Economic evaluation of environmental research

The value of environmental research used in the Great Lakes Coastal Catchments Initiative

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1 Introduction

Environmental research has been increasing due to growing diverse environmental concerns regarding sustainability, climate change, natural resource depletion, waste management, and air and noise pollution. Economic valuation of environmental research can assist in guiding research planning and expenditure. Yet environmental research is difficult to evaluate due to the dominance of non-market benefits and difficulties identifying tangible outputs and outcomes from research. This paper attempts to apply an existing valuation framework to an empirical case study to examine the difficulties and limitations of economic valuations of environmental research.

In the empirical case study environmental research and other technical and managerial inputs were used to develop a policy output. Policy implementation will result in environmental outcomes with subsequent economic benefits. The primary purpose of this paper is to explore the complexities and limitations of valuing environmental research, in particular the counterfactual and uncertainty.

Section 2 outlines the generic framework for valuing environmental research. Section 3 describes the valuation method used in this empirical analysis. Section 4 provides background to the case study and applies the chosen method to value the environmental research. The limitations encountered during the assessment are highlighted in Section 5, and Section 6 concludes with final comments regarding economic valuations of environmental research.

2 Framework

Environmental research is aimed at improving environmental decision making and thus the quality of the natural environment. Environmental research falls under three broad categories; basic, applied and interface, where applied environmental research is predominantly used by government to inform environmental decision making and policy (Kutschukian 2008).

Significant economic benefits can result from improved environmental decision-making. Economic valuation of environmental research can assist in guiding research planning and expenditure. An ex ante economic valuation of a project portfolio enables comparison and selection of projects which are anticipated to give the greatest return from an investment. An ex post analysis examines the efficiency of funds previously spent on environmental research.

There is a general absence of empirical analysis of environmental research in the literature primarily because valuing the output of the research is a difficult task. Valuing environmental research is difficult because research outputs are often intangible and have public good characteristics, being both non-rival and non-excludable. Environmental research is valuable when its usable knowledge is used. However, unlike many other types of research which result in new products or processes, the discernible value of environmental research is its contribution to environmental policy and decision making. In many cases the usable knowledge is used in conjunction with other inputs to inform decision making. This can complicate the link between the environmental research *output* and the environmental decision making *outcome*. Establishing this link is necessary to resolving how to value the environmental research.

There are many intermediate stages that link the environmental research *output* and the environmental decision making *outcome* (Figure 1). At each stage there is a different type of uncertainty, for instance:

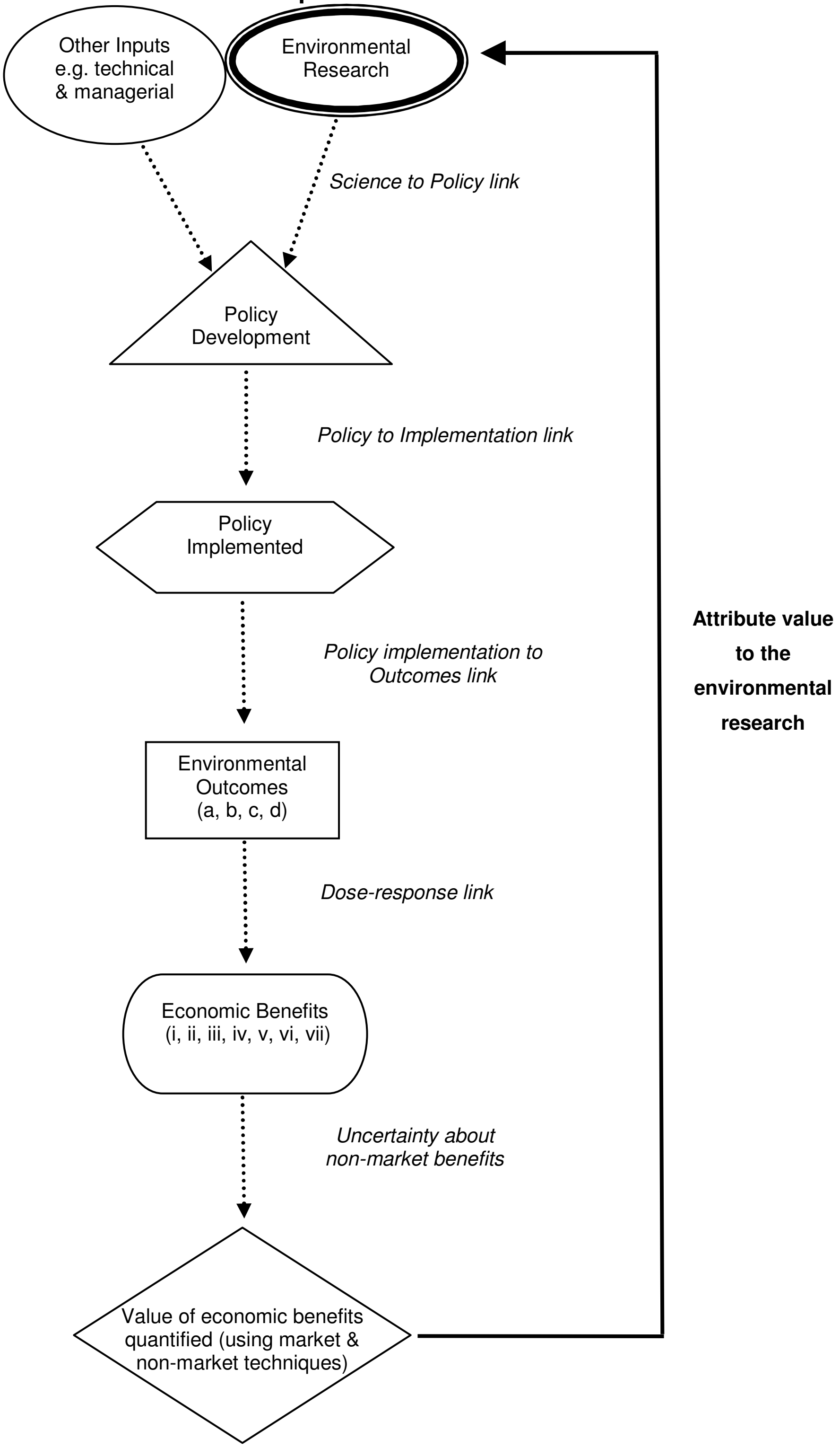
- ***Science-to-policy link*** examines the degree to which usable knowledge from environmental research is incorporated into environmental decision-making (Kutschukian 2008).

- ***Policy-to-implementation link*** is the probability that a policy will be implemented. A policy may not be implemented because of external factors such as limited funds or public opinion.
- ***Policy implementation to outcomes link*** is the uncertainty about the anticipated environmental outcomes. The United States Environment Protection Authority (2002) suggested attaching probabilities to environmental outcomes to account for this uncertainty; yet this only works if probabilities are known.
- ***Dose-response link*** is uncertainty about the anticipated economic outcomes linked to environmental outcomes. Once again probabilities, if known, can be attached to the economic outcomes.
- ***Uncertainty about non-market benefits***: is caused by the difficulties in estimating the value of non-market benefits.

Each input used in environmental decision making will influence the policy output. Therefore each input influences the environmental outcomes and the subsequent economic benefits. It is very difficult to isolate the influence any one input has had on the policy output and subsequent outcomes. Yet an economic valuation of environmental research requires just that; separating the research contribution to the final outcomes from the contribution of the other inputs.

The value of environmental research is its contribution to environmental decision making. This contribution can rarely be valued directly because it is often intangible and depends on the contribution of the other inputs and organisational context. The value of applied environmental research can be valued indirectly as its contribution to the outcomes resulting from the policy, the latter developed by environmental decision making. Particular attention should be paid to the uncertainties arising during the policy development and implementation stages and also the contribution from the other inputs to policy development. An indirect method to attribute value to environmental research and the uncertainties at each stage of the process is shown in Figure 1.

Figure 1: The economic valuation process[2]



The value of the economic benefits (established in the final stage of Figure 1) is the incremental change in benefits relative to the counterfactual. The counterfactual is the existing situation in the absence of the environmental research and/or policy. It is unobservable and must be inferred by considering evolving technologies, input

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[2] Concepts adapted from Kutschukian 2008

markets, available information, environmental conditions and policy reform agendas (Davis et al. 2008).

An economic valuation of environmental research must account for lags in research findings, adoption and delivery of benefits. Research and development costs may be incurred upfront whilst there may be a lag in the benefits. All the costs and benefits of the research must be captured in the time horizon assessed (Kutschukian 2008) and discounted to estimate the net present benefit of environmental research. The discounted net present benefit depends on the size and timing of the benefit flow net of implementation costs. All else being equal, earlier flows give higher returns in the base year than later flows. The time horizon for benefits and costs of applied research will generally be shorter than basic research.

Research is generally continuous with no discrete start or finish. Current research findings are often the further development of previous research findings and can also influence future research findings. Where possible an economic valuation of research should account for linkages to previous and future research to avoid overestimating or underestimating, respectively, the value of the current research.

There is no ‘one-size fits all’ economic valuation method for environmental research. Environmental research varies by category (basic, applied and interface) and how its usable knowledge can be applied. The objective of this paper is to apply this conceptual framework to an empirical case study of ‘applied’ environmental research to highlight the advantages and disadvantages of one possible valuation method.

3 Valuation method using the cost share approach

The applied environmental research assessed in this case study modelled environmental processes for the specific purpose of informing environmental policy. The implementation of this policy has anticipated environmental outcomes and subsequent economic benefits. The valuation method used comprised three main steps:

1. Specifying the costs of the policy’s development and implementation
2. Estimating the value of the benefits resulting from the policy outcomes
3. Attributing value from the policy outcomes to the environmental research

This case study was in between ex ante and ex post because at the time of the valuation the policy had been developed but was yet to be implemented. Hence the policy development costs were specified and the policy implementation costs were estimated in a decision support system. The benefits resulting from the policy outcomes were determined by linking environmental outcomes to expected economic benefits. A cost benefit study was completed during the policy development stage and estimated the value of these economic benefits primarily using benefit transfer (Great Lake Council 2009b).

Value was attributed to the environmental research as a function of the value of the policy outcomes. The environmental research was one of many inputs used to develop the environmental policy. Thus the estimated value of the environmental research was some (unknown) proportion of the value of the policy outcome, specifically the economic benefits. A ‘cost share approach’ was used to attribute value to the environmental research. The outcome’s value is apportioned to an input based on the input’s cost share, relative to the cost share of the other inputs used to achieve the outcome. Davis et al (2008) recommend that attribution, in the absence of any other information indicating otherwise, should be based on cost shares. In particular the cost share approach should be used when the research and development (R&D) outputs are necessary but by themselves not sufficient to deliver the impact (Davis et al 2008).[3]

The cost share approach is mathematically depicted in Equation 1 for a hypothetical project using four inputs, A, B, C and D to achieve a final outcome. The first term in Equation 1 is the cost share of Input A. Given a project involving four inputs (A, B, C, D), the cost share of Input A, is the cost of Input A divided by the total input cost. The total input cost is the summation of the cost of each input (A, B, C, D) used to deliver the outcome. The value of Input A (*V.InputA*) is estimated by multiplying the cost share of Input A by the value of the programme’s final outcome (*V.Outcome*).

Equation 1

$$\frac{CostA}{\sum CostA, CostB, CostC, CostD} * V.Outcome = V.InputA$$

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[3] This contrasts with R&D leading to marketed goods and services where, for example, a supply curve shift attributable to R&D enables the value of the R&D to be estimated directly, and compared to R&D cost.

The cost share approach attributes an average rate of return to all inputs used. Hence a cost share approach should not be applied to inputs which have made only a marginal contribution to a final outcome. The assumption that a cost share approach attributes a constant rate of return to all inputs used can be shown algebraically as follows:

> Let x = R&D expenditure, and X = total expenditure to implement policy j. Let a = x/X be the cost share for R&D. Let Y be the (economic) benefit of policy j; then the cost share approach implies that the allocation of Y to R&D is a.Y. Then the return to R&D is a.Y/x. From above x = a.X, hence the return to R&D and, indeed, to all inputs is a constant rate Y/X.

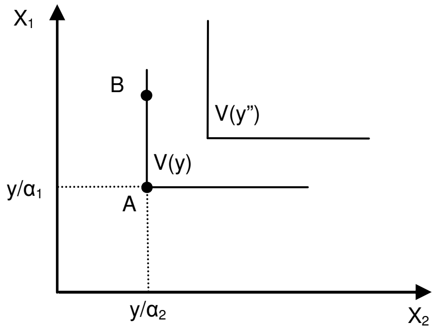
An attribution method, such as a cost share approach, is required when the return from R&D cannot be separated from the return from other inputs. This is particularly the case for research which informs policy. In many cases the policy process, which uses R&D as an input, resembles a Leontief production process where inputs are used in fixed proportions with little or no substitutability. A Leontief production function is often written as:

$$f(x) = \min\{\alpha_1 x_1, \ldots, \alpha_n x_n\},$$

where input x_j is used in fixed proportion relative to input x_i. Additional quantities of x_j holding x_i constant will not increase output (Chambers 1988).

Figure 2 represents a Leontief production function for the two input case. Point A on the production function V(y) produces maximum output whilst minimising the quantity of inputs x_1 and x_2. If the quantity of x_1 increases to point B, holding the quantity of X_2 constant, the output remains constant. Output will only increase when the quantities of both x_1 and x_2 increase by the fixed proportion determined by V(y), moving to a higher production function V(y”). When the quantity of one input decreases, output will also decrease regardless of the other inputs. Hence there is no substitutability between the two inputs (Chambers 1988).

Figure 2 Leontief production function



Source: Chambers 1988 p.15 (figure 1.4)

The production function V(y) in Figure 2 determines the quantities of conventional inputs x_1 and x_2 required to produce at point A. Research is an unconventional input which is hard to quantify making it difficult to incorporate it into a production function to determine the required quantity to achieve a given output. There is potential that excess research can be used to achieve the same level of output, such as point B in Figure 2. Research is particularly susceptible to this because unlike conventional inputs it is generally a non-constrained input.

Additionally, in the case of the policy process, there may be only a single output – e.g. represented by point A where the policy is implemented – rather than a surface of outputs (general production function).

Once value is attributed to the current research, the remaining task is to attribute value to any supporting previous research. Research is not conducted in isolation and is often aided by previous research findings and/or aids future research findings. An additional tier of attribution is required to account for this continuous nature of research. Attribution of value to relevant previous research avoids overestimation of the value of Input A. Similarly, when research provides benefits to future research, the value of these benefits should be incorporated in the present economic valuation where possible. Given the obvious difficulties of this final task, only the most recent and relevant research should be considered while other supporting research should be considered as 'sunk'.[4]

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[4] 'Sunk' is an economic term describing the situation where the benefits or costs of an item have already been incurred and cannot be recovered.

In the following section the valuation method discussed above is applied to the case study of the catchment and estuary models. These models were used as an input into the Great Lakes Coastal Catchments Initiative. Background to the Great Lakes Coastal Catchments Initiative is given in the first instance, followed by the empirical valuation and discussion of its limitations. The limitations result from three main causes:

1. Inability to directly value the *outputs* of the environmental research;
2. Link between the research *outputs* and the policy *outcomes* was blurred because the project inputs were combined in a process similar to a Leontief production process; and
3. Various sources of uncertainty in the *input* to *output* to *outcome* process.

4 Empirical case study

The environmental research examined in this case study was the catchment and estuary models developed by DECCW (Water Science). The models were used in conjunction with technical and managerial inputs to develop a Water Quality Improvement Plan as part of the NSW Great Lakes Coastal Catchments Initiative. The models were an *input* into the Water Quality Improvement Plan which was the *policy output*, where the latter was expected to cause subsequent environmental *outcomes*. The Great Lakes Coastal Catchments Initiative is the umbrella term for the *inputs* to *outputs* to *outcomes* process. This process is discussed in more detail below.

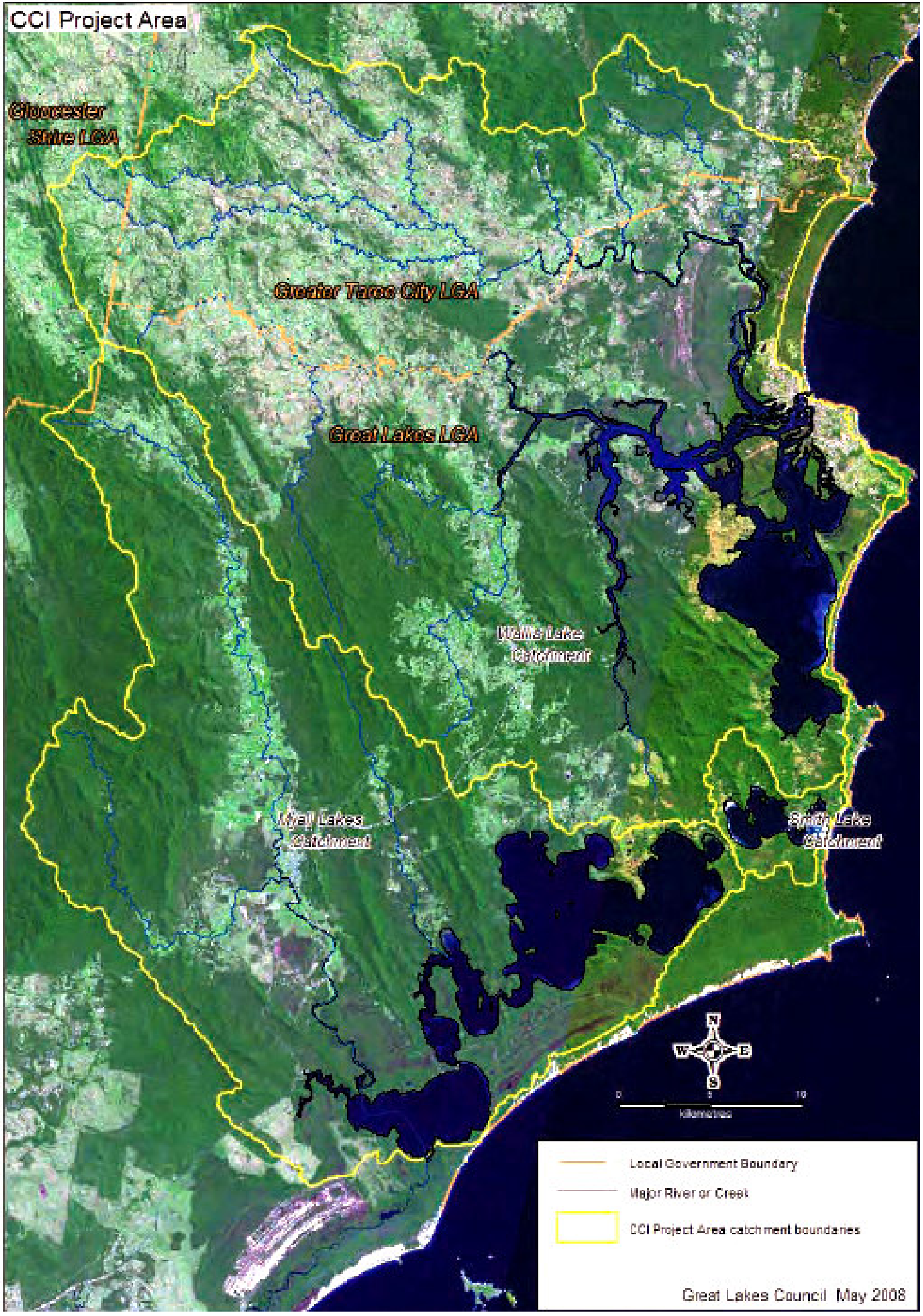
4.1 Background to the Great Lakes Coastal Catchments Initiative

The Coastal Catchments Initiative was an Australian Government initiative that focused on improving water quality in Australia’s coastal waterways through partnerships with State and local governments in ‘hotspots’ (Australian Government 2006). In this context ‘hotspots’ were coastal waters of high conservation value threatened by pollution but where there was capacity to improve water quality.

In 2005, the Great Lakes Council received $2.09 million from the Australian Government to implement the Great Lakes Coastal Catchments Initiative. The Great Lakes Coastal Catchments Initiative (hereafter ‘Initiative’) was specific to the Smiths, Myall and Wallis Lakes on the mid North Coast of NSW (Figure 3) and aimed to:

- identify the specific levels of nutrients and sediments that allow a healthy lake ecology and provide the environmental values desired by the community;
- identify the best way to manage activities to reduce key pollutant loads entering the lakes; and
- review pollution control and faecal coliform management systems as they relate to the management and protection of the three lakes (Great Lakes Council 2009a).

Figure 3: The Great Lakes Coastal Catchments Initiative project area, showing the Myall Lakes, Smiths Lake and Wallis Lake catchments, and local government area boundaries



Source: Great Lakes Council 2009a

The concept of the Initiative was that land uses within the catchment have the potential to alter the loads of nutrients and sediments entering the creeks and rivers, which consequently have the potential to substantially affect the ecological values of the lakes (Scanes et al. 2008). Water pollution in the Great Lakes is caused by land-based activities and water-based activities. Land-based activities include urban development, roads, runoff, vegetation clearing, agricultural chemicals, stock access to waterways, sewage and septic discharges, erosion and sedimentation. The water-based activities include boating, fishing, aquaculture, fish passage barriers and lake entrance management.

Public concern about water quality in the Great Lakes was intensified by two events: an hepatitis outbreak in Wallis Lake in 1997; and a toxic blue-green algal bloom in Myall Lakes in 1999. Both events highlighted the impacts that faecal coliforms, or sediments and nutrients, can have on the suitability of lake water for particular uses. The Initiative aimed to improve water quality to the required level to support the desired uses of the lakes, as identified by the community, such as commercial and recreational fishing, and contact recreation (Great Lakes Council 2009a).

The main output of the Initiative was the Water Quality Improvement Plan (hereafter 'Plan'). The Plan outlined the cost-effective[5] actions required to improve water quality in Wallis, Smiths and Myall Lakes; for example riparian rehabilitation, riparian and wetland protection, and management of fertiliser, infrastructure (dams), and groundcover. The Plan recommended tools, planning systems and institutional arrangements to support implementation of these actions across the Great Lakes region. The inputs used to develop the Plan included scientific modelling, management research and planning, and stakeholder input combined with existing knowledge about the lakes and their catchments gained from past research and current catchment management (see 4.1.1 for detailed description of the main inputs used). Although the Plan is yet to be implemented, the anticipated improvement in water quality is expected to deliver environmental outcomes and subsequent economic benefits (Figure 4).

The expected environmental outcomes resulting from an improvement in water quality include improved river and estuary health, improved native vegetation wetland

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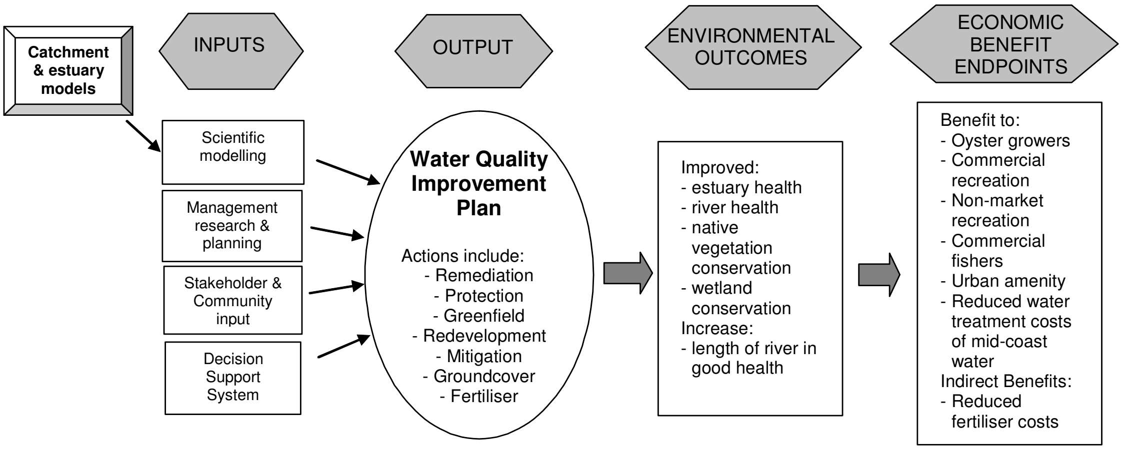
[5] A cost per unit of "load of catchment export controlled" was estimated for each management action to identify the cost-effective actions. A unit of load controlled refers to one kilogram for total nitrogen, one kilogram for total phosphorus or one tonne of total suspended sediments (Great Lakes Council 2009a).

conservation, and an increase in 'length of river in good health' (Figure 4). The economic benefits linked to these environmental outcomes include market and non-market benefits, such as:

- improved harvests for oyster growers and commercial fishers;
- improved non-market and commercial recreation;
- reduced water treatment costs;
- reduced fertiliser costs; and
- increased agricultural productivity where dams are eliminated (Great Lakes Council 2009a).

Figure 4: The process from *input* to *output* to *outcome*



The value of one specific input used to develop the Plan, the catchment and estuary models developed by DECCW (Water Science), is estimated in this paper. The catchment and estuary models were a component of the scientific modelling input (see Figure 4 and Figure 5). The models were used to estimate the current water quality status of the Great Lakes and highlighted the external factors detrimentally affecting the ecological health of the waters. The models were used to estimate the level of biological indicators (total nitrogen, total phosphorus and total suspended sediments) required to meet the community's desired level of water quality.

4.1.1 Overview of inputs used to develop the Water Quality Improvement Plan

Stakeholder input

Stakeholder input occurred at numerous stages throughout the process and included consultations with community, agencies and industry groups (Figure 5). Stakeholder input was viewed as equally important to the technical solutions because in most cases it is the stakeholders who would implement the technical solutions. Stakeholder input occurred during the development and review stages of the Water Quality Improvement Plan with:

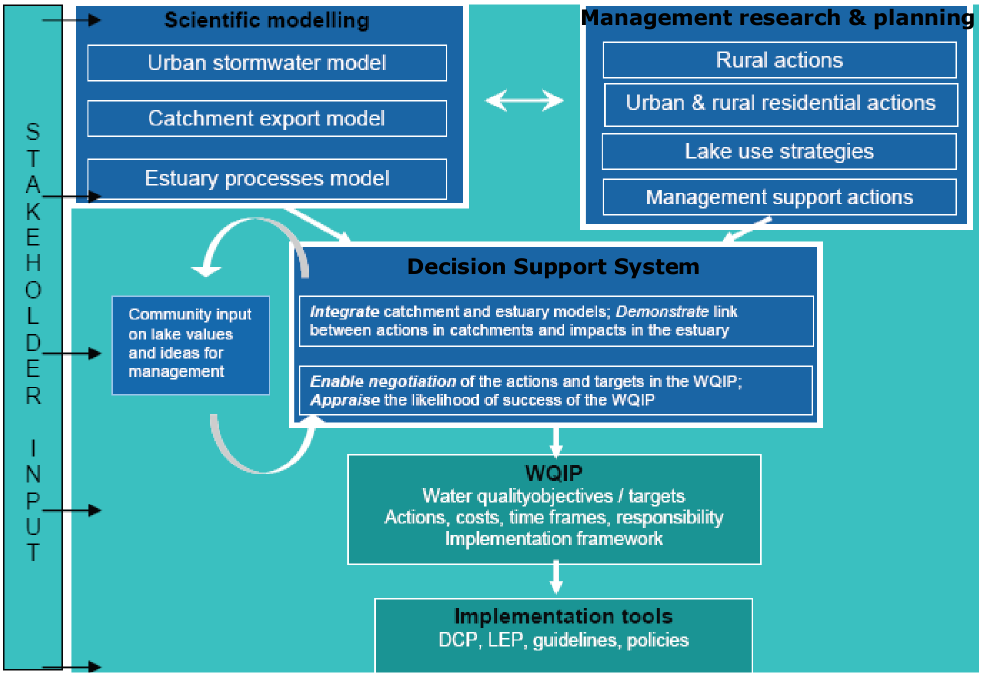
- parties who would implement components of the Plan, and
- parties in urban and rural areas that would be affected by the recommendations in the Plan.

Scientific modelling

The scientific modelling included three models: the catchment and estuary models and the urban stormwater model. The NSW Department of Environment, Climate Change and Water (DECCW) developed and implemented models of catchment run-off and estuary function. The models simulated the processes occurring in the catchments and estuaries of the Great Lakes region.

Separate to these two models, the urban stormwater model simulated impacts from stormwater on water quality in the lakes. The three models were developed independently and integrated in the decision support system (Figure 5).

Figure 5: The Great Lakes Coastal Catchments Initiative process



Source: Great Lakes Council (2009a)

Management research and planning

The management research and planning identified the appropriate technical solutions and management systems to reduce pollutant export from both rural and urban lands. It also identified the management actions necessary to support technical solutions, such as planning tools, regulations and incentive programs.

The scientific modelling and the management research and planning were completed simultaneously (Figure 5). The results of the management research and planning were also incorporated into the decision support system.

The Decision Support System

The decision support system underpinned the Water Quality Improvement Plan by integrating the management research and planning, scientific modelling, and community and stakeholder input into a computer tool to assist decision making. Various scenarios to reduce sediment and nutrients entering the lakes in urban and rural sub-catchments were run in the decision support system to show the likely impacts of these scenarios on pollutant exports and the ecological condition of the estuary. The cost of individual management actions was also included enabling comparison of the effectiveness of individual strategies based on changes in ecological indicators and cost. In general, the costs of protection were found to be considerably less than the costs of rehabilitation.

The decision support system enabled decision-makers to explore the impacts of a range of management actions on water quality, ecological indicators, and economic and social values.

4.2 Valuing the environmental research

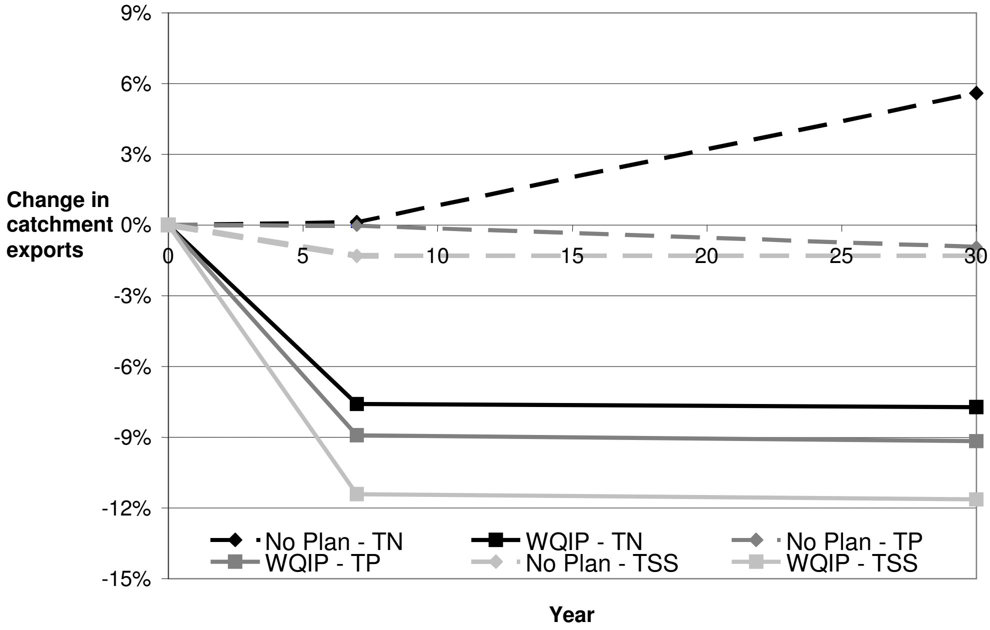
The value of the environmental research was indirectly estimated as its contribution to the policy outcomes, the environmental outcomes and subsequent economic benefits (Figure 4). The process to value the environmental research required four steps:

1. identify the environmental outcomes from implementing the Plan relative to the counterfactual;
2. quantify the policy development and implementation costs;
3. identify and quantify the economic benefits; and
4. attribute value to the environmental research.

The counterfactual was established to identify the incremental change in environmental outcomes. The counterfactual for this case study was 'without the Water Quality Improvement Plan'. In the absence of the Plan, water quality would be maintained through the existing Great Lake Catchment Management Plans. Conveniently the decision support system estimated the change in water quality over 30 years in each of the three lakes for both scenarios '*with*' and '*without*' the Plan. Comparison of the two scenarios identified the incremental change in water quality *with* the Plan relative to the counterfactual of *without* the Plan. The three indicators of water quality assessed were total nitrogen, total phosphorus and total suspended sediments. Figure 6 shows the change in water quality '*with*' and '*without*' the Plan in Wallis Lake based on these three indicators[6].

In Wallis Lake, all indicators of water quality improve '*with* the Plan*'* (WQIP) relative to '*without* the Plan' (No Plan). After implementing the Plan, the greatest marginal improvements in water quality at Wallis Lake are achieved during the first seven years.

Figure 6: Catchment Exports for Wallis Lake With and Without the WQIP[7]



Source: Great Lakes Council (2009b)

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[6] This report only includes the analysis at Wallis Lake for demonstration purposes. The 'with and without' scenarios at Smiths and Myall Lake are available in Great Lakes Council (2009b).

[7] TN is total nitrogen, TP is total phosphorus and TSS is total suspended sediments.

The results in Table 1 correspond to Figure 6. Total nitrogen catchment exports increase by over 5 per cent *without* the Plan but decrease by over 7 per cent *with* the Plan, an absolute change in exports of total nitrogen of 12 per cent.

Table 1: Water quality indicators at Wallis Lake represented by the change in sediments exported into the catchment

Without Plan (counterfactual)	With Plan
Total nitrogen increases by over 5%	Total nitrogen declines by over 7%
Total phosphorus declines by 1%	Total phosphorus declines by over 9%
Total suspended sediments declines by 1%	Total suspended sediments declines by over 11%

The improvement in water quality *with* the Plan results in environmental outcomes including increased estuary area and river length in good health, and increased native vegetation and wetland conservation. The economic benefits linked to these environmental outcomes comprise market and non-market goods and services, including increased fish and agricultural production (e.g. oyster production), enhanced market and non-market recreation (e.g. water sports and fishing) and improved urban amenity. The estimated value of the economic benefits and the costs of implementing the Plan were assessed through a cost benefit analysis (results for Wallis Lake given in Appendix 1).[8] The cost benefit analysis, completed by a consultant, estimated the net present benefit of implementing the Plan at Wallis, Myall and Smiths Lakes (Great Lakes Council 2009b), summarised in Table 2.

Table 2 presents the discounted stream of costs, benefits and the net present benefits resulting from implementing the Plan at Wallis, Myall and Smiths Lake (using a discount rate of 7 per cent per annum and aggregated over 30 years). [9] Sensitivity of the results to the discount rate was assessed using a four and ten per cent discount rate. The estimated net present benefit of implementing the Plan at Wallis Lake and Myall Lakes, using a 7 per cent discount rate, was $32.3 million and $29.4 million respectively. The estimated net present benefit of implementing the Plan at Smiths Lake was negative $1.2 million.

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[8] Results for Myall and Smiths Lake are given in Appendix 2 and Appendix 3 respectively.

[9] The present value of the benefits and costs is summed over a finite period of 30 years. Assuming only benefits occur after 30 years, limiting the time horizon to 30 years excludes a proportion of the present value of the benefits. The proportion that is excluded depends on the discount rate that is applied. Specifically, assuming a constant annual value, 31 per cent of the present value of benefits will be excluded with a 4 per cent discount rate, 13 per cent will be excluded with a 7 per cent discount rate and lastly 6 per cent will be excluded with a 10 per cent discount rate.

Table 2 Net present benefits from WQIP at the Wallis, Myall and Smiths lakes

	DISCOUNT RATE		
LAKE	**4%**	**7%**	**10%**
Wallis			
Total Costs ($m)	130.0	92.3	69.7
Total Benefts ($m)	163.0	125.0	99.4
Net Benefts ($m)	**33.2**	**32.3**	**29.8**
BCR	1.3	1.4	1.4
Myall			
Total Costs ($m)	13.5	10.2	8.1
Total Benefts ($m)	55.8	39.6	29.7
Net Benefts ($m)	**42.4**	**29.4**	**21.6**
BCR	4.1	3.9	3.7
Smiths			
Total Costs ($m)	2.0	1.5	1.2
Total Benefts ($m)	0.5	0.3	0.2
Net Benefts ($m)	**-1.5**	**-1.2**	**-1.0**
BCR	0.2	0.2	0.2

Source: Great Lakes Council (2009b)

The fourth and final step of the economic valuation is to attribute value to the environmental research. As previously mentioned, this involves understanding the uncertainties encountered along the process from *inputs* to *outputs* to *outcomes* and separating the contribution of the input in question from the other inputs used.

The Plan was developed by combining numerous inputs; the catchment and estuary models were just two of these inputs. The value attributed to the catchment and estuary models is therefore a proportion of the economic benefits given in Table 2. The cost share approach was the attribution method used to estimate this proportion, chosen because the catchment and estuary models were necessary, but by themselves not sufficient, to develop the Plan. The cost share approach requires the following information:

- the cost of the environmental research (the catchment and estuary models);
- the investment cost to develop the Plan;
- the total discounted cost to implement the policy (given in Table 2); and
- the estimated total discounted benefit of the policy outcomes (given in Table 2).

The total cost of the catchment and estuary models was $1.45 million and the total investment cost required to develop the Plan was $3.22 million (Table 3). The discounted cost of implementing the plan at Wallis, Myall and Smiths Lake was $92.3 million, $10.2 million and $1.50 million, respectively (assuming a seven per cent discount rate) (Table 2). The cost of implementing the Plan at each of the three lakes is the summation of the costs of individual actions as outlined in the Plan, for example management of dams and fertiliser. The specific actions outlined for each lake are given in Appendices 1, 2 and 3.

The total cost to develop and implement the Plan was $107 million (assuming a seven per cent discount rate) (Table 3), thus the cost share of the catchment and estuary models was 1.35 per cent. The value of the catchment and estuary models is calculated by multiplying the models' cost share by the total benefits (cf. Equation 1). For this case study the value of the final outcome is the discounted value of the economic benefits (given in Table 2). Using the cost share approach, the gross value of the catchment and estuary models is estimated to be $2.22 million (Table 4). Deducting their cost gives a net value of $775,000 for the catchment and estuary models.

Table 3: Cost share of the catchment and estuary models

Total Cost ($m)	
Catchment & Estuary modelling (CEM)	1.45
Coastal Catchments Initiative (incl. CEM)	3.22
Discounted cost of WQIP actions	104.00
Total development and implementation cost	*107.22*
Cost share of CEM	**1.35%**

Table 4: Value of the catchment and estuary models (CEM)

Value ($m)	
Discounted benefit of WQIP	164.59
Gross value of CEM	2.22
Net value of CEM	0.78

Two previous projects informed, to some degree, the catchment and estuary models; the Comprehensive Coastal Assessment (CCA) and a pilot study of the modelling package Annualized Agricultural Nonpoint Source model (AnnAGNPS) at Currency Creek. To reflect this contribution, a portion of the models' value (estimated as $2.22 million), should be attributed to these two previous projects.

The cost share approach was also used to attribute value to previous research. The total estimated cost of the two projects was $25,000 ($20,000 for the Comprehensive Coastal Assessment and $5,000 for the pilot study at Currency Creek). This total cost of the previous projects should be added to the total cost of the catchment and estuary models for a total cost of $1.48 million. Using this cost information, the cost share of the previous research was 0.02 per cent (Table 5); the estimated gross value of the two previous projects was approximately $38,400 and the net value $13,400 (Table 6). Accounting for the contribution of the previous research, the adjusted gross value of the catchment and estuary models was $2.19 million and the adjusted net value was $762,000.

Table 5 Cost share of previous research

Total Cost ($m)	
Comprehensive Coastal Assessment & Currency Creek Pilot Study	0.03
Catchment & Estuary modelling (CEM)	1.45
Coastal Catchments Initiative (incl.CEM)	3.22
Discounted cost of WQIP actions	104.00
Total development and implementation cost	*107.25*
Cost share of CCA & Pilot Study	**0.02%**

Table 6 Value of previous research (CCA & Pilot Study)

Value ($m)	
Discounted benefit of WQIP	164.59
Gross value of CCA & Pilot Study	0.04
Net value of CCA & Pilot Study	0.01

This approach to attributing value to previous research is deficient for two reasons. Firstly the total benefits of the two previous projects have not been included except inasmuch as that they contributed to the Initiative. Secondly the total cost of the two projects has been included which overstates their cost share and thus the value attributed to them. Including the total cost of the two projects incorrectly assumes that they were completed specifically to support the catchment and estuary models. Despite these limitations, this example has been included to highlight the importance of attributing value to previous research to avoid overestimating the value of the environmental research under evaluation.

There is limited funding available to implement the Water Quality Improvement Plan. It is possible that the Plan will not be completely implemented and individual actions will be selected. The cost benefit study included an analysis of the benefits, costs and net benefits of individual actions where possible. Some individual actions have a positive benefit cost ratio whilst others have a negative benefit cost ratio. With limited funding the optimal solution may be to only implement actions which have a benefit cost ratio greater than one.

There is some ambiguity about whether handpicking individual actions is appropriate. The environment is a complex interacting system and it may not be feasible to estimate the economic benefit of isolated actions. Despite this ambiguity, the value of the catchment and estuary models was also estimated when only a select group of actions were implemented. The rule used for selection of actions was a benefit cost ratio greater than one. The costs and benefits of individual actions are given for each of the three lakes in Appendix 4.

Table 7 Cost share of catchment and estuary models (selected actions)

Total Cost ($m)	
Catchment & Estuary modelling (CEM)	1.45
Coastal Catchments Initiative (incl. CEM)	3.22
Discounted cost of WQIP actions	31.33
Total development and implementation cost	*34.56*
Cost share of CEM	**4.19%**

Table 8 Value of the catchment and estuary models (selected actions)

Value ($m)	
Discounted benefit of WQIP	149.52
Gross value of CEM	6.27
Net value of CEM	4.82

As expected, the value of the catchment and estuary models increased when actions with a benefit cost ratio greater than one were handpicked. This is driven by two factors, firstly the reduced discounted cost of implementing WQIP actions in Table 7 increased the cost share of the catchment and estuary models to 4.19 per cent from 1.35 per cent in Table 3. Secondly, the overall benefit cost ratio increased as only actions with a benefit cost ratio greater than one were implemented. The corresponding gross value of the catchment and estuary models was $6.27 million and the net value was $4.82 million (Table 8).

5 Limitations of assessment

An important part of an economic valuation of research is to assess the confidence in the results, highlighting areas of uncertainty and classifying the confidence level as low, medium or high. Generic areas of uncertainty include the counterfactual, external events and the environmental outcomes. The key limitations for this case study were the counterfactual, the non-market benefit estimates, the cost share approach and the *policy-to-implementation link*.

5.1 The counterfactual

The theoretical counterfactual for the economic valuation was the policy-making process *without the environmental research*. This counterfactual permits direct estimates of the incremental value to the policy process contributed by the environmental research. This counterfactual was not used in this economic valuation because the contribution of the environmental research could not be separated from the other inputs. The process used to develop the policy is potentially analogous to a Leontief production function; the inputs are used in essentially fixed proportions with no substitutability between inputs.

The counterfactual used in the economic valuation was the scenario *without* the policy development and implementation. The value of the economic outcomes resulting from the policy was estimated as the incremental change in economic benefits relative to the scenario *without the policy*. Subsequently, the value of the environmental research was indirectly estimated as its cost share of the incremental value of the policy outcomes. The value of the environmental research therefore depends on the policy outcomes. Outcomes from environmental research are very different to outcomes from policy, hence ideally the environmental research would be valued separately from policy implementation.

The issue of attribution is closely related to the established counterfactual (Davis et al. 2008). As mentioned the counterfactual should be *without the research*. This is rarely feasible because inputs into a policy process are often all necessary with an elasticity of substitution equal to zero. The inability to establish the counterfactual for this economic assessment as *without the research* necessitated an attribution method, in this instance a cost share approach. Potentially the analogy between the policy process used to develop the Plan and the Leontief production process justifies the use of the cost share approach. The inputs are used in fixed proportions which is comparable to the cost share approach which attributes value to inputs in fixed proportions.

5.2 Non-market benefit estimates

The limitations of estimating non-market benefits are well documented in the literature (Boardman et al. 2006). Two particular limitations were present in this case study: benefit transfer was used to estimate non-market benefits and there was uncertainty about the dose-response link between environmental outcomes and economic benefits.

Benefit transfer was used to value the non-market benefits which are expected to occur once the policy (the Plan) is implemented. Benefit transfer applies previously estimated non-market values to the current situation. The technique assumes the characteristics, such as region, relative scarcity, quality and nature of change are comparable between the previous site and the current site. There is concern about the validity of using benefit transfer to estimate values for social and environmental impacts as these values tend to be situation and site specific (Davis et al. 2008). Yet it is considered better to include such indicative values in a cost-benefit analysis rather than ignore them; absence of a value suggests the outcome is unimportant. The valuation of these non-market benefits via benefit transfer gives a general understanding of the trade-offs being faced (Davis et al. 2008).

Particular economic benefits have a level of uncertainty regarding the impact of a change in environment outcomes on producer and consumer surpluses (Great Lakes Council 2009b). For instance, there is uncertainty about the degree to which improved water quality in the Great Lakes will lead to improved oyster production and recreation (both commercial and non-commercial). The United States Environment Protection Authority (US EPA 2002) acknowledged this uncertainty and suggested prioritising economic benefits based on confidence. A higher ranking applied to changes in benefits which are more certain and a lower ranking applied to changes in benefits that are less understood or more variable.

5.3 The cost share approach

The cost share approach assumes all inputs in a project are used efficiently, requiring the efficient quantity of each input is used and each input is cost effective. When either requirement is violated the constant average rate of return attributed to all inputs via a cost share approach is reduced. This raises two problematic scenarios depending on the relationship between the input being evaluated and the inefficient input. When the input being evaluated has been used in conjunction with the inefficient input its value will be underestimated because the constant average rate of return has decreased. Alternatively, when the inefficient input is the input being evaluated its value will be overestimated because its cost share is inefficiently increased.

Lastly the cost share approach does not distinguish between private and public sources of funding therefore not capturing the social cost of taxation.

5.4 Policy to implementation

> “The results of research may be wasted because there is a difference between recommending a policy and implementing it” (Zilberman and Heiman 2004, p.280)

The aim of the Initiative was to develop the best Water Quality Improvement Plan ignoring the financial constraint. The extent of available funding will determine the scale of implementation of the Plan. It is stated in the Plan that sourcing funds is one of the major challenges confronting the implementation of the Plan (Great Lakes Council 2009c). The cost benefit study estimated the costs and benefits of the actions and economic outcomes resulting from the complete implementation of the Plan. In this case study the cost share approach incorporated these estimated costs and benefits. In the absence of necessary funding, limited environmental benefits and therefore limited economic benefits may result. Given this the value of the environmental research may have been over-estimated in this study. To avoid discrepancies caused by the *policy to implementation link*, the probability of implementing each element of the policy should be included to calculate an *expected* benefit estimate. This was not done in this study as the data were sourced from secondary information and the probability of implementation was unknown.

It was possible to account for a scenario of limited funding because the cost benefit study also included an analysis of individual actions. The value of the catchment and estuary models was estimated with the restriction that only individual actions with a benefit cost ratio greater than one were implemented.

6 Final comments

This paper provides an empirical valuation of a particular example of environmental research. The approach used in this paper indirectly estimated the value of the catchment and estuary models used to develop the Water Quality Improvement Plan as part of the Great Lakes Coastal Catchments Initiative. The focus of this paper was the methodology; the estimated value of the research was only indicative.

The key limitation of the analysis was the inability to use the counterfactual of *without the research* to directly value the environmental research. Assessing what would have happened if the Water Quality Improvement Plan was developed and implemented without the usable knowledge from the catchment and estuary models. This scenario could not be assessed because the models were necessary to develop the Plan, without the models the Plan would not have been developed. The policy process was analogous to a Leontief production process where inputs were used in fixed proportions with no substitutability.

There is not a “one size fits all” method for valuation of environmental research. The development and implementation of applied environmental research is often unique to the project it is produced for. Differences between projects include the type of inputs used in a project and how they are combined, the nature of the outputs and outcomes, and the uncertainties encountered throughout the development and implementation stages.

An important consideration for future economic valuations of environmental research is the feasibility of the valuation. The *input* to *output* to *outcome* process needs to be clearly established and will partly determine if valuation is feasible. Assessing the feasibility is important to prevent the use of scarce resources, such as labour, to conduct a valuation which is not feasible. The timing of an economic valuation may also affect the feasibility of a valuation. For instance there are more uncertainties encountered in an ex ante valuation relative to an ex post. Yet the current demand is for ex ante evaluations to assist trade-off decisions between research programmes.

One of the key limitations for this economic valuation was the complex link between environmental research *outputs* and policy *outcomes.* It is expected the link between outputs and outcomes is relatively clearer for applied research than basic research. Given the limitations experienced in this economic valuation of *applied* research, it is anticipated additional limitations and uncertainties will be uncovered by economic valuations of *basic* research.

Environmental research is pivotal for improved management decisions relating to the environment. Hence, economic valuations of environmental research are important to demonstrate accountability and efficiency which promote increased funding towards further environmental research. However it is not a simple task and many projects may not be easily amenable to economic valuation due to the *input* to *output* to *outcome* process and/or the nature of the outcomes.

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Appendix 1 Estimated costs and benefits resulting from implementing the Water Quality Improvement Plan at Wallis Lake ($'000)

	NPV @ 4%	NPV @ 7%	NPV @ 10%
ECONOMIC COSTS			
Direct Program Costs			
Fertiliser	991	711	541
Dams	6,565	4,711	3,579
Groundcover	4,952	3,554	2,700
Riparian rehabilitation	925	664	504
Riparian protection	6,435	4,618	3,508
Wetland protection	11,522	9,977	8,729
Greenfield	33,228	25,363	20,071
Redevelopment	54,306	34,359	23,170
Mitigation	4,120	3,133	2,505
Sea Sponge protection	831	646	528
Water Sensitive Urban Devices (WSUD) protection	485	363	286
Lake use actions	470	408	358
Pollution control systems	58	55	52
Adaptive management strategy	96	69	52
Ecological monitoring	434	320	250
Future Investigation for Farm Scale Action Plan	570	489	427
Rainwater tanks	2,438	2,013	1,716
Sub-total	***128,427***	***91,453***	***68,975***
Indirect Program Costs			
Riparian			
Opportunity Costs of Riparian	844	606	460
Dams			
Cost of alternative water supplies for Dams	261	253	246
Sub-total	***1,104***	***859***	***706***
TOTAL COSTS	**129,532**	**92,312**	**69,682**
Benefits			
Improvements in Estuary Health	13,693	10,674	8,578
Improvements in River Health	78,274	61,016	49,034
Increased Native Vegetation Conservation	489	475	462
Increased Wetland Conservation	21,928	18,989	16,612
Benefits to Oyster Growers	2,922	1,902	1,313
Benefits to Commercial Fishers	614	400	276
Benefits to Non-market Recreation	16,581	10,796	7,452
Benefits to Comercial Recreation	12,155	7,915	5,463
Benefits to Urban Amenity	3,750	3,645	3,545
Sub-total	***150,405***	***115,811***	***92,735***
Indirect Program Benefits			
Ground cover and Fertiliser			
Reduce fertliser costs and increased productivity	12,263	8,800	6,685
Dams			
Increased agricultural production	38	27	21
Sub-total	***12,301***	***8,828***	***6,706***
TOTAL BENEFITS	**162,706**	**124,639**	**99,441**
NET BENEFITS	**33,174**	**32,327**	**29,759**
BCR	**1.3**	**1.4**	**1.4**

Source: Great Lakes Council 2009b

Appendix 2 Estimated costs and benefits resulting from implementing the Water Quality Improvement Plan at Myall Lake ($'000)

	NPV @ 4%	**NPV @ 7%**	**NPV @ 10%**
ECONOMIC COSTS			
Direct Program Costs			
Fertiliser	991	711	541
Dams	2,067	1,483	1,127
Groundcover	2,576	1,848	1,404
Riparian remediation	650	467	355
Greenfield	1,984	1,545	1,250
WSUD protection	72	54	43
Pollution control systems	35	33	32
Adaptive management strategy	58	42	32
Ecological monitoring	264	195	152
Future Investigation for Farm Scale Action Plan	347	297	260
Riparian protection	2,176	1,562	1,187
Wetland protection	2,097	1,816	1,588
Sub-total	***13,318***	***10,053***	***7,969***
Indirect Program Costs ($'000)			
Riparian			
Opportunity Costs of Riparian Revegetation	72	51	39
Dams			
Cost of alternative water supplies for Dams	87	84	82
Sub-total	***158***	***136***	***121***
TOTAL COSTS	**13,477**	**10,189**	**8,090**
Benefits			
Improvements in Estuary Health	570	444	357
Improvements in River Health	21,208	16,532	13,286
Increased Native Vegetation Conservation	97	94	91
Increased Wetland Conservation	2,608	2,258	1,976
Benefits to Oyster Growers	0	0	0
Benefits to Commercial Fishers	234	148	100
Benefits to Non-market Recreation	21,112	13,404	9,036
Benefits to Comercial Recreation	5,167	3,281	2,211
Mid Coast Water Treatment Savings	32	20	14
Sub-total	***51,026***	***36,182***	***27,070***
Indirect Program Benefits			
Ground cover and Fertiliser			
Reduce fertliser costs and increased productivity	4,793	3,440	2,613
Dams			
Increased agricultural production	13	9	7
Sub-total	***4,806***	***3,449***	***2,620***
TOTAL BENEFITS	**55,832**	**39,631**	**29,691**
NET BENEFITS	**42,356**	**29,442**	**21,600**
BCR	**4.1**	**3.9**	**3.7**

Source: Great Lakes Council 2009b

Appendix 3 Estimated costs and benefits resulting from implementing the Water Quality Improvement Plan at Smiths Lake ($'000)

	NPV @ 4%	NPV @ 7%	NPV @ 10%
ECONOMIC COSTS			
Direct Program Costs			
Groundcover	22	16	12
Gravel roads	415	298	226
Greenfield	415	309	237
Water Sensitive Urban Devices (WSUD) protection	3	2	1
Pollution control systems	1	1	1
Adaptive management strategy	2	2	1
Ecological monitoring	11	8	6
Future Investigation for Farm Scale Action Plan	15	13	11
Mitigation	1,088	851	695
TOTAL COSTS	**1,972**	**1,499**	**1,193**
Benefits			
Improvements in Estuary Health	0	0	0
Improvements in River Health	0	0	0
Increased Native Vegetation Conservation	0	0	0
Increased Wetland Conservation	0	0	0
Benefits to Oyster Growers	0	0	0
Benefits to Commercial Fishers	3	2	2
Benefits to Non-market Recreation	334	219	152
Benefits to Comercial Recreation	106	69	48
Benefits to Urban Amenity	0	0	0
Sub-total	***444***	***290***	***201***
Indirect Program Benefits			
Ground cover and Fertiliser			
Reduce fertliser costs and increased productivity	40	28	22
Sub-total	***40***	***28***	***22***
TOTAL BENEFITS	**483**	**319**	**223**
NET BENEFITS	**-1,488**	**-1,180**	**-970**
BCR	**0.2**	**0.2**	**0.2**

Source: Great Lakes Council 2009b

Appendix 4 WQIP Benefit Cost Analysis of Individual Actions[*]

Wallis Lake ($'000)

Individual Actions	Direct Costs	Indirect Costs	Total costs	Direct Benefits	Indirect Benefits	Total Benefits	BCR
Fertiliser	711	0	711	829	483	1,312	**1.8**
Dams	4,711	253	4,964	27	240	267	0.1
Groundcover	3,554	0	3,554	7,971	2,114	10,085	**2.8**
Riparian rehabilitation	664	431	1,095	25,571	0	25,571	**23.4**
Riparian protection	4,618	174	4,792	35,921	2,178	38,098	**7.9**
Wetland protection	9,977	0	9,977	18,989	2,771	21,759	**2.2**
Greenfield	25,363	0	25,363	0	10,029	10,029	0.4
Redevelopment	34,359	0	34,359	0	4,167	4,167	0.1
Mitigation	3,133	0	3,133	0	13,194	13,194	**4.2**
Sea Sponge Protection	646	0	646	0	NM	0	0.0
Water Sensitive Urban Devices (WSUD) Protection	363	0	363	0	156	156	0.4
Lake use actions	408	0	408	0	NM	NM	
Pollution control systems	55	0	55	0	NM	NM	
Adaptive management strategy	69	0	69	0	NM	NM	
Ecological monitoring	320	0	320	0	NM	NM	
Future Investigation for Farm Scale Action Plan	489	0	489	0	NM	NM	
Rainwater tanks	2,013	0	2,013	0	NM	NM	
Total	**91,453**	**859**	**92,312**	**89,308**	**35,331**	**124,639**	**1.35**

Source: Great Lakes Council 2009b

Myall Lake ($'000)

Individual Actions	Direct Costs	Indirect Costs	Total costs	Direct Benefits	Indirect Benefits	Total Benefits	BCR
Fertiliser	711	0	711	858	1,979	2,838	**4.0**
Dams	1,483	84	1,568	9	159	168	0.1
Groundcover	1,848	0	1,848	2,581	1,192	3,774	**2.0**
Riparian remediation	467	21	487	2,702	40	2,742	**5.6**
Greenfields	1,545	0	1,545	0	4,414	4,414	**2.9**
Water Sensitive Urban Devices (WSUD) Protection	54	0	54	0	175	175	**3.2**
Pollution control systems	33	0	33	0	NM	NM	
Adaptive management strategy	42	0	42	0	NM	NM	
Ecological monitoring	195	0	195	0	NM	NM	
Future Investigation for Farm Scale Action Plan	297	0	297	0	NM	NM	
Riparian protection	1,562	31	1,593	13,924	5,543	19,467	**12.2**
Wetland protection	1,816	0	1,816	2,258	3,794	6,052	**3.3**
Total	**10,053**	**136**	**10,189**	**22,333**	**17,298**	**39,631**	**3.9**

Source: Great Lakes Council 2009b

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[*] NM: the outcomes of these activities were not able to be modelled as part of the decision support system

Smiths Lake ($'000)

Individual Actions	Direct Costs	Indirect Costs	Total costs	Direct Benefits	Indirect Benefits	Total Benefits	BCR
Groundcover	16	0	16	28	10	39	**2.4**
Gravel Roads	298	0	298	0	5	5	0.0
Greenfield	309	0	309	0	248	248	0.8
Water Sensitive Urban Devices (WSUD) Protection	2	0	2	0	2	2	0.8
Pollution control systems	1	0	1	0	NM	NM	
Adaptive management strategy	2	0	2	0	NM	NM	
Ecological monitoring	8	0	8	0	NM	NM	
Future Investigation for Farm Scale Action Plan	13	0	13	0	NM	NM	
Mitigation	851	0	851	0	26	26	0.0
Total	**1,499**	**0**	**1,499**	**28**	**290**	**319**	**0.2**

Source: Great Lakes Council 2009b