3. Environmental Water: The Benefits of Ecological Goods and Services

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Introduction

Water has been viewed primarily as an exploitable commodity for human consumption, either directly or for growing food and fibre. As such, the wider range of benefits that might be derived from the ecological goods and services that are also dependent on water has not been recognised. Stocks of natural capital and flows of ecosystem goods and services are rapidly shrinking, caused by unprecedented rates of land-use change, water scarcity, and changing climate. Thus, there is a need for quantified trade-offs between social, ecological and economic objectives across a landscape that informs initiatives in three areas. First, to increase the equity, effectiveness and/or efficiency of resource use by revealing information on the sources and drivers of change, and the economic and social values generated across the full range of ecological goods and services. Second, to recognise and then improve the management and protection of existing ecosystem goods and services with a view to understanding their relevance and value. Third, to introduce incentive-based mechanisms (such as payments for maintaining ecosystem goods and services) for ecosystem conservation and management. This chapter aims to explore the range of water-dependent ecological goods and services and their importance in sustaining environmental futures in the Murray–Darling Basin.

The Murray–Darling Basin, like all river basins, naturally comprises a set of interconnected physical, chemical and biological elements, which revolve around the flow of water. Thus, the outcomes of activities and management decisions in one place have implications elsewhere in the Basin. This interconnectedness and the limited amount of water in the Basin means that the flow needs of any ecosystem along the rivers cannot be met without compromising the needs of another elsewhere (Roberts et al. 2001). Markets, property/water rights, government structures and social networks might all lead to overuse or misuse of natural resources. Treating ecological goods and services as if they were 'free' when they are not, or not recognising the adverse consequences of their use, will lead to reductions in potential human welfare or increased real costs to meet their loss. Explicit consideration is needed of the ecological implications of social and economic decisions of water use to understand the true costs and benefits (Costanza and Farber 2002). The Basin Plan should provide a framework for feedback to facilitate the management of water use in the context of the human and ecological benefits and costs, and therefore better understanding of their wider 'value'.

An assessment of the ecosystem services provided by the lowland rivers, wetlands and floodplains of the Murray–Darling Basin using the approach adopted by Costanza et al. (1997) estimates their value at between $187 and $302 million per annum (Thoms and Sheldon 2000). While this is small compared with the 2004–05 estimate of agricultural production of $15 billion (Australian Bureau of Statistics: <http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/4610.0.55.007/>), it does underpin much of that production, and its potential loss is not usually factored into considerations of water use. To provide the ecological goods and services that are fundamental to sustaining the uses to which they are put, the rivers need to be in good condition.

The Basin Plan is a key requirement of the *Water Act 2007* and includes an Environmental Water Plan (EWP) to protect and restore rivers, wetlands and other environmental assets, and to protect biodiversity dependent on the Basin's water holdings in accordance with the EWP.

Under Section 28(2) of the *Water Act 2007*, the EWP must specify

a) the overall environmental objectives for the water-dependent ecosystems of the Murray–Darling Basin;

b) targets by which to measure progress towards achieving the environmental objectives specified in accordance with paragraph (a);

c) an environmental management framework for planned environmental water and held environmental water;

d) the methods to be used to identify environmental assets in the Murray–Darling Basin that will require environmental watering;

e) the principles to be applied, and methods to be used, to determine the priorities for applying environmental water (including applying that water to environmental assets that are identified using the methods specified under paragraph (d));

f) the principles to be applied in environmental watering.

These specifications require that water allocations should be in the context of how ecosystems function and to achieve ecological outcomes. They also require ecological understanding of both the ecological processes and the features being protected and restored, and for relevance these could be related to specific ecological goods and services (see Table 3.1). The Department of the

Environment, Water, Heritage and the Arts (DEWHA 2009) has produced a discussion paper on *A framework for determining Commonwealth environmental water actions*. The paper reiterates an aim of the *Water Act 2007* that ecosystems have sufficient water to perform key ecological functions into the future. Central to this is an Environmental Water Plan to enable the environmental water of all holders and managers to be coordinated in a complementary basin-wide manner. An environmental plan also needs to be in the context of the National Water Initiative (NWI), which defines the environmentally sustainable level of extraction as 'the level of water extraction from a particular system which, if exceeded would compromise key environmental assets, or ecosystem functions and the productive base of the resource' (Commonwealth of Australia 2004). These definitions fit the specifications noted above but are much wider than the current focus on icon sites through the Living Murray and floodplain wetlands noted in the Sustainable Yields project (CSIRO 2008). Also, the NWI definition focuses on limiting extraction to maintain ecological values, rather than how much should be put back—a subtle but important difference in line with the restatement of the title question.

Thus, a primary aim of the Basin Plan is to fulfil the specifications above and guide water trading and recovery to achieve efficiencies and desired ecological outcomes. Stating these ecological outcomes in terms of ecological goods and services would provide a clearer understanding of the basis for their relevance and how they might be valued more widely than just maintaining the environment for its own sake. This chapter aims to elaborate on how various strategies might maintain ecological goods and services supplied by rivers and wetlands. In taking this approach, communities should be better informed as to the potential costs of losing ecological goods and services and of other ways of gaining benefit, rather than just consuming water. Inevitably, there is also a need to consider that ecological damage is caused by more than just water use, and that there is a requirement for assessment and the need for adaptive management.

Water to Achieve Ecological Outcomes

Rivers supply ecological goods and services that are much more than just water (Table 3.1). At present these goods and services are not captured in the market systems that primarily consider only the value of water for human consumption or the production of food and fibre. Defining 'ecological goods and services' is done to convey the important idea that ecosystems are socially valuable and to convey the benefits of nature to human welfare, households, communities and economies (Boyd and Banzhaf 2007; Daly and Cobb 1989). This section considers each of the major functions in Table 3.1 and how they might be addressed by current or proposed management activities likely to come from the Basin Plan.

Regulation Functions

Humans rely on healthy, functioning systems extensively for waste treatment and nutrient regulation (Table 3.1) at significant cost savings. Whenever effluents that are not fully treated are discharged to rivers (for example, from sewage-treatment plants), the riverine ecological processes are being relied on to undertake the final treatment, especially when downstream users depend on the water. The failure of the river ecosystem to supply this service with regard to nutrient regulation resulted in the Darling River algal bloom in 1992, which effectively shut down the entire community at substantial costs way above any treatment costs. The financial advantage of this ecological service would be easily calculated by factoring the additional costs of full treatment. The current scourge of European carp in many lowland rivers is, in part, likely to result from rivers fragmented by water-regulation structures and low flows that together reduce the competitiveness of native species and provide a habitat advantage to alien species. Flow management orientated to supplying human needs without consideration of environmental needs has exacerbated these problems again with significant environmental and economic costs caused directly by the activities of carp and loss of recreational amenity.

Habitat Functions

There has been an emphasis in past management—which is likely to be continued in the Basin Plan—on flow management to make use of refuges (for example, icon sites) to provide some protection against low flows and the current dry conditions. This approach will meet some of the requirements of habitat functions. Icon sites and other floodplain refuges that might be protected will also meet some of the needs of nurseries, although many species breed in areas other than such sites. This approach has not, however, properly considered other ecological goods and services provided by habitat, or been implemented with a view to protect them to maintain other benefits such as biodiversity (to meet the requirements of the *Environment Protection and Biodiversity Conservation Act*), production and dispersal, particularly with regard to connectivity throughout the Basin (Table 3.1).

Table 3.1 Ecologically dependent functions, goods and services of rivers.

Functions	Ecosystem processes and components	Goods and services
Regulation functions	*Maintenance of essential ecological processes and life-support systems*	
Waste treatment	Role of vegetation and biota in removal or breakdown of discharges to rivers	Pollution control Reduction in full treatment costs
Nutrient regulation	Role of biota in storage and recycling of nutrients (N&P)	Maintenance of water quality Reduction of algal blooms
Biological control	Population control through trophic relationships	Balanced native populations Control of pest numbers (eg., European carp)
Habitat functions	*Providing habitat for native plants and animals*	
Refuges	Suitable living space for native plants and animals	Maintenance of biodiversity Sources for re-colonisation. Minimum population support
Nurseries	Suitable reproduction habitat	Maintenance of population numbers Natural recruitment
Complexity	Variety of niches to support complex communities	Resilient food webs Diverse ecosystem structure supporting long-term stability
Vertical structure	Floodplain inundation and riparian growth	Vertical habitat, especially in arid zones Connected zones throughout catchments
Connectedness	Migration and dispersal throughout catchments	Catchment-wide maintenance of ecological communities via channels and riparian corridors
Production functions	*Provision of natural resources*	
Genetic resources	Genetic material, evolution and adaptation flexibility in native plants and animals	Adaptation to changed conditions because of use or climate change Chemical models and tools Test and assay organisms
Recreation	Sport fishing, aquarium plants	Populations with sufficient production for harvesting
Food	Commercial fishing and aquaculture	Harvestable populations Source material for aquaculture
Raw materials	Conversion of solar energy into biomass for human construction and other uses	Specialist riparian species—eg. river red gum

Functions	Ecosystem processes and components	Goods and services
Information functions	*Providing opportunities for education and cognitive development*	
Aesthetic value	Attractive landscapes	Enjoyment of scenery
Recreation	Variety in riverine landscapes	Travel and ecotourism Outdoor sports
Culture	Traditional people's values and significance	Understanding the place and its value for long-term human habitation
Art	Natural features with artistic value	Nature as motive in books, film, painting, folklore, national symbols, advertising, and so on
History	Variety of features with value	Historical development of the country via rivers
Science and education	Variety in nature with scientific and educational value	Use of natural systems for education Use of nature for scientific research

Source: Adapted from de Groot et al. 2002.

Production Functions

Healthy ecological resources also provide for fishing, boating and passive recreation that all benefit from proper environmental flow management (Table 3.1). Fish-population recruitment, healthy riparian zones and the maintenance of genetic diversity are dependent on adequate flows. Genetic diversity will be fundamental to river ecosystems being able to adapt to changed conditions including climate change.

Information Functions

Rivers also have considerable traditional, historical, cultural and educational values. They have been central to Aboriginal inhabitation, avenues for exploration and features of early inland development. The natural thirst for knowledge and understanding of the world around us is also provided for by natural systems. Thus, ecotourism, travel and understanding of our cultural heritage and history are fundamentally linked to healthy river systems. In places, the rivers have been so damaged that these ecological goods and services have been all but lost.

Current conservation assessment for rivers is based on the principles of selecting areas that are comprehensive, adequate and representative (CAR). While useful, this approach neglects other important features of condition, vulnerability, irreplaceability and complementarity (see Linke et al. 2007). Complementarity involves selecting successive adjacent sections of rivers to achieve the highest levels of protection. Irreplaceability represents the likelihood that an area will be required as part of a conservation system that achieves all conservation targets (Linke et al. 2008). In conservation planning for rivers it is important to recognise their inter-connectedness, so that the upstream catchments of selected reaches are also protected, and vulnerability also recognises threatening processes such as flow regulation (Cullen 2003). This latter approach applied to Victoria indicated that quite small catchment areas (<20 per cent; Linke et al. 2007, 2008) might achieve desired conservation goals, although the authors hasten to point out that their study should not be seen as an attempt to direct conservation policy. Thus, if decisions on flows are to be made that adequately protect biodiversity, a broader approach to planning is needed that also includes how successive river sections are chosen and linked and their irreplaceability, condition and vulnerability.

Generally, desired ecological outcomes from environmental watering are stated only in general terms and from the position of the water available, rather than how much water is needed to achieve the outcomes. The science behind the development of the Living Murray Initiative (<http://thelivingmurray.mdbc.gov.au/>) initially made strong arguments that 1500 gigalitres of water allocated for the environment would have a moderate chance of achieving ecological outcomes. As a first step, 500 GL was agreed but with a second step now being $3 billion of government purchases that would be likely to retrieve a further 1200–1500 GL, albeit with varying levels of security. Supplying water to achieve specific ecological outcomes should, however, involve an integrated approach that begins with ecology, rather than economics and availability. Water purchased from the Riverina cannot be supplied to the Darling and water bought from the northern rivers is unlikely to be of benefit to the Murray mouth. The ecological outcomes, and the ecological goods and services that they supply, integrated across whole catchments need to be decided first and the water recovery and delivery decided in response to the desired outcomes. In places, this might mean that sufficient water will never be available to achieve the desired outcomes and this should be clearly acknowledged. In other places, more expensive water might need to be purchased because it is the only source to achieve the desired outcome.

Desired ecological outcomes can be determined from the general to specific and from short to long term. Some outcomes will be basin wide, such as connectedness and fish-species distribution; some might be highly targeted such as endangered species and refuge sites. It is important to decide on short-term outcomes (days to weeks) such as carbon and nutrient processing and flushing algal blooms and sediment. Defining and targeting these things will demonstrate the immediate benefits of environmental watering, which is also important in maintaining support for the allocations. Medium-term ecological outcomes (months to one year) might include providing water for habitat maintenance, channel-forming flows and specific flows for recruitment events. Long-term outcomes might include overall ecosystem condition, maintenance of population numbers of endangered or threatened species and maintenance of biodiversity including distribution ranges and survival. Clearly, the watering regimes (timing and volumes) will be different for each of these sets of outcomes, although there might be some overlap.

Assets and Condition

Considerable ecological information is available on the rivers of the Murray–Darling Basin. The *Snapshot of the Murray–Darling Basin River Condition* (Norris et al. 2001a) assessed the overall condition of rivers in the Basin, and in particular the Murray River, using information available at the time. The Sustainable Rivers Audit is a major program now run by the Murray–Darling Basin Authority (MDBA) in conjunction with the Basin States, which collects data to assess the condition of all rivers in the Basin using an approach with multiple ecological indicators similar to the snapshot. The Australian Water Resources 2005 assessment (Norris et al. 2006) summarised and mapped environmental assets that had some legal protection, national parks, designated rivers, wetlands of national significance and Ramsar wetlands. The recent Sustainable Yields project (CSIRO 2008) showed that historical water availability was greatest in the southern part of the Basin. Therefore, ecological outcomes might need to be viewed both basin wide and regionally.

The poor ecological condition—and thus loss of ecological goods and services—of rivers in the Murray–Darling Basin is clearly demonstrated by all of these studies. The snapshot concluded that 40 per cent of the river length assessed had biota that was significantly impaired and more than 95 per cent of the river length assessed had degraded environmental condition. Catchment disturbance and changes to nutrient and suspended sediment loads were the greatest contributors. Data on flows, however, were not available for much of the Basin, although more than half the river reaches assessed had modified hydrology, with the greatest changes immediately downstream of dams and in lowland reaches used for irrigation supply—for example, the River Murray, the Murrumbidgee, Wimmera/Avon, Loddon and Darling rivers (Norris et al. 2001a). Nationally, the results were similar for the intensive land-use zone, with almost one-quarter having lost at least 20 per cent of the kinds of aquatic biota expected and more than 85 per cent of the river length assessed as significantly modified in terms of catchment disturbance, hydrological disturbance, habitat condition and nutrient and suspended sediment loads (Norris et al. 2001b, 2007). Multiple causes of damage were noted, with unseasonal flooding of wetlands, loss of connection with the floodplain, habitat simplification, water quality and bank erosion all being assessed as significant issues. Thus, managing flows is only one part of sustainable use.

The Sustainable Rivers Audit provided an assessment of rivers in the Basin for 2004–07 (MDBC 2008). Fish condition was considered to be very poor in most river valleys in the Basin and worst in the more heavily developed areas of the south and east. The assessment confirmed the well-known decline of native fish in the Basin, which was also compounded by alien species that rivalled, outnumbered or outweighed native fish in nine of the 23 valleys of the Basin. Although not as severely damaged, the macro-invertebrate assessment showed a similar trend, with the highest ranking being moderate and falling to very poor. Therefore, it is clear that the ecological goods and services represented by these assessments have been severely degraded. Assessment of their loss, however, hardly figures in arguments about potential loss of food and fibre production through reduced water availability.

Legislated protection, such as national parks, is one way of preserving Australia's natural capital. The Australian Water Resources assessment done by the National Water Commission (NWC 2005) showed more than 3500 wetlands nationally that had some sort of legislative protection (Ramsar Convention, National Significance and State legislation), but only 48 rivers (43 in Victoria and a few more that have since been protected in Queensland). While the number of wetlands seems large, it is actually a very small proportion of the tens or hundreds of thousands that exist nationally, or even in the Basin alone. National parks and other reserves are not designed to protect rivers or wetlands and their boundaries do not coincide with catchments. Additionally, there is considerable development in national parks that harms rivers (for example, ski resorts and the Snowy Mountains Hydro-Electric Scheme in the Kosciuszko National Park). It was concluded that Australia's legislative commitments to the National Strategy for Conservation of Australia's Biological Diversity 1996 and the *Environmental Protection of Biodiversity Conservation (EPBC) Act 1999* are unlikely to be well served in most of Australia under the current level of conservation protection that is afforded to rivers and associated wetlands (Norris et al. 2006).

In summary, damage to the ecological condition of Australia's rivers (including floodplain wetlands) is extensive and has been demonstrated in several reports. Rivers are beset by multiple stressors including changes to their catchments, water quality, habitat, riparian vegetation and hydrology, and these are likely to act synergistically meaning that addressing only one aspect is unlikely to achieve the expected benefits. There are few rivers that have explicit legislative protection, and current protected areas such as national parks are generally not designed to protect rivers and their biota. Thus, many of the ecological goods and services listed above are likely to be degraded or lost with little assessment of the consequences relative to the use of water for consumption.

Climate Change and Environmental Water

Climate-change predictions so far deal mostly with likely changes in the volumes of water available, with predictions that water availability might fall by 9–11 per cent in the north of the Murray–Darling Basin and 13 per cent in the south (CSIRO 2008). Little is known, however, about the concomitant changes in water quality (Whitehead et al. 2009) and ecological outcomes. Climate-change projections indicate that Australia will see changes in the magnitude and frequency of extreme events (Francis and Hengeveld 1998; Jackson et al. 2001), particularly droughts, floods and fires. Although droughts, floods and fire are the major disturbance events in Australia, their infrequency means they have generally been studied and managed in isolation. Thus, individually there is some understanding of the water-quality and ecological responses to drought, flood and fire (that is, it is known that disturbance plays a major role in structuring stream ecological communities and stream water quality), but they are rarely considered in combination. Nor have they been considered with regard to the management and supply of ecological goods and services of the rivers.

An increase in the frequency of extreme events might result in an increase in the frequency with which ecosystem thresholds would naturally be exceeded and consequently the capacity for ecosystem recovery might be severely impeded (Murdoch et al. 2000). Under such circumstances, simply managing to avoid exceeding thresholds will no longer be sufficient to protect ecosystem function, but other factors such as the period of, and time between, exceeding events must also be considered. Thus, the way in which environmental watering is planned and managed might need to fundamentally change. In part, this underpins the current flow-management predicament, especially for the lower Murray River.

If the frequency of disturbance events increases, it becomes likely that they will act in combination to cause changes to water quality and ecosystem processes. Such a combination of effects might lead to ecological responses outside current ranges. Thus, there is a need to consider disturbance events not individually, but in combination. The potential impact of changes in the frequency of events requires that these are also considered over the long term. Such forecasting of future conditions has only recently attracted the attention of the international research community (Batterbee et al. 2008; Kundzewicz et al. 2007) and has yet to be considered by the natural-resource management community, particularly in relation to environmental watering.

Need for Assessment to Determine Effectiveness and Adaptive Management

Statement of desired ecological outcomes of environmental watering effectively provides hypotheses that can be tested to determine whether management actions have been effective. This is a necessary step that subsequently leads to adaptive management, but that has too often been neglected. The term 'adaptive management' has been used for more than 30 years to describe an approach to natural-resource management (Holling 1978). It is the application of experimentation to the design and implementation of natural-resource and environmental management, which relies on learning from experience (Walters and Holling 1990). Adaptive management is done to learn and better manage ecosystems (Holling 1978; Lee 1999). The same search for scientific understanding is shared by scientists and those wanting to make better management decisions (Norton 2005). Yet it has been said that adaptive management has been more influential as an idea than as a practical means of gaining insight into ecosystem behaviour (Lee 1999).

Features of adaptive management critical for success are

1. scientists independent of stakeholder groups leads to efficiencies through single agreed projects, rather than each group commissioning their own and each consequently being viewed suspiciously by the other parties
2. clear statement of desired ecological outcomes of flow management and assessment to test the effectiveness of the decisions made to achieve them
3. the translation of ecological outcomes to flow volumes and the release regime
4. robust study design critical for unforeseen events
5. implementation of the feedback loop and flexibility.

Independent Scientists

Scientists provide crucial input in structuring the questions, developing the models for testing and in formulating appropriately scaled experiments that can test and improve system understanding and provide alternative options for the future under changing conditions (Hughes et al. 2007). Testability, objectivity, and impartiality are the criteria used by science to evaluate the reliability of a scientific finding (Christie 2008). The usual give and take of criticism that science relies on (Christie 2008) might also be conducive to the flow of information and open communication among the parties needed for an effective adaptive approach to environmental management (Norton 2005). These characteristics of scientific objectivity and independence from the stakeholders are critical for efficiency and success.

Clear Statement of Desired Ecological Outcomes and Assessment to Test the Effectiveness of Decisions to Achieve Them

Adaptive management is 'place sensitive' in both a physical sense and the need to take into account the local environmental values (Norton 2005). The desired ecological outcomes of the management actions will be motivated by the environmental values held for any given place. Adaptive management requires the parties involved to have agreed on the desired ecological outcomes of the adaptive approach. According to Lee (1999), there was little evidence that the adaptive-management approach was being used this way. The lack of agreed questions and failure to clearly state the desired ecological outcomes would be two reasons adaptive management would fail to provide a practical means of gaining insight into ecosystem behaviour. Some iconic examples of adaptive management have declared great success—for example, the experimental releases of large volumes of water to the Colorado River from the Glen Canyon Dam (Walters et al. 2000). These experimental releases enabled better scientific understanding of sediment dynamics and of how water temperature and introduced pests influence the recruitment of endangered native fish (Hughes et al. 2007).

The Translation of Ecological Outcomes to Flow Volumes and the Release Regime

> In principle, the scientific approach leads to reliable determination of causes; in practice, that means being able to learn over time how management does and does not affect outcomes. (Lee 1999)

Environmental watering guidelines should specify precise flow volumes, and include specification of drought and other special-purpose flow rules. The transformation of ecological outcomes into flow volumes, release regimes, and published rules will have the effect of removing environmental flows as a source of great uncertainty from those with responsibility for release and those who see it as a potential loss (Purves et al. 2009).

Robust Study Design Critical for Unforeseen Events

Adaptive management for environmental flows requires a shift from measuring change (for example, more fish were found) to 'measuring and understanding change' (for example, the fish community responded because of the changed flow regime) (Souchon et al. 2008). Making that shift requires acknowledgment that the distinction between survey and experimental study designs is in the replication. Surveys (without sample replication) are generally used only to make correlative assessments, whereas field experiments that employ replication and keep particular factors constant while others vary can be used to investigate causation (Souchon et al. 2008). While trial and error are part of the adaptive-management process, nothing can be learned from the trial or the error without an adequate study design to learn something about the ecosystem's processes and structure (Lee 1999), and thus build capacity to apply that knowledge and achieve desired ecological outcomes in a dynamic environment. Thus, evidence-based decisions for setting environmental flows require rigorous data collection and study designs that test hypotheses, answer specific questions and provide for extrapolation to similar systems or systems undergoing change (Souchon et al. 2008).

Feedback Loop

There is no 'one' or right solution to most environmental problems; rather there is a choice of better or worse solutions (Norton 2005). Further, the resolution might be only temporary until things change—for example, with drought, fire, climate change, or changing demands of competing values. Adaptive management requires flexibility to take advantage of the inherent feedback loop between science and management so that decisions can be modified based on new information (Souchon et al. 2008). This flexibility and willingness to confront uncertainty provides the capacity to deal with moving targets presented by environmental change (Hughes et al. 2007). A static approach to water-resource management that ignores the likelihood of unforeseen dynamics is doomed to failure (Hughes et al. 2007); the many NSW water-sharing plans currently under implementation in Australia might prove to be such examples (<http://www.dwe.nsw.gov.au/water/plans.shtml>). The ability to reassess and make changes while a project is ongoing adds to the likelihood of success (Souchon et al. 2008)

Approach to Managing Environmental Watering

The approach suggested here includes consideration of the ecological goods and services supplied by the Murray–Darling Basin in addition to water as a commodity. This opens the way for communities to consider the wider set of values and the benefits derived from them, rather than the current narrow, exploitative view that tends to dominate the debate over water use. The steps taken could include the following.

1. Determine and map ecological assets—places, features, species, and communities. Cullen (2003) lists four reasons to maintain the biodiversity of aquatic ecosystems. First, national (Commonwealth of Australia 1992, 1999) and international (UNCED 1992) obligations on biodiversity conservation have to be met. Second, protected areas provide a reference condition for comparative assessment of impacted regions (Bailey et al. 2004; Reynoldson et al. 1997); and third, act as re-colonisation pools for taxa extinct in other parts of a catchment. Fourth, aquatic species bear intrinsic values (Angermeier 2000; Sarkar 2002) and often provide irreplaceable ecosystem services

(Cullen 2003). Ecological processes such as final treatment of effluents that have been discharged not fully treated should be regarded as assets, and the full range should be defined (Table 3.1).

2. Determine the desired ecological outcomes in relation to the range of recognised ecological goods and services, including protection of those defined in (1) above, and various processes such as management of algal blooms, maintenance of habitat, channel-forming flows, and flushing of nutrients and organic matter.
3. Prioritise the desired ecological outcomes both basin wide and regionally as suggested by the Sustainable Yields project.
4. Estimate how much water would be needed to achieve the desired outcomes. This important step would be a marked departure from much current practice whereby decisions are made on how to distribute available water, rather than how much is needed to achieve particular outcomes.
5. Based on the preceding estimates of how much water is needed, determine which of the ecological outcomes and where they are that could be achieved with the available water.
6. What would be the risks associated with achieving, or failing to achieve, the desired ecological outcomes?
7. What would be the indicators of environmental watering outcomes in the short (weeks–months), medium (months to a year) and long (several years) term?
8. Model where can water be bought or traded to give the best return in volumes for the environment for the dollars spent. This would be part of another, related project and would need iteration dependent on where water was needed to achieve priority ecological outcomes.
9. Model where will the water retrieved for the environment actually be stored, or let run? Understanding this question will direct how much water and where it can be allocated for the environment. Answering this question will require hydrological modelling based on economic-modelling scenarios.

Water Recovery

Water that becomes available through recovery and trading will determine what can be achieved through appropriate allocation. If desired ecological outcomes are also framed in the context of ecological goods and services, however, there is also a need to determine the volumes and delivery regimes to achieve specific desired ecological outcomes and the water that might be needed to do this. Such an approach is philosophically different from the former in that desired outcomes are determined first and then the watering regime is estimated subsequently. Thus, the questions being asked would be what do we want to achieve and how much water will it take, rather than what changes might be possible with whatever water becomes available? The former would be realistic and targeted, and the latter just making do with whatever becomes available without clear direction or incentive for modifying volumes and delivery.

Economic modelling has indicated that significant volumes of water might be reclaimed for the environment for only small changes in net economic returns on production. To maximise environmental benefits of reclaimed water, the relationships between trading/buyback and environmental outcomes need to be understood. Ecological modelling has not been combined with economic modelling to prioritise trading/buyback so that both economic and ecological outcomes can be modified.

It is also possible that the highest-priority ecological outcomes might be in places that do not coincide with the cheapest or largest volumes of water that can be delivered. Thus, it might be necessary to prioritise the ecological outcomes and direct water-reclamation buyback, trading and infrastructure investment to places that might be less economic but more ecologically beneficial.

Conclusion

1. The National Water Initiative defines the environmentally sustainable level of extraction as 'the level of water extraction from a particular system which, if exceeded would compromise key environmental assets, or ecosystem functions and the productive base of the resource' (Commonwealth of Australia 2004).
2. The full range of ecological goods and services that is supplied by rivers needs to be recognised before they can be properly valued and managed. Some of these might be difficult to value economically but they provide important components of our culture and quality of life. Recognition of these values will broaden the debate over water use and clarify its true costs as well as suggest alternative economic benefits that might be derived from healthy rivers.
3. There is ample evidence to show that Australia's rivers are damaged, and recognition of this has led to several pieces of legislation: the NWI and government water recovery.
4. Few rivers are explicitly protected and conservation planning for rivers has been based largely on defining areas that meet the criteria of comprehensive,

adequate and representative. There is also an urgent need to consider complementarity, condition, irreplaceability and vulnerability across whole catchments. Arguments for conservation might be strengthened if they are made in the context of the ecological goods and services that will be maintained or enhanced.

5. Climate change will almost certainly require adaptation of current views on environmental water and its management to achieve environmental outcomes.
6. Managing only environmental water is unlikely to achieve the maximum desired benefits if other factors damaging rivers are not also coincidentally addressed.
7. Desired ecological outcomes need to be determined first; then these should be translated into the volumes and regime of water needed to achieve them, rather than the reverse. The desired outcomes need to cover the short, medium and long term.
8. Assessment and adaptive management are necessary for achieving the best ecological outcomes most efficiently in the long term.

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