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Integrated valuation of ecosystem services obtained from restoring water to the environment in a major regulated river basin

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ABSTRACT

Evaluating different environmental policy options requires extensive modelling of biophysical processes and attributes linked with metrics to measure the magnitude and distribution of societal impacts. An integrated ecosystem services assessment (IESA) has potential to provide salient, credible and legitimate information for environmental policy- and decision-makers. Here we present results of an IESA of the Murray-Darling Basin Plan, an Australian Government initiative to restore aspects of river flow regimes to improve the ecological condition of floodplains, rivers and wetlands in south-eastern Australia. The main outcome from the IESA is that the supply of most ecosystem services (ES) improves under Basin Plan policy and that these improvements have considerable monetary value. An IESA can provide actionable ecological, economic and social information for policy- and decision-makers. In the Basin Plan case the IESA was underpinned by hydrological scenarios that were input into ecological models and interdisciplinary integration across scales, values and variables.

1. Introduction

Ecosystem service (ES) assessments are an integrated approach that links the condition of ecosystems with the provision of benefits from those ecosystems and the contribution of those benefits to human wellbeing. There are practical lessons from the application of these approaches: ES assessments can identify the many values nature provides to society (MEA, 2005) and these values can be incorporated into decision-making (Fisher et al., 2008), for example, in the context of land-use planning (Bateman et al., 2013), biodiversity conservation (Nelson et al., 2009), water management (Keeler et al., 2012) and infrastructure investments (Crossman et al., 2010). Ideally an ES assessment provides salient, credible and legitimate information (Cash et al., 2003) on the benefits associated with natural resources, and their management, over and above standard policy assessment tools such as benefit cost analysis (BCA).

Operationalising the ES framework involves the provision of useful evidence on the benefits received from ecosystems (Fisher et al., 2008; Daily et al., 2009). ES assessments typically consist of global or national assessments of the stock of natural capital and the flow of ES (Costanza et al., 1997; MEA, 2005; TEEB, 2010; UK NEA, 2011), or analyses of how ES flows are likely to change under different policy options: so-called "programme evaluation" (Nelson et al., 2009; Bateman et al., 2011). Both types of ES assessment require interdisciplinary, integrated research that links ecosystem processes and functions to the supply of ES and then to human wellbeing (de Groot et al., 2010). Integration is complex because ecological and social systems each have their own spatio-temporal and self-organising dynamics (Levin, 1998; Liu et al., 2007) and embody a plurality of values, some of which can conflict.

An ES assessment may assist in decision-making, context setting and accountability in contested settings (Trabucchi et al., 2012). In its simplest form, an ES assessment compares intervention against a "business-as-usual" scenario, or comparisons of policy options. Superficially the worthwhile investment and comparison of alternatives criteria matches a BCA. However, ES assessments also require an understanding of the type, magnitude,

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supply, timing and distribution of ES and the consequences of changes in ecosystem condition, functions and resilience (Folke et al., 2004; Mäler et al., 2008). In this way, it provides more comprehensive information, for example, on whether the benefits to society from preventing and reversing decline of natural ecosystems and ecosystem functions, exceed the societal costs (Balmford et al., 2011).

In this paper we reflect on an integrated ES assessment (IESA) completed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO, 2012) of the Murray-Darling Basin Plan (Commonwealth, 2012; hereafter, 'the Basin Plan'), a multi-jurisdictional water sharing initiative intended to address over-allocation of water resources for irrigation and other consumptive uses in a major drainage basin in south-eastern Australia. The paper proceeds with a description of the case study, the methods used and results including updates of the integrated biophysical-economic valuation and tools we developed to better support decision making. We end with a discussion on how an IESA can provide additional credibility, legitimacy and saliency for decision support and on the operational challenges of integrating different values in actual programme assessments.

2. Case study

The Murray-Darling Basin occupies one seventh of the Australian continent (1.06 million km^2; Fig. 1). Policy makers face problems typical of many large river basins globally: over-extraction of water for irrigation, declining health of flow-dependent ecosystems (Davies et al., 2010) and climate change impacts that are expected to reduce inflows (Vörösmarty et al., 2010). Additionally, balancing the interests of multiple uses of limited water resources – conservation significance, recreational, cultural, including Aboriginal culture, irrigated agriculture, urban

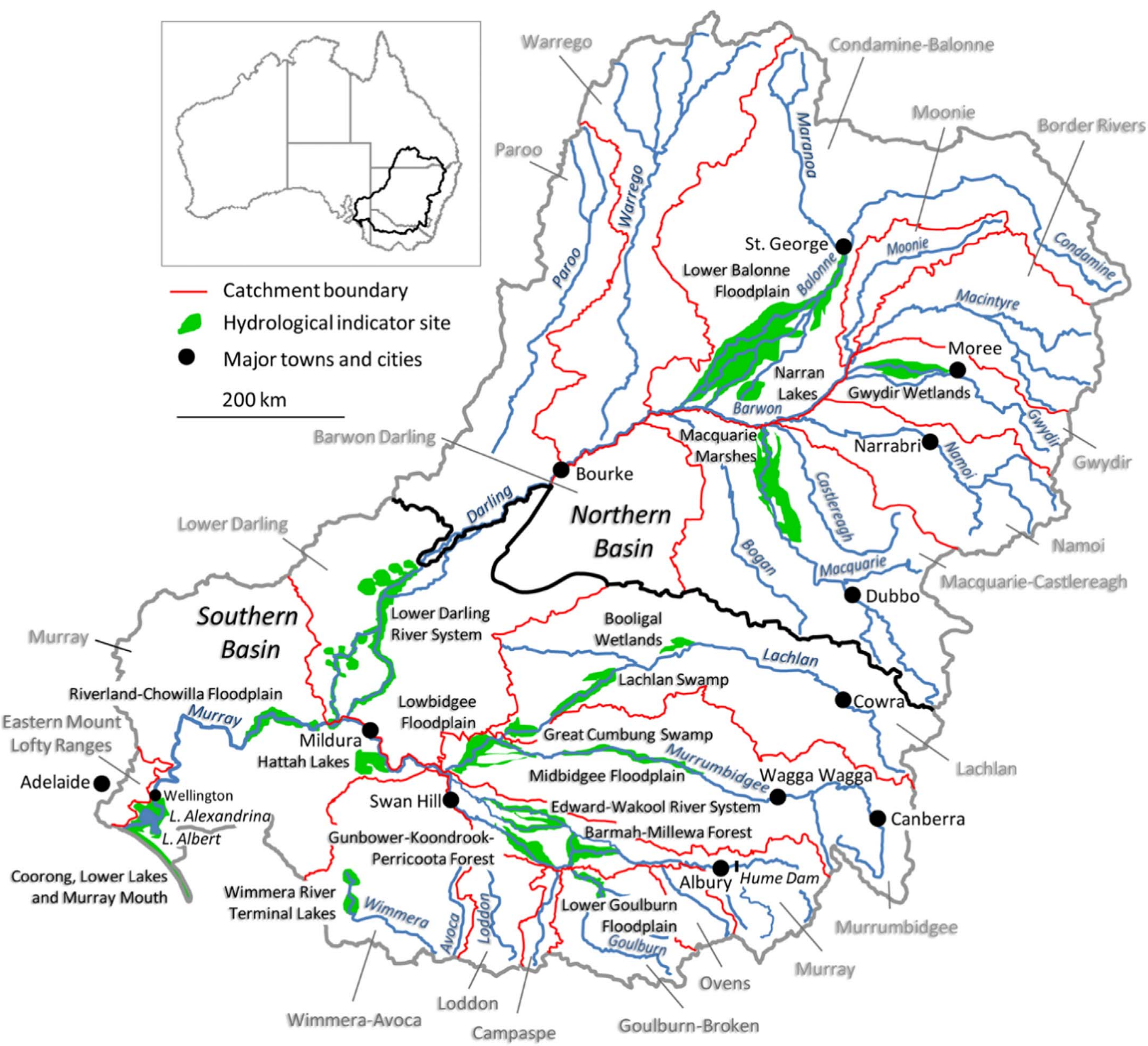

Fig. 1. The Murray-Darling Basin showing the major catchments, rivers and key hydrological indicator sites, subject to ecological targets under the Basin Plan (MDBA, 2012a). Inset: location map within Australia.

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and regional water consumers and commercial fisheries – represents a major challenge for national and State governments. The *Water Act 2007* (Cwth.) is the most recent policy response in a national programme of water reform undertaken since the 1980s to address over-allocation and long-term environmental decline.

The Act sets out the responsibility for preparing a Basin Plan to an independent statutory federal agency, the Murray-Darling Basin Authority (MDBA). The objectives of the Act are to uphold international agreements, to return to environmentally sustainable levels of extraction, to protect and restore and provide for the ecological values and ecosystem services of the Murray-Darling Basin (floodplains, wetlands, rivers, and the estuary) and their functions, and to optimise the economic, social and environmental outcomes to the Australian community. Recovering water from irrigation diversions and re-allocating water as environmental flows (Arthington, 2012) is the means by which ecological improvement will be achieved. The Basin Plan is a statutory instrument that sets a legally-binding extraction limit (the environmentally sustainable level of take), it is not a prescriptive blueprint for ecological restoration.

The rationale is that river flows are essential for maintaining ecological condition of rivers and floodplains, driving ecological processes and the stocks and flows of energy, nutrients and biota (Naiman et al., 2005). In the basin, river regulation and irrigation water diversion have resulted in changed flow regimes, including shifts in frequency, duration, extent and seasonal occurrence of high and low flows and flood events, leading to poor condition of flow-dependent ecosystems, fragmentation of vegetation communities and changes in biodiversity and ecosystem function (Vörösmarty et al., 2010). The Basin Plan will re-allocate an annual average of 2750 GL of water, or 20% of baseline average water diversions, to the environment by 2019, with an additional 450 GL by 2024 (Commonwealth of Australia, 2012). To achieve this reallocation, the Australian Government is purchasing irrigation water entitlements from willing sellers, as well as investing in infrastructure to improve efficiency of irrigation and delivery of environmental water.

3. Methods

The IESA (CSIRO, 2012) was a "programme evaluation" of the Basin Plan. Our aim in this paper is to reflect on lessons learned in the application of an IESA to inform water reallocation decisions overseen by the Commonwealth government. Here we systematically consider the biophysical, economic and social research reported by CSIRO (2012), as well as the IESA research process. The IESA was subject to peer review by an Independent Science Review Panel (ISRP)[1] and was conducted in a transdisciplinary manner with six workshops in which methodology and results were discussed with stakeholders (cf. Hatton MacDonald et al., 2014 for more detail). A post-IESA review provided the opportunity to fully articulate the development of a conceptual model that underpinned the research project, re-evaluate multiple datasets, models and assumptions and develop confidence scales.

An initial step in an IESA is to understand the processes by which ecological and wellbeing outcomes are expected to be achieved. To this end, we adapted a conceptual model based on the generalised framework of Keeler et al. (2012). Fig. 2 records the flow of logic and outputs used here; it illustrates the steps taken in our integrated valuation, whereby we linked policy intervention through to monetary estimation of incremental ES benefits. We provide detail on each stage below.

3.1. Flow scenarios

Underpinning the IESA were three river flow scenarios supplied by the MDBA to CSIRO: "Without development", corresponding to modelled flows prior to irrigation diversions and water resources development; "Baseline", corresponding to modelled contemporary flows without the proposed Basin Plan; and " 2800", representing modelled flows following the implementation of the Sustainable Diversion Limit (SDL) where irrigation water is reduced by an average of 2800 GL/yr.[2] Each scenario is based on a 114-year record of simulated flows (1 June 1895–30 June 2009) and each preserves the same underlying climatic variability. The marginal benefits were modelled as if the water resources of the Basin had been managed as per the three scenarios, where each flow scenario is characterised by different flow and flood regimes that determine the extent and condition of flow-dependent ecosystems and the ES derived from them.

3.2. Ecological modelling

3.2.1. Vegetation

Changes in area (ha) of five major floodplain vegetation communities were modelled (river red gum *Eucalyptus camaldulensis*, black box *E. largiflorens*, coolibah *E. coolabah*, river coobah *Acacia stenophylla,* and lignum *Muehlenbeckia florulenta*) under different flood recurrence intervals (1 in 1, 2, 5 and 10 years) along the River Murray between the 2800 scenario and Baseline. These communities are widespread, ecologically important and their environmental water requirements are well known (MDBA, 2010; MDBA, 2011). Data on the location and extent of vegetation communities provided by State agencies was overlain with flood inundation modelling outputs from the River Murray Floodplain Inundation Model (RiM-FIM) (Overton et al., 2006).

3.2.2. Fishes

Habitat suitability scores for native fishes (Young et al., 2003) were modelled for each scenario, for nine different hydro-ecological regions of the River Murray, using the Murray Flow Assessment Tool (MFAT). Four functional groups of fishes were evaluated based on their flow requirements: 'Main channel generalists' spawn and recruit in the main channel regardless of flow conditions, 'main channel specialists' spawn and recruit during high or low flows in the main channel, 'flood spawners' spawn and recruit during periods of floodplain inundation and 'rising-flow spawners' do not require floodplain inundation, but spawning and larval recruitment are enhanced by rising flows. Habitat suitability scores were derived from preference curves for spawning habitat (flood magnitude, spawning timing, rate and duration of flow rise and fall, substrate condition and percentiles of flow) and larval habitat (inundation area and duration, dry period, rate of flow fall and percentiles of flow).

3.2.3. Waterbirds

The percentage of years in which breeding was likely was calculated at nine important breeding sites for colonially nesting waterbirds for each scenario. Colonially nesting waterbirds require flood events lasting ca. 4–7 months. Breeding is successful if thresholds of flood depth and duration are exceeded (Arthur et al., 2012). Most adult female egrets need to breed in most years for

[1] The five-person ISRP comprised an economist, two ecologists, a hydrologist and a social psychologist.

[2] The discrepancy between the 2800 GL scenario and the proposed 2750 GL to be restored to the environment under the Basin Plan is because revisions to the final volume of water were made after we completed our assessment.

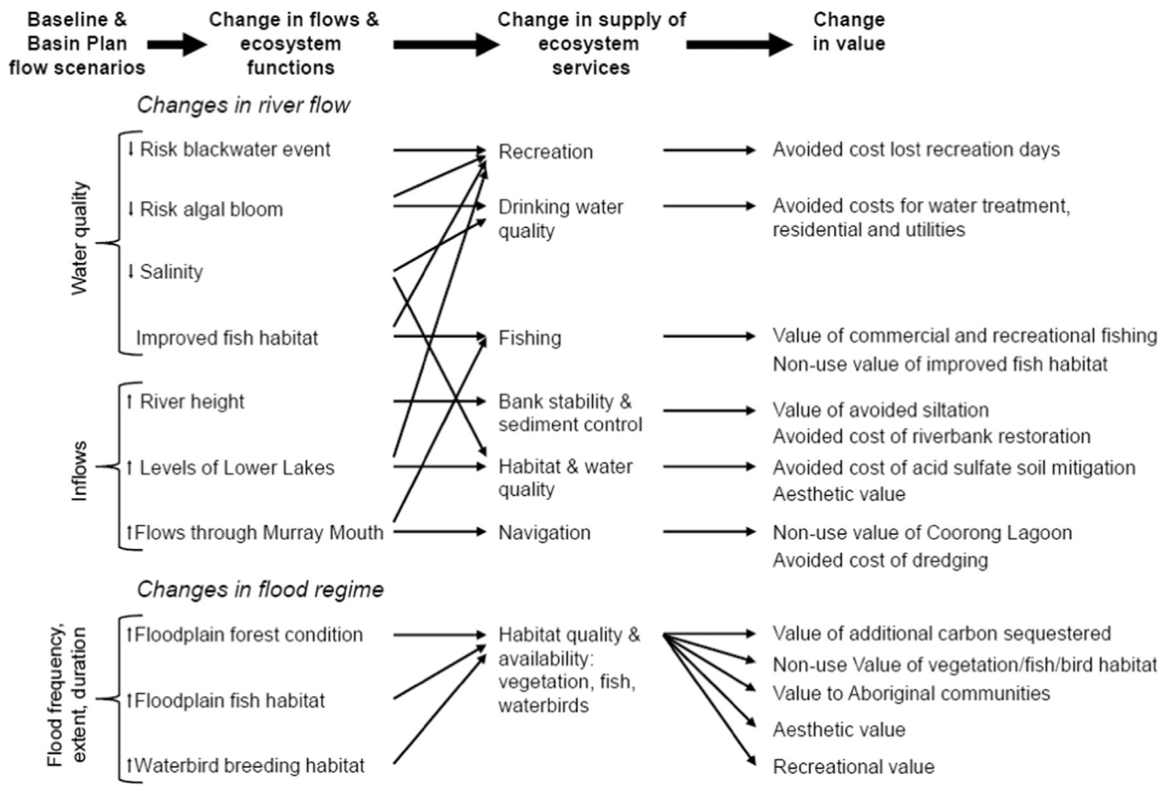

Fig. 2. Ecosystem services assessment: conceptual linkages. Connections between policy intervention, changed river flows and inundations patterns, modelled ecological responses and incremental change in ES flows and the monetary valuation of incremental changes.

populations to be maintained (Arthur, 2011). Outcomes for colonially nesting waterbirds were assessed, using the IBIS decision support system (Merritt et al., 2010), MFAT (Young et al., 2003) or estimates of environmental flows required to meet breeding targets (MDBA, 2012a).

3.2.4. Estuary

The Coorong estuary (Fig. 1) is dependent on freshwater inflows. The proportion of time in each of eight ecosystem states (estuarine/marine; marine; unhealthy marine; degraded marine; healthy hypersaline; average hypersaline; unhealthy hypersaline and degraded hypersaline) was modelled for each scenario using the model of Lester and Fairweather (2011). The differentiation of various states was based on water quality and flow variables.

3.2.5. Aboriginal cultural values

Maps of Aboriginal land use and cultural practices for the Wamba Wamba community of the Edward River and the Werai State Forest were overlain with flow regimes to meet these culturally-important subsistence and spiritual values and modelled ecological outcomes (Jackson et al., 2015).

3.2.6. Water quality

Salinity concentration, risk of cyanobacterial (blue-green algae) blooms (which render water bodies toxic and unsuitable for recreation), risk of blackwater events (excess dissolved organic carbon leading to low dissolved oxygen and risk of hypoxia to freshwater biota), and risk of acidification of the Lower Lakes from acid sulphate sediments were modelled for each scenario.

3.3. Monetary valuation

The monetary values were estimated for incremental changes in cultural and habitat ES and provisioning and regulating ES attributable to differences in flows between the 2800 scenario and Baseline scenario. While the scenarios have the advantage that they embed the variability in flow regimes recorded in the gauged record (frequency, duration and seasonal occurrence) a consequence of their use is in the valuation stage we do not discount incremental benefits. This is because the scenario approach taken, and required by the MDBA for its purposes, did not require information on the time at which the benefits occurred. Rather it emphasises the importance of long-term water resources management and its effect on ecosystem condition in contrast to outcomes based on shorter-term forecasts that would be strongly influenced by inter-annual variability.

3.3.1. Cultural and habitat ES

3.3.1.1. Aesthetic experience. An initial hedonic analysis of house prices (2000–2011) were modelled as a function of typical structural, neighbourhood and environmental variables. The modelled values for lake level and flow were used in combination with modelled changes in lake levels and river flow between the two scenarios and extrapolated over nearby properties.

3.3.1.2. Basin ecosystems. Incremental changes in modelled outcomes between the Baseline scenario and 2800 scenario in each sub-catchment for floodplain vegetation inundation (as a proxy for condition), availability of spawning habitat for native fish (as a proxy for population growth) and thresholds for colonially nesting waterbird breeding were combined with values from a stated preference study (Hatton MacDonald et al., 2011) and benefit transfer study (Morrison and Hatton MacDonald, 2010). In this paper we update native vegetation outcomes from those in CSIRO (2012) to reflect new ecological modelling. We also revised the valuation approach to adhere to the original stated preference study assumptions in which survey respondents were asked to value a percent change in native vegetation extent from pre-

(water) development extent where recovery was capped to 80% of this level. As recovery is expected to exceed this cap in some catchments, we provide capped and uncapped results.

3.3.1.3. Coorong estuary. Three estimates of the monetary benefits from a healthier Coorong estuary were calculated based on data from Hatton MacDonald et al. (2011) by: i) transferring the proportional change in the modelled probability of being in a healthy state (Lester and Fairweather, 2011) to the estimated total value of saving the Coorong from ecological collapse (i.e. a non-marginal value); ii) the incremental time spent in a healthy ecosystem state in the 2800 scenario which is used to calibrate the healthy condition values, and; iii) the total uncalibrated value.

3.3.1.4. Recreation in the Southern Murray-Darling Basin. To estimate benefits to general recreational users and to recreational fishers, the reduced risk of cyanobacterial blooms and blackwater events under the 2800 scenario (12 fewer days annually and 6 fewer years, respectively) were converted to river days open to recreation. These river day estimates were then combined with estimates of future recreationalist numbers by affected catchment based on: i) actual recreation numbers in the period 2003–2010; ii) an estimate of water recreationists based on survey information (DRET, 2010), and; iii) benefit transfer of a general recreational value (Morrison and Hatton MacDonald, 2010).

3.3.2. Provisioning and regulating ES

3.3.2.1. Climate regulation. Additional areas of river red gum, black box and coolibah inundated under the 2800 scenario at hydrological indicator sites were calculated from the percent difference in flow parameters required to meet ecological targets for floodplain trees between the Baseline scenario and 2800 scenarios (MDBA, 2012a). Annual carbon sequestration at each site was estimated by overlaying a map of hydrological indicator sites with zones of increment in carbon dioxide equivalents (median CO_2e; tonnes per hectare per year) predicted for hardwood carbon plantings across the Murray-Darling Basin (Polglase et al., 2008; Fig. 17 therein) and multiplying the value by the additional area of woodland and forest inundated under the 2800 scenario. The CO_2e estimates for black box and coolibah were adjusted by a third because these tree species are slower growing than is river red gum. Estimates of CO_2e increments (t ha^{-1} yr^{-1}) were multiplied by three different carbon prices: AU$23 per tonne, the initial price placed on CO_2e under the Australian Government carbon tax legislation (Commonwealth of Australia, 2011); the European Union Emissions Trading Scheme price at the end of 2011 (AU$10.50 per tonne; Talberg and Swoboda, 2013, Fig. 2 therein) and an estimate of the benefits of reducing greenhouse gas emissions based on revised 2011 social cost of carbon/marginal damage estimates used by the US government (IWGSCC, 2013; 3% discount rate therein and an annual average exchange rate) at AU$42 per tonne. The estimate of AU$ 15.6 m per year in Table 1 and Fig. 3c is based on the AU$23 per tonne price.

3.3.2.2. In the Southern Murray-Darling Basin. The value of ES improvements linked to water quality improvements were estimated using avoided cost methods. This estimate is entirely separate to recreation values (derived through water quality improvements) because the benefits of water quality are additive: both recreationists and water utilities benefit. A new estimate not found in CSIRO (2012) is of the benefits to the commercial catch in the Coorong and Lower Lakes. This fishery responds to changes in freshwater inflows that affect breeding and recruitment of several commercial species (Ferguson et al., 2013). The relationship between catch and inflows is complex and non-linear (Gilson et al., 2012), but mean annual catch per fisher day during 1984–2008 was 246 kg (derived from total catch divided by fisher days). We estimated a conservative 20% increase in catch per unit effort over the long-term average associated with achieving the Murray-Darling Basin Plan target of average freshwater inflows of >2000 GL/y in $>95\%$ of years and maintenance of average salinity of <60 g/L in the Coorong Southern Lagoon and <20 g/L in the Northern Lagoon (MDBA, 2012b two of these). An increase in annual gross value of AU$1.54 m based on mean annual gross value of fishery production (2006/07–2009/10) of AU$7.04 m (EconSearch, 2012; Table 3.2 therein).

3.3.2.3. Water and soil quality ES. A suite of water and soil quality regulating ES benefits were estimated using avoided cost estimates for ES losses and hazard damage catalogued during the 1997–2009 drought (Banerjee et al., 2013) and biophysical thresholds, e.g. minimum lake height linked to acid sulphate soil formation in the Lower Lakes region, and a minimum Mouth Opening Index (Close, 2002) linked to Murray mouth sedimentation. For erosion prevention the threshold was minimum river height based on a 4-year consecutive low-flow proxy: widespread bank instability and bank collapse has been linked to low river height which desiccated the banks leaving them unstable (Liang et al., 2012).

3.4. Valuation of benefits to the Aboriginal community

To estimate the benefits accruing to the Wamba Wamba we used two sets of modelled results: the frequency that environmental flows (the 2800 scenario) met Aboriginal cultural values based on land use, occupancy and 'bush tucker' maps; and an estimate of supplementary flow requirements to meet unmet values.

4. Results

There is evidence that returning river flows and restoring flood regimes to a major drainage basin results in large ES improvements (see, CSIRO 2012 for details). The largest monetary values estimated were for the supply of habitat: this value likely also captures the socio-cultural significance of the basin and the importance of indicator sites for ecosystem health across the basin (Johnston et al., 2012). Other examples, were higher lake levels (Australian Height Datum) were found to be positive and significant determinants of house prices in the Coorong and Lower Lakes region of South Australia, as were higher river flows near the Barmah-Millewa Forest and the Lower Darling and mid-Murrumbidgee wetlands in New South Wales. Table 1 summarises the metrics, models used, levels of uncertainty and monetary valuation estimates.

To better support decision making, we develop confidence levels for the IESA. We assigned confidence to the modelling and valuation using the following criteria: i) consistency between different models and other research; ii) robustness of methods used to derive the data (e.g. a maximum confidence level of 'medium' was assigned to those monetary estimates based on avoided costs methodology), and; iii) degree of congruence between the spatial scale of data, models and the ES. Confidence levels were assigned to a recognised five-point scale (Mastrandrea et al., 2010). Assignment of 'low' confidence indicated greater reliance on expert opinion and limited evidence to support the assumptions in a model. A 'medium' value indicated supporting evidence for several aspects of the model, whereas a 'high' confidence indicated minimal or no assumptions. No assignment of 'very high' confidence was made because of time constraints on the validation of primary source data.

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Table 1
Data, models, valuation methodology and monetary values of, and confidence levels in, incremental ecosystem service benefits. Abbreviations: AC=avoided costs; BT=benefit transfer, CM=choice modelling; MO=mouth opening; ESLT=environmentally sustainable level of take.

Ecosystem service	Data/metrics	Biophysical/ecological Modelling	Economic Valuation	AS million	Confidence	
Regulating Services					**Biophysical**	**Economic**
Carbon sequestration	Area of woody perennial vegetation in good condition and annual rates of growth and carbon sequestration	RiM-FIM (Overton et al., 2006); modelling to support ecological targets (MDBA, 2012b); growth modelling of carbon plantings	Carbon price (Commonwealth, 2011)	50.0	Low to medium - RiM-FIM used for Murray; Basin Plan hydrological models used for other sites	Medium - values same in southern and northern Basin, no risk discount
Moderation of acid sulphate soil formation	Lower Lakes height threshold	MDBA hydrology (MDBA, 2012b)	AC (Banerjee et al., 2013; CSIRO, 2012)	9.2	High - lake level height data	Medium - AC methodology southern Basin issue
Moderation of sedimentation	End-of-system flows and MO Index	MDBA hydrology (MDBA, 2012b) Threshold MO Index (Close, 2002)	AC (Banerjee et al., 2013; CSIRO, 2012)	17.8	High - established model	Medium - AC, southern Basin issue
Maintenance of bank stability	River in-channel height and threshold	MDBA hydrology (MDBA, 2012b) Threshold river height (CSIRO, 2012; Liang et al., 2012)	AC (Banerjee et al., 2013; CSIRO, 2012)	23.7	Low - no river height data	Medium - new methodology, southern Basin issue
Provisioning Services						
Floodplain grazing	Ha floodplain grazing	Estimates (GHD, 2012) based on MDBA flow duration curves and overbank flows	BT (GHD, 2012)	32.2	Medium - different methodology	Medium - different methodology
Fresh water quality	Salinity concentration	MDBA hydrology (MDBA, 2012b) and BigMOD salinity model	Productivity losses and AC utilities and users (GHD, 1999; Allen Consulting Group, 2004), probabilistic calculation (Banerjee et al., 2013; CSIRO, 2012)	1.1	Low - salinity modelling (but unsure of impact of environmental watering on salt loads)	Medium - uses dose response but low congruence with (CIE, 2011)
	Cyanobacterial bloom risk	Hydrological risk model (CSIRO, 2012)	AC (CSIRO, 2012)	0.9	High - model for outbreak risk	Low - develops a methodology but low congruence with (CIE, 2011)
Fishes	Commercial catch	Difference in mean annual catch under years of medium-high and years of low barrage flow	BT (EcoSearch, 2012) Estimated increase in catch per unit effort and proportion gross production value	1.5	Low - not based on ecological response model.	Low – different methodology, comparable study estimates increase in producer surplus of AU $2.6 (EconSearch, 2012)
Cultural Services						
Aesthetic appreciation	House prices in basin 2003–2010, historic and modelled river flows and lake level height	MDBA hydrology (MDBA, 2012b)	Hedonic models (CSIRO, 2012)	337.0	High - Modelled lake levels. Medium - Modelled river flows. Four regions only	High - Project-funded study, visible link lake height, exposed banks for nearby homes Medium - Project-funded study, river flows proxy for river health, regional economy, recreation.
Indigenous values	Geocoded cultural and 'bush tucker' (food) sites for Wamba Wamba People	Response models: native fish, vegetation water fowl, linked to land use, occupancy and 'bush tucker' maps (CSIRO, 2012)	Qualitative only	No dollar value ascertained	Medium - no explicit modelling of beneficial flows, but expert judgement of ecological responses and a methodology developed (Jackson et al. 2015)	Medium - Qualitative assessment, but one that relied upon local sites of interest and opinions of affected community
Recreation and tourism	Increased flows, additional days with water quality adequate for recreation	Changes in good flow days Changes in cyanobacterial bloom and blackwater risk - days with adequate water quality for recreation (CSIRO, 2012). Improved conditions for recreational fishing (Deloitte Access Economics, 2012)	Recreation and tourism numbers (CSIRO, 2012) BT values (Morrison and Hatton MacDonald, 2010) BT (Deloitte Access Economics 2012)	161.4 10.3–20.6 107.0	Low - correlation only as no model that links visitation rates with changes in flow. High - modelling of water quality risk combined with health alerts Medium - different assumptions	Low - multiple assumptions, BT value unrelated to flow. Low - multiple assumptions, BT unrelated water quality Medium - consumer surplus
Habitat Services						
Native vegetation	Floodplain vegetation mapping (various sources)	Modelled area of inundation for dominant floodplain vegetation	Southern Basin CM (Hatton MacDonald et al., 2011) and BT (Morrison	1902.4 (capped) 2110.0	Medium - southern Basin vegetation response model extended to	High - MDBA-funded study, southern Basin extended to northern

		communities (Overton et al., 2006)	and Hatton MacDonald, 2010)	(uncapped)	northern Basin using ESLT data	Basin using reproducible method
Native fishes	Habitat suitability of native fish guilds	Response relationships derived, predictions based on habitat suitability for recruitment (Young et al., 2003)	Southern Basin CM (Hatton MacDonald et al., 2011) and BT (Morrison and Hatton MacDonald, 2010)	339.9	Low - habitat suitability model has limited validation	Medium - MDBA-funded study, based on targets from Native Fish Strategy, southern Basin
Colonially nesting waterbird breeding	Frequency and extent of habitat suitability for nesting and fledging of colonially nesting waterbirds	Environmental water requirements; ecological response models (Merritt et al., 2010); bird breeding and inundation modelling (Arthur et al., 2012)	Southern Basin CM (Hatton MacDonald et al., 2011) and BT (Morrison and Hatton MacDonald, 2010)	693.1	Medium - only threshold responses were available for some sites, whereas other sites were based on habitat-based ecological response models	Medium - MDBA-funded study, southern Basin transferable to northern Basin: breeding event is equally ecologically valuable but may be tempered by scope effects
Coorong, Lower Lakes and Murray Mouth	Duration in healthy state	Ecological response model of ecosystem states (Lester et al., 2011)	Southern Basin CM (Hatton MacDonald et al., 2011) with new method (CSIRO, 2012)	480.0 4000.0 4300.0	High – based on statistical modelling	Medium - MDBA-funded study, new ecology

Table 1 provides no information on the spatial distribution of benefits therefore we produced a series of maps that can be useful to communicate the array of ES benefits (Hauck et al., 2013), to visualise benefits and losses across space, and to inform regional economic development policy (Bateman et al., 2013). Fig. 3a displays the relative proportions of additional water available to the environment by catchment (MDBA, 2012a, 2011). Fig. 3b shows a key policy trade-off from the re-allocation: the distribution of estimated costs to irrigated agriculture with reduction in gross value of production (ABARES, 2011) are strongly negatively correlated (R^2=0.87) with reductions in sustainable diversion limits, but in four catchments there are modest estimated increases in the value of irrigated production. Fig. 3c–f illustrates the spatial nature of benefits. River flow is a critical driver for many ES benefits, for example, increases in mean annual carbon sequestration tend to be relatively large throughout the basin (Fig. 3c) and are strongly positively correlated with increases in river flows, as are habitat ES for native species (Figs. 3e, 3f), and provisioning and cultural services.

5. Discussion

The Basin Plan is a water sharing plan that seeks to restore water-dependent ecosystems and optimise social, economic and environmental outcomes within a multi-jurisdictional basin. Restoration requires changes to flow and flood regimes. Under the Basin Plan 2012, an average 2800 GL/yr of water once allocated to irrigators will be re-allocated to the environment. Water re-allocation at this scale has the scope to improve the current condition of ecosystems in the Basin and to supply a suite of enhanced ES that benefit human wellbeing. Our case study demonstrates that an IESA can produce policy relevant information, not only on the condition of, in this case, flow-dependent ecosystems, but also provide monetary and non-monetary valuation of incremental changes.

In Crossman et al.'s, (2015) review of CSIRO (2012), the authors discuss four advances of using the ES approach to support decision making. The central aim of this paper is to advance discussions of mainstreaming IESA and to report on the post-project learnings. The Methods section makes evident the prerequisite ecological modelling and interdisciplinary integration to undertake an IESA. In the introduction we identified three criteria for an integrated ecosystem services assessment: that it provides salient, credible and legitimate information to policy makers (Cash et al., 2003), where salience is defined as the relevance of the ES assessment to the needs of decision-makers; credibility as the scientific adequacy of the research and legitimacy as an expression that the researchers acknowledged diverse stakeholder values and beliefs and were unbiased in their treatment of opposing views and interests. Table 2 summarises the different types of integration we achieved – of values, variables, and scales – in relation to the criteria. It also extends the findings of Hatton MacDonald et al. (2014), where users of the CSIRO (2012) report were surveyed and provides examples of tools to better support decision-making, such as confidence heuristics (CH), maps, comprehensive summary material (Table 1), a conceptual model (CM) and elements in the research process, specifically, ISRP review and participatory approaches (PA) including stakeholder engagement to determine comprehensive coverage of all values (e.g. Jackson et al., 2012a).

There are operational challenges to integrating different value systems in IESA. This includes a tension between Tables 1 and 2. While post-project we assigned a low confidence level to some ecological modelling, the same results were viewed as credible by the research users (Hatton MacDonald et al., 2014). There are also tensions among the three criteria in Table 2. For example,

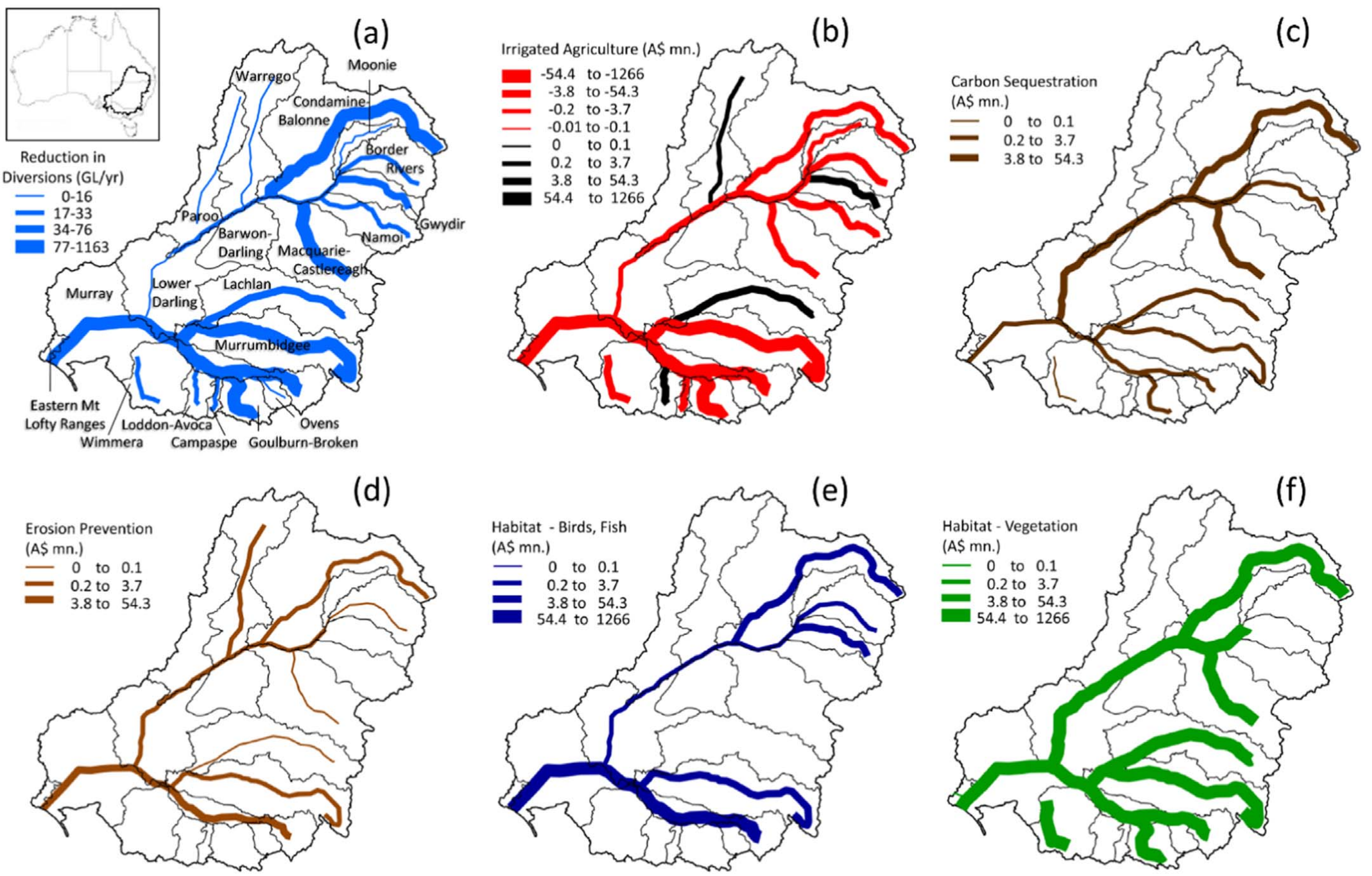

Fig. 3. Spatial distribution of the costs and ecosystem service benefits under the Basin Plan (MDBA, 2012a). (a) Increases in environmental flows, assumed as equivalent to reductions in diversions under the 2800 scenario (MDBA, 2012b, Table 1, column 3). (b–f) the relative values (in $AU million per year) of marginal changes in the supply of ES within catchments of the basin under 2800 scenario: based on $AU values for each river catchment (CSIRO, 2012; Table 6.3). Assessments are for (b) provisioning services (irrigated agriculture; red (grey)=reduction in annual gross value of production; black=increase in value); (c) annual incremental carbon sequestration; (d) prevention of erosion; and (e, f) habitat services. Absence of a line corresponding with a catchment and ES, indicates there was no estimation of value undertaken, not that the value was zero. Scales are based on minimum, maximum, interquartile and median pooled values.

Table 2
Integration for policy-making. Square bullets indicate tools to better support decision-making.

Integrating factor	Salience	Credibility	Legitimacy
Values	Biophysical modelling demonstrated ecological benefits and large monetary values of ES that were used in the MDBA Regulation Impact Statement of the Basin Plan to Federal Parliament (MDBA, 2012a). • CM • Table 1: Maps	Biophysical modelling was viewed as credible but there were issues with monetary values, e.g. the retrospective analysis, BT and AC (Hatton MacDonald et al., 2014). • ISRP • CH incorporates a consistency with other studies criterion	Inclusion of different values and knowledge types, i.e. Aboriginal knowledge, widens scope of enquiry and coverage of interests. Some questioned the use of CM values from outside of basin. • PA
Scale	Whole-of-basin required by MDBA. • Table 1 lists scale of assessment.	Few of the models and valuations are at basin scale, however, not all of the ES are at this scale. • CH incorporates a scale criterion	Greater spatial specificity of ES benefits and disbenefits was required by States and regional stakeholders (Hatton McDonald et al., 2014). Enables targeted policy responses • Maps
Variables	Information is provided on the condition of flow dependent ecosystems and incremental ES benefits. However, sometimes proxies are used, e.g. fish habitat suitability not fish populations. • CM	Based on the best available biophysical science and biophysical thresholds for valuation. Nevertheless, there is possibility of correlated variables, i.e. the CM, hedonic, and AC values. • ISRP • CH incorporates a method criterion	Omitted variables, e.g. pollination benefits, other Aboriginal communities and non-Aboriginal cultural ES. • PA

integration of values in a settler colonial state such as Australia requires the inclusion of Aboriginal cultural benefits. Traditional owner interests have historically been excluded from Basin water governance (Bark et al., 2012) but are now given modest consideration under the Water Act and the Basin Plan. However, while a traditional cost-benefit rests on aggregating individual welfare measured in dollar values using quite specific economic methodologies, an IESA does not necessarily require a common numéraire.

A key operational challenge is the timeframes required for careful consultation with rural communities[3] and marginalised Aboriginal groups more specifically (Jackson et al., 2012b). Developing up-to-date, fit-for-purpose metrics that are deemed valid and appropriate across cultures may not be possible in the tight timeframes required by central agencies requesting economic analyses of a programme or of regulatory impacts (Jackson et al., 2014). The values expressed by the Wamba Wamba in their land uses and cultural practices maps could be seen as deliberative responses by individuals with complex social relationships. While relevant for decision-making generally, such deliberative values would be treated as indicative at best in a traditional cost-benefit analysis. Yet, a deliberative, participatory approach that brings historically disenfranchised groups together with scientists and water managers can help build trust and relationships that could prove beneficial for future water management (Ascher and Steelman, 2006).

Further, the inclusion of out-of-basin (e.g. of Sydney residents) non-use values fits with the objective of the Water Act 2007 to maximise benefits to the Australian community, yet to some the inclusion of these values undermined the legitimacy of the monetary valuations (Hatton MacDonald et al., 2014). The avoided cost approach although common when valuing provisioning and regulating ES (Farber et al., 2006) also has problems (Bockstael et al., 2000; UNSRC, 2005). To address these, we utilised biophysical and political thresholds (see Banerjee et al., 2013). Finally, many of monetary estimates were based on benefit transfer. A consideration in using benefit transfer is the fulfilment of all three NOAA (1996) criteria for good benefit transfer: i) close correspondence of sites; ii) comparability of change in quality or quantity of ES, and; iii) correspondence of quality of studies. The IESA, for most ES valued, satisfied criteria (i) and (iii) by using recent peer-reviewed Australian valuation studies for closely matched types of benefits, most of which were undertaken within the basin but not at the whole-of-basin scale. Integrated valuation simplifies the task of meeting criterion (ii) because valuation studies measure benefits in different ways (e.g. areas of river red gum, change in habitat suitability of fishes, numbers of waterbird breeding events per decade, value of a recreation day per person), and there is no guarantee that without an integrated study that these metrics coincide with outputs of ecosystem response and water quality models. Overall the comprehensiveness of the IESA meant that some estimates of monetary value were from reports, not peer-reviewed literature, or required numerous assumptions (e.g. for recreation), and often assumed the relationship between flow, ecological responses and benefits was linear, and that diminishing marginal returns were not a factor, e.g. the uncapped basin ecosystems monetary value estimate assumes marginal values do not diminish beyond the 80% threshold. In summary there remains a need for coupled ecological and monetary valuation research to better understand nonlinear and interdependent ecological responses.

For integration over scale, we note a tension between scaling up and scaling down. Ecological models were sometimes extended to another part of the basin to underpin the integrated valuation and while this was seen as fit for purpose at the federal level; it was used in the Regulation Impact Statement (MDBA, 2012a) submitted to the Australian Parliament (salience), it was not deemed as useful for policy purposes at the State level (legitimacy). This tension between broad-scale assessment that is relevant and applicable to policy scenarios and the need for finer-scale, scalable, functional analysis of a single ES (Nelson, et al., 2009), to inform trade-off decisions and achieve multiple benefits, is likely to emerge in iterations of water sharing plans by State water planners. This is because the conventional approach to modelling in the basin is based on icon (sites of inter/national ecological significance) site analyses which may not reveal the benefits that are realised at smaller scales as flows move through the basin. The IESA can reveal local values and on a practical level state water planners may wish to incorporate locally-important site-specific targets or flow-specific rules aimed at enhancing local and Aboriginal valued ES (Robinson et al., 2014).

Operationally to address concerns of credibility and legitimacy, we incorporated review, participatory approaches and maps. Review and participatory approaches enabled knowledge exchange and communication of the data, methodology and results (Villa et al., 2014). In addition, our post-project assignment of confidence levels for the biophysical and valuation results provides context for stakeholders and decision-makers in the basin. Over time as new data accumulates confidence levels can be re-evaluated. Maps showed that for some ES, the restoration of flow regimes is insufficient to realise benefits, for example, improvement in habitat for native fishes. A future assessment might include consideration of how installation of pipelines, regulators, weirs, pumps, as well as, for instance the provision of fish ladders to aid spawning migrations, and the restoration of physical habitat and control of exotic invasive fishes could affect potential trade-offs and synergies in achieving ES outcomes. Further, when Fig. 3a–f are viewed together, it is clear that there are winners and losers in each catchment. Such a realisation might help shift the policy debate from one of contested values towards policies aimed at reducing losses and maximising benefits, as well as directing attention to the need for inclusive processes that enable stakeholders to deliberate over policy options and their impacts to engender improved community confidence in water planning (Tan et al., 2012).

The monetary benefit values in CSIRO (2012) were used in federal parliamentary submissions (MDBA, 2012a), indicating that a BCA was salient for their needs. However, the integrated valuation provided credibility and legitimacy that was not provided by the BCA alone. Credibility was partially achieved through rigorous ecological modelling, and the identification of biophysical thresholds for the monetary valuation. The broad scope of the IESA, derived from the objectives of the Water Act, helped provide legitimacy. The comprehensive, whole-of-basin ES assessment embodied a wide range of issues that people care about, including biodiversity values and cultural values of flow-dependent ecosystems. The explicit consideration of ES in the Water Act not only marks a shift in water management in Australia but meant that for the MDBA to gain evidence on the state of the supply of ES, it commissioned an IESA not a BCA. The process represents a step in the evolution of a policy-science action arena. The IESA complements recent initiatives, such as those in the UK, to develop natural capital accounts with a focus on types of ecosystems and their extent and dynamic condition (e.g. Khan and Din, 2015).

6. Conclusions

The supply of ES for human wellbeing is dependent on the linkages between abiotic drivers of ecosystem function, ecological responses resulting in changes in rates of ecosystem functions and, hence, the supply of ES. In practice, an IESA relies on prior investments in data collection, model development, valuation studies and on researchers working in interdisciplinary teams. The

[3] Since our IESA a large study on the well-being of rural communities, including those in the Murray-Darling Basin, was commissioned which provides self-reported assessments of well-being and resilience at points in time (Schirmer et al., 2016).

Murray-Darling Basin has been the focus of considerable investment in biophysical and social sciences research. Despite such efforts, confidence in some aspects of the IESA was low. Ideally, integrated models would be developed that are capable of providing integrated biophysical, economic and social information required to assess large-scale environmental policy options.

The existence of the water crises that necessitated a Basin Plan, and the multiple objectives the Plan seeks to simultaneously attain, highlight an implicit schism in public values relating to water. Water for the environment is considered by some segments of society as an unproductive use in comparison to consumptive uses. Whilst this IESA provides evidence that water for the environment represents a resource that provides and sustains multiple benefits to a broad range of stakeholders and for human wellbeing, it in turn contains a cautionary insight. If we are to better appreciate the full range of benefits from human use and management of ES, we will need to ensure that monetary outcomes do not exclude all other forms of value in the approaches we take and in public discourse and decision-making.

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