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An Integrated Assessment approach to linking biophysical modelling and economic valuation tools

***M.E. Kragt*[a,b], *J.W. Bennett*[a] *and A.J. Jakeman*[b]**
[a] The Crawford School of Economic and Government, The Australian National University, Canberra
[b] Integrated Catchment Assessment and Management Centre,
The Fenner School of Environment and Society, The Australian National University, Canberra
(marit.kragt@anu.edu.au / jeff.bennett@anu.edu.au / tony.jakeman@anu.edu.au)

Abstract: Catchment natural resource management (NRM) involves complex decisions that affect a wide variety of values, issues and stakeholders. Designing efficient NRM policies requires assessments of the environmental impacts, and costs and benefits of management interventions in an integrated manner. However, despite the need for integrated assessment (IA), there are few comprehensive frameworks that integrate biophysical models with economic valuation. Cost-benefit analysis (CBA) is a framework that can support efficient NRM by assessing and comparing the total social costs and benefits of management interventions. However, the environmental modelling that has underpinned CBA has typically been poor, reducing the credibility of the framework to assist in the formulation of policy efficiencies. IA provides an approach to integrate the several dimensions of catchment NRM by considering multiple issues and knowledge from various disciplines and stakeholders. In this paper, we demonstrate how IA can be used to consistently integrate economic information with environmental data in a systematic framework to guide economically efficient decision making. We develop a Bayesian Network (BN) model that can be used as a decision support tool to evaluate the welfare impacts of NRM actions.

Keywords: Bayesian Networks; Catchment Management; Cost-Benefit Analysis; Environmental values; Integrated Assessment and Modelling; Non-market valuation

1. INTRODUCTION

Natural resource management (NRM) typically entails complex decision problems that involve a variety of issues and evolve in a dynamic social context [Ritchey, 2004]. Integrated assessment (IA) provides an approach to analyse the various dimensions of NRM by considering multiple issues and sharing scientific and stakeholder knowledge drawn from multiple disciplinary backgrounds [TIAS, 2009]. IA can support the development of economically efficient catchment NRM if all the marginal social costs and benefits associated with the impacts of alternative NRM actions are assessed. However, despite an increased interest in IA, there are few integrated modelling studies that combine biophysical modelling tools with economic valuation techniques in a robust framework to guide NRM decisions [Kirkpatrick and Lee, 1999; Croke et al., 2007].

Environmental impacts and financial costs and benefits of NRM changes may be relatively easy to estimate. However, changes in catchment environments will also impact non-market (intangible) values that people derive from ecosystem goods and services [Hanley and Barbier, 2009: 40]. Non-market economics valuation tools can be used to obtain estimates of the non-market costs and benefits of NRM policies. Although there are challenges involved in estimating non-market values [Hanley and Barbier, 2009: 55-61, 67-70 and 91-93], not accounting for non-market values of environmental impacts may lead to a misallocation of resources and less efficient decision making [Bennett, 2005]. The decision framework for economic valuation is based on cost-benefit analysis (CBA). The CBA decision rule is that if the marginal benefits of a policy change exceed its costs by a larger amount than any other management alternative, then the proposed policy should be adopted.

In this paper, we demonstrate how economic non-market valuation tools can be integrated with predictions of biophysical changes in one Bayesian Network (BN) modelling framework, to support an IA of catchment NRM changes. The BN integrates a process-based water quality model, ecological assessments of native riparian vegetation, estimates of management costs and non- market values of changes in riparian vegetation for the George catchment, Tasmania. The modelling approach illustrates how different tools can be combined in one framework to evaluate the environmental and economic impacts of NRM actions, as well as the uncertainties associated with the estimated welfare effects. The evaluation of impacts in a CBA framework can provide more economic rationality to NRM decisions. The next section introduces the IA approach that underlies this study. The various tools that were used to predict impacts of NRM actions on catchment water quality, native riparian vegetation and non-market environmental values are briefly described in Section 3. The model development process and the techniques used to integrate information about multiple systems in the BN model are described in Section 4. The results are illustrated by a model scenario in Section 5. The final section concludes the paper.

2. INTEGRATED ASSESSMENT

In this study, an IA approach is used to assess environmental[1] and socio-economic changes resulting from catchment NRM options (Figure 1). Different tools can be employed to inform the various stages of the assessment process [De Ridder et al., 2007].

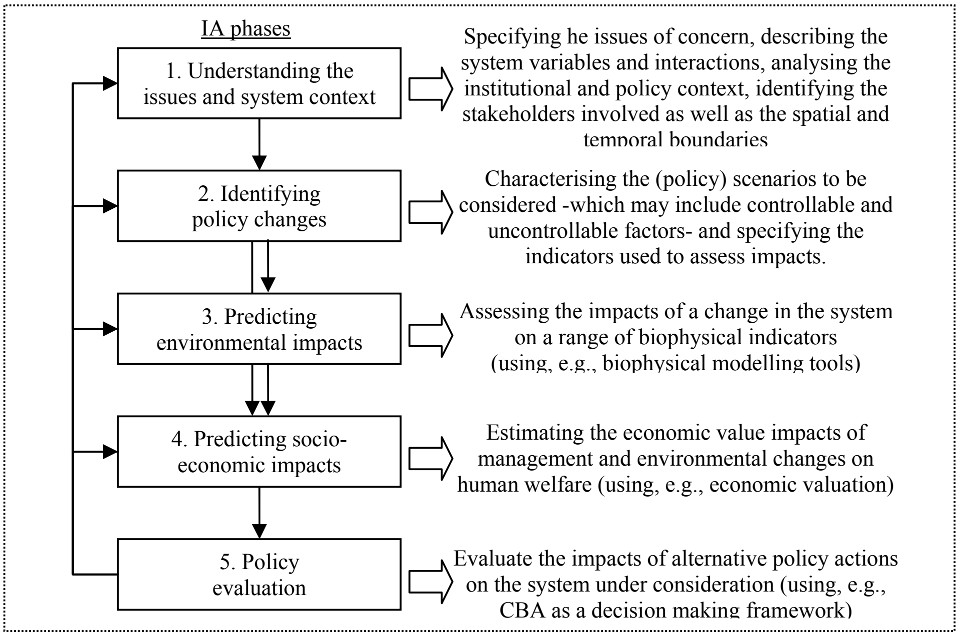

Figure 1. Analytical steps in an IA process to policy analysis.

An IA process starts with developing an understanding of the issues and system variables under consideration [Jakeman et al., 2006]. An iterative IA participatory approach that involves multiple stakeholders can strengthen a shared understanding about the economic, environmental and social issues of concern. Stakeholders in the process may include different scientific disciplines, model developers, natural resource managers, and/or local landholders, who will typically have different (and sometimes conflicting) ideas about the issues at stake. Conceptual influence diagrams or cognitive mapping techniques may be used to describe the system variables and their interrelationships.

The aim of the second phase is to identify the range of alternative future management scenarios that may be undertaken to address the issues identified in the first phase (including a ‘business as usual’ scenario) [De Ridder et al., 2007]. It is important that the scenarios match the (scientific, political and socio-economic) context of the system and are relevant to the stakeholders involved. The identification of alternative courses of action can be aided by, for example, surveys, focus group discussions or other tools such as General Morphological Analysis [Ritchey, 2004].

All the potential bio-physical impacts of the alternative management actions need to be assessed. Science-based modelling tools are useful to characterise environmental processes, and to predict changes in a range of (biophysical) indicators.

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[1] In this paper, the term ‘environmental’ refers to natural systems and impacts on biophysical indicators.

IA modelling studies often focus on natural systems, with a sparse representation of socio-economic costs and benefits [Ward, 2009]. Economic valuation tools are needed to estimate the cost and benefit impacts of NRM actions in monetary terms.

The impacts of alternative policies on multiple system variables need to be evaluated to provide support for decision making. The use of multiple indicators in biophysical modelling means that impacts are measured in disparate units, which does not allow for a comparison of impacts in a meaningful way [Brouwer et al., 2003: 32]. CBA provides a decision making framework to consistently compare NRM impacts across different systems (such as water quality and biodiversity changes), by measuring all impacts in identical (monetary) units[2] [Ward, 2009]. This enables an analysis of the trade-offs between the marginal costs and benefits of alternative policy proposals and can aid decision makes to evaluate the economic efficiency of management changes.

3. METHODS

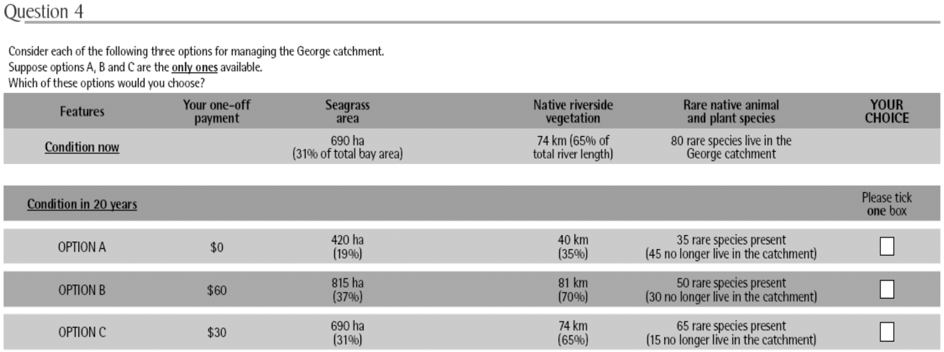
A variety of tools were used to inform an IA of catchment management changes in the George catchment, Tasmania. This study engaged multiple academic disciplines along with public and other stakeholder representatives, to develop an integrated BN model that incorporates water quality changes, riparian vegetation condition and economic costs and benefits.

3.1 Water quality modelling

A physically based, semi-distributed catchment model was developed for the George catchment, based on the Catchment Scale Management of Diffuse Sources framework [CatchMODS - Newham et al., 2004; Drewry et al., 2005]. The CatchMODS framework was adapted for the George catchment to integrate a range of process-based hydrologic, erosion and economic sub-models that simulate the impacts of different management actions on river flows, sediment delivery and nutrient loads, calculated as steady-state averages [Kragt and Newham, 2009].

3.2 Choice Experiments

Information about the non-market value impacts of changed catchment NRM was elicited using choice experiment (CE) techniques. In a CE survey, respondents are presented with a series of choice questions describing the outcomes of alternative hypothetical policy scenarios [Bennett and Blamey, 2001]. These outcomes are described in terms of different levels of a monetary attribute (costs) and several non-marketed attributes. Respondents are asked to choose their preferred option in each choice question. This allows an analysis of the trade-offs that respondents make between attributes. If cost is included as one of the attributes, these trade-offs can be used to estimate the marginal value of each environmental attribute in monetary terms.



Question 4

Consider each of the following three options for managing the George catchment.
Suppose options A, B and C are the <u>only ones</u> available.
Which of these options would you choose?

Features	Your one-off payment	Seagrass area	Native riverside vegetation	Rare native animal and plant species	YOUR CHOICE
Condition now		690 ha (31% of total bay area)	74 km (65% of total river length)	80 rare species live in the George catchment	
Condition in 20 years					Please tick **one** box
OPTION A	$0	420 ha (19%)	40 km (35%)	35 rare species present (45 no longer live in the catchment)	☐
OPTION B	$60	815 ha (37%)	81 km (70%)	50 rare species present (30 no longer live in the catchment)	☐
OPTION C	$30	690 ha (31%)	74 km (65%)	65 rare species present (15 no longer live in the catchment)	☐

Figure 2. Example choice question in the George catchment CE [see: Kragt and Bennett, 2009].

For the present study, a CE survey was developed using a combination of literature review, biophysical modelling, interviews with science experts and regional natural resource managers and feedback from focus group discussions [Kragt and Bennett, 2008]. An example choice question is shown in Figure 2. The survey was administered in various regions in Tasmania between November 2008 and March 2009.

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[2] Note that an assessment of physical impacts remains an essential prerequisite to environmental valuation.

3.3 Bayesian Networks

A major challenge in this study was the integration of knowledge from different sources into a logically consistent modelling framework. A process-based model provided predictions of water quality changes. Literature values and expert judgements were used to assess changes in ecosystem variables. CE survey data provided information about non-market value impacts. BN modelling techniques were used here to combine the information from various assessments in a single integrated model for decision support.

BNs (sometimes called belief networks) are probabilistic, graphical models consisting of a directed acyclic graph of variables (called 'nodes'). The values that each variable can assume are classified into discrete, mutually exclusive 'states'. BNs can incorporate different data sources, including expert opinion when observational data is not available [Pearl, 1988]. The propagation of information between variables is described by conditional probability distributions, thus incorporating the uncertainties in relationships between [Borsuk et al., 2004]. BNs are widely used for knowledge representation and reasoning under uncertainty in NRM and have been applied to different catchment issues [see, for example, Bromley et al., 2005; McCann et al., 2006; Castelletti and Soncini-Sessa, 2007]. There are, however, few BN applications that focus on non-market economic impacts of environmental changes [an exception is described in Barton et al., 2008].

4. THE GEORGE CATCHMENT MODEL

The George catchment, in North-Eastern Tasmania, was chosen as a suitable study area for both the biophysical modelling and the economic research. Land use is dominated by native vegetation, forestry, plantations and agriculture. The catchment has significant socio-economic values through its environmental assets, recreational values and aquaculture production in the estuary. Although the catchment environment is currently in good condition [Davies et al., 2005], there are significant concerns that land use changes are affecting ecosystem conditions [Sprod, 2003; BOD, 2007].

The first phases of the IA process were aimed developing a conceptual influence diagram to define the scale and scope of the George catchment system. Natural scientists, policy makers and community stakeholders were involved in the conceptual model development[3], to ensure that the considered variables and links between variables matched the scientific and policy context of the system. The geographical scale of the system was based on the contours of the George catchment, delineated using digital elevation models. A twenty-year period was considered an appropriate temporal scale, as it is thought to be long enough for management changes to have a demonstrated biophysical impact on the George catchment environment, and short enough to be pertinent to policy makers and CE survey respondents.

Further model development was an iterative process, aimed at identifying a parsimonious model that would represent the interactions between catchment management actions and environmental variables that impact human welfare [Kragt et al., in press]. The resulting conceptual model for the George catchment (Appendix A) incorporated four local management changes that were assumed to impact catchment ecosystem conditions: stream-bank engineering works; riparian zone management through limiting stock access to rivers and establishing buffer zones; changed catchment land use, and; vegetation management through weed removal. Some of these actions are already being implemented in the George catchment on a small scale, which increases the plausibility of the modelled management scenarios. Three indicators of George catchment environmental conditions were considered in the conceptual model: native riparian vegetation, number of rare native species and the area of seagrass in the estuary. The ecosystem component was integrated with the CE survey by using expert predictions and modelling results of changes in the ecosystem indicators as environmental attribute levels in the CE survey.

There was not enough information about changes in all the variables included in the conceptual model to develop a fully functioning BN for the George catchment. To adequately populate the conditional probability tables for all variables, one needs to know the probability that a certain state is observed at *every possible combination* of the input variables. Within the time frame of this study, it was not feasible to collect data about all the variables in the conceptual model and specify the relationships between them as probability distributions. Research efforts therefore focused on a sub-section of the conceptual model. A BN was developed that combines the costs of management actions with predictions of river water quality, native riparian vegetation length and non-market values (Figure 3). Each of the model variables is

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[3] The consultation process involved three workshops with Tasmanian scientist between November 2007 and September 2008, 31 structured interviews with experts on river health, threatened species, bird ecology, forestry management, riparian vegetation, estuary ecology and local natural resource managers and eight focus group discussions with members of the public in Hobart, St Helens and Launceston in February and August 2008.

described in more detail in Appendix B. The different techniques used to predict the levels of the variables and the ways in which they were integrated in one BN model are described below.

4.1 Predicting management costs

The main focus of this research was the integration of biophysical modelling and non-market valuation techniques. However, in order to demonstrate how the integrated model can be used in a CBA, the financial costs associated with implementing and maintaining management actions were included in the model. Assumptions about the costs of NRM in the George catchment were based on literature values (see Appendix B). The impacts of land use changes were represented as the change in aggregate land use returns for different catchment land use scenarios. The marginal costs of establishing riparian buffer zones and stream-bank engineering works were calculated as the present value (PV) of the summed one-off implementation costs and discounted maintenance costs over a twenty year period. A discount rate of three percent was used in the PV calculation.

Notwithstanding efforts to obtain accurate information, the knowledge about management costs in the George catchment remains limited. Uncertainties arise from, for example, knowledge gaps about the returns to land use, the types of materials used and the labour time involved in implementation and maintenance. These uncertainties are represented in the BN model by estimating a range of costs, rather than a single value. Given the limited number of data-sources and the high levels of uncertainty in knowledge, the predicted costs should be seen as illustrative rather than accurate estimates for a CBA.

4.2 Predicting water quality changes

George-CatchMODS was used to predict the impacts of management changes on steady-state mean annual river flow (MAF in ‘000 ML/year), and total suspended sediment (TSS in tonnes/year), total phosphorus (TP in tonnes/year) and total nitrogen (TN in tonnes/year) loadings to the George catchment streams and estuary. Monte Carlo simulations of George-CatchMODS were run that combined scenarios of land use changes with varying lengths of stream-bank engineering works and riparian buffer. The results from these Monte Carlo simulations were used to define the conditional probability distributions for the water quality variables. Uncertainties in the predictions arise from uncertainty in the model parameters and were specified as an uncertainty bound around the deterministic predictions from the George-CatchMODS model. Note that George-CatchMODS is integrated with the other components by considering the same management scenarios in each model.

4.3 Predicting impacts on native riparian vegetation

The impacts of NRM actions on native riparian vegetation were predicted based on information collected through literature reviews and expert interviews [Kragt and Bennett, 2008].[4] The most important management actions assumed to impact native riparian vegetation in the George catchment are land use changes, establishing riparian buffer zones[5] and weed management (Figure 3). An intermediate node (‘Native Veg in riparian zone given different land uses’) was included to measure the length of native vegetation in the riparian zone under alternative land use scenarios. Assumptions about the proportion of the riparian zone that is likely to be vegetated under each land use, and the ‘naturalness’ of that vegetated riparian zone were based on Tasmanian digital vegetation mapping [DPIW, 2005a; DPIW, 2005b] and expert review [Daley, 2008]. It was assumed that areas with native vegetation for non-production purposes have a fully vegetated riparian zone with at least 80 percent native vegetation. Native production forests and forestry plantations were assumed to have a respectively 90 and 80 percent vegetated riparian zone, with 70 and 30 percent native vegetation respectively. The base case assumption was that agricultural and urban areas did not have any vegetation in their riparian zones, but that the establishment of riparian buffers and weed management could increase this.

The ‘Length of Native Riparian Vegetation’ variable in Figure 3 measures the total length of rivers in the George catchment with healthy native vegetation along both sides of the river. The intermediate node ‘Native Veg given land use’ was assumed to contribute directly to the total Length of Native Riparian Vegetation in the George catchment. The ‘nativeness’ of newly established riparian buffers was assumed to depend on the extent of weed management in the riparian zone: (i) ‘low’ weed management was assumed to result in 15% of healthy native vegetation; (ii) ‘medium’ weed management was assumed to

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[4] The review included regional, State and National documents about the impacts of catchment management on native vegetation conditions, and previously developed models of vegetation changes in river catchments. Structured interviews were conducted with Tasmanian experts on river health and riparian vegetation.

[5] Note that establishment of riparian buffer does not change catchment land use in our model.

result in 50% of healthy native vegetation; and (iii) 'high' weed management was assumed to result in 85% of healthy native vegetation in the established riparian buffer zones [Daley, 2008]. These assumptions mean that if, for example, six km of riparian buffer is established with 'medium' weed management, the contribution to the total Length of Native Riparian Vegetation in the George catchment is three km (in addition to the native vegetation in the riparian zone under the given land use scenario). Uncertainty in the assumptions was accounted for by imposing a 95% uncertainty bound on the calculated values.

The riparian vegetation model was used to predict the length of native riparian vegetation in the George catchment under a 'best case' and 'worst case' scenario. The predictions ranged from 40km (the 'worst case' scenario) to 81km (the 'best case' scenario) and were integrated with the attribute levels in the CE survey [Kragt and Bennett, 2009].

4.4 Estimating non-market values

Results from the CE study were used to estimate non-market values of native riparian vegetation in the George catchment. Marginal willing to pay (WTP) estimates indicated that Tasmanian households were, on average, WTP \$3.57 for every km increase in native riparian vegetation, over the presented base case scenario of 40km of native riparian vegetation [Kragt and Bennett, 2009]. The CE results also provided information about the uncertainty range in the WTP distribution, with an estimated standard deviation of 0.532.

Household marginal WTP was aggregated over the total numbers of households in the 'relevant' population to calculate the total non-market values of changed native riparian vegetation condition in the George catchment. What constitutes the 'relevant' population and which proportion of this population has a positive WTP is subject to debate [Morrison, 2000]. To reflect the aggregation issue, an additional variable 'Aggregation assumptions' was included in the BN. This variable represents three alternative assumptions for aggregating the household WTP estimates: (i) Only the survey respondents have a positive WTP = 832 households; (ii) 64 percent[6] of all households at the sample locations has a positive WTP = 35,799 households; and (iii) 64 percent of all Tasmanian households have a positive WTP = 116,418 households [ABS, 2006a].

5. RESULTS

The process-based water quality model and native riparian vegetation assessment predicted the state of the environmental conditions in the George catchment, given a certain management input. The economic estimates of *marginal* values required predictions of *changes* in environmental conditions resulting from implementing new management actions. In the integrated model, this was achieved by using predictions from the biophysical models before and after the management change (Figure 3).

5.1 Scenario analysis

To illustrate how the model enables an integrated impact assessment of NRM actions on a range of system variables, results of an example scenario are presented in Figure 3. In this scenario, land use in the George catchment is as currently observed, and no stream-bank engineering works are undertaken. The top part of the figure illustrates the predicted environmental conditions before implementing new management actions. For example, the model predicts a 73.3 percent probability that TSS loads are between 6900 and 8000 tonnes/year. The bottom part of Figure 3 illustrates the impacts of establishing 'between six and twelve' kilometres of additional riparian buffers combined with 'medium' weed management actions. TSS loads are now predicted to be between 6100 and 6900 tonnes/year. The direct costs of establishing additional riparian buffers are approximately \$149,000 (Figure 3). Uncertainty in the predicted costs is represented in the model by predicting a 92.3 percent probability that costs are somewhere between \$100,000 and \$200,000.

In the presented scenario, the length of native riparian vegetation is most likely to increase from between 45 and 67 kilometres ('before') to between 67 and 78 kilometres ('after'). Note that uncertainty in the model still leads to a 32.4 percent probability that the length of native riparian vegetation remains between 45 and 67 kilometres.

If we assume that 64 percent of the population at the sample locations has a positive WTP for riparian vegetation changes, there is a 32.4 percent probability that the total non-market value (NMV) of the change in native riparian vegetation is between two and five million dollars. However, uncertainty in the

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[6] The average survey response rate was 64 percent (Kragt and Bennett, 2009b).

predicted length of native riparian vegetation, and uncertainty in household WTP results in a predicted probability of 24.3 percent that the total NMVs are between one and two million dollars, and even a 21.9 percent probability that there is no change in NMVs at all. Hence, although the length of native riparian vegetation is likely to increase as a result of establishing riparian buffer zones in the George catchment, there remains a probability that the benefits will not outweigh the costs.

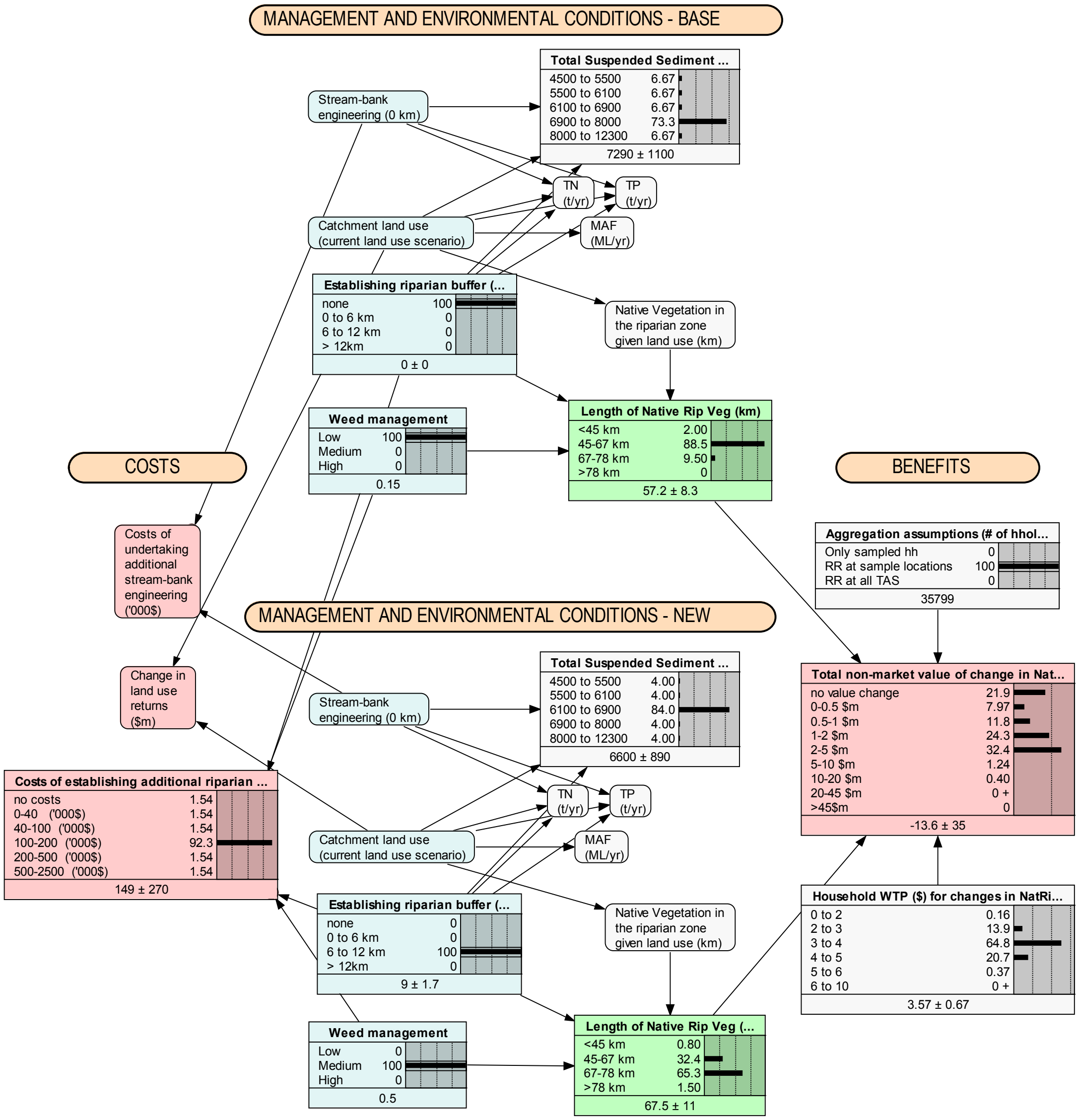

Figure 3. Scenario analysis of establishing between 6-12 km new riparian buffers with 'medium' weed management in the George catchment, assuming that 64 percent of the population at the sample locations have a positive WTP and keeping land use and stream-bank engineering constant.

5.2 Sensitivity analysis

Sensitivity analyses were also conducted, to assess which variables have the largest influence on the uncertainty in predicted length of native riparian vegetation and total non-market values. These analyses revealed that, in our model, establishing new riparian buffer zones, land use changes, and the assumptions about native vegetation under different land uses have the largest impact on uncertainty in the predicted total Length of Native Riparian Vegetation. Uncertainty in the predicted total non-market values is mostly affected by uncertainties in the predicted Length of Native Riparian Vegetation, establishing riparian buffers and land use changes.

6. DISCUSSION AND CONCLUSION

The research described here aimed to assess the biophysical and economic impacts of catchment NRM actions in the George catchment, Tasmania, in an integrated manner. Following an IA approach to model development, various academic disciplines, policy makers and community stakeholders were engaged in the project. The iterative consultation process provided valuable information about different stakeholder perspectives, to be included in the final integrated model. Probabilistic modelling techniques were used to integrate results from deterministic models, expert interviews and survey data into one BN model. The integrated process to developing the biophysical models and the economic non-market valuation survey tailored the information exchange between separate model components and ensured that the outputs of the different tools were compatible with each other.

The integrated BN can be used to assess the impacts of NRM actions on a range of indicators, including water quality parameters, native riparian vegetation condition and non-market environmental values. Including the management costs of NRM actions as well as non-market benefits allows a CBA to determine which management investments deliver the greatest net returns to society. Contrary to traditional CBA studies, the BN modelling approach used here accounts for uncertainties in the relationships between NRM actions, environmental impacts and economic consequences in a probabilistic way. The wide probability distributions in the scenario predictions show the large uncertainties in predicted costs and benefits. The explicit recognition of these probabilities enables an assessment of the risks associated with implementing new management actions.

Some challenges related to using BN modelling should also be mentioned here. The experts involved in the model development process found it difficult to express their knowledge about relationships between variables as probability distributions. Another limitation of BN models lies in its use of discrete states, rather than continuous probability distributions. Information losses arise from discretisation of probability distributions, which may affect modelling outcomes.

The model development was based on limited information about management costs and ecosystem changes in the George catchment. This means that model predictions of the net welfare impacts should not be considered as accurate inputs into a CBA. Results from the sensitivity analysis indicated that future research is needed to more accurately predict the impacts of riparian buffers or land use changes on native riparian vegetation. It is also recommended that the estimated management costs undergo further peer review to reduce the uncertainty in the model predictions.

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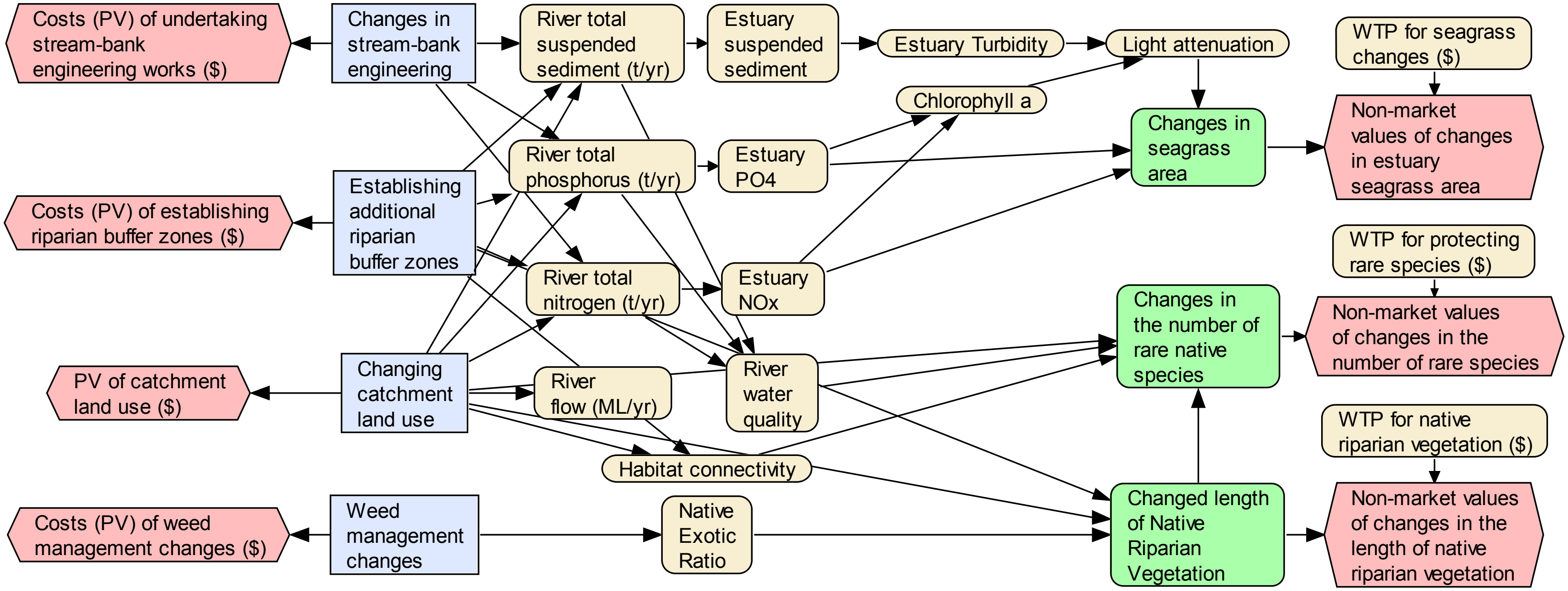
Appendix A. Conceptual model for the George catchment, incorporating four management actions (stream-bank engineering, creating riparian buffer zones, land use changes and weed management) and three environmental attributes (seagrass, rare native species and native riparian vegetation)



Appendix B. Variables in the integrated model for the George catchment model

Variable	Description	States	Variable type	Data/information sources
Costs of undertaking stream-bank engineering works	Present value of the one-off implementation costs of stream-bank engineering works plus the discounted maintenance costs^	0, 0-50, 50-100, 100-150, 150-200, 200-400 (‘000$)	Utility, continuous	Literature values from NLWRA [2000], Liff [2002], Freemand and Dumsday [2003], Sprod [2003], ABS [2006b], FPA [2007], Thorn [2007] and ABARE [2009].
Changed returns to catchment land use	Difference in total returns to land use in the George catchment between alternative land use scenarios.	<-10, -10to-5. -5to-2, -2to0, 0, 0-2, 2-5, 5-10, >10 ($m)	Utility, continuous	
Costs of established riparian buffer zones	Present value of the one-off implementation costs of establishing a riparian buffer zone plus the discounted maintenance costs associated with continuing weed management in the riparian buffer zone^	0, 0-40, 40-100, 100-200, 200-500, 500-2,500 (‘000$)	Utility, continuous	
Stream-bank engineering	Length of stream-bank engineering works undertaken in the George catchment to reduce stream-bank erosion	none, 0-3, 3-7, >7 (km)	Management action, continuous	Observed length of actively eroding sites from George Rivercare Plans [Lliff, 2002; Sprod, 2003].
Changing catchment land use	Changes in the total catchment area under alternative land uses (native vegetation non-production, native production forest, forestry plantations, grazing pastures, irrigated agriculture, urban area)	Current land use, loss native vegetation, expanding native vegetation, expanding production forest, expanding plantation forest, expanding agriculture, urbanisation (low, medium, high)	Management action, discrete	Modelling assumptions
Establishing riparian buffer zones	Length of riparian buffers established on agricultural and urban lands to reduce stream-bank erosion and trap sediment runoff from hill-slope erosion	none, 0-6, 6-12, >12 (km)	Management action, continuous	Modelling assumptions
Weed management	Weed control measures and planting native vegetation to improve the naturalness of the riparian zone	low, medium, high	Management action, discrete	Australian National Resource Atlas [NLWRA, 2000]
River total suspended sediment (TSS)	TSS loads into the Georges Bay at St. Helens under alternative management scenarios	4500-5500, 5500-6100, 6100-6900, 6900-8000, 8000-12300 (tonnes/year)	Nature, continuous	Modelled in George-CatchMODS water quality model
River total phosphorus (TP)	TP loads into the Georges Bay at St. Helens under alternative management scenarios	2.4-3.6, 3.6-4.1, 4.1-4.6, 4.6-5.7, 5.7-12 (tonnes/year)	Nature, continuous	Modelled in George-CatchMODS water quality model

Variable	**Description**	**States**	**Variable type**	**Data/information sources**
River total nitrogen (TN)	TN loads into the Georges Bay at St. Helens under alternative management scenarios	66-80, 80-90, 90-100, 100-120, 120-220 (tonnes/year)	Nature, continuous	Modelled in George-CatchMODS water quality model
Mean annual flow (MAF)	Total river flows into the Georges Bay at St. Helens under alternative land use scenarios	178-183, 183-188, 188-191, 191-203, 203-230 (‘000 ML/year)	Nature, continuous	Modelled in George-CatchMODS water quality model
Native Veg in the riparian zone given different land uses	The total length of native vegetation in the riparian zone under alternative land use scenarios	<60, 60-65, 65-70, >70 (km)	Nature, continuous	Calculated in the model, based on modelling assumptions
Length of Native Riparian Vegetation	The total length of native riparian vegetation given land use changes, creation of riparian buffers and weed management	<45, 45-67, 67-78, >78 (km) (equivalent to <40%, 40-60%, 60-70%, >70% of total catchment stream length)	Nature, continuous	Calculated in the model, based on expert assumptions
Aggregation assumptions	Assumptions on the total number of households in Tasmania with a positive marginal willingness-to-pay	Only sampled households (= 832), RR at sample locations (= 35,799), RR at all TAS (= 116,418)	Nature, discreet	Modelling assumptions based on CE response rate and total number of households in Tasmania
Household WTP for changes in native riparian vegetation	Household marginal willingness-to-pay for every additional km of native riparian vegetation, compared to the base case scenario (= 40km of native riparian vegetation left in the catchment)	<2, 2 to 3, 3 to 4, 4 to 5, 5 to 6, >6 ($)	Nature, continuous	CE survey results
Total NMVs of changes in native riparian vegetation	The total non-market value of increased length in native riparian vegetation in the George catchment, compared to the base case scenario	0, 0-0.5, 0.5-1, 1-2, 2-5, 5-10, 10-20, 20-45, >45 (m$)	Utility, continuous	Equation combining parent nodes ‘WTP’, ‘Aggregation assumptions’ and ‘Native Riparian Vegetation’

^ Discounted at three percent over a twenty year period.