10 Using an ecosystem services-based approach to measure the benefits of reducing diversions of freshwater

A case study in the Murray-Darling Basin, Australia

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10.1 INTRODUCTION

Ecosystem services-based approaches have been applied to decisions about trade-offs between alternative uses of land (Raudsepp-Hearne *et al*. 2010; Maes *et al*. 2012; Bryan & Crossman 2013; Geneletti 2013; Seppelt *et al*. 2013), but have been used less commonly to assess trade-offs in alternative uses of water (Schluter *et al*. 2009; Rouquette *et al*. 2011; Liu *et al*. 2013). In this chapter we provide an overview of a case study into quantifying the ecosystem services and associated benefits (and their monetary values) of a new water-sharing plan that will return water to the environment in the Murray-Darling Basin, Australia. This serves as an illustration of how to operationalize an ecosystem services-based approach, as defined in this book. Chapter 2 in this book emphasizes that there is a gap between the conceptualization and endorsement of ecosystem services by both researchers and policy makers and the incorporation of ecosystem services-based approaches into natural resources management practice. The present chapter demonstrates the operationalization of an ecosystem services-based approach in the context of water resource planning and management. We estimate the changes to a range of final ecosystem services (Boyd & Banzhaf 2007; Kumar 2010) that result from the implementation of a discrete policy scenario, and provide economic estimates for the associated benefits. Our work contributes to the still scarce literature on real-world examples of integrating empirical data on the biophysical supply of ecosystem services with their socio-cultural context and monetary valuation to inform investment decisions (Martín-López *et al*. 2014; see also Mulligan *et al*., this book).

The Murray-Darling Basin contains iconic and internationally important wetlands and is Australia's major food-producing area. In terms of gross value, about 40% of Australia's agriculture and 50% of irrigated agriculture is produced in the Basin (Australian Bureau of Statistics 2013). However, the dominance of food production has come at the expense of other ecosystem services provided by land and water resources in the Basin, primarily due to the decline in health of river, wetland, and floodplain ecosystems (Kingsford 2000; Kingsford *et al*. 2011). Here we summarize a project (CSIRO 2012) commissioned by the Murray-Darling Basin Authority, an Australian Federal Government Agency, to support decision-making on water allocations associated with the development of policy guiding the re-allocation of water resources under a new government policy and legislative framework, the Murray-Darling Basin Plan. A detailed report of the research is presented in CSIRO (2012). The objective of that project was to quantify the benefits, and where possible the monetary values, of returning water to the environment to improve the supply of the other, non-provisioning ecosystem services. We use the 'cascade diagram' conceptual framework from Kumar (2010) to structure the analysis because this framework clearly shows the links between biophysical changes in ecosystems, to changes in ecosystem services, through to changes in benefits and then monetary values. Specifically, we: (1) modelled increases in river flows in each of the catchments of the Murray-Darling Basin; (2) related additional flows to predicted ecological responses at important wetland indicator sites; (3) identified the ecosystem services associated with those predicted ecological responses; (4) assessed the marginal change in supply of selected regulating, habitat, and cultural ecosystem services under the Basin Plan scenario compared with a baseline or 'do nothing' scenario; and (5) undertook monetary valuation, where possible, of marginal changes in supply of ecosystem services for use by the Australian government in cost–benefit analysis of the impact of the proposed regulations.

10.2 THE MURRAY-DARLING BASIN

The Murray-Darling Basin covers one-seventh of the land area of Australia (Figure 10.1) and contains the only major permanently

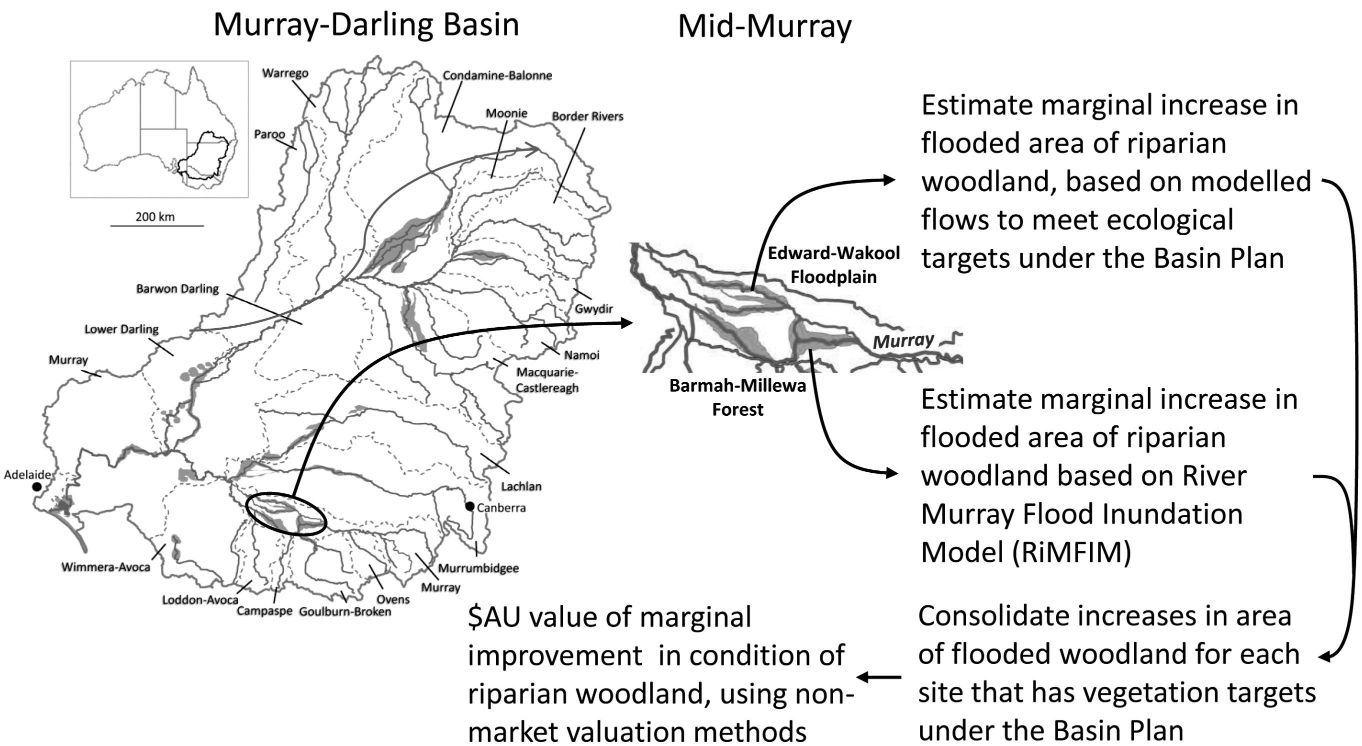

Figure 10.1 Steps in the methodology for the valuation of improved vegetation condition in the Murray-Darling Basin, Australia. Hydrological modelling provided an estimate of marginal change in areas of riparian woodland likely to be inundated under the Basin Plan and maintained in good ecological condition. The monetary value of the increase in areas of woodland in good condition was then estimated. Shadowed areas = hydrological indicator sites subject to ecological targets for vegetation.

flowing river systems on the continent (see Box 10.1). Environmental degradation has prompted a series of water reforms by the Australian government. Introduction of the Water Act (Commonwealth of Australia 2007) provided the legislative mechanism to reduce the volume of water that can be diverted for irrigated agriculture. In support of the Water Act is a planning process (the Basin Plan) that stipulates the volume of water that would need to be returned to the environment in order to meet a set of hydrological targets that, if achieved, will match the water requirements of aquatic ecosystems to maintain them in good condition. While not explicit in the draft Basin Plan, there is an assumption that maintaining the aquatic ecosystems in good condition will ensure the continued supply of ecosystem services from those ecosystems, especially the non-provisioning services which have been compromised by increased water diversions for irrigation. The draft Basin Plan contained a proposed reduction of 2800 gigalitres[1] (GL) per year from the 2009 average irrigation diversions of 13 623 GL per year (a 21% reduction).[2]

Box 10.1 The Murray-Darling Basin

The Murray-Darling Basin covers one-seventh of the land area of Australia (Figure 10.1) and contains the only major permanently flowing river systems on the continent, including the Murray, Murrumbidgee, Barwon–Darling, Condamine–Balonne and Macquarie–Castlereagh River systems and tributaries. Many of the catchments contain nationally and internationally significant wetlands (including 16 Ramsar wetlands) that provide foci for aquatic biodiversity, recreational activities, and spiritual values. Gross value of agricultural production was AU$18.6 billion in 2012, of which 36% was from irrigation (Australian Bureau of Statistics 2013). However, many of the rivers, wetlands, floodplains, and the Murray estuary are in poor ecological condition and have been for some time, in part as a result of changes in flood and flow regimes due to increased water diversions from the rivers (Sims & Colloff 2012). Poor ecological condition has been exacerbated by five severe, widespread droughts since 1940, of which the Millennium Drought (1997–2010) was the most severe in recorded history.

[1] 1 gigalitre is equal to 1 billion (10^9) litres, or approximately 810 acre feet.
[2] In the final Basin Plan, an annual average of 2750 GL of water will be recovered for the environment by 2019, with an additional 450 GL to be recovered by 2024.

During the latter stages of the development of the draft Basin Plan in 2011, attention focused on the economic costs of reduced irrigation diversions. These were estimated by the Australian Bureau of Agricultural and Resource Economics and Sciences as an average annual reduction of AU$542 million in the gross value of irrigation production (Murray-Darling Basin Authority 2012b). But there was no detailed assessment and valuation of the social, economic, and environmental benefits of the Basin Plan. In response to this knowledge gap, the Murray–Darling Basin Authority, the agency responsible for developing and implementing the Basin Plan, commissioned us to identify and quantify the ecological and economic improvements that were likely to eventuate from returning 2800 GL per year of water to the environment. We used an ecosystem services-based approach as a framework and reporting tool to quantify the benefits, and when possible the monetary values, of reduced diversions. Monetary estimates of the values were an important input into the cost–benefit analysis of the proposed Basin Plan used by the Australian government to assess the potential impacts of new policy regulations (Murray-Darling Basin Authority 2012a).

10.3 ASSESSING THE ECOSYSTEM SERVICES BENEFITS AND MONETARY VALUES OF WATER RE-ALLOCATION

People depend on potable freshwater for drinking and domestic supply, and indirectly via production of food and energy, industry, and transportation (Grey & Sadoff 2007). Flow-dependent ecosystems also provide other important hydrologically mediated ecosystem services that support human wellbeing, including recreation and amenity value, habitat for biodiversity, and spiritual and cultural values (Brauman *et al*. 2007; Maltby & Acreman 2011; Keeler *et al*. 2012). One of the greatest challenges in natural resource management is to implement equitable sharing of finite water resources between consumptive uses and the environment in order to maintain condition and function of these flow-dependent ecosystems and maintaining the services these ecosystems provide (Gordon *et al*. 2010; Grafton *et al*. 2013). In the Murray-Darling Basin, equitable sharing involves reducing water diverted for irrigation, thereby re-balancing supply of ecosystem services from the provisioning services to the other non-provisioning services (Gordon *et al*. 2010).

10.3.1 Changes in the biophysical conditions underpinning ecosystem services

Following the 'cascade diagram' (De Groot *et al*. 2010; Haines-Young & Potschin 2010; Kumar 2010) that shows the link between changes in ecological processes, functions, services, human wellbeing, and benefits and their values, the marginal change in ecosystems, ecosystem services, and subsequent benefits and their (monetary) values that result from reducing the water that is diverted for irrigation was calculated by comparing a baseline scenario (the current level of diversions) to a future scenario (the Basin Plan scenario of reducing diversions by 2800 GL per year, hereafter the '2800 GL/year scenario'). The baseline for ecological condition was established using a modelled hydrologic flow sequence of 114 years (1895–2009), assuming historic climate, current river operation rules and basin infrastructure (includes dams, infrastructure for moving water to key environmental assets, and diversions for consumptive use). The 2800 GL/year scenario was also based on the 114-year flow sequence, assuming historic climate, current infrastructure, and Basin Plan operating rules, including the new river flow regimes resulting from the 2800 GL/yr reduction in water diverted for irrigation. This data was provided by the Murray-Darling Basin Authority. The models, scales, spatial extents, and sources of information used in the analyses are summarized in Table 10.1; Figure 10.1 demonstrates one of the methods, in this case to estimate changes to extent of inundation of mapped floodplain vegetation. To undertake the biophysical analyses, the following steps were used:

(1) Calculate flow metrics for the baseline hydrologic scenario (i.e. current flow) and for the 2800 GL/year scenario. Flow metrics were used to calculate frequency of exceeding known thresholds of salinity, bank erosion, and sedimentation.
(2) Using the hydrologic model scenarios as inputs, ecological response models were used to predict likely changes to ecosystem condition for the 2800 GL/year scenario. Model predictors were the frequency of waterbird breeding events, habitat condition for native fish, the extent of inundation of mapped floodplain vegetation, and the condition of the Coorong Lakes. Water quality models were used to predict the likelihood of blackwater events[3] and blue-green algal blooms, and the potential for acidification of the Lower Lakes. Carbon sequestration measures were derived from a floodplain vegetation model.

ECOLOGICAL IMPROVEMENTS FROM REDUCING DIVERSIONS

All ecological response variables were modelled as improved under the 2800 GL/year scenario relative to the 'do nothing'

[3] Blackwater can be a natural feature of lowland river systems and occurs during flooding when organic material is washed into waterways and consumed by bacteria, leading to a sudden depletion of dissolved oxygen in water.

Table 10.1 *Monetary values of benefits under the 2800 GL/year scenario compared with the 'do nothing' scenario*

Ecosystem service	Biophysical metrics	Economic modelling	AU$ million
Regulating			
Carbon sequestration	Hectares of native vegetation in good condition and woody carbon potential	Based on different carbon prices	120.0–1000.0
Moderation of acid sulphate soils	Lower Lakes height threshold	Avoided costs	9.2
Moderation of sedimentation	End-of-system flows and Mouth Opening Index	Avoided costs	17.8
Maintenance of bank stability	River in-channel height and threshold	Avoided costs	23.8
Provisioning			
Floodplain (grazing)	Hectares	Transfer from another study	32.2
Freshwater quality	Salinity concentrations	Avoided salinity productivity losses and costs to utilities and users	1.1
	Cyanobacterial bloom risk	Avoided treatment costs	0.9
Fish	Commercial catch, Coorong and Lower Lakes Fishery	Regression estimates	0.2 (annual)
Cultural			
Aesthetic appreciation	House prices in basin 2003–2010, historic and modelled river flows and lake level height	Hedonic models	337.0
Indigenous values	Geocoded cultural and bush tucker sites for Wamba Wamba of the Werai Forest		+
Tourism	Swimmable, fishable, boatable water quality days	Benefit transfer values	161.4 10.3–20.6
Native species diversity			
Native vegetation	Inundation model and floodplain vegetation mapping	Choice modelling	2303.9
Native fish	Response relationships derived from the Murray Flow Assessment Tool	Choice modelling	339.9
Colonial waterbird breeding	Environmental Water Requirements; Ecological Response Models	Choice modelling	693.1
Coorong, Lower Lakes	Ecosystem states model	Choice modelling	480.0/ 4000.0/ 4300.0*

* Depends on assumptions.

scenario (Table 10.1). Ecological responses tended to be greater for those response variables that depend on flooding (e.g. waterbird breeding) than for those that depend on in-channel flows (fish groups). Increased floodplain inundation under the 2800 GL/year relative to the 'do nothing' scenario benefited the lignum shrubland and river red gum forest and woodland vegetation communities on the lower- and mid-level floodplains along the Murray River. Higher elevation floodplains along the Murray River are likely to remain vulnerable under the 2800 GL/year scenario and their capacity to continue to support river red gum and black box communities could be compromised. There are important ecological benefits for the Coorong, Lower Lakes, and Murray Mouth under the 2800 GL/year scenario, including reduced occurrence of time when the Coorong is in an ecologically unhealthy state.

WATER QUALITY IMPROVEMENTS FROM REDUCING DIVERSIONS

Reducing by 2800 GL per year the amount of water diverted in the Basin resulted in improved water quality (Table 10.1). First, through reduced numbers of days of low flow when cyanobacterial blooms could develop. Second, through less frequent periods of low water levels in the Lower Lakes, when acidification could occur. Third, through more frequent inundation of vegetated floodplains, which reduces the number of days of high oxygen demand due to oxidation of floodplain carbon sources, which in turn reduces the number of blackwater events and fish kills.

10.3.2 Assessing marginal changes in ecosystem service supply and value

Building on the modelled improvements to biophysical conditions, the following steps were used to undertake the analyses of change in ecosystem service supply and value:

(1) Flow metrics (salinity, bank erosion, sedimentation) and ecological response models were used as inputs to the ecosystem services assessment. The incremental changes in the supply of ecosystem services were predicted under the 2800 GL/year scenario relative to the baseline scenario. The major ecosystem services modelled are listed in Table 10.1.

(2) The monetary value of the incremental changes in the supply of ecosystem services was calculated for different scenarios. Standard economic valuation techniques were used to value services listed in Table 10.1. These included benefit transfer methods, using values obtained from previous studies inside and outside the basin and hedonic methods, which were used to estimate aesthetic appreciation. Improved quality of freshwater sourced from the Murray-Darling Basin was modelled to reduce treatment costs and costs associated with lost recreation and tourism opportunities. Further detail on the valuation is provided below.

REGULATING ECOSYSTEM SERVICES

We valued a subset of the regulating ecosystem services for which we were able to quantify marginal change in supply from reducing irrigation diversions, namely climate regulation (through carbon sequestration), water purification (through moderation of acid sulphate soils), and erosion prevention (through moderation of sedimentation and maintenance of river bank stability). Carbon market prices were used to value climate regulation, and avoided cost was used to value the other regulation services based on methods described by Banerjee *et al.* (2013). Carbon sequestration was estimated as the incremental increase in standing carbon between the two scenarios as a result of changes in inundation. The changes in the supply of the other regulating services were valued using data on remediation costs incurred by governments and individuals during the 1997–2010 Millennium Drought (Banerjee *et al.* 2013) combined with the probability of exceeding hydrologic and ecological response thresholds between the two scenarios. Despite their theoretical limitations (National Research Council 2005), damage cost avoidance methods provided a reasonable proxy estimate of value because remediation costs have previously been incurred, demonstrating demand for the services.

PROVISIONING ECOSYSTEM SERVICES

We valued the marginal change in supply of freshwater, livestock production from floodplains, and fish production provisioning ecosystem services using available data and models. Improvements in freshwater quality between the scenarios were estimated by modelling changes in likelihood of algal blooms and the subsequent reduced treatment costs for water utilities. Increases in livestock production on floodplains were estimated in floodplains where grazing already occurs and where floodplains are expected to receive more frequent inundation under the 2800 GL/year scenario. Commercial fishery outcomes in the delta region were estimated using regression relationships between river flows and historic catch.

CULTURAL ECOSYSTEM SERVICES

Noting that many cultural ecosystem services exist (see Church *et al.*, this book), a number of which are very difficult to value (Chan *et al.* 2012), we selected those services which have pedigree in economic valuation studies, namely recreation and tourism (Rolfe & Dyack 2011) and aesthetics (Tapsuwan *et al.* 2012). Tourism and recreation values were estimated using benefit transfer of recreation estimates from the Basin (Morrison & Hatton MacDonald 2010), threshold water quality indicators and historic visitation data. Following methods in Tapsuwan *et al.* (2012), an original hedonic study modelled the relationship between river flow and lake level height and nearby house sale prices. These results were then used with modelled changes in river flow and lake level height between the two scenarios to estimate aesthetic values.

HABITAT ECOSYSTEM SERVICES

The Kumar (2010) ecosystem service framework identifies a group of habitat services as a discrete fourth category of final services that can be sensibly valued. We valued enhanced native species diversity from improved health of floodplain vegetation, increased waterbird breeding, and increased stocks of native fish; healthier Coorong and Lower Lakes ecosystems were valued using monetary estimates from an earlier study undertaken in the Basin (Hatton MacDonald *et al.* 2011), a benefit transfer approach (Morrison & Hatton MacDonald 2010), combined with incremental ecological outcomes between the two scenarios.

ECONOMIC VALUES OF REDUCING DIVERSIONS

In general, a healthy and functioning environment will provide positive economic value to society through enhanced supply of ecosystem services. Table 10.1 lists our monetary estimates for the benefits in terms of ecosystem services from increasing the volume of water in the Basin by an annual average 2800 GL per year. The values are dominated by habitat ecosystem services, specifically improved health of floodplain vegetation, increased waterbird breeding, increased stocks of native fish, and a healthier Coorong. There are other large benefits from carbon sequestration, aesthetics, recreation, and enhanced provision of regulating ecosystem services. In total the estimated monetary value of the marginal change in ecosystem services between the two scenarios is around AU$4 billion to AU$9 billion in current prices, depending on assumptions.

10.4 WHAT DOES AN ECOSYSTEM SERVICES-BASED APPROACH BRING?

This case study provides an opportunity to reflect on advances made in the integration of biophysical quantification of ecosystem services delivery with valuation techniques. Here we discuss how our operationalization of the ecosystem services-based approach can help support improved decision-making in the context of the four core elements outlined in Chapter 2 of this book.

> *The integration of natural and social sciences and other strands of knowledge for a comprehensive understanding of the service delivery process (core element 3).*

Absent in the drafting of the Basin Plan was a clear description of the social and economic benefits that would accrue to Australian communities from reducing by 2800 GL per year the volume of water diverted to agriculture. The draft Basin Plan was focused mainly on the volumes of water required to reach hydrological targets that if achieved would maintain or improve the ecological health of important wetlands. The narrow disciplinary focus made it more difficult for the Australian government to counter the concerns of those potentially impacted by the reduction in diversions for irrigation. Ecosystem services-based approaches provide an analytical framework for interdisciplinary integration between biophysical and socio-economic sciences. Integration allows for improved quantification and explanation of the benefits to human wellbeing and the economy flowing from sustainable resource management and policy.

> *The understanding of the bio-physical underpinning of ecosystem functions in terms of service delivery (core element 2).*

An important step to take advantage of the integration potential offered by an ecosystem services approach is to co-develop ecosystem services endpoint models. We relied primarily on existing biophysical models and valuation studies to apply the ecosystem services approach to assess the benefits of reducing the amount of water diverted for irrigation. A note of caution in such circumstances is that biophysical models and valuation studies not developed for the purpose of an ecosystem services assessment may face scale mismatches between models and assessment, and model outputs may not be entirely fit for purpose. The outcome for the ecosystem services assessment is that confidence in the underlying biophysical models and valuation techniques varies with each ecosystem service assessed.

Nonetheless, the ecosystem services-based approach applied here was found to be a useful tool to improve understanding of how changes to biophysical processes in freshwater ecosystems lead to multiple benefits that arise from reduced irrigation diversions in the Murray-Darling Basin. In our case study we found that existing biophysical models and valuation studies linking changes in flow and inundation to regulating and cultural ecosystem services were particularly lacking. In this way ecosystem services-based approaches can identify research gaps in how biodiversity and ecosystem functioning supplies ecosystem services that contribute to human wellbeing, and provide opportunity for an integrated future research agenda. A prominent example is the need to better understand how improvements in wetland health and functioning impact (positively or otherwise) on spiritual and cultural values held by Australia's indigenous people.

> *The assessment of the services provided by ecosystems for its incorporation into decision-making (core element 4).*

Integrating biophysical modelling and valuation within a single ecosystem services framework provides a means for decision-makers to trace the connection between policy reform (reductions in irrigation diversions), to hydrologic outcomes in terms of changed flow and inundation timing, extent, and patterns, to incremental changes in ecosystem outcomes and the flow of ecosystem services, to monetarily valuing the ecosystem services benefits. The integration of biophysical quantification of ecosystem services delivery with valuation methodology provided valuable information for the Australian government's cost–benefit analysis that is required for any major policy implementation. Our study was also useful as a communication tool, particularly through conceptual maps of the connections between biophysical changes and human wellbeing. Nevertheless, the acceptance of ecosystem services-based approaches by decision-makers and stakeholders in the Murray-Darling Basin is mixed: survey results from Hatton MacDonald *et al*. (2014) report that the approach is considered experimental and is not well understood, particularly outside of the Australian government. Studies that investigate science impact have the potential to provide lessons on how to improve the relevance of ecosystem services-based approaches, or science more generally, in policy decision-making.

> *The recognition that the status of ecosystems has an effect on human wellbeing (core element 1).*

Using an ecosystem services-based approach is challenging because the science of quantifying and valuing the contribution of ecosystem services to human wellbeing, while conceptually powerful, is relatively novel and experimental. While the contribution to wellbeing is recognized, we found, in our case study, a relative dearth in the indicators and data available at appropriate spatial and temporal scales to describe the full suite of ecosystem service benefits that may arise from recovering more water for the environment. More difficult to identify with any precision were the contributions to wellbeing and subsequent benefits of the regulating services, including wastewater treatment, erosion prevention, maintenance of soil fertility, and moderation of extreme events. Also, more research needs to be done to place (monetary and non-monetary) value on cultural ecosystem services, such as spiritual and sense of place, and mental health. In some cases improvements might be best captured with indices, or mapped using participatory approaches (Plieninger *et al*. 2013).

However, monetary measurements of improvements to wellbeing and the subsequent benefits from reducing water diverted for irrigation in the Murray-Darling Basin are amenable to cost–benefit analysis which places in context any costs arising from reduced irrigated agricultural production. Valuing ecosystem service benefits is fraught with difficulties because many of the ecosystem services provided by the wetlands and floodplains in the Murray-Darling Basin are public goods for which there are no indicators of market value (Boyd 2007). While there is a growing body of non-market valuation techniques and an increasing acceptance of placing a monetary value on the environment (Atkinson *et al*. 2012), the commoditization of nature comes with deep ethical and moral challenges (Chan *et al*. 2012). Other ways to measure ecosystem service contributions to human wellbeing may be more acceptable to different people, for example by using non-monetary measurements and indicators, and ranking these in participatory process such as multi-criteria analyses (Liu *et al*. 2013).

10.5 CONCLUSION

The objectives of the Water Act (Commonwealth of Australia 2007), among others, are to ‘protect, restore and provide for the ecological values and ecosystem services of the MurrayDarling Basin’ and to ‘maximise the net economic returns to the Australian community from the use and management of the Basin water resources’. Yet in Australian (and international) water management and planning there are few examples where an ecosystem services approach helps determine how much water is delivered where, and when to maintain or improve freshwater ecosystem health. In Australia, water-sharing plans typically contain targets for water flow volumes and timing based on relatively simple relationships between flow and ecology, with the assumption that achieving particular flow targets at key locations along the river will achieve ecological goals in the river and on floodplains, and then presumably achieve ecosystem outcomes.

We demonstrate that reducing by 2800 GL per year the water that can be diverted for irrigation in the Murray-Darling Basin, and thereby leaving this water in the river system, can offer significant improvements to ecosystems, which translate to improved flows of ecosystem services and the potential for significant economic benefits. At the risk of double counting, the assessment of the benefits may be worth up to AU$9 billion. Reduced diversions, principally for irrigation, will have an economic cost, estimated at approximately AU$550 million annually (Murray-Darling Basin Authority 2012b), or in present value terms approximately AU$7 billion (7% discount rate over 30 years). The cost of returning water to the environment may not be as high as projected if the economic value of improved ecosystem services is considered. Research into restoration of dryland systems is relatively well advanced in the investigation of spatially explicit land management strategies that maximize ecological, ecosystem service and therefore benefits and associated values (Crossman & Bryan 2009; Bryan *et al*. 2011). We suggest ecosystem services-based approaches offer a new way to manage water resources for maximum economic benefits to all water users, including the environment.

Box 10.2 Key messages

- The Australian government has proposed a 21% reduction in the volume of water that can be diverted for irrigation in the Murray-Darling Basin, Australia.
- The reduced irrigation diversions may lead to economic costs through lower crop production.
- Using ecosystem services-based approaches, we estimate that the benefits, and where possible the monetary values, of reduced diversions are in the same order of magnitude as the costs.
- Our case study demonstrates that ecosystem services-based approaches are very useful for supporting decision-making and the cost–benefit analyses often required under policy implementation.

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References

Atkinson, G., Bateman, I., & Mourato, S. (2012). Recent advances in the valuation of ecosystem services and biodiversity. *Oxford Review of Economic Policy* **28**, 22–47.

Australian Bureau of Statistics (2013). *Gross Value of Irrigated Agricultural Production, 2011–12*. Australian Bureau of Statistics, Canberra.

Banerjee, O., Bark, R., Connor, J., & Crossman, N. D. (2013). An ecosystem services approach to estimating economic losses associated with drought. *Ecological Economics* **91**, 19–27.

Boyd, J. (2007). Nonmarket benefits of nature: what should be counted in green GDP? *Ecological Economics* **61**, 716–723.

Boyd, J. & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics* **63**, 616–626.

Brauman, K. A., Daily, G. C., Duarte, T. K. E., & Mooney, H. A. (2007). The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* **32**, 67–98.

Bryan, B. A. & Crossman, N. D. (2013). Impact of multiple interacting financial incentives on land use change and the supply of ecosystem services. *Ecosystem Services* **4**, 60–72.

Bryan, B. A., Crossman, N. D., King, D., & Meyer, W. S. (2011). Landscape futures analysis: assessing the impacts of environmental targets under alternative spatial policy options and future scenarios. *Environmental Modelling & Software* **26**, 83–91.

Chan, K. M. A., Satterfield, T., & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. *Ecological Economics* **74**, 8–18.

Commonwealth of Australia (2007) *Water Act 2007: Basin Plan 2012*. Commonwealth of Australia, Canberra.

Crossman, N. D. & Bryan, B. A. (2009). Identifying cost-effective hotspots for restoring natural capital and enhancing landscape multifunctionality. *Ecological Economics* **68**, 654–668.

CSIRO (2012). Assessment of the ecological and economic benefits of environmental water in the Murray-Darling Basin. In: *CSIRO Water for a Healthy Country*. National Research Flagship, Canberra.

De Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* **7**, 260–272.

Geneletti, D. (2013). Assessing the impact of alternative land-use zoning policies on future ecosystem services. *Environmental Impact Assessment Review* **40**, 25–35.

Gordon, L. J., Finlayson, C. M., & Falkenmark, M. (2010). Managing water in agriculture for food production and other ecosystem services. *Agricultural Water Management* **97**, 512–519.

Grafton, R. Q., Pittock, J., Davis, R., *et al.* (2013). Global insights into water resources, climate change and governance. *Nature Climate Change* **3**, 315–321.

Grey, D. & Sadoff, C. W. (2007). Sink or swim? Water security for growth and development. *Water Policy* **9**, 545–571.

Haines-Young, R. & Potschin, M. (2010). The links between biodiversity, ecosystem services and human well-being. In D. G. Raffaelli & C. L. J. Frid (eds), *Ecosystem Ecology: A New Synthesis*. Cambridge University Press, Cambridge.

Hatton MacDonald, D., Morrison, M. D., Rose, J. M., & Boyle, K. J. (2011). Valuing a multistate river: the case of the River Murray. *Australian Journal of Agricultural and Resource Economics* **55**, 373–391.

Hatton MacDonald, D., Bark, R. H., & Coggan, A. (2014). Is ecosystem service research used by decision-makers? A case study of the Murray-Darling Basin, Australia. *Landscape Ecology* **29**, 1447–1460.

Keeler, B. L., Polasky, S., Brauman, K. A., *et al*. (2012). Linking water quality and well-being for improved assessment and valuation of ecosystem services. *Proceedings of the National Academy of Sciences* **109**, 18619–18624.

Kingsford, R. T. (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology* **25**, 109–127.

Kingsford, R. T., Walker, K. F., Lester, R. E., *et al*. (2011). A Ramsar wetland in crisis: the Coorong, Lower Lakes and Murray Mouth, Australia. *Marine and Freshwater Research* **62**, 255–265.

Kumar, P.(2010). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Earthscan, London and Washington, DC.

Liu, S., Crossman, N. D., Nolan, M., & Ghirmay, H. (2013). Bringing ecosystem services into integrated water resources management. *Journal of Environmental Management* **129**, 92–102.

Maes, J., Paracchini, M. L., Zulian, G., Dunbar, M. B., & Alkemade, R. (2012). Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation* **155**, 1–12.

Maltby, E. & Acreman, M. C. (2011). Ecosystem services of wetlands: pathfinder for a new paradigm. *Hydrological Sciences Journal* **56**, 1341–1359.

Martín-López, B., Gómez-Baggethun, E., García-Llorente, M., & Montes, C. (2014). Trade-offs across value-domains in ecosystem services assessment. *Ecological Indicators* **37**(Part A), 220–228.

Morrison, M. & Hatton MacDonald, D. (2010). *Economic Valuation of Environmental Benefits in the Murray-Darling Basin. Report Prepared for the Murray–Darling Basin Authority*. Murray–Darling Basin Authority, Canberra.

Murray-Darling Basin Authority (2012a). *Regulation Impact Statement: Basin Plan*. Murray-Darling Basin Authority, Canberra.

Murray-Darling Basin Authority (2012b). *The Socio-economic Implications of the Proposed Basin Plan*. Murray-Darling Basin Authority, Canberra.

National Research Council (2005). *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*. National Academies Press, Washington, DC.

Plieninger, T., Dijks, S., Oteros-Rozas, E., & Bieling, C. (2013). Assessing, mapping, and quantifying cultural ecosystem services at community level. *Land Use Policy* **33**, 118–129.

Raudsepp-Hearne, C., Peterson, G. D., & Bennett, E. M. (2010). Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences* **107**, 5242–5247.

Rolfe, J. & Dyack, B. (2011). Valuing recreation in the Coorong, Australia, with travel cost and contingent behaviour models. *Economic Record* **87**, 282–293.

Rouquette, J. R., Posthumus, H., Morris, J., Hess, T. M., Dawson, Q. L., & Gowing, D. J. G. (2011). Synergies and trade-offs in the management of lowland rural floodplains: an ecosystem services approach. *Hydrological Sciences Journal* **56**, 1566–1581.

Schluter, M., Leslie, H., & Levin, S. (2009). Managing water-use trade-offs in a semi-arid river delta to sustain multiple ecosystem services: a modeling approach. *Ecological Research* **24**, 491–503.

Seppelt, R., Lautenbach, S., & Volk, M. (2013). Identifying trade-offs between ecosystem services, land use, and biodiversity: a plea for combining scenario analysis and optimization on different spatial scales. *Current Opinion in Environmental Sustainability* **5**, 458–463.

Sims, N. C. & Colloff, M. J. (2012). Remote sensing of vegetation responses to flooding of a semi-arid floodplain: implications for monitoring ecological effects of environmental flows. *Ecological Indicators* **18**, 387–391.

Tapsuwan, S., MacDonald, D. H., King, D., & Poudyal, N. (2012). A combined site proximity and recreation index approach to value natural amenities: an example from a natural resource management region of Murray-Darling Basin. *Journal of Environmental Management* **94**, 69–77.