Ecosystem Services and Environmental Flows:

A case study of the North West Bay River, Tasmania

Shane Olsen
University of Tasmania[1]

Abstract

Current attention has focused on the concept of 'ecosystem services' to understand the environmental resource base on which society depends. This presentation discusses the ecosystem services approach using an application to a local water management issue in Tasmania, Australia. Recent community and political initiatives in the North West Bay River Catchment have advocated for the provision of an environmental flow downstream of the city of Hobart's water supply intakes for the benefits to various stakeholders. The ecosystem services at question here include the benefits of the river for providing ecological habitat and diversity, maintaining public and private water supplies, and enhancing recreational and cultural values associated with a less regulated river. A number of future management scenarios are developed in conjunction with an expert panel of stakeholder and scientific representatives. Potential changes in ecosystem services are evaluated across these scenarios using a multi-criteria analysis (MCA) framework. The results suggest that a focus on achieving overall catchment management outcomes, including the provision of an environmental flow, will have the greatest positive benefit for ecosystem services associated with the North West Bay River.

1 Introduction

Mounting evidence is emerging to show that every ecosystem on the planet is showing signs of deterioration (Brown 2000). Important characteristics of natural ecosystems are being dramatically altered in the atmosphere, oceans and terrestrial systems (Vitousek et al. 1997; Daily 1999). The scope and magnitude of these environmental problems is seriously threatening the ability of nature to provide crucial goods and services to human society (Dasgupta et al. 2000; MA 2005).

Recent attention has focused on the concept of 'ecosystem services' to describe the environmental resource base on which society depends (Cork 2001). Ecosystem services are the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfill human life (Daily 1997). They include goods such as those of food, raw materials and fresh water, cultural values such as scenery, educational and heritage values, as well as the services that maintain biodiversity and life-supporting functions, which

[1] School of Geography and Environmental Studies, University of Tasmania, Hobart, Tasmania, Australia 7001; Email: snolsen@utas.edu.au

includes the pollination of crops, the maintenance of fertile soil, and the movement of water through a river catchment.

Currently, many ecosystem services are in decline due to human ignorance of their value and inadequate social and economic mechanisms to manage them sustainably (Cork et al. 2001). Because ecosystem services are not fully captured in economic markets or adequately quantified in terms comparable with other types of services, they are often given little weight in decision-making and policy formulation (Costanza et al. 1997; Jansson et al. 1999). Furthermore, many services are considered as 'free' and excluded from human ownership. As no one owns or has rights to these services and cannot be excluded from gaining benefits from them, little incentive exists for beneficiaries to manage them sustainably (Dasgupta et al. 2000).

Despite a general understanding that ecosystems are valuable, there is a need to know how valuable they are, and how the value of ecosystems is affected by different management actions (Pagiola et al. 2004). Unfortunately, little progress has been made in integrating economic techniques with ecological impact assessment in order to reach balanced decisions about the overall acceptability of ecological change (Farber et al. 2006). This paper provides an overview of the development of an evaluation tool that explicitly considers the interdependencies between ecosystems and the values of human society, particularly for those values that cannot be directly expressed in markets and by monetary measures. The aim is to more effectively take into account the full complexity of human's relationship with natural systems.

To begin, a typology of ecosystem services is described, which broadly classifies services into three types: ecological, provisioning and cultural services. This typology is applied to a case study of a water management issue for the North West Bay River in Tasmania, Australia. Recent community and political initiatives in the North West Bay River Catchment have advocated for the provision of an environmental flow downstream of the city of Hobart's water supply intakes for the benefits to various stakeholders. Four future management scenarios are developed in conjunction with an expert panel of stakeholder and scientific representatives. Potential changes in ecosystem services are evaluated across these four scenarios using a multi-criteria analysis (MCA) framework. The results outline that an emphasis on protecting the quality of the river environment, through such measures as riparian enhancement and the provision of an environmental flow, will have the greatest positive benefit for ecosystem services associated with the North West Bay River.

2 Ecosystem Services

Ecosystem services are derived from ecosystem functions (processes and components) that operate at varying scales in time and space (Limburg et al. 2002). The distinction between ecosystem functions and services is brought about when human values are implied (de Groot et al. 2002). A function may or may not have a corresponding service, depending on whether humans value it (Scott et al. 1998). Thus, they rely on the presence of human beings as valuing agents to make the transition between basic ecological processes and value-laden entities (de Groot et al. 2002).

2.1 Ecosystem Service Classifications

Ecosystem services can be defined and classified in a number of ways depending on scale and perspective (Daily 1997). However, developing any form of ecosystem service classification is extremely challenging, and worthy of caution, given the complex relationships that exist in ecosystems. A key problem ecologists face is the high level of interconnectedness between and within ecosystems, which makes it difficult to understand specific systems for analysis (Gilbert and Janssen 1998).

Ecosystem services are provided by ecosystem-wide or community attributes that are characterised by component populations, species and habitat types that produce them (Kremen 2005). No single ecosystem attribute lives in isolation, but is connected to a much wider system, meaning that it is often not straightforward in distinguishing between services. In many cases, a single ecosystem service may correspond to input from two or more ecosystem functions, while on the other hand, one function may correspond to two or more services (Costanza et al. 1997; de Groot et al. 2002). For example, the 'gas regulation' function in terms of bio-geochemical cycles, such as the carbon cycle, influences both the maintenance of good air quality and also climate regulation in the form of the greenhouse effect (de Groot et al. 2002).

Ecosystem services depend on people's understanding and perceptions of the services and their benefits, both of which can be poorly informed (Cork and Procter 2004). For example, Lewan and Soderqvist (2002) examined the knowledge and recognition of ecosystem services by the general public using the case of a plant nutrient abatement programme in the Kavlinge River basin in southern Sweden. They found that there was significant public uncertainty regarding relationships among and the importance of perceived 'invisible' services, such as the range of ecosystem services generated from forests (Lewan and Soderqvist 2002; Silvano et al. 2005). This is because people may not be able to comprehend some services because of a non-scientific worldview or a lack of scientific knowledge (Lewan and Soderqvist 2002).

2.2 A Typology of Ecosystem Services

Several studies have focused on developing a typology or classification for ecosystem services. Ecosystem services have been classified in a number of different ways, including by functional, organizational and descriptive groupings (e.g. Norberg 1999; de Groot et al. 2002; MA 2003). For example, a classification by de Groot et al. (2002) outlines ecosystem services as derived from four main ecosystem functions – regulation, habitat, production and information functions. For practical purposes, I distinguish ecosystem services into three major types: provisioning services, which people directly derive utility from their actual or potential use; ecological services which regulate and support ecosystem processes and are needed to maintain other services, and cultural services, which are those elements of the environment based on different worldviews and conceptions of nature.

Table 1: Classifications of Ecosystem Services

	Costanza et al. (1997)	***De Groot et al. (2002)***	***Millennium Ecosystem Assessment (2003)***
Ecological Services (Regulating, Habitat and Supporting Services)	Gas regulation Climate regulation Disturbance regulation Water regulation Soil formation Erosion control and sediment retention Nutrient cycling Waste treatment Pollination Biological control Refugia	Gas regulation Climate regulation Disturbance prevention Water regulation Soil formation Soil retention Nutrient regulation Waste treatment Pollination Biological control Refugium function Nursery function	Air quality maintenance Climate regulation Storm control Water regulation Soil formation Erosion control Nutrient cycling Water purification & waste treatment Pollination Biological control Regulation of human diseases
Provisioning Services (Ecosystem Goods)	Food production Raw materials Water supply Genetic resources (including medicines)	Food Raw materials Water supply Genetic resources Medicinal resources Ornamental resources	Food & fibre Primary production Fuel Freshwater Genetic resources Biochemicals, natural medicines & pharmaceuticals Ornamental resources
Cultural Services	 Recreation Cultural (including aesthetic, artistic, educational, spiritual and scientific values)	Aesthetic Recreation Cultural & artistic information Spiritual & historic information Science and education	Aesthetic Recreation & ecotourism Cultural heritage Cultural diversity Sense of place Social relations Spiritual & religious values Knowledge systems Educational values Inspiration

2.2.1 Provisioning Services

Individual parts (or groups of components) within ecosystems have properties that make them of direct value in satisfying human needs. These are the products (or ecosystem "goods") obtained from ecosystems that human populations use in abundance, such as the supply of clean water and food products for direct human consumption. A number of other products fall into this category of services, including materials that serve as a source of energy, genetic resources, and natural medicines and biochemicals.

The distinction between a provisioning service (ecosystem good) and other services can be recognised when value is added by human labour (Hueting et al. 1998). For example, a forest that is involved in providing various services, such as soil retention, water regulation and plant and animal habitat (as well as being an end-product of the ecosystem itself), is converted to an ecosystem good when human labour is involved in harvesting the forest as a source of timber.

2.2.2 Cultural Services

There are a range of non-material benefits that people obtain from ecosystems. Cultural services include benefits received from ecosystems relating to aesthetic values, cultural heritage, sense of place, spiritual enrichment, and the enhancement of knowledge systems. These services can constitute the identity of people and relate to ecosystems in which they live and depend on (MA 2003). Cultural services also include the variety of ways that humans experience and enjoy nature (Lewan and Soderqvist 2002). Examples of these types of services are the variety of recreational pursuits that people are involved in. These include more active pursuits such as bush walking, sailing, or bungy-jumping, to less vigorous activities, such as nature observation and enjoying the peace and quiet that natural areas provide.

Cultural services are based largely on the fact that people value elements of nature with a wide range of different worldviews and conceptions of nature and society (Goulder and Kennedy 1997; MA 2003). They are strongly connected to human values and behaviour, as well as human institutions and patterns of social, economic and political organisation (MA 2003). Because of their attachment to human behaviour, values of cultural services are more likely to differ among individuals and groups, compared with the value of a provisioning service (MA 2003).

2.2.3 Ecological Services

This category emphasises that ecosystems as a whole and as individual species make an essential contribution to human well-being as ecological services (Norton 1986). While most other services can quite easily be identified as an object or through an experience, many ecological services are invisible to the uninformed observer. Furthermore, the impacts of ecological services on people often occur indirectly or over long time periods compared with provisioning and cultural services (MA 2003). Therefore, understanding the roles of these types of ecological services depends on education (Lewan and Soderqvist 2002).

Ecological services incorporate regulation, habitat and supporting services, which are closely linked to the functioning occurring within and between ecosystems. This category is in slight contrast to the Millennium Ecosystem Assessment and other similar classifications because there is no distinction between ecological and supporting services. In essence, there are a wide variety of ecological services representative of the complexity inherent in ecosystems that occur at varying scales in time and space (Limburg et al. 2002). Ecosystem functions and services that occur at higher levels emerge and interact with more localised interactions and processes at lower levels. This makes it difficult to distinguish between types of ecological services. For example, a service such as erosion control can be categorised as both a supporting and regulating service depending on the time scale and immediacy of impact on people (MA 2003).

For the most part, the value of ecological services is reflected in the value of provisioning and cultural services. Therefore, the direct valuation of ecological services, may lead to 'double-counting'. For example, pollination is vital in sustaining fruit production. Including both the 'pollination' and 'fruit production' services would lead to double counting, because the value of pollination of fruit trees is already incorporated in the value of the fruits (Hein et al. 2005).

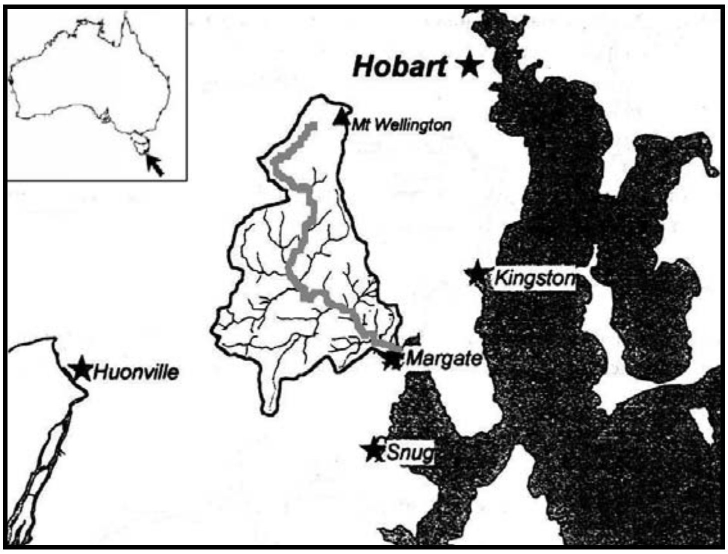
At present, it remains unclear as to what role supporting services and ecological services should be included in, or excluded from, a valuation study. Specific ecological services may require inclusion where they have an impact outside the ecosystem being valued, or if they have direct benefits to people living in the specified area that does not involve sustaining or improving another service (Hein et al. 2005). However, for this study, I consider that the value of ecological services is reflected in the valuation of provisioning and cultural services.

3 Case Study: Water Management in the North West Bay River, Tasmania, Australia

The North West Bay River is located in south-eastern Tasmania, only a short distance from the state capital of Hobart. The river drains the plateau and southern slopes of Mount Wellington, an iconic natural landscape overlooking the city of Hobart, before winding its way to sea level at North West Bay (Figure 1). The river is relatively short in length, at only 25 kilometres, and descends from an altitude of over 1000 metres near the summit of Mount Wellington. The sharp gradient makes the river highly unique and powerful in flood. Several features of the river have been identified as having outstanding significance, including for its many attractive natural values, active geomorphology and close proximity to Hobart (Green 1999).

The upper catchment, within the natural reserve of Wellington Park, serves as a major water supply catchment to the city of Hobart, providing up to 20% of the greater Hobart region's supply. Diversion from the North West Bay River Catchment commenced in 1900, and is one of the oldest piped water supplies in Australia. A regional authority, Hobart Water, has the responsibility for transferring water from the river to local councils in south-eastern Tasmania. Most of the water is taken from the main river channel in Wellington Park, amounting to the majority of baseflow at this point. In addition, there are eight other smaller takes that capture water from the major tributary in the upper catchment.

Figure 1: Location of the North West Bay River Catchment, Tasmania, Australia



The local municipal council, Kingborough Council, has for many years recorded concerns over the lack of water flow in the North West Bay River, particularly during the summer months (Doole 2004). Low flows, particularly downstream of the water supply intakes, have impacts on ecological habitat and water quality (Duddles et al. 1998). The net loss of water from the lower catchment is also significant in terms of the provision of local water supply directly from the river and for the maintenance of downstream water quality (Green 1999). However, there is limited knowledge of the impact the water supply intakes have on the river downstream, and insufficient measurement of the amount of water taken to supply the greater Hobart region at any particular time.

A major management priority of the North West Bay River Catchment Management Committee (NWBRCMC) is the provision of an environmental flow downstream of the Hobart water supply intake for the benefit to river users (Green 1999). The basis for this initiative was to improve the ecological, economic and social benefits associated with a healthy functioning river. This is particularly significant given that the North West Bay Catchment is due to become part of a water management planning process in the near future conducted by the relevant state authority.

The issue presents an example of a complex environmental problem involving a range of stakeholders, conflicting values across these groups, and limited scientific understanding of the river system. Recent emphasis has been placed on over-regulated and allocated freshwater systems, and the desire to return a greater quantity of water as an 'environmental flow', such as in the Murray-Darling Catchment. The regulation of rivers, for various purposes including irrigation, hydro-electric generation, and domestic water supply, has dramatic impact and consequences for riverine habitats, as well as significant economic, social and cultural impacts to downstream communities. These impacts include the influence that regulated flows have on physical habitat and biotic composition, and the influx of exotic species associated with altered flow regimes (Bunn and Arthington 2002).

4 Methods

A MCA framework was developed as a tool for structuring the knowledge process, and to enable an integrated method of analytical thinking and the input of stakeholder value preferences. Multi-Criteria Analysis seeks to make explicit the process that is carried out by an individual when coming to a decision (Abel et al. 2003). The greatest advantage is the approach's ability to provide a framework for allowing complex problems to be broken down and structured in a simple way.

In its most basic form, a multi-criteria model is made up of evaluative criteria, a set of weights explaining the importance of each criterion, a set of alternatives, and a set of performance measures for evaluating the criteria. Each aspect of the model is represented in the form of an effects table. The effects table is an $m \times n$ matrix with m criteria and n alternatives. Weightings for each m criteria indicate the relative importance of each criterion.

A combination of methods was used to gather information for input into the MCA framework. Firstly, an expert panel was formed, incorporating stakeholder representatives and scientific experts in various river management disciplines. Prospective panel members were required to have at least some experience or knowledge of the North West Bay River Catchment. Seventeen people were invited on to the panel, of which twelve people indicated their wish to contribute.

The expert panel process was conducted using email questionnaires. An iterative approach was employed using a combination of secondary data collection and synthesis and expert panel review. Two questionnaires were sent out to the panel, which included summaries of scientific analysis conducted by relevant parties to provide emphasis. For each questionnaire, panel members were given the opportunity to respond to the feedback from other members in an anonymous fashion. The expert panel contributed to the development of an ecosystem services classification for the North West Bay River, defining credible management scenarios, and outlining potential impacts of these scenarios.

The second method involved the use of a stakeholder survey to evaluate the importance of relevant ecosystem service values. Development of the survey occurred after completion of the expert panel, when a list of 21 ecosystem service values were finalised. The aim of the survey was to develop weightings for each ecosystem service value, and to indicate changes in the weightings across major stakeholder groups.

5 Components of the MCA Framework

Four major components made up the MCA framework. These are the development of an ecosystem services typology for the North West Bay River, development of future management scenarios, assessment of the impacts of these scenarios on ecosystem services, and the development of weightings for individual ecosystem service values.

5.1 Ecosystem Services Classification

There are a wide range of ecosystem services that are present in the North West Bay River Catchment. However, this study focuses on the implication of any potential change in water management regime (e.g. the provision of an environmental flow in the river) is the potential change in the levels of services, such as water supply to various stakeholders or changes in the scenic value of the river landscape. Therefore, the identification of ecosystem services was limited to those that were likely to be significantly changed as a consequence of a water management scenario.

The North West Bay River provides a wide range of ecosystem services to stakeholders, both within and outside catchment boundaries. Despite the significant interactions between many services, four ecological services were considered to have a major influence on the values of the North West Bay River (Figure 2). Services were delineated into four categories associated with the biophysical characteristics of the river system: water regulation (quantity), water quality, maintenance of landscape processes (geophysical), and provision of habitat and environmental diversity (biological).

Figure 2: Significant Ecological Services of the North West Bay River

1. *Water regulation* – the timing and magnitude of channel flows which explains the flow of water through the system. This includes groundwater recharge and discharge, the maintenance of natural irrigation and drainage, buffering of extreme flows, provision of a medium for transportation, and freshwater input to the estuary and North West Bay.
2. *Water quality* – the ability of the freshwater system to provide good quality water. Freshwater systems help to filter out and decompose organic wastes introduced to inland waters and subsequently to coastal and marine ecosystems. Includes the protection of water from pollutants, the transport of nutrients downstream, and contribution to water quality in the estuary and North West Bay.
3. *Maintaining landscape processes* – the geomorphological functioning of the river environment. Includes the preservation of stream channel, bank & riparian form and structure, the maintenance of floodplains & landscape character, and the movement of sediments downstream and impacts on the estuary and North West Bay.
4. *Provision of habitat & environmental diversity* –the provision of living space for wild plants and animals. Includes the retention of water in the stream channel to provide for habitats, flora & fauna, maintenance of population and community structure of different species, and preservation of instream debris for habitat purposes.

A total of 21 ecosystem service values were identified, which incorporate the direct values and benefits to stakeholders (Figure 3). Provisioning services generally relate to tangible products received from ecosystems and are easier to distinguish than other services. The major provisioning service from the North West Bay River is water supply. Water supply was divided into five main uses. Hobart water supply users can be separated into those for businesses and industries and domestic households. Water is also extracted by private users in the catchment for domestic use, animal use and irrigation, totaling up to one megalitre per day. The other main provision from the river is for food supply, which is primarily centred on aquaculture in the northern region of North West Bay near the river estuary.

Figure 3: Provisioning & Cultural Services (Values) for the North West Bay River

Food supply

1. Fisheries (primarily aquaculture farming in North West Bay)

Water supply

2. Water supplied for drinking & domestic use in the Hobart region
3. Water supplied for businesses & industry in the Hobart region
4. Water extracted by catchment residents for drinking & domestic use
5. Water extracted by catchment residents for stock
6. Water extracted by catchment residents for irrigation of crops

Recreational uses

7. Recreational boating (in North West Bay)
8. Kayaking & Rafting
9. Recreational fishing (including in North West Bay)
10. Walking
11. Swimming
12. Horse-riding
13. Mountain-biking/Cycling

Cultural values

14. Educational value
15. Sense of place (important feature of the local area)
16. Cultural heritage (local history)
17. Spiritual attachment
18. Satisfaction of knowing the river supports native wildlife
19. Scenery and natural beauty of the river
20. Peace & quiet of the river environment
21. Protection of property from river flooding and erosion

Cultural services, on the other hand, are tightly bound to human values and are likely to differ in perception across a range of stakeholder groups. These were divided into two main groups: recreational uses and cultural values. Seven recreational uses were identified for the river, including walking, swimming and kayaking. Eight cultural values were identified for the river covering a wide assortment of human values for nature, from cultural heritage, spiritual and scenic values, to the river environment protecting adjacent property from flooding and erosion, and the satisfaction of knowing that the river supports native wildlife.

5.2 Future Management Scenarios

A number of future management scenarios were created to evaluate different options available for water management in the North West Bay River. The development of future scenarios involves identifying possible water management options for the catchment in order to tackle the uncertain consequences of river management. Scenario planning involves the creation and use of scenarios in a structured way to stimulate thinking and evaluate assumptions (Bohensky et al. 2006). The central aim is to consider a variety of possible futures that incorporate many of the uncertainties in the system (Peterson et al. 2003).

Panel members were initially asked to identify their vision for the catchment in terms of water management, and also to identify relevant objectives for use in any water management plan. These were used to develop a number of preliminary scenarios, which were subsequently fed back to the expert panel for an assessment of the credibility of each scenario. The timeframe selected for the scenarios was 10 years (i.e. 2016) encompassing the likely period necessary for the development and implementation of a water management plan in the catchment.

As a result of the expert panel process, four management scenarios were identified. The differences between each scenario illustrate a range of possible consequences from system drivers in the catchment and beyond. Each of the scenarios is based on social and ecological processes relating to such aspects as land development and subdivision, water extraction and use, river health and riparian management.

The *Status Quo* scenario is a continuation of the existing management regime for the North West Bay River, with little change to the current regulated flow regime. Land development and subdivision provide a major issue both within the catchment and throughout surrounding areas, with resulting impacts on the condition of the river. Further development in the catchment results in an increase in private water extractions from the river, particularly during drier periods.

The alternative three scenarios aim to further a number of catchment management objectives, including the provision of an environmental flow. The *Flow Threshold* scenario represents a restriction of Hobart Water uptakes from the main river channel during extreme low flow periods, representing approximately the lowest 5% of flows in the catchment. However, because of insufficient flow gauging there is still little indication of the flow in the river at any given time, and awareness of the impacts on the river from reduced flows in the upper catchment. The *Summer Flows* scenario provides an environmental flow of 4 megalitres per day during the drier months of the year when flows are generally at their lowest. Increased land development in the catchment has a number of impacts, including a noticeable decline in some water quality indicators, and an increase in the number of private water extractions along the river. The *Catchment Management Outcomes* scenario is based on the implementation of a range of ecologically-based outcomes, many of which are stated in the catchment management plan. These include enhancement of riparian areas, provision of an environmental flow over the drier period, and restrictions on water extractions by private users.

5.3 Impacts of Future Scenarios

The four different scenarios required scientific investigation and analysis to be undertaken. Data collected and analysed included the historic flow record, various scientific and catchment management reports. This data was complimented by the analysis of likely impacts from each scenario by members of the expert panel.

The impacts are divided into those primarily ecological in nature (ecological services) and those affecting the value systems held by people (ecosystem service values). A key benefit of the MCA framework is that it can handle performance measures in different units. Thus, ecological performance measures used in the MCA include flow levels, ecological risk levels and qualitative water quality indicators. Performance measures also include changes at different locations along the river, and at different times of the year.

Changes in the provision of ecological services have resulting impacts on ecosystem service values. A 5-point value impact scale was developed to explain the impact on ecosystem service values for each management scenario. The scale ranged from -2 to indicate a major negative change in value to +2 to indicate a major positive change in value. A value of 0 indicates no change or insignificant change in any ecosystem service value.

Using this scale, the connection between the two types of services can be seen as relatively subjective in nature, despite the input of qualified opinion from members of the expert panel. Therefore, in order to assess relevant impacts across scenarios in a consistent manner, a number of decision rules were created to link the impacts of ecological services on ecosystem service values. Ecological services are measured in a number of different units (e.g. ML per day, 1 to 4 qualitative scales), and it is useful to apply linear transformation functions to the raw data values in order to place them on the same index measure. This was done by placing the average performance scores for each scenario on a scale from zero to one, where zero represents lowest utility and one represents the highest utility. Those scores with a significant change in utility (>0.1) across the indicators for each ecological service were considered to have an impact on relevant ecosystem service values.

5.4 Value Weightings

Because some ecosystem services are more important than others, value weightings were developed for inclusion in the MCA framework using input from stakeholders. The value weightings were generated from responses to a mail survey conducted to evaluate the importance of the range of values of the North West Bay River. 1200 surveys were mailed out to a range of stakeholders, including catchment residents, private and public water users, and river visitors across the greater Hobart region. A response rate of 53.9% for the survey was received. The proportion of surveys was reduced to a usable response rate of 47.3% after the removal of surveys that were incomplete or had missing value data.

The most important component of the survey focused on rating the importance of each of the 21 ecosystem service values on a scale ranging from 1 (not important) to 4 (very important). Overall weightings were developed from the value ratings and standardised to show percentage weightings. Weightings from different groups of stakeholders were also calculated for inclusion in the MCA framework. These weightings could be used to show how the views of different stakeholders affect the overall outcomes for each scenario.

6 Results from the Multi-Criteria Analysis

6.1 Aggregation

A spreadsheet model was developed for use in this project using Microsoft Excel 2003™. A set of impact matrices showing the change in ecosystem service values under each of the different scenarios was finalised. There are two parts to the model. Firstly, an impact matrix shows changes in ecological services across the four scenarios using a number of performance measures for each ecological service. A number of different performance measures can be included

Table 2: Example of the Ecological Impact Matrix across North West Bay River Scenarios

	Current Levels	Scenario 1: Status Quo	Scenario 2: Flow Threshold	Scenario 3: Catchment Outcomes	Scenario 4: Summer Flows
Water Regulation					
Mean Annual Hobart Water Takes (Megalitres)	6124	6124	6079	5396	5396
Mean No of Days without HW Take (Dec-May)	6	6	15	23	23
River Flow: Betts Road (Megalitres per day)					
Median flow	6.9	6.9	6.9	8.6	8.6
95 percentile flow	0.5	0.5	3.5	4.5	4.5
River Flow: Margate Weir (Megalitres per day)					
Median flow	33.1	32.9	33.1	34.6	34.4
95 percentile flow	1.3	1.1	3.2	5.0	4.8
Water Quality (Scale: 0=Extreme modification, 1=Major modification, 2=Moderate, 3=Minor, 4=Close to reference site)					
Betts Road	4	4	4	4	4
Margate Weir	3	2.5	3	3.5	2.5
North West Bay	2	2	2	2.5	2
Landscape/Geomorphological Condition (Scale: 1=highly impacted, 2=moderately impacted, 3=good, 4=near natural)					
Upper Catchment	3	3	3	3.5	3
Mid-Catchment	2.5	2.5	2.5	3	2.5
Lower Catchment	3.5	3.5	3.5	3.5	3.5
Habitat Provision (Ecological risk for instream habitat)					
Betts Road *Median flow*	Moderate	Moderate	Moderate	Low	Low
95 percentile flow	High	High	High	Moderate	Moderate
Margate Weir *Median flow*	Low	Low	Low	Low	Low
95 percentile flow	High	High	High	High	High

Secondly, the model includes an impact matrix for each scenario outlining the impacts on ecosystem service values. Different value weightings can be inserted manually into the model to outline different changes in ecosystem service value provision. The user also has the option to change the specific impacts on an ecosystem service value using the 5-point value scale. For example, Table 3 shows an impact matrix for the summer flows scenario. This shows that due the major changes in ecosystem service values result from changes in water regulation and habitat provision. This causes a significant decline in Hobart water supply values, but results in the enhancement of a number of recreational and cultural values.

Table 3: Example of the Ecosystem Service Value Impact Matrix

Summer Flows Scenario	Value % Weight	Water Regulation	Water Quality	Maintaining Landscape Processes	Provision of Habitat & Diversity	TOTAL	% CHANGE
Fisheries (primarily Aquaculture)	4.87	0	0	0	0	0.00	0.00
Water for households in catchment	5.79	+1	0	0	0	5.79	0.72
Water for Hobart households	6.32	-2	0	0	0	-12.63	-1.58
Water for Hobart businesses	5.63	-2	0	0	0	-11.27	-1.41
Water for stock in catchment	5.51	+1	0	0	0	5.51	0.69
Water for irrigation in catchment	5.41	+1	0	0	0	5.41	0.68
Recreational Boating (in bay)	4.18	0	0	0	0	0.00	0.00
Recreational Fishing (river & bay)	4.09	+1	0	0	0	4.09	0.51
Swimming	3.66	+2	0	0	+1	10.98	1.37
Walking	5.52	0	0	0	+1	5.52	0.69
Kayaking	3.08	0	0	0	0	0.00	0.00
Cycling & Mountain-Biking	3.64	0	0	0	0	0.00	0.00
Horse-riding	2.65	0	0	0	0	0.00	0.00
Environmental education	4.81	0	0	0	+1	4.81	0.60
Peace & Quiet	5.14	0	0	0	0	0.00	0.00
River as important feature	5.34	0	0	0	0	0.00	0.00
Cultural history & heritage	4.47	0	0	0	0	0.00	0.00
Spiritual attachment	3.83	+1	0	0	+1	7.67	0.96
Satisfaction of river supporting wildlife	5.58	+2	0	0	+2	22.31	2.79
Scenery & Natural beauty	5.41	+1	0	0	+1	10.83	1.35
Protection of property	5.07	0	0	0	0	0.00	0.00
TOTAL	**100%**	**6**	**0**	**0**	**7**	**59.03**	**7.38**

Results from all components were combined into the multi-criteria impact matrices. Weightings were multiplied by the total standardised impact for each value, and totaled across all values. The total for each scenario shows a percentage change in the provision of ecosystem service values. All four scenarios have upper and lower limits of change incorporating the uncertainty in prediction associated with changes to ecosystem services, particularly for ecological services.

6.2 Overall Value Change

The results for each of the scenarios are outlined in Table 4. Average percentage changes in value are calculated for each scenario. These include lower and upper limits for each scenario to show the uncertainty associated with impacts on ecosystem service values. The *Catchment Management Outcomes* scenario has the best outcome in terms of a positive change in value. Lower and upper limits for this scenario both involve a positive value change of 0.86% and 16.42%, respectively. However, each of the alternative scenarios is within the lower limits of the *Catchment Management Outcomes* scenario, and therefore the outcomes of the alternative scenarios may still have the greatest positive benefit on ecosystem services.

The *Status Quo* scenario has the lowest average change amounting to a decline in the provision of ecosystem service values. As a result, this scenario should be considered as not an appropriate management option for the river. There is little difference between the *Flow Threshold* and *Summer Flows* scenario which had expected average change of below one percent. This shows that the provision of an environmental flow downstream of Hobart Water supply takes has only a minor influence on the average change in ecosystem service values.

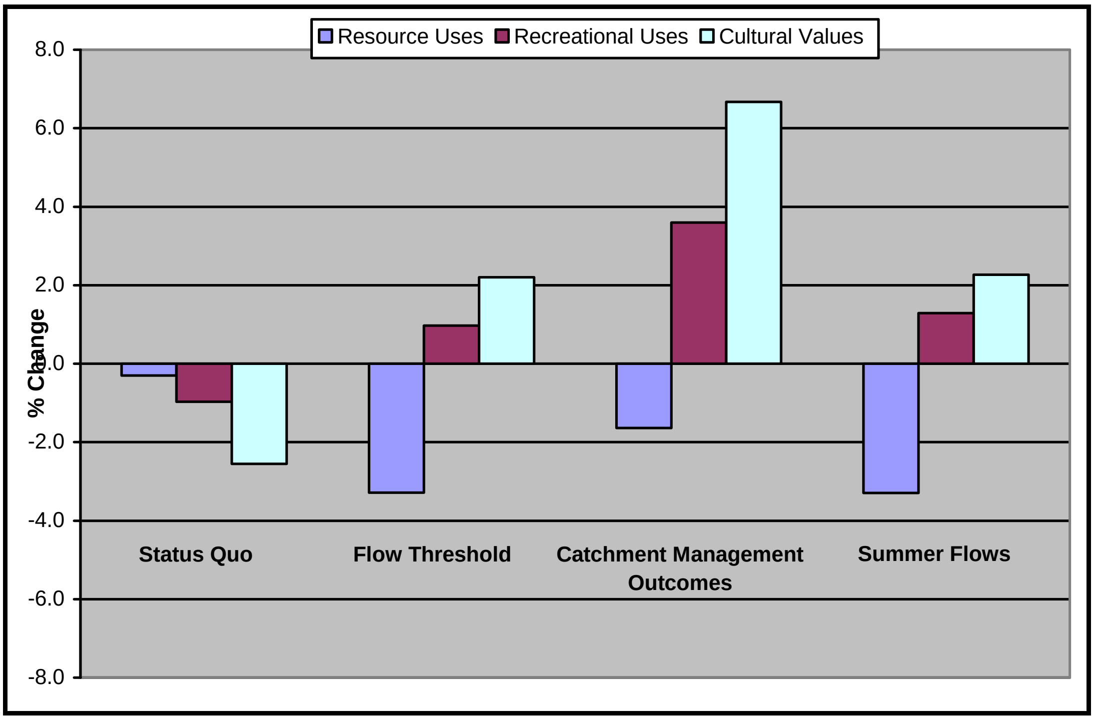
The differences between the lower and upper estimates for each scenario outline that there is considerable uncertainty involved in ecosystem service prediction, particularly where there are a range of changes to management conditions. For example, both the *Summer Flows* and *Catchment Management Outcomes* incorporate the provision of an environmental flow to improve downstream river flows and habitat provision. The uncertainty over the overall benefits that an environmental flow will provide, such as on the abundance and diversity of freshwater fish and macroinvertebrates, leads to a greater uncertainty in value change for these scenarios.

Table 4: Percentage Change in Value for North West Bay River Management Scenarios

Scenarios	**Lower Estimate**	**Upper Estimate**	**Average Change**
Status Quo	-9.74 %	2.09 %	-3.83 %
Flow Threshold	-4.38 %	4.15 %	-0.12 %
Catchment Management Outcomes	0.86 %	16.42 %	8.64 %
Summer Flows	-6.84 %	7.38 %	0.27 %

Although the multi-criteria model does indicate a best option, the most important component is outlining what type of changes influence the final outcomes. One such outcome is the impact on different types of values associated with each scenario. The percentage value change across different value groups describes another story to the impacts of each of the four scenarios. Resource uses are reduced under all of the scenarios, due to the decline in values around increased river flows and decreased water quality. With the exception of the *Status Quo* scenario, both recreational uses and cultural values are enhanced under the different environmental restoration scenarios. The greatest enhancement of values occurs in the *Catchment Management Outcomes* scenario with recreational uses on average increased by over 3% and cultural values by over 6%.

Figure 4: Average Percentage Change in Value Groups for each Scenario



6.3 Changes in Value across Stakeholder Groups

The multi-criteria model was also used to assess changes through the input of different weightings for each stakeholder. One such example of the different in stakeholders is between catchment and non-catchment residents. Using each group's weightings, there is only a slight difference in the outcomes for each scenario, noticeably all within 0.5% of each other. Under the *Status Quo* scenario, the change in value is similar with a decrease of approximately 4%. The largest difference in value change occurs for the *Catchment Management Outcomes* scenario which results in an average of 9.58% value increase for catchment residents, compared with a 9.12% value increase for non-catchment residents. This is due to the benefits that will be gained for recreational uses and cultural values within the catchment under this scenario, and the differences in the value weightings between these two stakeholder groups.

A number of other stakeholder groups were identified and analysis using the multi-criteria model. These included frequent and infrequent river visitors, and Hobart Water supply users. In general, there is little difference in the outcomes for each scenario between different stakeholders. This is because the value weightings for each group did not have considerable differences, despite the existence of a number of statistically significant importance ratings identified from survey responses between stakeholder groups.

6.4 Sensitivity Analysis

Sensitivity analysis is a widely used and popular tool for investigating the impact of uncertainty and variability on the outcomes of a particular multi-criteria analysis (Saltelli et al. 2000; Procter and Dreschler 2003). Conducting a sensitivity analysis is advisable to assess the robustness of the evaluation, and to record the influence of each component on the final outcome. For example, one might explore the change in impact of one value has on the overall performance of a scenario or the impact of changes to the weightings for specific ecosystem service values.

A detailed sensitivity analysis was carried out after the initial results from the Multi-Criteria Evaluation to further assess the decision problem. There are two issues in the multi-criteria model that specifically require sensitivity analysis. Firstly, changes to the impacts on values were assessed for each scenario. Much of this analysis can be included in the uncertainty predicted for each scenario. Lower and upper limits for each scenario show that changes to the magnitude of a series of impacts can have a considerable effect on the percentage change of ecosystem service value provision. For example, in the *Catchment Management Outcomes* scenario the percentage increase in value can vary from approximately 1% to 16%.

Secondly, changes to the way weightings of the ecosystem service values were calculated was made. A ranking procedure based on given the highest weightings to the highest rated values was undertaken and fed into the multi-criteria model. This test had limited impact on the overall percentage change for each scenario. Average percentage change for each scenario was still within ±1% of the original results.

7 Conclusions

This paper has revealed the development of a MCA framework for assessing change in the provision of ecosystem services under alternative management scenarios. The multi-criteria framework provides a useful tool for analysing changes in ecosystem services as a result of different management actions. However, considerable uncertainty exists in the outcomes of the multi-criteria model due to the uncertainty in ecological prediction and subsequent impact on ecosystem service values. Improvement in ecological prediction is likely to reduce the difference between lower and upper limits of value change.

The model was applied to water management issues existing in the North West Bay River Catchment, Tasmania. The optimal scenario incorporating the overall weightings developed from the stakeholder survey suggests that the *Catchment Management Outcomes* scenario is likely to have the greatest percentage increase in ecosystem service values. This outcome can be extended to all stakeholder groups, including for those whose only direct connection to the river is through the water supply that is used for their household.

Furthermore, an emphasis on the provision of an environmental flow in the North West Bay River downstream of the Hobart Water supply intakes is unlikely to lead to significant increase in ecosystem service values, unless other catchment management initiatives are introduced, such as the enhancement of riparian areas and restrictions on extractions by private water users.

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