Australia’s Environmental Flow Initiative: filling some knowledge gaps and exposing others

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Abstract Many of Australia’s river systems have been seriously degraded by inappropriate management of regulated flows. Other systems are facing threats from future water resources developments. There is a lack of information available to aid in allocation of environmental flows to rivers in order that they are managed in an ecologically sustainable manner. The Environmental Flows Initiative (EFI) is a major Australia-wide R&D program into environmental flows, funded through the Natural Heritage Trust (NHT), and administered by Environment Australia (EA). The program aims to identify environmental values, undertake targeted research to identify risks to river systems and flow requirements to sustain environmental values, to trial flow management options, and to evaluate these trials. The NHT relies on matching funding provided by the State and Territory authorities, and supports integrative approaches with emphasis on works on-the-ground where possible. While the EFI will close significant knowledge gaps, other gaps remain. Some of these relate to development and validation of rapid assessment techniques, understanding the importance of flow variability and how to define it, manipulation of flows to control alien species, developing a system of prioritising rivers for environmental flows, and enhancing flows with other catchment, channel and floodplain rehabilitation measures.

Keywords Environmental flows; river management; Australia; instream flows; river rehabilitation

Introduction

While some excellent research and development work has been done on environmental flows in Australia, it has also served to highlight the lack of basic data, the limited understanding of the relationships between flow and the ecological and geomorphological components, and the dearth of studies of what happens when flows are actually implemented (Arthington et al., 1998a,b). Environmental flows research and development activities are progressing in Australia within universities, government agencies, and cooperative research centres such as the Cooperative Research Centre for Freshwater Ecology (http://enterprise.canberra.edu.au/WWW/www-crcfe.nsf) and the Cooperative Research Centre for Catchment Hydrology (http://www.catchment.crc.org.au/), and the Cooperative Research Centre for Sustainable Development of Tropical Savannas (http://savanna.ntu.au/). A major recent injection of funding for environmental flows R&D in Australia was provided by the Commonwealth of Australia’s Environmental Flows Initiative (EFI), through the Natural Heritage Trust (NHT).

The Commonwealth has a major interest in river health, especially with the recent introduction of the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), in force from 16 July 2000. This is the most fundamental reform of Commonwealth environment laws since the first environment statutes were enacted in the early 1970s. The Act enables the Commonwealth to join with the States and Territories to provide a national scheme of environment protection and biodiversity conservation (http://www.erin.gov.au/epbc/).

The Natural Heritage Trust will inject $260 million into projects improving water quality and the ecological health of Australia’s river systems, including extra funding of almost $100 million for Rivercare activities. The $97 million National Rivercare Program will
assist the sustainable management, rehabilitation and conservation of rivers outside the Murray-Darling Basin (the Murray Darling Basin has a separate allocation of funds). A major component of Rivercare is the National River Health Program (NRHP), which has two components: Monitoring River Health and the Environmental Flows Initiative (EFI) (http://www.nht.gov.au/overview/rivers.html). The EFI is primarily delivered as a partnership between the Commonwealth, State and Territory governments and research organisations.

The EFI program will attempt to address some of the gaps in knowledge in the environmental flow field. The bulk of the projects being undertaken in this program were devised by State and Territory agencies, with assistance from research and consulting groups. The call for proposals was not restrictive in terms of the research topic, so the submissions should have reflected the range of problems being experienced in environmental flow management. The number of projects approved for funding was much lower than the number originally submitted, so it can be said that the EFI program does not comprehensively deal with all the concerns of the State and Territory agencies. The EFI program also has a small commissioned research component.

This paper summarises the current state of EA’s R&D under the EFI program on environmental flows, but it does not review progress or findings of the individual projects (no projects have yet been completed). This program is reviewed in light of the perceived gaps in knowledge in this field. The paper leans heavily on AACM International (1997) and Arthington et al. (1998a,b), but makes extensive use of reviews on the topic recently published in the worldwide literature. This paper does not attempt to review the current state of knowledge in the field of environmental flows, nor does it attempt to compile a list of current research. Rather, this paper uses previous reviews, and other information, to suggest priority topics for research and development that are likely to provide significant outcomes in terms of improved river management.

Current state of environment Australia’s environmental flows R&D under the EFI
Commissioned research

Three projects were commissioned in 1999 by Environment Australia in order to examine three environment types that are not well represented in the environmental flows literature, which has traditionally focused on the flows in rivers and streams: estuarine systems, groundwater dependent ecosystems, and wetlands of national and international importance. These projects had common objectives (with minor variations):

- to identify those environments (wetlands, groundwater dependent systems or estuaries) in Australia that are significant from an environmental perspective, and which are threatened by current or future changes to flow regime, or water supply;
- to develop a method for determination of appropriate environmental flows (including groundwater fluxes where relevant) that will protect these environments against decline in their ecological character;
- to identify information gaps; and
- to identify the practical limitations and opportunities available for implementation of environmental flows (including groundwater fluxes where relevant) to these systems.

State/Territory agency projects

State/Territory agency projects all have matching funding. They also involve collaboration with established research bodies and community organisations. Proposals considered for funding under the EFI were required to satisfy all or some of the following criteria:

- improve scientific understanding of ecosystem responses to natural and altered flow regimes across appropriate temporal and spatial scales
• develop or use trade-off mechanisms to clearly demonstrate the decision-making process in defining environmental flow allocations
• validate, improve or develop methods of devising and providing environmental flow allocations
• articulate specific environmental objectives for the system of concern and specify environmental outcomes expected from the intervention
• include monitoring and evaluation strategies that are designed to demonstrate the achievement of defined environmental objectives preferably relevant to prior and/or reference conditions.

Approved projects (Table 1) will identify environmental values, evaluate environmental flow needs, identify and trial management options, and assess management regimes. The research will be conducted Australia-wide, with several of the projects examining poorly understood but ecologically valuable systems, such as arid zone rivers, and rivers in northern Australia. The projects are generally investigating the relationships between flows and various aspects of the river environment (at various scales) in systems that are under development pressure. The Snowy Benchmarking Project is investigating how to measure the impact of an environmental flow in a river with a long history of regulation. The successful projects all have community consultation and technology transfer components.

Environment Australia’s research priorities

One challenge that is common to all EFI projects is transfer of the results to managers and the wider community. The States and Territories have traditionally been autonomous with respect to water resources management decisions, so cooperation and coordination between States and Territories was not seen to be necessary. For this reason, attempts by the Commonwealth to influence water resource management decisions could understandably meet with some resistance from the States and Territory governments. However, cross-border issues do arise in Australia, and creation of the Murray Darling Basin Commission (http://www.mdbc.gov.au/index.htm) to manage the Murray River, and the recent signing of the Lake Ayre Basin Agreement by the Commonwealth, Queensland and South Australian governments and launch of Strategic Plans (http://www.LakeEyreBasin.org.au) evidence a willingness to cooperate. Environment Australia is seeking to have best practice followed in all States and Territories. This can only succeed if the technology transfer component of the EFI takes an Australia-wide perspective.

In order to gain confidence by State/Territory agencies, at this stage Environment Australia's most effective position is one of supporting and promoting independent investigations that have wide application in solving the most pressing management problems (as defined by the States and Territories). At the same time, Environment Australia is seeking support from the States and Territories in achieving Commonwealth goals and objectives with respect to management of the aquatic environment. There is also value in supporting strategic research of a more fundamental nature. This research may address issues that are not currently high priority from the management perspective, but which could result in long-term environmental solutions or benefits. Other potentially important research questions are being developed in universities, Cooperative Research Centres, and other organisations dedicated to research activities.

Environmental flows in Australia – gaps in R&D

Introduction

The current state of knowledge and practice in Australia in the field of environmental flow assessment techniques was soundly reviewed in a series of Land and Water Resources R&D Corporation (LWRDRC) publications authored by Prof Angela Arthington (Griffith
Table 1  State/Territory projects approved for funding under the EFI for 1999/2000 - 2000/2001.  
State/Territory abbreviations are: NSW (New South Wales), Qld (Queensland), SA (South Australia), WA (Western Australia), NT (Northern Territory), and Vic (Victoria) (Australian Capital Territory and Tasmania are not represented in EFI).  Other abbreviations are CSIRO (Commonwealth Scientific and Industrial Research Organisation) and CRC (Cooperative Research Centre)

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<th>Project Title</th>
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<td>Environmental flow requirements of Vallisneria nana</td>
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<td>Assessment of the impact of private dams on seasonal stream flow</td>
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<td>Vic Department of Natural Resources and Environment, Sinclair Knight Merz, Melbourne Water, The University of Melbourne</td>
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<td>Environmental Flows in the Paroo and Warrego Rivers</td>
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<td>NSW National Parks and Wildlife, Qld Department of Natural Resources, NSW Department of Land and Water Conservation, Paroo River Association</td>
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University) and colleagues. (Arthington, 1998; Arthington and Zalucki (eds), 1998; Arthington et al., 1998a). Some Australian case studies of environmental flow investigations were described by Gippel (2000). The R&D requirements for environmental flows in Australia were identified by Arthington et al. (1998b) and AACM International (1997). In general, it could be said that there has been a focus on defining flows for rivers just below dams, with little information available on the consequences of flow regulation for areas further downstream, including coastal ecosystems, and very little consideration of groundwater dependent ecosystems and floodplain environments.

The AACM International (1997) report for the National River Health Program was based on a review of existing policy frameworks, consultation with a wide range of water industry stakeholders, and a workshop of R&D stakeholders. The final report recommended broad categories of research, suggested decision rules for allocating investment, and proposed three project design arrangements (multidisciplinary projects, targeted projects and innovative projects) with recommended investment allocations to each. The proposed portfolio was comprehensive and fairly specific, but stopped short of suggesting detailed hypotheses that required testing. Arthington et al. (1998b) presented two main strands of R&D: that required to improve individual methods of environmental flow assessment [based on recommendations concerning geomorphology, wetland and riparian vegetation, freshwater fish, coastal fisheries, and invertebrates in Arthington and Zalucki (eds) (1981)], and that required to improve existing holistic methodologies and the proposed best practice framework for environmental flow assessment [as described in Arthington (1998) and Arthington et al. (1998a)]. Arthington et al. (1998b) detailed specific issues that are worthy of investigation, but they were not prioritised.

This paper is not intended to be a review or reiteration of AACM International (1997) or Arthington et al. (1998b). Rather, it attempts to identify important research gaps that can be expressed as testable hypotheses which can then be rapidly translated into commissioned research projects. This is a discussion paper that makes no attempt to prioritise the research needed to close the knowledge gaps. At this stage there is no rationale on which to base priorities. Also, the list of issues is far from comprehensive and is open to modification. In the discussion below, environmental flow R&D concerns are not categorised according to a rigid system. Rather, the subheadings deal with certain dominant environmental components (e.g. groundwater) or disciplines (e.g. geomorphology) or methodologies (e.g. frameworks for assessment) where knowledge gaps were perceived.

Methodologies for assessment of environmental flows

Frameworks. Two basic approaches to environmental flow determinations are available in Australia (Arthington et al. 1998a). The first is a bottom-up approach, which uses a starting point of zero flows and builds a regime based on flows requested for specific purposes. The second is a top-down approach where all water is initially available for the environment and the amount of water that can be diverted from the system without producing undesirable environmental impacts is evaluated. With respect to environmental flow methodologies, Arthington et al. (1998) concluded that the bottom-up approach seems likely to form the basis of most assessments in the foreseeable future. Water managers appear to have accepted the idea that some features of the natural flow regime are more important than others, and if maintained will protect system integrity. This is largely an untested hypothesis. The alternative hypothesis (top-down approach) is that only the natural flow regime will maintain the natural levels of ecological integrity (perhaps measured by biological diversity and abundance). Any departure from the natural regime will cause degradation of ecological integrity and the relationship between the degree of flow alteration and the biological impact is likely to be non-linear. If this is the case, the objective of environmental flow
assessment (given sufficient knowledge of the system) is to establish the tolerable level of system modification.

Construction of an environmental flow regime using the bottom-up approach requires a sound understanding of the flow requirements of the ecosystem components, but unfortunately this is limited in most Australian catchments (Arthington et al. 1998). Thus, there is a need for research and development to improve fundamental understanding of flow-driven geomorphological and ecological processes, and also to improve the assessment process itself. Arthington et al. (1998) considered that the most rigorous approach to environmental flow assessment was a combined bottom-up and top-down approach. The bottom-up approach would be used to make initial assessments, then the regime would be checked against a top-down assessment that used benchmarking to determine the impacts in similarly regulated systems.

There would appear to be a need for a national framework for determination of environmental flows. As suggested by Dunbar et al. (1998), the framework should be based around a hierarchy of techniques, and should be updated as new knowledge is gained.

**Expert panel approach.** Arthington et al. (1998a) correctly focused on recommending the best practice methodologies, and identifying ways to improve these methodologies. In practice, environmental flow assessments are often constrained by financial resources, and even more so by time limitations. The common response to this problem is to employ a rapid assessment technique. Many such environmental flow assessments have been made in Australia using the expert panel approach (Swales and Harris, 1995). Under this method, a group of experts (not necessarily all from scientific backgrounds) conducts one or more field visits and workshops (limited data analysis and review of existing data are usually involved), and then agree on a flow regime to meet the objectives (although too often these are of a very general nature). For example, the Snowy Inquiry methodology is grounded in the expert panel approach (Snowy Water Inquiry, 1998; Gippel et al., 1999).

While generally accepted as a rapid and relatively cheap method to evaluate environmental conditions, there are a number of serious concerns associated with the expert panel process (Bishop, 1996). Expert panels can come to very different conclusions. Ultimately, it cannot be determined whether one panel or another has arrived at the “correct” result, but it should be realised that the deliberations of a single expert panel cannot be taken as representing the views of all experts in that field. Other factors involved in the results of an expert panel approach include the role of interpersonal dynamics, the potential for groupings to arise within the panel, the impact of a single dominant personality, and the possibility that consensus can be a product of collective bias (rather than independent assessments) (Bishop, 1996). In a comparison of 18 assessments made by two expert panels examining the same rivers in NSW, the two panels agreed in only one case (Pusey 1998). This alarming finding suggests that there is a need to research the limitations of this method.

**Rapid hydrological assessment techniques.** Rapid techniques are sometimes known as look-up methods. Various desktop techniques have been developed overseas (mainly North America), whereby flow recommendations can be made solely on the basis of analysis of hydrological records (Petts and Maddock, 1996; Pusey, 1998). Dunbar et al. (1998) noted that there are considerable operational attractions in the use of look-up techniques for preliminary objectives, and national, strategic monitoring. However, there is no universally agreed percentage of annual or monthly flow that will maintain the biological integrity of a regulated river. Studies worldwide have produced recommendations that fall across a wide range of percentage of unregulated flow.
It must be noted that most desktop methods were based on field studies of flow-ecology relationships (e.g. see Tennant, 1976; Orth and Leonard, 1990). Despite warnings from the authors of these methods that they are appropriate only in the region where the field investigations were conducted, they have been applied to diverse environments, even other countries with very different physiographic and biological environments (Pusey, 1998). The major tenet of the natural flow regime paradigm (Poff and Ward, 1989; Poff et al., 1997) is the overwhelming importance of flow variability for maintaining ecological integrity. In Australia this has been quickly converted into environmental flow policy objectives by adoption of flow translucency as a rapid assessment technique (termed "mimicking the natural flow"). Flow translucency means scaling-down natural flows (various functions have been applied) so that while annual regulated discharge is lower than natural, the regulated hydrograph exhibits daily, seasonal and annual variations that resemble those of the natural hydrograph. To some extent, claims of the importance of maintaining flow variability are grounded in the observation that the flows in Australian rivers are naturally highly variable [e.g. see Finlayson and McMahon (1988), Pusey and Arrington (1996), Pusey (1998) and Puckridge et al. (1998)]. However, this approach (i.e. scaling down flows) may fail to recommend threshold events that are necessary for normal ecological and geomorphological functioning. Another weakness of the flow translucency approach is that while it simply scales down the flows, the channel in which the flows are passed is not necessarily scaled down; thus, for low flows, a given reduction in flow could produce a disproportionately large loss of hydraulically-suitable habitat area.

Uncritical application of flow translucency rules could result in inefficient and ineffective delivery of flows for the environment. This issue is especially critical in areas with heavy competition for scarce water resources, where only a relatively small percentage of the natural flow is allocated for the environment. Rapid environmental flow assessment techniques are potentially highly valuable tools, but they should not be devised rapidly on the basis of flimsy assumptions or overseas practice; rapid assessment techniques should be grounded on fundamental investigations (involving extensive fieldwork) of flow-ecology relations in representative catchments (Pusey, 1998).

Physical habitat simulation. Physical habitat simulation (e.g. PHABSIM) is a detailed technique of quantifying habitat for particular species of interest (target species) at the micro-scale level. The simulations are performed within a broader methodological framework, termed in-stream flow incremental methodology (IFIM) (Bovee and Milhous, 1978). This is regarded as the most defensible approach to environmental flow determination, but it does have weaknesses and limitations (Dunbar et al., 1998; Pusey, 1998). IFIM has been criticised recently, with claims that its misuse has actually hastened the decline of rivers in the western U.S., particularly the large alluvial rivers (Woo, 1999). Two major criticisms of PHABSIM are that it promotes the application of flows that are too low for sediment mobilisation, and that it promotes relatively constant flows. It is crucial that PHABSIM be used within the wider IFIM framework (or other holistic framework). One difficulty with the PHABSIM approach is that it requires extensive field work, and knowledge of the habitat requirements of the species of interest. Application of physical habitat simulation to environmental flows problems in Australia were reported by Gippel and Stewardson (1995) and Davies and Humphries (1995), but the method has not been widely used in this country.

Components of the aquatic system

Surface water hydrology. Most of the standard statistical analysis tools used by hydrologists were developed in response to the traditional engineering problems of drought
management, flood mitigation, or development of water supply systems. In contrast, environmental flow assessment uses established or hypothesised relationships between hydrological characteristics of a stream and ecological response, so that the regulated flow regime can be tailored to provide a basic level of ecosystem protection. Some standard hydrological indices may be appropriate, but it is also necessary to describe discharge records in other ways that relate well to ecological and geomorphological processes. The holistic expert panel approach, which either builds a flow regime from ecologically and geomorphologically critical facets, or deconstructs the natural flow regime and removes the less important facets, requires hydrological characterisation of the relevant facets.

Initially, the magnitude of each important hydrological facet may not be expressed by expert panel members in terms of a flow rate, but rather in such terms as “flow that overtops the banks”, “flow that inundates the channel bed”, “flow that allows fish passage through riffles”, “flow that disturbs surface sediment”, “flow that will de-stratify pools”, or “flow that will mobilise bed material”. The hydrological questions that arise regarding these facets are usually: What is their magnitude? How frequently do they occur? What is their duration? When do they occur? What is the rate of change? and, What volume of water do they require? These are the primary characteristics because they translate directly to specifications for an environmental flow regime, and they allow estimation of the volume of water required for allocation to the environment. Hydrologists would benefit greatly from production of a manual that provides: guidance for translating verbal statements of flow requirements into hydrological indices; suggestions for linking hydrological processes with ecological and geomorphological processes; methods for dissecting and describing the facets of the flow regime; techniques for clearly presenting the results of hydrological analyses to a wide range of interested parties; and ways of transforming the results of hydrological analysis into practical flow recommendations (Pusey, 1998). Individual investigations have had to address these issues [e.g. Arthington et al. (2000) and Brizga (2000)], but a general approach has not yet been thoroughly researched and published.

**Groundwater hydrology.** The tradition in Australian hydrology is to separate groundwater and surface water into two disciplines, with little research on the interactions between these two aspects of the hydrological cycle. Environmental flow research grew out of surface water hydrology and ecology, so it is not surprising that very few studies have ever been done on groundwater processes with respect to environmental flows. Strongly groundwater dependent systems occupy only a small percentage (2%) of the area of the continent. However, given the characteristically variable hydrology of Australian systems, these relatively well watered groundwater-fed systems are highly significant from a conservation perspective. Many of the ecosystems associated with groundwater discharge form the bases of many of Australia’s national parks, particularly in the arid and semi-arid zones (Hatton and Evans 1998). The EFI commissioned project on determining the environmental water requirements of groundwater dependent systems (Table 1) will hopefully spawn interest in this area, identify research needs, and encourage consideration of groundwater processes in environmental flow decision making. The EFI projects centred on the Daly River in the Northern Territory (Table 1) also have relevance here, as the dry season flows in this river system are almost entirely dependent on groundwater flows.

**Geomorphology.** Geomorphological components of environmental flow methods have focused on the presumed dominance of medium and high flows in shaping and maintaining channel morphology (i.e. flushing and channel maintenance flows). There is a need to consider the geomorphic relevance of the full range of flows (Brizga, 1998). Where flows for geomorphic processes have been recommended (e.g. Snowy Water Inquiry, 1998), they...
invariably represent only a small part of the natural medium and high flow regime, so such recommendations should be seen as little more than hypotheses waiting to be tested.

Many of the important habitat features of rivers are also geomorphic features, such as bars, undercut banks, pools and riffles. Geomorphic features like rock bars and cascades limit fish passage under regulated flow conditions. There is currently only limited understanding of how hydrology controls these major geomorphic features of channels. Research is required on how to maintain channels, not just the overall channel size and shape, but the nature of the major in-stream features. There is also a lack of information on the implications of environmental flows for sediment mobilisation, and substrate flushing (Brizga, 1998).

Vegetation. Only limited information is available on plant-water relationships, so the benefits of environmental flows to wetland and riparian vegetation are largely unknown. A prescriptive method for assessing the water regime of aquatic vegetation does not yet exist (Arthington et al., 1998). However, this has been partly addressed in a recently published guide on water requirements for plants of floodplain wetlands (Roberts et al., 2000). This guide makes the point that most of the environmental flow effort, whether ecological research or flow delivery, has been on the in-channel riverine environment and its immediate riparian zone, with less attention on the surrounding wetlands and floodplain. Techniques for estimating the water requirements of individual wetlands and billabongs are partly covered in manuals produced by some states but these do not apply to large floodplain systems such as Macquarie Marshes or the Great Cumbung Swamp. Roberts et al. (2000) addresses this gap. Brock (1997), Brock and Casanova (2000) and Brock et al. (2000) provide practical advice on wetland management and rehabilitation, based on the results of extensive research. One of the EFI commissioned projects (Table 1) developed a framework for determining water allocations for wetlands of national and international importance.

Fish. There is a growing understanding of the relationship between flow management and freshwater fish. More knowledge is required on habitat requirements, life history, patterns of migration, and links between freshwater and estuarine systems. There is almost a complete absence of validation of the sustainability of prescribed environmental flow allocations (Pusey, 1998). This applies even for icon species such as the river blackfish (Gadopsis marmoratus) where some knowledge of ecology-flow relationships exists (Koehn and O’Connor, 1990; Gippel and Stewardson, 1995).

Introduced fish species have been associated with negative impacts on some Australian native fish species (Pusey, 1998). Despite this, some environmental flow evaluations have included introduced angling species as target taxa. The assumption that the needs of native species are met by addressing the in-stream flow needs of taxa of recreational importance is probably incorrect (Pusey, 1998). Where maintenance of the recreational values of a river is perceived to rely on encouragement of introduced angling species, the environmental flow evaluation process is faced with a difficult dilemma.

The delivery of flows may help to restrict trout success by stressing them in mid-summer (trout have been associated with negative impacts on some native fish species). In times of very low flow trout experience heat/oxygen mortality, while native fish are less sensitive to this. Stressing rivers with very low flows for a few weeks in Jan-Feb may disadvantage trout without harming the native fish. In contrast, consistent high flows probably advantage trout (Gippel et al., 1999). There are many rivers in Australia where the idea of disadvantaging alien species with environmental flows could be readily tested.
Invertebrates. The review of Growns (1998) found that only a small proportion of the information necessary to develop environmental flow methods for invertebrates is being addressed by current Australian research efforts. Growns (1998) concluded that while some research is needed to further develop and refine methods of flow determination, most research should be directed at understanding the specific flow requirements of invertebrates. The flow requirements of some invertebrates may be easy to define, but it is likely to be more subtle for many others, and the problem is even more complex when considering invertebrate community structure (Growns, 1998).

Water quality. With respect to environmental flows, the main water quality parameters of interest are nutrients, turbidity and temperature. These are all to some extent flow-dependent and they also affect algal growth. Thus, there would appear to be some scope to control algal blooms by appropriate flow release strategies. It may be possible to use environmental flows to control unnatural pool stratification, which can be a problem in saline areas and in regulated rivers with deep pools.

The main cause of poor water quality in regulated rivers is not necessarily the flow regulation itself, although this can exacerbate the problem. Poor water quality usually results from inappropriate catchment and channel management, so it could be argued that manipulation of flows (under the guise of “environmental flows”) to ameliorate this problem, by flushing or diluting contaminants for example, addresses the symptom and not the cause of the problem. However, manipulation of flows to improve water quality has potential as an expedient measure to complement longer-term catchment and channel rehabilitation programs. In some highly regulated and disturbed rivers, water quality and environmental flow objectives may have to be determined together. One example of this approach is the recently announced Murray-Darling Basin Commission project Water Quality and Environmental Flows Objectives for the River Murray (Mr Trevor Jacobs, MDWC, pers. comm. 2000).

Some regions of particular concern
Hydropower impacts. Rapid fluctuations in discharge are known to have deleterious impacts on aquatic environments (Petts, 1984: 183-185; Boon, 1998). However, most of this research work has been done outside of Australia (e.g. Trotsky and Gregory, 1974; Weisberg et al., 1990). The highest concentration of hydropower stations is in Tasmania, a state which is not represented in the EFI program (Table 1). In Tasmania, the impact of hydropower stations on river flows is superimposed on seasonal flow reversal, so some of the most serious water development impacts in Australia can be expected in those systems. This would appear to be an issue of major concern, given Tasmania’s unique mountainous environments, southern extent, and island climate. The Basslink project, a planned undersea power cable across Bass Strait that will link Tasmania’s electricity grid with Australia’s national electricity grid, will ensure ongoing exploitation of hydropower resources in Tasmania (http://www.basslink.tas.gov.au/).

Estuaries. Despite the known positive links between river discharge and coastal ecosystems, and the fact that a significant proportion of Australia’s total fisheries harvest is derived from estuarine and inshore waters, there still exists a common perception that “water going to the sea is wasted” (Bunn et al., 1998). There is little information available on the consequences of flow regulation in headwater areas for coastal ecosystems, but there are suggestions that it could be significant. For example, in a study of the largely unregulated Logan river, Queensland, the strongest positive correlations were observed between prawn catches and summer discharge (Bunn et al., 1998), and it is summer flows that are
usually most impacted by regulation. Research is required to investigate causal mechanisms and to develop predictive models using existing catch and flow data (Bunn et al., 1998). The EFI commissioned project on determining the environmental flow requirements of estuaries (Table 1) will help to address this gap, but research is also needed to establish the causal mechanisms that underlie observed relationships between flow and estuarine and coastal ecological processes (Bunn et al., 1998).

Inland and tropical rivers. Although these rivers make up the bulk of the length of river channels in Australia, they have received relatively little research attention compared with rivers in the humid areas of the south-east. This is understandable, due to the remoteness of these areas from the major population centres, relatively low levels of water resource development, and difficulty of observing process due to the highly variable flow regimes. However, these rivers are beginning to receive more attention both in terms of research and environmental management (e.g. Puckridge et al., 1999; Semeniuk and Semeniuk, 1997; Lake Eyre Basin Coordinating Group, 2000). The dry season flow in many rivers in the northern part of Australia is sourced entirely from groundwater stores, so recent development pressure to harvest this water may threaten the future integrity of these systems. The vast arid zone rivers of the Lake Eyre Basin do not flow to the sea, but terminate in inland lakes. Their flows originate in higher rainfall areas in the uplands, so any water resources developments are likely to have serious impacts on the drier areas downstream. The EFI supports research in the hydrologically sensitive areas of Northern Territory, the Ord River valley and the arid zone (Table 1), so that future developments can be planned to minimise impacts on river systems.

Implementation of environmental flows

Setting visions and objectives for environmental flows. To establish a vision for environmental flows based on pre-disturbance conditions is simply to produce a template that may help shape the desired outcome. The vision describes a condition that was probably, at a previous time, (putting definitional problems aside) ecologically sustainable. This is a logical reference point, if the goal of river management is to maintain an ecologically diverse and sustainable system (as proposed by Brookes and Shields, 1996, p. 385 for example). However, rivers have many other (non-ecological) values, some of which may be mutually exclusive and/or incompatible with this ecological goal. The template of a pre-existing system that was sustainable could provide the common ground to an otherwise disjointed or uncooperative group of stakeholders (who would probably agree unanimously that, given another chance, they would manage the river differently to the way that it has been done since European occupation). Conflicts could be resolved through a combination of scientific and economic investigation, negotiation, compromise, or even voting by majority. In the process, some elements of the template would be modified, scaled down, sacrificed, or traded for alternative elements. It seems unreasonable to expect any single group (e.g. “expert panel”) to be able to establish a set of integrated, achievable and acceptable rehabilitation objectives prior to and independently of this process (Gippel, 1998). Establishing an appropriate vision allows stakeholders to take a holistic view of the system. The current stream condition can then be understood within the historical context of catchment, flow and channel change.

Realistic rehabilitation objectives are more likely to be a set of specific objectives for certain river reaches, plant or animal species or community, chemical or physical features, or aesthetic or recreational values, rather than a well intentioned but nebulous proposal to rehabilitate a stream to what is perceived to be a more “natural” condition (Gippel, 1999).
continuing to produce dubious and varied results by simply repeating the trial-and-error approach in each case), these ideas can be more formally developed into a system, or set of guidelines, that assist the complex process of setting visions, priorities and objectives for environmental flows. The holistic methodologies reviewed by Arthington (1998) all require setting of visions, priorities and objectives, but they tend to rely on small groups of experts with a strong focus on ecological outcomes. An environmental flows decision support system currently under development (Young et al., 1995) is likely to be a useful tool for environmental flow evaluation. The strongly visual and flexible computer-based model may provide a consistent and common language of understanding between members of the various interest groups, scientists and managers involved in environmental flows issues.

Environmental flows and river rehabilitation. Implementation of environmental flows is only one of the tools that can be used to rehabilitate rivers. River rehabilitation can involve flow issues, as well as floodplain issues, riparian issues, catchment management and in-channel works. It would be rare for rehabilitation of a degraded river to require consideration of flow issues only. Ideally, clearly defined rehabilitation objectives should guide the direction of the environmental flow evaluation. The current best practice model of stream rehabilitation stresses the importance of first setting goals and developing measurable objectives. Brierley (1999) and Rutherfurd et al. (1999) emphasise the importance of prioritising rehabilitation reaches, with least disturbed reaches being the main target for rehabilitation and highly degraded reaches receiving the lowest priority for action. These same principles could be applied to prioritising rivers, and reaches of rivers, for implementation of environmental flows (Arthington, 1997; Arthington et al., 1998a). One major impediment to progress is the lack of a consistent method for assessing the ecological management class of rivers in Australia. Research on this topic is in progress, with Dunn (2000) recently producing a system for assessing the ecological values of rivers. It may be possible to adapt the five-scale classification system used in South Africa (Kleynhans, 1999) to the Australian situation.

Given that environmental flow regimes are nearly always different to the natural flow regime, often with lower flow levels for longer periods of time, habitat quality or availability is likely to be lower than under unregulated conditions. There may be opportunities to offset this difference by enhancing the habitat through channel reshaping or addition of large woody debris. In rivers that have suffered loss of riparian and in-stream vegetation, excessive sedimentation, channel erosion or other disturbance, rehabilitation of these components could add value to any environmental flows that were provided. Indeed, there may be little benefit in providing environmental flows alone to highly disturbed channels.

Testing environmental flow hypotheses. The number of Australian studies that report environmental flow recommendations greatly outweighs the number of studies that report scientific evaluation of the results of implementation of these recommendations. In fact, very few such studies can be found in the Australian or international literature. It is impossible to say, on the basis of previous experience and knowledge, how far the environmental flow regime can depart from the natural flow regime in order to maintain or improve biological diversity. One guiding principle is that the closer the environmental flow regime is to the natural flow regime, the greater is the confidence that ecological integrity will be maintained. Benchmarking, as used in the Queensland WAMP process (Brizga, 2000; Arthington, 1998, p. 28) is a useful method in this regard. Benchmarking involves collating information from other river systems that have suffered varying degrees of degradation from flow regulation. These benchmarks are then used to assess the potential impacts of modified flow regimes in the river of interest. In the case of rivers with established dams
and weirs, Gippel and Stewardson (1995) and Gippel (2000) advocated thorough review of the scientific evidence for ecological impact due to regulation as a guide to setting improved environmental flow regimes.

The best way to test hypotheses regarding environmental flows is to trial full-scale implementation. The EFI Snowy Benchmarking Project will provide some much needed guidance here. It is an especially valuable project, because it is examining the full length of the Snowy River, from Jindabyne Dam where environmental flows are expected to vastly improve the condition of the river, to the lower reaches, where the physical and ecological responses to environmental flows may be difficult to detect, especially in the short-time frame. A similar large-scale environmental flow trial is underway on the Campaspe River in Victoria (Humphries and Lake, 1996). One of the most important outcomes expected from these trials is the development of appropriate methodologies and indices for measuring the effects of implementing environmental flows.

Conclusion
The recent injection of funding into investigation of environmental flows has certainly been directed at filling some major knowledge gaps. The Environmental Flows Initiative represents a significant component of the effort to understand environmental flows problems in Australia, with other important research and development being undertaken by State and Territory agencies, universities and other research groups. However, large gaps in knowledge remain. The knowledge gaps create uncertainty and risk when making environmental flow decisions, so a continued effort should be made to resolve them. Reducing the knowledge gaps involves research on two linked fronts: developing better frameworks, tools, techniques and models for determining interim environmental flows, and gaining a better understanding of how flows drive river geomorphology and ecology.

It should be noted that the search for a universal flow allocation technique may be fruitless, as the practical reality is that environmental flow problems are highly diverse, in terms of the characteristics of the environment, the funds available, the time available, the scope of the study, and the potential cost of making an error in the allocation. Thus, while the importance of developing methods and testing hypotheses cannot be understated, there is a need to ensure that the industry develops the capacity to make prudent use of the outcomes of environmental flow research (Gippel, 2000). At the same time, it is vital that the stakeholders and wider community are informed of, and involved in, developments in the environmental flows field (this has not been a strong feature of progress to date). Lack of understanding disempowers community advisors and stakeholders – a problem that could threaten successful implementation of environmental flows.

References


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