Socio-economics: triple-bottom-line accounting

A technical report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy

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Important disclaimer

Flinders and Gilbert Agricultural Resource Assessment acknowledgments

This report was prepared for the Office of Northern Australia in the Australian Government Department of Infrastructure and Regional Development under the North Queensland Irrigated Agriculture Strategy <http://www.regional.gov.au/regional/ona/nqis.aspx>. The Strategy is a collaborative initiative between the Office of Northern Australia, the Queensland Government and CSIRO. One part of the Strategy is the Flinders and Gilbert Agricultural Resource Assessment, which was led by CSIRO. Important aspects of the Assessment were undertaken by the Queensland Government and TropWATER (James Cook University).

The Strategy was guided by two committees:

(i) the **Program Governance Committee**, which included the individuals David Crombie (GRM International), Scott Spencer (SunWater, during the first part of the Strategy) and Paul Woodhouse (Regional Development Australia) as well as representatives from the following organisations: Australian Government Department of Infrastructure and Regional Development; CSIRO; and the Queensland Government.

(ii) the **Program Steering Committee**, which included the individual Jack Lake (Independent Expert) as well as representatives from the following organisations: Australian Government Department of Infrastructure and Regional Development; CSIRO; the Etheridge, Flinders and McKinlay shire councils; Gulf Savannah Development; Mount Isa to Townsville Economic Development Zone; and the Queensland Government.

Director’s foreword

Northern Australia comprises approximately 20% of Australia’s land mass but remains relatively undeveloped. It contributes about 2% to the nation’s gross domestic product (GDP) and accommodates around 1% of the total Australian population.

Recent focus on the shortage of water and on climate-based threats to food and fibre production in the nation’s south have re-directed attention towards the possible use of northern water resources and the development of the agricultural potential in northern Australia. Broad analyses of northern Australia as a whole have indicated that it is capable of supporting significant additional agricultural and pastoral production, based on more intensive use of its land and water resources.

The same analyses also identified that land and water resources across northern Australia were already being used to support a wide range of highly valued cultural, environmental and economic activities. As a consequence, pursuit of new agricultural development opportunities would inevitably affect existing uses and users of land and water resources.

The Flinders and Gilbert catchments in north Queensland have been identified as potential areas for further agricultural development. The Flinders and Gilbert Agricultural Resource Assessment (the Assessment), of which this report is a part, provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of agricultural development in these two catchments as part of the North Queensland Irrigated Agricultural Strategy. The Assessment seeks to:

- identify and evaluate water capture and storage options
- identify and test the commercial viability of irrigated agricultural opportunities
- assess potential environmental, social and economic impacts and risks.

By this means it seeks to support deliberation and decisions concerning sustainable regional development.

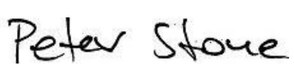
The Assessment differs from previous assessments of agricultural development or resources in two main ways:

- It has sought to ‘join the dots’. Where previous assessments have focused on single development activities or assets – without analysing the interactions between them – this Assessment considers the opportunities presented by the simultaneous pursuit of multiple development activities and assets. By this means, the Assessment uses a whole-of-region (rather than an asset-by-asset) approach to consider development.
- The novel methods developed for the Assessment provide a blueprint for rapidly assessing future land and water developments in northern Australia.

Importantly, the Assessment has been designed to lower the barriers to investment in regional development by:

- explicitly addressing local needs and aspirations
- meeting the needs of governments as they regulate the sustainable and equitable management of public resources with due consideration of environmental and cultural issues
- meeting the due diligence requirements of private investors, by addressing questions of profitability and income reliability at a broad scale.

Most importantly, the Assessment does not recommend one development over another. It provides the reader with a range of possibilities and the information to interpret them, consistent with the reader’s values and their aspirations for themselves and the region.



Dr Peter Stone, Deputy Director, CSIRO Sustainable Agriculture Flagship

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Shortened forms

AEM	airborne electromagnetics
AHD	Australian Height Datum
APSIM	Agricultural Production Systems Simulator
AWRC	Australian Water Resources Council
CGE	Computable General Equilibrium
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	digital elevation model
GCMs	global climate models
GCM-ES	global climate model output empirically scaled to provide catchment-scale variables
IPCC AR4	the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
IQQM	Integrated Quantity-Quality Model – a river systems model
Landsat TM	Landsat Thematic Mapper
MODIS	Moderate Resolution Imaging Spectroradiometer
NQIAS	North Queensland Irrigated Agriculture Strategy
NRM	natural resource management
ONA	the Australian Government Office of Northern Australia
OWL	the Open Water Likelihood algorithm
PAWC	plant available water capacity
PE	potential evaporation
RCP	representative concentration pathway
Sacramento	a rainfall-runoff model
SALI	the Soil and Land Information System for Queensland
SLAs	statistical local areas
SRTM	shuttle radar topography mission
TRaCK	Tropical Rivers and Coastal Knowledge Research Hub
WRON	CSIRO's Water Resource Observation Network

Units

MEASUREMENT UNITS	DESCRIPTION
GL	gigalitres, 1,000,000,000 litres
keV	kilo-electronvolts
kL	kilolitres, 1000 litres
km	kilometres, 1000 metres
L	litres
m	metres
mAHD	metres above Australian Height Datum
MeV	mega-electronvolts
mg	milligrams
ML	megalitres, 1,000,000 litres

Preface

The Flinders and Gilbert Agricultural Resource Assessment (the Assessment) aims to provide information so that people can answer questions such as the following in the context of their particular circumstances in the Flinders and Gilbert catchments:

- What soil and water resources are available for irrigated agriculture?
- What are the existing ecological systems, industries, infrastructure and values?
- What are the opportunities for irrigation?
- Is irrigated agriculture economically viable?
- How can the sustainability of irrigated agriculture be maximised?

The questions – and the responses to the questions – are highly interdependent and, consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports must be read as a whole if they are to reliably inform discussion and decision making on regional development.

The Assessment is producing a series of reports:

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the 12 research activities (outlined below) has a corresponding technical report.
- Each of the two catchment reports (one for each catchment) synthesises key material from the technical reports, providing well-informed but non-scientific readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture.
- Two overview reports – one for each catchment – are provided for a general public audience.
- A factsheet provides key findings for both the Flinders and Gilbert catchments for a general public audience.

All of these reports are available online at <http://www.csiro.au/FGARA>. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

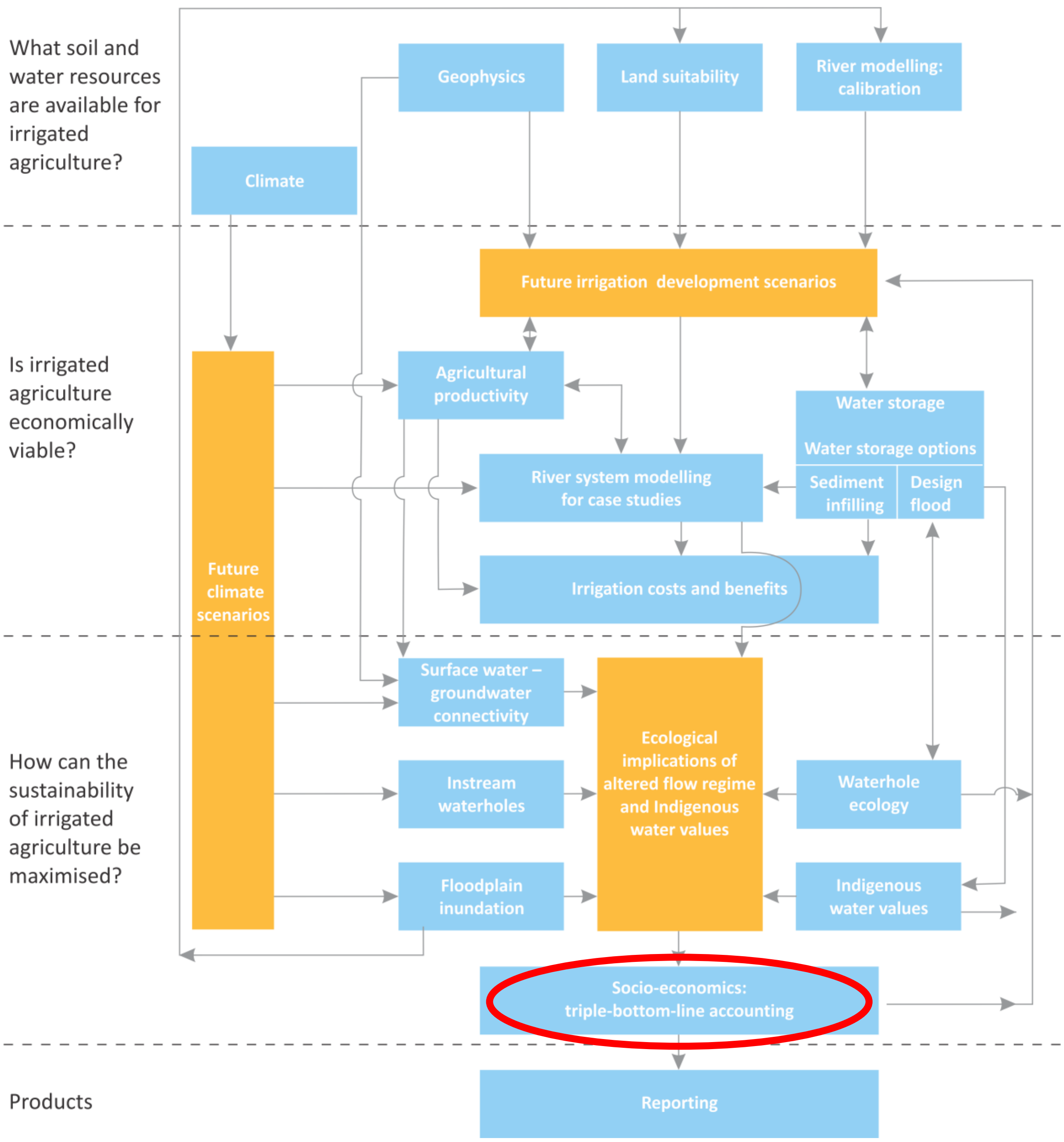
The Assessment is divided into 12 scientific activities, each contributing to a cohesive picture of regional development opportunities, costs and benefits. Preface Figure 1 illustrates the high-level linkages between the 12 activities and the general flow of information in the Assessment. Clicking on an 'activity box' links to the relevant technical report.

The Assessment is designed to inform consideration of development, not to enable particular development activities. As such, the Assessment informs – but does not seek to replace – existing planning processes. Importantly, the Assessment does not assume a given regulatory environment. As regulations can change, this will enable the results to be applied to the widest range of uses for the longest possible time frame. Similarly, the Assessment does not assume a static future, but evaluates three distinct scenarios:

- Scenario A – historical climate and current development
- Scenario B – historical climate and future irrigation development
- Scenario C – future climate and current development.

As the primary interest was in evaluating the scale of the opportunity for irrigated agriculture development under the current climate, the future climate scenario (Scenario C) was secondary in importance to scenarios A and B. This balance is reflected in the allocation of resources throughout the Assessment.

The approaches and techniques used in the Assessment have been designed to enable application elsewhere in northern Australia.



Preface Figure 1 Schematic diagram illustrating high-level linkages between the 12 activities (blue boxes)

This report is a technical report. The red oval in Preface Figure 1 indicates the activity (or activities) that contributed to this report.

The orange boxes indicate information used or produced by several activities. The red oval indicates the activity (or activities) that contributed to this technical report. Click on a box associated with an activity for a link to its technical report (or click on 'Technical reports' on <http://www.csiro.au/FGARA> for a list of links to all technical reports). Note that the Water storage activity has multiple technical reports – in this case the separate reports are listed under the activity title. Note also that these reports will be published throughout 2013, and hyperlinks to currently unpublished reports will produce an 'invalid publication' error in the CSIRO Publication Repository.

Executive summary

This report presents the methodology and results of the triple bottom line (TBL) assessment completed as part of the Flinders and Gilbert Agricultural Resource Assessment (FGARA). A TBL assessment of benefits and costs of a development typically includes monetary indicators describing environment and economy as well as broader social considerations.

The TBL assessment brings together a number of results and pieces of information from the FGARA project and uses a Bayesian Decision Network (BDN) as the tool estimate the utility of irrigation development in the Flinders and Gilbert catchments. Specifically, results from other activities in the FGARA project (land suitability, aquatic ecology and irrigation costs and benefits) are summarised for input into the BDN. A BDN has many properties that make them useful for performing a triple-bottom-line assessment, in particular their ease of construction; their ability to handle quantitative and qualitative data types; their preservation of system knowledge and; their ease of use in aiding decision making.

This report aims to:

1. Capture expert knowledge estimating potential impacts to aquatic and terrestrial ecosystems from irrigation development;
2. Survey regional stakeholders on their values associated with ecosystem services, their priorities for managing ecosystem services, and their preferences for irrigation development more broadly (i.e. social values);
3. Review and summaries the unit economic values of ecosystem services supplied by land and water ecosystems in the region, and;
4. Build a BDN that integrates results from 1-3 above to estimate the utility of irrigation development based on social, environmental and economic benefits and costs.
5. Identify and investigate scenarios that could increase the utility of irrigation development.
6. Discuss the institutional and natural resource management options that minimise trade-offs between irrigation development and ecosystem service impacts.

From the perspective of the TBL, the total utility of irrigation development is negative in both the Flinders and the Gilbert catchments. The explanation for the negative utility is that the negative impact to ecosystem service social and economic values is not balanced by the positive benefits of irrigation development. Irrigation development, if fully realised, will result in large areas of land use change, impacting on the supply of ecosystem services from the terrestrial land system. The benefit to ecosystem services supplied by the land system will be largely neutral to negative following irrigation development.

Diversion of water for irrigation and the subsequent alterations to hydrology and freshwater and riverine ecosystems, while not necessary large overall, will impact on the crucial dry-season pool refugia, as well as potentially impacting on riparian zones and estuarine environments. Results of the ecosystem services social surveys demonstrate that the ‘food production’ and ‘habitat for species’ ecosystem services were highly valued by respondents. The estuarine (prawns and fish) and in-stream fish food ecosystem services and the freshwater and terrestrial habitat ecosystem services are important components of the BDN model and the medium to high impact to them, plus their high social and economic value, contributes to the negative utility.

Thirdly, the negative utility is further explained by the low economic value at farm scale of irrigation development as demonstrated in the FGARA irrigation costs and benefits activity, and the high frequency of locations of relatively low land suitability for many irrigated crops. The irrigated agriculture potential estimated in the BDN model is therefore most likely to be low and the benefit for food production (crops and beef) is therefore neutral.

The overall utility of irrigation development in both the Flinders and the Gilbert catchments could enter positive territory in a number of scenarios: i) irrigation development is highly sensitive to the environment and there are no or very low environmental impacts, or ii) in addition to the absence of environmental impacts, much higher net economic returns to irrigators eventuate, possibly through higher commodity prices, lower capital costs of irrigation development or some combination of both.

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1 Introduction

This report presents the methodology and results of the triple bottom line (TBL) assessment completed as part of the Flinders and Gilbert Agricultural Resource Assessment (FGARA). A TBL assessment of benefits and costs of a development typically includes monetary indicators describing environment and economy as well as broader social considerations.

The TBL assessment brings together a number of results and pieces of information from the FGARA project and uses a Bayesian Decision Network (BDN) as the tool estimate the utility of irrigation development in the Flinders and Gilbert catchments. Specifically, results from the land suitability (Bartley *et al.* 2013), aquatic ecology (Burrows & Waltham 2013) and socio-economic costs and benefits (Brennan McKellar *et al.* 2013) activities are summarised for input into the BDN. A BDN has many properties that make them useful for performing a triple-bottom-line assessment (Haines-Young 2011; Chan *et al.* 2012), in particular their ease of construction; their ability to handle quantitative and qualitative data types; their preservation of system knowledge and; their ease of use in aiding decision making.

This chapter provides a brief description of the study area and a problem statement, followed by definition of concepts and terminologies used in the triple-bottom-line assessment: green accounting, ecosystem services and Bayesian Belief Networks. The next chapter provides a more detailed information and background to ecosystem services because this framework is central to the TBL assessment. That is followed by the chapter describing methods used in the TBL assessment, which is followed by the results chapter. The discussion and conclusion chapter wrap up the report.

1.1 Brief description of study regions

The more northern Gilbert catchment expands over nearly 47,000 km^2 around the Gilbert-Einasleigh river system (Figure 1.1). Depending on the intensity of the wet season, the Gilbert-Einasleigh River has the sixth-highest discharge of any river in Australia, and its runoff totals about 2.2% of the total runoff from the whole country. Both the Gilbert and the Einasleigh Rivers rise in ancient uplands to the west of the Atherton Tableland in northern Queensland and discharge in the Gulf of Carpentaria.

The more southern Flinders catchment (Figure 1.1) covers an area of approximately 100,000 km^2. It is bordered in the north by the Flinders River which, at around 1,000 km, is the longest river in Queensland and the sixth longest river in Australia. The river rises in the Burra Range, part of the Great Dividing Range, 110 km northeast of Hughenden and flows in a westerly direction past Hughenden, Richmond and Julia Creek then northwest to the Gulf of Carpentaria 25 km west of Karumba, Queensland. The south of the catchment is bordered by the Selwyn Range.

The Gilbert and Flinders catchments have a semi-arid tropical climate, with high incidence of monsoon variability and occasional severe cyclones. As a result, seasonality of rainfall is the most defining characteristic of the climate of both catchments, with 93% and 88% of rainfall occurring during the wet season (November to April inclusive) in the Gilbert and Flinders catchments, respectively. Spatially, mean annual rainfall varies from about 1050 mm on the coast in the north of the Gilbert catchment to about 650 mm in the south-east of the catchment, and from about 800 mm on the coast in the north of the Flinders catchment to about 350 mm in the south of the catchment (Petheram & Yang 2013).

Figure 1.1 Map of the northern Queensland gulf catchments, including Georgetown in the Gilbert catchment and Richmond in the Flinders catchment

1.2 Agricultural development in contemporary Australia

Historically, management of water resources and river ecosystems in northern Australia focussed predominantly on resource development (Jackson *et al.* 2008). In recent decades the community values associated with water resource development have changed and diversified. Jackson *et al.* (2008) demonstrate that unregulated healthy river systems make an important contribution to human well-being and cultural identity. People have strong attachments to tropical rivers and wetlands and ecological and aesthetic values compete with development-focussed values. Increasingly, local residents, recreational and commercial fishers, tourists and conservationists hold considerable amenity and lifestyle values for tropical rivers (Stoeckl *et al.* 2012) and communities are prepared to forgo direct private economic benefit to see healthy river systems that are managed for conservation and a broader set of benefits and values (Zander & Straton 2010; Zander *et al.* 2013).

There is growing acceptance in the use of more holistic frameworks to account for the impact on a broader values from land and water management decisions. One such accounting framework is the triple bottom line (TBL) assessment that has its origins in corporate reporting. The TBL concept of calculating benefits and costs on economic, social and natural capital from corporate (or broader) activities is central to the idea of a green economy. The TBL approach and the use of ecosystem services as an organising framework is described below.

1.3 Triple bottom line assessments and green economies

The concept of the green economy was first articulated nearly a quarter of a century ago by Pearce *et al.* (1989) who published *Blueprint for a Green Economy*. There is now a high-level interest in a *Global Green New Deal* and transitioning to a green economy (United Nations Environment Program 2011). The concept of a green economy is one which is resource and energy efficient, promotes human wellbeing (current and future generations) and social equity, and reduces environmental risks. The goal of a green economy is to provide greater protection for natural resources to ensure continued provision of ecosystem services.

A pillar in this shift is to adopt metrics of economic performance that take into account the scarcity and the condition of natural resources or natural capital (World Business Council for Sustainable Development 2010). Green accounting frameworks provide opportunity to incorporate sustainability criteria into common metrics of growth such as GDP. In 2012 the UN Statistical Commission adopted a standardised accounting method that provides a conceptual framework for integrating statistics on the environment and its relationship with the economy. This System of Environmental-Economic Accounting (SEEA) was developed in 1993 and amended in 2003 and includes experimental ecosystem accounting (United Nations Statistical Division 2012). Meanwhile, the World Bank is leading the Wealth Accounting and Valuation of Ecosystem Services (WAVES) partnership which aims to extend SEEA by applying ecosystem services and other natural resources accounting practices across 10 case study countries (World Bank 2012). The objective is to further develop green (i.e. triple bottom line) accounting protocols and to incorporate these into national policy and development planning. The widespread adoption of TBL assessments has the potential to be a significant force in moving towards a greener world economy.

1.4 Ecosystem services framework

Ecosystem services are the benefits people obtain from ecosystems (Costanza *et al.* 1997; Millennium Ecosystem Assessment 2005). These include:

- ‘provisioning services’ such as food and water
- ‘regulating services’ such as regulation of floods, drought, land degradation and disease
- ‘supporting services’ such as soil formation and nutrient cycling
- ‘cultural services’ such as recreational, spiritual, religious and other nonmaterial benefits.

The term ecosystem services first appeared in the early 1980s (Ehrlich & Ehrlich 1981). It was popularised by two publications in 1997 – the book *Nature's services* (Daily 1997) and a paper on valuing the services provided by global ecosystems published in Nature (Costanza *et al.* 1997). Ecosystem services were employed by the Millennium Ecosystem Assessment (MEA) – a four-year global effort involving more than 2000 experts – as its main conceptual framework to assess nature’s essential contribution to human wellbeing (Figure 1.2) (Millennium Ecosystem Assessment 2005). The MEA fundamentally changed the landscape in ecosystem service research by switching attention from ecological processes and function to the service itself (Perrings 2006).

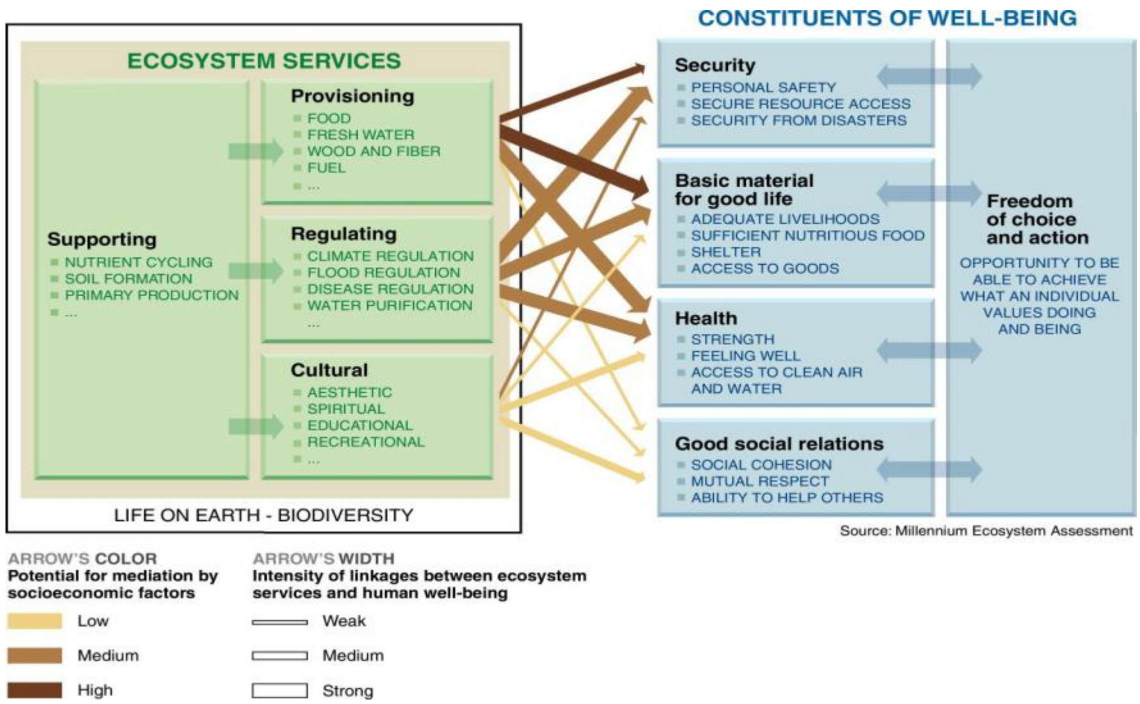


Figure 1.2 The contribution of ecosystem services to human wellbeing. Source: Millennium Ecosystem Assessment (2005)

More recently, The Economics of Ecosystems and Biodiversity (TEEB 2010), another major international initiative, also used the ecosystem services framework to draw attention to the global economic benefits of ecosystems and to highlight the growing costs of biodiversity loss and ecosystem degradation. Building on the MEA foundation, the TEEB project further developed a schematic representation to disentangle the pathway from ecosystems and biodiversity to human wellbeing. Figure 1.3 shows the pivotal link provided by ecosystem services between human wellbeing and ecological systems and how land and water management policy and decisions further impact on well-being. Ecosystem services bridge the divide between healthy and functioning ecosystems and the social and economic benefit we subsequently derive. An ecosystem that is unhealthy and has lost its functional integrity will supply few ecosystem services, resulting in lost benefit to society. An argument then exists to protect ecosystem health and integrity to ensure the services it supplies are maintained.

In Figure 1.3, functions represent the ‘potential’ that ecosystems have to deliver a service which in turn depends on the properties of the ecological such as structure and processes. Services are labels of the ‘useful things’ ecosystems provided for people, directly and indirectly (TEEB 2010). Through governance, policy and land [and water] management, the private and public sectors make decisions that influence either the functions or services. The difference between processes, functions and services can be demonstrated by using a couple of examples of freshwater ecosystems. The process of photosynthesis and primary production in grasslands (function) is required to maintain a viable herbivore population which can be harvested to provide food (a type of provisioning services). Nutrient cycling (process) is needed for water purification (function) to provide clean water (another provisioning service). Photosynthesis and primary production sequester carbon which regulates atmospheric greenhouse gases and climate (a type of regulating services).

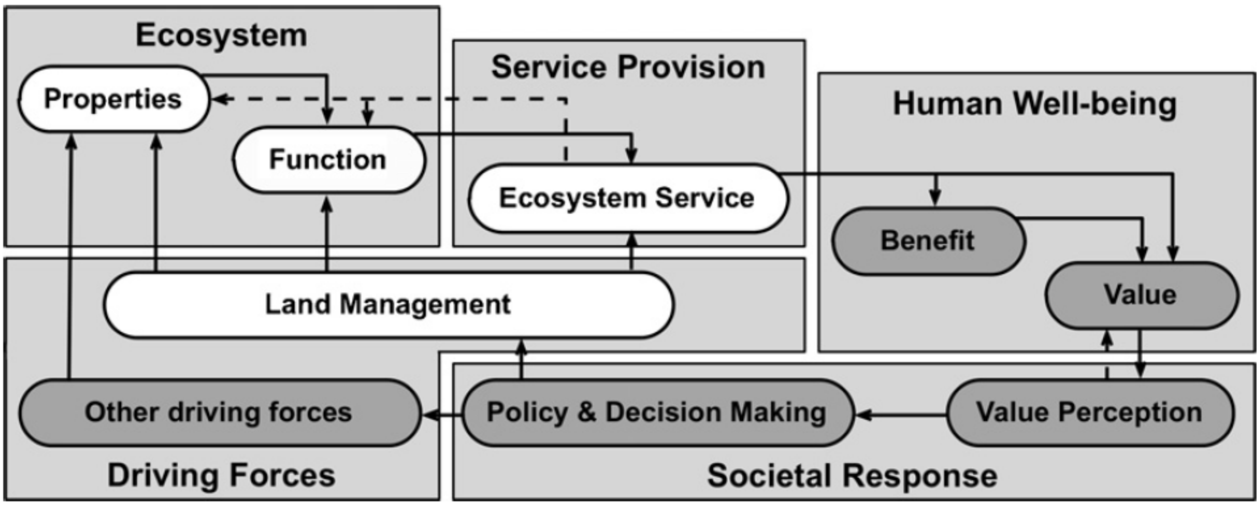


Figure 1.3 Framework linking management and decision-making to ecosystem functions to human wellbeing, with ecosystem services as the bridging link. Source: van Oudenhoven *et al.* (2012)

1.5 Bayesian Networks

Bayesian networks are graphical models consisting of a set of interconnected nodes and arcs (or arrows) incorporated with probability tables. Nodes represent discrete or continuous variables (referred to as 'Nature' nodes), while arcs represent causal relationships between variables. A Bayesian network graph structures a problem such that it is visually interpretable by stakeholders and decision-makers while serving as an efficient means for evaluating the probable outcomes of management decisions on selected variables (Chen & Pollino 2012). Bayesian networks can be used to integrate different forms of evidence, particularly in relating the potential outcomes of management interventions to a defined set of endpoints. In natural resource management, Bayesian networks are increasingly becoming a modelling platform of choice.

A notable strength of Bayesian networks relative to other modelling platforms is their ability to investigate the impacts of multiple factors in complex environments, including integration problems (Ticehurst *et al.* 2007; Barton *et al.* 2008; Molina *et al.* 2010). Bayesian networks are inherently adaptable, allowing new information to be incorporated with ease and efficiency. They also allow different types of information to be integrated into a single framework, and multiple, complex scenarios to be run. Bayesian networks most evident limitations are a tendency to overemphasise expert opinion and the potential for large networks to become unmanageable (Uusitalo 2007). Bayesian Decision Networks (BDNs) incorporate 'Decision' nodes, and 'Utility' nodes. Decision nodes represent two or more choices that a manager can take which can influence the values of other nodes. Utility nodes in BDNs are a way of explicitly representing the value, either cost or benefit, of some outcome or decision within the network of each possible outcome state, describing the relevant expected cost or benefit for every possible combination of input states (Pollino & Henderson 2010).

1.6 Aims and objectives

The aim of this report is to develop and apply a model framework that attempts to integrate a number of analyses to evaluate the interactions between biophysical changes and irrigation development (from other parts of the FGARA project) with socio-economic data collected here and in the other socio-economic activity report (Brennan McKellar *et al.* 2013) for TBL assessment. Here a TBL assessment is defined as the overall utility of irrigation development given the potential impacts to ecosystem services as well as potential costs and benefits to society from development (e.g. regional economic growth, employment). The ecosystem services framework is used to organise and describe the impact of potential water resource development on the wider set of ecosystem values now generally accepted as being important within the context of northern Australian river systems (Jackson *et al.* 2008). The BDN model is used to integrate the social, economic and ecosystem service / natural capital benefits and costs because the BDN is a very flexible model that can integrate many data sources and types, both quantitative and qualitative/probabilistic. The BDN has a number of advantages over the use other decision support models in water resource planning, as described in Castelletti and Soncini-Sessa (2007) and Chen and Pollino (2012)

Specifically, this report aims to:

7. Capture expert knowledge estimating potential impacts to aquatic and terrestrial ecosystems from irrigation development;
8. Survey regional stakeholders on their values associated with ecosystem services, their priorities for managing ecosystem services, and their preferences for irrigation development more broadly (i.e. social values);
9. Review and summaries the unit economic values of ecosystem services supplied by land and water ecosystems in the region, and;
10. Build a BDN that integrates results from 1-3 above to estimate the utility of irrigation development based on social, environmental and economic benefits and costs.
11. Identify and investigate scenarios that could increase the utility of irrigation development.
12. Discuss the institutional and natural resource management options that minimise trade-offs between irrigation development and ecosystem service impacts.

2 Ecosystem service values and their use in water management

2.1 From ecology to economic value

2.1.1 DEFINITIONS

Clarity on definitions of ecosystem services is necessary for the robust valuation and accounting of ecosystem services in water management. There has been a lot of recent activity (de Groot *et al.* 2002; Boyd & Banzhaf 2007; Wallace 2007; Fisher *et al.* 2009; van Oudenhoven *et al.* 2012) in improving the definition and classification of ecosystem services so that the concept can be operationalised in decision-making (see Box 1). The favoured approach to valuing ecosystem services in accounting processes such as Green GDP is to value *final* services that provide benefit to humans exclusive of other forms of capital. It is argued that *final* services should only be valued to avoid double counting (Boyd & Banzhaf 2007; Fisher *et al.* 2008; Fisher *et al.* 2009; Bateman *et al.* 2011). There are also ecosystem services that are called *intermediate* services which provide the support (or means) toward the *final* services. The *intermediate* services are commensurate with the *ecosystem function* terminology used in de Groot et al (2002), TEEB (2010) and van Oudenhoven et al (2012) whereby the ecosystem function is the capacity of ecosystems to provide a service, also called supply, and the *ecosystem service* is the contribution to well-being (commensurate with the *final* services).

2.1.2 TYPOLOGIES

Building on the typologies used in the seminal papers by (Costanza *et al.* 1997) and (de Groot *et al.* 2002), the MEA classified ecosystem services into four major categories: i) provisioning; ii) regulating; iii) cultural, and; iv) supporting (Figure 1.2). More recently, for the purposes of economic valuation and the need to avoid double counting and only value final services, the TEEB (2010) study omitted the MEA supporting services category. The supporting services are a subset of ecological processes and functions and therefore do not have direct economic value because they are a means (e.g. primary production) to an end (e.g. herbivore for food). Instead the TEEB (2010) introduce a category of habitat services to highlight the importance of ecosystems to provide habitat for migratory species (e.g. migratory species) and maintaining the vitality of the gene-pool. Habitat services provide direct economic value when, for example, commercial fish spawn in mangroves at some distance from where they are fished. Habitat also provides direct economic value through the vast array of genetic material that could be used to improve the genotypes of the major global food crops.

The exponential growth in interest in ecosystem services, as evidence by the sharp increase in scientific publications and national and global policy and supporting documentation, calls for standardisation of classification systems. National governments, with the support of global organisations such as the World Bank and the United Nations Statistical Division, are developing a more rigorous classification system for incorporating ecosystem services into environmental-economic accounts such as Green GDP. The Common International Classification of Ecosystem Services (CICES) is a framework currently under development (European Environment Agency 2012) that describes ecosystem services using a five-level hierarchical structure:

- Section (e.g. Provisioning)
- Division (e.g. Water supply)
- Group (e.g. Water for agricultural use)
- Class (e.g. Irrigation water)

- Class type (e.g. Abstracted ground water).

Box 1: Ecosystem Service Definitions

Ecosystem services: contributions of ecosystem structure and function – in combination with other inputs – to human well-being (Burkhard *et al.* 2012a).

Ecosystem processes: changes or reactions occurring in ecosystems; either physical, chemical or biological; including decomposition, production, nutrient cycling and fluxes of nutrients and energy (Millennium Ecosystem Assessment 2005).

Ecosystem structures: biophysical architecture of ecosystems; species composition making up the architecture may vary (TEEB 2010).

Ecosystem functions: are intermediate between ecosystem processes and services and can be defined as the capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly (de Groot *et al.* 2010)

Intermediate ecosystem services: biological, chemical, and physical interactions between ecosystem components. E.g., ecosystem functions and processes are not end-products; they are intermediate to the production of final ecosystem services (Boyd & Banzhaf 2007).

Final ecosystem services: depending on their degree of connection to human welfare, ES can be considered as intermediate or as final services (Fisher *et al.* 2009).

Ecosystem service supply: refers to the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period (Burkhard *et al.* 2012b). Depends on different sets of landscape properties that influence the level of service supply (Willemen *et al.* 2012).

Ecosystem service demand: is the sum of all ecosystem goods and services currently consumed or used in a particular area over a given time period (Burkhard *et al.* 2012b).

Ecosystem service trade-offs: The way in which one ecosystem service responds to a change in another ecosystem service (Millennium Ecosystem Assessment 2005).

2.1.3 VALUING ECOSYSTEM SERVICES

Ecosystem service valuation is the process of assessing the contribution of ecosystem services to meeting a particular goal or goals. In economics this goal is efficient allocation, that is, to allocate scarce ecosystem services among competing uses such as development and conservation (Liu *et al.* 2010).

There are several different types of values, starting at total economic value (TEV) which is an all-encompassing measure of the economic value of any environmental asset (Pearce *et al.* 2006). TEV is divided into use and non-use values with further sub-classifications of direct use values, indirect use values, options values, bequest values and existence values. Figure 2.1 shows the classification system of TEV and also gives the definitions of each type of value.

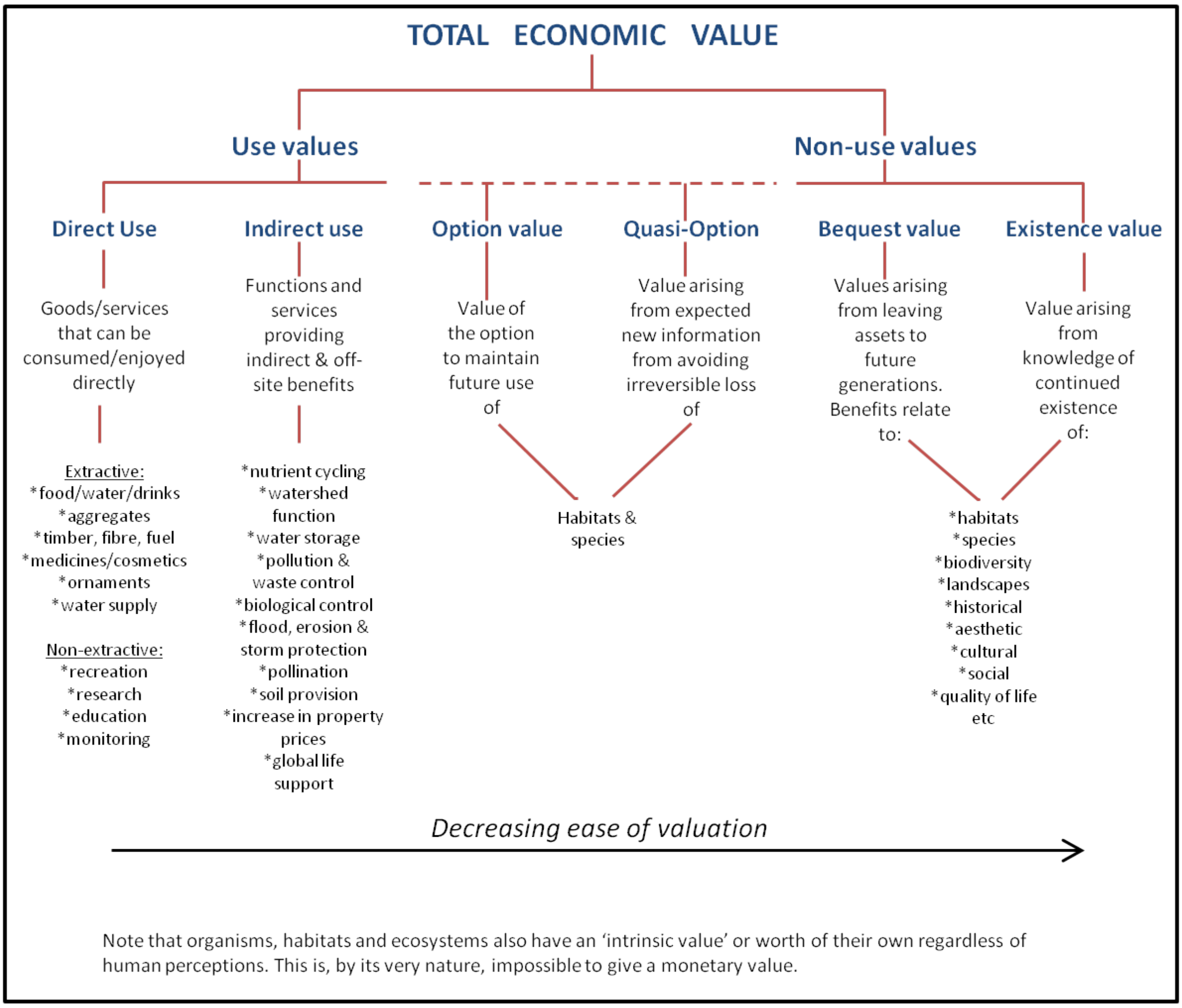


Figure 2.1 The different values included in the concept of Total Economic Value.

Many economic valuation methods are available for calculating the different values shown in Figure 2.1, a few of which have been around for some time. Around 50 years ago economists developed techniques such as travel cost (Clawson 1959) and contingent valuation (Davis 1963) and proposed the concepts of option value (Weisbrod 1964) and existence value (Krutilla 1967). However, moving from left to right in Figure 2.1, the valuation methods are well established and widely available for use values but become more difficult to define and measure for non-use values. Non-use values a more difficult to estimate because they often are not reflected in market transactions and they accrue to a broad set of beneficiaries (e.g. cultural landscapes). On the other hand, direct use values are measured by the benefits to individuals and therefore are easier to measure because in many cases the good or service is traded through a market (e.g. food).

Ecosystem services that have no obvious market are subject to market failure in which the market cannot send the correct price signals to determine the appropriate provision of ecosystem services (Farley 2008). A spectrum of non-market valuation techniques have been developed to value ecosystem services, including both non-monetary valuation methods and economic valuation techniques based on a monetary metric (Freeman III 2003; National Research Council 2005) (Table 2.1).

While non-monetary valuation methods are very important, the focus of valuation has been heavily skewed toward monetary approaches because the measurement of economic value of ecosystem services can be an effective way to weigh trade-offs between development and conservation (Costanza *et al.* 1997; Farber *et al.* 2002; National Research Council 2005). In addition, monetary valuation is arguably the only way to incorporate values of ecosystem services into cost–benefit analysis, currently the most dominant decision-making framework.

Monetary and non-monetary valuation approaches can be used together for decision support. Alternative decision-making procedures do exist; for instance, cost-effectiveness analysis and multi-criteria analysis. In general, only multi-criteria analysis is as comprehensive as cost-benefit analysis and may be more comprehensive because broader values can be included that overcome the problems associated with distributional equity and market efficiencies often found with monetary values (Pearce *et al.* 2006).

Table 2.1 Ecosystem service valuation methods. Source: Liu *et al.* (2010)

Monetary valuation
Revealed preference approaches
Market methods: Valuations are directly obtained from what people must be willing to pay for the service or good (e.g. timber harvest).
Travel cost: Valuations of site-based amenities are implied by the costs people incur to enjoy them (e.g. cleaner recreational lakes).
Hedonic methods: The value of a service is implied by what people will be willing to pay for the service through purchases in related markets, such as housing markets (e.g. open-space amenities).
Production approaches: Service values are assigned from the impacts of those services on economic outputs (e.g. increased shrimp yields from increased area of wetlands).
Stated preference approaches
Contingent valuation: People are directly asked their willingness to pay or accept compensation for some change in ecological service (e.g. willingness to pay for cleaner air).
Conjoint analysis: People are asked to choose or rank different service scenarios or ecological conditions that differ in the mix of those conditions (e.g. choosing between wetlands scenarios with differing levels of flood protection and fishery yields).
Cost-based approaches
Replacement cost: The loss of a natural system service is evaluated in terms of what it would cost to replace that service (e.g. tertiary treatment values of wetlands if the cost of replacement is less than the value society places on tertiary treatment).
Avoidance cost: A service is valued on the basis of costs avoided, or of the extent to which it allows the avoidance of costly averting behaviours, including mitigation (e.g. clean water reduces costly incidents of diarrhoea).
Benefit transfer: The adaptation of existing ecosystem service valuation information or data to new policy contexts that have little or no data (e.g. ecosystem service values obtained by tourists viewing wildlife in one park used to estimate that from viewing wildlife in a different park).
Non-monetary valuation or assessment
Measures of attitudes, preferences and intentions
Civic valuation
Decision science approaches
Ecosystem benefit indicators
Biophysical ranking methods

2.1.4 THE WORTH OF ECOSYSTEM SERVICES

The 1989 Exxon Valdez oil spill was a prominent case where non-use (e.g. intrinsic) values of the environment were estimated by contingent valuation and used in a quantitative assessment of damages. Prior to the spill, the methodology was not a well-developed area of research. After the widely publicised oil spill, the attention given to the conceptual underpinnings and estimation techniques for non-use value increased dramatically (Carson *et al.* 2003).

In the 1990s, Gretchen Daily's book *Nature's services* (Daily 1997) and the (Costanza *et al.* 1997) paper on valuing the services provided by global ecosystems published in *Nature* popularised the ideas of ecosystem services and valuation. *Nature's services* brought together world-renowned scientists from a variety of disciplines to present a detailed synthesis of the latest understanding of a suite of ecosystem services and a preliminary assessment of their economic value. Robert Costanza and his colleagues published the often-cited paper in *Nature* on valuing the services provided by global ecosystems. They estimated that the annual value of 17 ecosystem services for the entire biosphere was US$33 trillion. More recently, the TEEB

(2010) study calculated the annual value of ecosystem services supplied by 10 biome across the globe, and TEEB has been followed by ecosystem services valuation projects at national and regional levels, for instance, in the United Kingdom (UK National Ecosystem Assessment 2011). These are discussed in more detail in Section 2.2.

One of the major efforts of TEEB (2010) was to build a database of economic valuations studies of the environment which has subsequently been published in (de Groot *et al.* 2012). The database consists of approximately 700 published values of ecosystem services supplied by the Earth's 10 broad aquatic and terrestrial biomes. Each published value was standardised to a common currency (2007 US$), areal measure (ha), and timeframe (annual), giving in effect a marginal value for each ecosystem service supplied by each biome (de Groot *et al.* 2012) (Table 2.2). The database also contains information on the original study (e.g. specific location, valuation method) to enable values to be sensibly used within a benefit transfer ecosystem service valuation exercise.

From Table 2.2 it is clear that ecosystem services supplied annually by coral reefs and coastal wetlands have the greatest economic value per hectare. The high value of coral reefs is driven by erosion prevention (principally protection from storms) and recreation services they provide. The high value of coastal wetlands is driven almost exclusively by the waste treatment services they provide. The lowest economic value per hectare of annual ecosystem service supply is from the marine environment and woodlands.

Table 2.2 Summary of monetary values for each service per biome (values in US$/ha/year, calibrated for 2007). Source: de Groot *et al.* (2012)

Service (from TEEB typology)	Marine	Coral reefs	Coastal systems	Coastal wetlands	Inland wetlands	Fresh water (rivers/lakes)	Tropical forest	Temperate forest	Woodlands	Grasslands
Provisioning services	**102**	**55,724**	**2,396**	**2,998**	**1,659**	**1,914**	**1,828**	**671**	**253**	**1,305**
Food	93	677	2,384	1,111	614	106	200	299	52	1,192
Water				1,217	408	1,808	27	191		60
Raw materials	8	21,528	12	358	425		84	181	170	53
Genetic resources		33,048		10			13			
Medicinal resources				301	99		1,504			1
Ornamental resources		472			114				32	
Regulating services	**65**	**171,478**	**25,847**	**171,515**	**17,364**	**187**	**2,529**	**491**	**51**	**159**
Air quality regulation							12			
Climate regulation	65	1,188	479	65	488		2,044	152	7	40
Disturbance moderation		16,991		5,351	2,986		66			
Regulation of water flows					5,606		342			
Waste treatment		85		162,125	3,015	187	6	7		75
Erosion prevention		153,214	25,368	3,929	2,607		15	5	13	44
Nutrient cycling				45	1,713		3	93		
Pollination							30		31	
Biological control					948		11	235		
Habitat services	**5**	**16,210**	**375**	**17,138**	**2,455**	**0**	**39**	**862**	**1,277**	**1,214**
Nursery service		0	194	10,648	1,287		16		1,273	
Genetic diversity	5	16,210	180	6,490	1,168		23	862	3	1,214
Cultural services	**319**	**108,837**	**300**	**2,193**	**4,203**	**2,166**	**867**	**990**	**7**	**193**
Aesthetic information		11,390			1,292					167
Recreation	319	96,302	256	2,193	2,211	2,166	867	989	7	26
Inspiration		0			700					
Spiritual experience			21							
Cognitive development		1,145	22					1		
Total economic value	**491**	**352,249**	**28,917**	**193,845**	**25,682**	**4,267**	**5,264**	**3,013**	**1,588**	**2,871**

2.2 Applications of the ecosystem services framework in water management and beyond

2.2.1 APPLICATIONS FROM AUSTRALIA

2.2.1.1 GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

A detailed assessment of the ecosystem services supplied within the Goulburn Broken Catchment Management Authority (GBCMA) in northern Victoria was completed as part of a collaboration between CSIRO and various public and academic institutions. The collaboration, known as the Ecosystem Services Project (www.ecosystemservicesproject.org/index.htm), was funded by a grant from the philanthropic Myer Foundation and ran from 1999 to 2003.

The major outputs of the ecosystem services assessment in the GBCMA were a stock take of the ecosystem services (Binning *et al.* 2001) and a testing of methods to quantify levels of biophysical production of ecosystem services from selected land uses in the catchment (Abel *et al.* 2003). The project was the first of its kind to evaluate the concept of ecosystem services in Australia, and to develop and test methods for quantifying ecosystem services. Another major goal of the project was effective communication to raise awareness of ecosystem services and influence policy and decision making at regional, state and national scales. The project was successful in raising awareness, with a number of federal and state government agencies launching programs on the back of the findings of the GBCMA ecosystem services assessment. Initiatives that followed include the New South Wales Environmental Services Scheme (www.environment.nsw.gov.au/salinity/opportunities/marketing.htm) and the Federal Government Market-based Instruments Pilot Program (www.marketbasedinstruments.gov.au/). Ecosystem services are now integral to the strategic planning and investment activities of the GBCMA as a consequence of the project (http://www.gbcma.vic.gov.au/default.asp?ID=land_and_biodiversity).

2.2.1.2 VICTORIAN ECOTENDER

In 2006 the State Government of Victoria introduced EcoTender (Department of Sustainability and Environment 2012b), a policy instrument that pays landowners for on-ground works that provide multiple environmental benefits. While not sold as an 'ecosystem services payment' (Wunder *et al.* 2008), the EcoTender program prioritises payment to native vegetation management activities that provide multiple ecosystem service benefits, namely habitat, water quality and quantity improvements and carbon sequestration. EcoTender uses a competitive tender process whereby landowners submit bids for the amount they want to be paid for their on-ground works. The environmental benefits provided by the proposed work are quantified using various biophysical modelling tools, and then scored to create a single metric of benefit. The benefit to cost ratio of the bid then determines its rank relative to other bids, and the bids that achieve the greatest environmental benefit for least cost are funded.

The EcoTender pilot run in 2006 funded 31 separate landowner proposals ('bids'), with 30 demonstrating two or more ecosystem service outcomes. A further three EcoTenders were run over the period from 2008 to 2010, allocating approximately AU$4 million directly to land owners for on-ground works that enhance multiple ecosystem services. EcoTender is one of a number of Victorian State Government programs under the banner of EcoMarkets, all of which create market-based incentives for private landowners to undertake various actions on their land that enhance the supply of ecosystem services (Department of Sustainability and Environment 2012a). The other programs, which include BushTender and BushBroker, have a narrower focus on the single 'habitat' ecosystem service. The EcoMarkets initiative has been allocated AU$14 million by the Victorian Government to be spent on on-ground works.

2.2.1.3 SEQ CATCHMENTS

SEQ Catchments is a community-based non-profit organisation whose aim is to protect and restore the natural environment in south-east Queensland. The organisation aims to partner with local, state and federal governments, businesses and the community to sustainably manage natural resources primarily through brokerage and networking activities. Their activities and investments are guided by a NRM Plan, a Regional Plan and Strategic Investment Plan. A major source of the income for SEQ Catchments comes from government, especially the Australian Government's Caring for our Country program. SEQ Catchments also receives considerable income from the private sector. One of the key programs of SEQ Catchments is implementation of an ecosystem services framework to inform their planning and investment decision making (www.seqcatchments.com.au/ecosystem_services.html).

The SEQ Catchments ecosystem services program is focused on mapping ecosystem services and their beneficiaries, and evaluating the economic benefits of ecosystem services. They have received financial support from all three levels of government and at time of writing have developed a large knowledge base (primarily maps) of the spatial extent of ecosystem services supplied within the SEQ Catchments jurisdiction (Maynard *et al.* 2010).

2.2.1.4 MULTIPLE BENEFITS OF THE MURRAY-DARLING BASIN PLAN

The Murray-Darling Basin Authority, the institution charged with managing water in the Basin, commissioned the Multiple Benefits of the Basin Plan project (CSIRO 2012) to estimate the ecological and economic benefits to the Basin from reducing the amount of water that can be diverted from the river system for irrigation. The water resources of the Murray-Darling Basin in southeast Australia have a long history of exploitation and diversion for agriculture. The consequence is the substantial decline in the condition of ecosystems that depend on the water in the Basin. The decine has been compounded by the recent 10-year drought, which saw the lowest inflows of water into the system since records began. The Australian Government has responded by introducing the Water Act (2007) that, among other things, will reduce the amount of surface water that can be diverted for irrigated agriculture. The reduction in diversions will be gradually implemented in the coming decade, but could come at a cost through reductions in the amount of irrigated agricultural output.

Using an ecosystem services framework, the economic benefits were calculated, with the hydrological and ecological benefits providing the biophysical basis for the economic assessments. The Multiple Benefits of the Murray-Darling Basin Plan project involved authors of the present report, and has been lauded as the first major attempt in Australia to calculate the impacts of a policy decision on ecosystem services (Pittock *et al.* 2012).

The project linked biophysical changes resulting from the reduced diversions to the economic benefits of changes in natural capital stocks and provision of ecosystem services. The project concluded that the benefit of returning more water to the wetlands and floodplains of the Murray-Darling river system is worth in the order of AU$4 billion to AU$9 billion in improved supply of ecosystem services (CSIRO 2012).

2.2.2 INTERNATIONALLY

2.2.2.1 THE MILLENNIUM ECOSYSTEM ASSESSMENT AND THE ECONOMICS OF ECOSYSTEMS AND BIODIVERSITY

The MEA (2005) documented the condition and trend of ecosystem services globally. Involving many hundreds of biophysical scientists from around the world, the MEA identified and then quantified the various ecosystem services supplied by ten broad biomes that cover the Earth's surface. However, the absence of economic valuation of ecosystem services in the MEA spurned the TEEB (2010) study that brought together a large number of social scientists and economists to estimate the value of ecosystem services: The TEEB (2010) identified 22 ecosystem services that could be sensibly valued because they provide direct benefit to human wellbeing, i.e. they can be thought of as final ecosystem services (Boyd & Banzhaf 2007). The ecosystem services valued for each biome are listed in Table 2.2. The typology of ecosystem services valued by the TEEB (2010) is consistent with those quantified by the MEA, but with one notable exception. The 'supporting' category in the MEA is dropped because supporting ecosystem services are indirect or intermediate (Boyd & Banzhaf 2007) and in its place is the 'habitat' category of ecosystem services, which includes gene pools and habitat for important species such as migratory birds and endangered wildlife.

In addition to the ecosystem services valuation database (TEEB 2010; de Groot *et al.* 2012), outputs of TEEB for use in decision making include guides on how to incorporate ecosystem service values into international and national (TEEB 2011b) or local and regional (TEEB 2011a) policy making and into private sector business operations (TEEB 2012).

2.2.2.2 UNITED KINGDOM'S NATIONAL ECOSYSTEM ASSESSMENT

The United Kingdom's National Ecosystem Assessment (UKNEA) has documented the condition and trend of ecosystem services supplied by the nation's eight broad aquatic and terrestrial habitat types (UK National Ecosystem Assessment 2011). The UKNEA also valued ecosystem services to estimate the nation's natural wealth to better inform future decision making. The UKNEA involved more than 500 natural scientists, economists, social scientists and stakeholders from government, academia, non-government organisations and the private sector and the work was undertaken between mid-2009 and early 2011. In addition to detailed accounting and valuations of ecosystem services, the intention of the UKNEA is to better understand historical and future drivers of change in the condition of ecosystem services. Furthermore, the UKNEA aimed to encourage better integration of the natural and social sciences and use the findings to raise awareness of the importance of the natural environment to human wellbeing and prosperity.

The UKNEA, while using MEA ecosystem services typology has made some notable advances on the MEA. Like the TEEB (2010), the UKNEA valued only the 'final' services that provide direct benefit to human wellbeing to overcome the double-counting critique often directed toward efforts to value ecosystem services. The UKNEA has also simplified the complex role biodiversity plays in underpinning ecosystem services. They identify biodiversity as a key element of the nation's natural heritage and, because biodiversity provides pleasure to many people, the UKNEA treats biodiversity as an explicit cultural service called 'wild species diversity' (Figure 2.2). The results of the UKNEA identified only a small number of ecosystem services that are improving in condition (Figure 2.2), demonstrating the importance of accounting for and valuing ecosystem services. The omission of ecosystem services in decision making in the UK may be a significant reason for the demise of many services.

2.2.2.3 US ENVIRONMENTAL PROTECTION AGENCY

In 2003, the US Environmental Protection Agency (USEPA) instructed their Science Advisory Board to review the concept of ecosystem services and the role valuing ecosystem services could play in the USEPA's decision making. Specifically, the USEPA was motivated to strengthen the scientific basis of their decisions. The 2009 review (US Environmental Protection Agency Science Advisory Board, 2009) recommended the USEPA value all relevant ecosystem services, develop new approaches to measure the impact of the USEPA's actions on ecosystem services, and use a wider range of valuation methods than previously employed, including methods outside the economics discipline.

The USEPA has an operational goal of providing management and policy makers the tools and resources to use when making decisions that impact ecosystem services (Rick Linthurst, USEPA, pers. comm.). The Agency now invests approximately US$70 million annually in ecosystem services related research (www.epa.gov/ecology/).

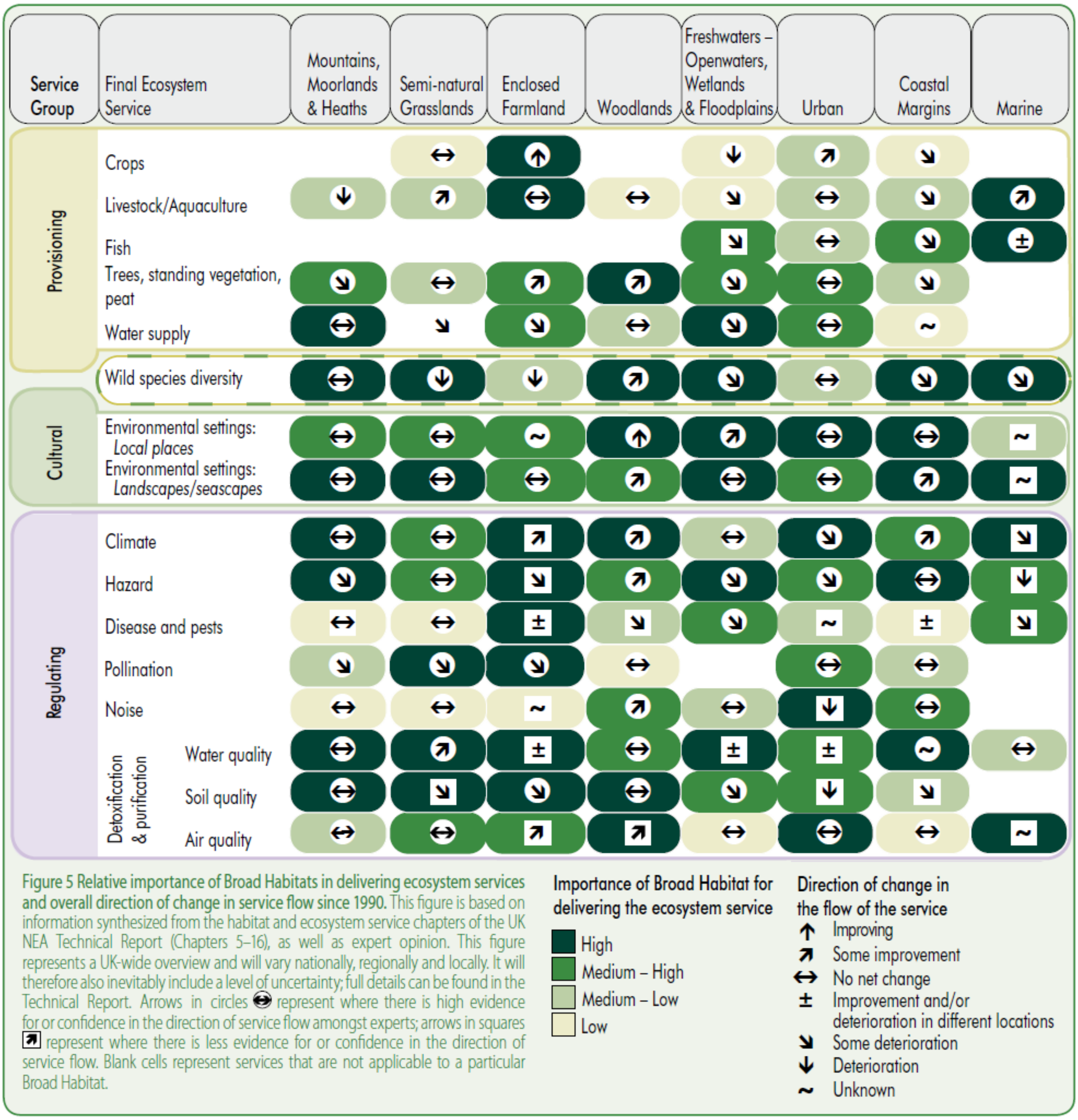


Figure 2.2 Summary of the United Kingdom's National Ecosystem Assessment ecosystem service condition and trend, and level of importance of each broad habitat in delivering the service. Source: UK National Ecosystem Assessment (2011)

3 Methods

3.1 Construction of the Bayesian Decision Net

3.1.1 WHY A BAYESIAN DECISION NET

A Bayesian Decision Net (BDN) was chosen as a decision support tool for estimating the utility of water resource development in the Flinders and Gilbert catchments. The BDN has a number of advantages of other decisions support tools (Castelletti & Soncini-Sessa 2007; Uusitalo 2007), including their ability to integrate quantitative and qualitative data, and ease of use in participatory model settings, which is important here given the dependence on qualitative expert opinion. BDNs are also very flexible and provide a good communication and visualisation tool.

3.1.2 BASIC MODEL COMPONENTS

The objective of the Bayesian network is typically encapsulated in how the model predictor is defined. In this study, the objective is defined as utilities, expressed as benefits and costs across use values, ecological features and productive (economic) benefits and costs. These are combined to express a total utility. The structure of the network is defined to provide the input to deriving the outcomes for these.

A typical BDN has three elements (from Cain (2001)):

1. A set of nodes representing system variables, each with a finite set of mutually exclusive states;
2. A set of links representing causal relationships between nodes, and;
3. A set of probabilities, one for each node, specifying the specific state of a node given the state of its parent nodes

Elements 1 and 2 for the BDN diagram and element 3 is the data within the BDN. The probabilities for each node, known formally as Conditional Probability Table (CPT) for a node, will contain entries for every possible combination of the states of the parent nodes. Once every CPT has been completed using modelled data, empirical data or expert knowledge, the BDN can be compiled. Post-evaluation, the model can be used for analysis of scenarios.

3.1.3 CONCEPTUAL MODEL DEVELOPMENT

A useful early step in constructing a BDN model is to develop a conceptual model that documents the basic logic of the system being investigated, including the causal linkages between important components of the system. A recent review of the application of BDN models to ecosystem service modelling and assessments (Landuyt *et al.* 2013) argues that the ecosystem service cascade diagram that links a change in biophysical condition to change in ecosystem services and then economic value from a management action or external driver (Figure 1.3), provides a good basis for developing conceptual models for BDN. The cascade diagram is therefore used here as the central structure for the flow of information in the BDN and TBL assessment.

The conceptual diagram underpinning the BDN is shown in Figure 3.1. The diagram begins with the decision variable, which in the present case is the development of water resources for irrigation in the Flinders or Gilbert catchments. Irrigation development may have impacts on land and water ecosystems (‘Biophysical impact’ in Figure 3.1), but development may also have direct social and economic benefit (‘Socio-economic benefit’ in Figure 3.1). The impacts on biophysical structure and process may have subsequent impact on ecosystem function (‘Ecosystem impact’ in Figure 3.1) which in turn may impact on ecosystem services that are supplied by and supported by the ecosystem functions (‘Ecosystem service impact’ in Figure 3.1). The level of benefit (or cost if the impact is negative) to ecosystem services is a function of the biophysical change and the economic and social value of the ecosystem service impacted ('Ecosystem service benefit' in Figure 3.1). For example, if there is a large negative impact on an ecosystem service which very few if any people value either in economic or broader social terms, then arguably the ecosystem service benefit is neutral or negligible because there are no beneficiaries. Therefore data that describes the economic and social value of ecosystem services is an important set of information into the BDN ('Social and economic value of ecosystem services' in Figure 3.1). Finally, the overall utility of irrigation development is estimated by the model ('Utility of development in Figure 3.1). Section 3.2 and Section 3.3 describe in detail the methods for populating the biophysical impacts and social and economic value of ecosystem services, respectively.

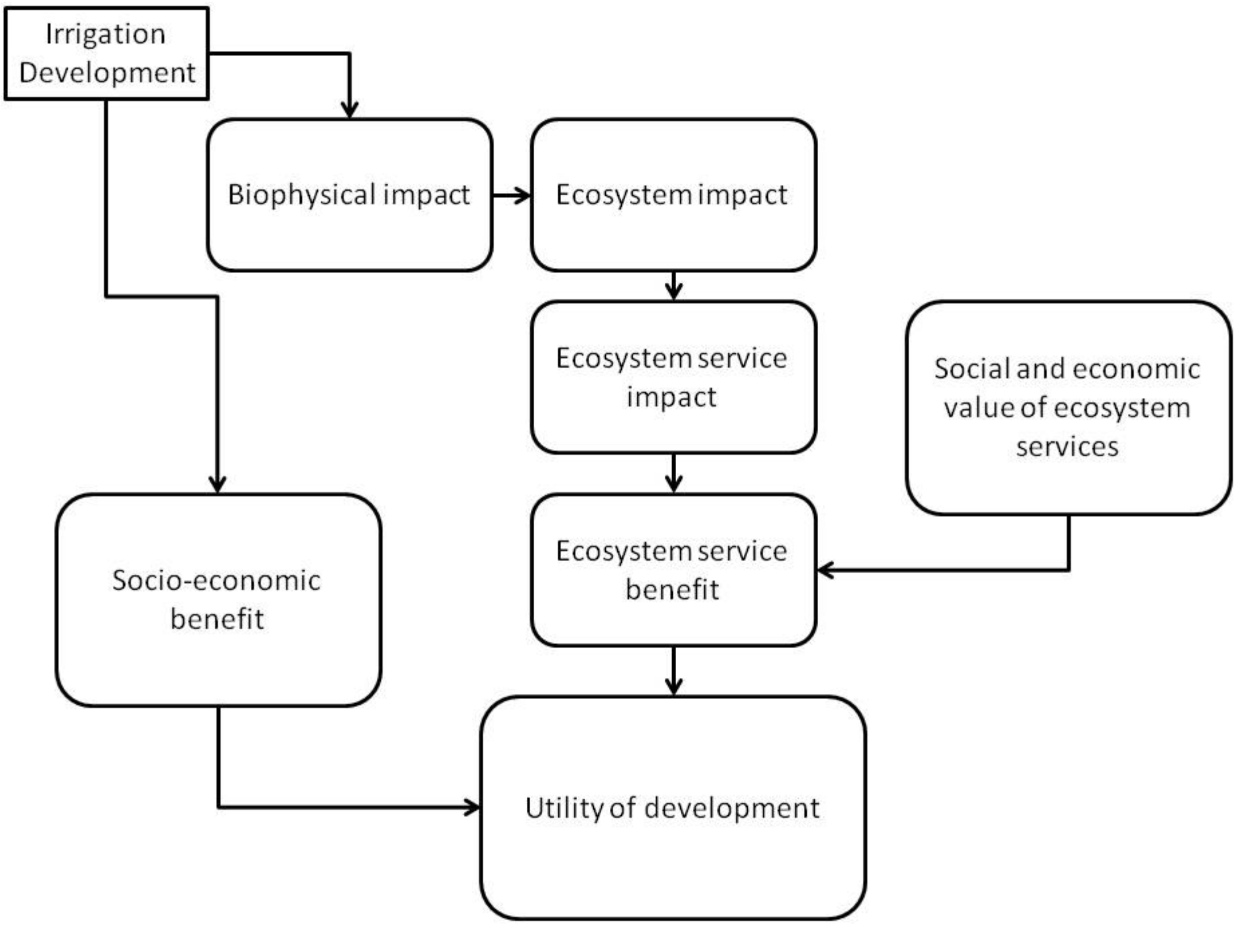


Figure 3.1 Conceptual overview of the Bayesian Belief Network model

3.1.4 MODEL INPUTS

The inputs into the Conditional Probability Tables (CPTs) are a mix of expert opinion and data. From Figure 3.1, *biophysical impact* and *ecosystem Impact* CPTs were populated using expert opinion and *social and economic value of ecosystem* services CPTs were populated using data from the literature (economic values) and data from a new social values survey (social values). The *socio-economic benefit* CPTs (Figure 3.1) were populated using data from other activities in the Flinders and Gilbert Agricultural Resource Assessment. Section 3.2 below provides detail.

3.1.5 MODEL OUTPUT

The fully populated BDN model with all CPTs complete (using data described below) estimates a utility (i.e. cost or benefit) of water resource development for new irrigation, ranging from a large negative to a large positive change (represented as dimensionless indices of – 100 to 1000). A relative comparison of scores indicates the utility of irrigation development. From the perspective of triple bottom line impacts, a large negative is considered to be very low utility. In other words a large negative score suggests development will have a large negative impact measured through many costs (dis-benefits) to ecosystem services. Alternatively, a large positive score for utility suggests the irrigation development will have a large positive impact measured through many benefits to ecosystem services or a large socio-economic benefit that outweighs the relatively small ecosystem service costs.

Sensitivity analysis is used to explore the behaviour of models, and it allows us to study how the variation (or uncertainty) in the output of a model can be apportioned to different sources of variation in the input of a model. Sensitivity analysis can be used to explore the influence of model inputs on model endpoints. The outcome is the ordering of importance, strength and relevance of the inputs in determining the variation of the output. The algorithms for analysing sensitivity are reported in (Pollino *et al.* 2007). To take advantage of the full functionality of the BDN model, sensitivities are identified and used to develop scenarios for improving the utility of irrigation development.

3.2 Populating Conditional Probabilities Tables (CPTs)

A range of data sources were used to populate the CPTs. Final CPTs are presented where they draw on analysis in other parts of the Flinders and Gilbert Agricultural Resource Assessment (i.e. land suitability, water availability, farm-scale economic viability, regional socio-economic benefit). The remaining CPTs were populated using new analysis: this section describes the methods for the new analysis and the final CPTs for the new analysis are presented in the Results section.

3.2.1 IMPACTS TO ECOSYSTEMS AND ECOSYSTEM FUNCTIONS

The potential changes to in-stream and riparian ecology from water resource development and changes to land use in the Flinders and Gilbert were qualitatively summarised through an expert elicitation process. Impacts to aquatic and riparian ecology are reported in Burrows and Waltham (2013). Damian Burrows and Nathan Waltham from the James Cook University TropWater Research Centre were engaged in a half-day workshop on August 14th 2013 to use their expert knowledge on assessing the aquatic ecology impacts of water resource development. During this workshop Damian and Nathan were asked to estimate probabilistic likelihoods of impact within each catchment from water resource development to the 'Biophysical impact' and 'Ecosystem impact' components of the Bayesian Net (Figure 3.1). Consensus was reached on each probabilistic distribution. Probabilities were estimated for the likelihood of whether there would be no change, small change, medium change or large change to the following biophysical and ecological processes:

- Flooding and inundation of the floodplain
- Functionality of dry season pools
- Riparian zones
- Nutrient loads within stream
- Cover of remnant vegetation

Probabilities were then estimated for the likelihood that changes to these processes would result in no change, small change, medium change or large change to the following ecosystems and ecosystem functions:

- Maintenance of wetlands and floodplains
- In-stream fauna production

- Estuarine fishery production
- Maintenance of terrestrial biodiversity

'No change' was defined as no or negligible impact to ecosystem process or function. A 'small change' was defined as a change that would have relatively minor impact and which could potentially be mitigated or prevented with careful management. A 'large change' was defined as a change that would have a large or potentially irreversible impact and where a threshold may be potentially breached. A 'medium change' was defined as an potential impact on ecosystem processes, functions and services which falls in between the small and large change categories.

3.2.2 LAND SUITABILITY

The probability of land being suitable for irrigated crops was summarised from outputs of the Land Suitability Activity (Bartley *et al.* 2013). Based predominantly on soil characteristics, the Land Suitability activity estimated the suitability of land in the Flinders and Gilbert catchments to various irrigated crops (cotton, soybeans, sorghum, sugarcane, capsicum, mango, rice, peanuts, Rhodes grass) under different irrigation water delivery mechanisms (furrow, spray, trickle, flood). Suitability of growing the crop delineated using five categories: 1) suitable land with negligible limitations; 2) suitable land with minor limitations; 3) suitable land with moderate limitations; 4) suitable land with severe limitations, and; 5) unsuitable. The total area in each catchment for each crop type and land suitability category is shown in

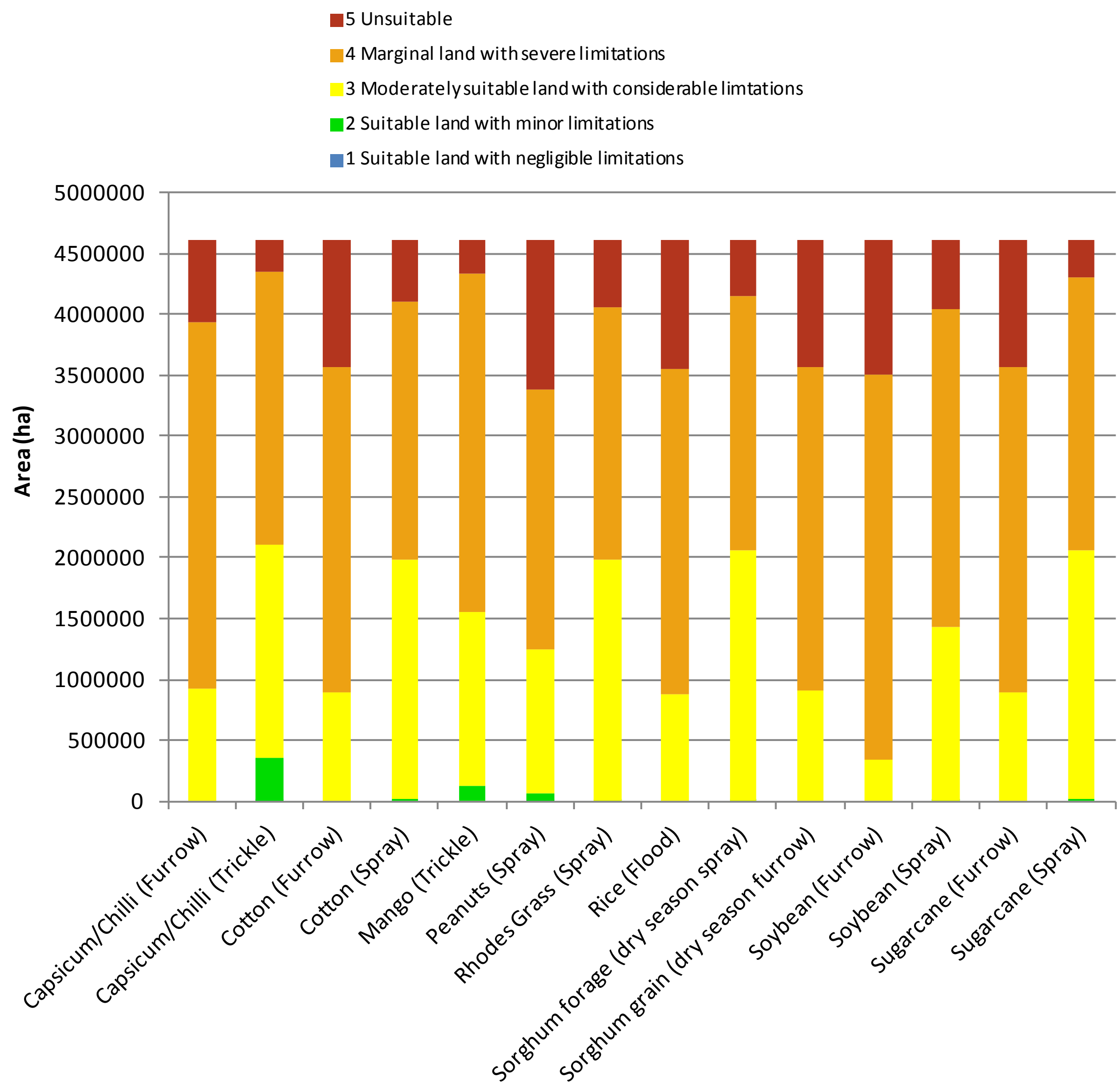


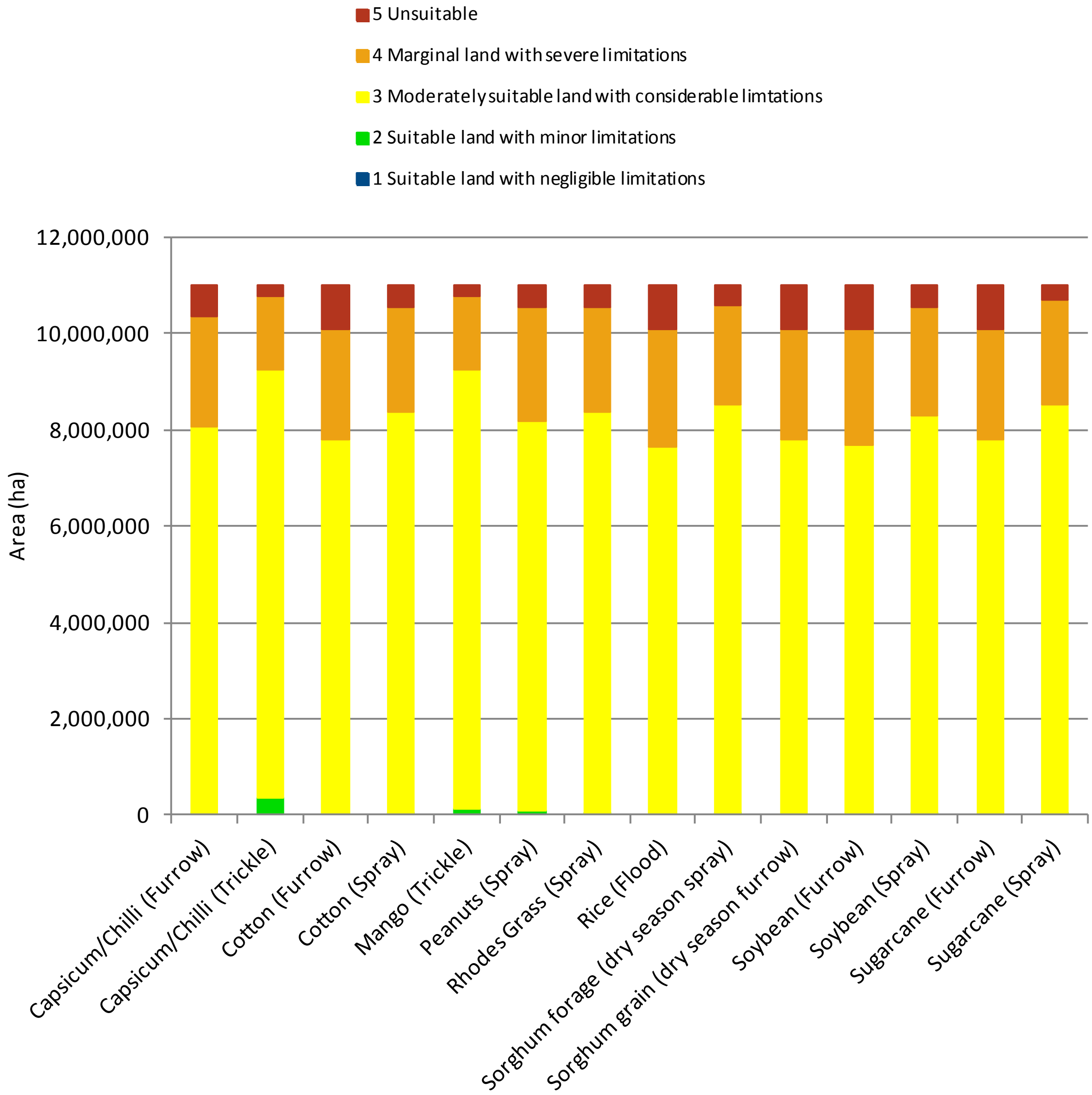
Figure 3.2.

To calculate the probability that any location in the Flinders or Gilbert is in one of the 5 categories, the mean area for each land suitability category across the 14 crop-water delivery mechanisms was calculated. The mean area for each category was then divided by the total area of the catchment, giving a proportion of the catchment in each category. It then follows that the probability of a location falling within a suitability category is related the proportion of the catchment in that category; for example if 10% of the catchment is Category 3, there is a 10% chance that the random selection of a location in the catchment would be Category 3. The probabilities for each land suitability category in the Flinders and Gilbert catchments are shown in Table 3.1.

Table 3.1 Probability (%) of land suitability categories in the Flinders and Gilbert.

Category	Flinders	Gilbert
Category 5 (Unsuitable)	5	16
Category 4(Marginal land with severe limitations)	20	54
Category 3 (Moderately suitable land with considerable limitations)	75	29
Category 2 (Suitable land with minor limitations)	0	1
Category 1 (Suitable land with negligible limitations)	0	0

a)


5 Unsuitable
4 Marginal land with severe limitations
3 Moderately suitable land with considerable limtations
2 Suitable land with minor limitations
1 Suitable land with negligible limitations
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
Area (ha)
Capsicum/Chilli (Furrow)
Capsicum/Chilli (Trickle)
Cotton (Furrow)
Cotton (Spray)
Mango (Trickle)
Peanuts (Spray)
Rhodes Grass (Spray)
Rice (Flood)
Sorghum forage (dry season spray)
Sorghum grain (dry season furrow)
Soybean (Furrow)
Soybean (Spray)
Sugarcane (Furrow)
Sugarcane (Spray)

b)

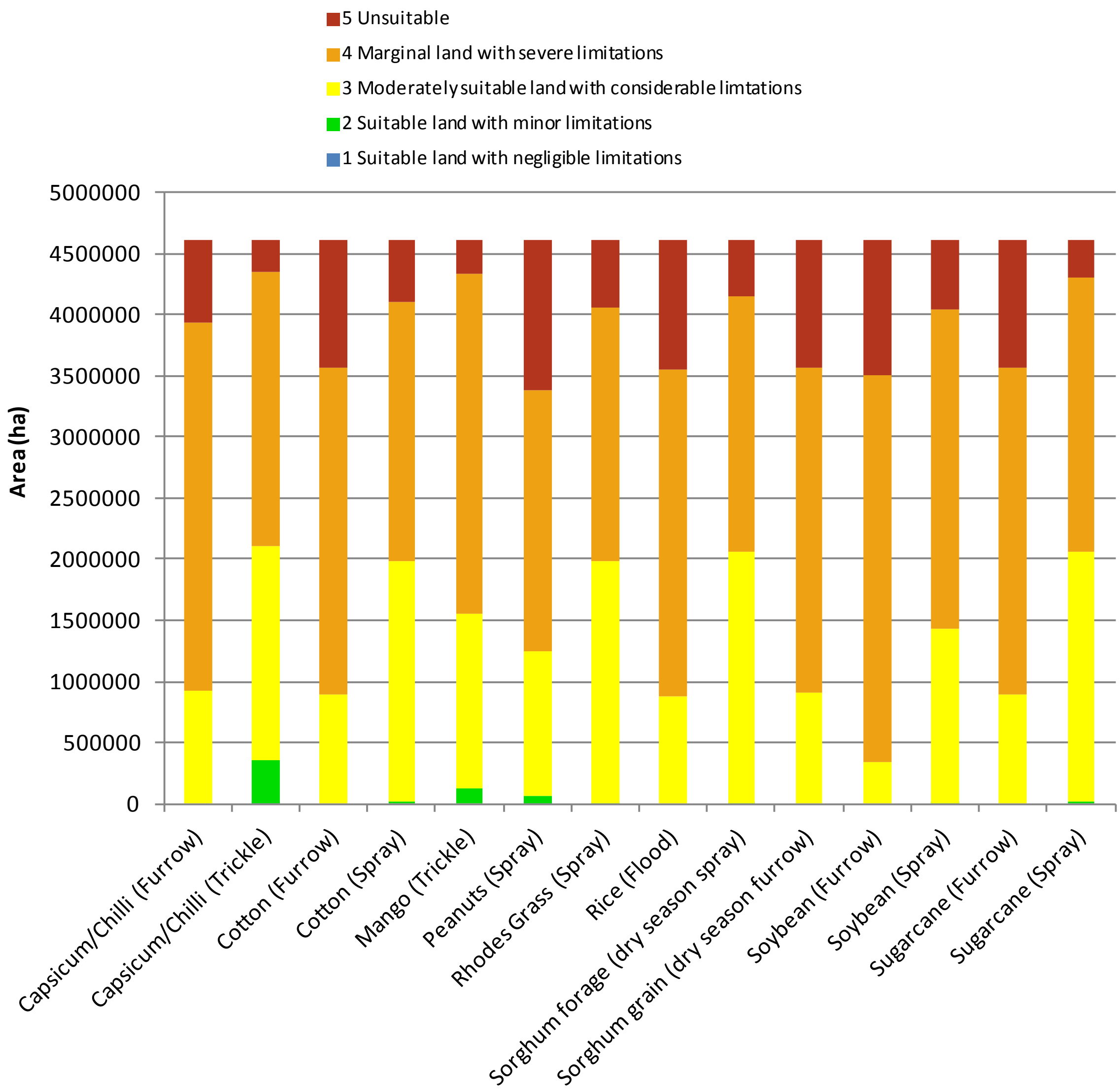


Figure 3.2 Area of suitable land for irrigated crops in a) Flinders, and; b) Gilbert. Source: Bartley *et al.* (2013)

3.3 Socio-economic values and probabilities

3.3.1 SOCIO-ECONOMIC BENEFIT OF IRRIGATION DEVELOPMENT

Irrigated agricultural potential (low, medium, high) is used to estimate the potential socio-economic benefit of irrigation development. Irrigated agricultural potential is a function of the probability of land being suitable, the probability of water available for irrigation, the probability that new irrigation is economically viable at the farm scale, and the probability that there are regional socio-economic benefits that flow from irrigation development. The probability of land being suitable for irrigation is described in Section 3.2.2 above. The total volume of water potentially captured by water storages, as reported in the Water Storage Options Activity (Petheram *et al.* 2013) was used to estimate the probability of water being available for irrigation (Table 3.2). According to Petheram *et al.* (2013), three potential water storage options in each catchment showed most promise for development and require detailed further investigation. In the Flinders catchment, Cave Hill (248 GL capacity), O'Connell Creek (127 GL) and Porcupine Creek (31 GL) could store approximately 400 GL for irrigation development. In the Gilbert catchment, Dagworth (498 GL), Greenhills (271 GL) and the raising of the Copperfield dam (25 GL) could store approximately 800 GL for irrigation development. From these potential total storages, the probabilities that particular volumes of water would be available in any particular year were calculated as shown in Table 3.2. The highest probabilities are given for those volumes related to total storage capacity, with lower probabilities ascribed to lower volumes to allow for reduced water availability in drier years. These figures are estimates and could be improved with detailed water reliability modelling.

Table 3.2 Probability (%) of water availability in the Flinders and Gilbert catchments.

Volume of water available (GL/yr)	Flinders	Gilbert
0 to 50	5	5
51 – 100	15	10
101 – 500	80	15
501 or more	0	70

The probability that new irrigation is economically viable at farm scale, and the probability that there are regional socio-economic benefits that flow from irrigation, were calculated from the results of the Socio-Economic Costs and Benefits Activity (Brennan McKellar *et al.* 2013). The results of both the northern Australia IAT beef model and the gross margin analysis suggest that farm-scale viability of new irrigation development is low, and in actual fact, the Net Present Value (NPV) of the scenarios modelled for growing irrigated fodder for beef were all negative on a $/ha basis (Brennan McKellar *et al.* 2013). From the gross margin analysis, break even or a small surplus is estimated to be possible only when commodity prices are high (Brennan McKellar *et al.* 2013), suggesting a relatively low probability of positive NPV. The probabilities of irrigation being economically viable in the Flinders and Gilbert catchments used in the BDN model are shown in Table 3.3.

Table 3.3 Probability (%) of irrigation being economically viable at farm scale in the Flinders and Gilbert catchments.

Net economic returns ($/ha/yr)	Flinders	Gilbert
-1,000 - 0	75	85
1 - 100	15	10
101 - 500	5	4
501 or more	5	1

The probability that irrigation development will provide regional socio-economic benefits was estimated based on the outputs of the CGE modelling reported in (Brennan McKellar *et al.* 2013). The size of the regional socio-economic benefits is a function of the scale of the potential dam and water delivery infrastructure costs and on-farm development costs. Bigger and more expensive dams and associated water supply and on-farm infrastructure will likely lead to a greater shock to regional employment and Gross Regional Product, all else being equal. From Brennan McKellar *et al.* (2013), it is clear the potential for larger dams and infrastructure in the Gilbert compared to the Flinders means a greater probability of high socio-economic benefits in the Gilbert. The probabilities of low, medium or high levels of regional socio-economic benefits in the Flinders and Gilbert catchments used in the BDN model are shown in Table 3.4.

Table 3.4 Probability (%) of regional socio-economic benefit in the Flinders and Gilbert catchments.

Regional socio-economic benefit	Flinders	Gilbert
Low (<$500m investment)	20	10
Medium ($500m – $1.5b investment)	50	30
High (>$1.5b investment)	30	60

3.3.2 ELICITING SOCIAL VALUES

Recent evidence has shown that economic values of ecosystem services is an insufficient measure of the full value society hold for services (Martin-Lopez *et al.* 2012). Economic value only partly describes the societal benefit received by services because not all services can be monetised and society has values outside of purely economic and monetary measures (Kahneman 2011). A number of recent studies have gathered information on community understanding, value and perceptions of ecosystem service supply and management priorities for eliciting a wider set of social values (Casado-Arzuaga *et al.* 2013; Liu *et al.* 2013). Due to the high rates of internet access (79% of Australian households had access to the internet at home (Australian Bureau of Statistics 2011)), online surveys are now a popular way to elicit social values because of their cost effectiveness and relatively wide reach. Traditional mail-based surveys, expensive, labour intensive and comparatively slow at building a panel dataset compared to the internet-based survey; the internet-based survey has been shown to provide values datasets comparable to the mail-based surveys (Windle & Rolfe 2011). Therefore an online social survey was developed and applied to get a better sense of how the broader community and stakeholders in the Flinders and Gilbert catchments understand and interpret the concept of ecosystem services and the benefits provided by nature and the environment. The aim is to elicit a 'social value' for each ecosystem service which acts as a weight for each service based on survey respondents' perceived level of importance of that service.

3.3.2.1 SURVEY DESIGN, TESTING AND DISTRIBUTION

A previous social survey about perception, understanding and management priorities of ecosystem services that was developed for the CSIRO Multiple Benefits of the Murray Darling Basin Plan project (CSIRO 2012) was built on and revised to the Flinders and Gilbert catchments. A number of companies offer online survey design software with many features that make survey design relatively simple. SurveyMonkey, a more popular product because of its ease of use and relatively advanced functionality, was used to develop the survey questions and create a webpage for respondents to complete. A set of 24 questions were developed grouped around 3 themes: 1) introductory material and questions about the respondent's demographics and general interests and experiences with nature; 2) understanding, perceptions and priorities for managing ecosystem services, and 3) broader questions relating to priorities for water resource management in the Flinders and Gilbert. Appendix A.1 contains the full survey.

Before wide distribution, the survey was pre-tested with a small number of project scientists (Cuan Petheram, Ian Watson, Damian Burrows, and Nathan Waltham) and revisions made based on their feedback. At the beginning of August 2013 invitations were sent via email across contact lists and networks of scientists, government water and agricultural policy people, regional natural resource management people and local beef producers and community leaders. The survey was also advertised among the Flinders Precinct Agriculture Producers group. Invitees were given until the end of August 2013 to complete the survey. A separate survey was created for each of the Flinders and Gilbert catchments to ensure respondents with expertise in either catchment were able to respond appropriately. Respondents with knowledge and expertise in both catchments could complete both surveys. Given the aim is to capture broad social values, no judgement was made about which values are more or less legitimate (e.g. FGARA project scientist or beef producer located in the catchments); all social values are treated equally.

3.4 Economic values of ecosystem services

3.4.1 BENEFIT TRANSFER APPROACH

Because of the lack of resources to undertake new valuation studies (except for the valuation of food production ecosystem service reported in (Brennan McKellar *et al.* 2013), the popular benefit transfer method (Wilson & Hoehn 2006; Liu *et al.* 2010) was used to ascribe the best possible economic values to ecosystem services supplied in the Flinders and Gilbert catchments. Benefit transfer (Table 2.1) involves identifying values derived from an original valuation study and transfer those values to the site in question. Values will be more robust when there is more similarity in space and time between the original (called 'study site') and the new site (called 'policy site'). A goal in benefit transfer is to identify previous 'study sites' that best match the new 'policy site'. A number of ecosystem services valuation databases are available[1] to assist with the search for previous studies to potentially transfer. In the present study the Environmental Valuation Reference Inventory (EVRI) was used to identify previous relevant empirical studies, and these were complemented by values reported in de Groot *et al.* (2012) in the absence of EVRI original values. In the present study, original values were selected if they were undertaken in rangeland (open woodlands and grasslands) environments, preferably in northern Australia, or from other study locations in a rangeland-type environment with comparable ecosystem and social characteristics.

A substantial challenge in benefit transfer is to have consistency in the biophysical units of measurement and timeframes of values between the original site and the new site. For example, studies can value linear units of riparian areas, areal units of habitat, number of tourists, number of sites of environmental assets, various volumes of food and water, and many more units of measurement. Studies can also calculate values on annual basis or some other longer terms such as decadal bases. Large databases of economic valuation studies of ecosystem services treat this problem by converting values into a common area, time and currency measure such as $/ha/yr. However this is not always possible because original studies may not provide sufficient detail for conversion, or alternatively units of measurement may not be commensurate. Therefore in the present study probabilities were ascribed to likely $/ha/yr value classes of economic values of services (1-100; 101-500; 501+) based on the frequency that original values fall into each range.

3.5 Scenario analysis

To illustrate the application of the BDN, a scenario analysis was performed to investigate the broad economy and management regimes that may be required to achieve a more sustainable outcome based on the TBL. The power of a BDN lies in its ability to support decision-making by exploring 'what-if' scenarios. In the BDN it is possible to investigate changes to utility following a hypothetical scenario. For example, one could calculate a new utility assuming irrigation development had no impact on riparian habitat, i.e. there was no change to riparian habitat. A number of different scenarios were run to look at how the overall utility of irrigation development changes according to different values for variables within the BDN. The scenarios assessed here for their impact on TBL utility were:

1) Baseline: All probabilities remain as per the baseline model described above;
2) Scenario 1: The economic benefits (viability of farm scale irrigated agriculture and regional economic benefits) are high, everything else remains the same as per the baseline;
3) Scenario 2: The ecosystem impact variables are all defined as 'No Change', i.e. there is no environmental impact from irrigation development, and the economic benefits remain the same as per the baseline, and;

[1] For example, EVRI (https://www.evri.ca/Global/HomeAnonymous.aspx); Ecosystem Valuation Toolkit (http://www.esvaluation.org/); and the TEEB/ESP ecosystem services valuation database (de Groot *et al.* 2012).

4) Scenario 3: The economic benefits are high and the ecosystem impact (cost) variables are ‘No Change’.

4 Results

4.1 Social values from the survey

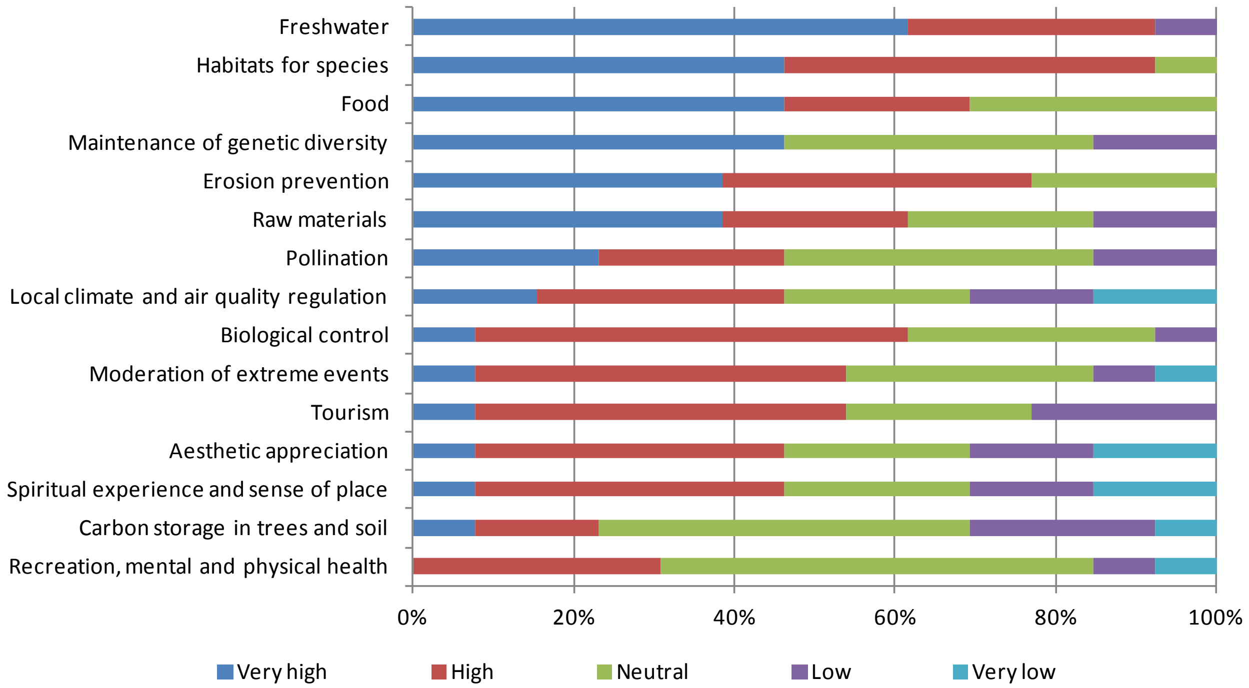
Responses to the survey were 14 for the Flinders and 17 for the Gilbert. The full results of the survey are provided in Appendix A.2 and the key findings for each catchment are presented here. The demographics of the respondents are summarized in Table 4.1. Males dominated the responses in both catchments. Respondents in both catchments consisted of a relatively even mix of scientific expertise and land managers (i.e. property owners) and natural resource managers, although the age distributions of respondents was confined to ages of 35-75. The younger and older spectrums of the age range are not represented in the responses.

Table 4.1 Summary information for respondents to the Flinders (n = 14) and Gilbert (n = 17) catchments social survey

	Flinders catchment (% respondents)	Gilbert catchment (% respondents)
Age		
18-24	0	0
25-34	0	0
35-44	31	35
45-54	38	47
55-64	23	12
65-74	8	6
75+	0	0
Expertise		
Ecologist	30	33
Hydrologist	20	20
Land manager	30	20
Policy specialist	0	7
Natural resource manager	30	20
Community representative	30	13
Gender		
Male	92	88
Female	8	12

Figure 4.1 shows the ecosystem services that respondents to the each of the Flinders and Gilbert catchment surveys consider are of most importance (i.e. they receive greatest benefit from). In the Flinders the supply of freshwater and food, and habitats for species are considered most important, while in the Gilbert habitats for species, the supply of freshwater and biological control are considered most important. In the Flinders, the provision of food and freshwater were identified by the most respondents as being ecosystem services that are worth paying to protect and improve, while in the Gilbert the ecosystem services considered worth paying for by the greatest number of respondents was erosion protection, habitat for species and freshwater (Figure 4.2). Interestingly the erosion prevention ecosystem service that identified by a high proportion of respondents as worth paying to protect and improve did not rate of particularly high importance (Figure 4.1).

a)



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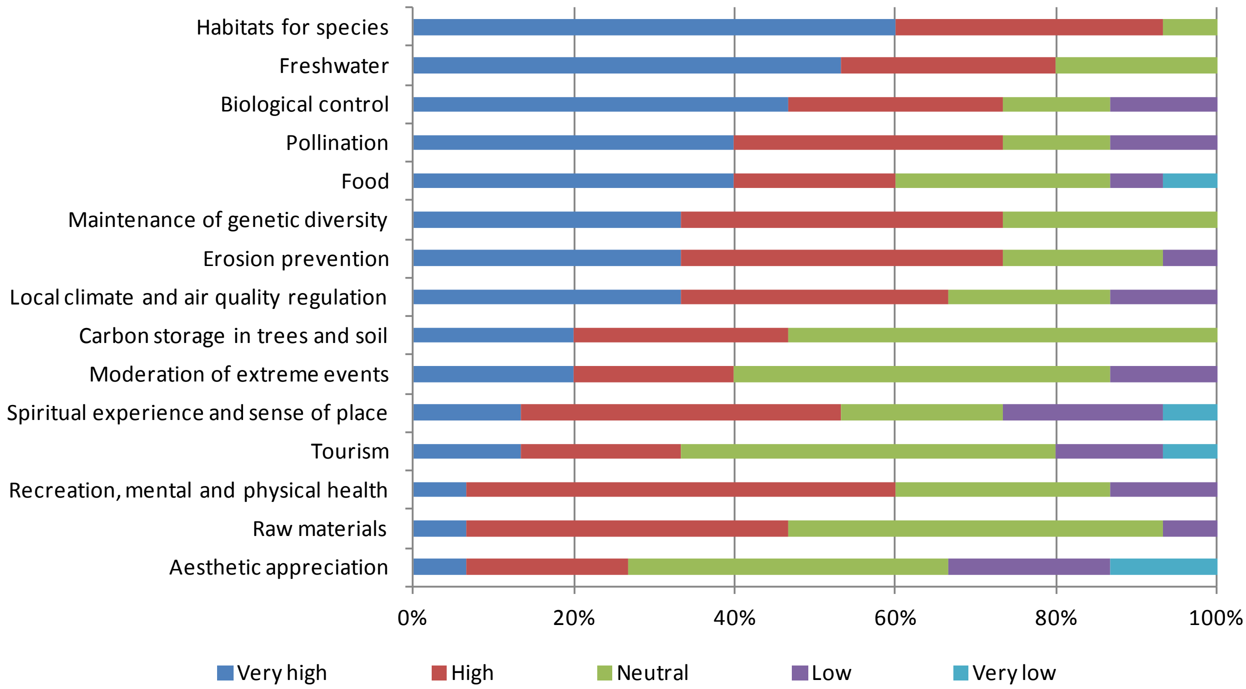
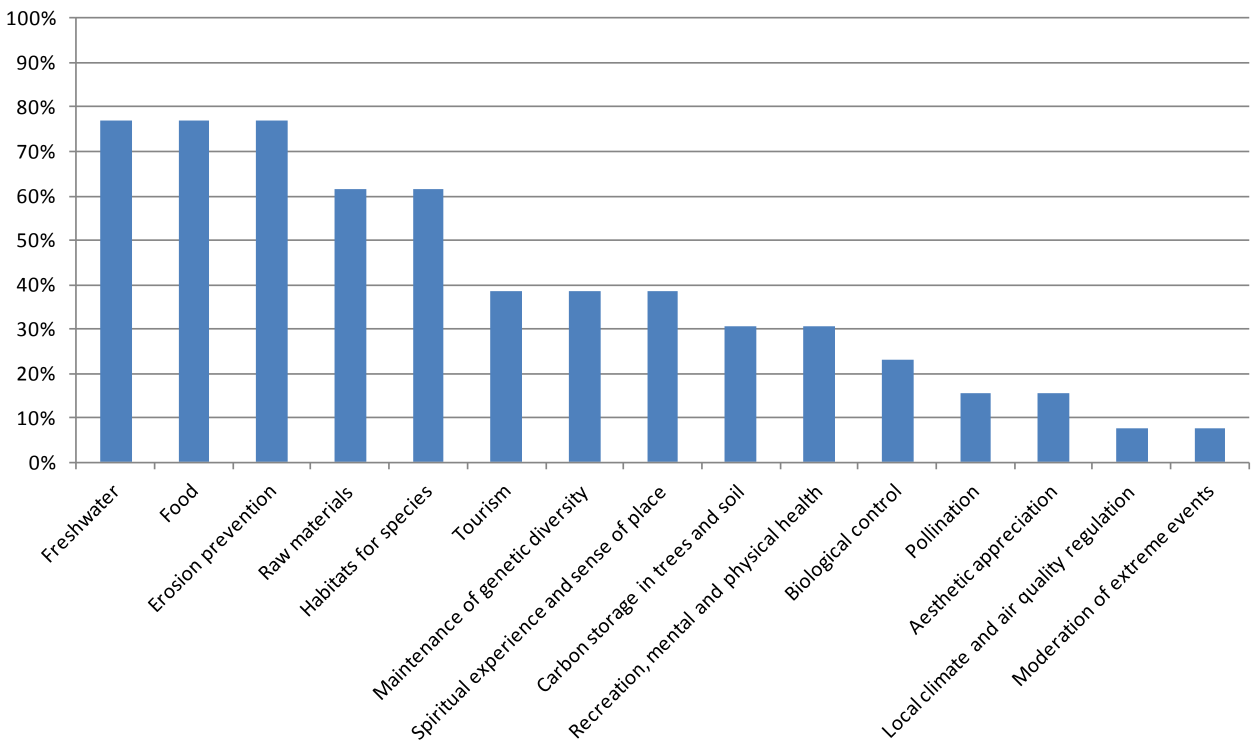


Figure 4.1 Respondents perceived level of importance of major ecosystem services supplied in: a) the Flinders catchment (n = 14), and; b) the Gilbert catchment (n = 17)

a)



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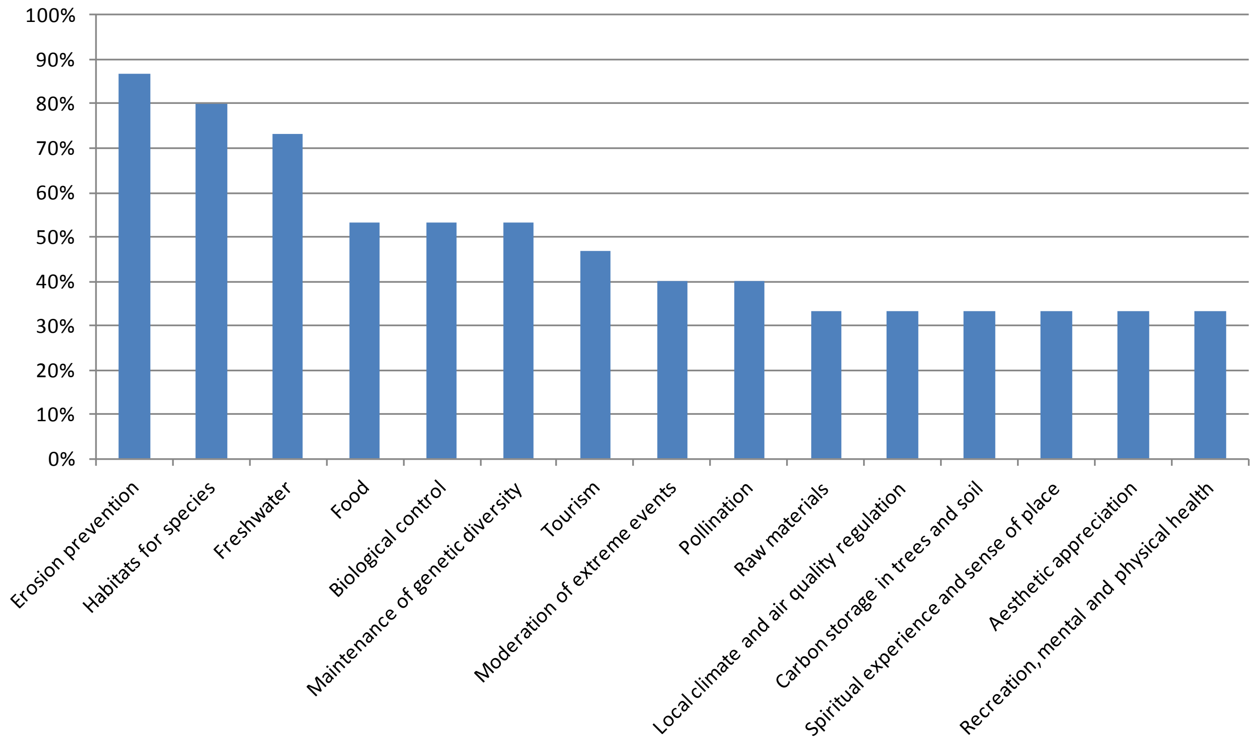
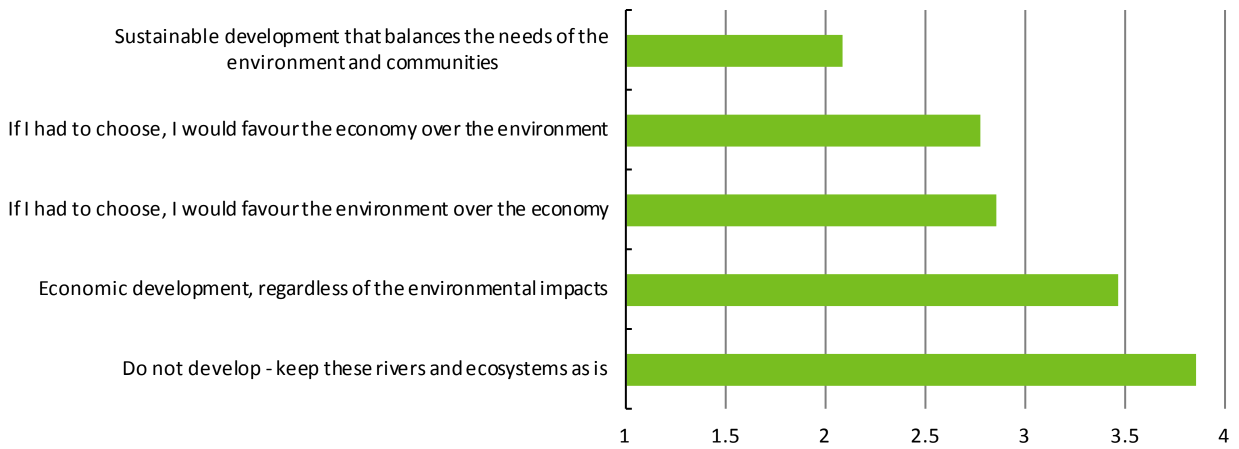


Figure 4.2 Proportion of respondents who identified each ecosystem service as worth paying to protect and improve in; a) the Flinders catchment (n = 14), and; b) the Gilbert catchment (n = 17)

The survey also questioned respondents about their position on economic development versus environmental protection (Figure 4.3). Sustainable development was most ranked the most important by respondents in both catchments, although more so in the Gilbert, whereas not developing water resources at all ranked least important in the Flinders and also ranked of low importance in the Gilbert. Development that gave no consideration to environmental impacts also ranked very low (Figure 4.3). The results need to be understood in the context of the background of the survey respondents: relatively even distribution of land manager (e.g. beef producers), natural resource manager, and scientist respondents (Table 4.1).

a)



b)

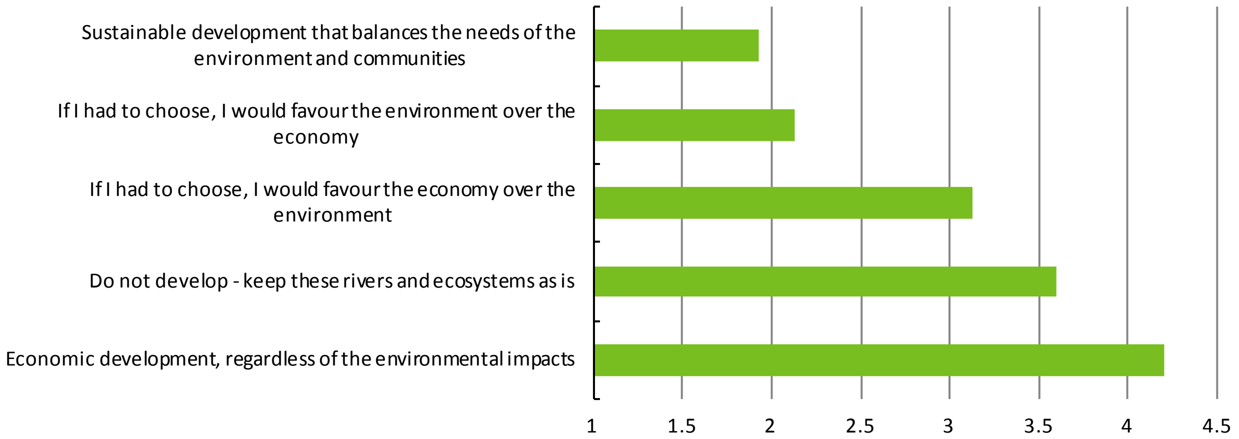


Figure 4.3 Respondents average ranking (1 = most important; 5 = least important) of statements about water resource development in: a) the Flinders catchment (n = 14), and; b) the Gilbert catchment

The probabilities for use in the BDN were calculated based on the respondents perceived level of importance of the benefits they receive from the major ecosystem services supplied in each of the Flinders and Gilbert catchments. The levels of importance for each catchment are presented in Figure 4.1. The probabilities are based on the proportion of responses to each level as follows: High (Very High and High importance); Medium (Neutral importance); Low (Low to Very Low importance). For example, in Figure 4.1 95% of respondents identified Habitat for Species as Very High and High, and the remaining 5% of respondents identified the service as Neutral. Therefore in the BDN the Social Value probabilities for Habitat for Species ecosystem service in the Gilbert are 95% for High and 5% for Medium. The full set of probabilities is listed in Table 4.2. Note that only a subset of ecosystem services used in the social values survey are listed in Table 4.2. The services listed in Table 4.2 are those which are relevant to the catchments and which biophysical impacts and economic values could be estimated.

Table 4.2 Probability (%) of each ecosystem service belonging to a social value class based on the Flinders and Gilbert catchments social value surveys. Note: each ecosystem service is a separate node in the BDN.

Ecosystem service	Flinders			Gilbert		
	Low	Medium	High	Low	Medium	High
Visual appreciation	31	23	46	33	40	27
Recreation and tourism	23	23	54	20	47	33
Cultural and spiritual	31	23	46	27	20	53
Carbon storage	31	46	23	0	53	47
Habitat for species	0	8	92	0	7	93
Food production (fish)	0	31	69	13	27	60
Food production (prawns)	0	31	69	13	27	60
Food production (crops/livestock)	0	31	69	13	27	60

4.2 Economic values from benefit transfer

The economic values for ecosystem services from original studies which were transferred to the Flinders and Gilbert study site are summarised in Table 4.3. The probability of an ecosystem services belonging to an economic values class is based on the frequency of value classes for service in Table 4.3. The probabilities for each ecosystem service are listed in Table 4.4.

Table 4.3 Summary of ecosystem service values reported in original studies and used for benefit transfer

Ecosystem service	Original method	Location	Economic value	Source	Economic value class ($/ha/yr)
Visual appreciation	Benefit transfer	Generic woodland & grassland biome	$167/ha/yr	de Groot *et al.* (2012)	101-500
	Benefit transfer	Generic inland wetland biome	$1,292/ha/yr	de Groot *et al.* (2012)	501+
	Choice modelling	Woodlands in south-eastern Australia	$96-$642/ha over 20 years (equals $9-$60/ha/yr)[A]	Van Bueren and Bennett (2004) and Crossman *et al.* (2010)	1-100
Recreation and tourism	Benefit transfer	Generic woodland & grassland biome	$7-$26/ha/yr	de Groot *et al.* (2012)	1-100
	Benefit transfer	Generic river/lake biome	$2,166/ha/yr	de Groot *et al.* (2012)	501+
Cultural and spiritual	Choice modelling	Fitzroy, Daly and Mitchell Rivers	$85 & $522/pp/yr WTP for Aboriginal waterholes (equals $90 & $553/ha/yr)[B]	Zander and Straton (2010)	1-100 501+
	Replacement cost	Wallis Lake Catchment, NSW	$283-$786/pp/yr WTP for wild resources (equals $5,458 - $15,162/ha/yr)[B]	Gray and Altman (2006)	501+
Carbon storage	Benefit transfer	Generic woodland & grassland biome	$7-$40/ha/yr	de Groot *et al.* (2012)	1-100
	Benefit transfer	Generic inland wetland biome	$488/ha/yr	de Groot *et al.* (2012)	101-500
	Market value	Australian mulga vegetation	$23/ha/yr[C]	Witt *et al.* (2011a)	1-100
Habitat for species	Benefit transfer	Generic woodland & grassland biome	$1,214-$1,277/ha/yr	de Groot *et al.* (2012)	501+
	Benefit transfer	Generic inland wetland biome	$2,455/ha/yr	de Groot *et al.* (2012)	501+
Food production (fish)	Replacement cost	Daly River	'bush tucker' $367/pp/yr (equals $389/ha/yr)[B]	Stoeckl *et al.* (2013)	101-500

Ecosystem service	Original method	Location	Economic value	Source	Economic value class ($/ha/yr)
	Market value	Queensland	$352m-$880m/yr	Geosciences Australia (2013)	501+
Food production (prawns)	Market value	Northern Prawn Fishery	$95m/yr	Geosciences Australia (2013)	501+
Food production (crops/livestock)	Market value	Australia	Crops: $27.7b/yr on 24m ha (equals $1,155/ha/yr)[D] Livestock: $21.3b/yr from 102.2m head	ABARES (2013)	501+

[A]Converted to equal annual equivalents using interest rate of 7%

[B]Hectare value calculated as: (WTP value X %Australian working-age population (18.9m)) / Total area (ha) of Indigenous Land Use Agreement in State of study. Total area for NSW is 980,000ha and for NT is 17,810,000ha (National Native Title Tribunal 2013).

[C]Calculated as $23/t (carbon price) multiplied by 1 t/ha/yr CO2e sequestration rate reported in Witt *et al.* (2011b)

[D]Calculated as gross value of crops ($27.7 b/yr) divided by total cropped area (24m ha)

Table 4.4 Probability (%) of each ecosystem service belonging to an economic value class. Note: each ecosystem service is a separate node in the BDN.

Ecosystem service	Economic value class ($/ha/yr)		
	1 - 100	101 - 500	501+
Visual appreciation	33	33	34
Recreation and tourism	50	0	50
Cultural and spiritual	34	0	66
Carbon storage	66	34	0
Habitat for species	0	0	100
Food production (fish)	0	50	50
Food production (prawns)	0	0	100
Food production (crops/livestock)	0	0	100

4.3 Ecological impacts from development

The CPTs populated during the workshop with TropWater Research Centre at James Cook University on 14th August 2013 are presented in Table 4.5 through to Table 4.11. Two CPTs are not presented here because they are too large. The complete set of CPTs in the BDN is available on request to the author.

In some cases the differences between catchments in the probability of impacts to ecosystems is negligible (e.g. changes to the riparian zone), while in other cases the impacts are potentially quite different between catchments (e.g. e.g. changes to cover of remnant vegetation). The negligible difference between the Flinders and Gilbert catchments for changes to riparian zone, dry-season pool functionality, and within stream nutrient loads is due to lack of detailed scientific knowledge about the impacts of water resource development and/or an absence of major differences in these processes between the two catchments. The relative large differences between the catchments for flooding and inundation of the floodplain and cover of remnant vegetation is due to the considerable differences in the potential of large water storages, with the Gilbert having a number of large dam sites of potential, whereas the Flinders has few large dam sites.

Table 4.5 Probability (%) of change to flooding and inundation of the floodplain following water resource development in the Flinders and Gilbert catchments

	Flinders	Gilbert
No change	10	5
Low change	25	10
Medium change	55	35
High change	10	50

Table 4.6 Probability (%) of change to functionality of dry-season pools following water resource development in the Flinders and Gilbert catchments

	Flinders	Gilbert
No change	5	5
Low change	10	15
Medium change	25	30
High change	60	50

Table 4.7 Probability (%) of change to the riparian zone following water resource development in the Flinders and Gilbert catchments

	Flinders			Gilbert		
	Low	Medium	High	Low	Medium	High
No change	10	5	0	10	5	0
Low change	80	65	50	80	65	50
Medium change	10	25	40	10	25	40
High change	0	5	10	0	5	10

Table 4.8 Probability (%) of change to nutrient loads within stream following water resource development in the Flinders and Gilbert catchments

	Flinders			Gilbert		
	Low	Medium	High	Low	Medium	High
No change	5	0	0	5	0	0
Low change	70	50	30	60	50	35
Medium change	20	40	50	25	35	45
High change	5	10	20	10	15	20

Table 4.9 Probability (%) of change to cover of remnant vegetation following water resource development in the Flinders and Gilbert catchments

	Flinders	Gilbert
No change	5	5
Low change	15	5
Medium change	60	15
High change	20	75

Table 4.10 Probability (%) of change to maintenance of wetlands and floodplains following water resource development in the Flinders and Gilbert catchments

		Maintenance of wetlands and floodplains			
		No change	Low change	Medium change	High change
Change to flooding and inundation of the floodplain	No change	100	0	0	0
	Low change	0	65	35	5
	Medium change	0	0	80	20
	High change	0	0	0	100

Table 4.11 Probability (%) of change to maintenance of terrestrial biodiversity following water resource development in the Flinders and Gilbert catchments

		Maintenance of terrestrial biodiversity			
		No change	Low change	Medium change	High change
Change to cover of remnant vegetation	No change	100	0	0	0
	Low change	0	65	35	5
	Medium change	0	0	80	20
	High change	0	0	0	100

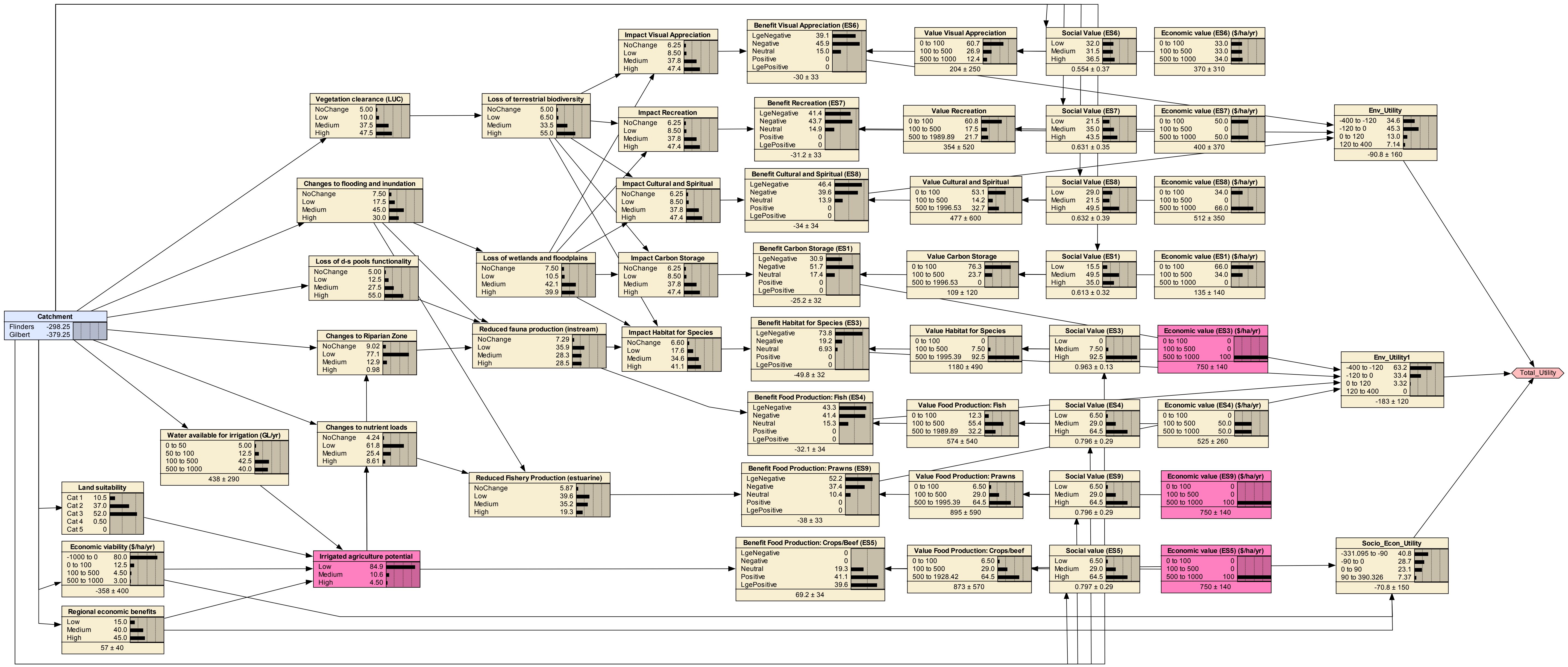
4.4 Bayesian decision net and utility of irrigation development

The final BDN is presented in Figure 4.4. The full set of CPTs is provided in Appendix **Error! Reference source not found.**. From the perspective of the triple bottom line, the total utility of irrigation development is negative in both the Flinders and the Gilbert catchments (Figure 4.4). The explanation for the negative utility is that the negative impact to ecosystem service social and economic values is not balanced by the positive benefits of irrigation development. Irrigation development, if fully realised, will result in large areas of land use change, impacting on the supply of ecosystem services from the terrestrial land system. The benefit to ecosystem services supplied by the land system will be largely neutral to negative following irrigation development (Figure 4.4).

Diversion of water for irrigation and the subsequent alterations to hydrology and freshwater and riverine ecosystems, while not necessary large overall, will impact on the crucial dry-season pool refugia, as well as potentially impacting on riparian zones and estuarine environments. Results of the ecosystem services social surveys demonstrate that the 'food production' and 'habitat for species' ecosystem services were highly valued by respondents. The estuarine (prawns and fish) and in-stream fish food ecosystem services and the freshwater and terrestrial habitat ecosystem services are important components of the BDN model and the medium to high impact to them (Figure 4.4), plus their high social and economic value, contributes to the negative utility.

Thirdly, the negative utility is further explained by the low economic value at farm scale of irrigation development (Brennan McKellar *et al.* 2013), and the high frequency of locations of relatively low land suitability for many irrigated crops (Bartley *et al.* 2013). The irrigated agriculture potential estimated in the BDN model (Figure 4.4) is therefore most likely to be low and the benefit for food production (crops and beef) is therefore neutral.

Figure 4.4 Bayesian Belief Network models for triple bottom line assessment of irrigation development in the Flinders and Gilbert catchments



4.5 Scenario analysis

The overall utility of irrigation development in both the Flinders and the Gilbert catchments is shown in Table 4.12. Under Scenario 1 where the economic benefits both at the farm and regional scale are high, the environmental and ecosystem service impacts are only just offset in the Flinders catchment, with a utility just above zero (Table 4.12). For comparison, in the Gilbert even a very large economic benefit from irrigation development would not offset the costs of irrigation development. In Scenario 2 where the economic benefits remain relatively low, yet irrigation development is highly sensitive to the environment and there are no environmental impacts, the utility of development is marginally positive in the Flinders (and Gilbert) catchment (Table 4.12). This is explained by the predominantly negative viability at farm scale of irrigation development. However, under Scenario 3 where economic benefits are high, and environmental impacts are absent, the utility is at a maximum.

Table 4.12 Triple bottom line utility of irrigation development under different economy and management regimes in the Flinders and Gilbert catchments

	Flinders catchment	Gilbert catchment
Baseline	-296	-378
Scenario 1	2	-54
Scenario 2	53	32
Scenario 3	314	314

5 Discussion and Conclusion

This report describes the construction and population of a large BDN to estimate the total utility of irrigation development according to the TBL criteria of social, economic and environmental sustainability. A TBL assessment aims to provide a complete picture of the social, economic and environmental costs and benefits of a development. The challenge in the FGARA project is the lack of a precise development for quantifying TBL costs and benefits; i.e. the FGARA project is reporting on generic irrigation development absent of a specific case study. While there are case studies examined in FGARA, they are limited to the water availability and irrigation conveyance design and costs of a small number of large dams and an on-farm water harvesting scenario. Therefore the TBL assessment is limited to more qualitative and generic irrigation development making the BDN highly suitable to this type of application.

The low response rate is disappointing and may therefore open the analysis and therefore the BDN to critique that the survey responses are not representative of the wider community. The professions of respondents were relatively evenly spread across scientists, policy and government, beef producers and local community leaders. This confirms that the responses that were received were from a cross section of stakeholders. A recent survey conducted by Larson *et al.* (2013) on nine different water values across the broad geographic area of northern Australia tropical rivers, which received 291 responses, had comparable results to the survey presented here. The values assigned the highest importance in the Larson *et al.* (2013) survey were 'Water for other life' (i.e. the 'Habitat for species' ecosystem service) and 'Water for human life' (i.e. the 'freshwater' ecosystem service). Those values were the top 2-3 values of importance in the Flinders and Gilbert catchments. Of fourth most importance in Larson *et al.* (2013) is water for 'Commercial purposes' (i.e. 'food production' ecosystem service), which was in the top 5 of ecosystem services of most importance here.

The TBL assessment can be used to support decision-making by investigating scenarios of water resource development in the Flinders and Gilbert catchments. Three scenarios are presented here for illustrative purposes; these scenarios are by no means exhaustive. In fact the scenarios could be designed to explore specific costs and benefits to specific ecosystem functions and ecosystem services from water resource development. Furthermore the BDN could be expanded and modified to allow investigation of the TBL costs and benefits of specific water resource development options.

There has been a number of recent studies estimating the ecosystem service values of northern Australian tropical rivers (Jackson *et al.* 2008; Zander & Straton 2010; Stoeckl *et al.* 2012; Zander *et al.* 2013), and they all come to similar conclusion that these rivers have a number of important values beyond their potential value for agricultural production. Northern Australia rivers are described by Greiner *et al.* (2009) as 'multi-functional' landscapes and ecosystems because they contain a mix of many consumption and protection related values.

Managing the Flinders and Gilbert rivers and catchments to maintain their multi-functionality is a challenge but policy instruments do exist. An instrument receiving much attention as a way to manage multi-functional landscapes is payment for ecosystem services (Wunder *et al.* 2008; Greiner *et al.* 2009; Wunder 2013). In its simplest form, payments for ecosystem services put a price on ecosystem services that are valued outside of markets. Typically, payments for ecosystem services offset the opportunity costs of reduced agricultural production that may be necessary to maintain the supply of (non-food) ecosystem services. Creating these markets is not easy and there are many problems associated with environmental markets and payments for ecosystem services (Engel *et al.* 2008; Norgaard 2010). Nonetheless, there are opportunities through existing regulatory and legislative mechanisms relevant to irrigation development in the Flinders and Gilbert catchments (reviewed in Brennan McKellar *et al.* (2013)) that could be expanded to include payments for ecosystem services. For example existing native vegetation protection and management legislation that contains offset mechanisms could be expanded to include broader ecosystem service values associated with vegetation and biodiversity, as has been trialled in Victoria (see Section

2.2.1.2). The future release of volumes of unallocated water could be conditional on the currently required land management plan give consideration to broader ecosystem service benefits and costs, and compensation.

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Appendix A

A.1 Social Values Survey Questions

Ecosystem Services Survey - Flinders Catchment

Welcome!

The Perceived Importance of Ecosystem Services in the Flinders Catchment

Ecosystem Services Survey - Flinders Catchment

Research Participant Consent Form

The Perceived Importance of Ecosystem Services in the Flinders Catchment

The aim of this research is to understand the perceived importance of water-related benefits and values in the Flinders Catchment. The study is being conducted by the CSIRO as part of a project funded by the Commonwealth Office of Northern Australia and in partnership with the Queensland State Government. This survey will help us understand the current level of public understanding and attitudes towards the variety of ecosystem services provided by water in the Flinders Catchment. We are also interested in opinions about the management of the water resources in the Catchment. The overall findings of this survey will contribute valuable information for informing further development of water resources in the area.

If you have any questions concerning your participation in the study feel free to contact the researchers involved (Dr Neville Crossman, neville.crossman@csiro.au).

By participating in this survey, you acknowledge that:
1) You understand that participation in the project is entirely voluntary and that you are free to withdraw from the study at any time and without having to provide a reason for your withdrawal.
2) You understand that the information you provide for this research will be used for the purposes of a report for policy makers and journal publications. You will not be identified in any of these publications except where you have given written permission for this to occur.
3) You understand that you may ask for the information you provide to be removed from the study and that this cannot be done after the point where de-identification has occurred.

1. Would you like to participate in the survey?

- (●) Yes
- ( ) No

Ecosystem Services Survey - Flinders Catchment

Thankyou for participating

Thanks for agreeing to participate in our survey!

We wish to reassure you that this is genuine scientific research and as always your individual survey responses will remain confidential and anonymous at all times.

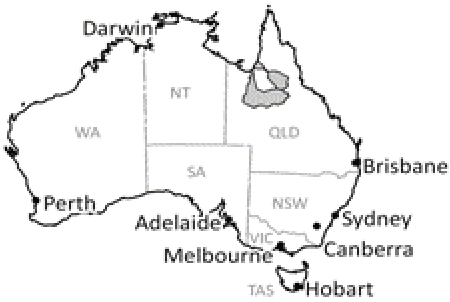
Please Keep In Mind...
Do not use your Back or Forward browser buttons while you are taking this survey. Please use the 'Prev' and 'Next' buttons if you want to go back and change an answer

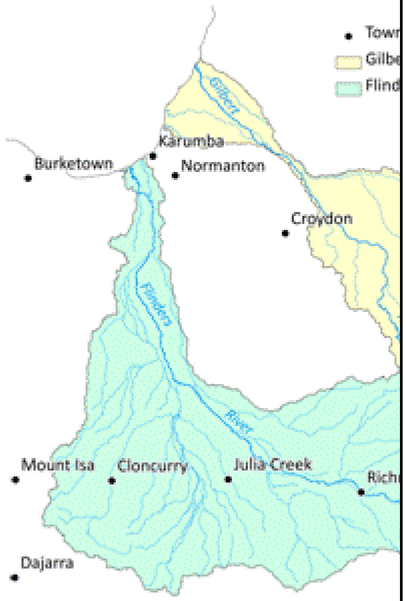
Before we go through to the main study we would like to ask you a number of questions to make sure we are interviewing a good cross section of people.

Ecosystem Services Survey - Flinders Catchment

Intoduction





2. Have you ever visited the Flinders Catchment?

◯ Yes

◯ No

Introduction

3. What were the reasons for visiting the Flinders Catchment?

- [ ] Cultural heritage
- [ ] Camping
- [ ] Nature experiences
- [ ] Walking
- [ ] I live there
- [ ] I work there
- [ ] Boating
- [ ] Fishing
- [ ] Four-wheel driving

Other (please specify)

Information about you

4. What is your age?

- ◯ 18 to 24
- ◯ 25 to 34
- ◯ 35 to 44
- ◯ 45 to 54
- ◯ 55 to 64
- ◯ 65 to 74
- ◯ 75 or older

5. What is your gender?

- ◯ Female
- ◯ Male

6. Please enter your postcode

7. Have you finished high school?

- ◯ Yes
- ◯ No

Information about you

8. Have you attained any other qualifications (please tick)?

- [ ] Vocational
- [ ] Bachelor and/or graduate degree
- [ ] Post graduate degree

Other (please specify)

Ecosystem Services Survey - Flinders Catchment

Information about you

9. Which of the following best describes your current occupation?

- ◯ Professional and managerial
- ◯ Trade and semi-professional
- ◯ Service industries
- ◯ Self-employed
- ◯ Not currently employed

Other (please specify)

10. Which of the following best describes your expertise in the Flinders Catchment (can select multiple answers)

- ☐ Ecologist
- ☐ Hydrologist
- ☐ Land manager (e.g. beef producer)
- ☐ Policy specialist
- ☐ Natural resource manager
- ☐ People and communities (e.g. councilor, small business operator)

Other (please specify)

11. What is your approximate average annual household income?

- ◯ Less than $50,000
- ◯ $50,000 - $99,999
- ◯ $100,000 - $149,999
- ◯ $150,000 or more

My feelings about the natural environment

12. Which of the following has/have an effect on how you feel about nature?

- [ ] Stories I heard, the experiences I had in my childhood and the values I was taught by family
- [ ] My experience with nature and the effect it has on me
- [ ] Social values, what people around me do
- [ ] Environmental organisations in Australia
- [ ] Education
- [ ] Media outlets (newspapers, TV, radio, social media)
- [ ] Movies, documentary films, fictional books

Other (please specify)

13. How important are the following as reasons for experiencing the Flinders Catchment

	Very important	Moderately important	Low importance	Not important
Nature and recreation activities (e.g. bird watching, fishing, camping)	○	○	○	○
Relaxation and mental rest	○	○	○	○
Sense of place, belonging and spiritual experience	○	○	○	○
Physical exercise	○	○	○	○
Learning from nature	○	○	○	○
Earning an income	○	○	○	○
Family / friendship bonding	○	○	○	○
Challenge of wilderness experiences	○	○	○	○
Enjoying the scenery	○	○	○	○
Privacy and getting away from it all	○	○	○	○

My feelings about the natural environment

14. How familiar are you with the following terms?

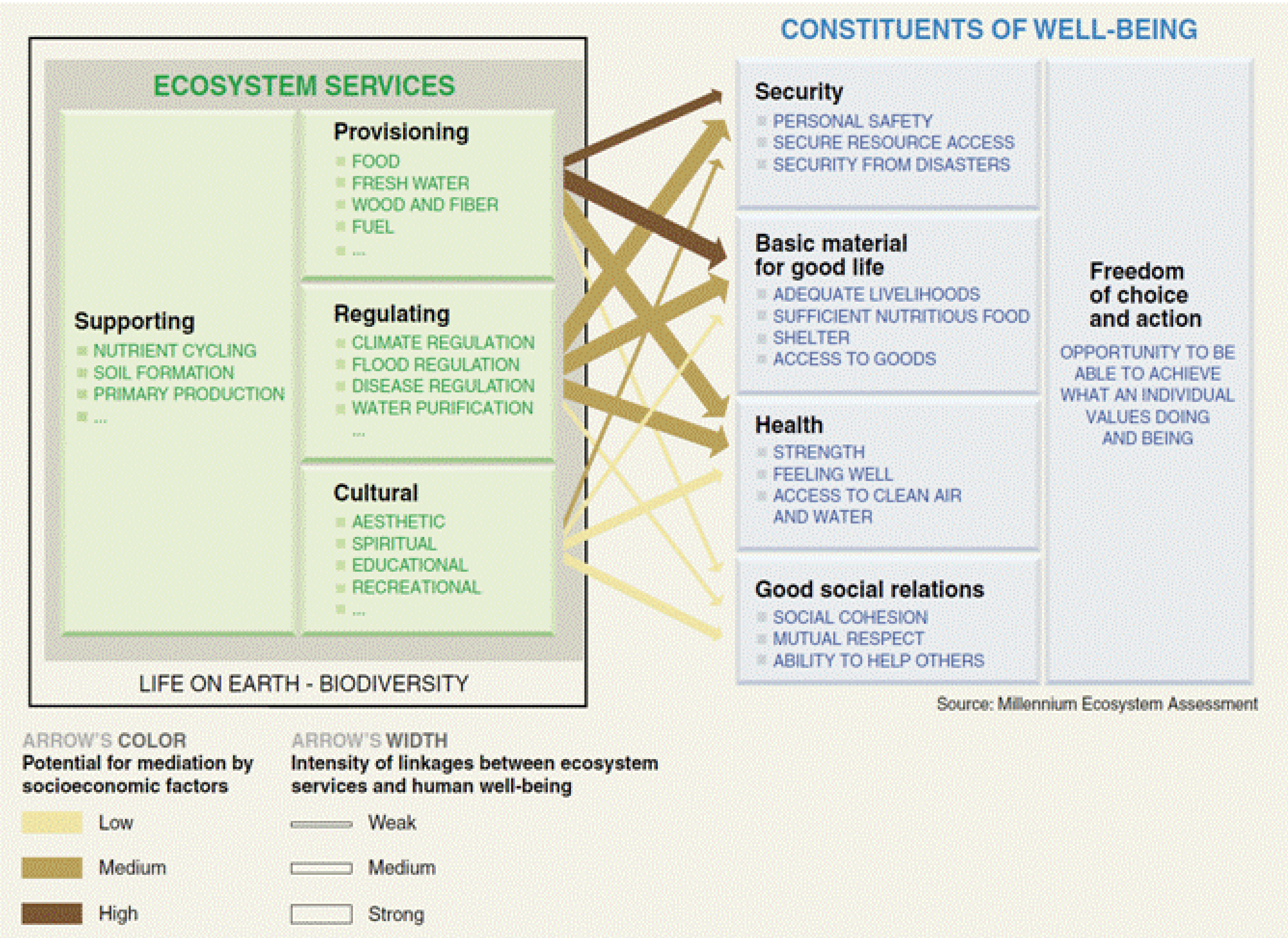
	Very familiar	Moderately familiar	Slightly familiar	Never heard of
Ecosystem services	◯	◯	◯	◯
Nature's benefits	◯	◯	◯	◯
Natural capital	◯	◯	◯	◯
Habitat	◯	◯	◯	◯
Biodiversity	◯	◯	◯	◯

Definition of ecosystem services

Ecosystem services are the benefits people obtain from ecosystems.

Ecosystem goods (such as food) and services (such as waste-water treatment) represent the benefits human populations derive, directly or indirectly, from ecosystem functions.

Many different types of ecosystem services provide many benefits to people, as shown in this picture:



15. Have you ever thought of nature and the environment in regards to the benefits and services it provides to people

- ◯ Very aware
- ◯ Moderately aware
- ◯ Slightly aware
- ◯ Never thought of it

Definition of ecosystem services

Definition of each ecosystem service (this list will re-appear with the next few questions):

	Provisioning Services
	Food: Ecosystems provide the conditions for growing food such as fish in wild habitats.
	Raw materials: Ecosystems provide materials for construction such as fine timbers.
	Fresh water: Ecosystems provide surface and groundwater.
	Medicinal resources: Many plants are used as traditional medicines and as input for the pharmaceutical industry.
	Regulating Services
	Local climate and air quality regulation: Water and vegetation reduce temperature extremes.
	Carbon sequestration and storage: As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
	Moderation of extreme events: Ecosystems can create buffers against natural hazards such as floods.
	Waste-water treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as pollutants.
	Erosion prevention: Vegetation prevents river and foreshore erosion.
	Pollination: Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.
	Biological control: Ecosystems are important for regulating pests and vector borne diseases.
	Habitat or Supporting Services
	Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.
	Maintenance of genetic diversity: Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial species.
	Cultural Services
	Recreation and mental and physical health: The roles of natural landscapes and green space for maintaining mental and physical health is increasingly being recognised.
	Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for some regions.
	Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
	Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Importance of ecosystem services in the Flinders Catchment

16. Please rate the importance of each ecosystem service category

	Very high	High	Neutral	Low	Very low
Regulating	◯	◯	◯	◯	◯
Cultural	◯	◯	◯	◯	◯
Habitat	◯	◯	◯	◯	◯
Provisioning	◯	◯	◯	◯	◯

Provisioning Services

Food: Ecosystems provide the conditions for growing food such as fish in wild habitats.

Raw materials: Ecosystems provide materials for construction such as fine timbers.

Fresh water: Ecosystems provide surface and groundwater.

Medicinal resources: Many plants are used as traditional medicines and as input for the pharmaceutical industry.

Regulating Services

Local climate and air quality regulation: Water and vegetation reduce temperature extremes.

Carbon sequestration and storage: As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.

Moderation of extreme events: Ecosystems can create buffers against natural hazards such as floods.

Waste-water treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as pollutants.

Erosion prevention: Vegetation prevents river and foreshore erosion.

Pollination: Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.

Biological control: Ecosystems are important for regulating pests and vector borne diseases.

Habitat or Supporting Services

Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.

Maintenance of genetic diversity: Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial species.

Cultural Services

Recreation and mental and physical health: The roles of natural landscapes and green space for maintaining mental and physical health is increasingly being recognised.

Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for some regions.

Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.

Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Importance of ecosystem services in the Flinders Catchment

17. The following are various ecosystem services provided by nature in the Flinders Catchment. How important are they to you?

	Very high	High	Neutral	Low	Very low
Biological control	○	○	○	○	○
Local climate and air quality regulation	○	○	○	○	○
Carbon storage in trees and soil	○	○	○	○	○
Spiritual experience and sense of place	○	○	○	○	○
Moderation of extreme events	○	○	○	○	○
Erosion prevention	○	○	○	○	○
Food	○	○	○	○	○
Raw materials	○	○	○	○	○
Tourism	○	○	○	○	○
Pollination	○	○	○	○	○
Maintenance of genetic diversity	○	○	○	○	○
Habitats for species	○	○	○	○	○
Freshwater	○	○	○	○	○
Aesthetic appreciation and inspiration for culture, art and design	○	○	○	○	○
Recreation, mental and physical health	○	○	○	○	○

	Provisioning Services
	Food: Ecosystems provide the conditions for growing food such as fish in wild habitats.
	Raw materials: Ecosystems provide materials for construction such as fine timbers.
	Fresh water: Ecosystems provide surface and groundwater.
	Medicinal resources: Many plants are used as traditional medicines and as input for the pharmaceutical industry.
	Regulating Services
	Local climate and air quality regulation: Water and vegetation reduce temperature extremes.
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	Waste-water treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as pollutants.
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	Biological control: Ecosystems are important for regulating pests and vector borne diseases.
	Habitat or Supporting Services
	Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.
	Maintenance of genetic diversity: Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial species.
	Cultural Services
	Recreation and mental and physical health: The roles of natural landscapes and green space for maintaining mental and physical health is increasingly being recognised.
	Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for some regions.
	Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
	Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Importance of ecosystem services in the Flinders Catchment

18. Please prioritise the following 'Cultural' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 4 = least important to protect

- [ ] Tourism
- [ ] Recreation, mental and physical health
- [ ] Spiritual experience and sense of place
- [ ] Aesthetic appreciation and inspiration for culture, art and design

Ecosystem Services Survey - Flinders Catchment

	Provisioning Services
	Food: Ecosystems provide the conditions for growing food such as fish in wild habitats.
	Raw materials: Ecosystems provide materials for construction such as fine timbers.
	Fresh water: Ecosystems provide surface and groundwater.
	Medicinal resources: Many plants are used as traditional medicines and as input for the pharmaceutical industry.
	Regulating Services
	Local climate and air quality regulation: Water and vegetation reduce temperature extremes.
	Carbon sequestration and storage: As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
	Moderation of extreme events: Ecosystems can create buffers against natural hazards such as floods.
	Waste-water treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as pollutants.
	Erosion prevention: Vegetation prevents river and foreshore erosion.
	Pollination: Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.
	Biological control: Ecosystems are important for regulating pests and vector borne diseases.
	Habitat or Supporting Services
	Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.
	Maintenance of genetic diversity: Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial species.
	Cultural Services
	Recreation and mental and physical health: The roles of natural landscapes and green space for maintaining mental and physical health is increasingly being recognised.
	Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for some regions.
	Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
	Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Importance of ecosystem services in the Flinders Catchment

19. Please prioritise the following 'Regulating' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 7 = least important to protect

- [ ] Local climate and air quality regulation
- [ ] Waste-water treatment
- [ ] Carbon sequestration and storage
- [ ] Moderation of extreme events
- [ ] Pollination
- [ ] Biological control
- [ ] Erosion prevention

Provisioning Services	
Food:	Ecosystems provide the conditions for growing food such as fish in wild habitats.
Raw materials:	Ecosystems provide materials for construction such as fine timbers.
Fresh water:	Ecosystems provide surface and groundwater.
Medicinal resources:	Many plants are used as traditional medicines and as input for the pharmaceutical industry.
Regulating Services	
Local climate and air quality regulation:	Water and vegetation reduce temperature extremes.
Carbon sequestration and storage:	As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
Moderation of extreme events:	Ecosystems can create buffers against natural hazards such as floods.
Waste-water treatment:	Micro-organisms in soil and in wetlands decompose human and animal waste, as well as pollutants.
Erosion prevention:	Vegetation prevents river and foreshore erosion.
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Habitats for species:	Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.
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Cultural Services	
Recreation and mental and physical health:	The roles of natural landscapes and green space for maintaining mental and physical health is increasingly being recognised.
Tourism:	Nature tourism provides considerable economic benefits and is a vital source of income for some regions.
Aesthetic appreciation and inspiration for culture, art and design:	Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
Spiritual experience and sense of place:	Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Importance of ecosystem services in the Flinders Catchment

20. Please prioritize the following 'Provisioning' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 4 = least important to protect

- [ ] Food
- [ ] Freshwater
- [ ] Raw materials
- [ ] Medicinal resources

Ecosystem Services Survey - Flinders Catchment

Provisioning Services

Food: Ecosystems provide the conditions for growing food such as fish in wild habitats.

Raw materials: Ecosystems provide materials for construction such as fine timbers.

Fresh water: Ecosystems provide surface and groundwater.

Medicinal resources: Many plants are used as traditional medicines and as input for the pharmaceutical industry.

Regulating Services

Local climate and air quality regulation: Water and vegetation reduce temperature extremes.

Carbon sequestration and storage: As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.

Moderation of extreme events: Ecosystems can create buffers against natural hazards such as floods.

Waste-water treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as pollutants.

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Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.

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Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.

Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Management of water and land in the Flinders Catchment

21. Which of the following ecosystem services do you think are worth paying to protect and improve in the Flinders Catchment?

- [ ] Habitats for species
- [ ] Local climate and air quality regulation
- [ ] Tourism
- [ ] Freshwater
- [ ] Aesthetic appreciation and inspiration for culture, art and design
- [ ] Carbon storage in trees and soil
- [ ] Raw materials
- [ ] Moderation of extreme events
- [ ] Maintenance of genetic diversity
- [ ] Biological control
- [ ] Erosion prevention
- [ ] Pollination
- [ ] Food
- [ ] Recreation, mental and physical health
- [ ] Spiritual experience and sense of place

Ecosystem Services Survey - Flinders Catchment

	Provisioning Services
	Food: Ecosystems provide the conditions for growing food such as fish in wild habitats.
	Raw materials: Ecosystems provide materials for construction such as fine timbers.
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	Local climate and air quality regulation: Water and vegetation reduce temperature extremes.
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	Biological control: Ecosystems are important for regulating pests and vector borne diseases.
	Habitat or Supporting Services
	Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migration routes.
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	Cultural Services
	Recreation and mental and physical health: The roles of natural landscapes and green space for maintaining mental and physical health is increasingly being recognised.
	Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for some regions.
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	Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Management of water and land in the Flinders Catchment

22. Which of the following statements comes closest to your opinion?

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
These areas are undeveloped and water resources should be used for new agriculture	◯	◯	◯	◯	◯
Managing the Flinders Catchment for the benefits it provides to ALL people is first and foremost	◯	◯	◯	◯	◯
Economic development is a priority, regardless of any damages to the natural environment	◯	◯	◯	◯	◯
Sustainable development is most important, even if that means missing some economic opportunities	◯	◯	◯	◯	◯
The cost of protecting and managing ecosystem services provided by water and land in the Catchment is not an issue; the water and land resources should be protected at all costs	◯	◯	◯	◯	◯
We have a moral obligation to maintain wilderness areas for future generations	◯	◯	◯	◯	◯
I do not see how the protection and management of nature and its benefits affects me	◯	◯	◯	◯	◯

Management of water and land in the Flinders Catchment

23. How do you feel about the following water development options for water resources in the Flinders Catchment

	Perfectly acceptable	Slightly acceptable	Slightly unacceptable	Totally unacceptable	Don't know
Leave sufficient water in the rivers to maintain ALL ecosystem services	◯	◯	◯	◯	◯
Leave sufficient water in the rivers to maintain the Regulating and Habitat ecosystem services	◯	◯	◯	◯	◯
Only leave sufficient water in rivers to prevent complete collapse of the natural system	◯	◯	◯	◯	◯
Develop all the available water resources	◯	◯	◯	◯	◯
No further development (Do nothing)	◯	◯	◯	◯	◯
Leave sufficient water in the rivers to maintain the Provisioning and Cultural ecosystem services	◯	◯	◯	◯	◯

Management of water and land in the Flinders Catchment

24. Please rank the following objectives for water development in the Flinders Catchment. 1 = most important, 5 = least important

- [ ] If I had to choose, I would favour the economy over the environment
- [ ] Sustainable development that balances the needs of the environment and communities
- [ ] If I had to choose, I would favour the environment over the economy
- [ ] Economic development, regardless of the environmental impacts
- [ ] Do not develop - keep these rivers and ecosystems as is

Final comments

25. You are welcome to make extra comments or suggestions on any issue in the space below. Please enter your response in the textbox.

Your contact details (optional)

We may choose to follow up with respondents, so would like your name and email address. Please note that this is entirely optional.

26. Your name:

27. Your email address:

A.2 Social Values Survey Results

Flinders Catchment

Have you ever visited the Flinders Catchment?		
Answer Options	**Response Percent**	**Response Count**
Yes	100.0%	14
No	0.0%	0

What were the reasons for visiting the Flinders Catchment?		
Answer Options	**Response Percent**	**Response Count**
Camping	23.1%	3
Nature experiences	30.8%	4
Fishing	23.1%	3
Boating	15.4%	2
Four-wheel driving	15.4%	2
Walking	7.7%	1
Cultural heritage	0.0%	0
I live there	15.4%	2
I work there	92.3%	12
Other (please specify)		5

What is your age?		
Answer Options	**Response Percent**	**Response Count**
18 to 24	0.0%	0
25 to 34	0.0%	0
35 to 44	30.8%	4
45 to 54	38.5%	5
55 to 64	23.1%	3
65 to 74	7.7%	1
75 or older	0.0%	0

What is your gender?		
Answer Options	**Response Percent**	**Response Count**
Female	7.7%	1
Male	92.3%	12

Have you finished high school?		
Answer Options	**Response Percent**	**Response Count**
Yes	100.0%	13
No	0.0%	0

Have you attained any other qualifications (please tick)?		
Answer Options	**Response Percent**	**Response Count**
Vocational	0.0%	0
Bachelor and/or graduate degree	30.0%	3
Post graduate degree	80.0%	8
Other (please specify)		1

Which of the following best describes your current occupation?		
Answer Options	**Response Percent**	**Response Count**
Professional and managerial	84.6%	11
Trade and semi-professional	0.0%	0
Service industries	0.0%	0
Self-employed	15.4%	2
Not currently employed	0.0%	0
Other (please specify)		0

Which of the following best describes your expertise in the Flinders Catchment (can select multiple answers)		
Answer Options	**Response Percent**	**Response Count**
Ecologist	30.0%	3
Hydrologist	20.0%	2

Land manager (e.g. beef producer)	30.0%	3
Policy specialist	0.0%	0
Natural resource manager	30.0%	3
People and communities (e.g. councilor, small business operator)	30.0%	3
Other (please specify)		3

What is your approximate average annual household income?

Answer Options	Response Percent	Response Count
Less than $50,000	0.0%	0
$50,000 - $99,999	46.2%	6
$100,000 - $149,999	30.8%	4
$150,000 or more	23.1%	3

Which of the following has/have an effect on how you feel about nature?

Answer Options	Response Percent	Response Count
Stories I heard, the experiences I had in my childhood and the values I was taught by family	53.8%	7
My experience with nature and the effect it has on me	84.6%	11
Social values, what people around me do	46.2%	6
Environmental organisations in Australia	30.8%	4
Education	61.5%	8

Media outlets (newspapers, TV, radio, social media)	38.5%	5
Movies, documentary films, fictional books	30.8%	4
Other (please specify)		0

How important are the following as reasons for experiencing the Flinders Catchment					
Answer Options	**Very important**	**Moderately important**	**Low importance**	**Not important**	**Response Count**
Physical exercise	0	2	8	2	12
Relaxation and mental rest	2	4	4	1	11
Challenge of wilderness experiences	1	3	7	1	12
Sense of place, belonging and spiritual experience	3	5	4	0	12
Learning from nature	3	4	5	1	13
Family / friendship bonding	3	2	6	1	12
Privacy and getting away from it all	2	4	5	1	12
Nature and recreation activities (e.g. bird watching, fishing, camping)	2	6	4	0	12
Enjoying the scenery	4	6	1	0	11
Earning an income	6	4	3	0	13

How familiar are you with the following terms?					
Answer Options	**Very familiar**	**Moderately familiar**	**Slightly familiar**	**Never heard of**	**Response Count**
Biodiversity	12	1	0	0	13
Ecosystem services	9	2	2	0	13
Habitat	11	2	0	0	13

Nature's benefits	7	5	1	0	13
Natural capital	7	4	2	0	13

Have you ever thought of nature and the environment in regards to the benefits and services it provides to people

Answer Options	Response Percent	Response Count
Very aware	84.6%	11
Moderately aware	15.4%	2
Slightly aware	0.0%	0
Never thought of it	0.0%	0

Please rate the importance of each ecosystem service category

Answer Options	Very high	High	Neutral	Low	Very low	Rating Average	Response Count
Cultural	5	3	2	3	0	2.23	13
Regulating	6	4	3	0	0	1.77	13
Provisioning	10	3	0	0	0	1.23	13
Habitat	9	1	2	1	0	1.62	13

The following are various ecosystem services provided by nature in the Flinders Catchment. How important are they to you?

Answer Options	Very high	High	Neutral	Low	Very low	Rating Average	Response Count
Freshwater	8	4	0	1	0	1.54	13

Food	6	3	4	0	0	1.85	13
Raw materials	5	3	3	2	0	2.15	13
Tourism	1	6	3	3	0	2.62	13
Local climate and air quality regulation	2	4	3	2	2	2.85	13
Moderation of extreme events	1	6	4	1	1	2.62	13
Carbon storage in trees and soil	1	2	6	3	1	3.08	13
Erosion prevention	5	5	3	0	0	1.85	13
Pollination	3	3	5	2	0	2.46	13
Biological control	1	7	4	1	0	2.38	13
Habitats for species	6	6	1	0	0	1.62	13
Maintenance of genetic diversity	6	0	5	2	0	2.23	13
Spiritual experience and sense of place	1	5	3	2	2	2.92	13
Aesthetic appreciation and inspiration for culture, art and design	1	5	3	2	2	2.92	13
Recreation, mental and physical health	0	4	7	1	1	2.92	13

Please prioritise the following 'Cultural' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 4 = least important to protect

Answer Options	**1**	**2**	**3**	**4**	**Rating Average**	**Response Count**
Tourism	5	3	0	5	2.38	13
Spiritual experience and sense of place	5	5	3	0	1.85	13
Aesthetic appreciation and inspiration for culture, art and design	2	2	3	6	3.00	13
Recreation, mental and physical health	1	3	7	2	2.77	13

Please prioritise the following 'Regulating' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 7 = least important to protect									
Answer Options	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Rating Average**	**Response Count**
Local climate and air quality regulation	1	1	3	1	2	1	4	4.62	13
Moderation of extreme events	1	3	2	2	3	1	1	3.77	13
Carbon sequestration and storage	2	1	1	1	4	2	2	4.38	13
Waste-water treatment	0	2	2	1	2	3	3	4.85	13
Erosion prevention	4	3	1	3	1	0	1	2.85	13
Pollination	1	2	4	1	0	4	1	4.00	13
Biological control	4	1	0	4	1	2	1	3.54	13

Please prioritize the following 'Provisioning' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 4 = least important to protect						
Answer Options	**1**	**2**	**3**	**4**	**Rating Average**	**Response Count**
Freshwater	9	2	1	1	1.54	13
Food	4	9	0	0	1.69	13
Raw materials	0	1	9	3	3.15	13
Medicinal resources	0	1	3	9	3.62	13

Which of the following ecosystem services do you think are worth paying to protect and improve in the Flinders Catchment?		
Answer Options	**Response Percent**	**Response Count**

Freshwater	76.9%	10
Food	76.9%	10
Raw materials	61.5%	8
Tourism	38.5%	5
Local climate and air quality regulation	7.7%	1
Moderation of extreme events	7.7%	1
Carbon storage in trees and soil	30.8%	4
Erosion prevention	76.9%	10
Pollination	15.4%	2
Biological control	23.1%	3
Habitats for species	61.5%	8
Maintenance of genetic diversity	38.5%	5
Spiritual experience and sense of place	38.5%	5
Aesthetic appreciation and inspiration for culture, art and design	15.4%	2
Recreation, mental and physical health	30.8%	4

Which of the following statements comes closest to your opinion?

Answer Options	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Rating Average	Response Count
I do not see how the protection and management of nature and its benefits affects me	0	2	2	4	5	3.92	13
We have a moral obligation to maintain wilderness areas for future generations	5	5	2	1	0	1.92	13
The cost of protecting and managing ecosystem services provided by water and land in the Catchment is not an issue; the water and land resources should be protected	2	3	4	4	0	2.77	13

at all costs							
Managing the Flinders Catchment for the benefits it provides to ALL people is first and foremost	5	3	3	2	0	2.15	13
These areas are undeveloped and water resources should be used for new agriculture	6	4	2	1	0	1.85	13
Economic development is a priority, regardless of any damages to the natural environment	0	3	3	2	5	3.69	13
Sustainable development is most important, even if that means missing some economic opportunities	5	2	4	2	0	2.23	13

How do you feel about the following water development options for water resources in the Flinders Catchment

Answer Options	Perfectly acceptable	Slightly acceptable	Slightly unacceptable	Totally unacceptable	Don't know	Response Count
Develop all the available water resources	4	2	1	6	0	13
Only leave sufficient water in rivers to prevent complete collapse of the natural system	0	2	4	7	0	13
Leave sufficient water in the rivers to maintain the Provisioning and Cultural ecosystem services	5	5	3	0	0	13
Leave sufficient water in the rivers to maintain the Regulating and Habitat ecosystem services	6	6	1	0	0	13
Leave sufficient water in the rivers to maintain ALL ecosystem services	3	6	2	2	0	13
No further development (Do nothing)	2	0	2	9	0	13

Please rank the following objectives for water development in the Flinders Catchment. 1 = most important, 5 = least important

Answer Options	1	2	3	4	5	Rating Average	Response Count

Economic development, regardless of the environmental impacts	2	1	3	3	4	3.46	13
Do not develop - keep these rivers and ecosystems as is	1	2	1	3	6	3.85	13
Sustainable development that balances the needs of the environment and communities	6	2	3	2	0	2.08	13
If I had to choose, I would favour the economy over the environment	2	4	3	3	1	2.77	13
If I had to choose, I would favour the environment over the economy	2	4	3	2	2	2.85	13

Gilbert Catchment

Have you ever visited the Gilbert Catchment?		
Answer Options	**Response Percent**	**Response Count**
Yes	88.2%	15
No	11.8%	2

What were the reasons for visiting the Gilbert Catchment?		
Answer Options	**Response Percent**	**Response Count**
Camping	46.7%	7
Nature experiences	33.3%	5
Fishing	20.0%	3
Boating	20.0%	3
Four-wheel driving	13.3%	2
Walking	6.7%	1
Cultural heritage	13.3%	2
I live there	33.3%	5
I work there	66.7%	10
Other (please specify)		3

What is your age?		
Answer Options	**Response Percent**	**Response Count**

18 to 24	0.0%	0
25 to 34	0.0%	0
35 to 44	35.3%	6
45 to 54	47.1%	8
55 to 64	11.8%	2
65 to 74	5.9%	1
75 or older	0.0%	0

What is your gender?

Answer Options	Response Percent	Response Count
Female	11.8%	2
Male	88.2%	15

Have you finished high school?

Answer Options	Response Percent	Response Count
Yes	93.8%	15
No	6.3%	1

Have you attained any other qualifications (please tick)?

Answer Options	Response Percent	Response Count
Vocational	7.1%	1

Bachelor and/or graduate degree	50.0%	7
Post graduate degree	50.0%	7
Other (please specify)		0

Which of the following best describes your current occupation?

Answer Options	Response Percent	Response Count
Professional and managerial	81.3%	13
Trade and semi-professional	0.0%	0
Service industries	0.0%	0
Self-employed	18.8%	3
Not currently employed	0.0%	0
Other (please specify)		1

Which of the following best describes your expertise in the Gilbert Catchment (can select multiple answers)

Answer Options	Response Percent	Response Count
Ecologist	33.3%	5
Hydrologist	20.0%	3
Land manager (e.g. beef producer)	20.0%	3
Policy specialist	6.7%	1
Natural resource manager	20.0%	3
People and communities (e.g. councilor, small business operator)	13.3%	2
Other (please specify)		3

What is your approximate average annual household income?		
Answer Options	**Response Percent**	**Response Count**
Less than $50,000	6.7%	1
$50,000 - $99,999	33.3%	5
$100,000 - $149,999	46.7%	7
$150,000 or more	13.3%	2

Which of the following has/have an effect on how you feel about nature?		
Answer Options	**Response Percent**	**Response Count**
Stories I heard, the experiences I had in my childhood and the values I was taught by family	53.3%	8
My experience with nature and the effect it has on me	80.0%	12
Social values, what people around me do	46.7%	7
Environmental organisations in Australia	46.7%	7
Education	66.7%	10
Media outlets (newspapers, TV, radio, social media)	33.3%	5
Movies, documentary films, fictional books	40.0%	6
Other (please specify)		0

How important are the following as reasons for experiencing the Gilbert Catchment

Answer Options	Very important	Moderately important	Low importance	Not important	Response Count
Physical exercise	2	4	4	4	14
Relaxation and mental rest	4	4	5	1	14
Challenge of wilderness experiences	3	4	4	3	14
Sense of place, belonging and spiritual experience	2	5	4	3	14
Learning from nature	3	7	4	0	14
Family / friendship bonding	3	2	6	3	14
Privacy and getting away from it all	5	2	4	3	14
Nature and recreation activities (e.g. bird watching, fishing, camping)	5	5	4	0	14
Enjoying the scenery	5	8	1	0	14
Earning an income	7	4	2	2	15

How familiar are you with the following terms?

Answer Options	Very familiar	Moderately familiar	Slightly familiar	Never heard of	Response Count
Biodiversity	11	3	0	0	14
Ecosystem services	8	6	0	1	15
Habitat	13	1	0	0	14
Nature's benefits	8	5	1	0	14
Natural capital	4	7	2	1	14

Have you ever thought of nature and the environment in regards to the benefits and services it provides to people		
Answer Options	**Response Percent**	**Response Count**
Very aware	73.3%	11
Moderately aware	20.0%	3
Slightly aware	6.7%	1
Never thought of it	0.0%	0

Please rate the importance of each ecosystem service category							
Answer Options	**Very high**	**High**	**Neutral**	**Low**	**Very low**	**Rating Average**	**Response Count**
Cultural	4	6	4	0	1	2.20	15
Regulating	4	9	2	0	0	1.87	15
Provisioning	7	5	3	0	0	1.73	15
Habitat	10	3	2	0	0	1.47	15

The following are various ecosystem services provided by nature in the Gilbert Catchment. How important are they to you?							
Answer Options	**Very high**	**High**	**Neutral**	**Low**	**Very low**	**Rating Average**	**Response Count**
Freshwater	8	4	3	0	0	1.67	15
Food	6	3	4	1	1	2.20	15
Raw materials	1	6	7	1	0	2.53	15
Tourism	2	3	7	2	1	2.80	15
Local climate and air quality regulation	5	5	3	2	0	2.13	15

Moderation of extreme events	3	3	7	2	0	2.53	15
Carbon storage in trees and soil	3	4	8	0	0	2.33	15
Erosion prevention	5	6	3	1	0	2.00	15
Pollination	6	5	2	2	0	2.00	15
Biological control	7	4	2	2	0	1.93	15
Habitats for species	9	5	1	0	0	1.47	15
Maintenance of genetic diversity	5	6	4	0	0	1.93	15
Spiritual experience and sense of place	2	6	3	3	1	2.67	15
Aesthetic appreciation and inspiration for culture, art and design	1	3	6	3	2	3.13	15
Recreation, mental and physical health	1	8	4	2	0	2.47	15

Please prioritise the following 'Cultural' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 4 = least important to protect

Answer Options	1	2	3	4	Rating Average	Response Count
Tourism	3	3	3	6	2.80	15
Spiritual experience and sense of place	5	4	2	4	2.33	15
Aesthetic appreciation and inspiration for culture, art and design	3	3	4	5	2.73	15
Recreation, mental and physical health	4	5	6	0	2.13	15

Please prioritise the following 'Regulating' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 7 = least important to protect

Answer Options	1	2	3	4	5	6	7	Rating Average	Response Count
Local climate and air quality regulation	1	1	4	3	1	**3**	2	4.27	15

Moderation of extreme events	2	4	3	0	3	2	1	3.53	15
Carbon sequestration and storage	1	1	1	1	2	6	3	5.13	15
Waste-water treatment	1	1	3	1	1	1	7	5.07	15
Erosion prevention	6	4	0	3	2	0	0	2.40	15
Pollination	1	0	4	3	4	1	2	4.33	15
Biological control	3	4	0	4	2	2	0	3.27	15

Please prioritize the following 'Provisioning' ecosystem services according to how important they are to protect from harm. 1 = most important to protect, 4 = least important to protect

Answer Options	1	2	3	4	Rating Average	Response Count
Freshwater	10	3	1	1	1.53	15
Food	3	9	2	1	2.07	15
Raw materials	1	3	6	5	3.00	15
Medicinal resources	1	0	6	8	3.40	15

Which of the following ecosystem services do you think are worth paying to protect and improve in the Gilbert Catchment?

Answer Options	Response Percent	Response Count
Freshwater	73.3%	11
Food	53.3%	8
Raw materials	33.3%	5
Tourism	46.7%	7
Local climate and air quality regulation	33.3%	5
Moderation of extreme events	40.0%	6

Carbon storage in trees and soil	33.3%	5
Erosion prevention	86.7%	13
Pollination	40.0%	6
Biological control	53.3%	8
Habitats for species	80.0%	12
Maintenance of genetic diversity	53.3%	8
Spiritual experience and sense of place	33.3%	5
Aesthetic appreciation and inspiration for culture, art and design	33.3%	5
Recreation, mental and physical health	33.3%	5

Which of the following statements comes closest to your opinion?

Answer Options	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Rating Average	Response Count
I do not see how the protection and management of nature and its benefits affects me	0	0	2	2	10	4.57	14
We have a moral obligation to maintain wilderness areas for future generations	7	3	2	1	1	2.00	14
The cost of protecting and managing ecosystem services provided by water and land in the Catchment is not an issue; the water and land resources should be protected at all costs	3	5	1	1	3	2.69	13
Managing the Gilbert Catchment for the benefits it provides to ALL people is first and foremost	2	5	3	1	3	2.86	14
These areas are undeveloped and water resources should be used for new agriculture	5	4	3	1	2	2.40	15
Economic development is a priority, regardless of any damages to the natural environment	0	2	1	3	8	4.21	14

Sustainable development is most important, even if that means missing some economic opportunities	6	6	0	2	0	1.86	14

How do you feel about the following water development options for water resources in the Gilbert Catchment						
Answer Options	**Perfectly acceptable**	**Slightly acceptable**	**Slightly unacceptable**	**Totally unacceptable**	**Don't know**	**Response Count**
Develop all the available water resources	1	2	3	8	0	14
Only leave sufficient water in rivers to prevent complete collapse of the natural system	0	2	1	11	0	14
Leave sufficient water in the rivers to maintain the Provisioning and Cultural ecosystem services	8	4	0	1	1	14
Leave sufficient water in the rivers to maintain the Regulating and Habitat ecosystem services	11	4	0	0	0	15
Leave sufficient water in the rivers to maintain ALL ecosystem services	9	3	2	0	0	14
No further development (Do nothing)	0	2	6	6	0	14

Please rank the following objectives for water development in the Gilbert Catchment. 1 = most important, 5 = least important							
Answer Options	**1**	**2**	**3**	**4**	**5**	**Rating Average**	**Response Count**
Economic development, regardless of the environmental impacts	1	2	0	2	10	4.20	15
Do not develop - keep these rivers and ecosystems as is	2	0	4	5	4	3.60	15
Sustainable development that balances the needs of the environment and communities	7	4	3	0	1	1.93	15
If I had to choose, I would favour the economy over the environment	1	2	6	6	0	3.13	15

If I had to choose, I would favour the environment over the economy	4	7	2	2	0	2.13	15

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