate relative abundance and species occurrence on snags	Sampled bimonthly between Feb 1997 and June 2002 and then 4 times a year until June 2004. Campaspe: 2 fixed run sites in each section Broken: 1 fixed run site in each section
Alteration in abundance and composition of shrimp fauna in Campaspe River to a more natural reference (Broken River) community.	Abundance and species composition of shrimp	Sampled monthly between Feb 1997 and June 2002 (except May and July), and now 4 times a year until June 2004. Campaspe: 2 fixed run sites in each section Broken: 1 fixed run site in each section
Alteration in areal coverage of littoral zone macrophytes	Extent and diversity of macrophytes	Measured initially, but eventually removed from sampling program due to technical difficulties and confounding factors of life history and growth with flows.
Change in macrophyte composition from more lentic to lotic associated flora	Extent and diversity of macrophytes	
Change in geomorphological features of main channel towards reference system		Initial surveys were conducted. No results available.
Longer winter flows that inundate marginal habitats will result in more habitat for fish	Types of habitats and area inundated	
Increase in the amount of snag habitat available to macroinvertebrates	Snag abundance	

Despite the absence of a significant environmental flow, the CFMP was successful in testing the effectiveness of various aquatic indicators to flow modifications, demonstrating that summer irrigation flows substantially alter the aquatic ecosystem, and has vastly improved knowledge of the variability and factors affecting fish larvae and macroinvertebrates in lowland rivers (eg. Humphries *et al.* 2002; Richardson *et al.* Subm.). The project has also been able to reassess the original conceptual model and linkages between flow and aquatic biota. For example, initial hypotheses proposed that successful native fish recruitment principally occurs when floodplain inundation triggers spawning of some species and an abundance of food and habitat input for larvae. However, results from both rivers have showed that most species spawn successfully every year irrespective of flow conditions, and suggested that river regulation has greater impact on post-spawning recruitment (Humphries & Lake 2000). Additionally, a number of species were found to be capable of spawning and recruiting during the summer low flow periods. This led to the development of the "low flow recruitment hypothesis", which postulates that fish can successfully recruit in low flow conditions in the main channel without access to the floodplain, by utilising still littoral and backwater habitats containing high densities of appropriate prey for fish larvae (Humphries *et al.* 1999). This in turn has led to the formulation of the 'window-of-opportunity hypothesis', which postulates that river regulation contributes to an alteration to the timing of critical habitat and food availability for first feeding larvae (Humphries 2001). Similar review of the mechanisms underlying the response of macroinvertebrates to flow regulation suggests that high water currents alter the biofilm composition on snags, resulting in a subsequent shift of the macroinvertebrate community composition from one of a lowland river to that similar to an upland stream (Humphries 2001).

At the time of writing this report, the CFMP was entering the final stages of the project. Specific recommendations outlining the project's successes, failures, and future lessons to be learnt have not been addressed at this stage. Whilst the CFMP was unable to modify its design or environmental flow approach based on its results, the review and modifications of the predicted responses to environmental flow changes will have important implications for the development of future conceptual models and monitoring designs for environmental flow assessment programs.

NSW Integrated Monitoring of Environmental Flows

The Integrated Monitoring of Environmental Flows (IMEF) program was established by the then New South Wales Department of Land and Water Conservation, to scientifically assess the response of major rivers and associated wetlands to environmental water allocations. The program focuses on one unregulated (Barwon-Darling) and six regulated (Gwydir, Hunter, Lachlan, Macquarie, Murrumbidgee and Namoi) river valleys throughout New South Wales but may be extended to other rivers in the future. Flow regulation and abstractions to support irrigated agriculture have reduced total flow through the seven targeted rivers and generally reversed seasonal flow regimes.

In 1997 the New South Wales Government instigated the water reform process and developed twelve broad River Flow Objectives that were aimed at protecting or restoring flow levels and variability in major rivers to natural ranges. These broad objectives were prioritised for individual river systems and in 1998 river management committees (RMCs) developed environmental flow rules for each of the seven river valleys considered in the IMEF program. Environmental flow volumes were restricted to ten percent of water that had previously been allocated for irrigation or other purposes within each valley. Prescribed flow rules were implemented in the six regulated river valleys in 1998-99 and in the Barwon-Darling Valley in 2000-2001.

The IMEF program was designed between 1997 and 2000 (Chessman & Jones 2001). It was intended as a long-term monitoring program that assesses environmental flows over a range of climatic conditions and is subject to annual review. An advanced draft of the second state summary report was completed in early 2003 (DLWC 2003) and presents data and analysis from 1998 to 2000, which was a period of above average rainfall in all of the studied river valleys. Most of the studies presented in this document are ongoing and has continued into 2000/01 and 2001/02, a period of lower than average rainfall across the whole of NSW. As a result most of the environmental flow assessments described in the initial document are preliminary.

The absence of suitable control sites and a lack of reliable data prior to the implementation of environmental flows meant that BACI type designs could not be used for the IMEF program. The Design Report (Chessman & Jones 2001) therefore recommended that various environmental parameters be measured in streams with different flow conditions and that predictive models be used to assess ecological responses to the prescribed flow rules. The IMEF program has three main objectives and intended outcomes that go beyond the scope of most monitoring programs. First, to investigate the relationship between water regimes, biodiversity and ecosystem processes. Second, to assess responses in hydrology, habitat, biota and ecological processes associated with specific flow events targeted by environmental flow rules. Third to use resulting knowledge to estimate the likely long-term effects of environmental flow rules and to provide information to assist future adjustment of the rules.

The IMEF uses a hypothesis-based approach (Chessman & Jones 2001) to assess ecological responses to the prescribed flow rules. Hypotheses were developed to link the prescribed flow rules, the River Flow Objectives that the rules were designed to address the expected environmental outcome of the rules and the biophysical mechanism by which the rules were expected to deliver that outcome. More than 40 hypotheses were initially developed, and from these a final list of 10 generic hypotheses were selected to apply to the seven study river valleys and a further six hypotheses that were developed to address specific issues within particular river valleys. The hypotheses selected for each river valley were intended to incorporate physical, chemical, biological and ecological aspects across a range of spatial and temporal scales. Hypotheses were prioritised for each river valley and appropriate variables were chosen to test them. Sites were selected on a stratified random design within each valley.

The IMEF State Summary Report (DLWC 2003) describes flow changes associated with the environmental flow rules implemented between 1998 and 2000 for all seven river valleys. It also describes studies that tested hypotheses related to phytoplankton, biofilms, terrestrial organic matter, wetlands and river fish in specific valleys.

Phytoplankton, specifically cyanobacteria and/or diatom concentrations, were measured in weir pools and below tributary junctions in the Darling-Barwon, Hunter, Lachlan and Namoi Valleys to test the hypothesis that environmental flows would suppress or reduce the persistence of algal blooms. Phytoplankton, nutrients and water temperature were sampled weekly during summer and autumn and fortnightly at other times. Algal blooms are common in these valleys, but high phytoplankton concentrations were only recorded at a few sites during this phase of the study. Cyanobacteria and diatom concentrations were inversely related to flow in the Barwon-Darling and Hunter Valleys respectively, but were independent of flow and nutrients in the Lachlan and Namoi Valleys. It was therefore concluded that environmental flow rules would potentially reduce the frequency and duration of algal blooms in rivers where phytoplankton levels were related to flow. The authors however stressed that different patterns may emerge during drought conditions.

Biofilms were compared in regulated and unregulated tributaries within the Hunter and Murrumbidgee Valleys to test the hypothesis that protecting or restoring freshes, high flows and natural flow variability will reset biofilm development and improve habitat for macroinvertebrate scrapers. Biofilm biomass, chlorophyll-a concentration, primary production, community respiration, macroinvertebrate functional feeding group abundance and stable isotopes that indicate whether macroinvertebrates use biofilms as a food source, were measured at paired sites on three to four rivers in each valley. Nested ANOVAs and NMS ordinations indicated a clear separation of algal and macroinvertebrate communities between sites and between rivers with different flow regimes. Clear differences were observed between regulated and unregulated rivers but the nature of these differences did not necessarily support the initial hypothesis.

Environmental flows that wet riparian litter are predicted to contribute terrestrial organic inputs to rivers, which in turn will stimulate river food webs. This hypothesis was tested in the Namoi Valley by measuring the concentration of dissolved organic carbon (DOC) and zooplankton at normal flow and after two small peak flows. This data was not formally analysed but DOC was not obviously related to flow on the day of sampling and zooplankton concentrations were higher at lower flows. These results seem rather inconclusive and a more intensive sampling program with a finer temporal resolution may be needed to properly assess these associations.

Environmental flows that protect or restore freshes, high flows and flow variability are hypothesised to replenish anabranches, riverine wetlands and restore floodplain biodiversity. This part of the IMEF program investigates how environmental flow rules are likely to affect wetland inundation patterns and investigates the relationship between wetland water regimes and ecological responses. It does not specifically test ecological responses to imposed environmental flows, but rather considers whether environmental flows can affect wetlands. These relationships were tested in the Gwydir, Lachlan, Macquarie, Murrumbidgee and Namoi Valleys. Selected wetlands within each valley were classified according to their historical wetting regime and a combination of nested ANOVAs and MDS ordinations were used to compare the abundance and composition of vegetation, macroinvertebrate, frog, bird and fish communities. Not all variables were measured in all valleys. At a smaller temporal scale, vegetation communities were compared between quadrats that were either wet, intermediate or dry at the time of sampling. Associations between the historical wetting regime of a particular wetland and its vegetation, macroinvertebrate or bird communities were established in at least one valley, while linkages between vegetation communities and recent inundation patterns were suggested in most valleys. There was relatively little evidence of a relationship between water regime and macroinvertebrate community composition, although there was some indication that time elapsed since last flood may be important for macroinvertebrates. This finding is consistent with other studies (e.g. Quinn *et al.* 2000, Sheldon *et al.* 2002). It suggests that wetland-flooding regimes within individual valleys are too similar to influence whole macroinvertebrate communities, or that the ability of macroinvertebrates to rapidly colonise wetlands after floods makes them a poor indicator of long-term flood regimes. Environmental flows of the magnitude proposed throughout NSW are unlikely to dramatically alter wetland flooding regimes and therefore population assessments of flow sensitive taxa rather than whole communities may be a better way of assessing the effect of prescribed flow rules.

Fish generally have a higher profile than other groups of aquatic fauna and many environmental flow programs are specifically targeted at improving habitat, passage and breeding conditions for native fish. The IMEF program hypothesised that the restoration of a more natural flow regime would promote the successful breeding and recruitment of native fish, and that as a result the abundance and dominance of native fish would increase over time. Fish populations have been regularly monitored throughout NSW, so the IMEF program has adapted existing survey techniques to the seven study valleys. Electrofishing was used to assess the abundance and diversity of adult and juvenile fish at 64 sites across all seven valleys during 1999 and 2000. ANOVA and NMS ordinations were used to compare species composition, catch effort and young of the year abundance across each of the targeted valleys. The abundance of native fish, the number of native species and the number of native juveniles were highest in the Hunter Valley, but there were only slight differences between the inland streams. This pattern is similar to that found in previous studies and suggests that the prescribed environmental flows did not affect native fish populations. It is probable that the prescribed environmental flow releases were too small to affect fish populations, or alternatively changes may only be observed over a longer time scale. If this latter point is true, then the data collected in 1999-2000 will provide a good baseline for future work.

Many of the studies described in the IMEF State Summary Report 1998-2000 (DLWC 2003) improve our understanding of the response of various biota to different flow regimes. This information will enable the IMEF program to be refined and assist other studies to select appropriate variables for assessing responses to environmental flows. The results presented in the 2003 report indicate that phytoplankton and biofilms are good short-term indicators of flow change, wetland plants are probably useful indicators but it may be better to focus on individual macroinvertebrate taxa rather than whole communities. Terrestrial carbon inputs may be a useful indicator but probably needs to be assessed at a finer temporal scale than was the case in this study. Other studies that test the response of various biota to flow changes (e.g. Murrumbidgee study) may highlight indicators that allow finer scale assessments of environmental flows. Such information will improve the resolution and monitoring capabilities of the IMEF program.

Overall the IMEF program is very good. It recognises the limitation of having no suitable control sites and the scarcity of reliable data prior to the implementation of environmental flow rules, and trials some interesting and pragmatic methods for monitoring ecological responses to environmental flows. The results presented in the State Summary Report (DLWC 2003) must be regarded as preliminary and subsequent reports, particularly if they include data from drought years, will need to be considered before the program can be fully assessed. It has many elements that could be applied to other monitoring programs, however the complexity and costs associated with some aspects of the program may be prohibitive for other monitoring studies.

Assessment of environmental flows for the Murrumbidgee River: developing biological indicators for assessing river flow management.

The Murrumbidgee River is one of the most regulated rivers in NSW with 48.6% of its flow diverted for human use (Macoun 1999). Prior to regulation, the flow regime was highly variable but peaked in winter and spring. Irrigation demands on the river have reduced the flow variability and reversed the natural peak flow periods so that maximum flows occur in summer.

Four environmental flow rules were developed for the Murrumbidgee River in 1997 and implemented in 1998. These rules were to 1) protect low flows (transparency), 2) protect end of system flow, 3) protect winter flow variability (translucent flows between April and October) and 4) provide water for contingencies. Flow rules 1 and 2 were consistently implemented between 1998 and 2000. Flow rules 3 and 4 were revised in 1998 and 1999 but were then implemented from August 1999 –2000. All of these flow rules are under constant review as part of the IMEF program (DLWC 2003).

The general effect of environmental flows in the Murrumbidgee River will be assessed as part of the Integrated Monitoring of Environmental Program (IMEF). An additional study was undertaken by researchers at Charles Sturt University to develop and assess biological indicators for assessing river flow management in the Murrumbidgee River (Watts *et al.* 2001).

The team identified three geomorphic zones that divided the catchment into upper, middle and lower sections and used a combination of field surveys and field and laboratory experiments to assess the response of a suite of biological indicators to various flow characteristics. Most of these field studies were conducted during a period of below average rainfall and therefore the described associations only relate to a limited range of flow conditions. The research team highlighted the need for further trials during periods of higher flow.

An extensive range of criteria was used to select which variables should be investigated for their effectiveness as indicators for environmental flows, including:

- responsiveness to changes in flow at spatial and temporal scales relevant to river management,
- responsiveness within the timeframe of the project,
- scientific justification,
- representation of important structural and/or functional component of the riverine ecosystem,
- easily measured and quantitative,
- easy to interpret responses,
- ability to determine and measure directions of change,
- ability to respond differently to background variability,
- cost effectiveness,
- relevance to policy and management needs, and
- that overall, the indicators should cover a range of habitats, trophic levels, several measures of biodiversity, range of organisational levels and a range of spatial and temporal scales.

Mayfly larval abundance, diversity and richness were associated with short-term changes in flow in the upper reaches of the catchment, and were deemed to be good potential indicators. However, associations between various measures of gastropod distribution and flow were inconsistent and other than a trend for a high proportion of exotic species in areas with sustained variable flow, were deemed unsuitable indicators for environmental flows. The abundance and weight of adult *Paratya australiensis* were associated with flow magnitude and variability in middle reaches of the Murrumbidgee River. It was suggested that these variables would be suitable indicators of short-term flow changes within reaches and of longer-term changes between reaches. However, the between reach patterns relate to differences at only one reach and therefore cannot necessarily be attributed to differences in flow regime. Biofilms were identified as good short-term indicators of flow variability and substrate disturbance within river reaches, but flow related patterns between reaches were inconsistent. The composition, growth and survivorship of riverbank plant communities were recommended as reliable indicators of flow regimes across growing seasons. However, the flow regimes tested in both the field experiment and survey were spatially confounded with sites and therefore the reported patterns cannot be directly attributed to flow. A separate greenhouse experiment did however demonstrate that some riverbank plants are sensitive to sedimentation during inundation. River red gums were shown to be sensitive to watering and the CSU research team highlights their potential use as an indicator of floodplain inundation. Table A.2 lists all of the indicators, describes the method used to test their response to flow and assesses their usefulness for monitoring environmental flows.

The primary objective of this program was to investigate different biological variables as indicators of flow regime changes. It did not specifically test the response to prescribed environmental flows in the Murrumbidgee River, but the results will be of great benefit to other environmental flow monitoring programs in general and the IMEF program in particular.

Table A.2: List of biological indicators and their responses tested in the Murrumbidgee River assessment of biological indicators project (Watts *et al.* 2001).

Type of Indicator	Specific Indicator (species/attribute)	Response at different scales	Comments
Macroinvertebrates (Mayfly larvae)	Abundance Species Richness Species Diversity Proportion of Baetidae	All parameters had a strong response to flow over relatively short temporal scales (10-30 days) and small spatial scales i.e. within a reach.	A good potential indicator: very common and abundant group that are likely to show relatively quick response to changes in flow.
Gastropods	Abundance Species Richness Species Diversity Proportion exotic No. egg masses Weight Proportion of exotic species	No consistent response to flow at any measured spatial scale. Proportion of exotic species was associated with high flow variability over 1year.	An unreliable indicator of flow, but proportion of exotic species may warrant further investigation as a long term indicator, or alternatively may vary flow in a particular system to control pest species in some cases.
Paratya australiensis	Adult Abundance Weight Berried Females	Abundance and weight of non-berried adults were associated with flow over long periods between reaches and over short periods (10-30 days) within reaches. Berried females and juveniles did not have consistent associations with flow and should not be used as indicators.	This taxa is abundant in many lowland streams and may potentially be a useful indicator. However different flow regimes were confounded with sites in this particular study and more work may be required to assess its suitability as an indicator species.
	(All macroinvertebrate studies were conducted during a period of lower than average flow for the Murrumbidgee therefore the authors stress that these patterns may vary in higher flows and recommend further trials in high flow conditions before these indicators are adopted.)		
Biofilms	Total Biomass Algal Biomass Organic Biomass Metabolism	All parameters responded to flow magnitude and frequency over relatively short temporal scales, and metabolism was sensitive to sedimentation associated with flood inundation. However patterns were lost over large spatial scales.	An excellent indicator of short term responses to Efs at individual sites. Biofilms are very abundant, easy to sample and are important components of food webs.
Riverbank Plants	Species composition, Distribution and Abundance Survival and growth rates.	Species composition varied between reaches with different flow regimes, survival and growth rates varied with frequency of inundation.. Patterns most likely to be seen over longer time period i.e. plant life cycle.	Has the potential to be a good indicator of longer term changes in flow however some of the associations described in this study were confounded between sites. Therefore more work may be required to test associations. Most of the community differences reported in this study relate to the presence or absence of only a few species so these could be good, easily measured indicators
Floodplain Trees	Chl fluorescence Relative Chl Spectral reflectance Leaf xylem water potential.	Experiments demonstrated a response inundation or watering frequency.	Some potential for remote sensing if reliable models can be developed. Will need to do more work to groundtruth data, but may be a reasonable indicator of floodplain inundation.

Snowy River Benchmarking and Environmental Flow Response Monitoring Project

The Project

The construction of the Snowy Mountains Hydro-Electricity Scheme (SMS) in the 1960s resulted in the diversion of 99% of the Snowy River's natural flow at Jindabyne Dam. Records from the Dalgety gauging station show that all aspects of the flow regime have been modified since commissioning of the 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 snow melt (Rose & Bevitt 2003). The results of such a significant change in flow regime coupled with other human influences have, and still do, negatively affect the ecological condition of the Snowy River (Pendlebury *et al*., 1996). Specific ecological effects are shown in Table A.3.

The Federal, Victorian and NSW governments agreed in October 2000 to release 21% mean annual natural flow (MANF) as environmental flows in the river, in the first ten years after corporatisation of the SMS. A further additional environmental flow release of 7% MANF may also occur but is 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 ecological condition of the river. The first environmental flow was released from the Mowamba Weir on 28 August 2002 (Rose & Bevitt 2003).

Table A.3. Environmental effects in the Snowy River downstream of Jindabyne Dam post SMS (source Pendlebury *et al*., 1996)

Change in flow regime and water quality	**Physical effects**	**Biological effects**
Loss of floods	Channel contraction, sediment infill in pools and riffles, bar formation. Impassable barriers eg., Snowy Falls, except for rare large floods. Reduced habitat area and diversity.	Fragmented fish populations, inhibition of breeding and migration. Changed macroinvertebrate species composition and abundance. Loss of fish and macroinvertebrate species. Reduced refuges and food sources.
Reduction in baseflows. Increase in water temperature and reduction in dissolved oxygen. Higher summer temperatures and colder winter temperatures.	Reduced wetted channel area. Reduced habitat availability and diversity.	Reduced fish movement, changes in fish species and reduced abundance. Restricted macroinvertebrate assemblages.
Loss of flow variability.		Lack of seasonal variation in macro-algal assemblages and reduced re-setting of biofilm growths.
Reduction in annual temperature cycles and flow velocity and/or volume.		Absence of triggers for life cycle events. Changes in macroinvertebrate and fish species diversity and abundance. Reduced fish migration and recruitment.
Loss of flushing flows.	Loss of fish passage over barriers. Non-cleaning of riffles and other fish spawning habitat.	Fragmented fish populations, inhibition of breeding and recruitment migrations. Reduction in native fish recruitment.
Sediment build up and low dissolved oxygen.	Increased colonisation by aquatic macrophytes, willows and native riparian and high levels of detritus build-up.	Weed invasion.
Thermal stratification in pools: low dissolved oxygen.		Loss of cold water macroinvertebrates in upper reaches. Dominance of species favoured by warm water temperatures.

The Snowy River Benchmarking and Environmental Flow Response Monitoring Project is a multi-disciplinary approach that combines the monitoring of ecological, hydrological and geomorphological indicators of the Snowy River environment to assess river response to the provision of environmental flows. It will also guide adaptive management of environmental water allocations and other rehabilitation works. The focus of the project is to measure the effect of environmental flow releases on the Snowy River downstream of Jindabyne Dam. The pre-flow release collection of data over a minimum of three years will benchmark pre-flow release river condition and determine the natural variability in the system (Rose & Bevitt 2003).

The broad aim of the environmental flow project is to achieve the maximum possible return of ecological and physical elements that characterised the river before flow regulation. The monitoring program of the environmental flow releases however, aims to develop a scientifically rigorous monitoring project to measure the physical, chemical and biological effects of environmental flow releases. The broad objectives of the monitoring program are to:

- Provide baseline data of pre-flow release river condition and measure the magnitude and direction of change in a number of ecosystem indicators 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; and,
- 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.

The different components of the new environmental flow regime are specified in terms of frequency, duration and magnitude and are separated into four essential components as recommended by an expert panel environmental flow assessment of the Snowy River below Jindabyne Dam (Pendlebury *et al.* 1996). These components are:

- 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;
- An increase in base-flow between 150 MLd^{-1} to 300 MLd^{-1} to provide adequate wet habitat area and reduce summer water temperature;
- 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,
- Two flushing flow events of 1,000 MLd^{-1} to remove the accumulation of bio-clastic and fine sediment form the interstitial spaces of the substrate that are important habitat for aquatic fauna.

The expected environmental responses to the new flow regime are briefly listed below:

- A shift in hydrology of the Snowy River towards flows more typical of pre-Jindabyne dam hydrological conditions;
- Expansion of the river channel and increase its depth, increase habitat quantity and diversity, destabilise vegetated bars, transport sediment, and increase grain size;
- Stripping of vegetation, increase in native vegetation species abundance, and a change in species composition and location of littoral vegetation communities;
- An increase in the abundance of fast water macro-algae species, and a decrease in macro-algae biomass;
- An increase in the diversity of fast flowing, cool river macroinvertebrate species; and,
- An increase in fish species richness, abundance and expanded population size structure of native species.

The project team classified the type and scale of the expected response to the environmental flows by examining the spatial and temporal organisation of river habitat classification for the Snowy River (Table A.4). This approach aided in their identification of the most appropriate scale for monitoring sites.

Table A.4. 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). Taken from Rose & Bevitt (2003).

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	10^4	Relatively homogeneous associations of topographic features and habitat types which distinguish them from adjoining reaches	↓	↓
Performance Reach	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	Short	High

The basis of the statistical design of the monitoring program was to divide the Snowy River into geomorphic reaches. Two or more performance reaches 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 to simplify reporting. Combinations of geomorphic reaches vary depending on what factors other than flow are perceived to drive change (Rose & Bevitt 2003). The general hypothesis is that with the introduction of environmental flow releases, the difference between the Snowy River geomorphic, or macro reaches, and the reference rivers will become smaller over time. Similarly, the difference between the Snowy River geomorphic, or macro reaches, and the control sites will become larger over time (Rose & Bevitt 2003).

Response variables and covariables for each indicator are measured repeatedly at representative Snowy River test, reference and control sites. This approach enables the measurement of changes in the selected variables and their relationship with specific covariables and the testing of hypotheses over time (Rose & Bevitt 2003). The study is a modified Before-After, Control-Impact (BACI) design, as there is not a control for all sites. Multistage sampling is used for most of the indicators and involves two or more hierarchically arranged levels of replication allowing the estimation of variability at different scales. Simple random, stratified or systematic sampling is used at each stage of sampling (Rose & Bevitt 2003).

A general hypothesis is made that 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 (Rose & Bevitt 2003). The design framework of Maher *et al.* (1994) was used to define the study question, to develop realistic and specific project objectives and testable hypotheses for sampling each indicator. Indicators for the project were selected following an expert panel assessment (Pendlebury *et al*., 1996) and the development of conceptual models of expected river response to the new flow regime. Indicators that were expected to respond strongly to different parts of the new flow regime were chosen (Rose & Bevitt 2003). These indicators were grouped into the following categories:

- Water quality;
- Geomorphology (channel morphology, sediment and habitat);
- Vegetation (including riparian, emergent macrophytes and macro-algae);
- Aquatic macroinvertebrates; and,
- Fish (broad-scale and recruitment).

Covariables, other than flow, which may influence change in the response indicators are also measured. The response variables incorporate wide time scales for an effect to be detected including immediate (eg. scouring of algal biofilms); short (< 5 years) (eg. lateral movement of sediment); and long term (>5 years) (eg. changes in physical habitat).

The sampling frequency for the Snowy Benchmarking Project is shown in Table A.5. These indicators are being measured to benchmark river condition before environmental flows are released, and will be monitored for at least a further seven years to determine river condition after environmental flows are released (Rose & Bevitt 2003). Not all indicators are sampled at each site.

Table A.5. Sampling frequency for the Snowy River Benchmarking Project (Rose & Bevitt 2001).

Project component	Response variable	Sampling frequency	Sites
Hydrology	Gauge heights	Continuous	14 gauging stations spread throughout the Catchment
Water quality	EC and temperature	Continuous and/or every two months	3 sites monitored
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.	15 sites monitored
Vegetation	Riparian (boundaries and reach census)	Once before flows, once immediately after flows then every five years.	10 sites monitored
	Transects (boundaries and quadrats[1]), emergent macrophytes and macro-algae (random quadrats)	Biannually (in autumn and spring)	10 sites monitored
Macroinvertebrates	Composition and abundance	Biannually (in autumn and spring	15 sites monitored
Fish	Composition and abundance	Annually (summer)	14 sites monitored
Fish recruitment	Composition and abundance	Single event: spring-summer	2 sites sampled

The project is currently in its initial post flow- release data collection stage and therefore details of changes brought about by environmental flow releases are not yet available. Rose & Bevitt (2003) present preliminary pre- flow release results and discussion on indicators measured in the project from 1999-2001. The next progress report will include all analyses for pre-flow release data to the 28 August 2002. Subsequent reports will define the environmental responses to the new flow releases.

Results to date: The environmental condition of the Snowy River

All parts of the flow regime have been altered since commissioning of the SMS. Before the SMS, floods of 20,000 MLd^{-1} magnitude occurred every 1.25 years on the annual maximum series, whereas post regulation, the same size flood has a return interval of 4.47 years. There has been a complete downward shift in the flow duration curve between the pre- and post- dam periods. Before the SMS baseflows of 100 MLd^{-1} occurred 100% of the time but only 17% of the time post- SMS. Similarly, baseflows of 300 MLd^{-1} occurred 97% of the time before the SMS but only 8% of the time post SMS. Flushing flows of 1,000 MLd^{-1} occurred 73% of the time pre- SMS but only 3% of the time post- SMS. These are significant changes in flow regime, measured at the Dalgety gauging station (Rose & Bevitt 2003).

Floods in the Lower Snowy after June 1998 showed that flood peak discharges four times greater than the mean annual flood are important in mobilising sediment. Similarly, hydraulic modelling conducted in the upper Snowy showed that flows greater than 1,000 MLd^{-1} are theoretically capable of flushing unconsolidated very coarse sand in pools, and cobbles in riffles. These are important results that show that the channel boundary can be re-formed and aquatic faunal habitat can be cleaned under particular size flows. Further modelling showed that a 30,000 MLd^{-1} capacity outlet structure is required on Jindabyne Dam to provide flexible manipulation of the environmental flow regime and to re-form the channel boundary in the upper catchment (Rose & Bevitt 2003).

Vegetation analyses explored site groupings that would minimise natural variability, and hence improve detection of changes brought about by environmental flows. Macro reach distribution explained most observed variation, while the weed flora was a strong seasonal component in explaining observed variation (Rose & Bevitt 2003).

Macroinvertebrate communities at the reference and control sites showed distinct differences to those of the Snowy River test sites. Macroinvertebrate taxa found in the Snowy River test sites were similar to those in still water assemblages and are likely to reflect altered environmental conditions of reduced flows. Macroinvertebrate communities found at reference sites may provide an indication of the macroinvertebrate community that would have been found in the Snowy River before the operation of Jindabyne Dam. This suggests that macroinvertebrates may become more abundant in the comparable cool fast flowing sites in the Snowy River following the implementation of environmental flows (Rose & Bevitt 2003).

Results from the fish assessment indicate that the distribution of fish communities in the Snowy River is explained by spatial rather than annual variation. A potential issue for the project is the need to better coordinate fish management and research in the Snowy River. Uncontrolled stocking of fish into the Snowy River may confound the project's ability to assess the impact of the environmental flow releases on fish communities of the Snowy River.

A pilot study on native fish recruitment was conducted in the lower Snowy River in the peak fish migration period between September 2000 and January 2001 to determine the abundance and species of juvenile native fish which move over a sand barrier in a section of the lower Snowy River. The results from the pilot study assisted in understanding fish recruitment into the Snowy River and the upstream movement of early life history stages within the system. This knowledge has assisted in the development of the native fish recruitment component of the Snowy River Benchmarking Project (Raadik *et al.* 2001).

Water temperature and electrical conductivity were measured at two NSW gauging stations in the Snowy River. Temperature exhibited strong seasonal patterns, and electrical conductivity generally corresponded with discharge, increasing with local rainfall flow events (Rose & Bevitt 2003). A pre-flow release pilot study into pool stratification was conducted in the summer of 2000 to determine if current regulated flow causes temperature, dissolved oxygen or electrical conductivity stratification in pools in the Snowy River downstream of Jindabyne dam, and to make comparisons with unregulated rivers. Further data analysis is required to explore the relationship between discharge and stratification in the pools of the Snowy River (Rose & Bevitt 2003). It appears however, that the size of the pools and discharge are key determining factors for stratification. Preliminary results show that the sampling designs are adequate for detecting responses to environmental flow releases. A list of 19 recommendations for further investigation or changes to the monitoring program has been included in the report. Present limited analyses of the vegetation data indicate that the sampling design should detect changes due to any significant flow releases. The project's 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 (Rose & Bevitt 2003).

At the time of writing this report, results for the Snowy River Benchmarking Project were only available for pre-flow release data up to June 2001. The results discussed are preliminary and subsequent reports including results on the effects of Jindabyne Dam on all components measured, and a fully detailed document of the project design and methods will be need to be considered before the program can be fully assessed. The Snowy River Benchmarking Project has developed a good set of results to benchmark, then measure and monitor the physical, chemical and biological effects of environmental flow releases in the Snowy River. The final results of the project and future monitoring for the environmental flows will guide adaptive management of, and refine environmental flow releases to the Snowy River, and provide a multi-disciplinary model for benchmarking and monitoring environmental flows in other Australian rivers (Rose & Bevitt 2003).

Ecological assessment of cyclic release patterns (CRP) from Dartmouth Dam to the Mitta Mitta River, Victoria

Flow conditions in the Mitta Mitta River are highly regulated by the operation of Dartmouth Dam. The timing and duration of releases into the Mitta Mitta River are reliant on the status of other River Murray storages, particularly Hume Dam. Transfer flows from Dartmouth to Hume are mostly made to minimise floodplain inundation in the Mitta Mitta valley and maintain constant discharge levels. However constant flow conditions are likely to have significant detrimental impacts on the ecological and geomorphological character of the River (Thoms *et al.* 2000; Gippel & Blackham 2002).

In response, River Murray Water proposed to introduce a cyclic release pattern (CRP) to their 2001/02 transfers, with the intention of introducing flow variability for ecological benefit. The CRP employed included three variable flow releases each of 14 days duration with 2 days of flow rise and 12 days recession, this was followed by a constant flow period. An ecological assessment of the CRP from Dartmouth Dam to the Mitta Mitta River was undertaken between December 2001 and February 2002 (Sutherland *et al.* 2002). A major limitation on the project was the inability to collect before data to describe the ecological condition of the Mitta Mitta releases prior to the commencement of the CRP, as the first variable flow release had already occurred when the project team was contracted. This placed major constraints on the statistical analyses and the strength of conclusions that could be drawn from the project, including a limited ability to infer the benefits of multiple flood pulses and the introduction of variable releases following constant flow conditions (Sutherland *et al.* 2002).

Sampling for the project was conducted at four sites with cobble benches on the Mitta Mitta River downstream of Dartmouth Dam and one reference site in the tributary, Snowy Creek. Cobble benches were selected as the experimental site as these areas were likely to undergo considerable hydrological change during the CRP. Littoral habitats were also sampled for macroinvertebrates. The sampling regime was restricted to assess three stages of the flow event; peak, mid- and base flows. A total of nine sampling events took place, one on the final day of the first release, three during the second and third releases, and two during the subsequent constant flow period. Based on previous research conducted in the Murrumbidgee River Catchment (Watts *et al.* 2001), the project team identified that benthic biofilm composition and production, enzyme activity and the structure of benthic macroinvertebrate assemblages (see Table A.6) would be the instream components most likely affected by the lack of flow variability, and most likely to demonstrate a rapid response to changes in flow conditions.

Table A.6: Predicted responses, justification and any recommendations about the use of the indicators selected to assess the ecological response of variable flow release patterns in the Mitta Mitta River (Sutherland *et al.* 2002).

Indicator	Prediction	Justification for inclusion	Recommendations on use
Extracellular enzyme activity of water column bacteria	Peak flows will increase overall activity of water column bacteria	Involved in the degradation of polysaccharides, carbohydrates and proteins derived from a range of autochthonous and allochthonous organic matter	Responses were short term responses, therefore future studies could target resources at specific flow events to streamline sample collection and cost
Biofilm structure and function, including assessment of biofilm composition and metabolism	1. Algal and total biomass biofilm will decrease following peak flows in CRP compared to biomass prior to peak due to scouring from increased velocity 2. Peak flows will change community composition of algal biofilms, promote early successional algal taxa and increase carbon respiration due to scouring and light deprivation at increased water depth 3. Newly inundated cobble with established biofilm communities will have increased carbon production relative to newly inundated areas with no established biofilm	Changes in species composition and metabolic rate of algal biofilms impact ecosystem function, by either reducing or increasing oxygen production depending on species present and controlling food resources	Responses were immediate following peak flows, temporal scale used in project therefore appropriate. Increased replication may help to reduce large variance found.
Macroinvertebrate composition, including both benthic and littoral habitats.	Variable flow releases will increase algal diversity on cobbles and will result in higher diversity of macroinvertebrates and increase the relative abundance of primary consumers.	Macroinvertebrates used worldwide as many taxa are known to respond to changes in flow conditions	Several macroinvertebrate attributes responded rapidly to releases, including number of families, SIGNAL scores and community composition. This suggests that both abundance and diversity should be measured. Spatial (four samples per site) and temporal replication of surber sampling was adequate. Considerable variation in sweep samples from littoral habitats, suggesting that factors other than flows influence this parameter and it may not be a useful measure.
Water quality parameters, including particulate organic matter (POC), dissolved organic matter (DOC), total suspended solids, water column chlorophyll-a and water column nutrients (total phosphorus, nitrate and phosphate)	Concentration of DOC, POC and suspended solids will increase during CRP compared to constant flows, due to increase riverbank and floodplain inundation and inchannel resuspension.	Standard parameters measured and requested in tender document.	Four replicate water samples provided minimum statistical power, and should therefore be increased in future studies.

The second and third releases produced substantial changes to the water quality and biotic parameters measured, and suggested that long periods of low and constant flows substantially alters the ecological condition of the Mitta Mitta River. However, due to the timing of the call for tenders, a comprehensive project design was not possible. Sutherland *et al.* (2002) recommended that future assessments of CRP's should include at least two sample dates prior to the first release, two samples during each subsequent release and several samples during the constant flow period. They also suggested that more detailed monitoring should be undertaken on the constant flow period, to identify thresholds at which constant flows become detrimental and perhaps therefore when CRP's should be introduced.

The unfortunate final temporal design of the project severely limits the projects conclusions. However, the conclusions included a number of recommendations about the design of future monitoring programs for CRP releases. These included suggested improvements to the sampling design to increase statistical power of indicators, the responsiveness of biological indicators used and suggested ways to target future sampling (see Table A.6).

Ecological monitoring of the Barmah-Millewa Forest Environmental Water Allocation

The Barmah (Victoria) and Millewa (NSW) Forests cover an area of approximately 65,000 ha on the Murray River flood plain upstream of Echuca. The Forest is the largest river red gum forest in the world and is widely recognised for its ecological values (BMF 1999a). The significance of the wetlands within the Forest are recognised nationally and internationally. The Barmah-Millewa Forest contains various wetland types including swamps and marshes, rushlands, grasslands, lakes, billabongs, creeks and red gum forest.

Since the commencement of regulated flows in the Murray River, the ecological health of the Barmah-Millewa Forest and associated wetlands and rivers, have been in serious decline. Regulated flow conditions in the River have resulted in:

- Unseasonally high and constant high summer-autumn river flow levels,
- Some previously ephemeral creeks now carry water more permanently into low-lying wetland areas,
- Inundation of some wetland areas for longer periods than under natural conditions,
- The capture of natural winter and spring flows, which has reduced the frequency, duration and height of flood events,

Between November and May localised rainfall events often cause irrigators to reject water released from storages to meet their orders. Consequently, river levels run higher than bankfull capacity in short peaks. These flows, often termed "rainfall rejection events" are also potentially detrimental to the health of the Forest because of their frequency, unseasonal nature and short duration.

To help ameliorate the detrimental effects of regulated river flows on the ecology of the Forest, in 1993 the Murray Darling Basin Ministerial Council directed that an Environmental Water Allocation (EWA) of 100 GL per year be allocated to meet the environmental needs of Barmah-Millewa Forest. This allocation is drawn equally from the States of Victoria and NSW. Additionally, numerous regulators and earthen embankments have been constructed throughout the Forest to exclude unwanted water.

These regulators are also used to actively manage any environmental water into different water management areas of the Forest.

The Barmah-Millewa Forest EWA has been used twice, once in 1998 (BMF 1999b) and again in 2000 (BMF 2001). Recommendations from the first use of the EWA in 1998 suggested that accumulating the EWA for a number of years to allow a larger periodical release would provide better environmental outcomes than releasing 100 GL each year (BMF 1999b). Given that for the most part, the Forest is a free-draining system with few contained wetlands, use of the EWA is now generally targeted at extending the duration of large natural floods, rather than creating large floods of short duration (Leslie & Ward In press). Current information suggests that flooding should occur in lower lying areas in the Forest at least twice each decade, ie. that 25% of the Forest should be inundated from September to January once every four years for colonial-nesting waterbirds (Leslie & Ward In press).

The EWA releases are to a large extent tailored to satisfy wetland water requirements, particularly for breeding waterbirds (Leslie & Ward In press). Indeed, breeding waterbirds are used as the primary biological indicator for the success of the EWA events as:

- they are top order consumers, suggesting that for example poor reproductive performance can signal long term environmental change related to diminished ecosystem productivity at lower trophic levels (Kushlan 1993),
- local waterbird abundance and diversity has declined substantially (Leslie 2001; Leslie & Ward In press),
- there is an established direct link between flow variability and waterbird breeding, particularly for Barmah-Millewa Forest (Leslie 2001),
- waterbirds have high public appeal, can be easily communicated to the wider public and can trigger local support and involvement in restoration activities,
- waterbirds can be surveyed effectively and efficiently, and results are often timely to enable appropriate water management decisions to be related to real-time biological requirements. For example, the extension of watering in particular water management areas allows completion of a successful breeding event.

Monitoring of waterbird numbers, species diversity and breeding occurrence has been conducted in the Forest once each season since 1998 in fixed locations throughout the Forest. The project aims to determine changes in waterbird breeding and non-breeding populations on a seasonal, yearly and between year basis. Prior to the establishment of this program, waterbird monitoring within the Forest generally occurred on an irregular basis, with records of the number of birds utilising wetlands and breeding events being kept irregularly, or at least when flood events occurred (BMF 2001). Three groups, NSW State Forests, Victorian Department of Natural Resources and Environment and a private consultant, Ecosurveys, conducted fairly opportunistic but intensive monitoring during the last EWA. Monitoring of waterbird numbers and breeding success throughout the Forest provided valuable information to the decision by the MDBC to release the Barmah-Millewa EWA. The second release of the EWA in 2000 was principally designed to extend the duration of the falling arm of the flood hydrograph to enable successful completion of nesting and fledging of young waterbirds. This was an extremely successful bird breeding event, with it being ranked as a 1 in 10 event in terms of numbers and species diversity (BMF 2001; Leslie 2001; Leslie & Ward In press).

Monitoring of amphibians was first conducted as a trial project in Barmah Forest during 2000/01, and was subsequently extended during 2001/02 to both Barmah and Millewa Forests (Ward 2001; Ward 2002). In general, monitoring was conducted monthly from September to January in a number of fixed, representative wetlands. Frogs were surveyed at night by call identification and active spot-light searches, although extra surveys were conducted for specific species based on response to tape-playback. Dip net sampling was also conducted in wetlands for tadpoles, enabling assessment of breeding success of individual species. This monitoring program has been successful in delivering appropriate recommendations specifically for amphibian requirements at a time when they were useful for water management decisions, and is likely to continue in the future (Ward 2002).

In general, monitoring biological responses of the use of the Barmah-Millewa Forest EWA is unfortunately fairly opportunistic, with the exception of the more recent regular monitoring programs for waterbirds and frogs. At present, other biological indicators such as fish populations and vegetation health, are either only reported during EWA events from opportunistic observations or from reference to other sampling programs. A recent project has begun to establish permanent vegetation transects for continual monitoring points within the Forest, which will assist in identifying both the short and long-term effects of the environmental flow releases on vegetation communities (BMF 2001). No results for this project are currently available.

Overall the biological indicators that are currently used in this monitoring program, have been extremely useful in providing timely and relevant advice to influence water management decisions for Barmah-Millewa Forest and for providing easily communicable results to the general public. The ability of the program to aid in water management within the Forest is therefore quite high. However, the program has a number of limitations:

- whilst there is a broad objective for returning environmental water to the Forest, there is no clear statement of the hypotheses for each indicator, creating a limited ability to accurately determine the success or otherwise of the flow event and the sampling program,
- following from this, there has been little attempt (except for waterbirds), to predict the likely benefits of any future EWA events on the health of the Forest,
- selection of biological indicators has been primarily based on indicators that are easy to communicate. The program lacks indicators that reflect the benefits that flooding the Forest may provide to the health of the riverine environment,
- Due to the sampling focus in the Forest alone for most indicators, the program is limited in its ability to confidentially extrapolate any responses to other similar wetland systems along the River.

Measuring the effectiveness of environmental water allocations – Barmah-Millewa

This study presents the results of the second stage of a research project established as a pilot study to develop protocols for monitoring programs to measure the response of floodplain wetlands in the Murray-Darling Basin to environmental water allocations (EWAs). The first stage of the project completed in July 1998, resulted in the development of a series of recommendations regarding appropriate indicators, study design and data analysis. These recommendations were based largely on literature review, expert consultation and analysis of existing data sets (Reid & Brooks 1998). The second stage of the project further developed these recommendations through a pilot monitoring program based on wetlands located within the Barmah-Millewa Forest on the Murray River floodplain (Reid *et al.* 2001).

One of the aims for EWAs is to maintain the extent of open plain wetlands, in particular of the moira grass plains, within Barmah-Millewa Forest (Reid *et al.* 2001). The study focused on wetlands in the Barmah-Millewa Forest on the Murray River floodplain. The wetlands included are typically open plain wetlands variously dominated by moira grass, swamp wallaby grass and common spike rush. The areal extent of these wetlands have been reduced as a result of hydrological changes wrought by river regulation through encroachment by river red gum and giant rush (Chesterfield 1986; Ward 1991). These areas are being targeted for conservation and restoration through EWA implementation strategies and other management efforts (Ward *et al.* 1994; MWEC 1997).

The study employed a modification of the BACI design known as MBACI, which incorporates multiple control and impact sites (Underwood 1991; Keough & Mapstone 1995). The use of the MBACI design is based on the notion that the Barmah-Millewa EWA constitutes an 'impact'. Accordingly, wetlands where flood frequency and duration will be largely unaffected by the EWA are classed as 'control' wetlands, and wetlands where flood frequency and particularly duration will be increased by the EWA are classed as 'impact' wetlands (Reid *et al.* 2001).

A total of nine wetlands were surveyed on four occasions from spring 1998 until autumn 2000 (two spring/summer and two autumn surveys). Eight wetlands are situated within the Barmah-Millewa Forest, and one situated within Bruce's Bend Forest. The timing on the surveys was in accordance with flooding patterns for the forest (Reid *et al.* 2001). However, data collected in the course of this study are 'before' data, because no EWAs were formally implemented in the system. Therefore, no absolute assessment can be made as to whether the EWAs are effective, but rather the data was collected to provide the baseline 'before' data, with 'after' data collected in future monitoring.

Reid & Brooks (1998; 2000) assessed the usefulness of a range of physical, chemical and biological indicators for measuring the effectiveness of EWAs during the first stage of the project. Those indicators identified to be most valuable were categorised as 'key indicators' and included: water depth (or soil moisture), aquatic macrophytes and aquatic macroinvertebrates. It was recommended that these indicators should be included in most, if not all, monitoring programs aimed at detecting ecological changes in wetlands in response to EWAs. A number of 'secondary indicators' were identified and were included principally because their measurement requires little additional time and effort. The 'secondary indicators' included: turbidity, electrical conductivity, water temperature, dissolved oxygen and pH (Reid *et al.* 2001). In contrast, zooplankton were included in the pilot study on the strength of growing evidence that strong relationships exist between the abundance and diversity of the zooplankton assemblages that emerge from flooded sediments and those sediments' flood histories

(Boulton & Lloyd 1992; Jenkins & Briggs 1997; Boulton & Jenkins 1998; Cartwright 2001). Aquatic macrophytes are the key indicator included in the study and were surveyed on every sampling occasion. Aquatic macroinvertebrates were sampled during one spring survey. Dry wetland sediments were also collected on one occasion. These were subsequently flooded under controlled conditions and the emergent microfaunal assemblages were sampled (Reid *et al.* 2001).

A pilot survey was conducted to assess the usefulness of the point counting method to survey macrophytes as recommended for use in herbfield and grassland communities, such as those present in the wetlands used in this study (Bonham 1989). The pilot survey showed point counting distinguished between sites equally well as surveys based on cover abundance within quadrats, but required less time (Reid *et al.* 2001).

The results of the pilot study provided valuable information on the performance of the indicators used and allowed for some predictions to be made on biological responses to EWA implementation. Strong relationships were detected between environmental variables, particularly those relating to hydrology, macrophyte and macroinvertebrate assemblages. The results did not support the continued inclusion of emergent fauna in future monitoring. The results show that aquatic macrophytes are the most suitable indicator group for detecting ecological responses to hydrological changes. This is due to the time efficiency of macrophyte surveys, their apparent sensitivity to hydrological cues and the relatively low level of botanical expertise required to carry out surveys. Whilst macrophytes are likely to be effective indicators, greater sensitivity may be achieved through focus on indicator taxa and functional groups. It is also very important that aquatic macrophyte surveys can be carried out cost-effectively (Reid *et al.* 2001). There was some evidence to suggest that macroinvertebrates are also sufficiently sensitive to hydrological cues. However, this was inconclusive due to confounding factors driven by short-term changes (Reid *et al.* 2001). The results highlight the need to include multiple wetlands in future or on-going monitoring. There is also a need to incorporate more frequent monitoring of the extent and depth of water (through the use of depth gauges with data loggers) to more accurately define hydrological changes (Reid *et al.* 2001).

Reid *et al.* (2001) conclude that it is difficult to assess fully the performance of the study design in the absence of 'after' data. Ideally, a monitoring program focussing on detecting responses to EWAs would employ a design in which wetlands could be assigned to control and impact categories randomly and where the EWAs would subsequently be confined to impact wetlands.

Mersey River Aquatic Fauna Monitoring Program

Parangana Dam on the upper reaches of the Mersey River, Tasmania, diverts flows to the Forth River for hydroelectric power generation. This diversion substantially reduces flow down the Mersey River, radically changing its hydrology (Knighton 1988), and is associated with a decline in the ecology and aesthetic quality of the river's middle and lower sections (MRWG 1998). In 1996, the Inter-Departmental Mersey River Working Group prescribed an environmental release from Parangana Dam to maintain a year round flow of 173 ML/day at Liena Bridge (approximately 7 km downstream of the dam). This requirement restores summer minimum flow levels while peak flows during winter and spring spates continue to occur as a result of dam spills. These releases commenced in winter 1999 and are ongoing.

The main objectives of the monitoring program were to evaluate any environmental benefits of the environmental flow release from Parangana dam and to assess the long-term economic, social and environmental justification of the releases. An additional stated aim of the monitoring program was to involve the local community since there were substantial community and political concerns regarding the releases (MRWG 1998).

The Inter-Departmental Mersey River Working Group predicted that increased flow downstream of Parangana Dam would increase available instream habitat, which would lead to an increase in the density and abundance of macroinvertebrate taxa that use these habitats and an overall increase in brown trout abundance (P. Davies pers. comm.). Macroinvertebrate populations were expected to respond to the dam releases within the first three years, but trout populations were not expected to show much change for five or six years. Native fish and algae were not likely to be affected by the dam releases (P. Davies pers. comm.).

The early implementation of the monitoring program allowed the use of a BACIP design, incorporating sampling Before and After, at Control and Impact locations with samples Paired in time. This is one of the few Australian studies where this has been possible, though a lack of spatially replicated control sites for the quantitative macroinvertebrate and fish surveys reduces the ability of the study to directly attribute downstream changes to the dam releases. This is a pity, since additional control sites (at least on the same river) were used in other aspects of the study and could have potentially been included for the more sensitive quantitative data as well.

Four main groups of environmental indicators were assessed. Electrofishing techniques were used annually to assess fish density (catch per unit effort) at 12 treatment and 5 control sites. Annual angler surveys have also been used to collect data on the response of the adult trout population to the flow releases, although it is expected that several years will be required for a response in the population to be seen. Filamentous algal biomass (as chlorophyll-a) was measured and overall cover was estimated at one control and three treatment sites. Macroinvertebrates were quantitatively assessed each year at one control site and at three treatment sites, with supplementary semi-quantitative samples taken twice a year at another 8 downstream sites. Standard AusRivAS techniques were used to sample macroinvertebrates and assess stream habitat at 5 sites downstream of Parangana Dam and at three control sites. AusRivAS O/E scores were calculated using both presence/absence and rank abundance macroinvertebrate data, with the latter being more responsive to flow change.

The monitoring program to assess the environmental effect of these releases commenced in 1996, ensuring at least three years data prior to flow releases for all parameters. Sampling is conducted annually for fish and quantitative macroinvertebrate sampling and angler surveys, and twice a year for AusRivAS assessment. Monitoring is still continuing four years after the commencement of flow releases in 1999, and is now demonstrating that a number of significant ecological responses (including substantial increases in macroinvertebrate density, abundance and diversity, and juvenile trout abundance) have occurred as a result of the flow change (P. Davies, pers. comm.).

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