The Valuation of South Australian Wetlands and Their Water Filtering Function:

A Cost Benefit Analysis

A thesis submitted by

CARMEL ELIZABETH SCHMIDT

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For Chris and Rachel Ey

"The real voyage of discovery consists not in seeking new landscapes, but in having new eyes." – Marcel Proust

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ABSTRACT

The Lower Murray dairy swamps were once part of a series of freshwater wetlands stretching along the Murray to the Coorong. Of the original 5700 hectares of wetlands only 500 hectares remain today. While the dairy industry that has developed on the swamps has considerable commercial value, it has destroyed the natural water filtration function that the wetlands provided. The industry also causes high levels of dairy effluent to enter the River Murray, contributing to blue-green algae outbreaks and associated economic losses for the local tourism industry.

This thesis provides valuable cost–benefit results on a set of three mutually exclusive land use and management options for dealing with the joint problems of water filtration and blue-green algae. The most important options examined involve the return of this area to wetlands for water filtration rather than continuing to use it for dairy farming.

The use of wetlands for water filtration significantly reduces the cost of supplying filtered water to consumers and also solves the dairy effluent problem. Indeed, one of the main conclusions of this thesis is that the most economically valuable use of this land is for wetlands for water filtration (rather than, for example, for dairy farming) and that the valuation of wetlands should be based on this use.

Little work has been undertaken in Australia to value the water filtration service that wetlands provide. In part this is due to poor data, considerable filtration variability between and across wetlands complexes and a focus on peoples 'willingness to pay' for selected wetlands attributes. This thesis contributes to the literature on wetland valuation by determining a value for the water filtration service they provide. It proposes a valuation methodology that can be used for both constructed and natural wetland complexes and which allows for variation both in water filtration efficiency across wetlands and in the amount of time that temporal wetlands are attached to the river.

The thesis is also of practical policy significance, providing sound arguments and empirical analyses to show that (i) there is a very strong prima facie case for retaining and restoring wetlands for their most valuable water filtration service alone, and (ii) that the valuation of wetlands in Australia solely on the basis of people's 'willingness-to- pay', i.e., ignoring their water filtering function, greatly underestimates the overall values and benefits of wetlands to society. The adoption of a 'function' or 'service' based valuation system would facilitate the introduction of a wetland mitigation banking system in Australia.

The results of this thesis will assist governments in Australia and elsewhere, when they deal with water filtration/quality problems, to make economically efficient and environmentally sound choices in their attempt to maximize the community's welfare.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Carmel Schmidt

December 2006

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1 INTRODUCTION

The Lower Murray dairy swamps were once part of a series of fresh-water wetlands stretching along the Murray to the Coorong. Of the original 5,700 hectare of wetlands only 500 hectare remain. The destruction of this wetland area is typical of wetland losses that have occurred across the country – it is estimated that over half of Australia's wetlands have been destroyed since European settlement (ANCA, 1996). While the causes of the destruction vary, ranging from conversion of wetlands to farming land, changes in wetland wetting and drying cycles as water is diverted to farming, and pollution from farming and industrial activities, the impact on the environment of the loss of wetland areas is little recognised, and has seldom been valued.

Politically, the return of the Lower Murray dairy swamps to wetlands is not seen as an option of high priority – wetlands are not viewed as having any great political or economic value. In contrast, the dairy industry that has developed on the wetlands has considerable commercial value; the only acknowledged drawback to the industry is the high level of effluent from the dairy pastures that enters the Murray River.

An important impact of this effluent is its contribution to blue-green algae (BGA) outbreaks. When outbreaks occur they have an economic impact on the local tourism industry and on drinking water quality. These impacts are well recognised, with Kennedy (1997) noting that "to avoid the dangers of BGA contaminated drinking water, costs must be incurred, either by eliminating nutrient loadings, or taking action to disperse blooms. Such costs may also be worth incurring to prevent the loss of recreational use of waterways and consequent loss of tourism revenue."

This thesis examines the question of how best to address the effluent problem arising from the use of this land for dairy farming. It questions whether returning this area to wetlands for water filtration might solve the effluent problem while at the same time providing one very important wetland function: water filtration.

Indeed, the aim of the thesis is to determine the value of wetlands for water filtration. This value will be used to show that, economically, this land should be returned to wetlands on the basis of its valuable wetland function alone.

The analysis presented in this thesis is based on the premise that water filtration plants have not yet been constructed in the study region, and thus the use of wetlands for water filtration could negate the need to construct all or part of future water filtration plants.

Results from this thesis will provide important information for other jurisdictions contemplating the use of wetlands instead of, or in conjunction with, water filtration plants. They will provide a valuable guide to natural resource managers trying to determine the value of the environmental services provided by natural wetlands when wetland areas are faced with destruction or rehabilitation. It is hoped that recognition of the valuable function that wetlands provide will slow their rate of destruction.

Using cost–benefit analysis criteria (benefit–cost ratio and net present value), this thesis shows that the value of the Lower Murray dairy swamps area is considerably greater when converted to wetlands for water filtration than when used for dairy farming. The thesis also demonstrates that the current methodology used in Australia to value wetlands is unable to capture the value of this very important function, and also shows how the principles behind wetland mitigation and mitigation banking can be used to more efficiently capture wetland functional values. The thesis examines the concept of wetland mitigation in the US, and also draws a comparison between the valuation and loss of native vegetation in South Australia, and the valuation and loss of wetlands.

It is important to note that this thesis does not attempt to determine the wide range of other wetland attributes that people desire to maintain or increase. As long as people are willing to identify and pay for their desired wetland attributes, then the benefits (net of additional cost for improving various wetland attributes) should be considered in conjunction with the value of wetlands for water filtration determined in this thesis. It is expected that the water filtering use of wetlands and their other environmental uses are complementary and not mutually exclusive.[1]

1.1 COST-BENEFIT ANALYSIS

The obvious question is why cost–benefit analysis was chosen to value wetlands. The answer lies in the fact that the government is both the actual and the proper decision-making body when considering the future uses of this land. Unlike firms, which are concerned mainly with private profits, the government is, or should be, primarily concerned with the net effect of the project on the welfare of the community. Cost–benefit analysis allows us to value all relevant inputs and outputs from the point of view of the farmer, the government or the community.

It is assumed that the government wishes to maximize social welfare, which is a function of the following variables:

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[1] To date studies undertaken in Australia to value wetlands have used non-market valuation techniques such as 'contingency valuation', 'choice modelling' or 'travel costs' methods, which are based on people's 'willingness to pay' for maintaining or increasing a range of wetland attributes, rather than on the value of the functions that wetlands provide. Seldom do the values obtained from these studies show that the public values wetland conservation more highly than an existing industry or farming activity . Because of this, wetland areas continue to be destroyed.

(i) Discounted present value of present and future consumption of all individuals within the community, and

(ii) A measure of the equality of income distribution among individuals.

It is reasonable to assume that the government is politically unable to use fiscal, monetary and legislative measures to achieve the optimal solution. Therefore, other things being equal, a project which has positive impacts on saving (at the expense of consumption), employment and consumption of the poor relative to that of the rich, and negative impacts on government expenditure or debt, would be deemed to be more desirable than one without such impacts.

It is beyond the scope of this thesis to quantify the value of saving in terms of consumption, of consumption by a poor individual in terms of a rich one, or of the provision (or removal) of employment for one extra person. This thesis also does not attempt to determine the impact on individual dairy farmers of changes to the existing dairy farming regime suggested in this thesis, nor does it delve into the restructure of the dairy industry. Such topics have been covered by others and are outside the scope of this work.

It should be noted that the economic benefits and costs of a project can be defined only by the effects it has on some fundamental objectives of interest to the decision-maker. There really is no analytical distinction between benefits and costs, *since costs are simply the benefits forgone by not using the project resources in other ways*. As Ray (1984) aptly puts it, by measuring both benefits and costs with the same yardstick, one can indicate in project analysis the net impact on the chosen objective. If the net impact is positive, or not negative, then the indication is that the project resources cannot be used in better ways from the point of view of that objective.

While the main aim and, indeed, the main contribution of the thesis lies in the provision of a sound assessment of the value of wetlands for water filtration, this thesis also contributes to the literature on cost–benefit analysis by resolving many complex problems concerning the valuation of numerous items of costs and benefits involved in each of the land use options – valuation from the point of view of the government as the decision-maker – as applicable for a State such as South Australia.[2]

By explicitly stating and providing arguments in support of each of the key assumptions, parameters and sources of information, the thesis provides not only (i) the basis to enable the readers to assess for themselves their validity, but also (ii) important practical questions for discussion which would benefit future research.

The thesis will also make a useful contribution to the literature on the application of cost–benefit analysis by discussing (*in the results chapter*): (i) the normative conclusions which can be drawn from the baseline results under different object function between scenarios; (ii) the changes in the baseline results as model parameters (e.g., discount rates, alternative costs of water filtering) are changed by undertaking (sensitivity analysis); and (*in the final discussion*) (iii) the potential implications of a change in government wetland valuation policy on income distribution in the region.

1.2 THESIS STRUCTURE

The next chapter of the thesis (Chapters 2) identifies and describe the issues being addressed in this work. Chapters 3 and 4 then go on to present and discuss the methodology to be used for evaluating results.

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[2] By overlooking the use of wetlands for water filtration, earlier studies undervalue wetlands considerably and this has most probably contributed to the continued destruction of wetlands and the consequent adverse environmental impacts this involves.

Chapters 5 – 7 examine the three alternative land use options being examined. Because the focus of this thesis is to determine a value for wetlands for water filtration, this option is examined first, in Chapter 5. Chapter 6 goes on to compare the Status quo with the options of rehabilitation and conversion to wetlands for their pollution alleviation function alone, while Chapter 7 draws on the results from the previous two chapters to consider returning the whole area to wetlands for water filtration. Chapter 8 then compares a sustainable land use option – Piped rehabilitation – with conversion to wetlands for water filtration.

A summary of results is presented in Chapter 9, while Chapter 10 draws conclusions from this work.

2 INFORMATION AND ASSUMPTIONS

2.1 BACKGROUND

This thesis is focused on the Lower Murray reclaimed swamps and considers three competing land uses: dairy farming and alternative farming options, domestic water filtration, and wetlands. In order to understand the economic options presented it is important to have an understanding of the complexities of each land use option. For this reason this part of the thesis investigates the important geographic, ecological and biological interactions that determine the costs and benefits and resulting economics of each land use option.

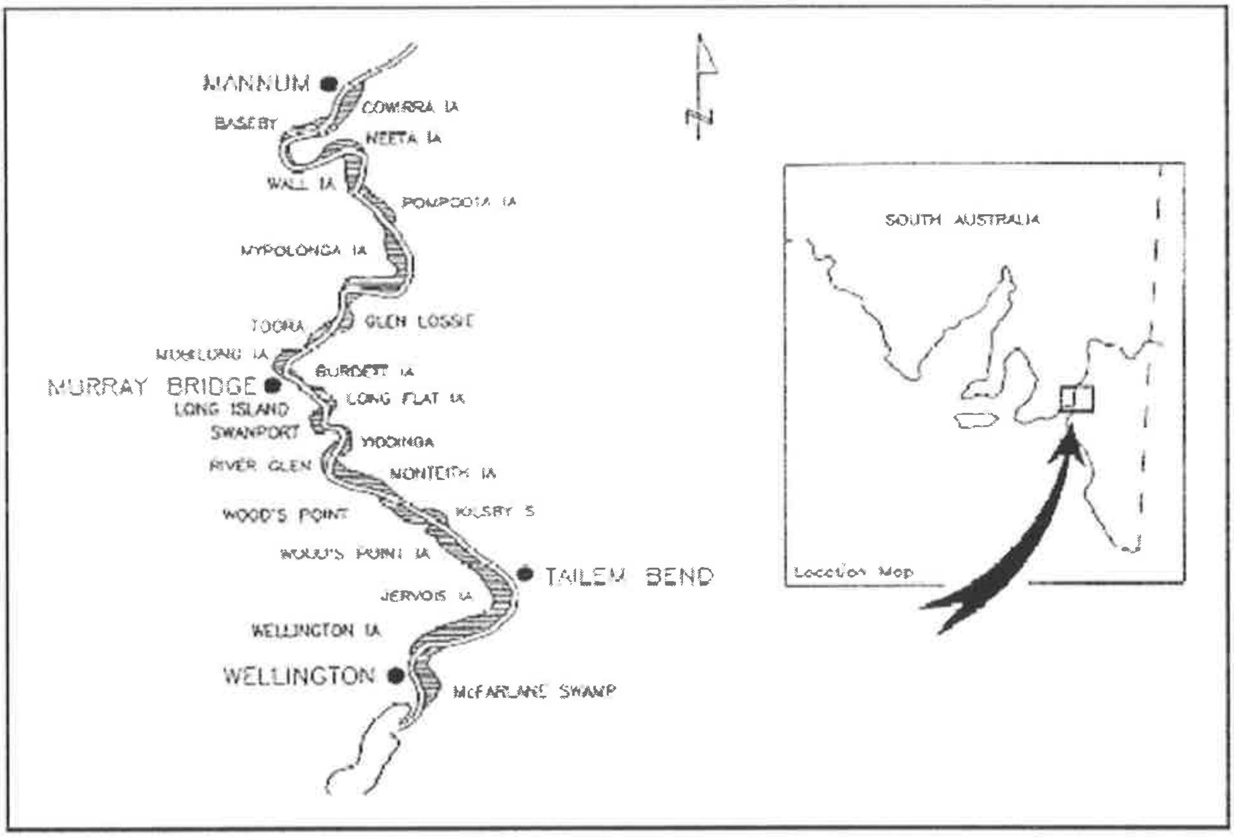
First, the location, geography and layout of the existing irrigation scheme are presented as these factors significantly contribute to the dairy effluent pollution problem and thus fundamentally limit land use options. Next, the ownership, management and administration of the irrigation scheme are examined to provide an understanding of the issues that must be overcome when determining land use and scheme ownership option for this region.

2.2 LOCATION

The Lower Murray flood plains comprise 20 reclaimed swamps located between Mannum and Wellington in South Australia (Figure 2-1). The reclaimed swamps consist of approximately 5,200 hectares of land, which is utilised almost exclusively as irrigated pasture for dairying.

FIGURE 2-1. LOCATION OF THE STUDY AREA (SHADED AREAS = DAIRY SWAMPS)

Source (Murray and Philcox, 1995)

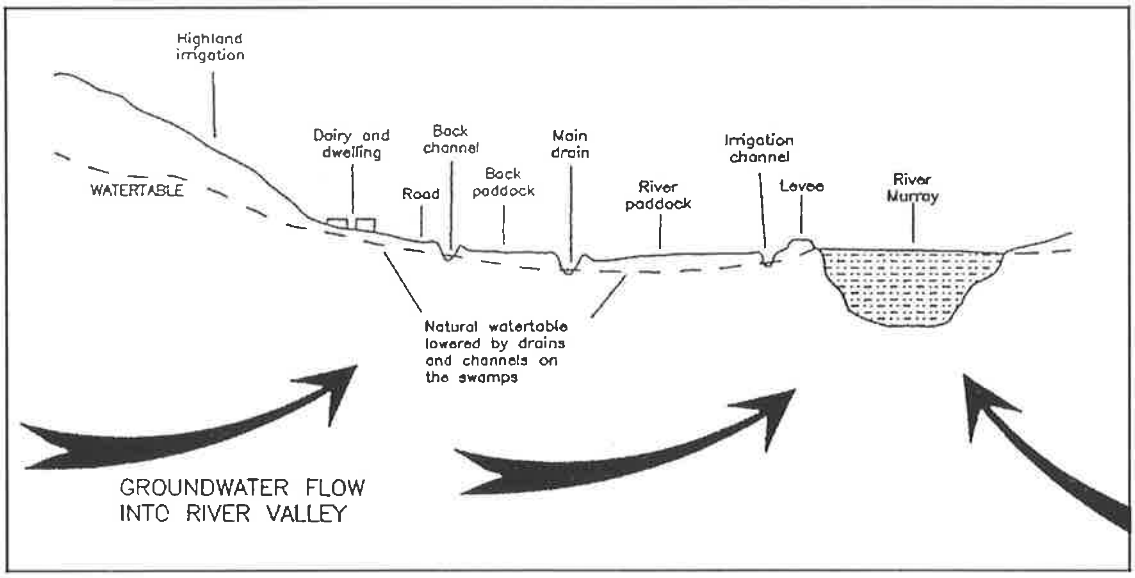


Approximately 4,100 hectares are administered as government irrigation areas while the remaining 1,100 hectares are managed as privately owned irrigation schemes.

After many years of development and change (see Appendix 2 for details), by 1929 the government-reclaimed swamps were established in their present form and are now predominantly sown to pasture for intensive dairy farming. An additional 600 hectares of land have also been developed on the highlands surrounding the swamp areas. These highlands are farmed in conjunction with the government swamps, and are predominantly reliant on water from either the swamp 'main drain' or 'back channel' for irrigation. For most swamps, water for irrigation of highland grazing areas is pumped from the back channel and piped up the hill to the highland irrigated areas (Figure 2-2).

FIGURE 2-2. TOPOGRAPHY OF A TYPICAL RECLAIMED SWAMP

Source (Cole, 1985)



A summary of the reclaimed areas (swamps) covered in this thesis and their dependence on the swamp for highland irrigation is presented in Table 2-1.

TABLE 2-1. RECLAIMED AREAS AND HIGHLAND IRRIGATION

Government swamp	Dependent on swamp for irrigation
Burdett	No
Cowirra	Yes
Jervois	Yes
Mobilong	Yes
Monteith	Yes
Mypolonga	Yes
Neeta	Yes
Pompoota	Yes
Wall Flat	Yes

2.3 TOPOGRAPHY

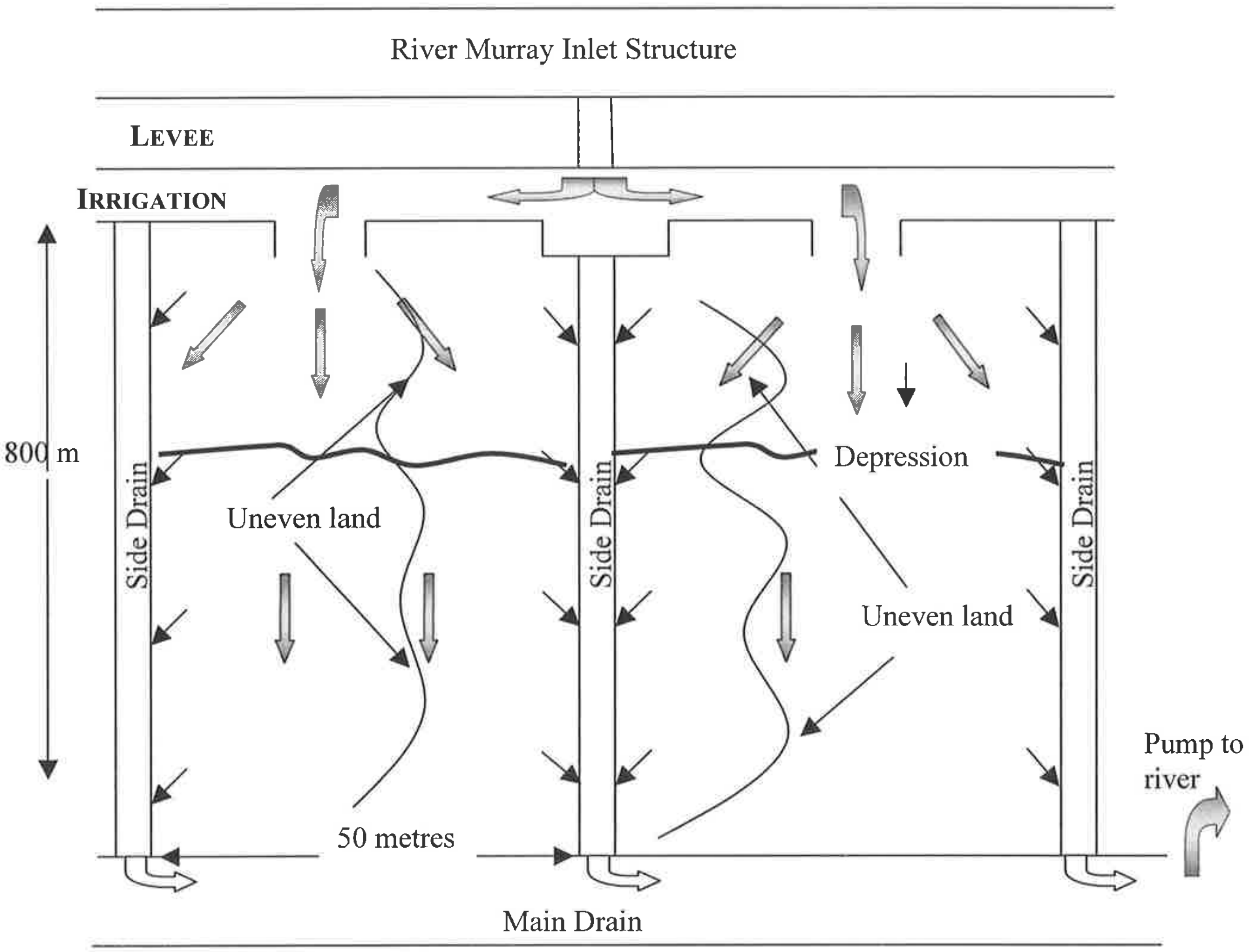
The Lower Murray dairy swamps consist of a system of levee banks, which maintain the pool level of the river at about 1.5 metres above the reclaimed swamp floor (Whittle and Philcox, 1996b).

The common topographical feature of the reclaimed swamps is a gradual downward slope extending from the river to a depression approximately two thirds of the distance to the valley side, from where the ground rises again. This slope is generally less than one metre over a distance of between 400 and 900 metres (Murray and Philcox, 1995). In conjunction with the available hydraulic head and the large flow rate provided by the river, these characteristics enable flood irrigation of the dairy pastures. Water flows across the swamps and is taken up by the pasture. Some of the remaining 'drainage' water (i.e., water not used for irrigation) is then pumped to the highlands for irrigation use while the remainder is returned to the river, as shown in Figure 2-2.

However, as seen in Figure 2-3, the land on the swamps is extremely uneven both across the bays and down the length. For this reason farmers must apply greater volumes of water than would normally be required on a level swamp to ensure that water reaches all parts of the pasture. It is this excess water that dissolves dairy effluent that is then returned to the river. Because of the complexities of the existing drainage system and slope of the land 'partial rehabilitation' is not possible, and therefore rehabilitation options do not follow the traditional marginal abatement cost curves as presented by Hanley *et al.* (1997).

The nutrients contained in the drainage (which is returned to the river) have an impact on the River Murray environment and contribute to the outbreak of blue-green algae in the Lower Murray. When algae outbreaks occur SA Tourism figures show there is a drop in tourism of approximately 20% to the region. Thus the income from tourism and that from the dairy industry are interrelated through the externality impacts of the drainage on water quality and algal blooms. The extent of these impacts is addressed in this thesis.

FIGURE 2-3. WATER MOVEMENT ACROSS IRRIGATION BAYS



Modified from LMIAG (1999)

2.4 ADMINISTRATION

The control and management of the government swamps has changed many times over the past 100 years, as summarised in Table 2-2. However, as far as the farmers are concerned these changes have made little difference to the operation of the irrigation system (LMIAG, pers com).

Because the irrigation scheme remains with the government, the government retains responsibility for its repair and maintenance. This ownership and liability is considered in this thesis when determining the cost-sharing arrangement with farmers.

Farmers consider the scheme to have been poorly run and maintained regardless of which government department was involved, and have expressed frustration at the lack of accountability of the various departments over time. Indeed, an independent examination of the irrigation scheme undertaken during the course of this work does indicate that it has been poorly maintained and managed for many years. Table 2-2 indicates that the control and administration of the scheme has been a 'political football', with responsibility regularly passed between government departments.

TABLE 2-2. ADMINISTRATION AND CONTROL OF GOVERNMENT SWAMPS

Year	Authority
Up to 1910	Survey Department
1910–1911 Irrigation and Reclamation Department	Commissioner of Crown Lands
1912 Irrigation and Reclamation Department	Minister of Agriculture
1913 Irrigation and Reclamation Department	Minister of Irrigation
1918 Irrigation and Reclamation Department	Minister of Agriculture
1919 Irrigation and Reclamation Department	Minister of Irrigation
1923	Irrigation Commission
1926	Irrigation and Drainage Commission
1931 Department of Lands responsible to:	Minister of Irrigation
1978 Engineering and Water Supply Department:	Minister for Works
2000 Department for Water Resources	Minister for Water Resources
2002 Department of Water Land and Biodiversity Conservation	Minister for the Environment and Minister for the River Murray

3 APPLICATION OF COST–BENEFIT ANALYSIS IN THIS THESIS

The purpose of the cost-benefit model written for this analysis was to determine a value for water filtration by wetlands. This value is then used to determine whether the Lower Murray dairy swamps should be converted to wetlands for water filtration or if the land should be rehabilitated (using either a channelled or piped irrigation system) and remain in dairy farming.

3.1 Brief review of literature on CBA

As early as 1808 Albert Gallatin, United States Secretary of the Treasury, was recommending the comparison of costs and benefits in water-related projects. This precedes the often-cited writings of French engineer Jules Dupuit by 50 years (Hanley and Spash, 1993). Cost–Benefit Analysis (CBA) saw its first widespread use in the evaluation of federal water projects in the United States in the late 1930s. Since then it has also been used to analyse policies affecting transportation, public health, criminal justice, defence, education, and the environment (Portney, 2002).

CBA defines benefits and costs in a particular way according to the satisfaction of wants or preferences. If something meets a want, then it is a benefit. If it detracts from a want, it is a cost (Turner *et al.*, 1994). Part of the difficulty in environmental economics is being able to measure environmental 'benefits' and 'costs', and hence the development of Benefit Direct Estimate (BDE) techniques (more commonly referred to as 'non-market valuation techniques'), as described later in this thesis. Once the benefits and costs of a particular course of action are determined it is then possible to determine whether the benefits outweigh the costs. The basic CBA rule is that a project is to be judged potentially worthwhile if its benefits exceed its costs (Pearce, 1983).

CBA has been used extensively in the field of environmental economics to make decisions on resource allocation, conservation, and pollution levels. It has been used over many years to determine the economics of projects ranging from: the Gordon-below-Franklin dam (Pearce, 1983), lead levels in petrol in the US (Turner *et al.*, 1994), the value of conserving biodiversity (Pearce and Moran, 1994), wetland rehabilitation (Petersen and Bennett, 2003) and augmentation of water supplies (Kerr *et al.*, 2003), to name but a few studies.

The CBA methodology adopted in this thesis is based on that developed in Little and Mirrlees (L&M), (1976), and the Handbook of Cost–benefit Analysis, Department of Finance (DOF) (1991). Even though L&M was published over three decades ago, much of it remains as relevant today as when it was first published. However, as usual with all guides or manuals, suggested rules for project evaluation are by their nature very general and have therefore to be modified to make them more appropriate for the particular circumstance of individual cases.

Cost–benefit analysis was chosen for use in this study because it has been identified in the DOF (1991) handbook as a methodology suitable for evaluating projects with a number of characteristics that can be identified in this thesis:

- It can provide guidance on the efficient allocation of resources in areas where no market exists to provide this information 'automatically'. This is particularly true in this thesis where no market exists for wetlands or the water filtration benefits they provide.
- It is helpful where, without commercial transactions taking place, projects impose costs or benefits on third parties. Again, this is directly relevant to this study where pollution externalities are having an impact on third parties (water consumers and the tourism industry).
- There are grounds for mistrusting the signals provided by market prices; for example, where inputs are underpriced relative to costs, or where outputs are overpriced. In this

thesis the contention is that the market is not adequately valuing water filtration services provided by wetlands.

- It is useful when a project is so large in scale that it is important to be fully aware of its wider economic effects. In this thesis, the suggestion that this whole region should be converted from dairy farming to wetlands has significant economic implications for farmers and therefore needs to be carefully evaluated before any decisions can be made.

3.2 STEPS IN COST–BENEFIT ANALYSIS

The main principles of cost–benefit analysis are encompassed within four key questions (DOF, 1991):

- Which costs and benefits are to be included?
- How are these costs and benefits to be valued?
- What is the interest rate at which these costs and benefits are to be discounted?
- What are the relevant constraints?

These four questions are addressed in this thesis for the three land use options examined. The following sections in this chapter provide an overview of the three land use options so that costs and benefits can later be identified and valued. They also detail the discount rate and relevant constraints. Finally, a section is included detailing the way results will be presented so that the costs and benefits of each option to all stakeholders can be clearly seen.

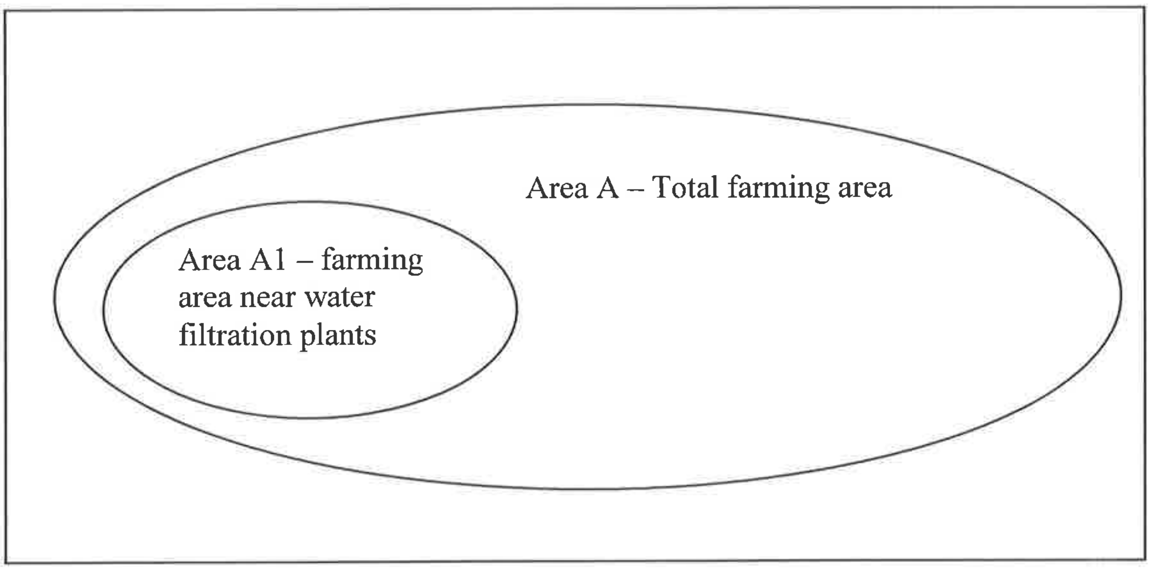
Thus, this part of the thesis serves as an introduction to chapters 5, 6 and 7, where identification and valuation of costs and benefits takes place and where results are presented.

3.2.1 Base Case scenario

This analysis is undertaken from a base, historical scenario before any measures have been undertaken to either build water filtration plants or to address the problems of water pollution related to dairy farming. This base case is referred to as the 'Status quo'. As the focus of this work is on determining a value for wetlands for water filtration, the selection of the situation as it existed at that time allows this value to be easily determined. It also allows the thesis to consider 1) the value that such wetlands would have if they were to be used alone, or in conjunction with the proposed filtration plants, and 2) the value such wetlands would have if they provided filtered water in excess of that currently demanded by consumers.

The three options to be investigated relate to both a subset and the entire dairy farming area, as presented in Figure 3-1. Area A represents the whole of the study area, which is used for dairy farming. Area A1 is a subset of area A, and represents those dairy swamps that are in the vicinity of the proposed water filtration plants. It is proposed that area A1 could be used as part of the water filtration system.

FIGURE 3-1. IDENTIFICATION OF AREAS TO BE EXAMINED IN THIS THESIS



3.2.2 The three options investigated

Part I. Before discussing the Status quo, the first part of this thesis examines the use of wetlands for water filtration in area A1. This part of the thesis is critical as it is from this section that it is possible to determine the value that wetlands have for water filtration.

The valuation of costs and benefits in this section requires an understanding of the commercial water filtration process, and of the type and nature of the wetlands that would need to be constructed to replace all or half of the filtration system. For this reason, Chapter 5 includes a review of literature on the water filtration process. Even though the conversion of this area to wetlands for water filtration will result in the alleviation of pollution at the same time, the SCBA in this part considers the benefits and costs of the swamps only in terms of water filtering.

Part II. The 'without-project' scenario for this part of the thesis relates to the case in which 'nothing will be done' to alleviate pollution, and is thus the 'Status quo' case for the whole of area A. An important part of the analysis undertaken is the effect that the dairy industry has on the riverine environment. It is clear from the irrigation effluent being returned to the river from the dairy farms that dairy farms in this region are polluting the environment and contributing to blue-green algae outbreaks, resulting in a loss of income for the local tourism industry. If we are interested in how to best tackle the algal bloom problem from an economic perspective, we need to know the damage costs of blooms, the causes of blooms, measures for countering the causes, and the costs of the measures (Kennedy, 1997). All these measures and costs are difficult to identify and quantify, and require drawing on existing literature in this field, as detailed in Chapter 6.

For this part, we shall consider two alternative 'with-project' scenarios for area A. The first scenario, 'Project IIA', will present the results for a Piped or Channelled rehabilitation scheme to deal with the problem of pollution for all the dairy swamp area (area A). For rehabilitation to be successful it is important to understand the causes of effluent run-off and to examine potential engineering solutions. (A discussion of alternative farming options on this land is presented in Appendix 2.)

The second scenario, 'Project IIB', will present the result of converting all the dairy swamp area (area A) to wetlands specifically for their pollution-alleviation function.

Part III. As it is the contention of this thesis that the most economically valuable use of this land is for wetlands for water filtration, the conversion of the whole of area A back to wetlands for water filtration is finally examined. This section therefore also includes a review of the existing methodology used to determine wetland values so that an understanding of the importance of valuing the water filtration function of wetlands can be understood.

3.2.3 Summary of options examined in this thesis

A summary of the options analysed in this thesis is presented in Table 3-1, while the implications of these options for farmers and the government are presented in Figure 3-2.

TABLE 3-1. A SUMMARY OF TREATMENTS ANALYSED IN THIS THESIS

Treatment no.	Treatment
Part 1	Convert swamp areas near proposed water filtration plants sites to wetlands for use as part of the water filtration system
Part II	Without project – Status quo
Part II A	Piped or Channelled rehabilitation
Part II B	Conversion to wetlands (either Managed or Permanent) for pollution alleviation
Part III	Return whole area to wetlands for water filtration and pollution alleviation.

Each of these solutions involves different costs and benefits for both farmers and the government. As can be seen in Figure 3-2, the option of returning part of this area to wetlands for water filtration (box 1) results in a reduction in pollution costs for the region, and removes some or all of the cost of water filtration plant construction. This option also allows farmers on the affected swamp to sell their water on the open market. In contrast, rehabilitation of the irrigation system (box 2) results in increased milk production (compared with the Status quo), but pollution impacts would still be of concern, and there would be no water filtration benefits.

Conversion of the whole area to wetlands for pollution control (box 4) removes pollution impacts associated with dairy farming in this region, and allow farmers to sell their irrigation water. However it means the loss of the dairy industry from the region.

Conversion of the whole area to wetlands for water filtration and pollution control provides the combined benefits and costs of boxes 1 and 4.

FIGURE 3-2. IMPLICATIONS OF ALTERNATIVE LAND USES

1 Water filtration

Farmers
- Some farming land converted to wetlands – small loss of milk production
- Can sell irrigation water associated with farming

Government
- Purchases farmers' water
- Pays for wetland construction
- Reduced water filtration costs
- Reduced effluent, reduced BGA
- Purchases water for evaporation
- Ongoing wetland r & m costs
- No need for UV plant
- Reduced tourism losses

2 Status Quo

Farmer
- Income from dairy farming
- Share repair and maintenance costs
- Pollute river

Government
- Regional benefits from dairy farming
- Owns and manages irrigation scheme
- Share repair and maintenance costs
- Tourism losses
- Ongoing irrigation scheme costs
- BGA/water quality costs

3 Piped & Channelled irrigation

Farmers
- Increased income, reduced labour costs
- Reduced fertiliser and feed costs
- Rehabilitation costs, ongoing monitoring cost
- All capital repair and maintenance costs
- Own irrigation scheme

Government
- Possible rehabilitation costs
- No longer own irrigation scheme
- No Ongoing irrigation scheme costs
- Regional benefit from production increase
- Training costs
- Reduced tourism losses
- Reduced BGA/water quality costs

4 Wetlands for pollution control

Farmers
- Can sell water and cease farming on swamps
- Farming continues on highlands
- Half farmers probably leave the region, rest remain farming on highland and semi retire

Government (**M**= Managed option only, **P**=Permanent option only)
- Wetland construction costs (**M**)
- Water filtration benefits
- No effluent to river
- No tourism losses associated with dairy farming
- Milk factory pays approx. 3c/litre for milk from other areas
- On-going management costs (**M**)
- Purchase water (**P**)
- No ongoing irrigation scheme costs

3.2.4 Discount rate and relevant constraints

3.2.4.1 Discount rate

Market interest and inflation rates varied considerably over the course of this investigation, making the selection of an appropriate real interest rate difficult. Eventually it was decided to use a real interest rate in this analysis of 3.55%, assuming an inflation rate of 2.12%. An interest rate of 5.75% has been used in this analysis based on the rate for government bonds at the time the final analysis was undertaken. This is based on the method of determining the real interest rate below:

$$r = (1+n)/(1+i) - 1,$$

where r = real interest rate, n = nominal interest rate and i = inflation rate.

A further discussion on the choice of the discount rate is presented in Chapter 4.2.

3.2.4.2 Ownership

The government owns the irrigation scheme used by the farmers, and hence the government is responsible for the repair, maintenance and capital costs associated with the scheme. The government recovers 87.9% of the repair, maintenance and capital costs from farmers. The government pays all other costs (see Appendix 3 for details).

3.2.4.3 Timeframe

The model is run for a period of 25 years. This period of time was chosen because after 25 years Riverland water's BOOT contract with the SA government (to build, own and operate the water filtration plants in the study area) will end, and the plants will revert to the government.

3.2.4.4 Industry future

The local dairy factory uses milk produced by farmers in this region. However, should farmers on these swamps cease producing milk, the dairy factories have indicated that they will simply truck milk in from neighbouring milk producers at a cost of three cents per litre. Therefore, as the fate of this industry is not expected to have a large impact on the surrounding region, output multipliers have not been used in this analysis.

3.2.4.5 Information sources

When comparing such disparate land uses, it was important to obtain information from a wide variety of sources including the dairy farmer themselves, SA Water, the Tourism Commission, plus numerous engineers, consultants and specialists, and then to convert this information into figures suitable for economic analysis. Appendices 3 and 4 present the information, calculations and reasoning behind the key figures used in the model for each option.

3.2.5 Presentation of results

Because the government is the owner of the irrigation scheme in this analysis, it is the assumed decision-maker on behalf of the community. The government has a number of instruments it can use to ensure that any decision it makes in regard to land use in this region is implemented. These measures include: the financial compensation of those affected by rehabilitation projects; imposition of pollution taxes and water use charges; legislation to affect land and irrigation leases; and the granting of water licenses. As the goal of the government is assumed to be economic efficiency, the results will **first** be presented from the community's viewpoint.

The results will then be presented from the point of view of the government, which will include identification of compensation payments required for farmers to be willing to take up land use change options. It is reasonable to assume that if any of the proposed projects require farmers to assume debt levels that are financially crippling, farmers will not be willing to undertake such options. Thus, compensation payments make a project possible, and therefore 'increase national income'. For this reason arguments (such as those posed by Gittinger (1985)) that such payments are inappropriate, do not apply.

The problem of considering compensation payments is not new, as noted by Mishan (1975). Mishan states that "the inclusion of a 'bounty' (payment made to a group so that a project takes place), it may be alleged, is granted in consideration of some benefit to the nation at large that is difficult to quantify. The economist may be able to salve his professional conscience by entering the value of the bounty as equal to the additional security provided for the nation by the project." In this case, it is possible to identify the greater benefit to society if the project proceeds and hence justify the inclusion of these payments in the analysis from the government's perspective.

If the government has determined not to participate in compensation payments, then there is no need for this presentation. In practice, however, the government is not indifferent to such payments to farmers, particularly as it is aware that the problem on the swamps is historically, to a large extent, of its own making (see Appendix 2).

3.2.5.1 Presentation within tables

For each of the land use options presented, the benefits of the Status quo (dairy farming) option to each party involved (i.e., the government, the farmers and the consumers/community) will be treated as (opportunity) costs and the costs of the Status quo will be treated as (opportunity) benefits. Furthermore, where relevant, cost-sharing ratios (which include any compensation to farmers for the change in wetlands' use) will also be presented. Thus, the results are generally presented in tables in the following way:

1. Column one shows the NPV, benefits, costs and benefit–cost ratios for the land use any change is being compared against (this is generally the Status quo option).
2. Column two shows the NPV, benefits, costs, and benefit–cost ratios of the alternative land use being considered.
3. Column three shows the net result of changing from one land use to another.
4. A separate table shows how much the government would have to compensate farmers for them to be willing to undertake the changes required under the various land use scenarios presented. This table is important because it clearly shows if it is not in the interest of farmers to make the land use change even if the NPV shows that the land use change is economic. From this step it is also possible to determine if under the 'Beneficiary pays principle' each party is receiving benefits in proportion to the costs they are paying.

The above method of presenting the results highlights that a change of land use comes with costs in terms of the 'loss' of benefits and costs associated with the current land use (dairy farming).

4 EVALUATING RESULTS

This chapter considers the methodology for evaluating the results obtained from undertaking the benefit–cost analysis in this thesis. While it has not been necessary to apply some of the techniques covered in this chapter (e.g., the use of multipliers, valuing foreign exchange and shadow wage rates), the application of these techniques can be important in certain CBA, and hence a short review of these topics has been included.

4.1 CRITERIA FOR RANKING MUTUALLY EXCLUSIVE PROJECTS

This thesis assumes that the government wishes to maximise its benefits when deciding which projects it will invest in. The total wealth for the government is defined as the sum of:

- The discounted present value of its income (from taxes, project earnings, etc.), and
- Its current net debt

When choosing projects in which to invest, the government must therefore first determine the NPV for individual projects. These NPVs can then be summed to determine which combination of projects produces the best economic return.

However, NPV is not the only criterion that can be used to determine which project to invest in. The three most popular methodologies (DOF, 1991; Sinden and Thampapillai, 1995; NSW Treasury, 1997) used to assist in project selection are:

- Net present value (NPV): $\text{NPV} = \sum_{t=0}^{N} B_t(1+r)^{-t} - \sum_{t=0}^{N} C_t(1+r)^{-t}$
- Benefit cost ratio (BCR): $\text{BCR} = \sum_{t=0}^{N} B_t(1+r)^{-t} / \sum_{t=0}^{N} C_t(1+r)^{-t}$

- Internal rate of return (IRR): IRR is obtained by solving the following implicit equation

$$\sum_{t=0}^{N} B_t(1+IRR)^{-t} - \sum_{t=0}^{N} C_t(1+IRR)^{-t} = 0,$$

where B_t and C_t are the benefits and costs in year t, with a discount rate of r.

4.1.1 BCR vs NPV

In this thesis, the set of options concerning the land uses examined are considered to be a set of mutually exclusive projects.[3]. The question arises as to which of the above methodologies should be used to rank these options to help the government choose between them? The answer depends on a number of factors.

- Case I, the government can and is willing to borrow as much as it wishes at interest r to finance projects, i.e., there is no constraint on its maximum borrowing. In such a case, the government should adopt the NPV criterion to rank the options and select the option which gives the largest positive value for NPV, even if it involves the largest *current* capital expenditure financed by borrowing or otherwise (*future* capital expenditure can be financed in part by future benefits or receipts from the projects). This is because without a constraint on borrowing, the adoption of any option has no effect on the availability of finance for other government projects.

- Case II, there is a limit on the amount the government is prepared to borrow to finance projects. The adoption of the option with a greater capital expenditure will decrease the money available for other projects by a greater amount. In this case, the option with the largest NPV may not necessarily to the best project to be chosen, since its adoption may

[3]It is recognised that numerous combinations of the conversion of different areas of dairy land to wetlands and/or rehabilitation are possible, however such analysis is beyond the scope of this work.

prevent the adoption of one or more other projects, which may also have very large NPVs. In this case, the BCR criterion may become relevant.

Thus, selecting projects on the basis of the ranking in terms of NPV alone, without comparing the BCRs of the mutually exclusive projects and those of other (marginal) projects may not lead to the selection of a set of projects which maximise total net present value.

4.1.2 IRR vs NPV

The next question to arise is whether we should select mutually exclusive projects on the basis of IRR, i.e., selecting the project that has the highest IRR?

Choosing the project with the highest IRR may not necessarily result in selecting the project with the largest NPV, and consistently choosing mutually exclusive projects on the basis of IRR criterion is unlikely to lead to the selection of the set of projects which maximise the total NPV, assuming that there is a budget constraint on the total capital costs for all projects.

The choice of IRR criterion tends to be biased against projects with a more distant stream of benefits, while projects with different scales (magnitudes of capital costs) have the same problems discussed above when there is a budget constraint.

One further serious problem of using IRR criterion for ranking is that a time stream of benefits net of costs may have no IRR (a project must have at least one negative cash flow period before it is possible to calculate IRR) or many IRRs (this is because the internal rate of return is just the solution for a polynomial, and the net benefit stream of the project will have more than one root, and hence more than one IRR if the project's net benefits cash flow becomes negative again after the initial investment period) (Perkins, 1994).

The DOF (1991) contends that one further problem with the IRR criterion is that IRRs cannot be summed. However, since we are interested in the contributions of projects to total NPV, we are interested in the sums of the NPVs of projects selected on the basis of IRR criterion or any other criterion. Therefore the fact that the IRRs of different projects cannot be summed is irrelevant in this thesis.

In light of the points explained above, this thesis will not present the IRRs for the land use options. The conclusion of Hanley and Spash (1993) that the IRR is flawed as a measure of resource allocation and that NPV should be used as a measure of a project's performance provides further support for the omission of IRR calculations in this thesis.

It is important to note however that both BCR and IRR may further assist in the selection of a project as these two methodologies measure the relative net gains, as the returns of benefits to costs, while NPV measures the actual net gains (Sinden and Thampapillai, 1995).

4.1.3 Budget constraints on farmers and the government

In this analysis, funding for each of the land use options comes from either farmers or the government. Farmers are normally limited in their ability to source funding, and therefore if several projects produce high returns it is possible that farmers may not be able to raise the required capital for the project with the highest NPV. In such a case, farmers may choose a land use option that has a lower NPV, but which involves less borrowing.

While the government may not face the same budgetary constraints as farmers, political factors may dictate that the government allocate funds elsewhere. In the case of environmental projects such as those in this thesis that require considerable capital investment, the government may decide to forego such an investment in order to avoid borrowing or to be able to retire State debt regardless of the NPV of the project.

A further consideration for the government is the timing of the various projects. The pollution problems associated with the dairy swamps mean the government is under pressure to address the issue of land use change. Of the land use options considered, rehabilitation of the existing dairy swamps is the least expensive for the government, and therefore it is more likely that the government will be able to rapidly progress this option once an agreement with farmers has been reached.

In contrast, conversion of the entire area back to wetlands is expensive, and the timing of this option depends not only on the government reaching agreement with the farmers over land retirement, but also on the market availability (and price) of any additional water required for wetlands. The expense of this option also means that the government is unlikely to be able to fund the project from the annual budget, and therefore there is the possibility of delays in completing the wetland options until future budget allocations allow. Such a delay may make the project less viable depending on the impact on the costs and benefits.

4.2 CHOICE OF THE DISCOUNT RATE

The great advantage of cost–benefit analysis is that it clarifies (or explicitly specifies) the exact nature and timing of all the consequences of action (or inaction) when dealing with a problem, it reduces these to a single monetary dimension, and it identifies winners and losers (Murray Darling Basin Commission, 2001).

When economists evaluate benefits and costs, which extend over more than one time period, they can use one of two approaches. In the first case, they must make allowance for the fact that individuals view more distant benefits and costs differently from more immediate ones. Generally, the pattern observed is that we prefer costs to be postponed and benefits to be received as soon as possible. This situation is referred to as 'positive time preference' and is mimicked by financial institutions in that they must pay interest on deposits, reflecting the need to return a higher amount to the individual at a later date in order to make use of these funds in the interim. To account for time preference in valuation and cost–benefit studies, economists use a discount rate to weight benefits and costs occurring in different time periods, similar to the payment of interest on bank accounts (Barbier *et al.*, 1997).

The four concepts of the discount rate that can usefully be distinguished (DOF, 1991) are:

1. *The social time preference rate* (STPR), which represents society's preference for present as against future (i.e., it measures the additional future consumption required to exactly compensate for postponement of a unit of present consumption).
2. *The social opportunity cost* (SOC), which represents the return on the investment elsewhere in the economy which is displaced by the marginal public sector project.
3. *The project-specific cost* of capital (an offshoot of SOC), which consists of SOC plus a risk premium, with the risk premium being higher the riskier the project.
4. *The cost of funds*, which implies the cost of borrowing for the government and is the long-term bond rate in most circumstances.

The DOF (1991) handbook indicates that because the stream to be discounted – the net benefit stream – is a consumption rather than an investment entity, it can be argued that the STPR is the more appropriate discount rate concept. However, its use raises the difficulty that the resources required for a public project may displace projects in the private sector, which would have earned a return greater than the STPR. NSW Treasury guidelines (1997) point out that in principle the SOC and STPR rates should be the same, however, for various reasons such as private sector profit and capital constraints in the public sector, the two will differ.

While the DOF (1991) handbook's preferred option is to employ a project-specific discount rate using the CAPM framework, it acknowledges that this approach is quite frequently infeasible and therefore not appropriate in the budget-dependent sector.

Sinden and Thampapillai (1995) note that there is no general consensus among economists on a single correct discount rate, partly because the rate would vary between situations and partly because of the two alternative bases (SOC and STPR) for a rate. Further, they state that even now the long-term bond rate, adjusted to real after-tax terms, is often taken as the basis of a rate, and net present values are often recalculated with slightly higher and lower rates. The following rates are recommended by various State governments:

- NSW Treasury (1990): 4, 7, and 10% with 7% at its central.
- Victorian government: 4%.
- SA government: 4, 7 and 10%.
- Commonwealth (DOF, 1991): 8% for projects in the budget dependant sector, where opportunity cost is the stronger basis for a rate.
- Commonwealth (DOF, 1991): 5% as a real risk-free rate, derived from benchmark rate.

The approach taken in this thesis is to use a real discount rate of around 4% (3.55%), and to undertake sensitivity analysis for discount rates up to 9.55%. These figures are consistent with the recommendations presented above.

4.2.1 Risk and uncertainty

The DOH (1991) handbook and NSW Treasury (1997) make a distinction between risk and uncertainty: Risk is measurable; it refers to situations with known probabilities. Uncertainty is vague; it refers to situations with unknown probabilities. However both sources agree that the definition is a fine one, and therefore the two terms are used interchangeably.

A degree of uncertainty will be associated with almost any significant capital project. The problem is particularly acute in regard to public sector investments, which are often comparatively long lived and of a substantial size, with little recoverable value (NSW Treasury (1997). Arrow and Lind (1970) argue that allowance for uncertainty and risk is irrelevant in government decisions because the risks arise from many projects and are spread across society. This has been criticised on several grounds including those raised by Sinden and Thampapillai (1995) who note that governments must have mechanisms for spreading risk, and that they rarely, if ever, use such mechanisms. They suggest that there are always advantages in selecting for less sensitive alternatives and that sensitivity analysis provides this information.

The other most commonly used technique to analyse the effects of risk and uncertainty is to raise the discount rate to include a safety margin or risk premium. However, Sinden and Thampapillai (1995) and the DOF (1991) handbook indicate that raising the discount rate is an inappropriate tool to use in assessing risk because very few risks increase at a compound rate through time. The DOF (1991) handbook also states that the method is only valid where the concern is that benefits, and especially late-occurring benefits, may be too high.

In this thesis, sensitivity analysis was undertaken on a number of variables identified as having the greatest impact on (and thereby imposing the greatest risk to) the profitability of the various land use options.

4.2.2 Environmental projects

When valuing environmental goods the question of which discount rate to use is very complex and the question arises of whether society should discount? And if so, what rate should be used? Does discounting violate rights of future generations? (Hanley and Spash, 1993). A common environmental critique is that discount rates are typically set too high even in economic terms (Winpenny, 1995). Howarth and Norgaard (1993), suggest that discounting can be justified on grounds of intertemporal efficiency but not on grounds of intertemporal equity.

Barbier *et al.* (1997) highlight the fact that the effects of different projects on the environment range widely, raising the question of whether the choice of discount rate might be expected also to vary with the circumstances. This view is also presented by Knetsch (1993), who indicates that it may not be inconsistent for individuals to demand a high rate of return for their private investments while choosing to have public funds devoted to demonstrably low-return reforestation activities. This view is based on work by Thaler (1981) and Prelec and Loewenstein (1991) that shows that people's choices and time preferences, to a large extent, depend on the characteristics of the different outcomes. Slovic (1987) also showed that people's actual aversion to uncertain outcomes has been found to vary greatly depending on the nature of the risk and the particular circumstances of their exposure.

However, the use of differing discount rates creates difficulties, since it is generally preferable to use a single rate for all projects evaluated to ensure consistency and to allow for comparisons amongst different projects.

Pearce *et al.* (1989) note that if a separately determined discount rate is used for each project, then the overall impact of high or low discount rates on the environment becomes ambiguous: with a high discount rate, for example, environmentally damaging projects are discouraged and the overall level of investment, and therefore the rate of natural resource use, declines, but this comes at the expense of weighting the consumption of the current generation higher than that of future generations. As a result, there is an emerging consensus that no adjustment be made to the standard economy-wide discount rate when evaluating environmental values, and instead other techniques should be used to adjust for any special conditions associated with environmental benefits and costs (Markandya and Pearce, 1988).

In this thesis only one environmental factor is considered: the benefit of wetlands for water filtration. This benefit is discounted at the same rate as other variables in the model. Unlike environmental benefit that can be expected to increase over time (such as the value of old-growth forests) it is not anticipated that the value of the filtration process would increase over time at a rate greater than other variables in the model.

Obviously it is impossible to foresee the environmental risks associated with any project and hence the Precautionary Principle should always be applied to all projects likely to have an environmental impact (Barbier *et al.*, 1997).

4.3 Farm Labour

The nature of the shadow wage rate and the derivation of its formulae have a special importance in the literature on cost–benefit methodology, particularly for developing countries (Little and Merlees, 1976). However, in developed countries, use of a shadow wage rate is not always considered necessary.

NSW Treasury (1997) states that it is generally considered that the problems of measurement of shadow prices may often be substantial and the size of the impact on the analysis comparatively small. Hence, this level of sophistication in the analysis will not generally be warranted, as it will introduce unnecessary controversy. In a similar vein, the DOF (1991, p.34) indicates that in cases where markets can be considered to be perfectly competitive (implying zero involuntary unemployment) labour can be regarded as being similar to any other project input.

In this thesis, the shadow wage rate for labour is of little importance as dairy farmers in this region employ very little external labour. Most farms are owned and operated by the farming family, with the average cost of labour per farm around $16,000, (representing only approximately 2 percent of production costs) and most of this is for relief milking or assistance with irrigation. The thesis however does include the *full* cost of paid labour and, in doing so, may *overestimate* the total cost saved for the community with a change in land use to the extent that some relief milkers may become unemployed as the result of the projects. However, this *overestimation* is likely to be relatively small - most farmers have indicated that relief milkers are difficult to get and hence, as indicated by Gittinger (1972) if labour is short and there is an active labour market, then the wage rate is probably a fairly good approximation of the real marginal value product of labour.

The thesis does not include the costs of the unpaid family labour and, in doing so may, *underestimate* the total cost saved for the community with a change in land use. This exclusion is made for the following reasons: (i) it is not possible to know the number of farmers to whom this will apply; (ii) it is expected that the number of farmers involved would be extremely low (given their other options - most farmers have indicated that they will continue to farm dry stock on the highlands, while many others have indicated that they will become self-employed, active traders in the water market or that they will move their dairy farming operation to the South East of the State, where dairy farming is well established); and (iii) it is expected that the magnitude of this total unpaid labour costs is so small that its inclusion would have a negligible impact on the results (and would be lost in the rounding up of the numbers in the presentation of the results).

Thus, the overestimation of the total cost saved for the community resulting from the failure to allow for the fact that some relief milkers may become unemployed may cancel out the underestimation resulting from the exclusion of unpaid family labour so that on the whole there may be little overestimation or underestimation of the total cost saved to the community in so far as labour costs are concerned.

4.4 ALLOWING FOR TAXES AND SUBSIDIES

Sometimes taxes and subsidies create a wedge between prices paid by purchasers and prices received by producers (DOF, 1991), resulting in two sets of prices – prices gross of taxes or subsidies, and prices net of taxes and subsidies. Where a change in output is sufficiently great to result in the displacement of other goods being sold in the market, it becomes necessary to determine a shadow price for the output. This shadow price is a weighted average between the market price including tax of the output and the market price minus tax of the output, which displaces other outputs being sold. Similar reasoning applies to inputs, with diverted inputs being valued gross of taxes and net of subsidies, while inputs resulting from increased production are valued net of taxes and gross of subsidies.

In this analysis, it is expected that the project's demand for any inputs and any increased outputs will be small relative to the total production. Therefore, the appropriate shadow prices will be extremely close to the market prices, and this sort of analysis is unnecessary.

4.5 RESTRICTIONS ON INTERNATIONAL TRADE

Where a project sources inputs that are subject to trade protection arrangements, as in the cases involving taxes and subsidies, the shadow price to be used for these goods depends on the how the project's inputs are sourced. It also depends on the protection arrangements that apply to the imports (DOF, 1991). If a quota rather than a tariff protects the domestic production of an input, and the additional demand would have to be met from local production, then the weighted average approach outlined above should be applied. International trade restrictions have not been identified with any of the inputs or outputs resulting from the various scenarios in this thesis.

4.6 VALUING FOREIGN EXCHANGE

If the outcome of the land use options in this project were to result in increased production, which may possibly earn additional foreign exchange through exports, should this additional foreign exchange be valued in the CBA at a premium? In effect, should the shadow price of foreign exchange (to be used in valuing traded goods) be higher than the actual exchange rate?

For most third world countries the shadow foreign exchange rate should be considerably higher than the official exchange rate, i.e., the currency of a typical third world country is overvalued because of trade distortions (e.g., import tariffs or quotas) (Nguyen and Alamgir, 1976). However, in Australia the deregulation of the dollar and the adoption of a floating exchange rate regime means that any difference between the shadow foreign exchange rate and the actual one would reflect the effect of tariffs, taxes and export subsidies. According to the DOF (1991), in general, adjustment to the market exchange rate would be entirely inappropriate because savings of foreign exchange resulting from a project is unlikely to remove or reduce any trade-related distortions.

For this reason, although the shadow foreign exchange concept plays an important role in the cost–benefit analyses for many countries, especially third world countries, it will be ignored in this thesis.

4.7 MULTIPLIER BENEFITS

When new resources are generated (or consumed) in a community, the total effect may be larger than the initial transaction would indicate. For example, suppose Josh Brown in the town of Bin inherits $1,000 from a distant aunt. Josh's net income is now $1,000 higher. Josh saves $600 of this inheritance and buys a new suit for $400 from Henry Smith. Henry's net income has increased by the profit on the suit, say $100. Henry saves $70 and spends $30. Obviously, by the time this chain of saving and spending peters out, the total increase in income of the whole community of Bin is larger than the original $1,000 windfall. The proportion by which the total effect is larger than the initial income gains (or smaller than the initial income losses – the process works symmetrically upwards and downwards) is called the multiplier or the *income multiplier*. The size of the multiplier varies from one community to another (Watson, 1998). Thus multipliers can provide a simple means of working out the flow-on effects of a change in output in an industry on one or more of imports, income, employment or output in individual industries or in total. Multipliers can show just the 'first-round' effects, or the aggregated effects once all secondary effects have flowed through the system (ABS, 2000).

Technically speaking, a multiplier is the ratio (net indirect plus net direct effects)/(net direct effects), with multipliers differing by industry and by size of the community. The validity of an estimate of indirect effects depends on the methodology employed to derive the multipliers. The best method for estimating multipliers is to use an input–output model developed specifically for regional studies (Glaeser and Oslund, 1996).

While multipliers used for dairy farming have been determined by Powell (1991, 1992), and Morrison (1996) for NSW and Victorian dairy regions, it was not considered appropriate to employ these multipliers in this work. Although the town of Murray Bridge, which services the Murray swamps, is dependent on the dairy industry for employment and regional exports, and benefits from this project may extend to employment and outputs, any alternative uses of the resources captured by this project may also produce a multiplier effect. The DOF (1991) handbook points out that instead of undertaking the project, the government could reduce taxes or increase expenditure, either of which could be expected to have an expansionary effect on income and employment.

4.8 PROBLEMS WITH CBA

While CBA is used extensively for making decisions of an environmental nature, there is criticism of its applicability to environmental problems. The 'rigour' of neoclassical analysis is seen as a convenient methodological smokescreen that obscures the true holistic and interdisciplinary nature of environmental decision-making (Pearce and Turner, 1992). There is also ongoing scepticism of the inclusion of values based on non-market techniques, as indicated earlier and which will be discussed further in the results section.

Taconni (2000) is critical of CBA because of the lack of knowledge about the functions of biodiversity that we are attempting to value and about the implications for ecosystem services of modification of these functions. This criticism predominantly relates to the methodology used to value non-market benefits, an issue addressed in this thesis, and which will again be discussed further in the results section.

Despite these shortcomings, CBA can provide estimates of the benefits derived from biological resources, the costs of implementation of biodiversity conservation initiatives and the foregone benefits of alternative uses of areas to be conserved. For these reasons (and until an alternative framework can be determined for making environmental choices based on biological and economic values), CBA provides an assessment method on which to base investment decisions.

4.9 Cost sharing

4.9.1 What is cost sharing?

Mishan (1975) states that "in examining an investment project, the economist addresses himself to the question of whether its introduction will affect a potential Pareto improvement as compared with the existing situation." However, the achievement of a Pareto improvement may come at the expense of one group in society, and thus the project may be seen as unacceptable to that group. Alternatively, a project may be required to address an externality problem caused by one group in society for another. In both cases, the argument exists that the costs of such projects should be shared across society.

Bowers (2002) has defined cost sharing as occurring when we have an uncorrected externality (e.g., pollution) with at least one economic unit as the initiating cause and a number of recipients. The recipients can extend to the whole community, the nation, or beyond. At least some of the benefits from correcting the externality (pollution) are normally in the form of public goods such as benefits to wildlife or biodiversity, although this is not essential.

Because recipients will benefit from the costs of correcting the externality, the recipients are asked to 'share the cost' of any remedial actions with the entity who is causing the externality problem. This in effect is cost sharing.

4.9.2 Cost-sharing principles

The two main principles that form the basis of cost-sharing arrangements are Beneficiary pays and Polluter pays.

The beneficiary pays principle requires anyone who benefits from an activity to contribute to the cost of undertaking it (MDBC, 1996). This principal has two components: 'user pays' and 'beneficiary compensates'.

The user pays principle requires anyone who derives a direct private benefit from an activity to contribute to the costs of undertaking that activity. In practice, adoption of this principle often involves individual beneficiaries making payments to a collective provider, typically the government (Marshal, 1998). Frequently, users of a resource are also polluters, in which case their user pays cost may be referred to as 'polluter pays' costs.

The beneficiary compensates principle requires anyone (including government, on behalf of the general community) who derives an indirect benefit from an activity to contribute to the cost of undertaking it (MDBC, 1996). This principle has also been labelled the 'community pays' principle (Hanley *et al.*, 1998; Kennelly, 1998; Stoneham *et al.*, 2000).

Governments may implement the beneficiary compensates components of the beneficiary pays principle through a variety of means (Aretino *et al.*, 2001).

- Non-financial 'payments' such as education and advisory services, and the provision of other goods and services in-kind.
- Payment schemes whereby governments provide financial grants or concessional loans to the private sector to undertake particular conservation activities (these may involve uniform payments for each activity).
- Annual financial payments to resource users to cease or reduce environmentally damaging activities or practices (often used with management agreements).
- Indirect financial incentives, such as tax deductions and rate relief.
- Payment for the acquisition of rights or land (Tobey and Smets, 1996).

The polluter pays principle was adopted in 1972 by the Organisation for Economic Cooperation and Development (OECD). This principle requires individuals to meet the full cost of their actions. It requires them to bear the costs of implementing pollution prevention and control measures necessary to maintain the environment in an 'acceptable state' (OECD, 1975; Aretino *et al.*, 2001). This principle is also often termed 'impactor pays' (SLWRMC, 1999).

Under this principle, impactors are required to contribute to the costs of activities that ameliorate or prevent biodiversity damage in proportion to their impacts on the environment. As impactors may pass on some of these costs as higher prices (e.g., the cost of grain rises as farmers are forced to pay for pollution control measures), consumers who benefit from activities that adversely impact on the environment may also meet a proportion of the higher costs.

The polluter pays principle may be implemented through various means (Pearce, Markandya and Barbier, 1989):

- Command and control mechanisms such as regulations that require resource users, in the first instance, to bear all the costs of undertaking conservation measures or refraining from actions that have an adverse impact on biodiversity.
- Charges levied on environmentally harmful outputs, inputs or practices.
- Tradeable rights or permits to achieve environmental standards.

By OECD agreement Australia is committed to applying the Polluter Pays Principle (PPP). The developing notion of duty of care places an obligation on the user of land to conduct his/her activities in conformity with PPP. However, there is sometimes another dimension to the property rights issue. Cases of land and water degradation are often the result of a long history of land use with the activities of the present occupants contributing little to the problem. In those cases the application of PPP or the enforcement of a duty of care will not provide a solution. With 'non-point' problems, PPP or a corresponding duty of care may be unenforceable. Therefore cost sharing may also include the application of the beneficiary pays principle (BPP) to the solution of the externalities.

4.9.3 Objections to cost sharing

The objections to the application of cost sharing have been summarised by Bowers (2002). They include:

1. The outcome may be seen as unjust. One reason for this view is the abandonment of PPP or duty of care. The reasons for abandonment are pragmatic rather than theoretical: that the strict application would not have achieved the desired result. With historical externalities, abandonment reflects views on responsibilities for the past that could be

disputed. Objections may not only come from recipients. With non-point problems the distribution of costs between beneficiaries is likely to be arbitrary and it will be difficult to maintain the condition that contributions should not exceed benefits.

2. Many of the public benefits are intangibles that cannot be given meaningful monetary values (see Bowers, 1997; Bowers and Young, 1999). Several problems follow from this:
    a) It cannot be shown that the benefits exceed the costs. One answer to this is the imposition of standards in the form of a requirement for a certain level of given classes of public benefits (habitat restoration, etc.), to be measured in appropriate non-monetary terms, before a cost-sharing deal is contemplated.
    b) But even if it is accepted that the project is worthwhile there remains the problem of cost attribution. Since total benefits cannot be meaningfully measured, neither can the division between private and public benefits. Hence cost shares cannot be determined. This problem can be overcome. The initiators could be charged their measured private benefits, less some allowance for profit, and non-initiators charged their private benefits. The community or society would then pay the rest of the costs. Given the judgement that the project is worthwhile under (a) there would still then be a social gain from the cost-sharing project. This solution carries an apparent problem that what the public pays for a given amount of environmental gain varies inversely with the scale of private benefits. However, if the test for social benefit is sound then the problem is more apparent than real, amounting to no more than a decision not to subsidise private benefits.

4.9.4 Which system to use?

A fundamental step in determining how the costs of a project should be allocated requires examining the problem and determining which principle to apply. As seen above, frequently it is not possible to apply just one principle and a combination of principles must be used, e.g., from a catchment perspective, the direct beneficiaries of some activities within the catchment should share the costs of activities undertaken in other catchments (Liverpool Plains Management Committee, 2000).

In determining the cost-sharing ratio for this analysis, the Polluter Pays principle was used to determine how much the farmers would need to pay the community to account for their pollution. This was a fairly obvious choice as farmers were clearly identified as polluters and the level of pollution could be identified. The real problem that arises when using this principle for this particular problem is the difficulty in determining the value of the impact of the pollution on the surrounding wetlands. Too little information is available to determine the extent of the impact, and the value of the wetlands themselves is poorly known.

The Beneficiary Pays Principle has been used to determine the cost shares that the farmers and the community should pay under the rehabilitation options, i.e., cost shares are distributed to stakeholders in direct proportion to the benefit they receive. As both the farmers and community will benefit from rehabilitation, this appears to be the most equitable system to use.

4.9.5 Application of the principles

When applying the beneficiary pays principle it is necessary to first identify and quantify the benefits, as done in Chapter 3. Once the benefits of the plan have been quantified, the stakeholder who is likely to receive the benefit needs to be identified. In this analysis the stakeholder groups considered were:

- farmers who receive a benefit on-farm, and
- the government.

Having allocated benefits between stakeholders, the process of allocating cost shares is then performed. However, in calculating the final cost-sharing ratio, allowance should be given for the difficulties that arise when valuing natural resources (such as the value of biodiversity), and the benefits of tourism to a region.

In addition to being feasible and transparent, cost-sharing arrangements should aim to reflect other criteria, including (Arentino *et al.*, 2001):

- effectiveness;
- efficiency;
- cost effectiveness, and
- equity.

Effectiveness is concerned with the achievement of objectives. It relates to overall outcomes, the quality of outcomes, and the extent to which required standards are met. Various factors can affect effectiveness, such as the extent of community acceptance of a cost-sharing arrangement.

Economic efficiency is concerned with society obtaining the highest net benefits from the allocation and use of its resources. For example, there is little point in insisting that stakeholders pay costs that they can clearly not afford. Allowance should be made during the negotiation phase for issues such as stakeholders' ability to pay and moral or social obligations.

Cost effectiveness is concerned with achieving objectives at least cost – that is, achieving 'value for money'. Cost effectiveness may be improved by targeting activities or practices that produce high environmental benefits for a given cost.

Equity is about fairness and means different things to different people. Horizontal equity requires all people to be treated the same, while vertical equity is concerned with the distribution of benefits across individuals with different income levels. From an environmental perspective, historical governance may need to be considered. For example, is it reasonable to insist that farmers be held totally responsible for revegetation costs where governments of the past have actively encouraged farmers to clear land?

Decisions about cost-sharing arrangements may involve trade-offs between some of these criteria; for instance, equity considerations, administrative feasibility and cost can affect the efficiency or effectiveness of cost-sharing arrangements.

5 PART I: WETLANDS FOR WATER FILTRATION

5.1 INTRODUCTION

With its relatively low rainfall and long, dry summers, South Australia depends heavily on water flowing down the River Murray to meet its requirements. In an average year, the inflow of the Murray supplies about half the State's urban water needs. In dry years, this can increase to as much as 90%. In addition to being a major source of supply for Adelaide, the Murray provides water for the domestic, industrial, livestock and irrigation requirements of the towns and farmlands both along its banks and further afield.

Prior to 1999, 100,000 people in rural communities in South Australia received water from the Murray that was chlorinated, but had no filtration. In 1999, the State Government contracted out the construction and operation of 10 new filtration plants. The cost of construction for all 10 plants was $115 million, with an annual repayment/operating cost of $20 million per year. Importantly, four of the 10 filtration plants (Mannum, Murray Bridge, Tailem Bend and Summit storage) are in the dairy swamps section of the Murray (Table 5-1), and the cost associated with these plants is $10 million per year.

TABLE 5-1. LOCATION AND CAPACITY OF NEW FILTRATION PLANTS IN SOUTH AUSTRALIA

(*Italics* = study area)

Location	ML/day capacity
Renmark	8
Berri	8
Loxton	14.5
Barmera	5
Waikerie	4
Swan Reach	90
Mannum	***4***
Murray Bridge	***38***
Tailem Bend	***28***
Summit Storage	***71***
Total	**270.5**

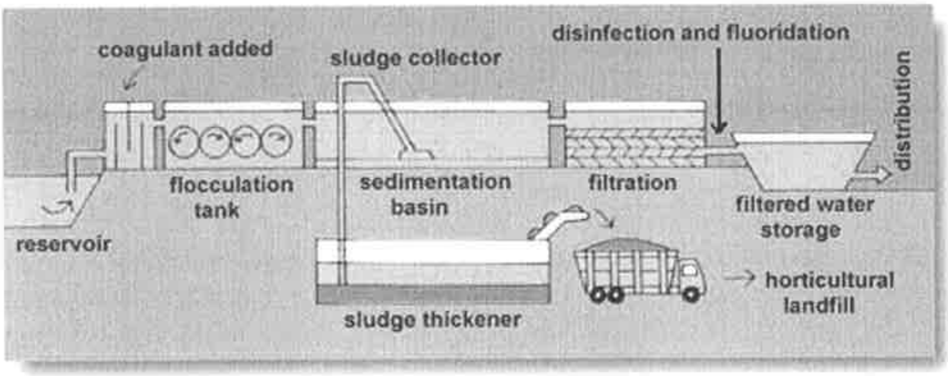
Given the important ability of wetlands to act as water filters, and the fact that this area was originally part of a wetland complex, the question arises as to whether those parts of the study area in the vicinity of the water filtration plants could be converted back to wetlands and used as part (or to replace all) of the water filtration process.

In order to determine this question it was important to first have an understanding of the water filtration process, to identify the possible wetland scenarios, and then to assess which parts of the process wetlands could replace (and hence the wetland benefits).

5.1.1 The water filtration process

Filtration is only one step in a five-stage cleaning process carried out at Adelaide's treatment plants, as illustrated in Figure 5-1 (SA Water, 2001).

FIGURE 5-1. WATER TREATMENT PROCESSES



The treatment process begins by dosing the water with powdered activated carbon to remove any unpleasant taste or odour from fine impurities in the form of suspended clay particles.

Coagulation and Flocculation

The first stage, to collect small particles and dissolved organic matter, is a complex physical and chemical process. A coagulant is added to the untreated water and this reacts with the impurities, forming them into 'floc' particles up to 5 mm in diameter. A flocculant aid is added to the coagulated water before it passes on to the secondary series of mixing tanks where the floc particles fully form.

Sedimentation

After 20 to 30 minutes conditioning in the flocculation tanks, the water and suspended floc particles pass through to sedimentation basins where, after about two hours, most of the floc settles to the bottom of the basins and forms a sludge. The water, now containing only a small amount of very fine floc particles, passes on to the filters. The sludge is removed for reuse.

Filtration

Water from the sedimentation process passes through a filtering medium – usually a deep bed of sand or sand/anthracite dual medium. As the water passes through the filter bed, most particles are trapped in the fine spaces within the medium resulting in clear, clean water being produced. Only some very fine particles can pass through the filter.

Disinfection

Disinfection is achieved by adding chlorine, generally between the filters and the filtered water storage tank, to destroy any micro-organisms that are not removed in the flocculation and filtration stages.

Storage and distribution

After disinfection the water passes to covered water storage tanks ready for distribution.

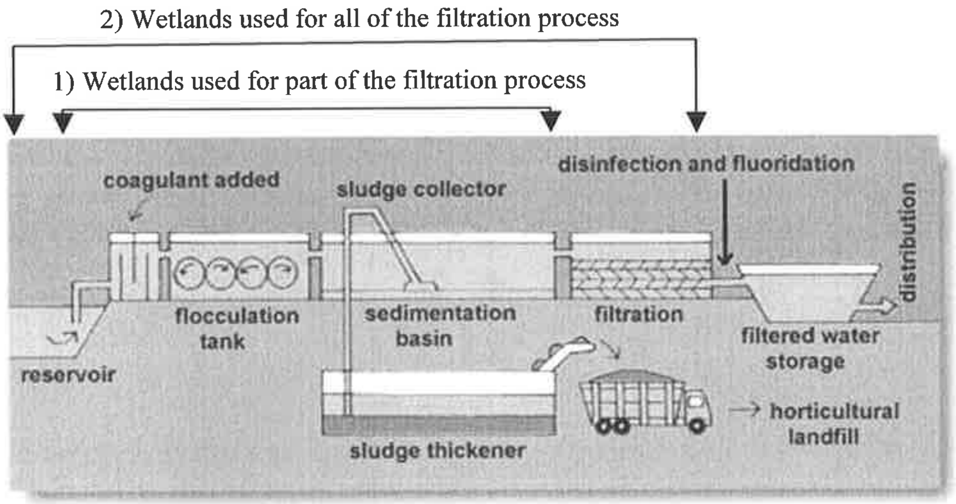
5.1.1.1 UV treatment costs.

In recent years concerns have arisen about the risk of Cryptosporidium poisoning in drinking water (see Part II and Appendix 2 for more details). For this reason SA Water is also considering the construction of ultra violet (UV) treatment plants in conjunction with the water treatment plants. It is anticipated that the plants will cost $2 million to build and $20,000 per year to operate. In the study region this represents costs of $1 million to build the plants and $10,000 per year for ongoing operation.

5.1.2 Questions examined in this section

This part of the thesis determines the value of wetlands for water filtration. It is assumed that constructed wetlands could be included in the water filtration system, replacing the need to construct either half or all of each of the proposed new water treatment plants, (Figure 5-2). Also examined is the additional value wetlands would have if they were also able to replace the proposed UV filtering process. The amount of water being filtered remains the same.

FIGURE 5-2. PORTION OF THE WATER FILTRATION PLANT REPLACED FOR EACH WETLAND OPTION



5.1.3 Identifying benefits and costs

Let the costs of supply of the target γ quantity of filtered water be λ, and the area of the wetlands constructed is exactly equal to what is required to produce γ of filtered water. The benefits attributable to this part of the swamps is therefore λ, i.e., the saving in the costs of the alternative scenario, building the filtration plants, θ (annual filtration costs avoided), plus the saving in the costs of building and running the UV plant, *Buv* and *Buav* (*Buv* = UV construction costs avoided ($), *Buva* = annual UV costs avoided).

5.1.4 Valuing benefits and costs

The complexity of the wetland ecological system means that the design and construction of wetlands must allow for input from a range of disciplines, e.g., ecologists, engineers, biologists, hydrologists and economists. All of these disciplines were involved in the sourcing of data for use in this part of the thesis, which considers constructed wetlands for water filtration.

Many researchers (Crance, 1984; Hemond and Benoit, 1988; Aust *et al.*, 1991; Johnston, 1991; USEPA, 1993; Osmond *et al.*, 1995) have shown that sediment deposition is variable across individual wetlands and wetland types, as deposition depends upon the rate and type of water flow (channelised or sheet flow), particulate size, and the vegetated area of the wetland. Therefore, if wetlands were to replace any part of the filtration system it was important in this study to ensure that the choice of plants, depth of the water, retention time, and the size of the facility were considered in their design (these factors have also been reviewed by Munday, 1997). As these factors can also substantially affect the cost of wetland construction, it was recognised that the cost associated with these factors would need to be considered carefully when investigating the viability of this land use.

5.1.4.1 Choice of plants

Wetlands filter suspended solids from water that comes into contact with wetland vegetation. Stems and leaves provide friction for the flow of the water, thus allowing settling of suspended solids and removal of related pollutants from the water column (Johnston, 1991). Constructed wetlands may be classified according to the dominant type of macrophyte within the system:

1) free-floating macrophyte-based treatment systems;
2) emergent macrophyte-based treatment systems;
3) submerged macrophyte-based systems, and
4) multistage macrophyte-based treatment systems.

The actual role of the macrophytes in the removal process varies according to the system design, however in general, macrophytes remove pollution by 1) directly assimilating them into their tissue and 2) providing a suitable environment for microbial activity. Aquatic macrophytes transport oxygen into their rhizosphere, thereby stimulating aerobic degradation of organic matter and the growth of nitrifying bacteria (Brix, 1993). In this thesis, the macrophyte chosen for water filtration is Phragmites because of its ability to slow down water flow to allow sedimentation to occur.

5.1.4.2 Depth of the water

Wetlands are characteristically shallow environments (less than two metres deep) that represent the interface between permanent water bodies and the land environment. They usually have fluctuating water levels and a regular-to-very-erratic drying cycle (Wong *et al.*, 1999). It is often recommended that constructed wetlands have a variable depth to promote diversity of habitat and biological and physical treatment processes. Urbonas and Stahre (1993) state that a shaped bottom assists in preventing the development of preferred flow routes by water within the wetland as sediments accumulate on the bottom with time. While wetlands may contain pockets of deeper permanent water, their characteristic feature is the presence of emergent microphytes (large aquatic plants whose parts protrude above the water line).

In this thesis, water depth is an average of 50 cm, although this will vary across the swamp due to the sloping nature of the ground. This depth is fairly typical of that found for natural wetlands in this region.

Because of the use of existing levee banks, major excavation of the site is not required, however, earthworks to form water channels (to slow water movement and allow a 10-day retention time) is allowed for in the model.

5.1.4.3 Retention times

Whittle and Philcox (1996a) have extensively reviewed the retention time needed for constructed wetlands. While retention times as long as 20 days have been used (Breen and Spears, 1995), 10 to 12 days is normally adequate for most wetland processes (Dawson *et al.*, 1995). The retention time suggested by Whittle and Philcox for constructed wetlands for treating dairy effluent was 15 days, and this has been used in this study where constructed wetland are used in conjunction with rehabilitation for effluent control (see part II). Where constructed wetlands are used as part of the municipal water treatment scheme, 10 days has been used, with sensitivity analysis undertaken for other retention times.

5.1.5 Benefit of domestic water filtration

The significant benefits that arise from this option are either a 50% or 100% reduction in the cost of water filtration (depending on whether wetlands can replace half or all of the filtration plants). As mentioned earlier, under the Build, Own Operate, Transfer (BOOT) contract between Riverland Water and the government, Riverland water will build, own and operate the 10 water filtration plants for 25 years. In return, the government will pay Riverland water $20 million per year. This money comes out of SA Water's annual revenue (The Advertiser, 1999).

The water filtering capacity of the plants in the study area totals 141 ML per day, i.e., 52% of the total. However, after consultation with SA Water it was determined that the costs associated with the plants in the study region are approximately 50% of the total. Thus, the value of these plants for water filtration (θ) is $10 million per year. This figure of $10 million is entered in the model as an annuity payment, however NPV figures are used in the determination of results from the model.

If wetlands are used as part of the water filtration process, SA Water would not have to build UV filtration plants in this region at a cost of approximately $1 million and with an ongoing operating cost of $10,000 per year. These figures are also used in the model.

Smaller benefits arise from the sale of irrigation water by farmers (who no longer require water for farming on the land which is converted to wetlands) and continuing income from the highland areas owned by the farmers and associated with the wetland area.

Obviously the benefits of using wetlands to replace all or part of the water filtration plants depend on their effectiveness to filter water. The majority of studies of the effectiveness of constructed wetlands have been conducted on wetlands built for handling wastewater, with extremely few studies focusing on the value of constructed wetlands for domestic water filtration. Two studies that have been published come from very different locations: Brazil and central Australia.

5.1.5.1 Brazil

One of the few studies on wetlands for domestic water was undertaken in Brazil where water supply is derived from rivers and artificial lakes. Manfrinato *et al.* (1993) developed a wetland technique for cleaning river water using purifying aquatic plants and soils cultivated with rice. Water was directed from the river, through the wetlands and then sampled and tested at the end of the filtering channel. Results showed a substantial improvement in the quality of water after passing through the decontamination process, with water reaching the levels required for potability. For consumption the water only needed to be chlorinated. The effectiveness of their system is presented in Table 5-2.

TABLE 5-2. PERFORMANCE DATA FOR RIVER WATER FOR DOMESTIC SUPPLY

Parameter*	Average Efficiency %
BOD	70
COD	70
Total Coliforms	99
Faecal Coliforms	99
Ammonium-nitrogen	60
Iron	80
Phosphorus	65
Aluminium	85
Nitrate	95
Colour	90
Turbidity	95

*Aquatic plant system (APS) with filtering soil beds. BOD: biochemical oxygen demand COD: chemical oxygen demand.

5.1.5.2 Australia

In Australia, the only domestic water filtration plant to use wetlands as part of the filtration system is at Mt Isa, Queensland. This system has been monitored for over 10 years (Wrigley *et al.*, 1991) and provides a cleansing system that gives Mt Isa a year-round supply of water of acceptable quality.

The water for the Mt Isa area comes from Lake Moondarra, which is fed by the Leichhardt River. The water of Lake Moondarra can be unsuitable for domestic use because of high turbidities. To overcome this problem, water is transferred to a wetland, Clear Water Lagoon, which forms an indispensable part of the Mt Isa water treatment system. All of Mt Isa's water now passes through Clear Water Lagoon and its standing crop of microphytes before chlorination and distribution.

During the dry season when turbidities are uniformly low (less than 10 NTU), passage of water through this wetland results in water consistently less than 2 NTU and usually below 1

NTU. (See Appendix 2 for details on NTU.) It is only during the wet season months of December, January and February, when the Leichhardt River has turbidities of around 100 NTU, that it becomes necessary to dose the incoming water with poly aluminium chloride (PAC). This is done by spraying the water through a spray bar at the end of a turbulent section of the water inlet flume. Baffles in the flume downstream from the spray bar ensure that the PAC is well mixed in the water before a settling pond at the end of the flume collects the floc obtained from dosing.

The innovative use of this ecologically sustainable system has provided the city and industry of Mt Isa with a reliable, cost-effective water treatment system. Wrigley *et al.* (1991) estimate that a similar capacity conventional water treatment plant would cost in the order of $10–20 million to design and build.

5.1.5.3 Filtration effectiveness

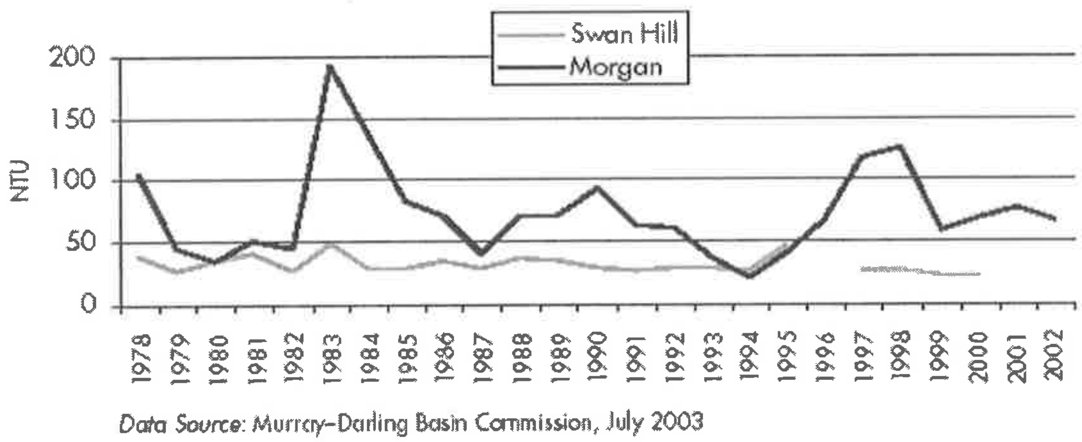
The two studies mentioned above are of particular interest because of the results for turbidity and colour, as these are the two components of water that often are of most concern to consumers (i.e., what the water 'looks like'), and therefore had to be considered for this study. (See Appendix 2 for more details.)

With the exception of one month, turbidity of the Brazilian study was consistently less than 5 NTU, while colour was averaged around 20 ppm PT Co. In Australia the turbidity and colour requirements for drinking water are: turbidity mean results less than 5 NTU; true colour mean results less than 15 HU, but up to 25 HU is acceptable if turbidity is low (Australian Government Publishing Service, 1996). Thus the results from the study above show that water filtered through the Brazilian wetlands would (in all but one month) meet the turbidity requirements for Australia, and come close to meeting the colour requirements.

The Australian study showed that wetlands could provide drinking water of acceptable turbidity for nine months of each year. It was only in the wet season when the addition of PAC was required. The colour of the water was not reported for this study.

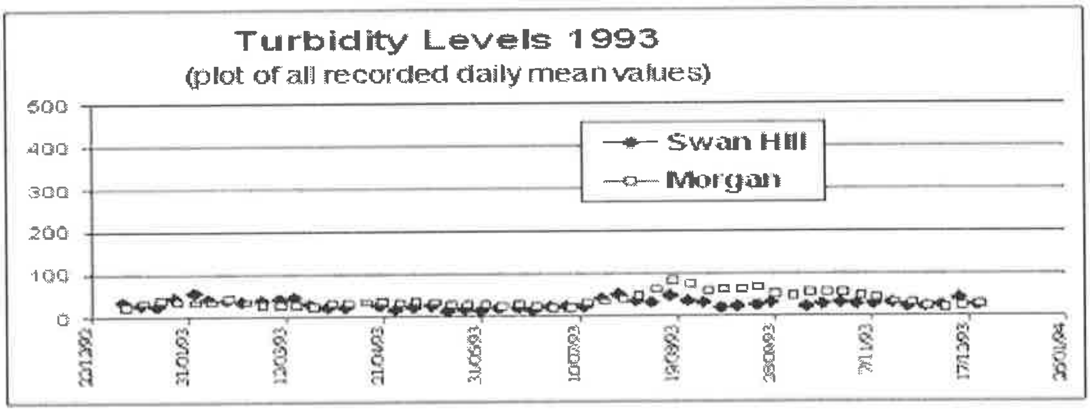
While the turbidities experienced at Mt Isa in the dry season are lower than those generally experienced in the study area, in general, turbidities in the Murray are not in excess of 100 NTU. Marohasy (2003) summarised the Murray–Darling Basin Commission (MDBC) turbidity figures since 1998. According to plots from data sourced directly from the MDBC, turbidity levels (NTU) at both Morgan and Swan Hill appear to be relatively stable below 100 NTU (Figure 5-3). Turbidity has been measured at both sites since 1978, and average yearly turbidity levels have not increased over this period.

FIGURE 5-3. TURBIDITY LEVELS IN THE RIVER MURRAY, 1978–2002



The relatively high turbidity levels during the second half of 1983 contributed to the high yearly average in 1983 (Figure 5-3). The high levels may have been a consequence of drought-breaking rains carrying higher than usual sediment loads because of increased erosion from reduced vegetation cover as a consequence of the drought in the early 1980s. During years of low mean turbidity, mean daily values for both Morgan and Swan Hill are typically in the 20–40 NTU range (Figure 5-4).

FIGURE 5-4. MEAN DAILY TURBIDITY LEVELS IN THE RIVER MURRAY, 1993



These figures suggest that it is indeed possible to incorporate wetlands into a water filtration system, and that they can provide some (but perhaps not all) of the filtration requirement for domestic water, particularly in years of average and low mean turbidity.

5.2 METHODOLOGY

The information presented in the previous section provides sufficient understanding to derive the most important figure to be used throughout the thesis: the value per hectare of wetlands for water filtration, ψ, as described below.

Numerous figures and equations combine to form the summary equations presented in this section. Details for the determination of the large number of individual components that make up these equations can be found in Appendix 4, section 4.1. All the variables and sources of information can be found in Appendix 3, while an index of symbols can be found in Appendix 9.

The methodology is presented in three steps:

- Step 1 shows how the value of the water filtration function performed by the wetlands is determined.
- Step 2 shows how the NPV and BCR of constructed wetlands for water filtration is determined, given the value of the water filtration benefit determined in Step 1.
- Step 3 shows how the NPV and BCR of using this land for water filtration as opposed to dairy farming is determined.

5.2.1 Step 1: Determining the value of wetlands for water filtration

In the model, wetlands are able to replace a percentage of each of the water filtration plants components at cost λ. To do this requires enough wetland area φ (ha), for a retention time of ξ days. In this analysis, ξ is determined to be 12 days: 10 days are required for sedimentation with a further two days required to allow one fifth of the area to dry out as part of the wetting/drying cycle (drying out a portion of the wetland allows the breakdown of vegetation and the release of carbon and nitrogen back into the atmosphere. While the literature suggests that a 10-day retention time is acceptable, sensitivity analysis has been undertaken for other retention times.

An alternative option to drying out part of the wetland is for wetland vegetation to be routinely harvested and sold as animal fodder. This option is not considered in this thesis.

Given the number of days needed and knowing the ML of water required to be filtered at each location allows the total hectares required for water filtration to be determined, as presented in Table 5-3.

TABLE 5-3. LOCATION, VOLUME OF WATER TO BE FILTERED AND HECTARES OF WETLAND REQUIRED

Location of filtration plants	Volume of water to be filtered ML/day	Hectares of wetland required
Mannum	4	9.6
Murray Bridge	38	91.2
Tailem Bend	28	67.2
Summit Storage	71	170.4
Total water volume/area required for water filtration	**141**	**338.4**

The question arises of just how much of the water filtration process these wetlands could replace. While research into wetlands for effluent treatment indicates that constructed wetlands can provide up to 97% filtration, this figure can vary considerably. Initially this thesis considers whether the wetlands could replace half or all of each filtration plant, and hence the need to include a percentage figure, α (filtration efficiency) in the filtration equation.

Thus the equation for the value per hectare of wetlands for water filtration, ψ , becomes:

$$\sum_{t=1}^{25}(\alpha\lambda_t / \varphi)/(1+r)^t \text{,} \qquad (5\text{-}1)$$

where α = filtration efficiency achieved (%), λ_t (filtration benefits at full filtration efficiency ($/year)) = θ_t + Buv + $Buva_t$, θ_t = annual filtration costs avoided ($), Buv = UV construction costs avoided ($), $Buva_t$ = annual UV costs avoided, φ = area of wetlands required for water filtration.

This equation provides the value of wetlands for water filtration regardless of the costs of wetland construction. This value is used later in the model when the thesis examines the return of this whole area to wetlands.

The model assumes that it takes three years for the wetlands to reach maximum filtration (Wood, 1990), and thus the filtration value in the first years is one third of that in the third and subsequent years. By far the most important components of this equation are the benefits that arise from the annual filtration costs avoided, the wetland area required (depending on the water retention time) and the costs associated with wetland construction.

5.2.2 Step 2: Determining NPV and BCR of wetlands for water filtration

In order to determine the NPV and BCR for wetlands for water filtration, we must determine the costs associated with this option.

5.2.2.1 Costs of evaporation water

It is necessary to purchase approximately 2,500 ML of water (on the 'Permanent' water market) to account for water losses from evaporation from the constructed wetlands (a detailed calculation of water required for evaporation from wetlands is provided in Chapter 6).

5.2.2.2 Costs of wetland construction

Wetland construction costs are the largest component of the costs associated with this option, and these costs are considerable. Wetlands suitable for water filtration are estimated to cost between $10,000 and $20,000 per hectare – this includes the earthworks to create channels in the wetlands so that water flow could be controlled. Few wetlands have ever been constructed specifically for water filtration and therefore there is some uncertainty about these costs. In this analysis the higher figure of $20,000 per hectare has been used. These construction costs have been minimised by the utilisation of the existing levee banks and inlet structures. Had it been necessary to construct these wetlands from scratch, i.e., excavating, constructing levee structures, purchasing pumps, etc, the costs would have been considerably greater, in the range of $100,000 per hectare.

Once wetlands have been constructed it is necessary to replant the area with appropriate wetland vegetation (such as Phragmites). This cost can vary greatly depending on the (planted) cost per plant and planting density. Plant costs are normally between $1 and $2 per planted plant, and planting densities range between four to six plants per metre squared. This gives a wide range of plants costs – from $40,000 to $120,000 per hectare. No information exists to indicate optimum planting densities for water filtration as wetlands have been constructed for stormwater and effluent treatment, but not specifically for drinking water filtration. For this thesis an average planting cost of $80,000 per hectare has been used, with sensitivity analysis undertaken using the higher and lower figures. Thus the cost of wetland construction for water filtration becomes:

$$Cwf = Cwfe \times \varphi , \qquad (5\text{-}2)$$

where Cwf = wetland construction costs for filtration, $Cwfe$ = cost of wetland establishment for filtration, φ = area required for filtration.

Once established, the wetlands should not require dredging for a period of up to 50 years, as water through-flow would ensure that silting up did not occur.

5.2.2.3 Cost of wetland maintenance

The wetlands formed would be managed in the same way as a temporal wetland, with one fifth of the area allowed to dry out at any one time so that plant matter is able to decay. The model assumes an ongoing maintenance cost equal to that currently paid by the government for maintenance of inlet/outlet structures, irrigation and run-off drains and levee banks. Financial figures provided by other wetland complexes constructed for environmental purposes suggest that the running cost should be considerably lower. However, as so few wetlands worldwide have been constructed for domestic water filtration, accurate costs are unknown. Because these costs are only a small part of the whole equation, the higher figure has been used. The cost of wetland repair and maintenance becomes:

$$Cgr = rm \text{ x } \varphi \, , \tag{5-3}$$

where Cgr = repair, maintenance and capital cost x total area required for water filtration.

Table 5-4 presents a summary of the costs involved in this project. Note that there are no costs associated with dairy effluent entering the River Murray now that this land is used for wetlands.

TABLE 5-4. COSTS OF WATER FILTRATION OPTION

	Year 1 costs $(000)	Ongoing costs $(000) (Years 2–25)
Evaporation water	3,201	–
Wetland construction	33,840	–
Repair and maintenance	104	104
Total government costs	37,145	

In summary, the NPV for the water filtration option can be written as:

$$\sum_{t=1}^{25}((\alpha\lambda_t)-(\chi+\lambda_t))/(1+r)^t\ ,\qquad (5\text{-}4)$$

where, α = filtration efficiency achieved (%), λ_t (filtration benefits at full filtration efficiency(\$/year)) = θ_t + *Buv* + $Buva_t$, θ_t = annual filtration costs avoided \$, *Buv* = UV construction costs avoided (\$), $Buva_t$ = annual UV costs avoided (\$), χ = cost of evaporation water (\$), λ_t = *Cwf* + Cgr_t wetland construction and annual maintenance costs(\$), *Cwf* = cost of wetland construction (\$), Cgr_t = government annual repair and maintenance costs (\$).

5.2.3 Step 3: Comparison with Status quo

In order to determine the NPV and BCR for wetlands for water filtration in comparison to the Status quo, we must also determine the benefits and costs associated with this option for farmers.

It is assumed that farmers sell their irrigation water (13.92 ML per hectare) associated with the land and currently used by them for pasture production. Farmers lose dairy income off the swamps, but continue farming on the highlands.

In summary the NPV for the water filtration option can be written as:

$$\sum_{t=1}^{25}((\beta_t+\alpha\lambda_t)-(\chi\ +\lambda_t))/(1+r)^t\ ,\qquad (5\text{-}5)$$

where β_t = η + Bh_t, η = income from farmer water sale (\$), Bh_t = income from highlands (\$), α = filtration efficiency achieved (%), λ_t = θ_t + *Buv* + $Buva_t$ filtration benefits at full filtration efficiency(\$/year), θ_t = annual filtration costs avoided (\$), *Buv* = UV construction costs avoided ($), $Buva_t$ = annual UV costs avoided ($), χ = cost of evaporation water ($), $\lambda_t = Cwf + Cgr_t$ wetland construction and maintenance costs ($), Cwf = cost of wetland construction ($), Cgr_t = government annual repair and maintenance costs ($).

TABLE 5-5. YEARS THAT BENEFITS AND COSTS OCCUR AND THE PERCENTAGE OF TOTAL BENEFITS AND COSTS FOR WATER FILTRATION VARIABLES

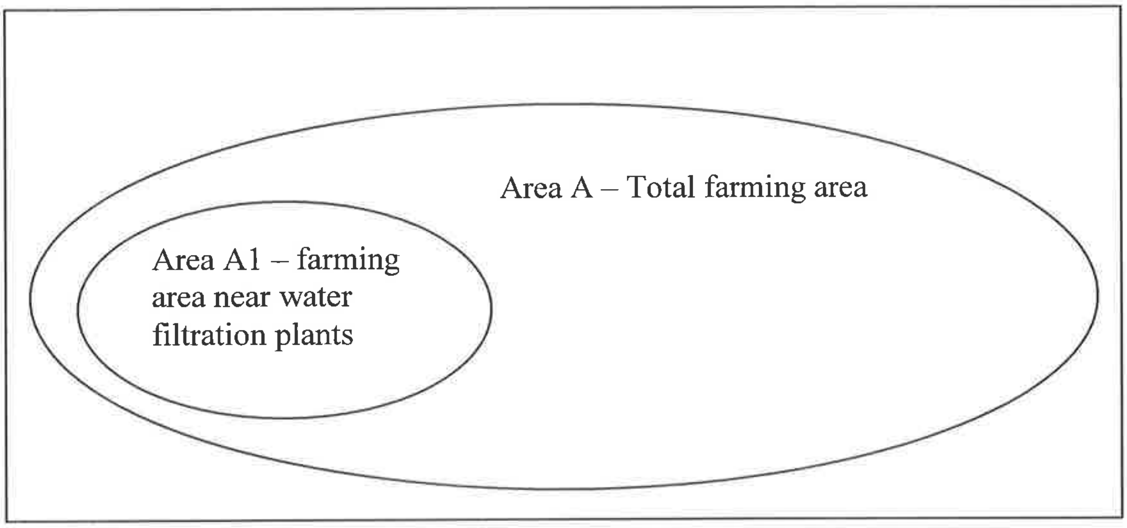
Benefit Variable	β		ψ		
Individual variables	η	Bh	θ	Buv	$Buva$
Years benefit occurs	1	1–25	1–25	1	1–25
Per cent of total benefit	6.96	0.93	90.78	1.14	0.19

Cost Variable	χ	λ	
Individual variables	χ	Cwf	Cgr
Years cost occurs	1	1	1–25
Per cent of total cost	8.25	87.20	4.55

5.3 Results

The current systems of wetland valuation commonly used in Australia are based on people's willingness to pay for various wetlands attributes, but do not consider the value of the various services wetlands provide (e.g., water filtration, stormwater treatment, flood mitigation). In this part of the thesis a value is determined for one vitally important wetland service, water filtration, on part A1 of the thesis study area (below) as identified in Chapter 3.

Figure 5-5. Identification of areas to be examined in this thesis



While the existing literature suggests that wetlands will filter up to 97% of suspended solids, which will in turn reduce the turbidity and colour of the water, it is uncertain whether the use of wetlands alone for water filtration would reduce turbidity and colour sufficiently to meet drinking water requirement at all times, including years of high turbidity. Therefore the option of replacing part or all of the filtration plants is looked at in this analysis.

The results are presented in three steps:

- Step 1 determines the value of the water filtration function performed by the wetlands (the benefits).

- Step 2 presents the BCR of constructing wetlands for water filtration, given the value of the water filtration benefit determined in Step 1.
- Step 3 examines the BCR of using this land for water filtration as opposed to dairy farming.

5.3.1 Step 1: The value of wetlands for water filtration

Equation 5-1 showed that the value per hectare for wetlands for water filtration, allowing for filtration efficiency, ψ. Using this equation, the value of wetlands to replace either half or all of the filtration system is shown to be $13,915 and $27,830 per hectare per year respectively, as in Table 5-6.

The value of wetlands for UV filtration is $203 per hectare per year. Obviously wetlands would not be constructed for their UV treatment benefits alone, but primarily for their filtration ability. Therefore the total value of wetlands for water filtration and UV treatment ranges from $14,118 to $28,032 per hectare per year, depending on whether wetlands replace all or half of the water treatment system, as shown in Table 5-6.

TABLE 5-6. SUMMARY OF BENEFITS OF CONSTRUCTED WETLANDS FOR WATER TREATMENT $/HA/YEAR

Option	Value of wetlands for water filtration $/ha/yr	Present value per hectare $
Replacing part of filtration system	13,915	228,099
Replacing all the filtration system	27,830	456,198
UV benefits	203	3,322
Total benefits	$14,118–$28,032	$231,421–$459,520

5.3.2 Step 2: BCR of water filtration.

As can be seen in Table 5-7, the use of wetlands to replace half the water treatment process is highly profitable, with the benefits clearly outweighing the costs. The NPV is $40.84 million or $7,361 per hectare per year.

TABLE 5-7. BCR OF CONSTRUCTED WETLANDS FOR WATER FILTRATION, WETLANDS REPLACING HALF OF EACH WATER FILTRATION PLANT, WITH ASSOCIATED UV BENEFITS

	Water Filtration ($Million)
TOTAL Community benefits	78.32
TOTAL Community costs	37.48
NPV	40.84
Community BCR	2.09

The use of wetlands to replace all of the water filtration process is again profitable (BCR = 4.15). The NPV is now $118.03 million or $22,486 per hectare per year (Table 5-8).

TABLE 5-8. SUMMARY OF ECONOMIC RETURNS FROM INCLUDING CONSTRUCTED WETLANDS AS PART OF THE WATER FILTRATION AND UV TREATMENT SYSTEM

Option	NPV ($Million)	Community BCR
Replacing ½ filtration system	39.71	2.06
Replacing all filtration system	116.90	4.12
Replacing ½ filtration + UV	40.84	2.09
Replacing all filtration + UV	118.03	4.15

One of the most important considerations for the government when choosing between these two land uses is the non-polluting activities of wetlands for water filtration versus the ongoing pollution of the River Murray from dairy farming effluent. The conversion of this land to wetlands for water filtration completely removes the water polluting activities on this land, reduces the level of nitrogen and phosphates entering the Murray and reduces the risks of cryptosporidium-related problems in drinking water. The specific benefits from removal of cows from the dairy swamps are examined in Part II of this thesis.

5.3.3 Step 3: Comparison with current farming practice

While it is clear that wetlands are very valuable when included as part of the water filtration system, the question arises of how this land use compares with the current farming practice (dairy farming) that it would replace. Converting this land to wetlands would mean a loss of farming income, but farmers would receive an income from water sales. At the same time, constructing the wetlands comes at considerable cost.

However, as can be seen from Table 5-9 it is more profitable to convert this part of the dairy swamps on the Lower Murray to wetlands for water filtration because of the large benefit of a reduction in the water filtration plants costs. While the BCR for water filtration is lower than for dairy farming, the NPV is substantially higher, resulting in a net benefit from converting to wetlands for water filtration.

TABLE 5-9. COMPARISON OF ECONOMIC RETURN FROM CONVERTING DAIRY SWAMPS TO CONSTRUCTED WETLANDS TO REPLACE HALF OF E WATER FILTRATION AND UV SYSTEM

	Status quo Dairy Farming ($Million)	Water Filtration ($Million)	Net Return ($Million)
TOTAL Community benefits	11.00	85.03	74.02
TOTAL Community costs	2.44	37.48	35.04
NPV	8.56	47.55	38.98
Community BCR	4.51	2.27	2.11

As seen in Table 5-10, farmers' benefits are higher for dairy farming than from the sale of their irrigation water under the water filtration option. While farmers do not have any costs associated with water filtration, their reduction in farming costs does not offset their income loss, therefore farmers lose approximately $2.8 million from this land use change.

TABLE 5-10. IMPACT ON FARMERS OF CHANGING FROM DAIRY FARMING TO CONSTRUCTED WETLANDS FOR WATER FILTRATION ON AREA A1[4,5]

	Financial analysis		Economic analysis	
	Farmers	**Government**	**Other**	**Total**
Benefits				
Dairy production (lost)	-11.00			-11.00
Extra benefits				
Irrigation water sold	6.70			6.70
Filtration plant costs avoided		78.32		78.32
Total benefits	**-4.30**	**78.32**	**0.00**	**74.02**
Costs				
Irrigation costs avoided	-1.5	-0.21		-1.71
Tourism losses avoided		-0.02	-0.71	-0.73
Extra costs				
Wetland costs		37.48		37.48
Total costs	**-1.5**	**37.25**	**-0.71**	**35.04**
NPV	-2.80	41.07	0.71	38.98
BCR		**2.10**		**2.11**
Compensation	2.80	-2.80		0.00
NPV after compensation	000	38.27	0.71	38.98
BCR after compensation	**1.00**	**1.99**		**2.11**

[4] The last column represents items of benefits and costs for the community as a whole, hence its BCR is in fact the social benefit cost ratio, whereas those for the farmers and the government are not. The table also illustrates that financial analyses for the farmers and the government are required to provide intermediate calculations for social cost benefit analysis (or economic analysis). The compensation of 2.8 to farmers increases the farmers' benefits from –4.3 to -1.5 and increases the government's cost from 37.25 to 40.05. While this affects the BCRs of the farmers and the government, it has no effect on the BCR for the community (given in the last column), since this compensation, being a pure transfer within the community, should have no effect on total benefits or costs for the community as a whole in economic analysis (or social benefit cost analysis). An alternative way of presenting this information would be first to convert benefits lost to costs, and costs saved to benefits. This would result in the same NPV, but slightly different BCR's. However, the way the results are presented in the table above are consistent with the excel model and with the other BCR calculations determined in the thesis.

[5] Subsequent tables in the thesis relating to farmer compensation will not present a detailed financial analysis.

Clearly it is unlikely that this project would proceed if farmers knew they would be losing money by giving up dairy farming. For this reason the government must compensate farmers by $2.8 million to leave the land, at which point the farmers' BCR equals one, and the overall project BCR remains the same. It is possible that the government may actually have to pay the farmers slightly more than this amount as an incentive to go.

5.3.4 Sensitivity analysis

The uncertainty associated with the magnitude of a number of variables within the model makes it necessary to undertake sensitivity analysis to determine if replacing dairy farming with wetlands for water filtration is a viable land use under other circumstances. The variables chosen for analysis are:

- Water retention time required -- this affects the area of land required for wetlands and hence the value of wetlands for water filtration per hectare.
- Interest rate – this analysis has used a real interest rate of 3.55%. This variable was chosen because of its likelihood of movement over the period that the model is run (25 years).
- The price of water – the price of water is a major cost in this analysis. Water price has increased substantially in recent years, and is expected to continue to rise.
- Water filtration plants annual costs – the cost of the water filtration plants has been set at $10 million (for this part of the river) as part of the agreement with SA Water. This cost is by far the greatest component in this model, and is directly related to the filtration value of wetlands. For this reason the impact of a change in this figure on wetland filtration values is examined.
- As identified in the methodology, wetland construction costs are a major component of the model, and can vary considerably, depending on plant costs and planting rates.

Therefore the sensitivity to a change in these costs and the impact on the viability of the filtration option is examined.

5.3.4.1 Water retention time required

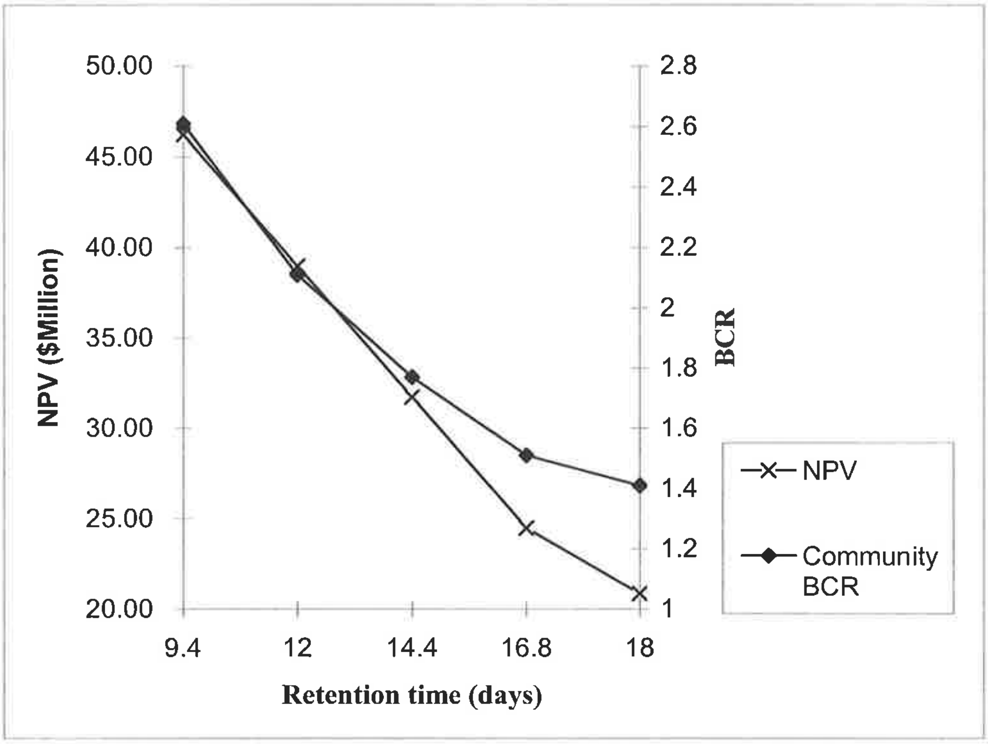
A water retention time of 10 days (plus two days to allow wetlands to dry out) has been used in the thesis model as the literature suggests that this is the standard time used in other wetlands built for stormwater filtration. However, because so few studies examining the retention times for wetlands for domestic water filtration exist, there is some uncertainty about this figure. As can be seen in Table 5-11, the area of land required for water retention has an impact on the value of wetlands for water filtration. The figures also show that the water filtration value of wetlands is high ($9,412 per hectare per year) even where a retention time of 15 days (plus three days for drying out) is required and wetlands replace only half of each water filtration plant.

TABLE 5-11. THE VALUE OF CONSTRUCTED WETLANDS FOR WATER FILTRATION WITH A RANGE OF RETENTION TIMES, ASSUMING WETLANDS REPLACE HALF OF EACH FILTRATION PLANT

Retention time (days)	**$8^{+1.6}$**	**10^{+2}**	**$12^{+2.4}$**	**$14^{+2.8}$**	**15^{+3}**
Half filtration $/ha/year	17,647	14,118	11,765	10,084	9,412
PV/ha/ $	289,276	231,421	192,851	165,301	154,281
All filtration $/ha/yr	35,041	28,032	23,360	20,023	18,688
PV/ha/ $	574,400	459,520	382,933	328,229	306,347

An increase in the retention time has a subsequent impact on the economics of this option, as indicated in Table 5-9, and Figure 5-6. However, even with a retention time of 15 days, this option is still more profitable than dairy farming.

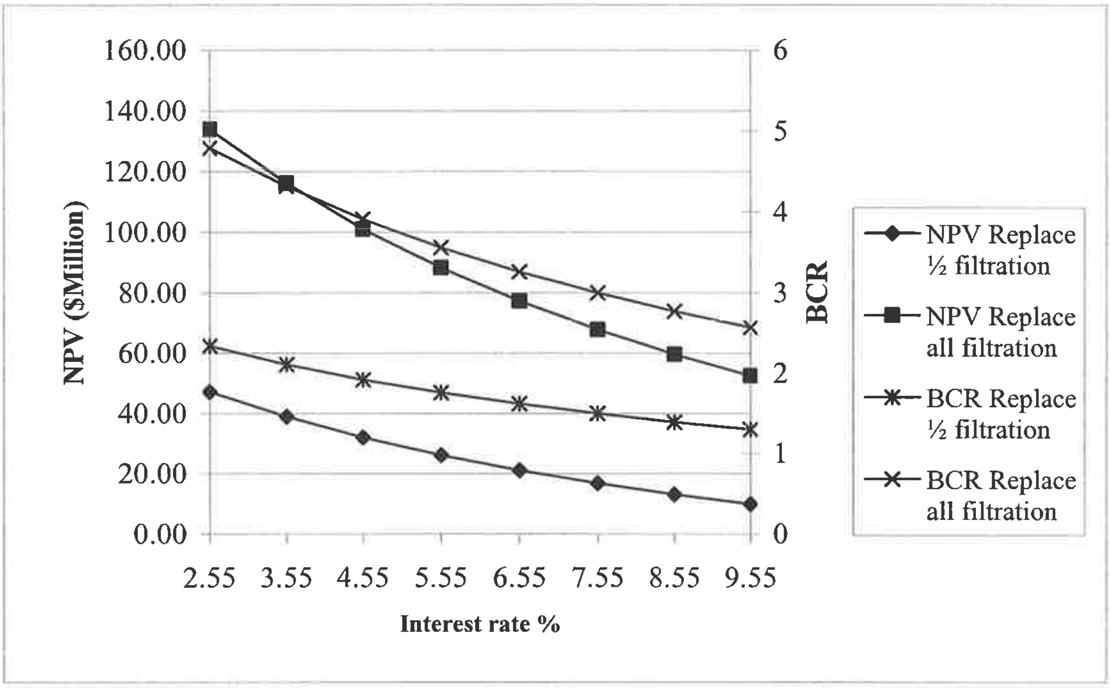
FIGURE 5-6. EFFECT OF WATER RETENTION TIMES ON THE ECONOMIC RETURN (NPV AND BCR) OF CONVERTING FROM DAIRY FARMING TO CONSTRUCTED WETLANDS FOR WATER FILTRATION, ASSUMING WETLANDS REPLACE HALF OF EACH WATER FILTRATION PLANT



5.3.4.2 Interest rate

Sensitivity analysis shows that the interest rate is important when comparing these two land uses. As can be seen in Figure 5-7, increasing the interest rate results in a net benefit for farmers, but less benefit for the community, reflecting the time delay before maximum filtration benefits are realised. As interest rates and farmers' benefits increase, the amount the government has to compensate farmers to leave the swamps (originally $2.8 million) decreases. At an interest rate of 8%, farmers' benefits from leaving the swamps outweigh costs by $2,652 and the government would not have to pay farmers to leave the land. However, even at an interest rate of 9.55% this option is still profitable for the government.

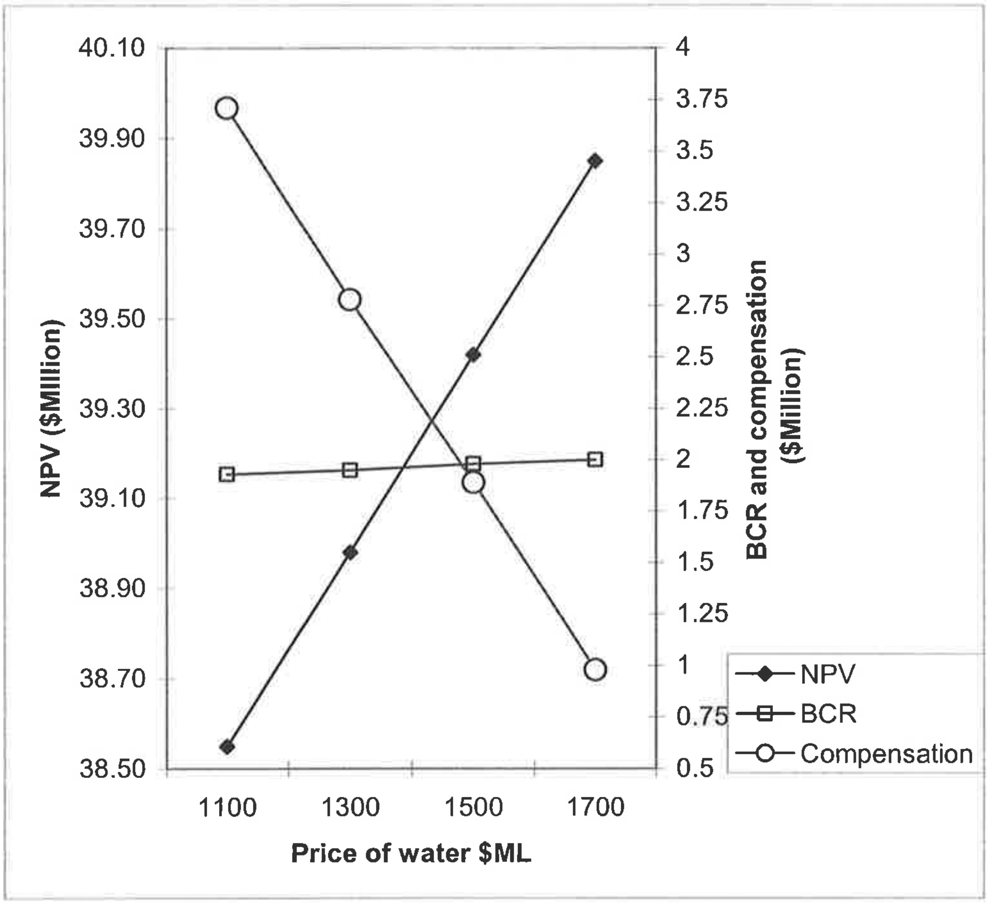
FIGURE 5-7. EFFECT OF INTEREST RATE ON THE ECONOMIC RETURN (NPV AND BCR) OF CONVERTING FROM DAIRY FARMING TO CONSTRUCTED WETLANDS FOR WATER FILTRATION



5.3.4.3 Changing the price of water

The figures presented in the analysis so far are based on a water price of $1,300 per ML. It is likely that water prices will rise as farmers are asked to become more efficient water users and environmental groups call for more water to be returned to the river.

FIGURE 5-8. EFFECT OF WATER PRICE ON THE ECONOMIC RETURN OF CONVERTING FROM DAIRY FARMING TO CONSTRUCTED WETLANDS FOR WATER FILTRATION, ASSUMING WETLANDS REPLACE HALF OF EACH FILTRATION PLANT



Farmers benefit from an increase in the price of water because their benefits from giving up dairy farming come from water sales. In contrast, the government receives no benefit, but has increased costs associated with the purchase of water to allow for the annual evaporation loss from constructed wetlands. The net effect of these two impacts is a slight increase in the NPV – farmers are able to sell a larger volume of water associated with this land than the government has to purchase to account for evaporation losses – so farmers' gains outweigh government losses (Figure 5-8). The net result is that while the model is relatively insensitive to water price, the amount that the government would have to compensate farmers to leave the land would fall.

5.3.4.4 Water filtration plant annual costs

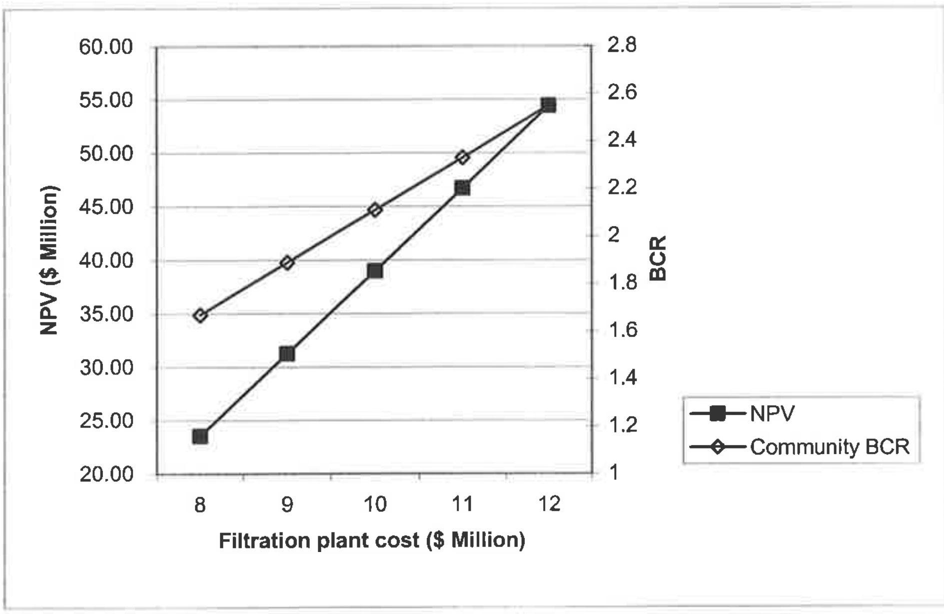
As expected, any increase in filtration plant costs makes wetlands a more viable option as the community benefits from not having to pay the higher costs associated with the filtration plants when wetlands are used, as shown in Table 5-12.

TABLE 5-12. THE VALUE OF CONSTRUCTED WETLANDS FOR WATER FILTRATION WITH A RANGE OF WATER FILTRATION PLANT COSTS, ASSUMING WETLANDS REPLACE HALF OF EACH FILTRATION PLANT

	$8 Million	$9 Million	$10 Million	$11 Million	$12 Million
$ha/year	11,335	12,726	14,118	15,509	16,901
PV/ha $	185,801	208,611	231,421	254,231	277,041

Figure 5-9 indicates that wetlands as part of the water filtration scheme are viable even where the cost of the filtration plants falls by 20%.

FIGURE 5-9. EFFECT OF WATER FILTRATION PLANT ANNUAL COSTS ON THE ECONOMIC RETURN OF CONVERTING DAIRY FARMING TO WETLANDS FOR WATER FILTRATION, ASSUMING WETLANDS REPLACE HALF OF EACH FILTRATION PLANT



5.3.4.5 Cost of wetland establishment

The cost of the plants for wetland establishment for water filtration in this analysis is assumed to be $80,000 per hectare. As mentioned earlier, these costs can vary substantially, with a range of between $40,000 per hectare (when plants cost $1 per planted plant, and plant density is four plants/metre sq, and $120,000 per hectare (when plants cost $2 per planted plant, and plant density is six plants/metre sq).

The results presented in Table 5-13 show that the profitability of this option is sensitive to planting costs – the BCR and NPV falling by approximately 50% when costs rise from $40,000 per hectare to $120,000 per hectare. However, even at the highest cost, this land use option is still optimal. Because a change in planting costs does not alter the benefits that farmers receive from this land use change, the government must still consider compensating farmers ($2.8 million) to leave the land.

TABLE 5-13. EFFECT OF PLANTING COSTS ON ECONOMICS OF CONVERTING DAIRY FARMING TO WETLANDS FOR WATER FILTRATION, ASSUMING WETLANDS REPLACE HALF OF EACH FILTRATION PLANT

	Planting costs ($/ha)				
	40,000	**60,000**	**80,000**	**100,000**	**120,000**
PV Farmer benefits	–4.30	–4.30	–4.30	–4.30	–4.30
PV Government benefits	78.32	78.32	78.32	78.32	78.32
TOTAL Community benefits	74.02	74.02	74.02	74.02	74.02
PV Farmer costs	–1.50	–1.50	–1.50	–1.50	–1.50
PV Government costs	23.47	30.00	36.54	43.08	49.61
TOTAL Community costs	21.97	28.50	35.04	41.58	48.11
NPV	**52.05**	**45.52**	**38.98**	**32.45**	**25.91**
Farmer BCR	0.35	0.35	0.35	0.35	0.35
Government BCR	3.34	2.61	2.14	1.82	1.58
Community BCR	3.37	2.60	2.11	1.78	1.54

5.4 Discussion

These figures indicate that the value of constructed wetlands for water filtration ranges from $14,118 and $28,032 per hectare per year (depending on whether wetlands replace all or only half of the water filtration system, using a retention time of 10 days), with a PV ranging between $231,421–$459,520 per hectare. This suggests that it would have been very profitable to include wetlands as part of the water filtration process instead of constructing the whole of the filtration plants.

The factor that has the biggest impact on the value of wetlands for water filtration is that of retention time. As mentioned earlier, only two studies have been found that look at using wetlands and aquatic plants to filter water. The first study by Manfrinato *et al.* (1993) in Brazil employed a retention time of just over one day for filtering river water. However Manfrinato *et al.*'s study differed from the wetlands proposed in this thesis as it involved passing water over aquatic plants and a filtering soil cultivated with rice.

The second study by Wrigley *et al.* (1991) at Clear Water Lagoon, Mt Isa, had a nominal water retention time of 30 days. However the retention time in the Clear Water Lagoon relates to the lagoon's storage capacity, not filtration requirements – the lagoon was originally constructed to receive water during periods of low turbidity, and to provide temporary water storage (up to 30 days) for Mt Isa during periods of high turbidity. The lagoon was subsequently extensively modified to allow all domestic water to pass through the lagoon, while the retention time was kept at 30 days so as to maintain a constant water level in the lagoon and prevent any adverse effects on rooted water plants resulting from drawdown. It is therefore difficult to know what the optimum retention time would be for this lagoon.

If we assume that a retention time of 10 days is adequate, the next question that arises is: Could wetlands be used to replace all of the filtration plants, or only half of each plant?

Only the Mt Isa study throws some light on this question. While turbidities at Mt Isa are generally in the range of 10 NTU during the dry season, they can reach 100 NTU during the wet season (turbidities of over 100 NTU also occur in the study region, especially after periods of drought). Wrigley *et al.* found that during maximum turbidity periods it was necessary to dose the water with poly aluminium chloride. This suggests that perhaps constructed wetlands in the thesis study region may not be able to cope when turbidities rise and that the second part of each filtration plant could be required. This view is supported by staff at SA Water who have indicated that while wetlands may be able to replace the primary and secondary parts of the filtration system (see Figure 5-2), the tertiary part of the filtration plants would still be required, particularly in years when there are large influxes of water from the Darling River which typically has high turbidities. Thus, the filtration service provided by the constructed wetlands is worth a minimum of $14,118 per hectare per year, but may not reach $28,032 per hectare per year.

Until 1999, water from the Murray was not commercially filtered so any filtration that did occur was done naturally by wetlands. However, as wetlands were destroyed so were the water filters for the community. It is doubtful that the community had any idea of the value that wetlands provided every year in water filtration, and if asked about their willingness to pay for wetlands for water filtration most would not have any understanding of the value of the function they were being asked to consider. Certainly it would not be expected that they would answer the question in terms of thousands of dollars per hectare per year. This, in effect, is market failure.

The fact that the community now requires the construction of water filtration plants indicates that they are willing to pay for water filtration services (which they had earlier destroyed).

If we consider the current operation/repayment costs for all plants ($20 million per year) and a population receiving water from these plants of just over 100,000, people's willingness to pay for water filtration is around $200 per person per year,[6] or $102 per person per year for wetlands to perform just over half of this task. Once again, this number appears high, but it is considerably lower than the saving from the wetland system constructed by Wrigley *et al.* (1991) to provide water filtration for 24,000 people at Mt Isa. Wrigley *et al.*'s system is estimated to have saved the community between $10 and $20 million in water treatment plant construction costs. This represents a saving of between $417 and $834 per person per year.

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[6] It is interesting to note that the current price for domestic water charged by SA Water is 46c for the first 125 kL, $1.06 per kL after 125Kl, plus a $145 supply charge. Using the average household use of 250 kL, the average cost per household for domestic water supply is $335.00 per year. Assuming 2.2 persons her household, this is equivalent to $152 per person per year.

6 PART II: STATUS QUO, REHABILITATION AND WETLANDS

The 'without-project' scenario for Part II relates to the case in which 'nothing-will-be-done' to alleviate pollution, which may amount to the adoption of the 'Status quo' case. The costs to society for this part of the thesis would therefore be the value of the impacts on tourism and the environment and of various groups of people living near the affected areas. It is only possible to quantity those impacts where information is available, and it is therefore recognised that some of the impacts from pollution and the benefits from such pollution alleviation will be underestimated.

For this part, two alternative 'with-project' scenarios are considered. The first one, 'Project IIa', will examine dealing with the problem of pollution by rehabilitating the existing irrigations scheme using either a Piped or Channelled irrigation system. The option of including constructed wetlands to further reduce pollution in conjunction with rehabilitation is included in the analysis.

The second scenario, 'Project IIb', examines converting the area back to wetlands, especially from their pollution-alleviation function.

6.1 Status quo

6.1.1 Introduction

Numerous figures and equations combine to form the summary equations presented in this section. Details for the determination of the large number of individual components that make up these equations can be found in Appendix 4, section 4.2. All the variables and sources of information can be found in Appendix 3.

In order to quantify the benefits and costs associated with dairy farming on the Lower Murray swamps, it was necessary to determine the incomes associated with dairy production and tourism for this region, and then to determine the costs associated with dairy production. These costs include those resulting from the significant volume of effluent entering the River Murray from the dairy farms. It was then necessary to investigate the contribution of the dairy effluent to BGA outbreaks so that the economic impact on the tourism industry could be determined.

Tourism and the Murray dairy swamps are important businesses for the study region. Farmers receive just over $6.81 million per year in income from milk production, while the community receives nearly $47 million in tourism revenue. The total value of dairy farming and tourism to the region is calculated to be approximately $54 million per year.

The most important cost in the Status quo analysis is the irrigation drainage from the reclaimed dairy swamps, which for many years has been disposed of either into natural wetlands or directly into the river. The swamps have now been identified as the single most important source of nutrient pollution in the Lower Murray in South Australia (Mackay and Eastburn, 1990; Gutteridge *et al.*, 1992). Therefore, in order to model the economics of a change to the present farming system, it was necessary to understand the impact of this effluent on:

1) tourism (via blue-green algae outbreaks);
2) domestic water quality, and
3) wetland function.

6.1.1.1 Tourism impacts

While BGA (cyanobacteria) occurs naturally in Australian waters, they only pose a problem when conditions lead to an algal bloom. Because they have few natural enemies, and their capacity for buoyancy regulation prevents sedimentation, the loss rates of blue-green algae populations are generally low. Thus, their slow growth rates are compensated for by the high prevalence of populations once they are established (Mur *et al.*, 1999).

BGA growth rates are affected by a number of factors including:

- light;
- turbidity of the water;
- nutrients (P and N: P), and
- temperature.

(Blue-green Algae Task Force, 1992)

Of these, man has contributed to changes in both water turbidity (by restricting water flow in the Murray, and by introducing European carp) and to the quantities of nutrients entering the Murray as irrigation run-off. These changes have resulted in multiple cases of BGA blooms. When these blooms occur, the chemical toxins released from the BGA pose problems for terrestrial mammals (Sivonen and Jones, 1999). These problems include impacts on water supply, human and animal health, livestock and fish production, and a loss of tourism and recreational facilities.

While it is unknown whether dairy farmers on the swamps contribute directly to water turbidity, the relationship between nutrients from faecal contamination of the Murray and dairy effluent is well established (Thomas, 1986; Gutteridge, Haskins and Davey, 1992). The EPA (2002) report states that for the period 1990 to 1999, the medium and 90th percentile concentration of soluble phosphorus increased substantially between Mannum (mean concentration 0.085 mg per litre) and Tailem Bend (0.122 mg per litre). They conclude that this increase is likely to be caused by dairy farms returning their irrigation drainage water to the river. These nutrient loads contribute to conditions that can result in a number of problems, the most important of which are wetland degradation and outbreaks of toxic blue-green algae (cyanobacteria) in the river, and in lakes Alexandrina and Albert.

The annual load of phosphorus transported to the river via the dairy drainage is estimated to be 50 tonnes. This represents approximately 19.6% of the total river load in a dry year and 2.8% of the total river load in a wet year. The annual load of nitrogen transported to the river via drainage is estimated to be 190 tonnes. This represents 12.2% of total river load in a dry year and 1.7% of total river load in a wet year (RMWRC, 1994).

There are two basic approaches for attempting to reduce the probability of outbreaks of BGA and the associated tourism losses: the reduction of nutrient loads into the water system, and increasing water flows at critical times (flow regulation) (Kennedy, 1997). While dairy farmers on the swamps have, for all practical purposes, no control over the rate of flow of the Murray, they can reduce the amount of nutrients that they deposit into the river. A reduction in nutrients is particularly important in dry years when water flow is reduced and BGA problems are most likely to occur. Nutrient reduction can only be done through either removal of dairy farming from the swamps or by rehabilitation of the irrigation scheme.

Given that many farmers are unwilling to leave the land, the most practical approach available to farmers is rehabilitation of the irrigation scheme. While it may take many years before the benefits of rehabilitation become apparent, this option also addresses other problems that arise from the disposal of drainage water into the Murray, such as the impact on drinking water quality.

6.1.1.2 Domestic water quality impacts

Drainage from the swamps contains significant faecal bacteria. E & WS studies conducted in 1986 (Thomas *et al.*, 1986) recorded that River Murray water below Mannum has regularly exceeded safe levels of bacteria for contact use, for example recreation and non-disinfected domestic supply.

The EPA (2002) report mentioned earlier also states that, for the period 1990 to 1999, the medium and 90th percentile faecal coliform numbers increased substantially between Mannum (E coli numbers 54 per 100 ML) and Tailem Bend (as high as 150–200 cells/ML). The presence of these E coli indicates the possible presence of cryptosporidium.

Cryptosporidium can have significant impacts on human health, and for this reason water filtration plants operating in the vicinity of the dairy swamps must consider the construction of UV treatment plants to address this issue (as described in Part I). While the health impacts of cryptosporidium on dairy calves is presented in Appendix 2, in this thesis we are more concerned with the impacts on human health, cases of which have been documented worldwide.

The E. coli incubation period in humans ranges from five to 28 days and is most commonly seven to 10 days. Symptoms in humans can be mild to severe diarrhoea, abdominal cramps, vomiting and fever. Symptoms are usually self-limiting, lasting about two weeks in immunocompetent patients, but can last six months and be fatal in immunocompromised patients. Both adults and children are susceptible, although the disease is more common in children. Cryptosporidiosis is not a reportable disease in humans. Treatment is limited to supportive care, since there are no specific anticryptosporidial medications currently available. During outbreaks, it is advisable to boil water for drinking and washing foods.

In March and April 1993 an outbreak of cryptosporidiosis in Milwaukee resulted in diarrheal illness in an estimated 403,000 persons transmitted through the municipal water supply (MacKenzie *et al.*, 1994). It is estimated that up to 130 people died as a result of this outbreak, with most of the dead being either immunocompromised or elderly. As a result of this disaster, water treatment authorities have investigated ways of filtering or killing the cryptosporidium in their water supplies. Cryptosporidium oocysts are small (4–6 μ), are resistant to chlorine, and have a high infectivity. The chlorine CT of 9600 needed to kill cryptosporidium oocysts is approximately 640 times greater than that required for giardia cysts (Current and Garcia, 1991). It is estimated that standard water filtration processes remove over 99% of oocytes, but that UV filtration is required to remove any remaining pathogens.

6.1.1.3 Wetland functional impacts

The reclaimed swamp areas currently used for dairying were originally natural wetlands which had the function of intercepting surface run-off, trapping sediments from floodwaters, sequestering metals and removing nitrogen and minerals from water. Thus, this area has gone from one with the function of water filtration to that of water pollution over the past 100 years.

The loss of natural wetlands is not unique to this region. A similar situation exists in the United States. In the 1600s, over 220 million acres of wetlands existed in the lower 48 states (Dahl and Johnson, 1991). Since then, extensive losses have occurred, with many of the original wetlands drained and converted to farmland. Today, less than half of the US original wetlands remain.

The reduction in wetland area in the Murray swamps comes not just from the conversion of wetlands to farming land, but also from the degradation of the remaining wetland from this farming activity. Kazepidis (1997) found that wetlands surrounding the dairy swamps are affected by drainage disposal resulting in:

- a far greater uptake of phosphorus by wetland vegetation than was found at sites receiving less concentrated irrigation water;
- humic acids and other organic matter affecting wetland water colour;
- remineralization of phosphorus in the wetland (which could result in significant algal blooms further down stream);
- high concentration of salts in irrigation drains in winter when irrigation has stopped, with this salt being received by one single wetland;
- ammonium levels almost double those of the non-irrigated wetland sites, and
- levels of E coli double those of non-irrigated wetlands.

Little work has been done on determining what effect these nutrient levels have on the biology (other than BGA) of the Murray waters. Richardson (1985) showed that the capacity for phosphorus adsorption by a wetland could be saturated in a few years if it has low amounts of aluminium and iron or calcium. The presence of aluminium is the significant predictor of dissolved phosphorus sorption and removal from water in most wetland systems (Richardson, 1985; Walbridge and Struthers, 1993; Gale *et al.*, 1994). Little is known about the aluminium levels in wetlands affected by dairy effluent drainage and hence the long-term ability of these wetlands to absorb phosphorus from the swamps. However, the incidence of blue-green algae outbreaks in the Lower Murray has increased over the past 20 years, indicating that surrounding wetlands may already be saturated and resulting in phosphorus and nitrogen levels rising in the river as the wetlands fail to cope with the volume of pollutants entering the river.

6.1.2 Methodology

6.1.2.1 Valuing benefits

The major benefit of the Status quo option is the income to dairy farmers from milk production. The gross value of farmers' income, Ω, was supplied by the two local dairy companies and confirmed by farmers. The costs of production, K, were provided by local consultants and are based on information supplied by farmers.

The most important components of K are labour, feed and fertiliser. The amount of feed purchased varies considerably between years, with costs ranging from 25 to 50% of operating costs (see Appendix 3). Fertiliser costs are also highly variable, representing between 2 and 8% of operating costs (see Appendix 3).

In summary, net income for the Status quo options can be written as:

$$\text{Net income } \Pi = \Omega - K, \qquad (6\text{-}1)$$

where Ω = farm income ($), K = production costs associated with farming ($).

6.1.2.2 Valuing costs and externalities

The government costs associated with the current system (detailed above) consist of pollution-related tourism losses, domestic water quality and wetland functional impacts. The government has the additional cost of the management, repairs and maintenance of the irrigation scheme, which it owns. All these costs are detailed below.

6.1.2.2.1 Costs to tourism of BGA outbreaks

Numerous studies have been undertaken on methods to increase dairy farm income (Armstrong *et al.*, 1998; ABARE, 1994, 2000); of the economic impacts of the dairy industry on particular regions (Powell, 1991; Morrison, 1996); the impacts of restrictions on irrigation water (Scoccimarro *et al.*, 1997; Brennan, 1997); reductions in the amount of phosphates applied to irrigated land (Yeates *et al.*, 1984); and requirements for the dairy industry to handle dairy shed wastes (Leidreiter, 1996). However, none appear to have considered the contribution of dairy irrigation to outbreaks of BGA, the impacts of these outbreaks on tourism and tourism attractions such as wetlands, biodiversity, fish and bird life, or the implications for changing the irrigation system to remedy a BGA problem.

Several studies have focused on the costs of the impact of BGA outbreaks on tourism itself. A report prepared for the Senate Standing Committee on Toxic Algae (1993) states that the costs of algal blooms in Australia in 1992/93 was estimated to be $10 million, and in most States was comparable to the previous year. It specifically notes that these costs refer to the treatment and prevention of blooms and did not include costs for tourism. It is only in recent years that any studies have been undertaken to determine the economic impact of BGA (caused by dairy cows or otherwise) specifically on tourism.

Read Sturgess and Associates (1996) have proposed a rapid appraisal method to determine the impact on tourism of BGA outbreaks. This methodology suggests determining:

- The loss of economic activity (e.g., the flow of money and resources set in train as a result of economic activity – this generally indicates the impact on the region). Measuring the loss of economic activity caused by a bloom is useful for demonstrating the need for a regional cost share, and
- The loss of economic value associated with an outbreak (e.g., what people are prepared to pay for something).

The loss of economic activity can be determined from the change in the number of tourists coming to a region as a result of a BGA outbreak (as measured by local tourism commissions), and the resulting drop in expenditure and associated employment that occurs (as measured directly by local businesses).

Figures from the Bureau of Statistics for the Murraylands estimate that the value of tourism to the region is $54 million per year (70% of which is associated with the river), with tourism numbers of approximately 185,500 persons. The costs for the study region have been determined from these figures based on the proportion of the river associated with the dairy swamps.

When algal outbreaks occur there is a significant drop in tourism to the region. This drop is estimated to be 20% (SA Tourism), resulting in significant tourism revenue losses each outbreak. This effectively takes revenue out of the region (it is thought that tourism moves up-river to Victoria) and has a direct impact on the employment and success of regional businesses as tourist dollars move elsewhere.

Both the Tourism Association and SA Water estimate the frequency of algal blooms in the region to be between one year in four or one year in five, and note that this frequency is increasing as sedimentation increases over time. Thus, the losses from BGA could be expected to increase over time if the situation is not addressed.

The loss of economic value to the broader community is more complex to determine, and there does not appear to be general agreement on which method or methods (travel cost (TC), contingent valuation (CV), or other willingness-to-pay methodologies (WTP)) provide the most accurate assessment. The situation is made even more complex by the fact that people may be willing to pay for the preservation or existence of a particular habitat even though they have no intention of ever visiting the place.

The following extract from Read Sturgess and Associates (1996) summarises the outcomes and methodologies of relevant studies undertaken to determine the net economic value of tourism and recreation i.e., amount that visitors would be willing to pay for particular recreational experiences. (Values expressed in 1992 A$ values unless otherwise stated):
The Resource Assessment Commission (1992) employed both the TC and CV methods to estimate that the community's WTP for recreational and non-use values associated with national estate forests was $9 per visitor day. Read Sturgess and Associates (1994) also used the TC method to value the recreation use of the Grampians National Park. The average length of stay for their survey sample was 4.2 nights and the WTP was $18 per visitor day ($1,994). This method was also used by Pitt (1992) to estimate a WTP for recreation on the NSW North Coast of $151 per visitor (using an average length of stay for visitors to the North Coast of 3.8 days, this suggests a WTP of $40 per visitor day), and by Sinden (1990) to estimate recreation values for 24 sites along the Ovens and King rivers in the 1989/90 summer. Sinden found an average value of $29 per day per group ($7 per visitor day), in

A$1990 values (see discussion below). Herath and Jackson (1994) again used a TC model to determine recreation values for day visitors at Lake Mokoan, Victoria, after the onset of sustained algal blooms in that water body. Their study estimated an average WTP of $4.70 per visitor.

Economic Associates Australia (1983) used the CV method to estimate a WTP for recreation at Green Island of $15 per visitor day, while Sloan (1987) used the CV method to estimate a WTP for recreation on Heron Island of $36 per visitor day. Walker and Greer (1992) used some novel indicative procedures for the loss of expenditure and economic value, which would be suitable for rapid appraisals when there is little other information available. They considered three examples of blooms in NSW, namely, a section of the Nepean–Hawkesbury River, towns along the Darling River, and a water storage facility. Their measures included the use of proxy variables (beer sales) and a travel cost model.

As noted by Read Sturgess and Associates (1996), the study by Sinden (1990) relates to rivers and streams in Victoria and differentiates between different types of visitors. For this reason, his results are of particular interest to this thesis. More than half the sample comprised residents of the local area on day visits, and most of the remaining sample comprised campers who had travelled mainly from Melbourne. These characteristics are common to conditions faced by tourists in this South Australian study.

Sinden found that the average net economic value of sites without close substitutes was twice that of sites with no good substitutes. His results (expressed in 1990 A$ values) showed values of $5 per visitor day for day trip visitors and $9 per visitor day for campers.

Sinden's valuations appear low compared to some of the others quoted above, but this is primarily because most of the sites that he valued had close substitutes within close proximity (indeed there were 24 sites within his study area). A similar situation occurs in SA, where tourists can simply cross the border to Victoria to find similar holiday sites. For these reasons, the figures chosen for use in this model are based on Sinden's (1990) work.

Overseas, Sanders *et al.* (1991) used CV and TC approaches to estimate that recreation at rivers and lakes in Colorado was valued at $41 to $43 per visitor day, while Walsh *et al.* (1992) undertook a systematic search of the available literature of 287 studies, which had estimated recreation values in the United States. Estimates reported by Walsh lie in the confidence interval A$13 to A$73 in 1994 values for recreational activities of picnicking, sightseeing, resorts, non-consumptive fish and wildlife, wilderness and boating. These results emphasise that the net economic value of recreation at particular sites varies greatly depending on the uniqueness of the particular site. Sites in Australia that are of national or international significance (i.e., sites such as Heron Island or the Grampians, for which there are very few close substitutes in Australia) tend to have net economic values of $15 to $40 (or even higher), while sites with many close substitutes have been found to have values of $5 to $15 depending on the particular site and the nature of the recreational activities undertaken at those sites.

6.1.2.2.2 Dairy industry contribution

The most difficult figure to determine in this part of the study was the proportion of BGA-related costs (tourism losses and water treatment/testing costs) that could be attributed to the dairy industry. While a number of factors contribute to BGA outbreaks (such as light, turbidity and temperature), the one important factor that farmers directly contribute to is the level of nutrients (nitrogen and soluble phosphorus) in the water.

As mentioned earlier, there are two basic approaches for attempting to reduce the probability of outbreaks of BGA and the associated economic losses: the reduction of nutrient loads into the water system, and increasing water flows at critical times (flow regulation) (Kennedy, 1997). Because BGA outbreaks occur in years of low water flow, the contribution to nutrient levels at these times was used as the basis for determining dairy farmers' contribution to BGA impacts.

Figures presented earlier show that the annual load of phosphorus transported to the river via the drainage represents approximately 19.6% of the total river load in a dry year and 2.8% of the total river load in a wet year, while the annual load of nitrogen transported to the river via drainage represents 12.2% of total river load in a dry year and 1.7% of total river load in a wet year. While it is known that both nitrogen and phosphate contribute to BGA outbreaks, the relationship between the ratios of nitrogen and phosphorus and BGA outbreaks are not well understood, and therefore an average of these two figures was taken and used in the model as the percentage contribution of the dairy industry to BGA outbreaks, and subsequently, BGA outbreak related costs.

Thus the equation for the value of the loss of tourism to this region becomes:

$$Ct = (vt + tb)fbg \times \%td \times \%dc, \qquad (6\text{-}2)$$

where Ct = cost to tourism of dairy effluent impact ($), vt = value of tourism to this region ($), $\%tb$ = per cent loss of value of tourism to the broader community ($), fbg = frequency of blue-green algae outbreak per hundred years, $\%td$ = percentage drop in tourist income it causes ($), $\%dc$ = per cent of costs associated with the dairy swamps ($).

6.1.2.3 Costs to domestic water quality

When BGA outbreaks occur it is necessary to test the water and to treat it with a range of chemicals including activated carbon, chlorine and aluminium in some regions, and in other cases for clean water to be trucked to areas where algae make the water unpotable. These costs are accounted for in the model (see Appendices 3 and 4). The human health costs associated with cryptosporidium in this region have not been assessed, and currently SA Water does not UV treat water for domestic consumption.

6.1.2.4 Costs to wetland functional impacts

While it is expected that the farmers' dairy effluent causes additional environmental problems, it is not possible to assess these impacts in this study because of the lack of research data.

6.1.2.5 Costs of irrigation

The government determines the repair and maintenance costs that have been used in this thesis, with the farmers paying a percentage of these costs on a per hectare basis. All costs and benefits occur every year, as presented in Table 6-1.

In summary, the NPV for the Status quo situation can be written as:

$$\sum_{t=1}^{25}(\Pi_t - (\partial_t + \vartheta_t))/(1+r)^t \text{ ,} \qquad (6\text{-}3)$$

where: $\partial_t = Cr_t + Cgr_t$, $\vartheta_t = Ct_t + Cw_t + Cbg_t$, Π_t = current value of production (\$), Cr_t = farmers' repair, maintenance and capital costs (\$), Cgr_t = government repair, maintenance and capital cost (\$), Ct_t = tourism loss due to dairy effect on algae (\$), Cw_t = water quality testing costs ($), Cbg_t = blue-green algal outbreak costs associated with dairy industry (treatment and transport costs) ($).

TABLE 6-1. YEARS THAT COSTS AND BENEFITS OCCUR AND THE PERCENTAGE OF TOTAL COSTS AND BENEFITS FOR STATUS QUO VARIABLES

Benefit Variable	
Individual variables	Π
Years benefit occurs	1–25
Per cent of total benefits	1.0

Cost Variable	∂		ϑ		
Individual variables	*Cr*	*Cgr*	*Ct*	*Cw*	*Cbg*
Years cost occurs	1–25	1–25	1–25	1–25	1–25
Per cent of total costs	61.53	8.47	28.99	0.23	0.78

6.1.3 Results

While the Status quo situation for dairy farming on the swamps shows that the dairy industry is receiving substantial benefits from milk production from the situation as it stands (Table 6-2), the problems remain of the inefficient use of irrigation water and of water pollution from dairy effluent run-off.

TABLE 6-2. STATUS QUO FARMER AND COMMUNITY INCOME, COSTS AND BENEFIT/COST RATIO FOR GOVERNMENT-OWNED IRRIGATION AREAS

	Status quo Dairy Farming ($Million)	Per year ($Million)
PV Total benefits	111.70	6.81
PV Total costs	24.75	1.51
NPV	**86.96**	
Community BCR	4.51	

6.1.3.1 Farmer and government costs

A breakdown of the benefits and costs associated with dairy farming on the swamps is presented in Table 6-3. Currently, the only cost farmers pay to the government is $270 per hectare for the use of the irrigation scheme, i.e., approximately $0.93 million in total per year. The government costs associated with the dairy swamps total $0.58 million per year. Twenty-two % ($0.13 million) arises from the repair, maintenance and capital costs ($37.22/ha/year) the government, as owners of the irrigation scheme, pays. The other 78% of the costs ($0.45 million) are environmental externalities resulting from dairy effluent drainage from the land the irrigation scheme services, i.e., $132/ha per year.

TABLE 6-3. BREAKDOWN OF COSTS AND BENEFITS TO FARMERS AND THE COMMUNITY FROM DAIRY FARMING ON THE LOWER MURRAY SWAMPS

	Status quo Dairy Farming NPV ($Million)	Per year ($Million)
PV Farmer benefits	111.70	6.81
PV Government benefits	–	–
PV Total benefits	111.70	6.81
PV Farmer costs	15.23	0.93
PV Government costs	9.52	0.58
PV Total costs	24.75	1.51
NPV	**86.96**	–
Farmer BCR	7.34	–
Government BCR	–	–
Status quo BCR	4.51	–

6.1.3.2 Polluter/User pays

If farmers were held responsible for the impact of the dairy effluent and had to compensate the government for their effect on tourism, their costs would rise to over $1 million per year, (PV $7.42 million increase) and their income/cost ratio would fall to 4.93 (Table 6-4). Alternatively, if farmers were held responsible for the government costs associated with the repairs and maintenance of the irrigation scheme and were to compensate the government for the impact of the dairy effluent on tourism, their costs would rise to $1.5 million per year (PV $24.75 million) and their income/cost ratio drop from 7.34 to 4.51.

TABLE 6-4. CHANGE IN FARMERS' COSTS IF FARMERS PAY GOVERNMENT COSTS ASSOCIATED WITH THEIR INDUSTRY

	NPV ($Million) Total costs	Cost/year ($ Million)	Ratio income/ costs
Farmers pay existing costs	15.23	0.93	7.34
Farmers internalise pollution costs	22.65	1.06	4.93
Farmers internalise pollution and infrastructure costs	24.75	1.51	4.51

6.2 Part IIa – Rehabilitation with either Pipes or Channels

Numerous figures and equations combine to form the summary equations presented in this section. Details for the determination of the large number of individual components that make up these equations can be found in Appendix 4, sections 4.3 and 4.4. All the variables and sources of information can be found in Appendix 3.

In order to determine and quantify the benefits that could arise from management and structural (rehabilitation) changes to the irrigation scheme of the dairy swamps it was necessary to determine the causes of the nutrient run-off problem and then identify management and rehabilitation solutions to address these causes.

6.2.1 Introduction

6.2.1.1 Identifying causes of effluent run-off

The four most commonly cited reasons for the high quantity of nutrients being present in the drainage water are:

- institutional (property rights) – farmers on government-owned swamps have no responsibility for drainage pumping costs and therefore there is no incentive for farmers to restrict the amount of water that flows on to their land);
- technical – the poor condition of the irrigation scheme itself (i.e., sluices, channels etc.);
- the undulating nature of the pastures, and
- the lack of metering of irrigation water use.

Whittle and Philcox (1996b) compared the drainage from privately owned swamps which had been rehabilitated and which were accountable for the volumes of irrigation water used with government ones which had not been rehabilitated and were not accountable for water use. In all other respects the swamps were the same.

Their figures showed a significant difference between the drainage generated per hectare from government-owned and privately owned irrigation systems. Government swamps generate approximately 20 ML/ha as against 7 ML/ha on private swamps. This is then reflected in the nutrient load exported from these areas. Government areas export approximately 11 kg/ha of phosphorus (P) and 54 kg/ha of nitrogen (N). Private areas export approximately 3 kg/ha of P and 18 kg/ha of N by contrast. At the same time, the private swamps have the advantage of increased production, reduced watering time and water use and improved water use efficiency (Watson and Cole, 1972; Murray and Philcox ,1995).

The difference between these two areas could be explained by two related factors:

- a higher number of private irrigators have rehabilitated their properties (i.e., smoothed out the uneven soil surface) by 'laser levelling', and
- private irrigators are responsible for the cost of pumping drainage from their swamp, therefore the opportunity to reduce these costs is an incentive for the greater adoption of laser levelling (Whittle and Philcox, 1996b).

The problem of high irrigation losses due to uneven soil surfaces is not unusual in the Murray Basin. Surface flooding, either of bays (border check) or of furrows, is the most common irrigation method in the Basin. As noted by Harrison (1994), the efficiency of surface irrigation can be poor where the soil surface is uneven and of the wrong slope. Slow water movement down shallow slopes and poor drainage can cause waterlogging and restrict plant growth, while water losses either from run-off and/or deep seepage are often substantial.

However, in other parts of the Murray Basin land forming and laser grading, to provide the desired slope and smooth finish to the soil surface, have simplified management and improved flood irrigation. Much greater efficiency of irrigation is now possible when new layouts are used in conjunction with high flow rates and recycling of drainage water. While some farmers on the dairy swamps, particularly those on private swamps, have undertaken some laser levelling of their paddocks, the majority has not, for several reasons:

- the costs of laser levelling are high, and production is lost while the earth works are undertaken;
- some soil types are not suitable for levelling;
- in many cases the existing irrigation scheme requires substantial and expensive rehabilitation so that sluice openings and pump sitings are compatible with lasered ground, and
- property rights: farmers on government-owned swamps do not own the irrigation infrastructure so do not have the option or incentive to undertake changes to the system required for compatibility with lasered land.

Considerable reduction in nutrient levels leaving reclaimed swamps in the drainage water can be achieved through:

- improvements in management practices on-farm, including adoption of irrigation scheduling;
- management of fertiliser application, and
- minimisation of surface run-off especially following the application of fertilisers (Murray and Philcox, 1995).

However, for most farmers the undulating nature of their pastures (the land needs levelling) and the poor condition of the existing irrigation scheme mean that substantial reduction in drainage water is unlikely. Without this reduction, high nutrient loss will continue as the large volumes of irrigation water crossing the paddock wash animal waste and applied fertilisers into the river.

6.2.1.2 Identifying management and rehabilitation solutions

Having established the cause of the nutrient pollution losses and the economic impacts, it was now important to determine the remediation options available, and then for the costs and benefits of these options to be determined.

Critically, the relationship between farmers, pollution levels and abatement costs is somewhat unusual, and does not follow the traditional marginal abatement cost curves as presented by Hanley *et al.* (1997). This is because the level of pollution entering the river is predominantly related to the geography of the swamp being irrigated and the location of the existing inlet structures and drains. For this problem there are only two options:

- removing cows from the swamp, or
- changing the irrigation management regime and rehabilitating the entire irrigation system so that drainage water is minimised.

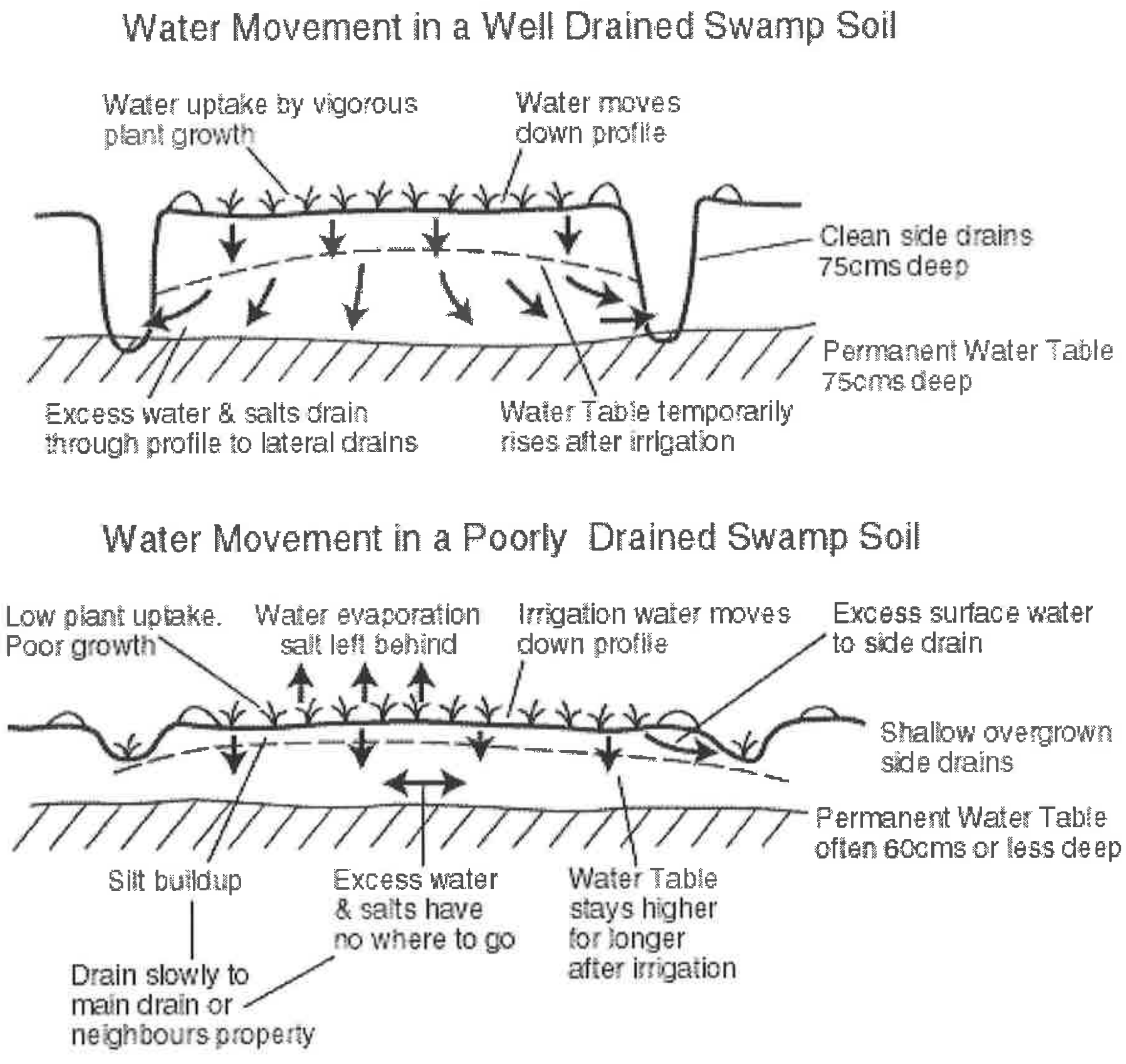
The effective reduction of run-off and nutrients from the dairy swamps thus requires:

- best management practice by farmers in conjunction with laser levelling of pasture swamps;
- rehabilitation/replacement of the existing irrigation scheme, and (possibly)
- construction of wetlands to filter remaining drainage.

6.2.1.3 Laser levelling and best management practice

As mentioned above, the potential benefits of laser levelling in the form of increased production, reduced watering time, reduced water use and improved water use efficiency have been well documented (Watson and Cole, 1972; Patto, 1988; Philcox and Scown, 1991; Philcox *et al.*, 1992). These benefits are illustrated in Figure 6-1, which shows how rehabilitated swamps can improve drainage and pasture growth.

FIGURE 6-1. WATER MOVEMENT IN WELL AND POORLY DRAINED SOILS



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The most recent work undertaken by Murray and Philcox (1995) showed that where irrigation of a typical rotation of 18–21 days was used on lasered and non-lasered sites, the lasered sites produced 49% more dry matter than the non-lasered sites. They also found that newly established pastures produced 67% more DM on lasered sites when compared with non-lasered ones, and that there was a 39.4%.reduction in the total number of seasonal hours required for irrigation on the lasered sites. In the thesis model these findings are reflected in increased farm income and decreased labour costs.

Thus, farmers on lasered ground spent less time watering their pastures, less water was used, and yet production (dry matter) was higher. With reduced volumes of water being used there is reduced drainage run-off volumes and consequently the reduced potential for removal of material containing nutrients and bacteria from the paddock surface and the soil profile (Murray and Philcox, 1995). In the model, the reduction in nutrient loss is reflected in a reduction in fertiliser costs.

Laser levelling of paddocks is consistent with the best management practices recommended by dairy farm advisers for increased production, and also addresses the problems of nutrient run-off that have an impact on the River Murray and the tourism industry. However, laser levelling only creates the potential to water more efficiently – farmers must still strive to turn the water off at the right time to minimise surface run-off and avoid expensive fertiliser losses, lost production through waterlogging, and poor pasture growth.

Waterlogging affects plants by depriving them of oxygen resulting in poor photosynthesis so that a pasture waterlogged for one to two days will lose up to 25% production. Clover will take three to four days to start growing after waterlogging, while ryegrass will not grow while waterlogged. In contrast, paspalum is reasonably tolerant of the long periods of waterlogging currently required to ensure that water flows across the whole paddock. Therefore, pastures that are continually waterlogged will have increasing amounts of weeds and paspalum while desirable pasture plants will gradually disappear (LMIAG, 1999).

Best management practice therefore requires a change in the pasture species paspalum, which is currently being used. If laser levelling is adopted, waterlogging is prevented and farmers are better able to match their watering routines to these more productive species. Philcox (1996) found an increase in dry matter of up to 30% in white clover/ryegrass pastures when laser levelling was used in conjunction with an optimal irrigation routine.

6.2.2 Methodology

The current irrigation scheme is owned by the government and was designed between 1881 and 1921 to take advantage of the natural features of the swamps (their backward slope) rather than to optimise efficiency. Serious problems exist which make efficient irrigation difficult. The irrigation layout on some swamps seriously limits the potential for new technologies and improvements in irrigation management, e.g., supply and drainage channels that are poorly located and inadequately maintained and inappropriate paddock widths and/or lengths. Leaking, inappropriately located and poorly maintained structures, which cause water wastage, waterlogged pastures and inefficient watering, will also restrict the extent of improvement of irrigation (Whittle and Philcox, 1996). Thus, as laser levelling alone will not achieve the required results, the large-scale on-ground works required to make paddocks suitable for efficient irrigation, combined with the implementation of efficient watering structures and channels, can only be achieved as part of a joint effort between the government and the farmers under the present ownership scheme.

The option of complete rehabilitation is therefore considered in this thesis. Complete rehabilitation can be achieved by using either a piped or channelled system. However, even if complete rehabilitation were to occur, the reduced irrigation run-off to the river would still contain some nutrients, hence the need to examine the inclusion of constructed wetlands to be used in conjunction with the rehabilitated scheme.

6.2.2.1 Rehabilitation with Pipes

6.2.2.1.1 Identifying benefits and costs

This part of the thesis examines the costs and benefits involved in rehabilitation of the irrigation scheme using the best possible irrigation technology presently available. This is referred to as 'Piped' rehabilitation, and involves transfer of ownership of the irrigation scheme to the farmers. The government will therefore no longer have responsibility for the costs of the scheme, which will now fall to the farmers.

Rehabilitation involves large-scale on-ground works, the movement of current irrigation infrastructure such as drains, channels, sluice gates and pumps, and replacement with new structures on land that has been levelled for more efficient water flow. The undertaking of these works will allow more efficient use of water and prevent waterlogging, thereby allowing an increase in pasture growth. Costs are entered as annuities, but are discounted to present value figures for undertaking the economic analysis.

When undertaking this rehabilitation, farmers must first take some land out of production so that the land can be levelled. Farmers who have already undertaken this process have stated that by undertaking levelling of portions of their land in winter when feed supplies are plentiful there will be sufficient pasture regrowth on the lasered land by summer when it is required. In this way production is not temporarily lost in the year that the land is laser levelled. Final milk production is expected to be 40% greater than current figures due to less waterlogging, better pasture species, improved watering regimes, increased stock carrying capacity, and income from the area previously used for irrigation channels (see Appendix 4.3). Although there is no increased production in the first year, production increases over the next five years at the rate of 8% until full production is reached, and then continues at this rate until year 25.

The increase in grass growth means additional feed costs are reduced by 10% as rehabilitation progresses. A further benefit of rehabilitation is a decrease in the time and labour required by farmers for irrigation scheduling/management and stock movement. Farmers estimate that this will result in a decrease in labour costs of $1,500 per year per farm after full rehabilitation.

A reduction in nutrient loss from the land means also less need for fertilizer and thus fertilizer costs decline by 40% as rehabilitation progresses. A summary of the annual benefits to farmers arising from rehabilitation is presented in Appendix 4.

At the same time, the amount of drainage containing nutrients that favour blue-green algae also declines. This is represented in the model by a gradual increase in tourism value (reduced losses) as the incidence of blue-green algae decreases.

6.2.2.1.2 Valuing benefits and costs

The key components in this option are the increase in farmer income, the cost of rehabilitation (for both farmers and government under a cost-sharing arrangement), and the increased repair, capital and maintenance costs associated with the new, farmer-owned irrigation scheme.

While farmers also benefit from reduced feed, fertiliser and labour costs σ, these are minimal benefits compared with the expected increase in production (see Appendix 4.3 for details).

The government benefits arise from a reduction in effluent entering the river and the resultant drop in dairy-related tourism and water treatment/testing costs. While these benefits are small compared with the increase in farmer production, they represent a significant drop in externality impacts. The only other benefit to the government of this option is that it no longer has to pay a share of the repair and maintenance costs.

6.2.2.1.3 Benefit of increased farm income

Farmers who have already lasered their farms have found that to ensure no significant loss of income it is best to laser approximately 20% of the farm per year for five years. Included in this increase is the area of land that was previously in channels, that has now been filled in for pasture use. Note that no increase in production occurs in the first year. Thus the equation for the production + increase per year for five years becomes:

$$\Pi_{p,t} = \begin{cases} \Pi(1+\%ip)^t + ia(ih*t) & t = 1,\ldots,5 \\ \Pi(1+\%ip)^6 + ia(ih*t) & t = 6,\ldots,25 \end{cases} \qquad (6\text{-}4)$$

where Π_p = Rehabilitation production (\$), *ip* = increased production/yr for five years, *ia* = increased area from filled channels (ha), *ih* = \$/ha dairy income year 1.

6.2.2.1.4 Benefit of reduction in externality impact costs.

These costs are determined by a gradual reduction in tourism and water treatment and testing costs as the volume of effluent entering the river decreases with rehabilitation over the five years it will take for farmers to rehabilitate their land. Thus the equation for reduction in tourism impact costs becomes:

$$Ctp_t = \begin{cases} Ct(1-\%dt)^t & t = 1,\ldots,4 \\ Ct(1-\%dt)^5 & t = 5,\ldots,25 \end{cases}, \qquad (6\text{-}5)$$

where *Ctp* = Tourism loss due to dairy effect on algae ($), *Ct* = Status quo Tourism loss due to dairy effect on algae ($), *dt* = percentage drop of 40% over five years ($).

Reductions in water treatment and quality costs are determined in the same way as tourism, above. (See Appendix 4 for details.)

6.2.2.1.5 Cost of rehabilitation.

Consulting Engineers, Kinhill, provided the costs associated with rehabilitation. These costs include: river channel, back supply channel, drainage/salt channel, Highland irrigation, off-farm survey/design/contingency costs, monitoring costs, and on-farm survey/design/contingency costs. Thus the equation for farmers' costs becomes:

$$Cfp = rc + bc + ds + hi + of + mc + onf, \qquad (6\text{-}6)$$

where *Cfp* = Farmer costs of rehabilitation ($), *rc* = river channel costs ($), *bc* = back supply channel costs ($), *ds* = drainage/salt channel costs ($), *hi* = Highland irrigation costs ($), *of* = off-farm survey/design/contingency costs, *mc* = monitoring costs ($), *onf* = On farm survey/design/contingency costs ($).

Rehabilitation costs for the government are determined in the same manner as for farmers, with the percentage that farmers and government pay determined by the cost-sharing arrangement.

6.2.2.1.6 Repair, capital and maintenance costs

These costs have been determined to be \$1.11 million per year. This figure represents 10% of the capital costs of rehabilitation (less the civil engineering works). Thus the equation for farmers' repair capital and maintenance costs of the new scheme becomes:

$$\varsigma = (rc + bs + ds + hi) \text{x } 10\% \qquad (6\text{-}7)$$

where ς = capital, repair and maintenance costs (\$), rc = river channel costs (\$), bs = back supply channel costs (\$), ds = drainage/salt channel costs (\$), hi = highland irrigation costs (\$) x 10%

The costs associated with laser levelling of farmers land (on farm works) are not included in this equation as once established, farmers will not need to further level pasture land and any ongoing costs will be related to normal pasture production.

In summary the NPV for the Piped rehabilitation option can be written:

$$\sum_{t=1}^{25}((\Pi_{p_t} + \sigma_t) - (\varsigma_t + \tau_t + \upsilon_t))/(1+r)^t \ , \qquad (6\text{-}8)$$

where: $\Pi_{p\,t}$ = increased value of production (\$), $\sigma_t = Bl_t + Bf_t + Bfr_t$, Bl_t = reduced labour costs (\$), Bf_t = reduced feed costs (\$), Bfr_t = reduced fertiliser costs (\$), ς_t = farmer capital, repairs, and maintenance costs (\$), $\tau_t = Ctp_t + Cgw_t + Cbgp_t$, Ctp_t = tourism loss due to dairy effect on algae (\$), Cgw_t = Water quality costs (\$), $Cbgp_t$ = blue-green algal outbreak costs associated with dairy industry (\$), $\upsilon_t = Cfp_t + Cgp_t$, Cfp_t = farmers costs of rehabilitation (\$), Cgp_t = government costs of rehabilitation (\$).

TABLE 6-5. YEARS THAT COSTS AND BENEFITS OCCUR AND THE PERCENTAGE OF TOTAL COSTS AND BENEFITS FOR PIPED REHABILITATION VARIABLES

Benefit Variable	Π_p	σ		
Individual variables	Π_p	*Bl*	*Bf*	*Bfr*
Years benefit occurs	2–25	2–25	2–25	2–25
Per cent of total benefits	88	1	7	4

Cost variable	ς	τ			υ	
Individual variables	ς	*Ctp*	*Cgw*	*Cbgp*	*Cfp*	*Cgp*
Years cost occurs	1–25	1–25	1–25	1–25	1–10	1–5
Per cent of total costs	37.82	7.39	0.06	0.20	54.44	0.09

6.2.2.2 Rehabilitation with Channels

6.2.2.2.1 Valuing benefits and costs

This option examines the costs and benefits involved in rehabilitation of the irrigation scheme using a cheaper, modified version of the Piped rehabilitation scenario. This is referred to as 'Channelled' rehabilitation, as channels will be used instead of pipes to access water from the river.

Channelled rehabilitation is basically the same as the Piped rehabilitation presented above expect that instead of using a piped irrigation scheme, this option uses channels, which come at a lower cost. This option involves large-scale on-ground works, the movement of current irrigation infrastructure such as drains, channels, sluice gates and pumps, and their replacement with new structures on land that has been levelled for more efficient water flow.

Once again farmers will be the owners of the scheme and will now be responsible for the ongoing repairs and maintenance and capital costs rather than sharing the costs with the government. These costs are determined to be $811,091 per year. This figure represents 10% of the capital costs of rehabilitation (less the civil engineering works).

The rehabilitation and maintenance costs of this option are considerably less than for the Piped irrigation scheme presented earlier. The benefits of this scheme are the same as those for the Piped option, with the exception of a slightly smaller increase in production as more land is taken up with irrigation channels. The significant difference between these two options is the reliability of water supply – if river levels are low, water may not be available under this rehabilitation option.

In summary the NPV for the Channelled rehabilitation option can be written:

$$\sum_{t=1}^{25}((\Pi_{ct}+\sigma_t)-(\varsigma_t+\tau_t+\upsilon_t))/(1+r)^t \ , \qquad (6\text{-}9)$$

where: Π_{ct} = increased value of production, $\sigma_t = Bl_t + Bf_t + Bfr_t$, Bl_t = reduced labour ($), Bf = reduced feed costs ($), Bfr_t = reduced fertiliser costs ($), ς_t = farmer, repairs, maintenance and capital costs ($), $\tau_t = Ctc_t + Cgw_t + Cbgc_t$, Ctc_t = tourism loss due to dairy effect on algae, Cgw_t = water quality costs, $Cbgc_t$ = blue-green algal outbreak costs associated with dairy industry, $\upsilon_t = Cfc_t + Cgc_t$, Cfc_t = farmers costs of rehabilitation, Cgc_t = costs of rehabilitation.

TABLE 6-6. YEARS THAT COSTS AND BENEFITS OCCUR AND THE PERCENTAGE OF TOTAL COSTS AND BENEFITS FOR CHANNELLED REHABILITATION VARIABLES

Benefit Variable	Π_c	σ		
Individual variables	Π_c	*Bl*	*Bf*	*Bs*
Years benefit occurs	1–25	2–25	2–25	2–25
Per cent of total benefits	88	1	7	4

Cost variable	ς	τ			υ	
Individual variables	ς	*Ctc*	*Cgw*	*Cbgc*	*Cfc*	*Cgc*
Years cost occurs	1–25	1–25	1–25	1–25	1–10	1–5
Per cent of total costs	36.15	9.78	0.08	0.26	53.61	0.12

6.2.3 Results

Rehabilitation of the Lower Murray dairy swamps is extremely complex, principally because it is the government that owns the irrigation scheme, while farmers own the land. This thesis therefore proposes a collective agreement between the government and all dairy farmers on the government controlled dairy swamps. This agreement would include a cost-sharing arrangement whereby the government shares the costs with the farmers of rehabilitating the farmers' land and the government irrigation scheme. In return farmers will assume responsibility and ownership of the irrigation scheme.

For farmers who are debt free, near retirement, and who do not want to pass their farm onto their children, the option of remaining with the 'Status quo' may appear attractive. However, it is not the purpose of this thesis to address the requirements of individual farmers, but rather to consider the impacts on water quality of a complete change in land use for this area, and therefore this thesis assumes that all farmers will be involved in rehabilitation of the dairy swamps. It is important to note that farmers cannot undertake this rehabilitation alone – the government owns the irrigation scheme and thus rehabilitation must be a joint initiative.

As indicated above, rehabilitation of the dairy can be done using pipes or open channels. An early analysis of these two options clearly shows that the Channelled option is unlikely to meet farmer water needs when River Murray water levels are low and water cannot be syphoned into the irrigation channels. Therefore only the results for the Piped option are presented here. Results for the Channelled option, and a comparison of the returns for both options, are presented in Appendix 6.

Both options include farmers taking over ownership of the irrigation scheme from the government, and thus becoming responsible for 100% of its repair, maintenance and capital costs.

It is assumed that the government will retain responsibility for the water monitoring costs associated with the scheme, and the management of government riverine areas associated with the swamps, as has happened in the privatisation of similar irrigation schemes.

6.2.3.1 Piped rehabilitation

This scheme essentially consists of 'off-farm' and 'on-farm' works. The on-farm works consists of the laser levelling and resowing of pasture, the remainder of the rehabilitation being off-farm. Both off- and on-farm works require substantial capital outlay, with Table 6-7 showing the costs of the Piped rehabilitation option. The complete success of this scheme is dependent on rehabilitation of both sectors.

Under this option the front supply channel is piped, the back supply and salt drains are refurbished, and the highlands are supplied with water via a ring main from the river. All channels are fenced and meters installed. At times the level of the River Murray drops due to the closing of barrages, low rainfall, or high winds blowing water away from irrigation inlets. To allow for these low river levels, a pumped supply system is included. All land is laser levelled and resown with modern pasture species.

TABLE 6-7. COSTS OF PIPED REHABILITATION OPTION

Total construction cost ($Million)	Off-farm construction costs ($Million)	On-farm construction costs ($Million)
24.78	19.21	5.57

The benefit to the farmers of implementing this scheme is an increase in milk production – once rehabilitation is underway, farmers expect to have an 8% increase in income each year for five years – plus reduced feed and fertiliser costs. (No increase in production occurs in the first year due to pastures being laser-levelled and unsuitable for grazing). There are also some small benefits in reduced maintenance costs from having a pipe instead of an open channel at the front of the scheme, and a small increase in production from the land not now taken up by a channel. The farmers have ownership and control of the scheme and guaranteed water for the future even when river levels drop.Table 6-8 shows the costs and benefits of this option when compared with the Status quo, assuming farmers pay 100% of the rehabilitation costs.

TABLE 6-8. COSTS AND BENEFITS OF PIPED REHABILITATION OPTION

	Status quo $(Million)	Piped Rehabilitation Farmers pay 100% costs ($Million)	Net return Farmers pay 100% costs ($Million)
PV Total benefits	111.70	170.07	58.37
PV Total costs	24.75	48.66	23.92
NPV	**86.96**	**121.41**	**34.45**
Community BCR	4.51	3.50	2.44

The benefits to the government of this rehabilitation option come in the form of a 60% reduction in externality associated costs associated with effluent entering the river, and the removal of all the repair and maintenance costs associated with the irrigation scheme. Compared with farmers, the benefits the government receive from undertaking this scheme are small, ($5.80 million versus $58.37 million). Of the government's benefits, $3.70 million are associated with the reduction in pollution impacts. The remainder ($2.10 million) occur because the government is no longer responsible for the repairs, maintenance and capital costs of the irrigation scheme. The only new cost that the government incurs with this rehabilitation option is associated with farmer training (PV $43,300). The split of costs between the farmers and the government are presented in. Column B assumes farmers pay all the costs associated with rehabilitation, with Column C showing the net return of this option.

However, it must be remembered that it is the government which owns the irrigation scheme, and it is unlikely that farmers would be willing to bear all the costs associated with the scheme's rehabilitation even if the benefits to the government are small. Therefore Column D shows the costs and benefits to government and farmers if each were to pay a proportional cost share for this project (i.e., farmers and the government would be paying the same proportion of their costs as the benefits they receive from undertaking this rehabilitation option). Column E shows the net return with proportional cost share.

TABLE 6-9. SPLIT OF COSTS AND BENEFITS BETWEEN FARMERS AND THE GOVERNMENT AFTER PIPED REHABILITATION

	A	B	C	D	E
	Status quo ($Million)	**Farmers pay 100% costs ($Million)**	**Net return Farmers pay 100% costs ($Million)**	**Shared costs ($Million)**	**Net Return Shared costs ($Million)**
PV Farmer benefits	111.70	170.01	58.37	170.01	58.37
PV Government benefits	–	–	–	–	–
PV Total Community benefits	111.70	170.01	58.37	170.01	58.37
PV Farmer costs	15.23	44.90	29.67	39.14	23.92
PV Government costs	9.52	3.77	– 5.75	9.52	–
PV Total Community costs	24.75	48.66	23.92	48.66	23.92
NPV	**86.96**	**121.41**	**34.45**	**121.41**	**34.45**
Farmers BCR	7.34	3.79	1.97	4.34	2.44
Government BCR	–	–	∞	–	1.00
Community BCR	4.51	3.50	2.44	3.50	2.44

These figures show that the government would have to pay only 21.7% of all costs. The farmers' BCR from this change in land use would then be 2.44. As the government is interested in maximising income for all the community, not just for the farmers, as long as farmers make a profit from the rehabilitation option (farmers' BCR is 1.97 even when paying 100% of the costs), then the government is unlikely to be interested in further subsidisation of farmers' costs.

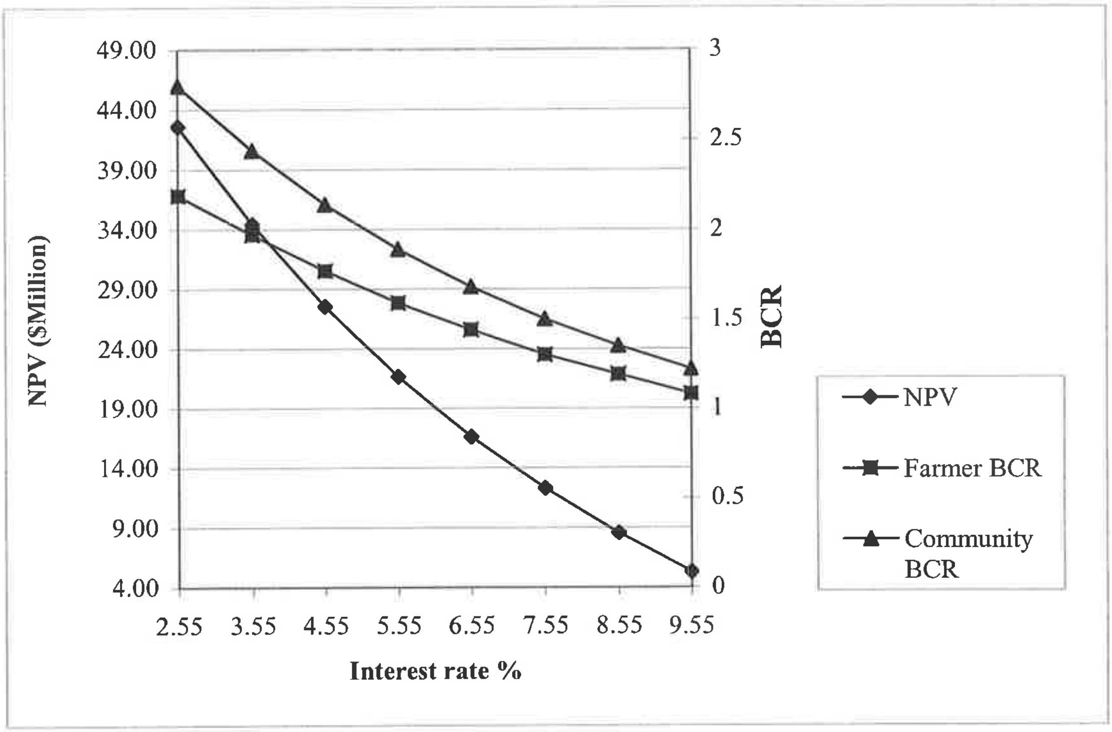
It is important to note that there are ongoing pollution problems valued at approximately PV $3.7 Million that are not remedied by this project, and thus pollution impacts still occur.

6.2.3.2 Sensitivity analysis

Interest rates

While an increase in the interest rate affects the profitability of this option, even if real interest rates rise to nearly 10%, rehabilitation is still profitable, Figure 6-2. The interest rate change has a marginally greater effect on the community's BCR than on the farmers'. This is because the government is not paying any of the costs associated with rehabilitation, but their income drops as interest rates rise. In contrast farmers income and costs are affected by a rise in the interest rate and therefore, in proportion to the government their drop in BCR is less.

FIGURE 6-2. EFFECT OF A CHANGE IN INTEREST RATE ON THE NPV AND BCR OF PIPED REHABILITATION OPTION. FARMERS PAYING ALL REHABILITATION COSTS



6.2.3.3 Including constructed wetlands for effluent control

6.2.3.3.1 Identifying benefits and costs

Numerous figures and equations combine to form the summary equations presented in this section. Details for the determination of the large number of individual components that make up these equations can be found in Appendix 4, section 4.5. All the variables and sources of information can be found in Appendix 3.

Constructed wetlands have been defined by Hammer and Bastian (1989) as a designed and constructed 'complex of saturated substrates, emergent and submergent vegetation, animal life and water that simulated natural wetlands for human use and benefits'.

The potential of constructed wetlands to reduce bacteria in wastewater is high, as reported by various authors (Gersberg *et al.*, 1989; Watson and Hobson, 1989; Roser and Bavor, 1995; Simpson and Woolley, 1995). For the agricultural sector constructed wetlands should be considered as part of an overall, integrated plan including adoption of best management practices on-farm, to reduce nutrients in the drainage water and thereby reduce the impact on receiving water, rather than the total solution to the problem (Cottingham, 1995). They are currently used around the world as a low cost, easily operated and efficient treatment for a variety of wastewaters, and can be seen in Adelaide at Barker Inlet, Greenfields, Salisbury and Cross Road. Further details of the effectiveness of wetlands for effluent control can be found in Appendix 2.

There are many inherent problems inhibiting the use of wetlands for controlling water quality for wastewater treatment, and these have been outlined by Mitchell (1995) as:

- Initial difficulties in determining the process involved in phosphorous (P) dynamics;
- Inadequate design and operation mainly relating to hydraulic short circuiting preferential flow paths in/around the root zone that can create a mix of retention times. This is difficult to avoid with continuous flow systems. Intermittent flow enables better management;
- Deciding whether to 'mimic or modify' is to take an ecological or engineering approach;
- Difficulties have been experienced in emulating the results achieved in bucket size trials to full scale wetlands;
- Uncertainty about selection of plant species and about the role of vegetation in constructed wetland system;
- Water quality criteria – standards are often set unrealistically high and do not focus on the ecological impacts or on any cost–benefit analysis of achieving the higher standard of treatment, and

- The issue of management of intellectual property resulting from the patenting of constructed wetland scientific developments, which restrict sharing of knowledge and delay the progress of research.

All these points indicate the complexity of the wetland ecological system. As mentioned earlier, the design and construction of wetlands must allow for input from a range of disciplines e.g., ecologists, engineers, biologists, hydrologists and economists (Hammer, 1992; Roser and Bavor, 1995; White, 1995; Simpson, 1995). All of these disciplines were again involved in the sourcing of data for use in this thesis which considers constructed wetlands for effluent control as part of an overall, integrated plan including adoption of best management practices on-farm, rather than the total solution to the problem.

Whittle and Philcox (1996a) studied the possibility of constructing a number of wetlands throughout the dairy swamps to handle the drainage water from irrigation before it was returned to the Murray. The wetland areas required for each swamp as determined by Whittle and Philcox are presented in Table 6-10. This table shows land area required with and without a 40% reduction in drainage due to rehabilitation changes (i.e., undertaking earthworks and making the necessary technical changes to fix up the irrigation and drainage scheme) and includes land areas required for earth works.

TABLE 6-10. AREA OF LAND REQUIRED FOR CONSTRUCTED WETLANDS WITH AND WITHOUT A 40% REDUCTION IN DRAINAGE WATER

Swamp	Wetland area no drainage change (ha)	Wetland area 40% drainage reduction (ha)
Burdett	.3.3	1.93
Cowirra	26.4	15.8
Jervois	25.0	54.6
Mobilong	23.7	14.2
Monteith	34.6	20.7
Mypolonga	127.5	76.5
Neeta	43.8	27.2
Pompoota	24.2	14.5
Wall Flat	47.7	28.6

Whittle and Philcox concluded that where possible 'unrated' and poorly productive land should be used for wetland construction, however some irrigation areas requirement for land for a constructed wetland may be too large to be practical without severe impact on the productive use of the area. For this reason the incorporation of constructed wetlands and 'weedy drains' (linear wetlands) should be considered as part of rehabilitation of the dairy swamps. A further important conclusion from their work was that water retention times would be variable, and dependent on irrigation intensity, which would result in quite variable volumes passing through the wetland. This may result in some wetlands drying out during the winter (non-irrigation) season, and for this reason management options that include the incorporation of river water may be required for the wetland to be maintained.

6.2.3.3.2 Valuing benefits and costs

The model developed for this thesis draws on the work of Whittle and Philcox (1996a) when determining the land area requirements and other requirements for including the option of constructed wetlands as a means of reducing nutrient run-off into the Murray. It applies the findings of Whittle and Philcox that these wetlands are able to further reduce effluent entering the river by 15%.

Both Piped and Channelled rehabilitation options are considered with and without constructed wetlands for drainage treatment. The majority of the benefits of this option arise from the expected drop in effluent entering the Murray, resulting in reduced externalities (tourism and water treatment/sampling costs), while the greatest cost associated with this option are for wetland construction.

6.2.3.3.3 Tourism

The Reduction in externality impact costs for tourism becomes:

$$Btv_t = \begin{cases} Ct(1-\%dt)^t & t = 1,\ldots,4 \\ Ct(1-\%dt)^5 & t = 5,\ldots,25 \end{cases} \qquad (6\text{-}10)$$

where Btv_t = reduction in tourism loss ($), Ct = Status quo Tourism loss due to dairy effect on algae x drop of 15% over five years. Tourism loss figures remain the same from five years on.

The total percentage drop effluent is 15% for Piped and Channelled rehabilitation options. The same equation form is used to determine the reduced water quality and algal outbreak costs (see Appendix 4 for details).

6.2.3.3.4 Wetland construction

Wetland construction costs for this option are substantial for two reasons: farmers must take some land out of production to allow for enough wetland area to treat dairy effluent, and constructed wetlands will be primarily constructed on unrated land which does not have existing levee banks or inlet/outlet structures to utilise. For this reason the earthworks component of this option are much greater than of other wetlands in this model. Planting costs are also substantial, even though the planting densities for this option are not quite as dense as those for domestic water filtration (it is expected that there will be some component of self-seeding from the river).

Thus the equations for total wetland construction for farmers and the government become:

$$Cfwc = hw \times wcp \times \%\text{ farmers cost share}, \qquad (6\text{-}11)$$

where $Cfwc$ = Wetland construction and planting ($), hw = land required for wetlands (ha), wcp = cost of wetland establishment ($), % farmers cost share = per cent of costs paid by farmers under cost-sharing agreement

Wetland costs for the government are determined in the same manner as for farmers, with the percentage that farmers and government pay determined by the cost-sharing arrangement.

In summary, the NPV of wetlands is represented by the following equation:

$$\sum_{t=1}^{25}((\phi_t)-(\zeta_t+\omega_t))/(1+r)^t\,, \qquad (6\text{-}12)$$

where $\phi_t = Btv_t + Brwc_t + Brbgw_t$, $\zeta_t = Cfwc_t + Cgwc_t$, $\omega_t = Cflp_t + Cglp_t$, Btv_t = reduced tourism loss due to dairy effect on algae, $Brwc_t$ = reduced water quality costs, $Brbgw_t$ = reduced blue-green algal outbreak costs associated with dairy industry ($), $Cfwc_t$ = farmers costs of wetland construction and planting ($), $Cflp_t$ = farmer lost production off wetland area ($), $Cgwc_t$ = government costs of wetland construction and planting ($), $Cglp_t$ = government lost production off wetland area ($).

TABLE 6-11. YEARS THAT COSTS AND BENEFITS OCCUR AND THE PERCENTAGE OF TOTAL COSTS AND BENEFITS FOR WETLAND VARIABLES

Benefits Variable	ϕ		
Individual variables	*Btv*	*Brwc*	*Brbgw*
Years benefit occurs	1–25	1–25	1–25
Per cent of total benefits	97	1	2

Cost Variable	ζ		ω	
Individual variables	*Cfwc*	*Cgwc*	*Cflp*	*Cglp*
Years cost occurs	1–10	1–10	1–25	1–25
Per cent of total costs	96	0	4	0

6.2.3.3.5 Results

The use of constructed wetlands is an extremely expensive option for effluent treatment. This is particularly so where rehabilitation of the scheme has already reduced effluent by up to 60%, and where wetlands will only reduce the remaining effluent by up to a further 15%.

Because on the reduced drainage leaving the Lower Murray dairy swamps after rehabilitation the area of wetlands required to handle the smaller water volume is 254 hectares. However, as can be seen from Table 6-12, while the government benefits from this option the farmers' BCR is negative, and it is farmers who must bear the wetland costs. Added to this, wetlands still allow 25% of the effluent to return to the river. The construction of wetlands capable of handling this effluent would take more farming land out of production and involve higher planting and earth works costs thus further reducing the viability of this option.

Table 6-12. Economic costs and returns of constructed wetlands for Piped rehabilitation (farmers paying 100% of costs)

Government Present value Benefits ($Million)	Farmer Present value Benefits $	Government Present value Costs ($Million)	Farmer Present value Costs ($Million)	NPV ($Million)	BCR Project
0.99	0	0	22.68	–21.70	0.04

6.3 PART IIB RETURNING THE BWHOLE AREA TO PERMANENT OR MANAGED WETLANDS

If the whole of the Murray dairy swamps were to be returned to either Permanent or Managed wetlands it would be necessary for farmers to relinquish their leases of the government-owned dairy pastures. Forty-five percent of farmers on the swamps are over the age of 45 (ABS, 1996), and many farmers have expressed a desire to walk away from the responsibility of the land (the value of the dairy swamp land itself is negligible when compared to the value of the water), and to sell the 13.92 ML of water per hectare associated with the land. A further 3.84ML of water has been allocated to all swamps for environmental land management (ELMA). ELMA is a government water allocation for each swamp, that cannot be sold and that must remain on the swamp regardless of the land use chosen by the swamp owner.

6.3.1 Permanent wetlands – Introduction

This option involves breaching the levee banks and allowing the whole area to return to the river as Permanent wetlands, as a result no dairy effluent will now enter the Murray. This in turn will remove the costs associated with the current system (detailed earlier) consisting of pollution-related tourism losses, domestic water quality and wetland functional impacts. It will also remove the costs associated with the existing irrigation scheme. The wetlands that develop will take on the environmental issues of the Murray.

The government has to enter the water market to purchase water to fill the Permanent wetlands, plus additional water to cover annual evaporation losses.

Highland farming land associated with these swamps would be retained by farmers for dryland production. Thus it is assumed that 93% of dairy income will be lost, with the remaining 7% of income continuing on the highland areas. The two local dairy factories have indicated that they will need to source milk from outside the region to keep the local factories running, resulting in an increased milk transport cost of 3 cents per litre when milk is trucked in.

This is the cheapest wetland option from a construction point of view as no rehabilitation costs are involved. The major benefit for farmers of this option is the ability to sell their irrigation water, while the social benefits result from:

- a reduction in irrigation drainage entering the Murray;
- a reduction in tourism losses;
- a reduction in algal outbreak costs, and
- a reduction in water treatment costs.

However, the costs of purchasing enough water for this option are substantial. Water must first be purchased on the open market to fill the wetlands, and then additional water must be purchased to account for the evaporation losses from the wetlands. The next most important cost is that of milk transport.

The disadvantage of these wetlands is that they would suffer from the same environmental degradation problems as other unmanaged wetlands, e.g., weeds, pollutants and (without fish screen) these areas would become home for European carp.

6.3.2 Methodology

6.3.2.1 Wetland benefits

Numerous figures and equations combine to form the summary equations presented in this section. Details for the determination of the large number of individual components that make up these equations can be found in Appendix 4, section 4.6. All the variables and sources of information can be found in Appendix 3.

The major benefit for the farmers comes from the sale of their irrigation water (13.92 ML/ha) on the open market (this water was previously used for dairy production).

$$\eta = T \times fwr \times rl, \tag{6-13}$$

where η = Income from water sale (\$), T = Price for water (\$/ML), fwl = water for sale by farmers (ML), rl = rated swamp land (ha).

The benefits of this option for the community arise from the removal of the costs associated with dairy effluent entering the Murray (ϑ) from equation (6–3).

$$\vartheta = Ct + Cw + Cbg,$$

where Ct = tourism loss due to dairy effect on algae (\$), Cw = water quality testing costs (\$), Cbg = blue-green algal outbreak costs associated with dairy industry (treatment and transport costs) (\$).

It is important to note that because these benefits are a reduction in the costs associated with the Status quo option, they are revealed when comparing this option of Permanent wetlands with the Status quo option.

The other important benefit comes from the value of water filtration by Permanent wetlands:

$$\Psi_p = \psi \times \delta \times \kappa, \quad (6\text{-}14)$$

where ψ = wetland filtration value (\$/ha/yr), δ = marginal utility of water, κ = area of Gov swamp land (ha)

6.3.2.2 Wetland costs

As mentioned earlier, the costs of purchasing enough water for this option are substantial. Water must first be purchased to fill the wetlands (ϖ). This water is purchased on the 'Temporary trade' market (this market allows the purchaser the right to use the amount of water purchased for a specified period of time, most usually one year), and then additional water must be purchased to account for the evaporation losses from the wetlands, χ. This water is purchased on the Permanent water trade market, as it required on a permanent basis to account for evaporation every year. Of these two components, water for evaporation is by far the largest cost. Thus the cost of the total water required μ becomes:

$$\mu = \varpi + \chi, \quad (6\text{-}15)$$

where ϖ is based on the area of the wetland and water required,

$$\varpi = \Delta \; x \rho \; x \, (\kappa - \Gamma/2), \quad (6\text{-}16)$$

where Δ = 7 ML (the volume of water per hectare to fill wetlands to 0.7 metre depth (ML)). This is based on:

1 ha = 10, 000 sq metres, 1 cubic metre = 1000 litres,

10,000 x 1000 = 10,000,000 = 10 ML to flood 1 ha to a depth of 1 metre. Therefore to flood 1 ha to a depth of 0.7 metre requires 7 ML.

ρ = price of water on temporary market (\$/ML)

κ = area of swamp land for Gov swamp (ha) (i.e., total area of land covered by government irrigation scheme. This includes both rated (irrigated) and unrated land).

$\Gamma/2$ = area of unrated land that would not be flooded (ha)

and χ is based on evaporations figures provided by the Bureau of Meteorology for the Lower Murray region, rainfall in the region and the ELMA component. ELMA is the volume of water allocated to each dairy swamp to assist in environmental land management. Thus the equation for the volume of water that must be purchased becomes:

$$\chi = (\Lambda - \mathrm{P} - ELMA) \text{ x } \mathrm{T} \text{ x } (\kappa - \Gamma/2), \qquad (6\text{-}17)$$

where Λ = Evaporation from wetlands (16.39 ML/year)

P = Rainfall (ML/year)

$ELMA$ = environmental water associated with this land (ML)

T = price of water for permanent trade (\$/ML)

Not all of the dairy swamp land would be flooded when the wetland is formed, as approximately half of the unrated land would be above the 0.7 metre water. These areas would provide natural islands and bird sanctuaries.

6.3.2.2.1 Milk transport

Should farmers on these swamps cease producing milk, both dairy factories have indicated that to meet factory requirements at Murray Bridge, they will simply truck milk in from neighbouring milk producers at a cost of 3 cents per litre. Thus the costs associated with milk trucking become:

$$\nu = .03 \text{ x } cmp, \qquad (6\text{-}18)$$

where ν = cost of trucking Milk, 0.03 (cents/litre), cmp = current milk production (litres).

In summary the NPV for the Permanent wetland option can be written as:

$$\sum_{t=1}^{25}((\varepsilon_t + \Psi_{p_t}) - (\mu + \nu_t))/(1+r)^t \, , \qquad (6\text{-}19)$$

where $\varepsilon_t = \eta + Bh$, η = income from water sale ($), Bh = annual income from highlands, Ψ_{pt} = filtration value of Permanent wetlands ($/year), $\mu = \varpi + \chi$, ϖ = cost of water to fill wetlands ($), χ = cost of evaporation water ($), ν_t = cost of milk transport ($)

TABLE 6-13. YEARS THAT COSTS AND BENEFITS OCCUR AND THE PERCENTAGE OF TOTAL COSTS AND BENEFITS FOR PERMANENT WETLAND VARIABLES

Benefit Variable	ε		Ψ_p
Individual variables	η	Bh	Ψ_p
Years benefit occurs	1	1–25	1–25
Per cent of total benefit*	88	12	0

Cost Variable	μ		ν
Individual variables	ϖ	χ	ν
Years cost occurs	1	1	1–25
Per cent of total cost	3	54	43

* Percentage of benefit depends on the value of δ. Figures presented are for δ value of 0.

6.3.3 Managed wetlands – Introduction

Managed wetlands utilise the existing inlet/outlet structures of the existing dairy irrigation scheme. The advantage of this system is complete control of the way the wetlands develop so that carp and weeds can be excluded and wetting/drying cycles can be incorporated into the system. As identified with Permanent wetlands, the benefits of this option for the community arise from the removal of the costs associated with dairy effluent entering the Murray, and the benefits of water filtration by wetlands. The disadvantage of this option is the cost of establishing the wetlands plus ongoing maintenance costs.

6.3.4 Methodology

Numerous figures and equations combine to form the summary equations presented in this section. Details for the determination of the large number of individual components that make up these equations can be found in Appendix 4, section 4.7. All the variables and sources of information can be found in Appendix 3.

6.3.4.1 Wetland benefits

The wetland benefits from water filtration are less for Managed wetlands than for Permanent wetlands because of the reduced number of months that Managed wetlands are connected to the river. Thus the water filtration benefits from Managed wetlands is:

$$\Psi_m = \psi \times \delta \times \kappa \times t / 12, \qquad (6\text{-}20)$$

where ψ = wetland filtration value ($/ha/yr), δ = marginal utility of water, κ = area of Gov swamp land (ha), and t = number of months wetland connected to the river.

The proportion of time that temporal wetlands are connected to the river varies enormously depending the location of the wetland, wetland depth and climatic conditions, with these conditions also affecting the filtration efficiency of the wetland. Therefore the form of equation (6–20) is important as it allows both the time (t) that wetlands are attached to the river and the filtration efficiency ψ of wetlands to be altered (ψ is a function of λ, and is the value of wetlands for filtration based on percent wetland filtration efficiency, α). Thus it is possible to determine a matrix for wetland filtration value based on the length of time the wetland is attached to the river and the filtration efficiency of the wetland.

6.3.4.2 Wetland costs

The largest cost for Managed wetlands is that of trucking milk (which is the same as for Permanent wetlands), followed by the comparatively small cost of wetland construction and maintenance.

In contrast to Permanent wetlands there are no water purchase costs associated with this option. The ELMA component allocated to this swamp for environmental land management is considered to be sufficient to account for the water requirements of this wetland type. This is because Managed wetlands, unlike Permanent ones, are not permanently filled with water, and therefore the amount of evaporation associated with this option is considerably less, and depends on the number of months of the year (t/12), they are connected to the river.

If for any reason additional water is required to manage these wetlands efficiently, it may be requested from the government as part of the environmental water allocation that can be used for wetland management purposes under the Water Allocation Plan for the River Murray (RMCWMB, 1997). Water held by the government for environmental water allocation is generally not available for commercial purposes, and therefore no cost would normally be incurred if this water were provided for wetland management. If for any reason additional water had to be purchased, then the costs associated with this water (i.e. the quantity required multiplied by the market price of water) would have to be incorporated in the thesis. However, as the quantity of any additional water required is unknown, it is not possible to include these costs at this time. This may mean that the costs of the project are underestimated, but it is expected that the extent of the underestimation is very small.

The wetland construction costs used for this option are based on the costs associated with Paiwalla swamp, which was originally a dairy swamp (and part of the study area) and has already undergone the process of being returned to Managed wetlands. These wetlands will utilise the existing inlet/outlet structures and levee banks, and hence the construction cost will be relatively small. While some initial planting will occur, the area will be allowed to self-seed over time. While Paiwalla is run by community volunteers (who provide ongoing maintenance for free), the thesis model includes annual management and maintenance costs for the wetland.

The equations for wetland construction becomes:

$$Cmc = mwe \text{ x } \kappa, \qquad (6\text{-}21)$$

where Cmc = Wetland construction costs (\$), mwe = cost of wetland establishment per hectare (\$), and κ = area swamp land for Gov swamps (ha)

The equations for wetland maintenance is defined as:

$$Cm = imc \text{ x } \kappa + omc, \qquad (6\text{-}22)$$

where Cm = wetland maintenance costs (\$), κ = area swamp land for Gov swamps (ha),

imc = initial maintenance cost \$100 per ha/yr for first three years x area of swamp land for government swamp, omc = ongoing maintenance cost \$50 per ha/yr.

In summary the NPV for the Managed wetland option can be written as:

$$\sum_{t=1}^{25}((\varepsilon_t + \Psi_{mt})) - (\pi_t + \nu_t))/(1+r)^t \,, \qquad (6\text{-}23)$$

where $\varepsilon_t = \eta + Bh$, η = income from water sale (\$),Bh = annual income from highlands (\$), Ψ_m = filtration value of Managed wetlands (\$/year), , $\pi_t = Cmc + Cm_t$, ν_t = cost of milk transport (cents/litre), Cmc = cost of wetland construction (\$), Cm_t = cost of wetland maintenance (\$).

TABLE 6-14. YEARS THAT COSTS AND BENEFITS OCCUR AND THE PERCENTAGE OF TOTAL COSTS AND BENEFITS FOR MANAGED WETLAND VARIABLES

Benefit Variable	ε		Ψ_m
Individual variables	Bh	η	Ψ_m
Years benefit occurs	1–25	1	1–25
Per cent of total benefits*	88	12	0

Cost Variable	π		ν
Individual variables	Cmc	Cm	ν
Years cost occurs	1	1-25	1–25
Per cent of total costs	7	9	84

* Percentage of benefit depends on the value of δ. Figures presented are for δ value of 0.

6.3.5 Results

6.3.5.1 Permanent wetlands – Comparison with Status quo

Results from simply breaching the banks and returning this area to Permanent wetlands are presented in Table 6-15. When compared with the Status quo it can be seen that this option is not optimal. The community benefit of this option is the complete removal of the externality costs associated with effluent entering the River Murray. **This benefit is worth $0.45 million per year, ($132/ha per year), PV $7.42 million ($2,161 per hectare),** but is not sufficient to account for the loss in dairy income.

TABLE 6-15. COSTS AND BENEFITS OF PERMANENT WETLAND OPTION

	Status quo ($Million)	**Permanent Wetlands ($Million)**	**Net return ($Million)**
TOTAL Benefits	111.70	68.08	–43.62
TOTAL Costs	24.75	84.00	59.25
NPV	**86.96**	**–15.92**	**–102.88**
BCR	4.51	0.81	

The split of costs between the farmers and the government are presented in Table 6-16. As can be seen from this table, both farmers and the government would lose money on this option. If the government decides to go down this path, it would have to subsidise farmers $28.40 million for farmers to break even. The economics of this option are dominated by the requirement for the government to purchase sufficient water to account for the annual evaporation from the Permanent wetlands that are formed ($46.87 million).

TABLE 6-16. SPLIT OF COSTS AND BENEFITS BETWEEN FARMERS AND THE GOVERNMENT AFTER CONVERSION TO PERMANENT WETLANDS

	Status quo ($Million)	Permanent Wetlands ($Million)	Net return ($Million)
PV Farmer benefits	111.70	68.08	–43.62
PV Government benefits	–	–	–
TOTAL Community benefits	111.70	68.08	–43.62
PV Farmer costs	15.23	–	–15.23
PV Government costs	9.52	84.00	74.48
TOTAL Community Costs	24.75	84.00	59.25
NPV	**86.96**	**–15.18**	**–102.88**
Farmer BCR	7.34	–	–
Government BCR	–	–	–
Community BCR	4.51	0.81	–

6.3.5.2 Managed wetlands – Comparison with Status quo

The important differences in costs between Managed and Permanent wetlands arise from Managed wetlands incurring construction and maintenance costs. In addition, Managed wetlands do not require the purchase of additional water (because of the Environmental Water Allocation (ELMA) that remains with the swamps) for wetting cycles.

Results from returning this area to Managed wetlands are presented in Table 6-18. When compared with dairy farming it can be seen that this is not as profitable as the Status quo.

TABLE 6-17. COSTS AND BENEFITS OF MANAGED WETLAND OPTION

	Status quo ($Million)	Managed Wetlands ($Million)	Net return ($Million)
TOTAL Benefits	111.70	68.08	–43.62
TOTAL Costs	24.75	43.00	18.26
NPV	**86.96**	**25.08**	**–61.88**
BCR	4.51	1.58	–

The split of costs between the farmers and the government are presented in Table 6-18 As can be seen from this table, both farmers and the government would lose money on this option. If the government decides to go down this path, it would have to subsidise farmers $28.40 million for farmers to break even (i.e. lost farmer benefit ($-43.62 million) minus reduced costs (-15.23 million) equals net farmer loss (-$28.40 million).

TABLE 6-18. COMPARISON OF ECONOMIC RETURN FROM CONVERTING DAIRY SWAMPS TO MANAGED WETLANDS

	Status quo Dairy Farming ($Million)	Managed Wetlands ($Million)	Net return ($Million)
PV Farmer benefits	111.70	68.08	–43.62
PV Government benefits	–	–	–
TOTAL Community benefits	111.70	68.08	–43.62
PV Farmer costs	15.23	–	–15.23
PV Government costs	9.52	43.00	33.48
TOTAL Community Costs	24.75	43.00	18.26
NPV	**86.96**	**25.08**	**–61.88**
Farmer BCR	7.34		–
Government BCR	–	–	–
Community BCR	4.51	1.58	–

6.4 Discussion

This analysis shows that while rehabilitation does not completely remove the externality costs associated with the dairy industry, it does drop these costs by just over 50%. At the same time, this option is very profitable for farmers.

Farmers are unlikely to be happy with paying approximately 100% of all rehabilitation costs as part of the cost-sharing arrangement. The majority of the farmers' benefits arise from undertaking the on-farm works component of the rehabilitation scheme, while substantially higher costs are associated with rehabilitating the government-owned off-farm component.

Thus while farmers may stand to gain substantial benefits from rehabilitation, a cost-sharing arrangement that recognises the high costs of rehabilitating the government-owned part of the irrigation scheme would be more agreeable to farmers. The government on the other hand does not want to have to pay the costs of fixing up the scheme and then have it handed to the farmers for free. If the government does not contribute to Rehabilitation by farmers, then this option costs the government only \$3.8 million, approximately \$3.7 million of which are externality pollution costs.

It must be recognised that in the rehabilitation of similar irrigation schemes throughout the region, farmers have only had to pay 20% of the costs. Therefore farmers in this area do not consider it unreasonable to expect a similar cost-sharing arrangement. Obviously the final decision of which scheme and cost-sharing arrangement to choose will have to reflect both the financial position and the willingness to pay of the parties involved. In this case it must also include the governments willingness to be involved in the ongoing management of this irrigation scheme.

While constructed wetlands used in conjunction with rehabilitation have the potential to drop this even further, they are not an economic choice mainly because they only drop effluent levels by another 15%. An increase in the area of these wetlands to make them more efficient would require taking even more land out of production and thus the costs associated with the wetlands would be even higher.

The externality benefits of converting this area back to either Permanent or Managed wetlands are not sufficient to cover the losses associated with these choices. If this area is returned to wetlands, the government costs are either $43.00 or $84.00 million depending on the wetland option chosen. The government thus has to decide if it is willing to spend this amount of money for $3.7 million of externality benefits.

As can be seen in Table 6-19 the Piped rehabilitation option clearly provides the best economic choice, even though the government still incurs externality costs associated with Piped irrigation, while pollution of the Murray River continues.

Importantly, the value derived for wetlands in the above analysis is purely based on the removal of externality costs associated with the dairy industry. It does not take into account the other numerous environmental services that these wetlands would provide, an important one of which is water filtration. This important issue is examined in the next part of the thesis.

TABLE 6-19. SUMMARY OF ECONOMICS OF THE PIPED REHABILITATION OPTION VERSUS CONVERSION OF DAIRY LAND TO WETLANDS, ALL NET OF STATUS QUO

	Piped Rehabilitation	**Permanent Wetlands**	**Managed Wetlands**
	Net return Farmers paying all costs ($Million)	**Net return ($Million)**	**Net return ($Million)**
PV Farmer benefits	58.37	–43.62	–43.62
PV Government benefits	–	–	–
PV Total Community benefits	58.37	–43.62	–43.62
PV Farmer costs	29.67	–15.23	–15.23
PV Government costs	– 5.75	74.48	33.48
PV Total Community costs	23.92	59.25	18.26
NPV	**34.45**	**–102.88**	**–61.88**
Farmer BCR	1.97	–	–
Government BCR	∞	–	–
Community BCR	2.44	–	–

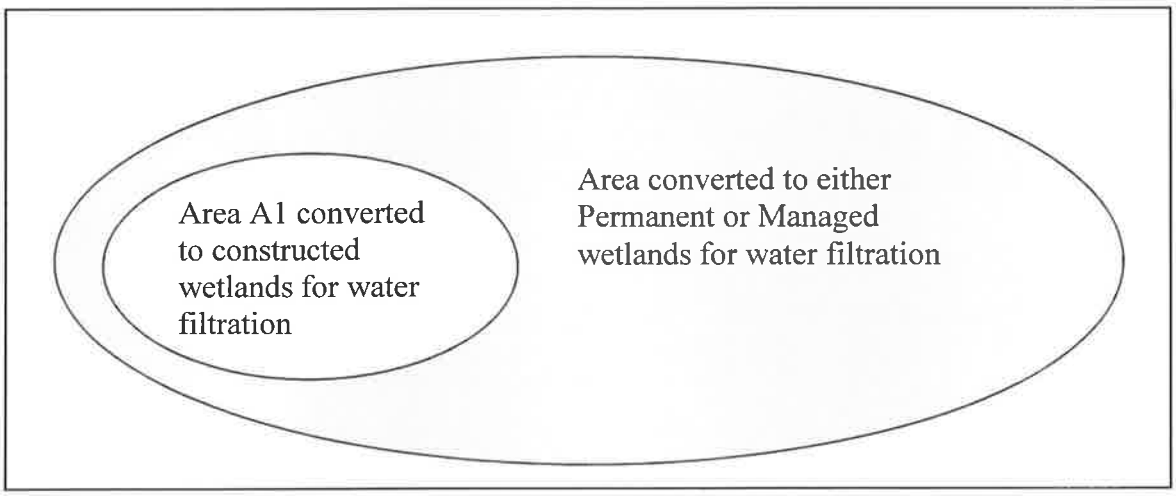
7 PART III: RETURNING THE WHOLE AREA TO WETLANDS FOR WATER FILTRATION

7.1 INTRODUCTION

It is the aim of this thesis to provide a tentative estimate of the value of the Murray Swamps in terms of their water-filtering and pollution-alleviating functions. The results from Part I show that the value of wetlands for water filtration in area A1 is ($14,118 per hectare per year), and is significantly greater than for pollution alleviation ($132 per hectare per year) as determined in Part II. It is interesting to note that pollution-alleviation has been of much interest to the media, government, and economists, and yet this function has turned out to be far less important, in terms of measurable benefits, than has water filtration.

Building on this information, this part of the thesis examines whether the most economically valuable use for the dairy swamps is therefore the conversion of the whole of this area (Figure 7-1) back to wetlands primarily for their water filtration function. Constructed wetlands will be built on Area A1, while the remainder of the area (A-A1) is converted back to either Permanent or Managed (temporal) wetlands similar to the wetlands originally found in this region.

FIGURE 7-1. CONVERSION OF DAIRY SWAMPS TO WETLANDS FOR WATER FILTRATION



The results presented in this thesis fill an important gap in our determination of wetland functional values, as at present there is a serious lack of knowledge in this field. Therefore, before identifying and valuing the benefits and costs of returning this area to wetlands, this section commences with a review of the existing 'Choice based' methodology predominantly used in Australia to determine wetland values so that an understanding of the importance of valuing the water filtration function of wetlands can be understood. It is then possible to compare the values obtained using Choice methods with those based on one wetland functional value, water filtration.

7.1.1 Review of 'Choice' based methodology

7.1.1.1 Wetland functions

Natural wetlands have functioned as natural water purification systems for as long as they have existed. Functions include sedimentation, filtration, adsorption, bacterial metabolism, plant metabolism, passive plant absorption and natural die-off. The net result is a substantial improvement in water quality as water passes through wetlands (Reaves *et al.*, 1994). Wetlands also play a critical role in regulating the movement of water within watersheds as well as in the global water cycle (Mitsch and Gosselink, 1993; Richardson and McCarthy, 1994). A summary of the known functions of wetlands is presented in Table 7-1.

TABLE 7-1. EXAMPLES OF KNOWN FUNCTIONS AND VALUES OF WETLANDS

Functions	Specific examples	Examples of Values
Hydrology	Aquifer recharge/discharge Water storage and regulation Climate control	Water quality/quantity Flood control/cost of climate change
Biogeochemical cycling and storage	Nutrient source/transformer/sink Sediment and organic matter sink	Water quality Erosion control
Bioproductivity and decomposition	Net primary productivity carbon storage/release detritus output for aquatic organisms mineralization and release of N,S,C,P	Food chain support Water quality recreation Commercial products
Ecosystem Processes	Habitat for species Food chain support maintenance of biotic diversity	Recreation/aesthetics, Commercial products Water quality/quantity

Modified from NCSU (2002)

7.1.1.2 Wetland value

While numerous studies have been undertaken to determine the habitat, recreation, preservation/existence of particular environments, few have been specifically targeted at wetlands. The studies that have attempted to value wetlands have generally relied on contingent valuation (CV), travel cost (TC), choice modelling (CM) and other willingness-to-pay (WTP) methodologies. Examples of the few Australia studies that have attempted to estimate the value of wetlands are presented in Table 7-2.

A careful analysis of Table 7-1and Table 7-2 indicates a mismatch in the functions that wetlands provide and the way that wetlands are currently valued. Table 7-1 shows that wetlands provide important hydrological and geological functions that affect water quality and storage and climate control. They also have significant mineralisation and decay functions for food chain balance, support and carbon storage. Table 7-2, however shows that valuation of wetlands in Australia has focused on recreation/aesthetics aspects. Effectively this means that what people 'see, feel and hear' is being valued rather than what wetlands 'do'.

Much of the reason why the water filtration value of wetlands has not been explicitly valued in Australia is the lack of available information on wetland water filtration rates. This problem is compounded by the variability in water filtration ability between wetlands and the amount of time that wetlands are connected to the river. These factors are examined in this part of the thesis.

TABLE 7-2. SUMMARY OF WETLAND VALUATION STUDIES IN AUSTRALIA

Location of wetland	Author	Method	Value	Value $	Evaluation (ENVALUE)
Jandakot Wetlands, Perth Western Australia	Gerrans, 1994	Contingent Valuation	Medium WTP to preserve the wetlands in their current state per annum per household	34.80	Results considered plausible, valid & consistent with economics
Sale Wetlands, Victoria	Sappideen, 1992	Contingent Valuation	WTP to preserve water quality from increased salinity to maintain recreation value, per person per visit	3.32	Evidence of response bias and starting point bias
Barmah Wetlands, Victoria	Stone, 1991	Contingent Valuation	WTP for recreation at and to preserve wetlands, per person one-off payment to trust fund.	33.18	Evidence of information bias
Macquarie, NSW	Morrison, Bennett and Blamey, 1998	Choice Modelling	WTP/household one-off payment to increase wetland area by 800 ha, breeding freq. increases from every four to every two years, species present increases from 12–20, no job impact Implicit price (WTP) for an extra irrigation related job preserved Implicit price for an additional endangered species	105.42 0.13 4.00	The technique is experimental
Australia	Van Bueren and Bennett 2000	Choice Modelling	WTP for species protection, landscape aesthetics, waterway health and social impact per person per year for 20 years	0.68/species 0.07/10,000 ha restored 0.08/10 km restored –0.09/10 persons leaving	The technique is experimental
Upper South East and Gurra Gurra Wetlands South Australia	Whitten & Bennett, 2001 Petersen & Bennett, 2003	Choice Modelling	WTP/household one-off payment for an additional 1000 hectares of wetland and remnant vegetation. NPV endangered species saved	1.51 and 0.92 4.81	The technique is experimental

Modified from PIRSA (2001)

7.1.1.3 Stated preference techniques

As indicated in Table 7-2, the majority of the wetland valuation studies undertaken in Australia have been based on 'stated preference' or 'choice' methodologies – either contingent valuation (CV) or choice modelling (CM).

Until the mid 1980s contingent valuation studies had been conducted using elicitation formats based on open-ended questions and iterative bidding games, either with or without the use of payment cards. Problems associated with these techniques (respondents trying to please the interviewer and saying 'yes' when they really should truthfully say no; an individual saying 'yes' to a much higher bid than his own valuation if this is the only way they can cast a vote; 'protest bids' where the respondent proposes a much higher or lower valuation on a good than they would normally attribute it, so as to bias the results in a certain way) led researchers to investigate alternative elicitation formats which did not require respondents to construct their maximum WTP for a particular environmental good, but instead asked them to choose between discrete alternatives relating to the specification of the good and its cost (Garrod and Willis, 1999). This resulted in the development of 'discrete choice' questionnaires, or 'choice modelling'.

Choice experiments and similar techniques have been utilised by psychologists since the 1960s, and in transportation and market research since the early 1970s (Louviere, 1988). In marketing, the discipline of CM has been used to determine consumer preferences for product attributes (Green and Srinivasan, 1978; Cattin and Wittink, 1982), and embraces a number of choice-based techniques including trade-off matrices; card sorts; hierarchical choice; the transfer price method, and various forms of preference-based analysis. Broadly speaking these techniques attempt to identify the utility that individuals have for the attributes of these goods or services by examining the trade-offs that they make between them when making choice decisions (Garrod and Willis, 1999).

Underlaying all of these techniques is microeconomic theory and the notion that utility or value is derived from attributes of a particular good or situation (Lancaster, 1966, 1975). Lancaster refers to 'characteristics' or 'indirect analysis' of consumer behaviour in which the consumer is assumed to derive actual utility or satisfaction from characteristics that cannot in general be purchased directly, but are incorporated in goods. The consumer obtains the optimum bundle of characteristics by purchasing a collection of goods so chosen as to possess *in toto* the desired characteristics.

Consumers derive their ultimate utility or welfare from these characteristics, which in turn are obtained from the specific product differentiates which are available. Each product is assumed to possess those characteristics in fixed proportions. Thus most choice experiments are predicated on the assumption that preferences are not based on a single attribute, but are based jointly on several attributes.

7.1.1.4 Criticisms of choice methods

While stated performance techniques can, in principle, be used to value any impact, in practice there may be cognitive limitations to stating preferences. People may not have enough information to express a preference with any accuracy, even if they are attempting to express a preference (Diamond and Hausman, 1994). For example, they may care about the survival of a species and not know about the range of natural variation in population size, about the probability of survival as a function of population size, nor about the effect of environmental damage on population size. Such derived preferences may be a poor guide to policy; it may be more informative to have 'expert' evaluation of the consequences of an environmental change than to consult the public directly. However, this raises the issue of the bias of 'experts', the nature of democracy and the role of elites.

Contingent valuation studies have shown that the provision of information affects respondents' behaviour. In particular it appears to increase their willingness to pay. This raises the question of how much information should be provided, and the form in which this information should be provided (Tacconi, 2000). Even where information is provided, people may not fully understand very small changes in risk, or highly complex goods. In the event that individuals cannot identify with the good whose provision is being changed (hypothetically, or in reality) or their understanding is faulty then revealed preference techniques will tend to produce 'wrong' estimates (Pearce and Ozdemiroglu, 2002)

Lancaster's (1966) theory assumed that combined consumption of characteristics was linear; i.e., the characteristics of the combination being the sum of the characteristics content of the individual goods. In choice modelling it is normal to work with this assumption and to assume that the value of the goods is equal to the sum of the parts, i.e., its attributes. However, this assumption may not be valid, particularly when applied to environmental resources. Elsewhere in economics objections have also been raised about this assumption (Hanley *et al.*, 2001).

Choice modelling experiments in Australia have typically asked respondents to choose between management options (at different costs that the respondents must be willing and able to pay) that will result in various changes in attributes (for example increased bird numbers, fish numbers or vegetation). From the results, a WTP for different management options is determined. This introduces two areas of bias: How are the different costs of the management options determined? (does not introducing limitations on the amount that individuals are able to pay in itself bias the results?); and secondly, if asked about changes in individual attributes alone, people's willingness to pay for a single change may be considerably greater than for the combination of attributes, in the same way that people are known to be willing to pay proportionally more for one item at a supermarket, but pay less if they buy in bulk. An illustration of this view comes from Kemp and Maxwell (1993) who asked one group for willingness-to-pay to minimize the risk of oil spills off the coast of Alaska, and found a mean stated willingness-to-pay of $85 (with a 95% confidence interval of +/– $44). Then they asked a different sample for willingness-to-pay for a broad group of government programs, followed by asking these people to divide and subdivide their willingness-to-pay among the separate programs. By the time they reached minimizing the risk of oil spills off the coast of Alaska, they found a mean of $0.29 (with a 95% confidence interval of +/– $0.21).

While CM experiments frequently attempt to overcome this problem by including scope as one of the attributes, some researchers have found significant scope insensitivity where respondents are given too many sets of choices (Pearce and Ozdemiroglu, 2002).

The conventional CM questionnaire usually posits a positive value to an increase in the attributes in question. But the mixed cases cannot be ignored, for changes in wetland size/management are 'bads' for some people and 'goods' for others. This is particularly true where changes in wetland use will impact on employment. The wetland preservation movement enjoys immense support in some quarters and is subject to genuine hostility in others. But no estimation of the value of certain kinds of management decisions makes any sense if the only question is what positive value can be attributed to proposed changes.

A key assumption of most CM models is the independence of irrelevant alternatives. In practice this means that the researcher assumes that the probability of choosing one alternative in preference to another is not influenced by other available alternatives that are not being considered as part of their study. Thus in a pair wise comparison the choice between thc two profiles on offer is assumed not to be influenced by the possibility that other profiles not presented as choices could be chosen. Some critiques regard this assumption to be a flaw in choice experiment methodology, arguing that consumers consider all available choices before making a decision (Garrod and Willis, 1999).

Further problems with choice experiments are identified by Andreoni (1989) and Diamond and Hausman (1993) who point out that individuals may receive a 'warm glow' from expressing support for good causes, or they may be describing what they think is good for the country, in a sort of casual benefit–cost analysis. Individuals may also be expressing a reaction to actions that have been taken (for example, outrage at allowing an oil spill results in people putting a significantly greater value on one part of the environment than they otherwise would) rather than evaluating the state of a resource.

Epstein (2002) suggests another bias in the world of contingent valuation (and CM). He states that 'we tend to ask about the exotic components, e.g., existence value, only with certain forms of goods and not with others. Thus it is easy to ask the question of whether we attach some existence value to redwood trees, to which the answer is yes. But that existence value is one among many existence values. Those of us who care about the cultural heritage think that classical furniture made of the finest woods are an appropriate object for present and future preservation. We also note that the collectables of tomorrow include the furniture made today from redwoods. To ask whether people attach existence value to the redwood trees does not tip the scales in favour of their preservation. It is necessary to pose a second question: do they also attach existence value to redwood furniture. But one cannot have both.'

7.1.1.5 Theoretical market

Perhaps the real problem stems from the fact that generally individuals do not purchase public goods directly, and therefore we usually do not have data on actual transactions for environmental public goods to compare with survey responses of hypothetical willingness to pay (Diamond and Hausman, 1994). When undertaking choice experiments we are attempting to replicate the workings of the market without a system where natural resource sites have well-defined private property rights (Bate, 1993). We are frequently asking individuals to provide values for unfamiliar commodities using unfamiliar transactions. This raises the problem of individuals being asked to express an attitude towards a public good (or class of public goods) in a dollar scale because they are asked to express it in a dollar scale (Kahneman and Ritov, 1993), even if they do not wish to express it in this way. The results may be interesting, but are little more than picking a number, any number (Bate, 1993).

As noted by Diamond and Hausman (1994), we do not expect that public policy would be improved by using choice methods to affect the levels and patterns of spending for school education, foreign aid, Medicare, construction of safer highways, medical research, airline safety, or police and fire services. Yet people have concerns for others in all of these areas that parallel their concern for the environment.

Finally, Tacconi (2000) suggests that the whole basis for using stated preference techniques for valuing people's preferences may be flawed. He states that 'CV and CM studies are said to measure utility levels enjoyed by individuals. Changes in these utility levels are at times referred to as money-valued gains and losses' (Randall and Peterson, 1984). If money-valued gains (losses) arising from contingent market studies are taken as indices of preferences, they cannot be aggregated across individuals and, furthermore, they cannot be summed to values derived from actual markets. However if money-valued gains (losses) are interpreted as actual monetary values, they may be aggregated across individuals and summed to values arising from actual markets. This interpretation is not consistent, however, with the view of contemporary microeconomics that utility cannot be measured'.

Wetland valuation studies relevant to the study area

As indicated in the previous section, few Australian studies have been undertaken to determine wetland value, and where studies have been undertaken, the focus has been on people's willingness to pay for changes to certain components or attributes of wetlands (e.g., species preserved, recreation, aesthetics, water quality), but not the functions of wetlands themselves. Two studies of particular interest are by Morrison *et al.* (1998), and Pettersen and Bennett (2003).

The first study looked at a range of options to improve the Macquarie Marshes. Respondents were told that the government did not have enough money from existing revenue to purchase the water to undertake these changes and that it would be necessary to charge households in New South Wales a one-off levy on water rates in 1998. The options presented to the Sydney participants included not only increases in wetland area by up to 80,000 hectares, but increased waterbird breeding frequency (from every four to every two years), and an increase in species present (from 12 to 20), with no impact on irrigation-related jobs.

It is interesting to note that this study includes both marginal changes (increase in breeding frequencies and species present on existing wetlands) plus restoring an area to wetlands which had been lost because of irrigation demands from farmers (a situation similar to that which occurs in this study). Morrison *et al.* showed a one-off willingness to pay per Sydney household for these increases of $105. Assuming 2,307,000 households in NSW (ABS, 1996) this represents a value of $1,315 per hectare, which equates to $82.42 per hectare per year (3.55% discount rate).

The second (South Australian) study by Petersen and Bennett (2003) examines the value of restoring wetlands at Gurra Gurra on the River Murray. This study is somewhat similar to this thesis in that it looks at recreating the combined effects of drowning and droughting that occurred naturally on this floodplain. The values determined in the Gurra study are based on a previous study by Whitten and Bennet (2001), which used Choice Modelling to determine people's value for additional wetland area, remnant vegetation and preservation of endangered species at wetlands in the Upper South East of South Australia. Peterson's study at Gurra showed benefits with an NPV of $3,553,017 for a project to rehabilitate 725 hectares of wetlands, floodplain and remnant vegetation. On a per hectare basis, this produces an NPV of $4,900, which equates to $299 per hectare per year (3.55% discount rate).

It is important to note that 94.7% of the total value of the change to this wetland arises from benefits derived from people's willingness to pay to preserve three endangered species – a turtle, bettong and poteroo. Only $22 per hectare per year was for improved wetlands/recovered floodplain/healthy wetlands/healthy remnant vegetation. Rather unusually, it would seem that both this community and that on which this study is based have an especially strong allegiance to these three species, but either poor or little knowledge of the water filtration value of wetlands.

7.1.1.6 Values based on wetland functions

In contrast to Australia, wetlands in the United States are valued extremely highly in recognition of their functional values, with several recent US studies placing very high values on wetlands. Costanza *et al.* (1989) estimated commercial and recreational values, and compared these with 'contributory values'. Contributory values are the contributions of the component parts of the ecosystem as a whole to the functioning of that system and the contribution of ecosystem as a whole to connected systems. Costanza used a system of energy accounting to estimate the total amount of energy captured by the ecosystem as an upper bound on its capability of providing useful work to the economic system. The gross primary production of the system, its capture of solar energy, is converted to fossil fuel equivalents, which are then converted to dollar values by multiplying by the ratio of gross national product of the US by conversion factor to determine total fossil fuel equivalent energy use. (The conversion factor is based on previous studies: Costanza, 1980, 1984; Cleveland *et al.*, 1984; Costanza and Herendeen, 1984). The end value also depended on the discount rates used. More conventional preference-based measures of economic value were also calculated.

A comparison of the two methods showed the 'contributory' value method produced a wetland value approximately three times greater than the preference-based method ($8,977 vs. $28,000, 3% discount rate). Costanza e*t al.* (1989) admit to misgivings over the fossil fuel equivalent to dollar value conversion, noting that only part of primary energy production is used.

However, more recently Costanza *et al.* (1997) attempted to value the world's ecosystem services and natural capital. Their valuation of wetlands at $14,785 per hectare, included such factors as disturbance regulation, raw materials, gas regulation, and water supply and waste treatment. His study showed that water supply/waste treatment is an important component of wetland value, with a value of $7,977 per hectare per year. If this figure is applied to the Murray swamps, the value would be $41.5 million per year.

In 1981 Thibodeau and Ostro valued the water supply benefits supplied by the Charles River wetlands in Massachusetts. Their results showed a daily saving of $16.56 per acre, or $6,044 per acre per year (Aus $14,190 in 2002). On a per hectare basis, this would be $35,000 per year.

One of the earliest studies into the value of wetlands was by Gupta and Foster (1975). They attempted to value wetlands in Massachusetts by placing values on wildlife, visual–cultural, water supply and flood control. They estimated that the cost of delivering water from a wetland wellhead was 0.773 cents per 1,000 gallons per day cheaper than the alternative source. The estimated capitalised value of a 10 acre wetland supplying one million gallons of water was $52 per acre, on the basis of annual benefits of $2,800 per acre. Importantly, on average the benefits of wetlands for water supply were 10 times higher than for the next category, visual–cultural.

In a similar vein, Gren (1994) conducted a total valuation study of the Danube River floodplains. Included in his study were values for nitrogen filtration (wetlands acting as a nitrogen sink) and recreation. He found the wetlands function as a nitrogen sink to account for 56% of the total value, while recreation accounted for only 29%.

Lerner and Pool (1999) estimated an annual value of water quality improvement provided by wetlands along a 5.5 km stretch of the Alchovy River in Georgia USA to be worth US$3 million. If a similar value of $500,000 per km were placed on the (approximately) 50 km of original wetlands in this study, they would be worth $25 million per year.

Jensen (1993) cites a Swedish study by Maltby (1991) that suggests nutrient retention in wetlands can be worth up to US$200,000 per hectare. When applied to the 5,200 hectares of reclaimed Murray swamps, this would equal a filtration value of $1.0 billion. A higher figure is estimated by Miller (1996), who estimated all economic benefits generated by a single acre of wetland to be worth $159,000 to $200,000.

These figures may seem high; however the value of the filtration to the community is dramatically illustrated in New York where the city is spending US$1.5 billion in restoration costs to protect 80,000 acres (approx 32,400 hectares) of watershed lands (including wetlands) required to ensure the quality of upstate drinking water supplies. If the upstate watersheds were not restored, the cost of installing an artificial filtration plant would be US$6 to 8 billion plus annual operating costs of $300 million (Commission on Geosciences, 2000).

The recognition of the value of wetlands' functional values has resulted in the growth of 'mitigation banks' where environmental derivatives can be traded, with a substantial number of these trades being in wetlands credits (The Economist, 2002).

Mitigation Banking

Mitigation banking arose as a result of the US Congress (1972), which was designed (among other things) to minimise damage to wetlands (Bayon, 2002). It set about achieving this goal by prohibiting the discharge of fill or dredged material into wetlands without a permit from the Army Corps.

Before granting a permit, however, the Corps must assay the potential impact. First, it must decide if the damage is truly unavoidable – whether there is any benign alternative that is practical. Second, if the Corps determines that the damage is unavoidable, it must look for ways to minimise harm. Finally, the Corps must require unavoidable harm to be 'mitigated.'

If a project harms a wetland at point A, the developer is required to compensate by creating, restoring or – in rare cases – protecting a similar wetland somewhere else.
This has led to the creation of an environmental currency: the wetland mitigation credit. And the credit, in turn, has created a variety of businesses specialising in enhancing or restoring wetlands in order to sell the credits to needy developers.

In 1993, the Clinton administration recognised the importance of the services that wetlands provide to the community and of mitigation banks (White House Office on Environmental Policy, 1993) by releasing a policy statement: "The Nation's wetlands perform many functions that are important to society, such as improving water quality, recharging groundwater, providing natural flood control, and supporting a wide variety of fish, wildlife and plants. The Nation's wetlands continue to be lost at a rate of hundreds of thousands of acres per year due to both human activity and natural processes. This continued loss occurs at great cost to society." The statement went on to say that, "the Administration endorsed the use of mitigation banks."

In 1995, the Administration released the Federal Guidance for the Establishment, Use and Operation of Mitigation Banks (Department of Defence, 1995). This document states that "the objective of a mitigation bank is to provide for the replacement of the chemical, physical and biological functions of wetlands and other aquatic resources, which are lost as a result of authorized impacts. Using appropriate methods, the newly established functions are quantified as mitigation 'credits' which are available for use by the bank sponsor or by other parties to compensate for adverse impacts (i.e., 'debits'). By consolidating compensation requirements, banks can more effectively replace lost wetland functions within a watershed, as well as provide economies of scale relating to the planning, implementation, monitoring and management of mitigation projects."

United States Government agencies generally require greater than one-for-one compensation before credits can be certified. For example, if wetlands are impacted during construction or operation of an industrial or commercial facility, agencies may require compensation ratios of 3:1 or even 20:1 (depending on the ecological significance of the impacted wetland) before regulatory compliance is assured. A new facility required to compensate for the loss of 10 acres of wetland will, on a 3:1 compensation basis, restore 30 acres of wetlands to satisfy regulatory requirements (Earth-assets, 2005). An important feature of wetlands credits is that the wetlands providing the credits must provide the same functions as the wetlands that are destroyed, usually in the same catchments or waterway system.

7.1.1.7 Impact on wetland value

The legal requirement that wetland functions be maintained removes the problem of relying on studies involving people's willingness to pay for wetlands – the cost of providing the wetland function now becomes the important factor which draws wetlands into the commercial market. The same laws of supply and demand that apply to any good or service also drive mitigation banks. Thus, a developer wishing to destroy a wetland must take into account the cost of destroying a wetland's functions.

The General Accounting Office estimates that developers have paid $64 million to mitigate damage on 1,440 acres of wetlands. Since a report by the National Academy of Sciences estimates that 24,000 acres were subject to mitigation from 1993 to 2000, a bit more than $1 billion was probably spent to obtain permits. By setting a price on the destruction of wetlands (on average US$44,000 per acre, or $108,680 per hectare), mitigation banking incorporates wetland ecosystems into the market system (Bayon, 2002).

Wetland mitigation costs can range substantially depending on whether mitigation involves the (relatively) cheap task of restoring damaged wetlands to the expensive need to construct new wetlands that are able to perform the required functions.

Valuation of filtration ability alone.

The introduction of mitigation banking allows for a value to be placed on the functions that wetlands perform. Sometimes these values can be considered all encompassing (i.e., a particular function is not singled out), while at other times wetlands are conserved for a particular function. For example, the Allegheny Power Corporation sold an area of wetlands in West Virginia for $32.6 million. $16 million of this was for the real estate value of the land; the remaining $16.6 was for marketable ecological services – carbon sequestration credits (Bayon, 2002). Clearly, such ecological values would not exist if the wetland did not function properly including as a water filtration system. Few studies have specifically looked at the filtration component of wetlands, but those that have include a USEPA (1995) study which determined that if the temporal wetlands of the Congaree bottomland hardwood swamp (South Carolina) were destroyed, the cost to the community to install a water treatment plant for water quality improvement would be $5 million. In another case, scientists estimate that a 2,500-acre wetland in Georgia saves $1 million in water pollution control costs annually; this is equivalent to US$988 per hectare per year (OTA, 1993). These cost figures relate only to the water quality improvement function of the wetlands.

7.1.2 Filtration efficiency of constructed versus natural wetlands

In this part of the thesis, both constructed and 'natural' (either Permanent or Managed wetlands) will be used to filter water. Area A1 is to be converted to constructed wetlands for water filtration (as described in Part I), while the remainder of the area is to be converted to Permanent or Managed (temporal) wetlands (as described in Part IIb). The question therefore arises of whether the filtration values determined for the constructed wetlands in this thesis can be used for valuing water filtration services provided by natural wetlands, i.e., do natural wetlands provide the same level of filtration as constructed ones?

Unfortunately no studies specifically comparing the filtration of constructed wetlands with natural ones are available for the River Murray. However studies from around the world suggest that the ability of natural wetlands to reduce sediments ranges enormously but can provide up to 97% of the filtration benefits of constructed ones. Sediment deposition is variable across individual wetlands and wetland types, as deposition depends upon the rate and type of water flow (channelised or sheet flow), particulate size, and vegetated area of the wetland (Osmond *et al.*, 1995).

An important factor in determining the efficiency of this process is the number of wetlands within a system, i.e., multiple wetlands within a system will slow the movement of material downstream and will increase the overall system efficiency for nutrient processing (Naiman *et al.*, 1986). The multiple nature of wetlands along this portion of the Murray suggests they originally would have had very high filtration values. Breen (pers.com.), who has been involved in wetland research in Australia for many years, suggests that natural wetlands along the Murray would provide at minimum 50% of the benefits of constructed wetlands and that this figure could be as high as 90%. These figures must be viewed as conservative given that these figures represent 50% and 90% of the filtration value determined when assuming that constructed wetlands replace only half of each filtration plant (i.e., the sedimentation process).

On top of these filtration values, natural wetlands also provide additional environmental services that are not easily met by constructed wetlands, such as nutrient assimilation and habitat diversity. Constructed wetlands have a higher likelihood of failure to meet the functional standards of these additional functions than restored wetlands (Kusler and Kentula, 1989; Mitsch and Wilson, 1996).

7.2 METHODOLOGY

If we assume that converting the remainder of this area to natural wetlands (A–A1) results in water filtration rates of between 50% and 90% of those found using constructed wetlands, then what is the total value of the wetlands formed in terms of their filtration and pollution alleviation functions? This question can be answered from two points of view:

- That of the provision of filtered water for human consumption or similar alternative use.
- That of the cost of replacing the environmental services provided by temporal or permanent wetlands if those wetlands are destroyed.

These two perspectives are examined in this part of the thesis.

7.2.1 View 1: The provision of water for human consumption – diminishing marginal utility

If all the water filtered by the wetlands was required for human consumption, and assuming natural wetlands have a filtration rate close to that of constructed wetlands, the value of the wetland areas as a whole would be the sum of the net benefits associated with water filtration C_1 (Part I) and pollution alleviation C_2 (Part IIb). Thus, the benefit (B_p) associated with this project is $B_p = C_1 + C_2$ (since it is assumed that neither water purification plants nor rehabilitation schemes have yet been installed) and $C_1 + C_2$ is the value of the costs the government would have saved by converting wetlands to swamps. Hence the net benefit of the wetlands project is:

$$Bp - Cp = C1 + C2 - Cp \text{ and the } BCR = (C1 + C2)/Cp, \qquad (7\text{-}1)$$

where Cp is the cost of this option.

However, the water filtered by the 'extra' natural wetlands on area A–A1 results in more filtered water than is currently demanded by consumers. Therefore, assuming that the quantity Q_{II} of water filtered in area A–A1 is subject to the law of diminishing marginal utility, what is the value of these wetlands for water filtration for human consumption?

Let $\delta \times \psi$ be the value of the wetlands for water filtration for the extra water filtered, where ψ is the value of wetlands for water filtration in area A1, determined in Part I of the thesis, and δ is a positive fraction. The extreme value of $\delta = 0$ implies that the utility of the extra water filtered in area A1 is zero and that of $\delta = 1$ implies that it is not subject to the laws of diminishing marginal utility. Hence in real life cases, it would be expected that δ would be in the range $1 > \delta > 0$.

The timeframe that this thesis is undertaken from assumes that filtration plants have not been built and therefore consumers are drinking unfiltered water. Thus, any improvement in water quality via wetland filtration is expected to be of value to consumers. While it is reasonable to assume that consumers may not value the extra water filtered by the natural wetlands to the same extent as the water in A1, the provision of additional filtered water does provide significant security for consumers in this region. On average, half of Adelaide's drinking water is sourced from the River Murray, with the other half coming from the Mt Lofty Ranges. However, in drought years, up to 90% of Adelaide's water can come from the Murray, increasing the demand for filtered water from this region. It is reasonable then to assume that population increases combined with severe drought conditions may result in the need for additional filtered water from the Murray to be available for rural users or to supplement metropolitan supply. In addition, the owners of holiday homes along the Murray draw their domestic water directly from the river, as do many farms for stock water supply. These water users will benefit directly from any water filtration undertaken by wetlands. The increase in water quality will also be beneficial for recreational activities, for example, for swimming, water skiing and boating, and thus would be valued by consumers. The thesis therefore examines converting this area to wetlands using the assumed utility values associated with δ equal to 0.25 and 0.50 for wetland area A–A1.

7.2.1.1 Relationship between δ, marginal utility and price elasticity (ε)

The examples presented below shows the relationship between δ, marginal utility and price elasticity (ε). They demonstrate that δ in the chosen range is consistent with a realistic range of values for elasticity for a linear demand function for filtered water.

The equations in Appendix 7 show that δ depends inversely on price elasticity of demand and the percentage increase in filtered water associated with the percentage increase in the supply of filtered water:

$$\delta = \theta[1-(\Delta Q/Q)/(2\varepsilon)] \qquad \text{(A7-7)},$$

where ε is the price elasticity of the demand for filtered water, $\theta = P/\psi$ and ψ is the unit value of filtered water (associated with Q). Solving (A7-7) for ε gives:

$$\varepsilon = (\Delta Q/Q)/[2(1-\delta/\theta)] \qquad \text{(A7-8)}$$

Example 1

This example considers the implication for ε when $Q_2=4Q_1$, so that $\Delta Q/Q=3$ and let $\theta = .8$.

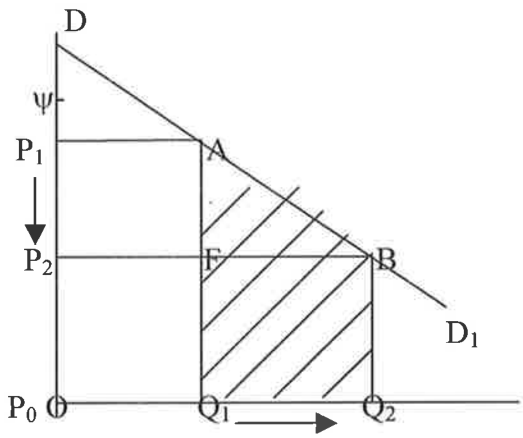
According to (A7-8), if δ =.5 and .25, then ε = 2.4 and 1.6 respectively. With a linear marginal utility (or demand) curve, such values for ε are reasonable for small quantity Q_1.

Example 2

This example considers the case in which. $Q_1 = 10$, Q_2=40, P_0=110, P_1=100, P_2=70, i.e. the units are so chosen that the slope of the inverse form of the demand curve is b=dP/dQ=1, ψ=105 and θ=100/105 = 0.95. Note that P_0 is the price at which Q=0 (see Figure 7-2).

The percentage change in quantity and price would therefore be 3 and .3 respectively and hence elasticity (in absolute value), being their ratio, is ε = 3/.3 = <u>10</u> and δ = 0.95(1-(3/20)) = 0.95(0.85) = 0.81 ~ <u>.8</u>.

FIGURE 7-2. VALUATION OF NON-MARGINAL CHANGES IN QUANTITY OF WATER PRODUCED



7.2.1.2 Filtration efficiency

The filtration efficiency of the Permanent or Managed (temporal) wetlands may also affect how consumers value the extra filtered water they supply. In this analysis it is assumed that if wetlands are only 50% as efficient at filtering water as are constructed wetlands, then they are only half as valuable. However, the value of the constructed wetlands is based on the cost savings associated with the water filtration plants, with the capital costs of the plant thought to represent around 50% of filtration plant costs, the remaining 50% being chemicals, repairs and maintenance, pumping, sludge disposal and labour costs. While it might be expected that chemical and sludge disposal costs would decrease with reduced filtration efficiency, the fixed costs and many of the running costs associated with filtration plants would still be incurred, meaning that the assumption of a 50% drop in value possibly undervalues these wetlands. Unfortunately, for reasons of commercial confidentiality, it is not possible to determine the split of these costs in this analysis.

7.2.2 View 2: Value of filtration benefits for the environment

In light of the information presented in the Introduction, the next part of this thesis considers the value that wetlands along the Murray may have if a mitigation banking system existed in Australia, requiring wetlands to be valued based on the water filtration function they provide. To date the cost of replicating the filtration services that wetlands provide has not been examined in Australia. If for some reason a wetland was to be destroyed, then the filtration function could be mitigated by the restoration of another wetland, construction of a new wetland or (as a last resort) use of water filtration plants. These options provide a range for the value of wetlands for water filtration.

Whether or not people are willing to pay these costs is another question that will be discussed later in the thesis. Thus, this part of the thesis examines results for Managed and Permanent wetlands where $\delta = 1$, and with wetland filtration efficiencies of 50% and 90%.

7.2.2.1 Permanent wetlands

7.2.2.1.1 Water filtration benefits

Water filtration benefits for these wetlands are based on the per centage of filtration that the wetland can achieve on a per hectare basis when compared with constructed wetlands, multiplied by the value per hectare of water filtration determined in the previous section ψ, (equation 6–14) and the area of wetlands formed, i.e.,

$$\Psi_p = \psi \times \delta \times \kappa \times (1 - rgs), \qquad (7\text{-}2)$$

where ψ = value of wetlands for filtration (\$/ha), δ = fractional value of water (1), κ = area of swampland for government swamps turned to wetlands (ha), *rgs* = per cent government swamp area already in constructed wetlands.

As before, this benefit occurs irrespective of the costs of wetland construction. Wetland construction costs for Permanent wetlands are presented in the previous section, and are modified to account for *rgs*, (per cent government swamp area already in constructed wetlands).

7.2.2.2 Managed wetlands

7.2.2.2.1 Water filtration benefits

As with Permanent wetlands, the water filtration benefits for these wetlands are based on the per centage of filtration that the wetland can achieve on a per hectare basis when compared with constructed wetlands, multiplied by the value per hectare of water filtration determined in the previous section ψ. Another component, time (*t*), is now included in the equation to account for the number of months that these Managed wetlands are connected to the river and are therefore able to filter water entering the wetlands (equation 6–20), and the area of wetlands formed, i.e.,

$$\Psi_m = \psi \times \delta \times \kappa \times t / 12(1 - rgs), \tag{7-3}$$

where ψ = value of wetlands for filtration per ha, δ = fractional value of water (1), κ = area swamp land turned to wetlands (ha), t = number of months connected to the river, and % rgs = per centage of government swamp area already in constructed wetlands.

7.3 RESULTS

The benefits of conversion of this area to wetlands for water filtration for domestic consumption is the sum of the cost savings associated with not having to build the water filtration plants C_1, and the drop in pollution externality costs C_2. The costs associated with this option, C_p, are those costs related to wetland construction for both the constructed wetlands (in area A1) and for the conversion to natural wetlands of the remaining area (A–A1). Hence the net benefit of the swamp project is:

$$Bp - Cp = C1 + C2 - Cp, \tag{7-4}$$

$$BCR = (C1 + C2)/Cp. \tag{7-5}$$

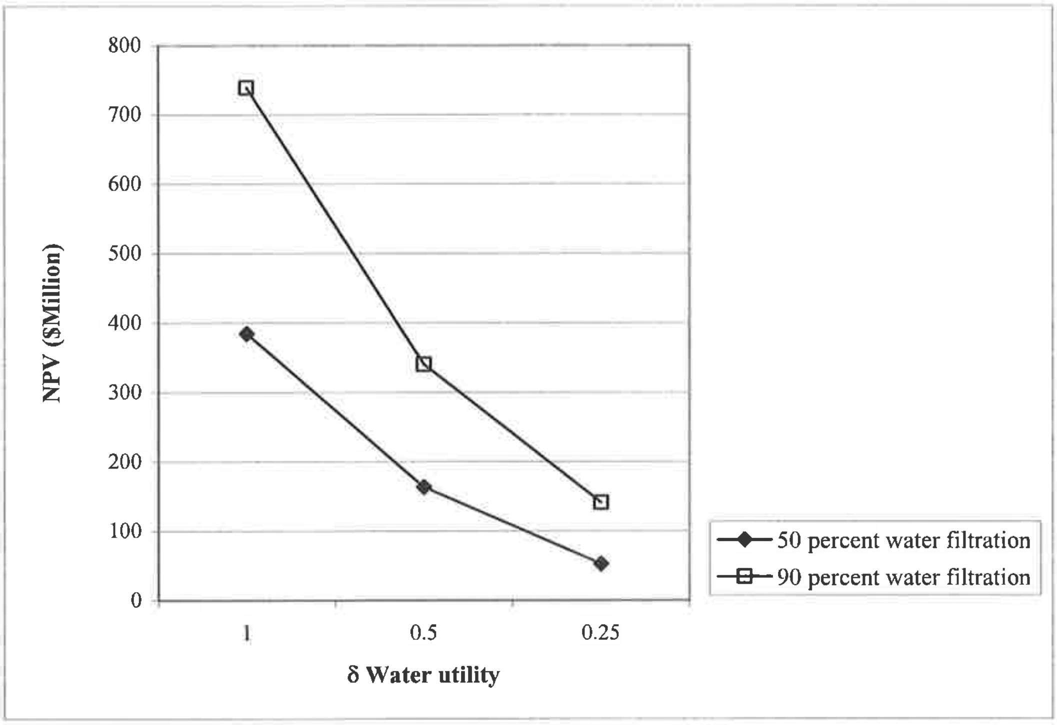
The results in Part I showed that wetlands were worth $11,557 per hectare per year if they can replace part of each water filtration plant, while the value of wetlands for pollution alleviation associated with the dairy industry is just $132 per hectare per year.

7.3.1 View 1: Declining utility value of δ between 0.25 and 0.5

The results for converting the whole area back to a combination of constructed and Permanent wetlands for water filtration are presented in Figure 7-3. Even with filtration rates of 50%

(meaning that Permanent wetlands are worth only around $7,100 per hectare per year) and a δ value of 0.25, conversion of this area to wetlands for water filtration and pollution alleviation is more profitable than the existing Status quo land use. The NPV decreases with decreasing values of δ, however δ would have to be 0.13 and 0.08 for break even with 50% and 90% filtration efficiencies, respectively.

FIGURE 7-3. NET RETURN FROM CONVERTING FROM STATUS QUO TO WETLANDS FOR WATER FILTRATION WITH DIFFERING VALUE OF δ, AND WATER FILTRATION EFFICIENCIES



The costs and benefits of this land use option for a δ value of 0.5 are presented in Table 7-3. As expected, the benefits for these options increase with increasing filtration efficiency rates.

TABLE 7-3. COSTS, BENEFITS AND NET RETURN OF WETLANDS FOR FILTRATION USING CONSTRUCTED AND PERMANENT WETLANDS. PERMANENT WETLANDS WITH 50% AND 90% FILTRATION EFFICIENCIES, AND δ OF 0.5

	Status quo ($Million)	Wetlands 50% filtration rate ($Million)	Net return ($Million)	Wetlands 90% filtration rate ($Million)	Net return ($Million)
PV Total benefits	111.70	367.74	256.03	544.80	433.10
PV Total costs	24.75	117.38	92.63	117.38	92.63
NPV	**86.96**	**250.82**	**163.41**	**427.43**	**340.47**
BCR	4.51	3.13	2.76	4.64	4.68

As indicated in Table 7-4, farmers stand to lose around $28.4 million if this area is converted to wetlands for water filtration (i.e. lost farmer benefit ($-43.62 million) minus reduced costs (-$15.23 million). The government must therefore consider compensating farmers by at least this amount if they want farmers to leave the land so that his option can proceed.

TABLE 7-4. IMPACT ON FARMERS OF CHANGING FROM DAIRY FARMING TO WATER FILTRATION ASSUMING 90% FILTRATION EFFICIENCY AND δ OF 0.5

	Status quo Dairy Farming ($Million)	Water Filtration ($Million)	Net return ($Million)
PV Farmer benefits	111.70	68.08	–43.62
PV Farmer costs	15.23	–	–15.23
NPV	**96.47**	**68.08**	**-28.40**
Farmer BCR	7.34	–	–

7.3.2 View 2: Value of filtration benefits for the environment (δ value of 1)

The information presented in the methodology section indicates that the value of the environmental services that wetlands provide is substantial, and it is only the lack of legal imperative in Australia that is causing them to be valued based on people's willingness to pay rather than on the cost of restoring or otherwise providing the services that wetlands supply. If the government in Australia was to place the same legal requirements for wetland mitigation as exist in the United States, then the value of these wetland would be recognised and a market for wetland functions (such as water filtration) would exist. This would mean that if wetlands were destroyed, it would be necessary to construct either new wetlands or filtration plants to replicate the functions these wetlands provided. The fixed costs associated with either of these options would therefore be incurred, plus the running costs to manage the system.

With this information in mind, the question arises: what would the economic return be of converting the area back to constructed and either Permanent or Managed wetlands when wetlands are valued for the filtration function they perform rather than on what people are willing to pay for this function, i.e., a δ value of 1 is used? This question is analysed in this part of the thesis.

7.3.2.1 Permanent wetlands

Table 7-5 shows the value of Permanent wetlands for water filtration based on the proportion of filtration they provide (when compared with constructed wetlands), assuming that constructed wetlands can only replace half of each mechanical water filtration plant. It is recognised that the values for water filtration in this table are probably underestimates of the true value - construction of a filtration plant would incur fixed costs regardless of the amount or the efficiency of water filtration, and it is unlikely that fixed costs would drop in a linear fashion (as assumed in this table), and indeed may not drop at all.

TABLE 7-5. VALUE OF PERMANENT WETLANDS FOR WATER FILTRATION BASED ON THE PROPORTION OF FILTRATION THEY PROVIDE

% Filtration achieved	Water filtration $/ha/year
90	12,706
70	9,883
50	7,059
30	4,235
10	1,412

The costs and benefits of converting this area to constructed and Permanent wetlands for water filtration for a δ value of 1 are presented in Table 7-6. As can be seen, the NPV from conversion to wetlands are considerably greater than for the Status quo option, with the benefits of this option increasing with increasing filtration efficiency rates. It is worth noting that Permanent wetlands would only need a filtration efficiency of 7% of that of constructed wetlands for this option to be more profitable than the Status quo.

TABLE 7-6. COSTS, BENEFITS AND NET RETURN OF WETLANDS FOR FILTRATION USING CONSTRUCTED AND PERMANENT WETLANDS. PERMANENT WETLANDS ASSUMED TO HAVE 50% AND 90% FILTRATION EFFICIENCIES AND δ VALUE OF 1

	Status quo ($Million))	50% filtration rate for Permanent wetlands ($Million)	Net return ($Million)	90% filtration rate for Permanent wetlands ($Million)	Net return ($Million)
PV Total benefits	111.70	589.01	477.37	943.21	831.50
PV Total costs	24.75	117.38	92.63	117.38	92.63
NPV	**86.96**	**471.70**	**384.74**	**825.83**	**738.87**
BCR	4.51	5.02	5.15	8.04	8.98

While this option is clearly profitable for the community, as can be seen in Table 7-7, farmers make a net loss (NPV $28.4 Million) (i.e. lost farmer benefit ($-43.62 million) minus reduced costs (-$15.23 million)). Therefore the government would have to consider compensating farmer for this option to be undertaken.

TABLE 7-7. IMPACT ON FARMERS OF CHANGING FROM DAIRY FARMING TO WETLANDS FOR WATER FILTRATION ASSUMING 50% AND 90% FILTRATION EFFICIENCY AND δ VALUE OF 1

	Status quo Dairy Farming ($Million)	50% filtration rate for Permanent wetlands ($Million)	Net return ($Million)	90% filtration rate for Permanent wetlands ($Million)	Net return ($Million)
PV Farmer benefits	111.70	68.08	–43.62	68.08	–43.62
PV Farmer costs	15.23	–	–15.23	–	–15.23
NPV	**96.47**	**68.08**	**-28.40**	**68.08**	**-28.40**
Farmer BCR	7.34	–	–	–	–

7.3.2.2 Managed (temporal) wetlands

The figures presented above are for wetlands that are Permanent and can filter water all year. Because of the flooding effect of the locks, many wetlands in the Lower Murray fall into this category. However, the Lower Murray dairy swamps were originally temporal wetlands and water filtration only occurred when these wetlands were connected to the river; for this reason the filtration value of these wetlands would be lower than for Permanent wetlands.

The proportion of time that temporal wetlands are connected to the river varies enormously depending on the location of the wetland, wetland depth and climatic conditions. While it is difficult to provide an exact figure for the length of time of connection to the river, typically, wetlands in the region of the Lower Murray dairy swamps would have been connected to the river for approximately five months of each year (Tucker *et al.*, 2002). Table 7-8 presents the value of wetlands for other flooding periods.

TABLE 7-8. VALUE OF WETLANDS FOR WATER FILTRATION BASED ON THE NUMBER OF MONTHS CONNECTED TO THE RIVER, WITH 50% AND 90% FILTRATION RATES

Number of months connected to the river	50% Water filtration $/ha/year	90% Water filtration $/ha/year
12	7,059	12,706
10	5883	10589
8	4706	8471
6	3530	6353
5	2941	5294
4	2353	4235
3	1765	3177
2	1177	2118

The matrix presented in Table 7-9 shows the range of wetland filtration values that can be expected under different filtration efficiency percentages and months of connection to the river. This matrix provides an easy method for managers of temporal wetlands to determine the filtration value ($/ha/year) of a range of wetland management options involving flooding regimes of different durations and water filtration efficiencies. The filtration ability of any particular wetland may change over time and under different flow volumes, however as long as filtration rates can be determined for these periods, the value of wetlands for water filtration can be found. Across large wetlands areas filtration rates can vary enormously and therefore care must be taken when applying these figures. This point is illustrated by Costanza *et al.* (1989) when deriving a valuation method for wetlands based on a study by Lynne *et al.* (1981), that included the income from the harvest of blue crabs. While marginal productivity of the salt marsh was 2.3lb per acre per year and average productivity was estimated at 28 lbs per acre year, marginal productivity of effort per trap was 214lb per trap per year, while average productivity of traps was 415lb per year. Constanza *et al.* (1989) conclude that this shows the inaccuracy of using average productivities to measure environmental values.

TABLE 7-9. VALUE OF WETLANDS ($/HA/YEAR) FOR WATER FILTRATION UNDER DIFFERENT FILTRATION EFFICIENCIES AND DURATION OF CONNECTION TO RIVER

Number of months connected to river	Percentage filtration efficiency				
	10	30	50	70	90
12	1,412	4,235	7,059	9,883	12,706
10	1177	3530	5883	8236	10589
8	941	2824	4706	6588	8471
6	706	2118	3530	4941	6353
5	588	1765	2941	4118	5294
4	471	1412	2353	3294	4235
3	353	1059	1765	2471	3177
2	235	706	1177	1647	2118

Assuming that natural wetlands provide between 50% and 90% filtration values of constructed ones, we therefore expect the filtration value of Managed (temporal) wetlands to range from around $2,900 to $5,300 per hectare per year.

The costs and benefits of converting this area to a combination of constructed and Managed wetlands, where wetlands are connected to the river for five months of the year, have a water filtration for a δ value of 1, and 50 or 90% filtration efficiency are presented in Table 7-10. As can be seen, the NPV from conversion to wetlands are considerably greater than for the Status quo option. As expected, the benefits for these options increase with increasing filtration efficiency rates.

Again it is worth noting that Managed wetlands would only need a filtration efficiency of just over 6% of that of constructed wetlands for this option to be more profitable than the Status quo.

TABLE 7-10. ECONOMIC RETURN OF CONSTRUCTED AND MANAGED WETLANDS FOR WATER FILTRATION. MANAGED WETLANDS WITH δ OF 1, AND 50% AND 90% FILTRATION RATE

	Status quo ($Million)	50% filtration rate ($Million)	Net return ($Million)	90% filtration rate ($Million)	Net return ($Million)
PV Total benefits	111.70	330.83	219.13	478.39	366.69
PV Total costs	24.75	79.93	55.35	79.93	55.35
NPV	**86.96**	**250.91**	**163.95**	**398.47**	**311.51**
BCR	4.51	4.14	3.97	5.99	6.65

Table 7-11 indicates that while conversion to wetlands for water filtration is clearly profitable for the community, farmers make a net loss (NPV $28.4 million) (i.e. lost farmer benefit ($-

43.62 million) minus reduced costs (-$15.23 million)). Therefore the government would have to consider compensating farmers if this option was to be undertaken.

TABLE 7-11. IMPACT ON FARMERS OF CHANGING FROM DAIRY FARMING TO WATER FILTRATION. MANAGED WETLANDS WITH δ OF 1, AND 50% AND 90% FILTRATION RATE

	Status quo ($Million)	50% filtration rate ($Million)	Net return ($Million)	90% filtration rate ($Million)	Net return ($Million)
PV Farmer benefits	111.70	68.08	–43.62	68.08	–43.62
PV Farmer costs	15.23	–	–15.23	–	–15.23
NPV	**96.47**	**68.08**	**-28.40**	**68.08**	**-28.40**
Farmer BCR	7.34	–	–	–	–

7.3.2.3 Managed vs. Permanent wetlands

A summary of the results for converting dairy land to a combination of constructed and either Permanent or Managed wetlands is presented in Table 7-12. (The table assumes that wetlands are only 50% as effective at water filtration as are constructed wetlands and that Managed wetlands are only connected to the river for five months of the year.)

As can be seen, conversion to Permanent wetlands results in a higher BCR and NPV for the government than does conversion to Managed wetlands. The community gains between approximately $171 and $382 million in benefits from Managed or Permanent wetlands respectively for costs of between $55 and $93 million.

TABLE 7-12. SUMMARY OF ECONOMICS OF CONVERSION OF DAIRY LAND TO A COMBINATION OF CONSTRUCTED AND EITHER PERMANENT OR MANAGED WETLANDS

	Status quo	**Managed wetlands 50% filtration efficiency, δ 1**		**Permanent wetlands 50% filtration efficiency, δ 1**	
	($Million)	**Project return ($Million)**	**Net return ($Million)**	**Project return ($Million)**	**Net return ($Million)**
	A	**B**	**C**	**E**	**F**
PV Total benefits	111.70	330.83	219.13	589.01	477.37
PV Total costs	24.75	79.93	55.35	117.38	92.63
NPV	**86.96**	**250.91**	**163.95**	**471.70**	**384.74**
Community BCR	4.51	4.14	3.97	5.02	5.15

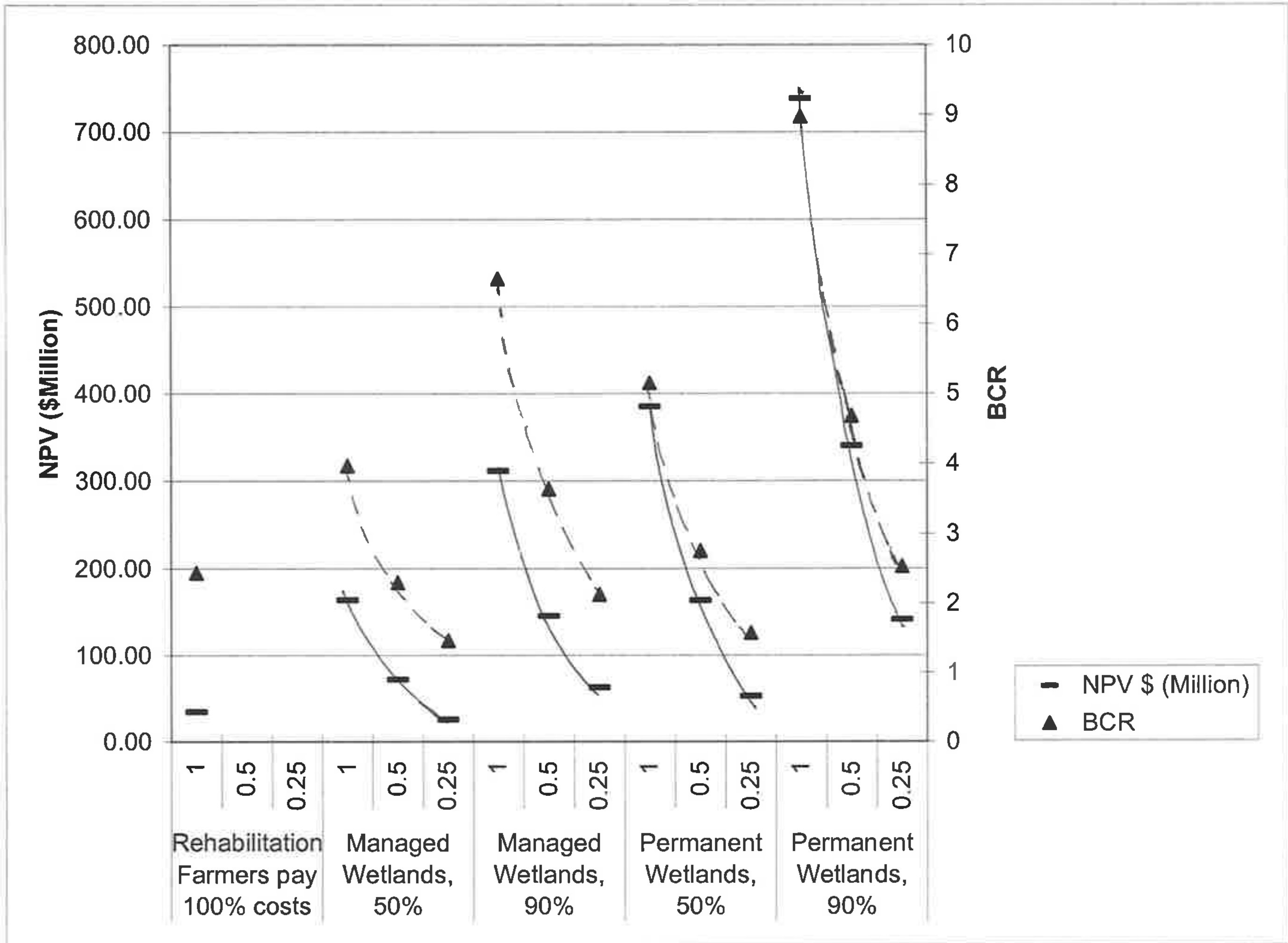
The greater return from Permanent wetlands arises because these are able to filter water for 12 months of the year (as apposed to only five months for Managed wetlands), resulting in significantly greater benefits than from Managed wetlands. However, while the higher BCR and NPV for Permanent wetlands may indicate that Permanent wetlands are a better economic choice, no value has been determined for the ecological benefits associated with returning this area to Managed wetlands similar to those that were historically present in this area. In theory, the Managed wetlands formed in this analysis will not suffer from the problems of European carp (because of screens on the inlet regulators), will be managed for weeds and pests and have controlled wetting and drying cycles. The biology of these wetlands should therefore be closer to the original environment of the Lower Murray swamps prior to their conversion to dairy farming land.

It is difficult to know if these benefits and others, such as the restoration of fish and bird habitat, the management of storm and flood waters, carbon sequestration, nitrogen assimilation and climate moderation, would be greater for Permanent or Managed wetlands without further research. However, the restoration of the original habitat may encourage the return of species that can only survive on wetlands that are temporal in nature. Regardless of which wetland type is chosen, given the huge volumes of water that currently flow through the Lower Murray without wetlands to provide any of the natural filtration that originally occurred, the restoration of this area would have considerable benefits for all flora and fauna all the way to the Coorong.

7.3.3 Comparison with rehabilitation

The results from Part II of the thesis show that rehabilitation of the irrigation system is very profitable. However, when compared to converting this area to wetlands for water filtration, Figure 7-4 shows that water filtration options generally result in a higher NPV. It is only when Managed wetlands are assumed to have a filtration efficiency of 50% and a δ value of only 0.25, that the Piped rehabilitation option has a greater NPV.

FIGURE 7-4. COMPARISON OF NPV AND BCR OF REHABILITATION AND WETLAND OPTIONS



7.4 Discussion

View 1: These results indicate that when the filtration value of wetlands is included in this analysis, converting the whole area to wetlands for water filtration is a far more profitable option than remaining with the Status quo, even where excess water is assumed to have a marginal utility of 0.25 and the wetlands formed are only 50% efficient in filtering water. Wetlands are also generally more profitable than rehabilitation of the dairy farming system.

Few studies have been undertaken into the value that people place on domestic water quality, or the cost to the environment of its supply. However, contingent valuation studies recently conducted in New Zealand by Kerr *et al.* (2001, 2003) show that the community can place high values on water quality especially where they can avoid the need for chemical water filtration. Kerr *et al.* (2001, 2003) found that residents were willing to pay $628 per household per year to maintain a water supply that was naturally filtered. Assuming 2.5 persons per household (Statistics NZ, 2003), this is equivalent to NZ$251 per person per year, which is remarkably similar to the costs paid by South Australian residents for the mechanical water filtration required now that the natural wetlands filtration system has been removed (see Part I).

At the same time, Kerr *et al.* (2003) undertook a CV study to determine willingness to pay per household to switch to an alternative water source that ensured that residents' water supply did not affect wetland flows and that avoided the need for water rationing. The results from that study indicate that residents place significant values on the preservation of wetlands. The highest value that people were able to choose in the study was a $400 (increase in rates per household per year), however maximum likelihood estimations methods used to fit response models to the data show that the mean and medium were both in excess of this amount – a logistic model showed Christchurch residents were willing to pay $527 per household per year. Kerr *et al.* (2003) conclude that the inclusion of a higher money value would have been advantageous. (This study highlights one of the problems identified with choice experiments – participants could not choose a higher value even if they had wanted to.) While it is uncertain what part the avoidance of water rationing played in reaching this figure, environmental concerns were clearly an important factor. Kerr *et al.* (2003) further state that responses from people uniformly indicated a strong commitment to environmental preservation, with many arguing along the lines of "$4 per week is a very low cost to preserve the environment".

The fact that the break-even values for wetlands in this thesis are so low, requiring Permanent or Managed wetlands to be far less efficient than the filtration plants, means that the water filtration efficiency of these wetlands only has to be around 11% of that of the mechanical water filtration plants for conversion of the whole of this area to a combination of constructed and either Managed or Permanent wetlands to be the best economic choice. Thus, wetlands do not have to be extremely efficient at filtering water to be very valuable to the community. Given that over 10% of the Australian population draws water from the River Murray for stock and domestic use, the preservation of wetlands along this river would seem to be of considerable value.

7.4.1 Wetland valuation technique

View 2: The results from this section (valuation of filtration benefits for the environment) show the significant value that wetlands have when their worth is based on the cost of replicating their filtration function. The values determined for water filtration in this thesis of around $7,100 per hectare per year (when replacing half of each filtration plant at 50% efficiency) and $12,700 per hectare per year (when replacing half of each of the filtration plants at 90% efficiency) are consistent with the four studies mentioned earlier: Costanza *et* *al.* (1997) place values of US$7,977 per hectare per year on wetlands for water supply and waste treatment; Lerner and Pool (1999) estimated an annual value of water quality improvement provided by wetlands along a 5.5 km stretch of the Alchovy River in Georgia, USA to be worth US$3 million; New York City is spending US$1.5 billion in restoration costs to protect 80,000 acres (approx 32,400 ha) of watershed lands (including some wetlands), saving the community an annual operating costs of $300 million, i.e., $9,259 per hectare per year (Commission on Geosciences, 2000) and a Swedish study (Maltby, 1991) suggests nutrient retention in wetlands can be worth up to US$200,000 per hectare.

Significantly if we compare the values determined in this thesis for Managed (temporal) wetlands (ranging from around $2,900 to $5,300 per hectare per year) with those cited in Chapter 3 from previous choice modelling studies (Morrison, 1998; Petersen and Bennett, 2003) of between $82 and $300 per hectare per year, it is clear that the values determined in this study for filtration value alone are easily in excess of the values currently attributed to wetlands based on peoples willingness to pay[7]. This suggests that choice experiments are unable to capture the value of resources where legislation fails to make people accountable for their environmental impacts.

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[7] It is acknowledged that significant problems arise when attempting to transfer benefits from one environmental study to another. Desvousges *et al.* (1992) state that to transfer a value from one study site to another:

1. The study site and the policy site need to be similar
2. The environmental change as the policy site needs to be similar to the environmental change at the study site, and
3. The socio-economic characteristics of the population and other details need to be similar.

These criteria make it extremely difficult to transfer environmental benefits from one study to another. It is therefore normal to establish a 'threshold value' and to compare that value to those obtained from other studies. However, having established a threshold value, the problem still remains of the choice of previous studies to compare this value with - it seems ironic that while resource economists are specifically warned against incorporating values determined from other studies, it is common practice to determine threshold values and then compare these with known values from other studies to see if our results are 'in the ball park'.

This failure to capture these values may arise from the way that choice experiments are designed and run. As mentioned earlier, most choice experiments are based on Lancaster's (1996) theory. Lancaster (1991) observes that when valuing an object many of the characteristics may be irrelevant from either a technical supply perspective or a human demand perspective. Blamey *et al.* (1997) state that from a human demand perspective, a characteristic is irrelevant if it has no bearing on consumer choice, irrespective of whether it is technically irrelevant. They further state that attributes that are irrelevant for any reason are typically excluded from choice sets in CM studies, although those that are technically irrelevant, but demanded by consumers when evaluating products, may sometimes be included.

This exclusion of attributes because they are not identified by the consumer (based on ignorance, perhaps, or the knowledge that governments will provide services such as water filtration even if wetlands are destroyed) can have an impact on the options chosen. What if an important function (such as water filtration) is not identified and therefore cannot be chosen? Because the interaction of all attributes (identified and not identified) can affect the possible levels of other attributes, such questions and combination of levels of attributes can become meaningless.

An example of this problem occurs when respondents are asked to value components such as 'waterway health', with the question arising of whether they really know what they are referring to. Van Buren and Bennett (2000) indicate that respondents in their study are valuing the recreational activities and preservation of habitats, defined in terms of fishing and swimming opportunities. There is no doubt that these values are important, but do they really reflect the health of a waterway or are they simply reflecting attributes respondents can see or feel, but not the intricate functions of wetlands themselves? If respondents do not find a wetland pleasant to look at, are they likely to want to preserve it? Alternatively, if the intricate function of a wetland is disturbed (for example, by chemical spillage), would this necessarily affect the aesthetics and recreational value of the wetland if respondents were not aware that these things are happening and related?

It is important to note that wetland valuation figures based on choice experiments to date in Australia have not specifically included wetland functions such as water filtration, pollution assimilation and life support. Thus, while choice modelling may throw light on people's preferences for individual attributes as presented, it may not take into account the value of important attributes not identified by consumers, the implications of attribute interactions, or the practicalities of such choices. We would therefore have to question the appropriateness of relying on values derived from people's willingness to pay for wetland attributes when determining wetland fates. Perhaps then, the strength of choice modelling in wetland valuation is its ability to rank public preferences for 'identified attributes', rather than to apply dollar figures to public goods.

Placing an upper bound on the amount that people are able to choose to pay (as has occurred in all CM studies of wetland value in Australia) places an upper limit on the value that wetlands can have. Therefore respondents in the studies mentioned earlier could not have valued wetlands at say $7,100 per hectare per year even if they had wanted to, and had the funds to do so. The option was not there. In the same way, requesting that a one-off lump sum will be paid also biases the results, as some respondents may prefer to pay a smaller amount over a longer period. This point is made by White *et al.* (2001) who showed that evidence from their study suggests that when payment types are standardised, annual figures tend to provide higher willingness-to-pay values than single one-off payments.

Another major form of bias that may lead respondents to place a lower value on wetland restoration/preservation/establishment is the presumption that they individually (as opposed to society as a whole) would have to pay for it. Bennett (1999) states that "an important component of the proposed solution must be a payment vehicle. The solution must be viable only if funds can be generated to pay for it and those funds must come from respondents indicating willingness to pay." As indicated in the earlier studies, respondents are not used to having to purchase these 'goods' and have no idea of their market value as, in Australia, no market exists. Similar questions relating to respondents willingness to pay for public goods such as road improvement would also be likely to fall short of the revenue raised per person via taxes for road maintenance. This leads to the question: is it sensible to ask respondents to privately fund a public good, especially where access to that public good is not controlled or regulated?

7.4.2 Mitigation Banking

These results have significant implications for the introduction of a wetland mitigation banking system in this area. If farmers in this region decided to give up farming and assumed all costs associated with returning their land to Permanent or Managed wetlands, they could possibly make profits of $5,552 and $2,034 per hectare per year when wetland credits were sold (assuming wetland credits are worth around $7,100 and $2,900 per hectare per year for Permanent and Managed wetlands, respectively, based on their water filtration function alone –50% filtration efficiency). The amount of profit obviously depends on the costs associated with restoring the wetlands and their percentage filtration efficiency. If these wetlands were more efficient at filtering water than the break-even figures, farmers could make even more profit off this land.

If it was necessary to construct wetlands for water filtration from scratch (involving earthworks, planting and construction costs), then the profitability would decline. The costs associated with wetlands in this thesis are greatest where wetlands are constructed to replace part of each water filtration plant. These constructed wetlands cost $100,000 per hectare to build and plant (equivalent to NPV $6,401 per hectare per year). This cost is considered to be low because, in effect, construction of these wetlands was restoration of an existing wetland, with the added bonus of being able to utilise the existing levee banks, pumps and water inlet /outlet structures from the existing irrigation scheme. However, where such facilities do not exist, the commercial costs of wetland construction (for filtering stormwater) average around $250,000 per hectare (equivalent to $15,300 per hectare per year (3.55% discount rate), (Breen, pers.com.).

These figures suggest that if legislation required the construction of mitigation wetlands that are able to provide the same services as natural wetlands, the value of water filtration from such wetlands can be expected to be around $15,300 per hectare per year. Even if we assume that natural wetlands provide between 50% and 90% of the filtration value of a constructed wetland (which may mean a reduction in mitigation wetland construction costs), this still places a value of between $7,650 and $13,800 per hectare per year for the water filtration services from natural wetlands. Thus, the figures determined in this thesis for the value of water filtration by wetlands when replacing part of each filtration plant are easily within the bounds of those that would be expected if mitigation was a legal requirement.

7.4.3 Other values

This thesis has not considered the additional values that wetlands might have if functions such as wastewater treatment, carbon credits, nitrogen sequestration, human and stock health, the survival of different species, or increases in tourism had been incorporated into the model.

Had the value of these functions been included, it would be expected that wetlands values would be considerably greater than they now are. Because stormwater and run-off from highland farming regularly enters the river via the Lower Murray dairy swamps, the value for wastewater treatment could be substantial.

Currently, the value of tourism associated with the river for this region per year is approximately $54 million, and, as the government swamps comprise approximately 81% of this area, the value of tourism associated with the swamps is approximately $44 million. We have no idea whether people who come to holiday on the Murray enjoy gazing at cows grazing along the river or whether they would prefer the area to be in wetlands. Many tourists would have no idea of the impact that the dairy swamps have on water quality, and may appreciate the variety in landscape that the grazing cows present. However, it is safe to assume that tourism figures may indeed rise once cows are removed.

7.4.4 Land use of choice

In this study the use of wetland values based on only one wetland function – filtration – results in wetlands becoming the land use of choice. It is important to remember that the range of filtration values used for the 'natural' wetlands in this analysis ($7,100 to $12,700) assume that wetlands are only half as effective at water filtration as constructed wetlands would be. In fact, natural wetlands may be of similar efficiency, and therefore the values used here must be viewed as conservative.

While the number of wetland complexes along the Murray continues to decline, each of these complexes is able, in its natural state, to provide water filtration services to the large number of rural and urban towns located along the length of the Murray – the Murray–Darling Basin is home to 1.9 million people and contains Australia's major inland urban centres, including

Albury–Wodonga, Canberra–Queanbeyan, Bendigo and Wagga Wagga (The Department of Industry Science and Resources, 2000). The Murray is also a major source of water for around 1.25 million people living outside the Murray–Darling Basin in South Australia, with the city of Adelaide drawing up to 90% of its mains water from the Murray in a drought year (this water is filtered via treatment plants in addition to those in the thesis study region) (Government of South Australia, 2005).

8 PIPED REHABILITATION AS STATUS QUO

The Status quo scenario used in this thesis is the state of the lower Murray dairy swamps at the commencement of the thesis, and thus if forms the appropriate basis to compare land-use options in South Australia in this region prior to the construction of water filtration plants or irrigation rehabilitation. Indeed the methodology used in this thesis could be applied to any areas where primary production is polluting the river, and options for rehabilitation need to be considered.

However, it has been argued that as the Status quo situation is unsustainable – the pollution of the river could not continue – and that in such a situation a sustainable farming scenario (such as the Piped rehabilitation option described in the thesis) could be used as the basis to compare other scenarios against. This suggestion is addressed in this chapter of the thesis. The comparison with the Piped rehabilitation scenario indicates whether this land should be converted to wetlands for water filtration even where a profitable, low polluting industry exists, and thus the results may have implications for other farming regions.

This chapter presents results for comparison with the Piped rehabilitation option in the same format as used previously in the thesis. Because it has already been established earlier in the thesis that converting this area to wetlands for pollution alleviation alone (i.e. without including a value for wetlands for water filtration) is not economic, the results for Part II are not re-presented in this section, but can be found in Appendix 8. A short discussion then follows addressing the implication of this base scenario choice.

It is important to recall that the value of wetlands for water filtration determined in this thesis is independent of whichever scenario is used as the basis for comparison.

8.1 PART I RESULTS

8.1.1 Step 3: Comparison with Piped rehabilitation

While it is clear that wetlands are very valuable when included as part of the water filtration system, the question arises of how this land use compares with dairy farming if the dairy swamps were rehabilitated using the Piped irrigation system.

For farmers, converting this land to wetlands would mean a loss of farming income, but farmers would receive an income from water sales, while the Piped rehabilitation would increase farmer's income from dairy farming address most of the water pollution problems. Both Piped rehabilitation and wetland construction come at considerable cost.

As can be seen from Table 8-1, it is more profitable to convert this part of the dairy swamps to wetlands for water filtration (rather than Piped rehabilitation) because of the large benefit of a reduction in the water filtration plants costs. While the BCR for water filtration is lower than for Piped rehabilitation, the NPV is substantially higher, resulting in a greater economic return.

TABLE 8-1. COMPARISON OF ECONOMIC RETURN FROM CONVERTING DAIRY SWAMPS TO CONSTRUCTED WETLANDS TO REPLACE HALF OF THE WATER FILTRATION AND UV SYSTEM

	Piped rehab ($Million)	Water Filtration ($Million)	Net Return ($Million)
TOTAL Community benefits	16.75	85.03	68.27
TOTAL Community costs	4.79	37.48	32.68
NPV	11.96	47.55	35.59
Community BCR	3.49	2.27	2.09

As seen in Table 8-2, farmers' benefits are higher for Piped rehabilitation than from the sale of their irrigation water on the open market under the water filtration option. However, while farmers do not have any costs associated with water filtration, their reduction in farming costs does not offset their loss of income, therefore farmers lose approximately $5.6 million from this land use change.

TABLE 8-2. IMPACT ON FARMERS OF CHANGING FROM DAIRY FARMING TO CONSTRUCTED WETLANDS FOR WATER FILTRATION ON AREA A1

	Piped rehab Dairy Farming ($Million)	Water Filtration ($Million)	Net Return ($Million)
PV Farmer benefits	16.75	6.71	–10.05
PV Farmer costs	4.79	–	–4.42
NPV	11.96	**6.71**	**-5.63**
Farmer BCR	3.50	–	–

Clearly it is unlikely that this project would proceed if farmers knew they would be losing money by giving up dairy farming. For this reason the government must compensate farmers by $5.6 million to leave the land, at which point the farmers' BCR equals one. It is possible that the government may actually have to pay the farmers slightly more than this amount as an incentive to go.

8.2 PART III RESULTS

8.2.1 View 1: Declining value of δ between 0.25 and 0.5

Even with filtration rates of 50% (meaning that Permanent wetlands are worth only around $7,100 per hectare per year) and a δ value of 0.25, conversion of this area to wetlands for water filtration and pollution alleviation is more profitable than the Piped rehabilitation option. The NPV decreases with decreasing values of δ, however δ would have to be 0.21 and 0.12 for break even with 50% and 90% filtration efficiencies, respectively using Permanent wetlands.

The costs and benefits of this land use option for a δ value of 0.5 are presented in Table 8-3. As expected, the benefits for these options increase with increasing filtration efficiency rates.

TABLE 8-3. COSTS, BENEFITS AND NET RETURN OF WETLANDS FOR FILTRATION USING CONSTRUCTED AND PERMANENT WETLANDS. PERMANENT WETLANDS WITH 50% AND 90% FILTRATION EFFICIENCIES, AND δ OF 0.5

	Piped rehab ($Million)	Wetlands 50% filtration rate ($Million)	Net return ($Million)	Wetlands 90% filtration rate ($Million)	Net return ($Million)
PV Total benefits	170.07	367.74	197.67	544.80	374.73
PV Total costs	48.66	117.38	68.71	117.38	68.71
NPV	**121.41**	**250.82**	**128.95**	**427.43**	**306.02**
BCR	3.50	3.13	2.88	4.64	5.45

As indicated in Table 8-4, farmers stand to lose around $57.09 million if this area is converted to wetlands for water filtration. The government must therefore consider compensating farmers by at least this amount if they want farmers to leave the land so that his option can proceed.

TABLE 8-4. IMPACT ON FARMERS OF CHANGING FROM DAIRY FARMING TO WATER FILTRATION ASSUMING 90% FILTRATION EFFICIENCY AND δ OF 0.5

	Piped rehab ($Million)	Water Filtration ($Million)	Net return ($Million)
PV Farmer benefits	170.07	68.08	–101.99
PV Farmer costs	44.90	–	–44.90
NPV	**125.17**	**68.08**	**-57.09**
Farmer BCR	3.79	–	–

As mentioned in section 7.33, the only time that wetlands do not provide a greater economic return than from Piped rehabilitation is where Managed wetlands have a filtration efficiency of 50% and a δ value of 0.25, as can be seen in Table 8-5.

TABLE 8-5. COSTS, BENEFITS AND NET RETURN OF WETLANDS FOR FILTRATION USING CONSTRUCTED AND MANAGED WETLANDS. MANAGED WETLANDS WITH 50% AND 90% FILTRATION EFFICIENCIES, AND δ OF 0.25

	Piped rehab ($Million)	Wetlands 50% filtration rate ($Million)	Net return ($Million)	Wetlands 90% filtration rate ($Million)	Net return ($Million)
PV Total benefits	170.07	192.51	22.44	229.40	59.33
PV Total costs	48.66	79.93	31.26	79.93	31.26
NPV	**121.41**	**112.58**	**-8.83**	**149.47**	**28.06**
BCR	3.50	2.41	0.72	2.87	1.90

8.2.2 View 2: Value of filtration benefits for the environment (δ value of 1)

8.2.2.1 Permanent wetlands

The costs and benefits of converting this area to constructed and Permanent wetlands for water filtration for a δ value of 1 are presented in Table 8-6. As can be seen, the NPV from conversion to wetlands are considerably greater than for the Piped rehabilitation option, with the benefits of this option increasing with increasing filtration efficiency rates. It is worth noting that Permanent wetlands would only need a filtration efficiency of 10.5% of that of constructed wetlands for this option to be more profitable than Piped rehabilitation.

TABLE 8-6. COSTS, BENEFITS AND NET RETURN OF WETLANDS FOR FILTRATION USING CONSTRUCTED AND PERMANENT WETLANDS. PERMANENT WETLANDS ASSUMED TO HAVE 50% AND 90% FILTRATION EFFICIENCIES AND δ VALUE OF 1

	Piped rehab ($Million)	50% filtration rate for Permanent wetlands ($Million)	Net return ($Million)	90% filtration rate for Permanent wetlands ($Million)	Net return ($Million)
PV Total benefits	170.07	589.01	419.00	943.21	773.13
PV Total costs	48.66	117.38	68.71	117.38	68.71
NPV	**121.41**	**471.70**	**350.29**	**825.83**	**704.42**
BCR	3.50	5.02	6.10	8.04	11.25

While this option is clearly profitable for the community, as can be seen in Table 8-7 farmers make a net loss (NPV $57.09 Million). Therefore the government would have to consider compensating farmer for this option to be undertaken.

TABLE 8-7. IMPACT ON FARMERS OF CHANGING FROM DAIRY FARMING TO WETLANDS FOR WATER FILTRATION ASSUMING 50% AND 90% FILTRATION EFFICIENCY AND δ VALUE OF 1

	Piped rehab ($Million)	50% filtration rate for Permanent wetlands ($Million)	Net return ($Million)	90% filtration rate for Permanent wetlands ($Million)	Net return ($Million)
PV Farmer benefits	170.07	68.08	–101.99	68.08	–101.99
PV Farmer costs	-44.90	–	–44.90	–	–44.90
NPV	**125.17**	**68.08**	–57.09	**68.08**	**-57.09**
Farmer BCR	3.79	–		–	–

8.2.2.2 Managed (temporal) wetlands

The costs and benefits of converting this area to a combination of constructed and Managed wetlands, where wetlands are connected to the river for five months of the year, have a water filtration for a δ value of 1, and 50 or 90% filtration efficiency are presented in the table below. As can be seen in Table 8-8, the NPV from conversion to wetlands are considerably greater than for the Piped rehabilitation option. As expected, the benefits for these options increase with increasing filtration efficiency rates.

Again it is worth noting that Managed wetlands would only need a filtration efficiency of just under 15% of that of constructed wetlands for this option to be more profitable than Piped rehabilitation.

Table 8-8. Economic return of constructed and Managed wetlands for water filtration. Managed wetlands with δ of 1, and 50% and 90% filtration rates

	Piped rehab ($Million)	50% filtration rate ($Million)	Net return ($Million)	90% filtration rate ($Million)	Net return ($Million)
PV Total benefits	170.07	330.83	160.76	478.39	308.32
PV Total costs	48.66	79.93	31.26	79.93	31.26
NPV	**121.41**	**250.91**	**129.50**	**398.47**	**277.06**
BCR	3.50	4.14	5.14	5.99	9.86

Table 8-9 indicates that while conversion to wetlands for water filtration is clearly profitable for the community, farmers make a net loss (NPV $57.09 million). Therefore the government would have to consider compensating farmers if this option was to be undertaken.

Table 8-9. Impact on farmers of changing from dairy farming to water filtration. Managed wetlands with δ of 1, and 50% and 90% filtration rates

	Piped rehab ($Million)	50% filtration rate ($Million)	Net return ($Million)	90% filtration rate ($Million)	Net return ($Million)
PV Farmer benefits	170.07	68.08	–101.99	68.08	–101.99
PV Farmer costs	44.90	–	–44.90	–	–44.90
NPV	**125.17**	**68.08**	**-57.09**	**68.08**	**-57.09**
Farmer BCR	3.79	–	–	–	–

8.3 Discussion

The results present in this section indicate that even though it is more profitable for farmers to rehabilitate the dairy swamps using a Piped irrigation system, the value to the community is greatest when this areas is converted back to wetlands for water filtration (using the values determined in this thesis for wetlands for water filtration). The only time when conversion to wetlands provides a smaller economic return than from the Piped rehabilitation option (and the difference is small in comparison with overall cost and benefits of the project)) is when Managed wetlands are assumed to have a 50% filtration efficiency rate and a δ value of only 0.25.

The greatest effect that the choice of base scenario – either Status Quo or Piped rehabilitation - has on the results is on the amount of compensation that the government would have to offer farmers to leave the land. This is because rehabilitation results in increased dairy income and thus conversion to wetlands would result in greater income losses for farmers. A summary of the amount of compensation required for each base casse scenario is presented in Table 8-10.

TABLE 8-10. A COMPARISON OF THE AMOUNT OF COMPENSATION REQUIRED FOR FARMERS FOR DIFFERENT LAND USE OPTIONS AND BASE CASE SCENARIOS

	Part I Wetlands for water filtration plant ($Million)	Part III Water filtration plant plus wetlands ($Million)
Status Quo	2.8	28.4
Piped rehab	5.6	57.09

9 SUMMARY AND IMPLICATIONS FOR FUTURE RESEARCH

Very little information exists in Australia on the ability of natural wetlands to filter water. This factor, in combination with the interdisciplinary skills required to assess the value of this environmental service, has probably been the main reason why previous resource economists relied on questionnaires seeking peoples' 'willingness to pay' to determine wetland values. Unfortunately such valuation methods are unable to capture wetland functions such as water filtration, because the public generally has little idea of what such functions are worth. This has resulted in wetlands being seriously undervalued, thereby providing misleading grounds for their destruction.

9.1 CONTRIBUTION TO METHODOLOGY

The methodology developed in this thesis addresses this lack of knowledge by focusing on the value of the water filtration process itself. It looks at the actual costs involved in building and running water filtration plants and thus determines the cost to the public of mechanically filtering water. The thesis then examines how much of these costs could be saved by utilising constructed wetlands to undertake all or part of the filtration process. In this way, the commercial value of wetlands for water filtration is determined. The thesis goes on to demonstrate the considerable value of water filtered by wetlands, even where the volume of water filtered is in excess of that required for domestic consumption (i.e. diminishing marginal utility).

The thesis then addresses the problem of valuing natural (rather then constructed) wetlands. It argues that if legislation required those who destroy natural wetlands to replace the water filtration process the wetlands once provided, it would be necessary to construct water filtration plants. The thesis then develops the methodology required and presents the equations for valuing natural wetlands based on the cost of mechanically undertaking the filtration process. The methodology devised in this thesis allows for variations in wetland filtration efficiency and in the amount of time wetlands are attached to the river - two important variables that make valuation of natural wetlands so difficult (Table 7.9). The methodology uses the water filtration plant costs avoided as a reference point, and thus wetlands can be valued based on the percentage water filtration efficiency they are naturally able to achieve relative to the filtration plant. This means that wetlands that are less efficient at water filtration are worth less than those that have higher filtration rates.

The introduction of a time component into the equation makes it possible to value wetlands which are temporal in nature and are only able to filter water for certain times of the year when they are attached to the river. This methodology therefore provides an important tool for helping other researchers to determine the economic value of any particular wetland they might study.

The thesis determines that the value of wetlands for water filtration is approximately $7,100 per hectare per year for Permanent wetlands. This figure substantially exceeds the economic return for all other land uses considered in this thesis (including income from dairy farming after rehabilitation of the irrigation scheme), and thus the most economically valuable use of the dairy swamp land is for wetlands for water filtration and that their proper valuation should primarily be based on this use.

The value of around $7,100 per hectare per year must be viewed as conservative for the following reasons:

- It assumes that wetlands could only replace the primary and secondary filtration processes of each water filtration plant (for much of the year it they are able to replace all of the filtration process).
- It assumes that natural wetlands are only half as efficient as constructed ones at providing filtration benefits, while existing literature shows that they may be up to 97% as effective.
- This value is based on the costs of the water filtration plant to provide water filtration, and assumes a linear reduction in wetland value as wetland water filtration efficiency drops, i.e. if wetlands are only half as efficient at filtering water as the filtration plant, they would save only half the filtration plant costs. In fact while it might be expected that chemical and sludge disposal costs associated with the filtration plant would change with changes in filtration efficiency, the fixed costs and many of the running costs associated with filtration plants would still be incurred and thus wetland filtration values may be greater than this figure.
- The many other benefits to waterways (e.g., removing other harmful algae and other water pollutants) that are by-products of the water-filtering function of wetlands are not included (because of a lack of reliable estimates for them).

At the same time, it is recognised that even though modelling shows that wetlands are worth at least $7,100 per ha for water filtration, there is great variability in wetland efficiencies and in wetland types across regions and therefore care must be taken when using these figures in other regions.

This thesis questions the rationale of wetland valuation methods which involve asking people about their willingness to pay for saving, maintaining or extending wetlands, and of relying on these estimates (which ignore the water-filtering function of wetlands) when decisions on wetlands are made. Such estimates can only be useful when considered in conjunction with valuation methodologies based on environmental functions. The potential loss of social benefits resulting from a valuation system that incorrectly overlooks environmental services such as water filtration has been shown in this thesis to be substantial.

It seems peculiar to environmental public goods that attempts are made to value them based on 'willingness to pay' methodologies, while other public goods are not treated in the same way e.g., people are not asked about their willingness to pay for public education, (nor is the value of education determined from its individual component such as literature and numeracy etc), nor are people asked about their willingness to pay for defence, and its value determined by components such as guns, troops and tanks. This type of questioning would seem illogical – it is fundamentally understand that the many services that education and defence provide cannot be disseminated into simple parts. And yet this same logic is not applied to the environment.

9.2 POLICY IMPLICATIONS

The results from this thesis indicate that if wetlands were used as part of the drinking water filtration process they could provide an extremely valuable service to the community. Unlike New York City, which made the decision to include natural water filtration processes as part of its water filtration system, the South Australian government does not appear to have considered using wetlands as part of the new filtration system. Indeed, it would seem that in Australia the value of this service is consistently overlooked.

The results from this thesis suggest that resource economists need to pay more attention to valuing wetlands as a series of key processes and to working in conjunction with researchers from other disciplines to understand such things as filtration and the impact of wetting and drying cycle. In support of this notion, Barbier *et al.* (1997) state that "regardless of the method selected to value wetlands, an interdisciplinary approach will be needed at virtually all stages in the assessment, and this should particularly involve collaboration between economists and ecologists."

The set of factors that have caused the valuation of wetland functions to be overlooked – the 'invisibility' of the functions performed, the complex nature of these functions, and the need for more interaction between economists and others involved in the research and development process – means that the government is poorly equipped to make investment decisions where wetlands are concerned. This has probably been partially or predominately responsible for the lack of legislation which ensures accountability and safeguards against ill-judged wetland destruction. This also highlights the difficulty of ensuring the allocation of money for environmental projects where the benefits are not clearly visible or understood by the public.

The difficulty for the government is the decision to allocate substantial funds to projects that do not show immediate or visible results. The government thus has to decide if it is willing to spend significant amounts of money for environmental benefits.

9.2.1 Implementation of policy implications

The value for wetlands determined in this thesis easily exceeds all other values determined for wetlands based on alternative non-market valuation techniques. Thus, the economics of converting this area to wetlands rests on the methodology chosen to determine wetland values – if wetlands are valued based on people's willingness to pay, it is unlikely that restoring this whole area to wetlands would be an economic choice. However, if the estimated value of wetlands includes their various functions (e.g., at a reasonable estimate of around $7,100 per hectare for their water filtration function), then it is in the interest of the community (or the government) to return this area to wetlands.

Following the example set in the United States, Australia should consider the introduction of a wetland mitigation banking system whereby businesses (or individuals) who enhance or restore wetlands are provided with wetland 'credits' that they are able to sell to needy developers. Such a system would help to ensure the protection of the important functions wetlands provide, a very valuable one of which is water filtration. Such a system could halt the destruction of wetland areas, or provide the incentive to rehabilitate degraded areas, and not only yield environmental benefits but have tangible economic benefits, based on market prices.

If a wetland mitigation banking system was adopted in the study area it would provide farmers with the opportunity of choosing to bear the cost of returning these areas to wetlands in return for being able to sell the resulting wetlands credits to developers in the region who may, for example, wish to convert wetland areas into marinas, and who require development off-sets (as occurs in the United States). A mitigation banking system would also allow for long-term land use planning, with farmers able to rehabilitate land and then 'bank' the credits in anticipation of future development needs. Given the additional benefits that wetlands can provide (e.g., flood mitigation and habitat), the government would be wise to consider this important option.

There is now some evidence that natural resources in Australia are beginning to be valued in different ways. Recently, amendments to the *Native Vegetation Act* (1991) by the South Australian Government have resulted in the proposal for the introduction of a credits system for the clearance of native vegetation. These amendments provide that the clearance of native vegetation must be conditional on a significant environmental benefit (SEB) to offset the clearance as determined by the Native Vegetation Council (2005). The implications of this system on the value of native vegetation can be quite considerable. For example, a landholder wanting to remove one tree may be required to off-set an area of 2.2 hectares if the area planned for the offset is of low habitat value. The costs of this off-set can be quite high, with fencing alone costing between four and eight thousand dollars per kilometre.

There are now plans for the establishment of an environmental mitigation banking system so farmers and industry can take real advantage of credits established.

9.3 LIMITATIONS

One of the issues to be considered in this analysis is that the benefits determined for wetlands from water filtration are based on the average cost of the water filtration plants in this region. How would these benefits change with a change in the cost of the filtration plants or if new technologies were used?

As can be seen from Table 9-1, the filtration costs associated with the Riverland plants in this analysis (resulting in a filtration cost of 14.1 cents per Kl), are at the lower end of the scale. As water filtration plant size becomes smaller (i.e., the plant has a smaller filtration capacity per day), average filtration costs rise, reflecting the economies of scale. However, while the filtration plant at Happy Valley, for example, can produce filtered water at less than half the price of the filtration plant at Myponga, the value of wetlands for water filtration may still rise (albeit at a smaller rate), depending on the proportion of fixed and operating costs.

TABLE 9-1. CAPACITY AND WATER FILTRATION COSTS (CENTS/LITRE) OF WATER FILTRATION PLANTS IN SOUTH AUSTRALIA

Source SA Water (pers com)

	Capacity Ml/day	Cents/Kl
Conventional plants		
Happy Valley	850	10
Riverland plants	270	14.1 (average)
Morgan	200	15
Myponga	50	25
Microfiltration plants		
Mt Pleasant	2.5	30
Small plants	0.2	50

The Riverland plants in this analysis use the standard sedimentation/flocculation technology used in most conventional filtration plants throughout the world at the time that they were commissioned (1993). An alternative to this technology is microfiltration, which, at the time these plants were being commissioned, was in its infancy and therefore not presented as an alternative filtration option.

Since that time, improvements in technology mean that microfiltration techniques (whereby water is passed through a filtration membrane) are being seen as an alternative filtration option, particularly in areas where only small volumes of filtered water are required. Depending on the quality of the water to be filtered, it may be necessary to pre-treat the water before it goes through the filtration membrane, or to chlorinate the water after treatment. Obviously, the need for these processes will affect the filtration costs.

Microfiltration plants have advantages over the current filtration system – because water is filtered through a membrane the system does not involve the use of chemicals, and therefore the products of filtration will not pollute the environment. Plants can also be automated, thereby reducing the number of staff required to keep the plant running. A microfiltration plant constructed at Mt Pleasant supplies 2.5 Ml of water per day, at a cost of 30 per Kl. While this filtered water comes at around twice the cost of that from the Riverland filtration plants, it was determined by SA Water that this system was less expensive than the construction of a traditional filtration plant. It is estimated that for very small filtration plants (e.g., 0.2ml per day) filtration cost would be around 50 cents per Kl. This is still expected to be considerably less expensive than the construction of a traditional plant in these remote locations.

The figures presented above indicate that if the benefit (and consequent value) of wetlands for water filtration was based on the costs associated with smaller plants, then on a per hectare basis they would rise, as the costs associated with these plants would be considerably greater (per Kl water filtered). This suggests that the benefits associated with wetlands in this thesis may actually underestimate their true value, and highlights one of the substantial benefits of returning areas to wetlands – there is no need to construct a filtration plant capable of filtering only small volumes when the same process could be achieved for little capital investment.

The economics of using wetlands to replace mechanical filtration plants will also depend on the cost of wetland construction. In the example in this thesis, if it were necessary to construct wetlands from scratch, their cost would increase significantly, possibly rising from $100,000 to $250,000 per hectare. If such wetlands could only replace half of the mechanical plant, their cost ($15,593 per ha per year) would slightly exceed their benefits ($14,118 per hectare per year), (BCR 0.91). If however they could replace the whole plant, their value would rise to $28,032 per hectare per year, and thus it would be more economic to use constructed wetlands than to build a mechanical filtration plant. (It must be remembered that the cost of $250,000 per hectare is based on wetlands constructed for the treatment of storm and wastewater. Such waters would have significantly greater pollutant loads and possibly different wetland requirements than the water in this study).

A further issue to be considered is the question of whether wetlands should be used to replace part or all of existing water filtration plants. Such an analysis would require a comprehensive knowledge of the fixed and variable costs of existing plants. Knowledge of the condition and life expectancy of these plants would also be required as the timing of replacement of any part of the plant with wetlands for water filtering would become relevant, otherwise some fixed costs would not be saved if the wetland project started too early. While this knowledge was unavailable for the filtration plants in the study region (due to commercial confidentiality issues), water filtration companies operating existing plants would be guided by the results from this thesis when considering the timing and replacement of existing filtration systems with wetlands.

As mentioned in the thesis, it has not been possible to accurately determine a number of variables (such as unemployment associated with land use scenarios, the volume of any extra water that may be required in future for wetland management, and wetland management costs) included in the model. While it is not anticipated that the accuracy of these figures has had any significant impact on the results, they are a source of limitation. This thesis also does not attempt to assess the impact of land use changes on the rest of the State, as this would require general equilibrium modelling, which is out-side the scope of this work.

9.4 Implications for further research

Future research is required into other wetland functions: while this analysis provides a value for wetlands based on their ability to filter water, this is only one of many functions that wetlands provide. In reality, this figure must be seen as only part of the total value of wetlands, and a part that should not be taken in isolation. It is not possible for wetlands to only 'filter water' and do nothing else.

Considerable research is also required into the ability of natural wetlands to filter water, and into the variation in filtration ability that occurs across seasons and between wetland complexes. This information would provide guidance for the application of the wetland filtration values determined in this thesis while at the same time assisting us to understand the complexity of the important functions that wetlands provide.

POSTSCRIPT

Since the commencement of this thesis significant changes have occurred on the Lower Murray dairy swamps.

The dairy farmers of the Lower Murray swamps (including the owners of private irrigation areas) came to a cost-sharing agreement with the government over rehabilitation. One option under the agreement was for farmers to take a $45,000 package to leave the dairy industry. As a result of this option, just over 1,000 of the original 5,000 hectares being dairy farmed has been retired.

Dairy farmers who remained on the swamps were offered up to $3,135 per hectare from the government to rehabilitate their land on the condition that they contribute at least $630 per hectare towards rehabilitation themselves. This represents an 83% to 17% cost split. However, it is estimated that the total cost of on-ground rehabilitation will be $16.5 million (this figure is very similar to the total cost of the Channelled rehabilitation option presented in this thesis of $18 million), with the government contributing around $12.5 million and farmers at least $4 million (this includes farmer costs over and above the $630 matching contribution). The resulting rehabilitation cost share paid by farmers is therefore 24%, and is in line with that paid by farmers for the rehabilitation of other irrigation areas at Loxton, Ral Ral, Berri and Waikerie. This cost share is significantly lower than the cost share determined in this thesis of around 78% based on beneficiary pays principles. The difference in these figures highlights the importance (and power) of cost-sharing negotiations and political sensibilities when economic decisions are being made.

Farmers expressed a strong preference for Piped irrigation when initial investigations were being undertaken for this thesis because of concerns of water access when river levels were low. However, with only one exception, farmers have chosen to rehabilitate their properties while retaining the existing channels (possibly because of the considerably greater costs associated with the use of pipes). The wisdom of this choice must now be questioned given the extremely low river levels being experienced in the current drought.

Riverland Water has built and now operates the 10 water filtration plants referred to in this thesis. Unfortunately, use of wetlands was not considered as part of the water filtration process. However, SA Water purchased Mobilong Swamp and two thirds of Toora Swamp (private irrigation area) because these two swamps are upstream of the intake for the Murray Bridge water filtration plant, and hence they considered that the removal of cows from these locations would decrease water filtration problems. The water allocations associated with these two areas were included in the purchase price. It is interesting to note that Mobilong is one of the four swamps suggested for the construction of wetlands for water filtration in this thesis. To date all land purchased by SA Water has been retired from dairy production and remains unused, however SA Water is considering the return of these areas to wetlands.

9 Appendices

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Appendix 1

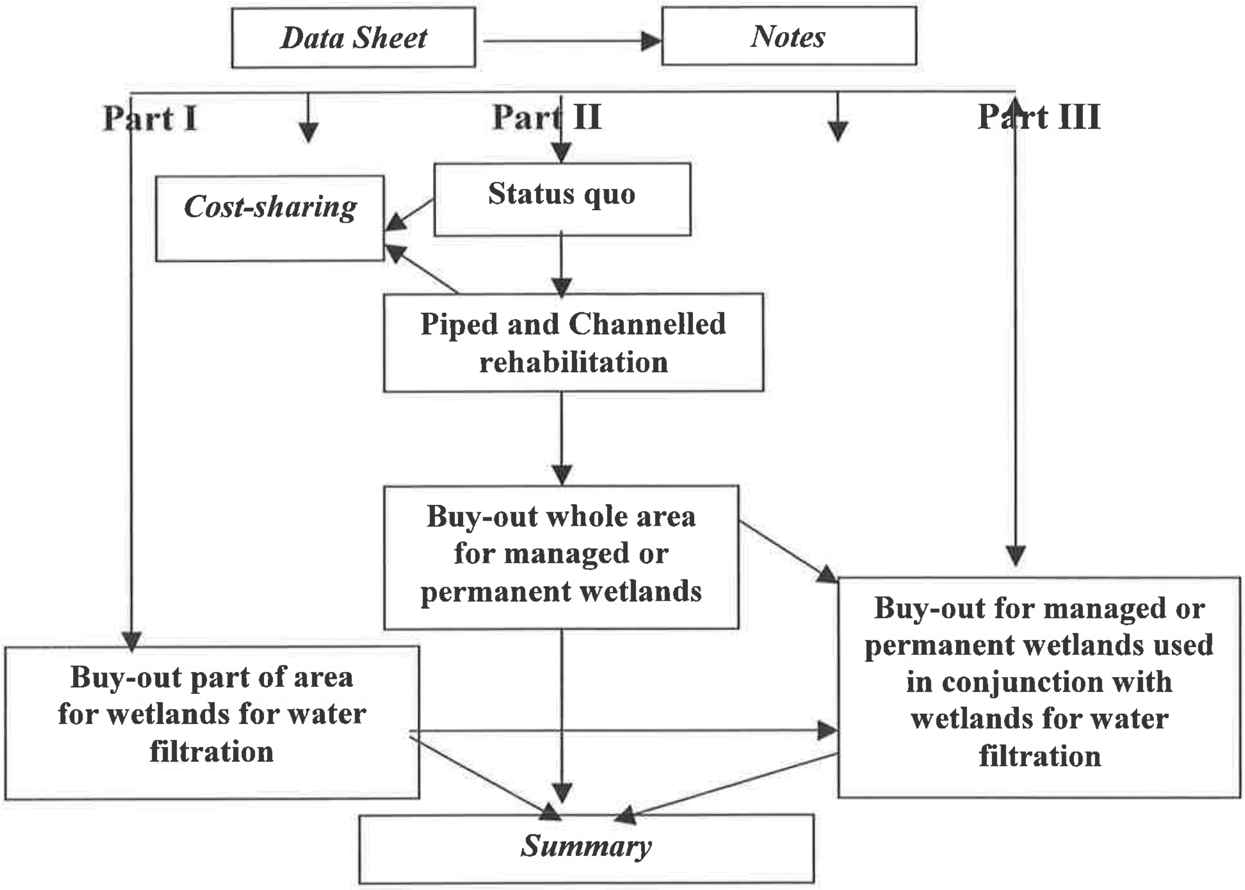
Model structure

1 MODEL STRUCTURE

1.1 MODEL LAYOUT

The Cost Benefits Analysis (CBA) model is written in Excel and Visual Basic and consists of inter-related spreadsheets, with each spreadsheet having a particular focus. The relationship between the spreadsheets is shown in Figure 1-1, with each box representing a spreadsheet in the model.

FIGURE 1-1. STRUCTURE OF THE LOWER MURRAY DAIRY SWAMPS ECONOMIC MODEL.



The Data and Notes spreadsheets contain all the variables used in the model, plus information on where the figures come from. In the cost-sharing sheet it is possible to change the percentage of costs paid for rehabilitation by the farmers and the government to see the impact of various cost-sharing options. The summary sheet shows the results of all calculations undertaken in other sheets, and it is these figures that are used in writing the thesis. The remaining spreadsheets contain the equations for each of the land-use options.

1.2 DATA SHEET

The data sheet contains all the figures used in the model. These include all the market and non-market values used for valuing the environment, the tourism and blue-green algae costs, the dairy farmer production figures, and all the costs and benefits associated with rehabilitation of the dairy swamps. Wherever possible these are 'total cost' or 'total benefit' figures; for example the individual costs of all aspects of milk production are not presented (as they do not change with rehabilitation), but rather the total cost of production. On some occasions figures are presented in red type as they are fixed figures, (for example the area of land for the swamps) and in general should not have to be changed.

All numbers are entered in response to a question, with every number entered in its own cell so that it can be easily changed. As mentioned above, it was decided to use this format so that numbers used in the calculations could be checked, varied and changed if necessary. This format also makes it easy to run sensitivity analysis, and to undertake 'threshold analysis' if required, by simply setting the relevant figures to zero.

TABLE 1-1. EXTRACT FROM THE DATA SPREADSHEET

Current gross value of production	$	**20,397,058**
Cost of production	$	0.187
Average price per litre	$	0.277
Current production litres	Litres	**73,555,925**
Income/hectare from non dairy land	$	**695**
Value of tourism for this swamp	$	**43,958,701**

The information entered in this spreadsheet is automatically used in subsequent spreadsheets that relate to each option.

1.2.1 Layout

The Data spreadsheet is divided into five sections with questions in each section related to the relevant options for rehabilitation. The sections are entitled:

- Status quo (farmers stay with the existing system);
- Rehabilitation with pipes. (The Piped rehabilitation option using a completely piped irrigation system);
- Rehabilitation with channels (Rehabilitation using a mixture of pipes and channels);
- Buy-out for wetlands. The buy-out of dairy farmers on the swamps and returning the swamps to either permanent or managed wetlands, and
- Wetlands for water filtration.

The questions relevant to each option are contained within each section. At the top of each section is a named button. This button provides a link to the spreadsheet where the figures in each section are used. This system makes it easy to change figures, to check up on equations and to undertake sensitivity analysis. Once again, the reason the model is presented in this form is so that it can be easily changed and updated.

1.3 Notes

This sheet contains all the information about the figures used in the model. It is linked to the Data sheet, and can be changed and updated as required. Information contained in this sheet is presented in Appendix 3.

This sheet is important as it allows the checking of data sources, and provides the names of individual people who have provided information. When changes to the numbers used in the model are made this sheet is updated so that the reasons for the changes made are clear.

Occasionally this sheet contains calculations. This occurs where the information supplied cannot be directly fed into the data sheet, but must be modified so that figures used are consistent with the region being studied.

Information for this sheet was obtained from a large number of sources (see Appendix 3):

- Meetings were held with the farmers so that relevant dairy production information could be gathered.
- SA Water provided figures on water pricing, irrigation management and running costs and water use.
- The Department of Environment and Natural Resources (now DWLBC) provided many of the environmental figures.
- Staff from Bolivar Water Treatment Station provided information for blue-green algae, as did University of Adelaide researchers.
- Other sources of information (too numerous to mention here) are detailed in this sheet.

1.4 COST-SHARING

This sheet draws together all the information calculated in the rehabilitation option spreadsheets and presents it in tabular form. It shows the costs, benefits and benefit/cost ratios of each of the wetland and rehabilitation options.

One of the unique features of this model is the ability to easily change the percentage of rehabilitation costs to be paid by the stakeholders. This feature is found on this sheet. After each rehabilitation option section there are questions asking what proportion of the costs are to be paid by farmers. By changing this number, the benefit/cost ratios of all parties can be changed, and thus the effect on the cost-sharing arrangements can be clearly seen.

This system also allows the model to determine which areas of rehabilitation farmers will be responsible for and which areas of rehabilitation farmers may prefer to see government responsibility.

TABLE 1-2. EXAMPLE OF QUESTIONS FACED BY FARMERS ON THE SUMMARY SPREADSHEET

% River channel rehabilitation paid by farmers	100
% Back supply channel rehabilitation paid by farmers	100
% Drainage/Salt channel paid by farmers	100
% Highland irrigation piping paid by farmers	100
% Off farm survey, design, contingency costs paid by farmer	100
% Monitoring costs paid by farmers	100
% On farm works paid for by farmers	100

1.5 SUMMARY

This sheet shows all the numerical results used in the thesis; changes made to all other sheets automatically change the figures in this sheet. Sensitivity analysis can be undertaken by changing figures in the DATA sheet and observing the changes in this sheet.

1.6 REMAINING SPREADSHEETS

The equations contained in the remaining spreadsheets are presented in Appendix 4.

Appendix 2

Background information

2 BACKGROUND INFORMATION

2.1 History

Pre 1900

The history of the reclamation and administration of the Murray swamps is complex, and has been comprehensively reviewed by Thomas *et al.* (1986). The important aspects of their review are summarised below.

Captain Charles Sturt noted the value of the swamps during his expeditions in 1829/30, however credit for the establishment of the first irrigation scheme in SA goes to Edward John Eyre. Eyre established his scheme at a town called 'Sturt' approximately 5km from Blanchetown. Eyre constructed barriers with sluices, and was thus able to irrigate an area of river flat on the western bank of the Murray River. This scheme continued until 1856, when the settlement was abandoned.

The next recorded irrigation of the area occurred in 1881 when Sir W F D Jervois reclaimed approximately 1340 hectares of swamplands near Wellington by erecting a levee to prevent the overflow of floodwaters onto the swamp. This was followed in 1886 by M R A McFarlane who reclaimed approximately 280 hectares on the opposite bank of the river. This initial reclamation work was elementary and crudely constructed, comprising low levee banks, which served to keep the river out for irrigation periods.

Between 1882 and 1908 Messrs H W Morphett and Co reclaimed 260 hectares at Woods Point by erecting a substantial levee bank. The land was used for growing onions, potatoes and lucerne. Other landowners soon followed suit and further land was reclaimed including 324 hectares by Hon J Cowan of Glen Lossie.

Post 1900

By 1904 the success of private developers in establishing a system of levee banks, drainage channels and pumping to reclaim the swamps encouraged the government to become involved in the reclamation, development, subdivision and settlement of swamps held by the Crown. In 1904/05 the surveyor General proceeded with the construction of embankments at Mobilong and Burdett. The area reclaimed in those swamps was 656 acres (266 hectares) and was let for $2 per acre per year.

Between 1905 and 1909 the government then proceeded to purchase and develop privately owned swamps. These swamps included Long Flat, Monteith, Mypolonga, Pompoota and Wall.

From an early date problems were noted with the way in which the developments occurred, with the Director of Irrigation noting in 1903 that '…unfortunately, through want of experience, several serious errors of judgement were made by the Survey Department in the original method of dealing with the swamp land.' This resulted in a number of problems including:

- levee walls that were not watertight, due to their construction from shrinking clay soils;
- no provision for drainage or the removal of surface water from the first areas to be reclaimed resulting in waterlogging and salt damage, and
- inadequate provision for the supply of water to the rear of the swamps.

Following the end of WW1, Pompoota, Cowirra, Neeta, Jervois, Baseby and Swanport were developed as Soldier Settlement Schemes. However Baseby was not completed and the partially reclaimed area has been leased in total as a 'private' area since the 1920s. Swanport was also eventually leased as a private area.

The drainage problems mentioned previously were addressed prior to 1913 and the allotment of land to the soldier settlers. A drainage system and pumping stations were constructed, and it was a condition of the soldiers' lease that they individually maintain that portion of the drain that ran through their property – it must be noted that these drains were public goods. This system was unsatisfactory to both soldiers and authorities; therefore responsibility for the drain was handed back to the Department of Lands in 1949.

Highland irrigation

Highland irrigation areas were developed for the government swamps in conjunction with reclaimed swamps at Mypolonga, Wall, Pompoota and Neeta, however Mypolonga was the only successful scheme according to a Royal Commission appointed in 1923. This Commission was highly critical of the attempted development of the latter three highland areas, because of the costs involved. They also recommended increasing the size of some holdings on the reclaimed areas to make the farms viable.

2.2 Soils

Taylor and Poole (1931) surveyed approximately 13,000 acres of swampland along the Murray River between Mannum and Wellington. This survey found that swamp soils have been formed by successive depositions of silt, following flooding over thousands of years. The silt has combined with the accumulated reed remains to form a soil of unusually heavy texture and high organic matter content. This gives the surface soil its characteristic dark colour and friability.

The most common soil consists of about 10 inches of black or brown friable clay overlaying a lighter coloured mottled clay, which in turn changes to a uniform grey clay at about three feet. There are a few less common soils that have differed in their formation. Some contain a sandy horizon at about 10 inches; others contain burnt layers. These layers are the red or grey residues of burnt organic matter, which have since been overlain by silt. Soils with sandy layers and burnt soils occur in pockets throughout the swamps.

The major differences in soils between areas and swamps are based on the thickness of the various layers (Whittle and Philcox, 1996b). Taylor and Poole (1931) note that the northern swamps Mypolonga and Mannum differ from the southern swamps in that they have a steeper fall from the river to the drain, have more organic solids in the 'back' of the swamps, may have ridges and high ground in the body of the swamp (e.g., Cowirra), less black clay, occasional absence of the brown layer, and the presence of sand layers. The friability of the surface soils is also variable, depending on the amount of organic matter present.

The soils have a high water holding capacity (150-400mm/m), and a high conductivity for water, 21cm/hr (Watson and Cole, 1972). The dominant clay mineral is smectite, giving the soils their high shrink/swell capacity, or cracking clay feature (the bulk density varies from 0.6 – 1.3 $g.cm^3$ from field capacity to wilt point (Philcox and Douglas, 1990).

The soils are naturally fertile with high levels of trace elements and high phosphorous and potassium levels (Whittle and Philcox, 1996b). Unlike other regions of South Australia, the soils of the reclaimed swamps are not naturally deficient in trace elements.

2.3 Climate

The reclaimed swamps are in an area of low annual rainfall, which varies from 293mm at Mannum in the north through to 342mm at Murray Bridge and 374mm at Wellington. Evapotranspiration figures for Mannum, Murray Bridge and Wellington are 1936, 1710 and 1636 respectively.

In all areas approximately 52 % of the annual average falls in the five months May to September inclusive. Irrigation is required to supplement rainfall during the hotter months.

2.4 Irrigation and irrigation water allocation

The method by which the volumetric allocation of irrigation water to farmers on the swamps was calculated, is probably the most contentious issue preventing rehabilitation of the dairy swamps. Because of the differences in evaporation and rainfall irrigation water used by pastures ranges from 1,045mm at Mannum, to 853mm at Long Flat and 781m at Wellington.

In 1991 the owners of the dairy swamp known as Long Flat wished to privatise their holding. The government therefore needed to determine a volume of water that would be provided to the farmers when privatisation occurred. Using Holmes and Watson's (1967) estimates of pasture water use and pan evaporation figures from Murray Bridge, Schrale (1989) derived the water requirements at Long Flat. This was then extrapolated for each of the swamps from Mannum to Wellington. Because of the differences in rainfall between the two points a line was drawn at Murray Bridge. Farmers above this line received 17.5ML/hectare, and those below 14.5ML/hectare.

These allocation figure are composed of two components: irrigation water for pasture use and conveyancing water i.e., sufficient water to push a head of water across the paddocks. This water must to be returned to the river as 'drainage'.

Finally after several years of negotiation and legal expense, farmers were allocated a total 13.92 ML/hectare, plus 22.2GL of environmental water known as 'ELMA'. The purpose of the ELMA allocation was to ensure sound environmental management of the dairy swamps in the event that farmers cease dairy farming. Thus ELMA water can be used for such things as salinity control or for flooding of a swamp should it be converted back to a temporal wetland. ELMA water must to be shared by all swamps, and cannot be sold.

However, in practice the quantity of water used for irrigation is not measured, and neither is the volume of drainage water, which is either pumped to the highland or returned to the river. Thus the farmers cannot be made accountable for the volumes of water entering their properties and flooding over the pastures. This is important because it means that there is no basis for incentives for farmers to be responsible for either the volumes of water they apply to their land or the amount of nutrient rich-run-off that leave their properties.

2.5 CRYPTOSPORIDIUM

Cryptosporidium is a protozoan of the subclass of Coccidia that includes Eimeria and Isospora (Centre for Epidemiology & Animal Health, 1993). It was first recognized as a pathogen in cattle in 1971 and the first human cases were identified in 1976. Each of the six currently recognized species of cryptosporidia infects different hosts. C. parvum infects mammals, including bovines and humans. C. muris infects mice and has recently been found in the abomasum of cattle. Other species infect avians and reptiles. There is a large reservoir for C. parvum including domestic and wild animals, rodents, and water.

A USDA, APHIS, VS (1993) study estimated that on any given day, 22 % of pre-weaned dairy calves, and as many as 50 % of dairy calves in the 1- to 3-week age group, are shedding Cryptosporidium. It is estimated that the parasite is present on nearly 90 % of dairy farms. Although oocysts are shed in greater numbers during the diarrheic phase, the organism has been found in normal faeces. No reproduction takes place in the intestinal tract. However, the oocyst is very hardy in the environment (may or may not be destroyed by freezing and drying) and is resistant to most disinfectants.

Although mixed infections are quite common (since many organisms affect the same age group of calves), Cryptosporidium can cause clinical diarrhoea in calves in the absence of other pathogens. In calves, the predominant sign of infection is diarrhoea that may be bloody. Symptoms persist for about eight days and clinical recovery is the usual outcome. There is no specific anticryptosporidial treatment currently available, so treatment is limited to supportive care for diarrhoea and dehydration. Control of C. parvum is difficult because it is immediately infective upon shedding, unlike other coccidia. It is resistant to chlorine, and because it is so small, it can pass through many water filter systems (including municipalities). However, hygienic management practices in the calf facilities will reduce the pathogen load.

As mentioned, the three major sources of cryptosporidial contamination are farm animals, human sewage, and wildlife. Transmission can occur through water supplies and animal or person-to-person contact.

2.6 Effectiveness of Wetlands for Effluent Filtration

Constructed wetlands for waste and storm water treatment have been found to be highly effective when designed and constructed properly. Several studies of the efficiency of constructed wetlands within the Adelaide region have shown that wetlands can prove an efficient filtering tool. Penny (1993) studied the effectiveness of Greenfields (Adelaide) wetlands for its pollutant removal efficiency of stormwater. These wetlands show a 98 % reduction in suspended solids, a 92 % reduction in nitrogen and a 97 % reduction in total phosphorus (Penny, 1993). He concluded that across the parameters monitored (suspended solids, oxidised nitrogen, total phosphorus, salinity) the quality of storm water was significantly improved, benefiting the marine environment at the same time.

Somewhat lower filtration rates were found at a wastewater treatment and reuse scheme designed and constructed for the Corowa Estate housing development in Waikerie, South Australia. Water Quality analyses performed throughout the 1998 show an average biochemical oxygen demand (BOD_5) reduction of 76%, average total phosphorus (TP) reduction of 79%, average total Kjeldahl nitrogen (TKN) reduction of 85%, and average total suspended solids (TSS) reduction of 54%. Thermo tolerant coliform counts decreased by 99% during passage through the wetland. Although these figures are lower than those found at Greenfields, the treated water consistently meets or exceeds the minimum Class B standards required by the South Australian Health Commission to protect public health (Rellney Group, 2000).

The disadvantages of wetlands include the lack of long-term experience with the systems, lack of understanding of the complexities of the biological and hydrological systems that are involved, the amount of land required, and potential pest problems (Mundy 1997).

2.7 Water quality

2.7.1 Turbidity

Turbidity is an 'expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample' (APHA 1980). Factors such as particle size distribution, shape, refractive index, and absorptivity affect light scattering, so it is impractical to consider relating scattered light measurement to the concentration of suspended solids (US fish and Wildlife, 2003). Turbidity may cause water to look muddy or discoloured and is therefore a measure of the clarity of water i.e., the more turbid the water, the murkier it is. Turbidity can be caused by soil erosion, waste discharge, urban runoff, bottom feeders like carp that stir up sediments, and algal growth. Within a specific water body, turbidity is a seasonal phenomenon depending on stream discharge, biotic activities, wind circulation, and chemical changes.

Typically, turbidity measurements are undertaken by determining light transmission through water, and measuring the light that is diffused by the particles in suspension. Turbidity is reported in Nephelometric Turbidity Units (NTU) or Formazine Turbidity Units (FTU). 1 FTU = 1 NTU. The American standard is referred to as the USEPA method and recommends using a visible light source. The European standard subscribes to the Infrared method that has the advantage of being less sensitive to the colour of the samples.

Historically, most of the water that has entered South Australia in the River Murray has come from the River's headwaters in Victoria and New South Wales. However, as a result of river regulation, the Darling River has become the main source of water entering the State, (up from 35% to 58%), and this water is generally very turbid (RMCWMB, 2003). In general, the turbidity of water flowing into South Australia varies according to the proportion of turbid Darling River water flowing in the River Murray at any time. Along the River Murray in South Australia, Median turbidity levels remain relatively constant fluctuating between 50 NTU and 57 NTU. These median levels are well above the recommended maximum for domestic use (ANZECC, 1992).

2.7.1.1 Implications of high turbidity

Increased turbidity has a significant depressive effect on the food-chain of the riverine ecosystem; it alters aquatic plant growth - submerged plants which can grow in deep water, are limited by its high turbidity which reduces the depth of the euphotic zone - and can therefore affect the livelihood of in-stream plant-eating organisms.

Native fish can find it more difficult to feed in turbid water because of the decreased visibility but, conversely, these conditions favour introduced fish species, such as European carp. High turbidity can also reduce the ability of water-treatment facilities to destroy potentially harmful micro-organisms (RMCWMB, 2003).

2.7.2 Colour

Causes and measurements of water colour have been comprehensively reviewed by Moore and Caux (1997). The colour of water and other materials have three main attributes: hue, brightness and saturation (Davies-Colley *et al.,* 1988). Hue refers to whether the water colour is described as blue, green or yellow, for example, and is determined by the dominant wavelength in the visible spectrum. Brightness depends on the amount of energy detected by the human eye, which is most sensitive to green light of wavelength 555 nm. Saturation depends on the spread of energy around the dominant wavelength. Saturation is also referred to as spectral purity (Jerome *et al.,* 1994).

Colour measured in water containing suspended matter is defined as apparent colour (APHA, 1992; Bennett and Drikas, 1993). True colour is due to natural minerals such as ferric hydroxide and dissolved organic substances such as humic or fulvic acids (Hongve and Akesson, 1996) and it is true colour that is determined when assessing water quality. A great variety of dissolved organic substances originating from anthropogenic sources such as dyes can also contribute to water colouration (McCrum, 1984; Brown, 1987; Borgerding and Hites, 1994). True colour can only be measured once a sample has been centrifuged or filtered (APHA, 1992; Environment Canada , 1989; Bennett and Drikas, 1993).

True colour can be measured by comparator and colorimetric methods. Comparator methods rely on visual comparison of a water sample with a standard colour solution or a set of coloured filter disks. The most common comparator method involves matching a water sample with one of a series of dilutions of a standard colour solution of platinum and cobalt chloride salts of molar ratio 2:1 where the platinum concentration in mg/L is equivalent to the colour value in Hazen units (Bennett and Drikas, 1993). The Fore-Ule colour scale involves comparisons to alkaline solutions of cupric sulphate, potassium chromate and cobaltous sulphate.

The Hazen scale of true colour measurement, however, has been adopted as the reference method by organizations that set standards for water quality analysis, and by many governments in deriving their drinking water quality guidelines (NH & MRC and AWRC, 1987; WHO, 1983; APHA, 1992; EN-ISO, 1994).

Standard measurement comparisons can be made with sealed containers (*e.g.,* the *Hellige Aqua Tester*). Natural waters range from <5 in very clear waters to 1200 mg/L Pt in dark peaty waters (Kullberg, 1992). As some of the compounds determining the colour of water are not very stable, measurements should be made within two hours of collection (Environment Canada, 1989).

2.8 Interest/discount rate

Interest and inflation rates rate varied considerably over the course of this investigation. The model uses a 2.12% inflation rate, and a nominal interest rate of 5.75% based on government rates at the time the final analysis was undertaken (real interest rate 3.55%).

2.9 Time frame

The model is run over 25 years. This period of time was chosen as a realistic period for the rehabilitation process to be completed, and for the costs to have been fully recovered. This time frame was acceptable to all stakeholders.

2.10 Labour

Unemployment levels in this region of 11.9 were slightly higher than that of the rest of the State 10.40 at the time of this study (ABS, 2002). However, experienced dairy labour was considered to be equal to demand (or occasionally in short supply) in this region.

2.11 Valuation of non-market goods

As shown previously in this review, the valuation of non-market goods can be very difficult to obtain and even more difficult to justify to large decision-making bodies. One of the key factors in the choice of valuation method used is the type and amount of information available, and the feasibility/cost of obtaining it (Winpenny, 1995). While great strides have been made in the monitoring or environmental conditions in some countries, the data situation in other is deplorable, and is often based on partial evidence from similar situations elsewhere.

Sinden (1994) in his extensive review of environmental valuation in Australia shows environmental valuation has a long history in Australian research and application. A wide range of valuation methods have been used, providing a rich history of reported valuations, and an important resources for potential valuers to draw on. In a review derived from many studies of land and water resources, Young (1991) found that the consistency of values across the body of valuations was far more important than the 'warts' of individual studies.

Sinden (1994) concludes that 'valuations provide a means of explicitly accounting for factors which are otherwise overlooked, and often wrongly valued by decision makers and resource managers. Any relevant information will help account for these factors even if the information is a partial value'.

The current valuation methods used to determine wetland values do appear to be 'partial', and therefore the figures presented in the review are used as part of a sensitivity analysis for the rehabilitation options, and as part of a threshold analysis where the swamps are completely returned to wetland use.

2.12 ALTERNATIVE FARMING ACTIVITY

In considering the most cost effective method to reduce pollutants entering the river, it was necessary to look at the opportunity costs of dairy farming – would this land be more profitable under another land use not considered in this thesis? For this reason alternative land uses for the swamps were examined. It was found that alternative land uses have been comprehensively reviewed by a number of researchers including Withers (1997) and most recently PIRSA (2001). Withers showed that, because of heavy clay soils, frost risk, and relatively small area of the swamps, no alternative land use compares with dairy farming. Alternatives considered by Withers and reasons for non-adoption are presented in Table 2-1.

TABLE 2-1. ALTERNATIVE LAND USE FOR THE LOWER MURRAY

Land Use	Reason for non adoption
Beef cattle	Financial returns less than one third of dairying
Fat lambs	Problems with pests, parasites and diseases due to the wet clay soil conditions. Financial returns less than one third of dairying
Alpacas	Susceptibility to skin diseases when kept on wet ground. Faecal contamination of the ground from dairy cattle occupation.
Ostriches	Fungal and disease problem from wet clay swamps.
Deer	Limited venison market. Financial returns unlikely to compare with dairying
Marron	Licence rejection by PISA due to proximity to Murray River and risk of displacing Murray crayfish.
Sugar beet	Soils and climate unsuitable. Area too small for commercial operation.
Market Vegetables	Clay soils, and high summer temperatures provide high-risk conditions. Greater distance to Adelaide market than other more suitable growing areas.
Viticulture	Major changes required to watering regimes. Vast areas of vineyards already planted in adjacent more favourable areas.
Farm Stay Holidays	Possible as a supplemental income only if using redundant existing buildings.

PIRSA (2001) eliminated crops for the swamps on the bases of their intolerance to severe salinity levels and waterlogging. These two factors eliminated all nut trees, fruit trees, bush food, vegetables, flowers, herbs and viticulture. They also concluded that while cereal crops such as barley, oats, safflower, triticale and salt tolerant species of wheat will possibly grow, there would be a 50 % yield reduction due to high salinity. Cotton was the only crop considered tolerant of the high salinity/waterlogging problems, but the problem of chemicals polluting the river would need to be considered.

For the reasons presented above, it was not considered necessary in this thesis to undertake further economic analysis of these alternative land uses.

Appendix 3

Variables used in the Model

3 VARIABLES USED IN THE MODEL

3.1 WETLANDS FOR WATER FILTRATION

See Appendix 4.1 and Table 5-5 in the text for equations containing these variables.

3.1.1 Benefits

3.1.1.1 Construction & on going costs of filtration plants

Riverland Water is paid $20 million dollars per year by SA to build, own and operate the 10 water filtration plants in the study area for the next 25 years. At the end of that time the plants revert to the SA government. Four of these plants: Mannum, Tailem Bend, Murray Bridge and Summit Storage are in the study region. Costs associated with these four plants are estimated by SA water as half of the total costs. Riverland Water won the contract to provide this service for the South Australia government. The project is under the direction of SA Water who made public the filtration contract financial details used in this analysis.

Per cent of water filtered in the study region	%	52
Annual cost of filtration plants in the study region	$	10,000,000
Per cent of plant cost reduced	%	50 or 100

3.1.1.2 Construction & on going costs of UV plants in the study region

SA Water has estimated the installation of UV filters in the study region will cost	$	1,000,000
Operation of the UV filters per year is expected to be	$/year	10,000

While these costs are estimates only, because they are relatively small compared with the construction and ongoing costs of the filtration plants they do not have a significant impact on the model and result outcomes.

3.1.2 Costs

3.1.2.1 Costs of wetland construction and planting

All information and costs for wetland construction are provided by Barry Ormsby, Peter Breen, Martin Philcox (all private consultants) or SA Water and PIRSA. All three consultants have been involved in design and construction of a number of wetland complexes. Dr Peter Breen was previously a senior researcher with the CRC for Freshwater Ecology, while Martin Philcox was instrumental in the return of the Paiwalla dairy swamp to a managed wetland.

Barry Ormsby has designed wetland complexes in South Australia and Victoria. Because of the wealth of experience of all three sources of information the figures used in the model are considered to be as relevant and accurate as possible. (See appendix 4.1 for equations containing these variables, and equation 5-2 in the text.)

Cost of wetland establishment	$/ha	20,000
Planting costs	$/ha	80,000

3.1.2.2 Water requirement

(See Appendix 4.1 for equations containing these variables).

Water to be filtered at Mannum	ML/day	4
Water to be filtered at Murray Bridge	ML/day	38
Water to be filtered at Tailem Bend	ML/day	28
Water to be filtered at Summit Storage	ML/day	71
Total water volume	**ha**	**141**

3.1.2.3 Land requirement

Area of wetland required at Mannum	ha	9.6
Area of wetland required at Murray Bridge	ha	91.2
Area of wetland required at Tailem Bend	ha	67.2
Area of wetland required at Summit Storage	ha	170.4
Total area required for water filtration	**ha**	**338.4**

Water retention time (10 days) + 2 days drying	days	12
Depth of wetland	metres	0.5

3.2 STATUS QUO FOR GOVERNMENT SWAMPS

See Appendix 4.2 and Table 6-1 in the text for equations containing these variables.

Regional figures		
Area of all swamps	ha	5172
Area of rated swampland requiring lasering for the region	ha	4922
Rated hectares in dairy production	ha	4452
Rated area in Beef Production	ha	470
Area of natural wetlands in region	ha	500

Government land figures (study area)		
Area of swamp land for government swamp	ha	4164
Area of unrated land (from aerial surveys)	ha	729
Percentage of total farming region requiring lasering	%	69.79
Hectares swamp requiring lasering (includes beef land)	ha	3435
No of farms on the swamp	no.	96
Rated area in dairy production	ha	3187
Area of rated land not in dairy farming	ha	248

3.2.1 Benefits

3.2.1.1 Regional farm income

See Appendix 4.2 for equations containing these variables.

Milk produced	litres	102,752,111
Milk value	$/lit	0.2773
Milk income	$Million	28.493
Income/hectare	$	6400
Net income	$	2084
Rated hectare requiring lasering	ha	4,922
Income from beef production	$/ha	695

Production figures and costs have been supplied by:

- farmers themselves;
- the two dairy companies in the region, and
- local consultants, S. Scown, and B. Handscomb, involved in the collection and collation of income data for Dairy SA.

3.2.1.2 Gov Swamps Income

Number of farms	No	96
Milk produced	litres	73,555,925
Average price per litre	$	0.277
Swamp income	$	20,397,058
Income/hectare	$/ha	6,400

Average cost of production in study area	c/litre	18.7
Net income	$/ha	2,084
Income from beef production/hectare	$/ha	695

3.2.1.3 Tourism income

Value of tourism to the region. Figures from the Bureau of Statistics for the Murraylands region.	$	78,000,000
The Bureau estimates that 70% of this is associated with the river, indicating the value of tourism to the region	$	54,600,000
Proportion for this area associated with the dairy swamps is determined on basis of percentage of total area	$	43,958,701

3.2.1.3.1 Number of visitors from outside the region

Jodie Brompton (Murray tourism) provided figures showing 265,100 visitors to the Murraylands from outside the region, 70% of whom visit this region. Therefore visitor numbers equal	no.	185,570
For Gov swamps on a proportional basis, this equals:	no.	129,507

3.2.1.3.2 Number of visitors from within the region

Visitor numbers from within the region are estimated at	no.	31,324
For Gov swamps on a proportional basis, this equals:	no.	21,861
Total number of visitors	**no.**	**151,368**

3.2.1.3.3 Annual impact of tourism to the broader economy for this swamp

Value for day trippers	$/day	6.00
Total value for day trippers	$	131,164
Value for overnight visitors	$/day	10.00
Total value for staying 2 nights	$	2,590,138
Total value	$	2,721,302

The figures chosen for use in this model for valuing tourism are a result of the literature review and are based on a number of estimates, but predominantly the work of Sinden (1990). SA Tourism provided tourism figures, while tourism losses due to dairy effluent contribution to algae outbreak are based on Whittle and Philcox (1996a) and figures supplied by SA Tourism. SA Tourism has indicated that while they consider their figures to be reliable, further work is required to accurately assess the impacts of algae impacts on tourism.

3.2.2 Costs

Area of government swamp	ha	3572

Note: The area of government swamp in this model is slightly smaller, and is based on recent, more accurate aerial surveys. Old maps of the region estimated this area to be 3435 hectares.

3.2.2.1 Repairs and maintenance of current irrigation scheme and associated land

These figures are the accurate costs provided by Glen Dorsey at SA Water.

Capital actual	$	10,100
Repair and maintenance actual for rated land	$	1,088,710
Total cost	**$**	**1,098,810**
Total operation and maintenance recovered from farmers	$	965,869
Operation and maintenance cost paid by farmers	**$/ha**	**270.40**
Capital cost for government	$/ha	2.83
Operation and maintenance cost paid by government	$/ha	34.39
Total government cost	**$/ha**	**37.22**
Total cost of scheme	**$/ha**	**388.24**

3.2.2.2 Blue-green algae

Frequency of algal blooms in the region is (estimated) at between	%	20–25

These figures were supplied by the tourism association at Tailem Bend, and supported by SA water. The frequency of algal blooms is increasing as sedimentation increases over time.

3.2.2.2.1 Water quality testing costs when algae outbreak

Calculation of water quality and treatment costs including the externality costs associated with blue-green algae outbreaks contributed by the dairy industry for this model was difficult, and required the assistance of a number of organizations and government departments. Both the EPA and SA water indicated that they cold not provide accurate costings because algae outbreaks have no set pattern, occurring in different parts of the river and for different lengths of time. However, on average the water quality costs were estimated by these organisations to be:
Water testing includes: toxin analysis $300 * 8 per week for 25 weeks.
Mice LD50 $3000 for 25 weeks.

Total cost per outbreak.	**$**	**135,000**

3.2.2.2.2 Water treatment costs

When a BGA outbreak occurs, it is treated with a range of chemicals including activated carbon, chlorine and aluminium. Once again these costs vary, however the average cost of treatment per outbreak lasting 2-3 days have been provided by Bolivar Water Treatment Station based on historical use of activated carbon, chlorine and aluminium when outbreaks have occurred.

Costs of treatment	$	160,000
Outbreak at Lake Alexandrina lasting 2 weeks estimated cost.	$	800,000
After discussion with SA Water staff, I have used an average cost of	$	400,000

It is recognised that the estimation of these costs is subject to errors, and that other costs relevant to this study may yet be identified. Because these costs are small compared with other costs in the model, they do not have any significant impact on the model and result outcomes.

3.2.2.2.3 Water transport

Transport of water to regions where algae make drinking impossible.	$	50,000
Peter Schultz pers. com and John Parsons		

3.2.2.2.4 Drop in tourism

Tourism drop in years of blue-green algae outbreak Figures provided by SA Tourism association.	%	25
The % attributed to the dairy industry is an estimate based on research showing the contribution of the dairy swamps to nitrogen and phosphate levels in the river. (River Murray Water Resources Committee, 1994).	%	15

3.3 REHABILITATION WITH PIPES

See Appendix 4.3 and Table 6-5 in the text for equations containing these variables.

3.3.1 Benefits

Target water use efficiency	%	65
Drop in nutrient level	%	60

3.3.1.1 Farmer benefits

Increased production (income)/yr for 5yrs	%	8

These figures are based on work done by Philcox (1990, 96) and Philcox *et al.* (1992) that shows an increase in farm income of approximately 40%. Farmers who have already lasered their farms have found that to ensure no significant loss of income it is best to laser approximately 20 % of the farm per year for five years.

3.3.1.1.1 Fertiliser, feed and labour costs

These figures are industry estimates based on figures collated for Dairy SA by Scown and Handscomb (1996), and work undertaken by Philcox (1990, 96) and Philcox *et al.* (1992). They indicate the changes in costs expected after lasering due to higher water use efficiency, increased production, and decreased nutrient loss. Because the figures are based on work undertaken on farms that have already been lasered, they are considered to be accurate.

3.3.1.1.2 Fertiliser costs

Number of farms	no.	126
	$/farm	15,730
	$/ha	402.68
Total cost	**$**	**1,383,198**
Expected reduction in fertiliser costs/year	%	40

3.3.1.1.3 Supplementary feed costs

Feed	$/farm	94,603
	$/ha	2421.78
Total cost	$	8,318,798
Expected reduction in feed costs/year	%	10

3.3.1.1.4 Labour

Labour (wages)	cents/litre	2.1

Average cost per farm per year	$	16,090
Expected reduction after rehabilitation (per farm)	$	$1,500

TABLE 3-1. ANNUAL BENEFITS TO FARMERS FROM PIPED REHABILITATION

	Year 1 benefit	Year 2 benefits	Year 3 benefits	Year 4 benefits	Year 5 benefits	On-going benefits (years 6-25)
Increased Production	0	551,004	1,102,008	1,653,012	2,204,016	2,755,020
Reduced labour	0	28,880	57,600	86,400	115,200	144,000
Reduced feed	0	166,376	332,752	499,128	665,504	831,880
Reduced fertiliser	0	110,656	221,312	331,968	442,623	553,279

3.3.2 Costs

The engineering company, Kinhill, has supplied all figures for piped irrigation rehabilitation. In general the number of sluices, outlet structures, metres of pipe, and metres of channels is determined, and these are then multiplied by the price for each component. Once again, these figures are considered to be accurate as they are based on tender figures supplied by Kinhill for rehabilitation of this area.

3.3.2.1 River channel

Capital repair and maintenance costs	ha	3435
Cost per hectare (whole scheme)	$	308
Sluices requiring refurbishment/replacement	no.	118
Cost per sluice	$	6000
Metres of old channel requiring filling	m	46,808
Cost per metre	$	3
Metres of pipeline requiring supply and installation	m	46,808
Cost per metre	$	70
Pumps and motors required	no	118.0
Cost per pump	$	22,000
Bay outlets required	no.	892.0
Cost per outlet	$	500
Number of meters required	no.	118
Cost per meter	$	3,000

3.3.2.2 Back Supply Channel

Number of sluices requiring replacement/refurbishment	no.	11.0
Cost per sluice	$	6,000

Number of meters required	no.	11.0
Cost per meter	$	3,000
Metres of old channel requiring filling	m	46,560
Cost per metre	$	3
Metres of new channel requiring construction	m	46,560
Cost per metre	$	21
Back channel bay outlets required	no.	669
Cost per outlet	$	250
Metres of fence required for channel	m	46,560
Cost per metre	$	4.5

3.3.2.3 Drainage (salt) channel

Metres of channel requiring cleaning/reshaping	m	65,180
Cost per metre	$	6
Drainage inlet structures required	no.	877
Cost per structure	$	800
Metres of fence required for channel	m	117,770
Cost per metre	$	4.5
Metres of bank stabilisation required	m	130,360
Cost per metre	$	7.5
Metres of cut off drain required	m	12,630
Cost per metre	$	87.8
Metres of cut-off drain connections required	m	4,400
Cost per metre	$	40

3.3.2.4 On farm works

All costs associated with lasering are taken from local contractors and Martin Philcox (PIRSA). All rated land requiring lasering is included.

Rated land for lasering	ha	3,435
Capital costs of BMP/lasering/hectare	$/ha	1,330

3.3.2.5 Highland irrigation

The engineering company, Kinhill supplied all figures. Once again the number of pumping stations, lengths of pipe and meters required are determined, and then multiplied by the costs. This is the market price at the time of writing this thesis. Primary Industries provided cost per farmer to receive training in management of new pasture species after rehabilitation.

Metres of ring main pipeline required and installed	m	35,100
Cost per metre	$	57
Pump station	ha	743
Cost per station	$	700

Outlet connections required	no.	177
Cost per connection	$	1,000
Meters required	no.	177
Cost per metre	$	1,000
Surveying/design	%	6
Contingency	%	15
Value of water	$/ML	1,300
Training per farmer	$	100

3.4 REHABILITATION WITH CHANNELS

See Appendices 4.4 and 6 for equations containing these variables.

All figures for the Channelled irrigation option are the same as for the piped option with the exception of the engineering costs, presented in this section. Once again the engineering company, Kinhill supplied all figures. In general the number of sluices, outlet structures, metres of pipe, and metres of channels is determined, and these are then multiplied by the price for each component.

3.4.1 Costs

3.4.1.1 River channel

Cost per hectare (whole scheme)	$	308
Sluices requiring refurbishment/replacement	no.	127
Cost per sluice	$	6,000
Metres of old channel requiring filling	m	46,808
Cost per metre	$	3
Channel and fencing	m	46,808
Cost per metre	$	30
Channel regulators required	no.	254
Cost per regulator	$	5,000
Bay outlets required	no.	892
Cost per outlet	$	250
Number of meters required	no.	127
Cost per meter	$	3,000

3.4.1.2 Drainage (salt) channel

Metres of channel requiring cleaning/reshaping	m	65,180
Cost per metre	$	6
Drainage inlet structures required	no.	877
Cost per structure	$	800
Metres of fence required for channel	m	117,770
Cost per metre	$	4.5

A summary of the Piped and Channelled irrigation costs is presented in Tables 3-2 and 3-3.

3.5 WETLANDS FOR STATUS QUO, PIPED AND CHANNELLED IRRIGATION

See Appendix 4.5 and Table 6-11 in the text for equations containing these variables.

3.5.1 Benefits – Status quo

Drop in nutrient levels based on work by Whittle and Philcox (1996a, 1996b). %	60

3.5.1.1 Farmer benefits

No farmer benefits for this option

3.5.2 Costs- Status quo

Hectares required for wetlands based on the work by Whittle and Philcox (1996a, 1996b)

Required hectares	ha	356.2
Loss of production off poorest areas	$/ha	193
Purchase of poorest land for wetlands based on local Real Estate agent's experience of the value per hectare of the	$/ha	400

3.5.2.1 Wetland construction and planting

Mr Barry Ormsby, a wetland construction specialist and consultant for Salisbury Council Wetlands has quoted these figures. Engineering costs are provided by Kinhill Engineers.

Quantity	**$Total**
Strip topsoil 24,200 m^2 x $0.3	$ 7,260
Cut and carry to stockpile 3,880 m^3 x $3.00	$11,640
Stockpile to fill and compact 3,880 m^3 x $4.5	$17,460
Re-spread topsoil 24,200 m^2 x $0.5	$12,100
Laser levelling reed beds 13,104 m^2 x $1,00	$13,104
Inlet/outlet culverts 2 x $2,000	$ 4,000
Fencing 968M x 4.5	$ 4,356
Pumps 2 x $5000	$10,000
Total per 2.42 hectare wetland area	$79,920
Total cost per hectare	**$35,700**

Wetland planting costs	$/ha	50,000

3.5.3 Benefits and costs for Piped or Channelled irrigation

Again, this is based on work undertaken by Whittle and Philcox (1996a, 1996b).

Area required for wetlands	ha	254.1
Further drop in nutrient level	%	15

(Assume rehabilitation drops by 60%, wetlands by further 15%)

TABLE 3-2. PIPED IRRIGATION REHABILITATION COSTS

Activity	River channel	Back channel	Drainage	Highland irrigation	On farm works	On farm survey	On farm contingency	Off farm survey	Off farm contingency
Total cost	$7,520,984	$1,593,210	$3,885,259	$2,874,800	$4,568,550	$274,113	$726,399	$952,455	$2,381,138
Payment per year over 10 years on borrowing including interest	$906,614	$192,053	$468,347	$346,542	$550,714	$33,043	$87,564	$114,813	$287,033

TABLE 3-3. CHANNELLED IRRIGATION REHABILITATION COSTS

Activity	River channel	Back supply channel	Drainage	Highland irrigation	On farm works	On farm survey	On farm contingency	Off farm survey	Off farm contingency
Total cost	$4,180,664	$1,593,210	$1,622,645	$2,874,800	$4,568,550	$274,113	$726,399	$616,279	$1,540,698
Payment per year over 10 years on borrowing including interest	$503,956	$192,053	$195,601	$346,542	$550,714	$33,043	$87,564	$74,289	$185,723

3.6 COST-SHARING

The Beneficiary Pays Principle (BPP) has been used as the basis for determining the cost-sharing ratio for this analysis i.e., cost shares are distributed to stakeholders in direct proportion to the benefit they receive.

This is undertaken is several steps:
1) The economic benefits of the plan are quantified.
2) The stakeholders who are likely to receive the benefit need to be identified.

In this analysis the stakeholder groups considered were:
- farmers who receive a benefit on-farm, and
- the greater community (represented by the government).

While this model is based on the 'Beneficiary Pays Principle', allowance must also be made during the negotiation phase for issues such as stakeholder's ability to pay and moral or social obligations, see main thesis text (hence the importance of the facility within the model to change the percentage of each component to be paid by the stakeholders so that these issues can be considered).

3.7 BUY-OUT FOR WETLANDS

See Appendix 4.6 and Tables 6-13 and 6-14 in the text for equations containing these variables.

3.7.1.1 Water requirements

Evaporation figures were provided by the Bureau of Meteorology for the lower Murray region. The total evaporation per year off permanent wetlands is much greater than from either dairy pastures or temporary wetlands because of the longer time period for which they are flooded. Therefore it is necessary to take the daily evaporation rate per hectare (e) and multiply this by the number of days that flooding occurs (d) to determine total evaporation (TE) for pasture and each wetland type.

$$TE = e \times d$$

3.7.2 Permanent wetlands

Evapotranspiration rate per hectare wetlands	ML/year	16.39
Evapotranspiration loss under current farming	ML/year	15.41
Rainfall (long flat)	ML/year	3.43
ELMA water per hectare	ML/year	3.84
Water required to fill swamp to 0.7m	ML/ha	7
Temporary water trade price	$/ML	100
Price of water	$/ML	1,300
Farmer water for sale	ML/ha	13.92

3.7.2.1 Loss of dairy income (income continues from highland)

Once dairy pastures are returned to wetlands, income from dairy farming on the swamps will cease. Income from farming will continue on the highland areas (predominantly dry-stock). Dairy companies will truck milk to the factory from other areas to meet production demands.

Loss of dairy income (income continues from highland)	%	78.4
Cost of trucking milk	$/lit	0.03

3.7.3 Managed wetlands

These figures are based on the actual costs incurred by farmers on the Paiwalla swamp, which was recently returned to managed wetlands.

Land selected for managed wetland construction	%	100
Cost of wetland establishment	$/ha	705
Management cost for first 3 years	$/ha/year	100
On going management cost	$/ha/year	50

Appendix 4

Thesis equations

4 THESIS EQUATIONS

This appendix presents in both word and numerical form the equations contained in the spreadsheet model. As so many prior equations were required to make up those equations presented in the three land use sections it was not possible to present this information earlier. The purpose of this appendix is therefore to provide an understanding of how the various equations were determined. Reference is provided (in brackets on the right) to show where major equations are presented in the three land use option sections.

4.1 FILTRATION

4.1.1 Government benefits

Annual filtration cost forgone = Annual cost of filtration plants in the study region

θ = 10 Million

Costs of UV plant foregone = Installation of UV filter in the study region

Buv = 1 Million

Annual running cost of UV forgone = Operation of UV filter costs

$Buva$ = 10,000

Total government benefits per hectare for water filtration = ψ (Table 5-5)

$$\sum_{t=1}^{25}(\alpha\lambda_t/\varphi)/(1+r)^t, \quad (5\text{-}1)$$

where α = filtration efficiency achieved (%), λ_t (filtration benefits at full filtration efficiency ($/year)) = $\theta_t + Buv + Buva_t$, θ_t = annual filtration costs avoided ($), Buv = UV construction costs avoided ($), $Buva_t$= annual UV costs avoided, φ = area of wetlands required for water filtration.

4.1.2 Farmer benefits

Repair and maintenance costs = no costs

Income from water sale = Total area required for water filtration x water required by farmers for this option x price of water at time of writing

$\eta = \varphi \times fwr \times T$

Income from Highland = value of production x filtration area x (100 - 97% Loss of dairy income) %

$Bh = \Pi \times \varphi \times (100 - si)\%$

Total farmer benefits = β ,
where $\beta = \eta + Bh$

Total benefits = $\beta + \psi$ (Table 5-5)

4.1.3 Government costs

Cost of water for evaporation over 4/5 area = (Evapotranspiration rate from wetlands – rainfall - ELMA water) x Maximum price for water under current conditions x area required for water filtration x 4/5

$$\chi = (\Lambda - P - ELMA) \times T \times \varphi \times 4/5 \quad \text{(Table 5-5)}$$

Wetland construction costs for filtration = Cost of wetland establishment for filtration x area required for filtration

$$Cwf = Cwfe \times \varphi \quad (5\text{-}2)$$

Infrastructure r & m cost of wetlands = Repairs and maintenance and capital cost x Total area required for water filtration

$$Cgr = rm \times \varphi \quad (5\text{-}3)$$

Total government costs = $\chi + \lambda$, (Table 5-5)
where $\lambda = Cwf + Cgr$

4.1.4 Farmer Costs

No costs. Lost production from area bought out is reflected in the Status quo.

Total costs = $\chi + \lambda$ (Table 5-5)

4.2 STATUS QUO

4.2.1 Farmer income

Net farm income = Farm income – production costs

$$\Pi = \Omega - K \qquad (6\text{-}1)$$

Farm income = (average price per litre - cost of production) x current production litres +(area of rated land not in dairy farming x income/hectare from non dairy land)

$$\Omega = (pl \times pc + ar \times nd)$$

K = production costs associated with farming.

Total net farmer income = Π (Table 6-1)

Total government income = 0

Total income = Π

4.2.2 Farmer costs

Repair and maintenance costs = farmer $/hectare for SA water infrastructure x hectares rated swamp land

$$Cr = fsa \times rl$$

Total farmer costs = *Cr*

4.2.3 Government cost

Repairs and maintenance and capital cost = Gov. $/hectare for SA water infrastructure x hectare rated swamp

$$Cgr = rm \times rl$$

Tourism loss due to dairy effect on algae = (Value of tourism for this swamp + annual value of tourism loss to the broader economy for this swamp) x frequency of blue/green algae per 100 years x percentage drop in tourist income it causes x per cent of costs are associated with the dairy industry

$$Ct = (vt + tb) \times fbg \times \%td \times \%dc \qquad (6\text{-}2)$$

Water quality costs = Water quality costs associated with testing during outbreak x frequency of blue/green algae per 100 years x per cent of costs are associated with the dairy industry x percentage of dairy farming region

$$Cw = wq \text{ x } fbg \text{ x } \%dc \text{ x } \%fr$$

Algal outbreak costs associated with dairy industry = Water treatment and transport costs associated with outbreaks x frequency of blue-green algae per 100 years x per cent of costs are associated with the dairy industry x percentage of farming region

$$Cbg = wt \text{ x } fbg \text{ x } \%dc \text{ x } \%fr$$

Total government costs = $Cgr + \vartheta$, (Table 6-1)

where $\vartheta = Ct + Cw + Cbg$

Total costs = $\partial + \vartheta$, (Table 6-1)

where $\partial = Cr + Cgr$

4.3 PIPED REHABILITATION

4.3.1 Farmer benefits

Production + increase per year for 5 years = (Status quo production + % increased production/yr for 5 years) + (increased area from filled channels x $/hectare dairy income/yr increasing for 5 years). Income continues at the same level from year 6 on.

$$\Pi_{p,t} = \begin{cases} \Pi(1+\%ip)^{t} + ia(ih*t) & t = 1,\ldots,5 \\ \Pi(1+\%ip)^{6} + ia(ih*t) & t = 6,\ldots,25 \end{cases} \tag{6-4}$$

Note that no increase in production occurs in the first year.

A 40 % increase in milk production over five years is based on figures provided by sCOWn (2000), Table 4-1. PIRSA (2001) state that if stocking rates and milk production increased to the same rate as the top 20 % of farms, than milk production would increase by 67 %. However, discussions with sCOWn (based on rehabilitation of other private irrigation areas) indicated that on average, production increases would be around 40 %. These figures are also supported by Philcox and Douglas (1990), Philcox (1990, 1996), Philcox and Scown (1991), and Philcox *et al.* (1992), which show an increase in net farm income of approximately 40 %.

TABLE 4-1. LMIAG FARM STOCKING RATE AND MILK PRODUCTION 1998-99

	Average for bottom 20%	Average overall	Average for top 20%
Stocking rate (no)	0.9	2.3	3.7
Milk production per cow (Litres)	4,573	6,450	8,396

In the model increased production is directly related to increased net income. Because of the variation in cost savings associated individual components when production increases, cost saving adjustments σ are made separately as detailed below.

Increased labour cost savings = labour cost savings per farm x 20% increase in cost savings per year over 5 years x number of farms. Labour cost saving figures remain the same from year 6 on.

$$Bl_{t} = \begin{cases} ls(1+\%lc)^{t} \times nf & t = 1,\ldots,5 \\ ls(1+\%lc)^{6} \times nf & t = 6,\ldots,25 \end{cases} \tag{Table 6-5}$$

Reduced feed cost = supplementary feed costs x 10% reduction in feed costs per year over 5 years. Feed cost figures remain the same from year 6 on.

$$Bf_t = \begin{cases} sf(1-\%rg)^t & t = 1,\ldots,5 \\ sf(1-\%rg)^6 & t = 6,\ldots,25 \end{cases} \qquad \text{(Table 6-5)}$$

Reduced expend on fertiliser = fertiliser costs % x 40% reduction in fertiliser costs per year over 5 years. Fertilisers cost figures remain the same from year 6 on.

$$Bfr_t = \begin{cases} fc(1-\%rs)^t & t = 1,\ldots,5 \\ fc(1-\%rs)^6 & t = 6,\ldots,25 \end{cases} \qquad \text{(Table 6-5)}$$

A summary of the benefits from rehabilitation is presented in Table 4-2 below.

TABLE 4-2. ANNUAL BENEFITS TO FARMERS ARISING FROM PIPED REHABILITATION

	Year 1 benefit $	Year 2 benefits $(000)	Year 3 benefits $(000)	Year 4 benefits $(000)	Year 5 benefits $(000)	On-going benefits $(000) (years 6-25)
Increased Production	0	551	1,102	1,653	2,204	2,755
Reduced labour	0	29	58	86	115	144
Reduced feed	0	166	333	499	666	832
Reduced fertiliser	0	111	221	332	443	553

Total farmer benefits = $\Pi_p + \sigma$, (Table 6-5)

where $\sigma = Bl + Bf + Bfr$

Government benefits=0.
(The reduction in externality costs is reflected in the cost difference between this option and the Status quo – see cost section below).

Total benefits = $\Pi_p + \sigma$

4.3.2 Farmer costs

Capital, repair and maintenance costs = (river channel + back supply channel + drainage/salt channel + Highland irrigation) x 10%

$$\varsigma = (rc + bs + ds + hi) \text{x } 10\% \qquad (6\text{-}7)$$

4.3.2.1 Farmer cost of rehabilitation

Costs of rehabilitation = river channel + back supply channel + drainage/salt channel + Highland irrigation + off-farm survey/design/contingency costs +monitoring costs + On farm survey/design/contingency costs

$$Cfp = rc + bc + ds + hi + of + mc + onf \qquad (6\text{-}6)$$

River channel = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **River channel costs**) x farmers per cent cost share

River channel cost = sluices x cost per sluice + fill for old channels x cost per metre + metres pipeline x cost per metre + pumps and motors x cost per pump + bay outlets x cost per outlet + water meters x cost per meter

Back supply channel = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **Back supply channel costs**) x farmers per cent cost share

Back supply channel cost = sluices x cost per sluice + water meters x cost per meter + fill for old channels x cost per metre +metres of new channel x cost per metre + metres of fence x cost per metre)

Drainage/salt channel = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **Drainage/salt channel costs**) x farmers per cent cost share

Drainage/salt channel cost = metres of channel reshaping x cost per metre + drainage inlet structures x cost per structure + metres of fence x cost per metre + metres of bank stabilisation x cost per metre + metres of cut off drain x cost per metre

Highland irrigation = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **Highland irrigation costs**) x farmers per cent cost share

Highland irrigation costs = metres of ring main x cost per metre + pump stations x cost per station + outlet connections x cost per connection + water meters x cost per meter

Off farm survey/design/contingency costs = (River channel + back channel + drainage + highland irrigation costs) x 6% x farmers per cent cost share+ (River channel + back channel + drainage + highland irrigation costs) x 15% x farmers per cent cost share
Monitoring costs = monitoring costs x percentage of farming region x farmers per cent cost share

Monitoring costs = monitoring costs x percentage of farming region x farmer per cent cost share

On farm survey/design/contingency costs = (**On farm works**) x 6% x farmers per cent cost share + (**On farm works**) x 15% x farmers per cent cost share

On farm works = hectares requiring lasering x cost per hectare x farmers per cent cost share

Total farmer costs = ς + Cfp (Table 6-5)

4.3.3 Government costs

Tourism loss due to dairy effect on algae= Status quo Tourism loss due to dairy effect on algae x drop of 40% over 5 years. Tourism loss figures remain the same from year 5 on.

$$Ctp_t = \begin{cases} Ct(1-\%dt)^t & t = 1,\ldots,4 \\ Ct(1-\%dt)^5 & t = 5,\ldots,25 \end{cases} \qquad (6\text{-}5)$$

Water quality costs = Water quality cost x drop of 40% over 5 years. Water quality figures remain the same from year 5 on.

$$Cgw_t = \begin{cases} Cw(1-\%dt)^t & t = 1,\ldots,4 \\ Cw(1-\%dt)^5 & t = 5,\ldots,25 \end{cases} \qquad \text{(Table 6-5)}$$

Algal outbreak costs associated with dairy industry = Status quo algae outbreak costs x drop of 40% over 5 years. Algal outbreak figures remain the same from year 5 on.

$$Cbgp_t = \begin{cases} Cbg(1-\%dt)^t & t = 1,\ldots,4 \\ Cbg(1-\%dt)^5 & t = 5,\ldots,25 \end{cases} \qquad \text{(Table 6-5)}$$

4.3.3.1 Government costs of rehabilitation

Costs of rehabilitation = river channel + back supply channel + drainage/salt channel + Highland irrigation + off-farm survey/design/contingency costs +monitoring costs + On farm survey/design/contingency costs + farmer training

$Cgp = rc + bs + ds + hi + of + mc + onf + ft$ (Table 6-5)

River channel = payment per year over 10 years on borrowing including interest x percentage paid by government = (interest rate %, 10 years, **River channel costs**) x government per cent cost share

River channel cost = sluices x cost per sluice + fill for old channels x cost per metre + metres pipeline x cost per metre + pumps and motors x cost per pump + bay outlets x cost per outlet + water meters x cost per meter

Back supply channel = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **Back supply channel costs**) x government per cent cost share

Back supply channel cost = sluices x cost per sluice + water meters x cost per meter + fill for old channels x cost per metre +metres of new channel x cost per metre + metres of fence x cost per metre)

Drainage/salt channel = payment per year over 10 years on borrowing including interest x percentage paid by government = (interest rate %, 10 years, **Drainage/salt channel costs**) x government per cent cost share

Drainage/salt channel cost = metres of channel reshaping x cost per metre + drainage inlet structures x cost per structure + metres of fence x cost per metre + metres of bank stabilisation x cost per metre + metres of cut off drain x cost per metre

Highland irrigation = payment per year over 10 years on borrowing including interest x percentage paid by government = (interest rate %, 10 years, **Highland irrigation costs)** x government per cent cost share

Highland irrigation costs = metres of ring main x cost per metre + pump stations x cost per station + outlet connections x cost per connection + water meters x cost per meter

Off farm survey/design/contingency costs = (River channel + back channel + drainage + highland irrigation costs) x 6% x government per cent cost share + (River channel + back channel + drainage + highland irrigation costs) x 15% x government per cent cost share

Monitoring costs = monitoring costs x percentage of farming region x government per cent cost share

On farm survey/design/contingency costs = **(On farm works**) x 6% x government per cent cost share + (**On farm works**) x 15% x government per cent cost share

On farm works = hectares requiring lasering x cost per hectare x government per cent cost share

Farmer training = cost per farmer x number farmers (for 5 years)

Total government costs = $Ctp + Cgw + Cbgp + Cgp$

$$\text{Total costs} = \varsigma + \tau + \upsilon, \qquad \text{(Table 6-5)}$$

where $\tau = Ctp + Cgw + Cbgp$, $\upsilon = Cfp + Cgp$

4.4 CHANNELLED REHABILITATION

4.4.1 Farmer benefits

Production + increase per year for 5 years = (Status quo production + % increased production/yr for 5 years). Income continues at the same level from year 6 on.

$$\Pi_{p,t} = \begin{cases} \Pi(1+\%ip)^t & t = 1,...,5 \\ \Pi(1+\%ip)^5 & t = 6,...,25 \end{cases}$$ (Table 6-6)

Increased labour cost savings = Labour cost savings per farm x 20% increase in costs per year over 5 years x number of farms. Labour cost saving figures remain the same from year 6 on.

$$Bl_t = \begin{cases} ls(1+\%lc)^t \times nf & t = 1,...,5 \\ ls(1+\%lc)^5 \times nf & t = 6,...,25 \end{cases}$$ (Table 6-6)

Reduced feed cost = supplementary feed costs x 10% reduction in feed costs per year over 5 years. Feed cost figures remain the same from years 6 on.

$$Bf_t = \begin{cases} sf(1-\%rg)^t & t = 1,...,5 \\ sf(1-\%rg)^5 & t = 6,...,25 \end{cases}$$ (Table 6-6)

Reduced expend on fertiliser = fertiliser costs % x 40% reduction in fertiliser costs per year over 5 years. Fertiliser cost figures remain the same from year 6 on.

$$Bfr_t = \begin{cases} fc(1-\%rs)^t & t = 1,...,5 \\ fc(1-\%rs)^5 & t = 6,...,25 \end{cases}$$

Total farmer benefits = $\Pi_p + \sigma$, (Table 6-6)
where $\sigma = Bl + Bf + Bfr$

4.4.2 Government benefits

No benefits.

4.4.3 Farmer costs

All capital, repair and maintenance costs = (farmer operation and maintenance costs/hectare + Gov operation and maintenance costs/hectare + Capital costs/hectare) x hectares requiring rehabilitation

$\varsigma = (fsa + rm) \text{x}\ rl$ (Table 6-6)

4.4.3.1 Farmer costs of rehabilitation

Costs of rehabilitation = river channel + back supply channel + drainage/salt channel + Highland irrigation + off-farm survey/design/contingency costs +monitoring costs + On farm survey/design/contingency costs

$Cfc = rc+bc+ds+hi+of+mc+onf$ (Table 6-6)

River channel = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **River channel costs**) x farmers per cent cost share

River channel cost = sluices x cost per sluice + fill for old channels x cost per metre + metres channel and fencing x cost per metre + channel regulators required x cost per regulator + bay outlets x cost per outlet + water meters x cost per meter

Back supply channel = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **Back supply channel costs**) x farmers cost share per cent

Back supply channel cost = sluices x cost per sluice + water meters x cost per meter + fill for old channels x cost per metre +metres of new channel x cost per metre + metres of fence x cost per metre)

Drainage/salt channel = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **Drainage/salt channel costs)** x farmers per cent cost share

Drainage/salt channel cost = metres of channel reshaping x cost per metre + drainage inlet structures x cost per structure + metres of fence x cost per metre

Highland irrigation = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **Highland irrigation costs)** x farmers per cent cost share

Highland irrigation costs = metres of ring main x cost per metre + pump stations x cost per station + outlet connections x cost per connection + water meters x cost per meter

Off farm survey/design/contingency costs = (River channel + back channel + drainage + highland irrigation costs) x 6% + (River channel + back channel + drainage + highland irrigation costs) x 15%

Monitoring costs = monitoring costs x percentage of farming region x farmers cost share per cent

On farm survey/design/contingency costs = **(On farm works)** x 6% x farmers cost share %+ **(On farm works)** x 15% x farmers per cent cost share

On farm works = hectares requiring lasering x cost per hectare x farmers per cent cost share

Total farmer costs = ς + Cfc (Table 6-6)

4.4.4 Government costs

Reduced tourism loss due to dairy effect on algae= Status quo Tourism loss due to dairy effect on algae x drop of 40% over 5 years. Tourism loss figures remain the same from year 5 on.

$$Ctc_t = \begin{cases} Ct(1-\%dt)^t & t = 1,\ldots,4 \\ Ct(1-\%dt)^5 & t = 5,\ldots,25 \end{cases} \qquad \text{(Table 6-6)}$$

Reduced water quality costs = Water quality cost x drop of 40% over 5 years. Water quality figures remain the same from 5 years on.

$$Cgw_t = \begin{cases} Cw(1-\%dt)^t & t = 1,\ldots,4 \\ Cw(1-\%dt)^5 & t = 5,\ldots,25 \end{cases} \qquad \text{(Table 6-6)}$$

Reduced algal outbreak costs associated with dairy industry = Status quo algae outbreak costs x drop of 40% over 5 years. Algal outbreak figures remain the same from 5 years on.

$$Cbgc_t = \begin{cases} Cbg(1-\%dt)^t & t = 1,\ldots,4 \\ Cbg(1-\%dt)^5 & t = 5,\ldots,25 \end{cases} \qquad \text{(Table 6-6)}$$

4.4.4.1 Government cost of rehabilitation

Costs of rehabilitation = river channel + back supply channel + drainage/salt channel + Highland irrigation + off-farm survey/design/contingency costs +monitoring costs + On farm survey/design/contingency costs + farmer training

$$Cgc = rc + bc + ds + hi + of + mc + onf + ft \qquad \text{(Table 6-6)}$$

River channel = payment per year over 10 years on borrowing including interest x percentage paid by government = (interest rate %, 10 years, **River channel costs**) x government per cent cost share

River channel cost = sluices x cost per sluice + fill for old channels x cost per metre + metres pipeline x cost per metre + pumps and motors x cost per pump + bay outlets x cost per outlet + water meters x cost per meter

Back supply channel = payment per year over 10 years on borrowing including interest x percentage paid by farmers = (interest rate %, 10 years, **Back supply channel** costs) x government per cent cost share

Back supply channel cost = sluices x cost per sluice + water meters x cost per meter + fill for old channels x cost per metre +metres of new channel x cost per metre + metres of fence x cost per metre)

Drainage/salt channel = payment per year over 10 years on borrowing including interest x percentage paid by government = (interest rate %, 10 years, **Drainage/salt channel costs**) x government per cent cost share

Drainage/salt channel cost = metres of channel reshaping x cost per metre + drainage inlet structures x cost per structure + metres of fence x cost per metre + metres of bank stabilisation x cost per metre + metres of cut off drain x cost per metre

Highland irrigation = payment per year over 10 years on borrowing including interest x percentage paid by government = (interest rate %, 10 years, **Highland irrigation costs)** x government per cent cost share

Highland irrigation costs = metres of ring main x cost per metre + pump stations x cost per station + outlet connections x cost per connection + water meters x cost per meter

Off farm survey/design/contingency costs = (River channel + back channel + drainage + highland irrigation costs) x 6% + (River channel + back channel + drainage + highland irrigation costs) x 15%

Monitoring costs = monitoring costs x percentage of farming region x government cost share per cent

On farm works/survey/contingency costs = **(On farm works)** x 6% x government cost share per cent+ **(On farm works)** x 15% x government % cost share per cent

On farm works = hectares requiring lasering x cost per hectare x government per cent cost share

Farmer training = cost per farmer x number farmers (for 5 years)

Total government costs = $Ctc + Cgw + Cbgc + Cgc$

Total costs = $\varsigma + \tau + \upsilon$, (Table 6-6)

where $\tau = Ctc + Cgw + Cbgc$, $\upsilon = Cfc + Cgc$

4.5 WETLANDS OPTION FOR STATUS QUO, PIPED AND CHANNELLED IRRIGATION

4.5.1 Farmer Benefit

There are no farmer benefits from including wetlands. All benefits go to the community (represented by the government).

Total Farmer Benefit = 0

4.5.2 Government benefit

Reducted tourism loss = Tourism loss due to dairy effect on algae x % drop in nutrient over 5 years. % drop = 60% for Status quo, 15% for Piped and Channelled rehabilitation.

$$Btv_t = \begin{cases} Ct(1-\%dt)^t & t = 1,...,4 \\ Ct(1-\%dt)^5 & t = 5,...,25 \end{cases} \quad (6\text{-}10)$$

Reduced water quality costs = Water quality cost x % drop over 5 years. Water quality figures remain the same from 5 years on. % drop = 60% for Status quo, 15% for Piped and Channelled rehabilitation.

$$Brwc_t = \begin{cases} Cw(1-\%dt)^t & t = 1,...,4 \\ Cw(1-\%dt)^5 & t = 5,...,25 \end{cases} \quad \text{(Table 6-6)}$$

Reduced algal outbreak costs associated with dairy industry = algal outbreak costs associated with dairy industry x % drop in nutrient level over 5 years. % drop = 60% for Status quo, 15% for Piped and Channelled rehabilitation.

$$Brbgw_t = \begin{cases} Cbg(1-\%dt)^t & t = 1,...,4 \\ Cbg(1-\%dt)^5 & t = 5,...,25 \end{cases} \quad \text{(Table 6-6)}$$

Total government Benefits = ϕ

Where $\phi = Btv + Brwc + Brbgw$ (Table 6-6)

4.5.3 Farmer cost

Farmers wetland construction = hectares required for wetlands x cost of wetland x % cost paid for by farmers

$Cfwc = hw$ x wcp x % farmers cost share (6-11)

Farmer lost production (wetlands) = hectares required for wetlands x loss of production (10% of production per hectare for worst land) x % farmers cost share

$Cflp = hw$ x 10% Bp/hectare x % farmers cost share

Total farmer costs = $Cfwc + Cflp$ (Table 6-6)

4.5.4 Government cost

Government wetland construction = hectares required for wetlands x cost of wetland establishment x (100-% cost paid for by farmers)

$Cgwc = hw$ x wcp x (100-% farmers cost share)

Total government costs = $Cgwc$

Total costs = $\zeta + \omega$ (Table 6-6)

Where $\zeta = Cfwc + Cgwc$, $\omega = Cflp + Cglp$

4.6 PERMANENT WETLANDS

4.6.1 Farmer benefits

Income from highlands = (Status quo income x (100-% dairy income from swamps))/3

$Bh = (\Pi \text{ x } (100 - \%si))/3$ (Table 6-13)

Income from water sale = Price for water x water for sale by farmers x hectares rated swamp land.

$\eta = \mathrm{T} \text{ x } fwr \text{ x } rl$ (6-13)

Total farmer benefits = ε, (Table 6-13)

where $\varepsilon = \eta + Bh$

4.6.2 Government benefits

Removal of the costs associated with dairy effluent entering the Murray = tourism loss due to dairy effect on algae + water quality testing costs + blue-green algal outbreak costs. It is important to note that because these benefits are a reduction in the costs associated with the Status quo option, they are revealed when comparing this option of Permanent wetlands with the Status quo option.

$\vartheta = Ct + Cw + Cbg$ (6-3)

Filtration value of Permanent wetlands = annual wetland filtration value x marginal utility of water x area of Gov swamp land

$\Psi_p = \psi \text{ x } \delta \text{ x } \kappa$ (6-14)

Total government benefits = Ψ_p (Table 6-13)

4.6.3 Farmer costs

No farmer costs are incurred.

4.6.4 Government costs

Cost of filling swamps to 0.7m = Water required to fill swamp to 0.7 Metre x temporary water trade price x (area of swamp land for Gov swamp – unrated land/2 (would not be flooded))

$$\varpi = \Delta \text{ x } \rho \text{ x } (\kappa - \Gamma/2) \qquad (6\text{-}16)$$

Cost of water for evaporation = (Evapotranspiration rate from wetlands – rainfall - ELMA water) x Maximum price for water price water for permanent trade x area of swamp land for government swamp minus area of unrated land which would not be flooded.

$$\chi = (\Lambda - \text{P} - \text{ELMA}) \text{ x T x } (\kappa - \Gamma/2) \qquad (6\text{-}17)$$

Cost of trucking Milk = 0.03 c/litre x current milk production litres

$$\nu = .03 \text{ x } cmp \qquad (6\text{-}18)$$

Total government costs = $\mu + \nu$,

where $\mu = \varpi + \chi$

Total costs = $\mu + \nu$ (Table 6-13)

4.7 MANAGED WETLANDS

4.7.1 Farmer benefits

Income from highlands = (Status quo income x (100-%Loss of swamp land%))/3

$Bh = (\Pi \text{ x } (100 - \%si))/3$ (Table 6-14)

Income from water sale = Maximum price for water under current drought conditions x water required by Farmers for this option x hectares rated swamp land.

$\eta = \text{T x } fwr \text{ x } rl$

Total farmer benefits $= \varepsilon$,

where $\varepsilon = \eta + Bh$ (Table 6-14)

4.7.2 Government benefits

Filtration value of Managed wetlands = (annual value of wetlands for water filtration x marginal utility of water x area of swamp land for Gov swamp)/number of months wetland connected to the river.

$\Psi_m = (\psi \times \delta \times \kappa) \times t / 12$ (6-20)

Total government benefits = Ψ_m (Table 6-14)

4.7.3 Farmer costs

No farmer costs are incurred.

4.7.4 Government costs

Wetland construction costs = Cost of wetland establishment x area swamp land for Gov swamps

$Cmc = mwe \text{ x } \kappa$ (6-21)

Wetland management costs = Initial management cost $100 per hectare/yr for first 3 years x area of swamp land for Gov swamp + Ongoing management cost $50 per hectare/yr

$Cm = imc \text{ x } \kappa + omc$ (6-22)

Cost of trucking Milk = 0.03 c/litre x current production litres

$$\nu = 0.03 \text{ x } cmp \qquad \text{(Table 6-14)}$$

Total government costs = $\pi + \nu$,

where $\pi = Cmc + Cm$

Total costs $= \pi + \nu$ (Table 6-14)

Appendix 5

Sensitivity analysis

5 SENSITIVITY ANALYSIS

The tables presented in this appendix relate to parts I and III of the results sections found in the thesis. While sensitivity analysis for the most important variables has already been presented in the relevant results sections, the tables in this appendix provide further information on the sensitivity of results to a range of variables.

5.1 PART 1. WETLANDS FOR WATER FILTRATION

TABLE 5-1. NET ECONOMIC RETURNS FROM CHANGING FROM DAIRY FARMING TO CONSTRUCTED WETLANDS AS PART OF THE WATER FILTRATION AND UV TREATMENT SYSTEM, WITH VARING REAL INTEREST RATES

Replace ½ filtration + UV	NPV	Gov BCR
Interest rate %		
2.55	47.18	2.34
3.55	38.98	2.11
4.55	32.05	1.92
5.55	26.16	1.76
6.55	21.13	1.62
7.55	16.83	1.50
8.55	13.12	1.39
9.55	9.92	1.30
Replace all filtration + UV		
Interest rate %		
2.55	133.94	4.79
3.55	116.17	4.32
4.55	101.01	3.91
5.55	88.25	3.56
6.55	77.25	3.26
7.55	67.78	3.00
8.55	59.59	2.77
9.55	52.49	2.57

TABLE 5-2. VALUE OF CONSTRUCTED WETLANDS FOR WATER FILTRATION WITH VARYING REAL INTERST RATES

Replace ½ filtration + UV	$/hectare/year	PV/hectare
Interest rate %		
2.55	14,182	259,798
3.55	14,118	231,421
4.55	14,051	207,286
5.55	13,983	186,653
6.55	13,925	168,925
7.55	13,842	153,617
8.55	13,769	140,333
9.55	13,696	128,751
Replace all filtration + UV		
Interest rate %		
2.55	28,177	516,187
3.55	28,032	459,520
4.55	27,883	411,328
5.55	27,728	370,133
6.55	27,570	334,740
7.55	27,408	304,181
8.55	27,244	277,666
9.55	27,079	254,551

TABLE 5-3. EFFECT OF A CHANGE IN WATER PRICE ON THE ECONOMIC RETURN OF CONVERTING FROM DAIRY FARMING TO CONSTRUCTED WETLANDS FOR WATER FILTRATION, ASSUMING WETLANDS REPLACE HALF OF EACH WATER FILTRATION PLANT

Water price $/ML	$1,100	$1,300	$1,500	$1,700
PV Farmer benefits	-5.21	-4.30	-3.39	-2.48
PV Government benefits	78.32	78.32	78.32	78.32
PV Total Community benefits	73.11	74.02	74.93	75.84
PV Farmer costs	-1.50	-1.50	-1.50	-1.50
PV Government costs	36.06	36.54	37.02	37.49
PV Total Community costs	34.56	35.04	35.52	35.99
NPV	**38.55**	**38.98**	**39.42**	**39.85**
Farmer BCR	0.29	0.35	0.44	0.61
Government BCR	2.17	2.14	2.12	2.09
Community BCR	2.12	2.11	2.11	2.11

TABLE 5-4. EFFECT OF A CHANGE IN WATER PRICE ON THE ECONOMIC RETURN OF THE WATER FILTRATION OPTION, ASSUMING CONSTRUCTED WETLANDS REPLACE ALL OF THE FILTRATION PLANTS

Water price $/ML	$1,100	$1,300	$1,500	$1,700
PV Farmer benefits	-5.21	-4.30	-3.39	-2.48
PV Government benefits	155.51	155.51	155.51	155.51
PV Total Community benefits	150.30	151.21	152.12	153.03
PV Farmer costs	-1.50	-1.50	-1.50	-1.50
PV Government costs	36.06	36.54	37.02	37.49
PV Total Community costs	34.56	35.04	35.52	35.99
NPV	**115.74**	**116.17**	**116.60**	**117.04**
Farmer BCR	0.29	0.35	0.44	0.61
Government BCR	4.31	4.26	4.20	4.15
Community BCR	4.35	4.32	4.28	4.25

TABLE 5-5. EFFECT OF A CHANGE IN THE PRICE OF THE FILTRATION PLANT ON THE ECONOMIC RETURN OF THE WATER FILTRATION OPTION, ASSUMING CONSTRUCTED WETLANDS REPLACE HALF OF EACH WATER FILTRATION PLANT

	$8million	$9 million	$10 million	$11 million	$12 million
PV Farmer benefits	-4.30	-4.30	-4.30	-4.30	-4.30
PV Government benefits	62.88	70.60	78.32	86.04	93.76
PV Total Community benefits	58.58	66.30	74.02	81.74	95.26
PV Farmer costs	-1.50	-1.50	-1.50	-1.50	-1.50
PV Government costs	36.54	36.54	36.54	36.54	36.54
PV Total Community costs	35.04	35.04	35.04	35.04	35.04
NPV	**23.54**	**31.26**	**38.98**	**46.70**	**54.42**
Farmer BCR	0.35	0.35	0.35	0.35	0.35
Government BCR	1.72	1.93	2.14	2.35	2.57
Community BCR	1.67	1.89	2.11	2.33	2.55

TABLE 5-6. EFFECT OF A CHANGE IN THE PRICE OF THE FILTRATION PLANT ON THE VALUE OF WETLANDS FOR WATER FILTRATION, ASSUMING CONSTRUCTED WETLANDS REPLACE HALF OF EACH WATER FILTRATION PLANT

	$8million	$9 million	$10 million	$11 million	$12 million
Half filtration $hectare/year	11,335	12,726	14,118	15,509	16,901
PV/hectare $	185,801	208,611	231,421	254,231	277,041

TABLE 5-7. EFFECT OF A CHANGE IN THE PRICE OF THE FILTRATION PLANT ON THE ECONOMIC RETURN OF THE WATER FILTRATION OPTION, ASSUMING WETLANDS REPLACE ALL OF THE WATER FILTRATION PLANTS

	$8million	**$9 million**	**$10 million**	**$11 million**	**$12 million**
PV Farmer benefits	-4.30	-4.30	-4.30	-4.30	-4.30
PV Government benefits	124.63	140.07	155.51	170.94	186.38
PV Total Community benefits	120.33	135.77	151.21	166.65	182.09
PV Farmer costs	-1.50	-1.50	-1.50	-1.50	-1.50
PV Government costs	36.54	36.54	36.54	36.54	36.54
PV Total Community costs	35.04	35.04	35.04	35.04	35.04
NPV	**85.29**	**100.73**	**116.17**	**131.61**	**147.05**
Farmer BCR	0.35	0.35	0.35	0.35	0.35
Government BCR	3.41	3.83	4.26	4.68	5.10
Community BCR	3.43	3.88	4.32	4.76	5.20

TABLE 5-8. EFFECT OF A CHANGE IN THE PRICE OF THE FILTRATION PLANT ON THE VALUE OF WETLANDS FOR WATER FILTRATION, ASSUMING WETLANDS REPLACE ALL OF THE WATER FILTRATION PLANTS

	$8million	**$9 million**	**$10 million**	**$11 million**	**$12 million**
Half filtration $hectare/year	22,466	25,249	28,032	30,815	33,598
PV/hectare $	368,280	413,900	459,520	505,140	550,760

TABLE 5-9. EFFECT OF A CHANGE IN WETLAND CONSTRUCTION COSTS ON THE ECONOMICS RETURN OF THE WATER FILTRATION OPTION, ASSUMING WETLANDS REPLACE ALL OF THE WATER FILTRATION PLANTS

	40,000	**60,000**	**80,000**	**100,000**	**120,000**
PV Farmer benefits	-4.30	-4.30	-4.30	-4.30	-4.30
PV Government benefits	155.51	155.51	155.51	155.51	155.51
PV Total Community benefits	151.21	151.21	151.21	151.21	151.21
PV Farmer costs	-1.50	-1.50	-1.50	-1.50	-1.50
PV Government costs	23.47	30.00	36.54	43.08	49.61
PV Total Community costs	21.97	28.50	35.04	41.58	48.11
NPV	**129.24**	**122.71**	**116.17**	**109.63**	**103.10**
Farmer BCR	0.35	0.35	0.35	0.35	0.35
Government BCR	6.63	5.18	4.26	3.61	3.13
Community BCR	6.88	5.31	4.32	3.64	3.14

5.2 PART III. PERMANENT WETLANDS IN CONJUNCTION WITH CONSTRUCTED WETLANDS FOR WATER FILTRATION

TABLE 5-10. IMPACT OF A CHANGE IN WETLAND WATER FILTRATION EFFICIENCY ON THE VIABILITY OF CONSTRUCTED AND PERMANENT WETLANDS. δ VALUE OF 1. CONSTRUCTED WETLANDS REPLACE HALF OF EACH FILTRATION PLANT

	Percentage Filtration efficiency of Permanent wetlands				
	10	**30**	**50**	**70**	**90**
Filtration value $/hectare	1,412	4,235	7,059	9,883	12,706
NPV ($Million)	**30.62**	**207.65**	**384.74**	**561.84**	**738.87**
Community BCR	1.33	3.24	5.15	7.07	8.98

TABLE 5-11. IMPACT OF A CHANGE IN WATER PRICE ON WETLAND VIABILITY OF CONSTRUCTED AND PERMANENT WETLANDS. δ VALUE OF 1. PERMANENT WETLANDS VALUED AT $12,706 (90% EFFICIENT). CONSTRUCTED WETLANDS REPLACE HALF OF EACH FILTRATION PLANT

Water price $/ML	**$1,100**	**$1,300**	**$1,500**	**$1,700**
PV Farmer benefits	-52.86	-43.62	-34.39	-25.15
PV Government benefits	875.12	875.12	875.12	875.12
PV Total Community benefits	822.27	831.50	840.74	849.97
PV Farmer costs	-15.23	-15.23	-15.23	-15.23
PV Government costs	101.01	107.86	114.70	121.54
PV Total Community costs	85.79	92.63	99.47	106.31
NPV	**736.48**	**738.87**	**741.26**	**743.66**
Farmer BCR	-	-	-	-
Government BCR	8.66	8.11	7.63	7.20
Community BCR	9.58	8.98	8.45	7.99

TABLE 5-12. IMPACT OF CHANGE IN MILK TRANSPORT COSTS ON CONSTRUCTED AND PERMANENT WETLANDS VIABILITY. δ VALUE OF 1. PERMANENT WETLANDS VALUED AT $7,059 PER HECTARE PER YEAR (50% EFFICIENT). CONSTRUCTED WETLANDS REPLACE HALF OF EACH FILTRATION PLANT

	2 cents	3 cents	4 cents	5 cents	6 cents
PV Farmer benefits	-43.62	-43.62	-43.62	-43.62	-43.62
PV Government benefits	520.99	520.99	520.99	520.99	520.99
TOTAL Community benefits	477.37	477.37	477.37	477.37	477.37
PV Farmer costs	-15.23	-15.23	-15.23	-15.23	-15.23
PV Government costs	95.80	107.86	119.91	131.97	144.03
TOTAL Community costs	80.57	92.63	104.67	116.74	128.80
NPV	**396.80**	**384.74**	**372.69**	**360.63**	**348.57**
Farmer BCR	-	-	-	-	-
Government BCR	5.44	4.83	4.34	3.95	3.62
Community BCR	5.92	5.15	4.56	4.09	3.71

5.3 Part III. Managed wetlands in conjunction with constructed wetlands for water filtration

Table 5-13. Community NPV ($Million) after conversion of dairy land to managed wetlands across a range of water filtration efficiencies and number of months attached to river. δ Value of 1. Constructed wetlands replace half of each filtration plant

	Percentage Filtration				
Months attached to river	**10**	**30**	**50**	**70**	**90**
6	23.79	112.34	200.88	289.37	377.92
5	16.39	90.20	163.95	237.76	311.51
4	9.05	68.06	127.08	186.09	245.10
3	1.65	45.93	90.20	134.48	178.75
2	-5.75	23.79	53.33	82.80	112.34

Table 5-14. Community BCR after conversion of dairy land to managed wetlands across a range of water filtration efficiencies and number of months attached to river. δ Value of 1. Constructed wetlands replace half of each filtration plant

	Percentage Filtration				
Months attached to river	**10**	**30**	**50**	**70**	**90**
6	1.43	3.04	4.64	6.24	7.85
5	1.30	2.63	3.97	5.31	6.65
4	1.16	2.23	3.30	4.37	5.44
3	1.03	1.83	2.63	3.44	4.24
2	0.90	1.43	1.97	2.50	3.04

Appendix 6

Channelled rehabilitation

6 CHANNELLED REHABILITATION

The cost of undertaking this rehabilitation option is presented in Table 6-1. As can be seen the majority of the costs associated with this land use change are off-farm, and are thus associated with fixing up the government-owned infrastructure.

TABLE 6-1. COSTS OF CHANNELLED REHABILITATION OPTION

$ Total Construction cost	$ Off farm Construction costs	$ On farm Construction Costs
17,997,358	12,428,296	5,569,062

Table 6-2. shows the economic return for the government and farmers where an equitable cost share is achieved (farmers and the government would be paying the same proportion of their costs as the benefits they receive from undertaking this rehabilitation option), and where farmers pay 100 % of the costs.

	Status quo $(Million)	Channelled Rehabilitation Farmers pay 100 % costs ($Million)	Net return Farmers pay 100 % costs ($Million)
PV Total Community benefits	111.70	169.67	57.97
PV Total Community costs	24.75	36.77	12.03
NPV	**86.96**	**132.90**	**45.94**
Community BCR	4.51	4.61	4.82

From the model we can determine that to achieve an equitable BCR for farmers and the government, farmers would have to pay 29.2 % of all costs. As before, the government is interested in maximising income for all the community not just for the farmers, therefore as long as farmers make a profit from the rehabilitation option the government is unlikely to be interested in further subsidisation of the farmers' costs. In this instance, farmer's BCR is 3.26 when paying all of the rehabilitation costs.

Once again, the government incurs only a very small cost associated with farmer training for this rehabilitation option (PV $42,700), however as with the Piped rehabilitation option there are ongoing pollution problems valued at approximately $3.7 Million that are not remedied by this project. While the net result of rehabilitation results in a benefit to the government because of a reduction in the original pollution costs, pollution impacts still occur. The NPV and BCR for this option are greater than for the Piped rehabilitation option described earlier (NPV $31.00) which involved piping the front supply. This is because of the substantially high costs involved in using pipes.

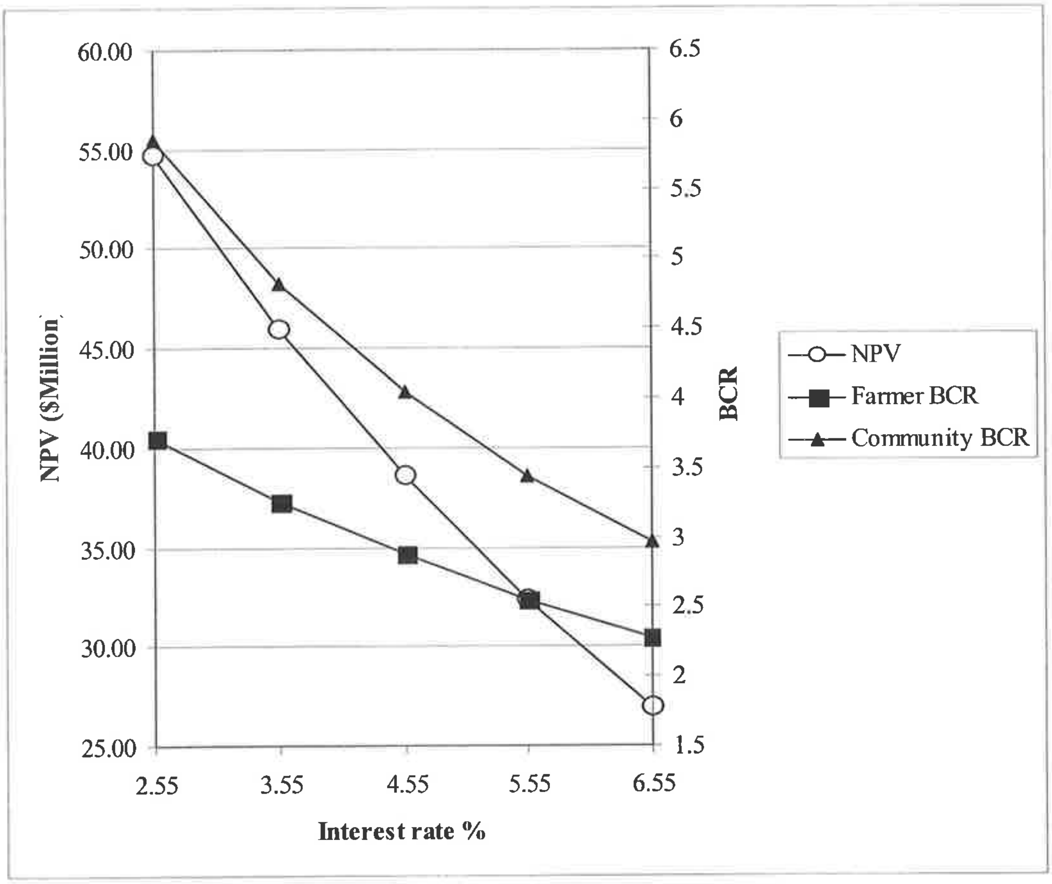
TABLE 6-2. ECONOMIC RETURN WITH FARMERS PAYING 100 % OF COSTS AND WITH EQUITABLE COST SHARE

	Status quo ($Million)	Farmers pay 100 % costs ($Million)	Net return Farmers pay 100 % costs ($Million)	Shared costs ($Million)	Net Return Shared costs ($Million)
PV Farmer benefits	111.70	169.67	57.97	169.67	57.97
PV Government benefits	-	-	-	-	-
PV Total Community benefits	111.70	167.67	57.97	167.67	57.97
PV Farmer costs	15.23	33.01	17.78	27.25	12.03
PV Government costs	9.52	3.77	-5.75	9.52	-
PV Total Community costs	24.75	36.77	12.03	36.77	12.03
NPV	**86.96**	**132.90**	**45.94**	**132.90**	**45.94**
Farmer BCR	7.34	5.14	3.26	6.23	4.82
Government BCR	-	-	∞	-	1.00
Community BCR	4.51	4.61	4.82	4.61	4.82

6.1 SENSITIVITY

The effect of a change in interest rate is presented in Figure 6-1. The results have exactly the same trend as for the Piped rehabilitation – an increase in the interest rate increases farmers' costs, but does not make this option unprofitable.

FIGURE 6-1. EFFECT OF A CHANGE IN INTEREST RATE ON NPV AND BCR FOR CHANNELLED IRRIGATION OPTION.



6.2 CHANNELLED REHABILITATION PLUS WETLANDS

As mentioned in the Piped rehabilitation section, the use of constructed wetlands is an extremely expensive option for effluent treatment, particularly so where rehabilitation has already reduced effluent by up to 60 %. Once again from an economic perspective, it is not in the government or farmers' interest to pursue the wetlands option (Table 6-3). As the area required is the same for this option as for Piped rehabilitation, the BCR is the same.

TABLE 6-3. ECONOMIC COSTS AND RETURNS OF CONSTRUCTED WETLANDS FOR CHANNELLED REHABILITATION (FARMERS PAYING 100% OF COSTS)

Government Present value Benefits ($Million)	Farmer Present value Benefits $	Government Present value Costs $	Farmer Present value Costs ($Million)	NPV ($Million)	BCR Project
0.99	0	0	22.68	-21.70	0.04

6.3 DISCUSSION

Farmers may have to choose between the Piped and Channelled rehabilitation options. A comparison of the return for both options is presented in Table 6-4. Column A shows the return from the Status quo option. Columns B and E show the return from the Piped rehabilitation and Channelled options respectively. Columns C and F show the net return (i.e., minus the Status quo) with farmers paying all costs for both rehabilitation options. Columns D and G show the net return with equitable cost share for both options.

From the government's perspective, either rehabilitation option is optimal where farmers are paying all rehabilitation costs. However from the farmers' perspective, to ensure water supply for the future (when more frequent, low river levels are anticipated) the Piped option is the obvious choice. Unfortunately, this scheme is expensive, but is the only one that ensures long-term water supply. The difference between the profitability of these two schemes represents the opportunity cost of water to farmers, (NPV $12.4 Million). Both rehabilitation schemes will drop pollution levels entering the Murray River by 60 %

TABLE 6-4. SUMMARY OF ECONOMICS ($MILLION) OF REHABILITATION OPTIONS WHERE FARMERS PAY ALL COSTS AND WITH 'EQUITABLE' COST SHARE

	Status quo	Piped rehabilitation			Channelled rehabilitation		
		With return Farmers paying 100% rehab costs	Net return (i.e., minus Status quo) Farmers paying 100% costs	Net return (i.e., minus Status quo) Equitable cost share	With project Farmers paying 100% rehab costs	Net return (i.e., minus Status quo) Farmers paying 100% costs	Net return (i.e., minus Status quo) Equitable cost share
	A	B	C	D	E	F	G
PV Farmer benefits	111.70	170.01	58.37	58.37	169.67	57.97	57.97
PV Government benefits	-	-	-	-	-	-	-
PV Total Community benefits	**111.70**	**170.01**	**58.37**	**58.37**	**167.67**	**57.97**	**57.97**
PV Farmer costs	15.23	44.90	29.67	23.92	33.01	17.78	12.03
PV Government costs	9.52	3.77	- 5.75	-	3.77	-5.75	-
PV Total Community costs	**24.75**	**48.66**	**23.92**	**23.92**	**36.77**	**12.03**	**12.03**
NPV	**86.96**	**121.41**	**34.45**	**34.45**	**132.90**	**45.94**	**45.94**
Farmer BCR	7.34	3.79	1.97	2.44	5.14	3.26	4.82
Government BCR	-	-	∞	1.00	-	∞	1.00
Community BCR	**4.51**	**3.50**	**2.44**	**2.44**	**4.61**	**4.82**	**4.82**

Appendix 7

Equation defining δ

7 THE DERIVATION OF THE EQUATION DEFINING δ

Figure 7-1 shows the total gain/benefit (associated with the increase in filtered water output from Q_1 to Q_2) is the area:

$$G_2 = \text{area } Q_1ABQ_2 = \text{area } FAB + \text{area } Q_1FBQ_2$$

or

$$G_2 = (\Delta P.\Delta Q)/2 + (P-\Delta P)\Delta Q$$

or

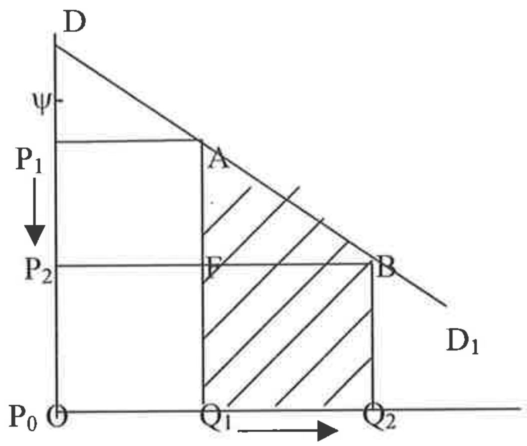
$$G_2 = \Delta P.\Delta Q/2 + P\Delta Q - \Delta P.\Delta Q$$

or

$$G_2 = P\Delta Q - \Delta P.\Delta Q/2 = (P-\Delta P/2)\Delta Q = (1-\pi/2)P.\Delta Q \qquad \text{(A7-1)}$$

where $P=P_1$ and $(P-\Delta P)=P_2$ and $\pi=\Delta P/P$ is the rate of change of price.

FIGURE 7-1. VALUATION OF NON-MARGINAL CHANGES IN QUANTITY OF WATER PRODUCED



The total benefit associated with Q_1 is the area $ODAQ_1$, which can be shown to be equal to:

$$G_1 = \text{area } P_1DA + \text{area } OP_1FQ_1$$

or $$G_1 = .5(D-P)Q+PQ = .5(D+P)Q = \psi Q \qquad \text{(A7-2)}$$

where $\psi = .5(D+P)$ and recalling that $P=P_1$ and $Q=Q_1$. Let $\psi = P/\theta$, where $\theta = P/.5(D+P)<1$.

On page 167, ΔQ is valued at $\delta\psi$ per unit, i.e.

$$G = \delta\psi\Delta Q \tag{A7-3}$$

Substituting P/θ for ψ into (A7-3) gives:

$$G = (\delta/\theta)P.\Delta Q \tag{A7-4}$$

Comparing (A7-3) and (A7-4) shows:

$$\delta = (1-\pi/2)\theta \tag{A7-5}$$

By definition, $\varepsilon = (\Delta Q/Q)/\pi$, hence:

$$\pi = (\Delta Q/Q)/\varepsilon \tag{A7-6}$$

Substituting (A7-6) into (A7-5) gives:

$$\delta = (1-(\Delta Q/Q)/(2\varepsilon))\theta \tag{A7-7}$$

Solving (A7-7) for ε gives:

$$\varepsilon = (\Delta Q/Q) /[2(1-\delta/\theta)] \tag{A7-8}$$

Appendix 8

Piped rehabilitation as Status quo

8 PIPED REHABILITATION AS STATUS QUO

8.1 Part IIb Results – no value for water filtration

8.1.1 Permanent wetlands – comparison with Piped rehabilitation

Results from simply breaching the banks and returning this area to Permanent wetlands for pollution alleviation (no value is attributed for water filtration) are presented in Table 8-1. When compared with Piped rehabilitation it can be seen that this option is not optimal. The community benefit of this option is the complete removal of the externality costs associated with effluent entering the River Murray. This benefit is worth $0.45 million per year, ($132/ha per year), PV $7.42 million ($2,161 per hectare), but is not sufficient to account for the loss in dairy income.

Table 8-1. Costs and benefits of Permanent wetland option

	Piped rehab ($Million)	Permanent Wetlands ($Million)	Net return ($Million)
TOTAL Benefits	170.07	68.08	–101.99
TOTAL Costs	48.66	84.00	35.34
NPV	**121.41**	**–15.92**	**–137.33**
BCR	3.50	0.81	

The split of costs between the farmers and the government are presented in Table 8-2. As can be seen from this table, both farmers and the government would lose money on this option. If the government decides to go down this path, it would have to subsidise farmers $57.09 million for farmers to break even (i.e. 101.99 (lost benefits) minus 44.90 (reduced costs)) The economics of this option are dominated by the requirement for the government to purchase sufficient water to account for the annual evaporation from the Permanent wetlands that are formed ($46.87 million).

TABLE 8-2. SPLIT OF COSTS AND BENEFITS BETWEEN FARMERS AND THE GOVERNMENT AFTER CONVERSION TO PERMANENT WETLANDS

	Piped rehab ($Million)	Permanent Wetlands ($Million)	Net return ($Million)
PV Farmer benefits	170.07	68.08	–101.99
PV Government benefits	–	–	–
TOTAL Community benefits	170.07	68.08	–101.99
PV Farmer costs	44.90	–	–44.90
PV Government costs	3.77	84.00	80.24
TOTAL Community Costs	48.66	84.00	35.34
NPV	**121.41**	**–15.18**	**–137.33**
Farmer BCR	3.79	–	–
Government BCR	–	–	–
Community BCR	3.50	0.81	–

8.1.2 Managed wetlands – comparison with Piped rehabilitation

The important differences in costs between Managed and Permanent wetlands arise from Managed wetlands incurring construction and maintenance costs. In addition, Managed wetlands do not require the purchase of additional water (because the Environmental Water Allocation (ELMA) that remains with the swamps) for wetting cycles. Results from returning this area to Managed wetlands for pollution alleviation (no value is attributed for water filtration) are presented in Table 8-3. When compared with dairy farming it can be seen that this is not as profitable as the Piped rehabilitation.

TABLE 8-3. COSTS AND BENEFITS OF MANAGED WETLAND OPTION

	Piped rehab ($Million)	Managed Wetlands ($Million)	Net return ($Million)
TOTAL Benefits	170.07	68.08	–101.99
TOTAL Costs	48.66	43.00	-5.663
NPV	**121.41**	**25.08**	**–96.33**
BCR	3.50	1.58	–

The split of costs between the farmers and the government are presented in Table 8-4. As can be seen, both farmers and the government would lose money on this option. If the government decides to go down this path, it would again have to subsidise farmers $57.09 million for farmers to break even.

TABLE 8-4. COMPARISON OF ECONOMIC RETURN FROM CONVERTING DAIRY SWAMPS TO MANAGED WETLANDS

	Piped rehab ($Million)	Managed Wetlands ($Million)	Net return ($Million)
PV Farmer benefits	170.07	68.08	–101.99
PV Government benefits	–	–	–
TOTAL Community benefits	170.07	68.08	–101.99
PV Farmer costs	44.90	–	–44.90
PV Government costs	3.77	43.00	39.24
TOTAL Community Costs	48.66	43.00	-5.66
NPV	**121.41**	**25.08**	**–96.33**
Farmer BCR	3.79		–
Government BCR	–	–	–
Community BCR	3.50	1.58	–

Appendix 9 Index to symbols

9 INDEX TO SYMBOLS

Symbol	Units	Definition
ar	ha	Area rated land not in dairy farming
Bf	$	Reduced feed costs
Bfr	$	Reduced fertiliser costs
Bh	$	Income from highlands
Bl	$	Reduced Labour
Brbgw	$	Reduced algal outbreak costs with wetlands under Status quo or rehabilitation options
Brwc	$	Reduced water quality costs under Status quo or rehabilitation options
bs	$	Back supply channel costs
Btv	$	Reduction in tourism loss
Buv	$	UV construction costs avoided
Buva	$	Annual UV costs forgone
Cbg	$	Blue-green algal outbreak costs associated with dairy industry
Cbgc	$	Algal outbreak costs associated with dairy industry under Channelled rehabilitation
Cbgp	$	Algal outbreak costs associated with dairy industry under rehabilitation
Cfc	$	Farmers cost of Channelled rehabilitation
Cflp	$	Farmer lost production off wetland area under Status quo or rehabilitation options
Cfp	$	Farmer cost of pref rehabilitation
Cfwc	$	Wetland construction & land purchase cost under Status quo of Rehabilitation
Cgc	$	Government cost Channelled rehabilitation
Cglp	$	Government lost production off wetland area

Cgp	$	Government cost Piped rehabilitation
Cgr	$	Government repair, maintenance and capital costs
Cgw	$	Water quality costs
Cgwc	$	Government cost of wetland construction
Cm	$	Cost of wetland maintenance
Cmc	$	Cost of managed wetland construction
Cmp	litres	Current milk production
Cr	$	Repair and maintenance costs
Ct	$	Tourism loss due to dairy effluent impact
Ctc	$	Tourism loss due to dairy effect on algae under Channelled rehabilitation
Ctp	$	Tourism loss due to dairy effect on algae under Piped rehabilitation
Cw	$	Water quality costs
Cwf	$	Wetland construction costs for filtration
Cwfe	$	Cost of wetland establishment for filtration
dc	$	Costs associated with dairy industry
ds	$	Drainage/salt channel
dt	%	Drop in tourism
ELMA	ML	Environmental water allocation per year
fc	$	Fertiliser costs
fgb	%	Frequency of blue/green algae per 100 years
fr	ha	Dairy farming region
fsa	$/ha	Farmer cost for SA water irrigation infrastructure
ft	$	Training cost per farmer
fwr	ML	Farmers water for sale
hi	$	Highland irrigation costs
hw	ha	Land required for wetlands under Status quo or rehabilitation

i	%	Inflation rate
ia	ha	Increased area from filled channels
if	no	Inflation adjustment
ih	$/ha	Dairy income per hectare over 5 years
imc	$	Initial wetland management cost (for first 3 years)
ip	$	Value of increased production/yr for 5 years
lc	%	Drop in labour costs per year
ls	$	Total labour cost savings
mc	$	Monitoring costs
mwe	$/ha	Managed wetlands establishment cost
nd	$	Income/hectare from non dairy land
nf	no	Number of farms
of	$	Off-farm survey/design/contingency costs
omc	$	Ongoing wetland management cost, after 3 years
onf	$	On farm survey/design/contingency costs
n	%	Nominal interest rate
pc	litres	Current production
pl	$	Average price per litre
r	%	Real interest rate
rc	$	River channel costs
rg	%	Reduced feed costs
rgs	%	Government swamp area in constructed wetlands
rl	ha	Rated land requiring rehabilitation
rm	$/ha	Government repair and maintenance costs per hectare
rs	%	Reduction in fertiliser costs per year
sf	$	Supplementary feed costs

si	\$	Dairy income from swamps
t	months	Number of months wetland is connected to the river
tb	\$	Annual value of tourism to broader community
td	no	Drop in tourism
vt	\$	Value of tourism for this swamp
wcp	\$	Wetland establishment and land purchase
wq	\$	Water quality costs associated with testing during outbreak
wt	\$	Water treatment and transport costs associated with outbreaks
Δ	ML	Volume of water required to fill wetlands to 0.7 metre
α	%	Percent filtration efficiency achieved of full filtration efficiency
Π	\$	Net farm income
ϖ	\$	Cost of water to fill wetlands
ϕ	\$	Wetland benefits from wetland in Status quo/rehabilitation options
φ	ha	Wetland area required for water filtration
ω	\$	Lost production from wetlands in Status quo/rehabilitation options
β	\$	Farmer benefits (income) from water filtration option
ε	\$	Income from wetland options
η	\$	Income from water sale
λ	\$	Value of water filtration/UV plants (wetlands for water filtration)
χ	\$	Cost of evaporation water
μ	\$	Cost of water for permanent wetlands
π	\$	Wetland costs for managed wetlands option
λ	\$	Wetland costs for water filtration option
κ	ha	Total area of land covered by government irrigation scheme. This includes both rated (irrigated) and unrated land.
ρ	\$/ML	Price of water for temporary trade

σ	\$	Reduced farming costs associated with rehabilitation
ψ	\$/ha	Value per hectare of wetlands for water filtration
ϑ	\$	Blue-green algae costs associated with Status quo
τ	\$	Blue-green algae costs associated with rehabilitation
ν	\$	Cost of milk transport.
υ	\$	Rehabilitation costs associated with Piped irrigation
ς	\$	Repair maintenance and capital costs for rehabilitation
∂	\$	Management and repair costs for Status quo
γ	ML	Volume of water per day to be filtered
o	ML	5 (ML water per hectare for flooding to 0.5metre depth)
ξ	days	Retention time (12 days)
Ψ_p	\$	Value of Permanent wetlands for water filtration
Ψ_m	\$	Value of Managed wetland for water filtration
δ	no	Fraction of utility
Γ	ha	Unrated land
P	ML	Rainfall per year
T	\$/ML	Price of water for permanent trade
Λ	ML	Evaporation rate from wetlands per year
θ	\$	Annual filtration costs avoided
ε	\$	Total farmer benefits from conversion to wetlands
ϕ	\$	Benefits of constructed wetlands for drainage when farming
ζ	\$	Farmer costs of wetland construction
K	\$	Production costs associated with farming.
Ω	\$	Farm income
Π_p	\$	Net value of production from Piped rehabilitation
Π_c	\$	Net value of production from Channelled rehabilitation

Appendix 10

Rehabilitation results for individual swamps

10 REHABILITATION RESULTS FOR INDIVIDUAL SWAMPS

10.1 Monteith Summary sheet

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	13.77	20.83	7.06	20.78	7.02
PV Government benefits	0	0	0	0	0
PV Total Community benefits	13.77	20.83	7.06	20.78	7.02
PV Farmer costs	1.79	4.75	2.97	3.48	1.69
Government costs	1.00	0.41	-0.59	0.38	-0.62
PV Total Community costs	2.78	5.16	2.38	3.86	1.08
NPV	**10.98**	**15.66**	**4.68**	**16.93**	**5.94**
Farmer BCR	7.71	4.38	2.38	5.98	4.15
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	4.95	4.03	2.97	5.39	6.53

10.2 Cowira Summary sheet

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	7.89	11.94	4.05	11.91	4.02
PV Government benefits	0	0	0	0	0
PV Total Community benefits	7.89	11.94	4.05	11.91	4.02
PV Farmer costs	1.02	3.22	2.20	2.19	1.17
Government costs	0.67	0.30	-0.37	0.27	-0.40
PV Total Community costs	1.70	3.52	1.82	2.46	0.76
NPV	**6.20**	**8.42**	**2.23**	**9.45**	**3.25**
Farmer BCR	7.71	3.71	1.84	5.43	3.44
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	4.65	3.39	2.22	4.84	5.25

10.3 Neeta Summary sheet

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	5.36	8.60	3.24	8.58	3.21
PV Government benefits	0	0	0	0	0
PV Total Community benefits	5.36	8.60	3.24	8.58	3.21
PV Farmer costs	1.01	2.96	1.95	2.39	1.39
Government costs	0.70	0.32	-0.38	0.29	-0.42
PV Total Community costs	1.71	3.28	1.57	2.68	0.97
NPV	**3.66**	**5.32**	**1.67**	**5.90**	**2.24**
Farmer BCR	5.33	2.91	1.66	3.59	2.32
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	3.14	2.63	2.06	3.20	3.31

10.4 Wall Flat Summary sheet

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	6.94	10.51	3.58	10.48	3.54
PV Government benefits	0	0	0	0	0
PV Total Community benefits	6.94	10.51	3.58	10.48	3.54
PV Farmer costs	0.90	3.98	3.08	2.78	1.88
Government costs	0.50	0.22	-0.27	0.19	-0.31
PV Total Community costs	1.40	4.20	2.80	2.97	1.58
NPV	**5.54**	**6.31**	**0.77**	**7.51**	**1.97**
Farmer BCR	7.71	2.64	1.16	3.76	1.88
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	4.97	2.50	1.28	3.54	2.25

10.5 Pompoota Summary Sheet

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	5.88	8.95	3.08	8.92	3.04
PV Government benefits	0	0	0	0	0
PV Total Community benefits	5.88	8.95	3.08	8.92	3.04
PV Farmer costs	0.76	3.30	2.53	2.17	1.41
Government costs	0.47	0.22	-0.25	0.19	-0.28
PV Total Community costs	1.23	3.51	2.28	2.36	1.12
NPV	**4.65**	**5.44**	**0.79**	**6.56**	**1.92**
Farmer BCR	7.71	2.71	1.21	4.11	2.16
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	4.78	2.55	1.35	3.79	2.70

10.6 Mypolonga Summary Sheet

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	17.81	26.91	9.10	26.84	9.03
PV Government benefits	0	0	0	0	0
PV Total Community benefits	17.81	26.91	9.10	26.84	9.03
PV Farmer costs	2.34	6.71	4.37	4.26	1.92
Government costs	1.62	0.68	-0.93	0.65	-0.96
PV Total Community costs	3.96	7.39	3.43	4.91	0.95
NPV	**13.85**	**19.52**	**5.67**	**21.93**	**8.07**
Farmer BCR	7.61	4.01	2.08	6.30	4.71
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	4.50	3.64	2.65	5.46	9.47

10.7 MOBILONG SUMMARY SHEET

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	3.56	5.77	2.21	5.75	2.19
PV Government benefits	0	0	0	0	0
PV Total Community benefits	3.56	5.77	2.21	5.75	2.19
PV Farmer costs	0.78	2.76	2.00	1.94	1.18
Government costs	0.49	0.23	-0.26	0.19	-0.29
PV Total Community costs	1.24	2.99	1.74	2.13	0.89
NPV	**2.32**	**2.78**	**0.46**	**3.62**	**1.30**
Farmer BCR	4.70	2.09	1.10	2.96	1.85
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	2.86	1.93	1.27	2.69	2.46

10.8 BURDETT SUMMARY SHEET

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	0.75	1.30	0.55	1.28	0.53
PV Government benefits	0	0	0	0	0
PV Total Community benefits	0.75	1.30	0.55	1.28	0.53
PV Farmer costs	0.20	1.10	0.90	0.57	372,531
Government costs	0.12	0.080	-0.038	0.05	-0.071
PV Total Community costs	0.31	1.18	0.86	0.61	0.30
NPV	**0.44**	**0.12**	**-0.31**	**0.67**	**0.23**
Farmer BCR	3.85	1.19	0.61	2.26	1.43
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	2.40	1.10	0.64	2.09	1.77

10.9 Jervois Summary sheet

	Status quo ($Million)	Piped Rehabilitation ($Million)	Net ($Million)	Channelled Rehabilitation ($Million)	Net ($Million)
PV Farmer benefits	49.74	75.26	25.52	75.14	25.39
PV Government benefits	0	0	0	0	0
PV Total Community benefits	49.74	75.26	25.52	75.14	25.39
PV Farmer costs	6.45	14.82	8.36	11.95	5.49
Government costs	3.96	1.58	-2.38	1.56	-2.40
PV Total Community costs	10.42	16.39	5.98	13.51	3.09
NPV	**39.33**	**58.86**	**19.54**	**61.63**	**22.31**
Farmer BCR	7.71	5.08	3.05	6.29	4.62
Government BCR	0.00	0.00	0.00	0.00	0.00
Community BCR	4.78	4.59	4.27	5.56	8.22

10 References

REFERENCES

ABARE. (1994). *Model of Irrigated Farming in the Southern Murray Darling Basin* (Project 94.4). Commonwealth of Australia: ABARE.

ABARE. (2000). *Dairy Industry 2000* (ABARE research report 2000.10). Commonwealth of Australia: ABARE.

ABS. (1996). *Population statistics*. Canberra: Australian Bureau of Statistics.

ABS. (2000). The input-output framework. Using input-output tables for analysis. *Australian National Accounts: Concepts, Sources and Methods*. Canberra: Australian Bureau of statistics.

ABS. (2002). Murray Bridge (RC) (Statistical Local Area). Canberra: Australian Bureau of Statistics.

ANCA. (1996). *Wetlands are important*. Canberra: Australian Nature Conservation Agency.

Andreoni, J. (1989). Giving with Impure Altruism: Applications to Charity and Ricardian Equivalence. *Political Economy, 97*, 1447-1458.

ANZECC. (1992). *Australian Water Quality Guidelines for Fresh and Marine Waters*. Canberra: Australian and New Zealand Environment and Conservation Council.

APHA. (1980). *Standard Methods for the Examination of Water and Wastewater* (15): American Public Health Association, AWWA-WPCF.

APHA. (1992). *Standard Methods for the Examination of Water and Wastewater* (18): American Public Health Association, Washington, D.C.

Arentino, B., Holland, P., Matysek, A., & Peterson, D. (2001). *Cost sharing for Biodiversity Conservation: A Conceptual Framework* (Staff Research paper). Canberra: AustInfo.

Armstrong, D., Knee, J., Doyle, P., Pritchard, K., & Gyles, O. (1998). *More Milk and Dollars from Irrigation Water*: Department of Natural Resources and Environment.

Arrow, K. J., & Lind, R. C. (1970). Uncertainty and the Evaluation of Public Investment Decisions. *American Economic Review, 60*, 364-378.

Aust, W. M., Lea, R., & Gregory, J. D. (1991). Removal of floodwater sediments by a clear-cut Tupelo-Cypress wetland. *Water Resource Bulletin, 271*, 111-117.

Australian Government Publishing Service. (1996). *Australian Drinking Water Guidelines*. Canberra, Australia.

Barbier, E., Acreman, M., & Knowler, D. (1997). *Economic valuation of wetlands: a guide for policy makers and planners*. Gland, Switzerland: Ramsar Convention Bureau.

Bate, R. (1993). *Pick A Number: A Critique of Contingent Valuation Methodology and its application in Public Policy Studies*: Competitive Enterprise Institute.

Bayon, R. (2002). A Bull Market in Woodpeckers? *The Milken Institute Review, First Quarter* (March), 30-39.

Bennett, J. W. (1999). *Some fundamentals of environmental choice modelling* (Choice Modelling Research Report No 11). Canberra: University College, The University of New South Wales.

Bennett, L. E., & Drikas, M. (1993). The evaluation of colour in natural waters. *Water resources, 27*, 1209 - 1218.

Blamey, R. K., Rolfe, J., Bennett, J. W., & Morrison, M. D. (1997). *Environmental choice Modelling: Issues and Qualitative Insights* (Choice Modelling research report No 4). Canberra: University College, The University of New South Wales.

Blue Green Algae Task Force. (1992). *Final report*. Parramatta: Department of Water Resources, NSW.

Borgerding, A. J., & Hites, R. A. (1994). Identification and measurement of food and cosmetic dyes in a municipal wastewater treatment plant. *Environment, Science and Technology, 28*, 1278 - 1284.

Bowers, J. (1997). *Sustainability and environmental economics: an alternative text.* London: Longmans.

Bowers, J. (2002). *The Economics of Cost Sharing*. Adelaide: CSIRO Land and Water.

Bowers, J., & Young, M. (1999). *Assessing Externalities: A valuation Methodology for urban water* (Report to the CSIRO Urban Water Program). Adelaide: CSIRO Land and Water - Policy and Economic Research Unit.

Breen, P. F., & Spears, M. (1995). *Conceptual design for a constructed wetland treating domestic wastewater.* Paper presented at the National conference on wetlands for water quality control conference papers, James Cook University Townsville, 25-29 September 1995.

Brennan, D. (1997). *Minimum flow standards in the Williams River: An assessment of the Impact on Dairy Farms.* Paper presented at the 41st conference of Australian Agricultural Economics Society, January, Gold Coast.

Brix, H. (1993). Wastewater treatment in constructed wetlands; system design, removal processes, and treatment performances. In G. A. Moshiri (Ed.), *Constructed wetlands for water quality treatment* (pp. 9-22). Boca Raton: Lewis Publishers.

Brown, D. (1987). Effects of colorants in the aquatic environment. *Ecotoxicity and Environmental Safety, 13*, 139-147.

Cattin, P., & Wittink, D. R. (1982). Commercial use of conjoint analysis; a review. *Marketing, 46*, 45 - 53.

Centre for Epidemiology and Animal Health. (1993). *Cryptosporidium Outbreak* (N1310194): USDA.

Cleveland, C., Costanza, R., Hall, C., & Kaufmann, R. (1984). Energy and the United States economy: a biophysical perspective. *Science, 255*, 890-897.

Cole, P. (1985). *The River Murray Irrigation and Salinity Investigation Programme Results and Future Directions* (Technical Report No. 69 Feb).

Commission on Geosciences Environment and Resources. (2000). *Watershed Management for Potable Water supply; assessing the New York City strategy Committee to Review the New York City Watershed Management Strategy*: National Research Council.

Costanza, R. (1980). Embodied energy and economic valuation. *Science, 210*, 1219-1224.

Costanza, R. (1984). Natural resource valuation and economic valuation: Towards an ecological economics. In A. M. Jansson (Ed.), *Integration of Economy and Ecology: An Outlook for the Eighties*. Stockholm: University of Stockholm Press.

Costanza, R., d'Arge, R., de Groot, R., Faber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van der Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*, 253-260.

Costanza, R., Farber, S., & Maxwell, J. (1989). Valuation and management of wetland ecosystems. *Ecological Economics, 1*(4), 335-362.

Costanza, R., & Herendeen, R. A. (1984). Embodied energy and economic value in the Unite States economy: 1963, 1967, and 1972. *Resource Energy, 6*, 129-163.

Cottinghan, P. (1995). *Nutrient removal from irrigation drainage using wetlands.* Paper presented at the Nutrient Management in Irrigated Agriculture Research and Implementation, June 19-20, Echuca.

Crance, J. H. (1984). *Habitat Suitability Index Models and Instream Flow Suitability Curves: Inland Stocks of Striped Bass* (FWS/OBS-82/1085). Washington DC: Government print office US Fish and Wildlife Service.

Current, W. L., & Garcia, L. S. (1991). Cryptosporidiosis. *Clinical Microbiology Review, 4*, 305-308.

Dahl, T. E., & Johnson, C. E. (1991). *Status and trends of wetlands in the coterminous United States Mid- 1970's to Mid-1980's*. Washington DC: US Department of the Interior Fish and Wildlife Service.

Davies-Colley, R. J., Vant, W. N., & Wilcock, R. J. (1988). Lake water colour: Comparison of direct observations with underwater spectral irradiance. *Water Resources Bulletin, 24*, 11 - 18.

Dawson, M. W., Lukas, G. P., & Sockhill, D. G. (1995, 25-29 September). *Establishment of constructed wetlands at Victoria Mill.* Paper presented at the National Conference on Wetlands for water quality control, James Cook University Townsville.

Department of Defense. (1995). *Federal Guidance for the Establishment, Use and Operation of Mitigation Banks* (NOTICE, Volume 60, 228): Department of Army Corps Engineers.

Department of Finance. (1991). *Handbook of Cost Benefit Analysis*. Canberra: Australian Government Publishing Service.

Department of Industry Science and Resources. (2000). *Corporatisation of the Snowy Mountains Hydro-electric Authority. Draft Environmental Impact Statement*. Canberra: The Department of Industry, Science and Resources.

Desvousges, W. H., Naughton, M. C., & Parsons, G. R. (1992). Benefit transfer: Conceptual problems in estimating water quality benefits using existing studies. *Water Resources Research, 28*, 675-683.

Diamond, P. A., & Hausman, J. A. (1993). On Contingent Valuation Measurement of Non-use Values. In J. Hansman (Ed.), *Contingent Valuation: A Critical Assessment.* (pp. 3 - 38). Amsterdam: North Holland Press.

Diamond, P. A., & Hausman, J. A. (1994). A Contingent valuation: Is some number better than no number? *Economic Perspectives, 8*(4), 45 - 65.

Earth Assets Group. (2005). *How Eco-Assets work*, [Website]. Earth Assets Group. Available: http://www.earth-assets.com/aboutEA.htm [2005, 1 June 2005].

Economic Associates Australia. (1983). *Green Island Economic Study*: Great Barrier Reef Marine Park Authority.

EN-ISO. (1994). *Water Quality - Examination and Determination of Colour*: International Organization for Standardization and European Committee for Standardization.

Environment Canada. (1989). *Methods Manual*. Burlington, Ontario: National Water Research Institute, Environment Canada.

EPA. (2002). *Water Monitoring Report Ambient Water Quality of the River Murray 1990 - 1999* (No 1): Department of Environment and Heritage.

Epstein, R. A. (2002, February 1 - 2). *The Regrettable Necessity of Contingent Valuation.* Paper presented at the Cultural Policy Centre Conference - The Contingent Valuation of Culture, Chicago.

Gale, P. M., Reddy, K. R., & Graetz, D. A. (1994). Phosphorus retention by wetland soils used for treated wastewater disposal. *Environmental quality, 23*, 370-377.

Garrod, G., & Willis, K. G. (1999). *Economic Valuation of the Environment. Methods and case studies*: Edward Elgar.

Gerrans, P. (1994). *An economic valuation of the Jandakot Wetlands* (Occasional Paper No 1): Edith Cowan University.

Gersberg, R. M., Lyon, S. R., Brenner, R., & Elkins, B. V. (1989). Integrated Wastewater Treatment Using Artificial Wetlands: A Gravel Marsh Case Study. In D. A. Hammer (Ed.), *Constructed Wetlands for Wastewater Treatment* (pp. 145-152). Chelsea Michigan: Lewis.

Gittinger, J. P. (1972). *Economic Analysis of Agricultural Projects*. Baltimore: John Hopkins.

Glaeser, V. C., & Oslund, P. (1996). *Impact survey report* (232). Kansas: Institute for public policy and Business research, Department of Economics, University of Kansas.

Government of South Australia. (2005). *Water Proofing Adelaide - Draft Strategy*. Adelaide: Government of South Australia.

Green, P. E., & Srinivasan, V. (1978). Conjoint analysis in consumer research; issues in outlook. *Consumer Research, 5*, 103 - 212.

Gren, I. M. (1994). *Valuation of Danube floodplains* (Report to WWF-Auen Institute). Rastatt, Germany: Institute for Danube Floodplain Ecology.

Gupta, T. R., & Foster, J. H. (1975). Economic Criteria for Freshwater Wetland Policy in Massachusetts. *American Journal of Agricultural Economics*(February), 40-45.

Gutteridge, Haskins, & Davey. (1992). *Investigation of Nutrient Pollution in the Murray-Darling River System*: Murray Darling Basin Commission.

Hammer, D. A. (1992). *Creating Freshwater Wetlands*. Ann Arbor USA: Lewis.

Hammer, D. A., & Bastian, R. K. (1989). Wetlands Ecosystems: Natural Water Purifiers. In D. A. Hammer (Ed.), *Constructed Wetlands for Wastewater Treatment* (pp. 6-19). Chelsea Michigan: Lewis.

Hanley, N., Kirkpatrick, H., Simpson, I., & Oglethorpe, D. (1998). Principles for the provision of public goods from agriculture: Modelling moorland conservation in Scotland. *Land Economics, 74*(1), 102 - 103.

Hanley, N., Mourato, S., & White, B. (2001). Choice Modelling approaches: A superior alternative for environmental valuation? *Journal of Economic Surveys, 15*(3), 435-462.

Hanley, N., Shogran, C. L., & White, B. (1997). *Environmental Economics in theory and practice*. Basingstoke: Macmillan.

Hanley, N., & Spash, C. L. (1993). *Cost Benefit Analysis and the Environment*. Aldershot: Edward Elgar.

Harrison, J. (1994). *Review of Nutrients in Irrigation Drainage in the Murray Darling Basin* (Series No 11). Canberra: CSIRO Division of Water Resources Water Resources.

Hemond, H. F., & Benoit, J. (1988). Cumulative Impacts on Water Quality Functions of Wetlands. *Envir Manag, 125*, 639-653.

Herath, G., & Jackson, J. (1994). *Estimation of recreational Benefits of Lake Mokoan Victoria.* Paper presented at the 38th conference of Australian Agricultural Economist Society, 7 - 12 February, Wellington New Zealand.

Holmes, J. W., & Watson, C. L. (1967). The water budget of irrigate pasture land near Murray Bridge, South Australia. *Agricultural Meteorology, 4*(4), 177-188.

Hongve, D., & Akesson, G. (1996). Spectrophotometric determination of water colour in hazen units. *Water Resources, 30*, 2771-2775.

Howarth, R., & Norgaard, R. (1993). Intergenerational transfers and the social discount rate. *Environment and Natural Resource Economics, 3*(4), 337-358.

Islam, A. I. A. (1970). An Evaluation of the Extent of Overvaluation of the Domestic Currency in Pakistan at the Official Rate of Exchange, 1948-1964. *Pakistan Development Review, X Spring*.

Islam, N. (1967a). Comparative Costs, Factor Proportions, and Industrial Efficiency in Pakistan. *Pakistan Development Review, Summer*.

Islam, N. (1967b). *Tariff Protection, Comparative Costs and Industrialisation in Pakistan* (Research Report No. 57). Karachi: Pakistan Institute of Development Economics.

Jensen, A. (1993). *Assigning values to Wetlands and Natural Resources in the South East of South Australia*: Department of Environment and Land Management Environmental Policy Division.

Jerome, J. H., Bukata, R. P., Whitfield, P. H., & Rousseau, N. (1994). Colours of natural waters: 1. Factors controlling the dominant wavelength. *Northwest Science, 68*, 43-52.

Johnston, C. A. (1991). Sediment and Nutrient Retention by Freshwater Wetlands: Effects on Surface Water Quality. *Critical Reviews in Environmental Control, 2156*, 491-565.

Kahneman, D., & Ritov, I. (1993). *Determinants of Stated Willingness to Pay for Public Goods: A Study in the Headline Method* (Mimeo. Department of Psychology). Berkeley: University of California.

Kazepidis, A. (1997). *A Comparative Study of the Impact of Irrigation Drainage on Water Quality in Lower Murray Wetlands* (Report prepared in partial fulfilment of requirements of Field Studies. Unpublished). Roseworthy: Dept. of Environmental Science and Management, University of Adelaide.

Kemp, M. A., & Maxwell. (1993). Exploring a Budget Context for Contingent Valuation Estimates. In J. A. Hausman (Ed.), *Contingent Valuation: A Critical Assessment,* (pp. 217-270). Amsterdam: North Holland Press.

Kennedy, J. O. S. (1997). *The economics of Algal Bloom control.* Paper presented at the 41st Annual Conference, Australian Agricultural and Resource Economics Society, 20-25 January, Gold Coast.

Kennelly, A. (1998). *Cost Sharing and Financial Assistance for Dryland Salinity Areas* (Economic Unit Discussion Paper no 48). Melbourne: Victorian Department of Conservation, Forests and Lands.

Kerr, G., Sharp, B., & White, P. (2001). *Non-market impacts of Ground Water Extraction.* Paper presented at the 45th Annual Conference Australian Agricultural and Resource Economics Society, 23-25 January, Adelaide.

Kerr, G. N., Sharp, B., & White, P. (2003). Economics of Christchurch Water Supply Augmentation. *Journal of Hydrology (New Zealand), 42*(2), 113-124.

Knetsch, J. L. (1993). *Environmental Valuation: Some Practical Problems with Wrong Questions and Misleading Answers*. Canberra: Resource Assessment Commission.

Kullberg, A. (1992). Benthic macro invertebrate community structure in 20 streams of varying pH and humic content. *Environmental Pollution, 78*, 103-106.

Kusler, J. A., & Kentula, M. E. (1989). *Wetland creation and restoration: the status of the science* (Vol 1. Regional review EPA/600/3-89/038). Corvallis, Oregon, US: Environmental Protection Agency, Environmental Research Lab.

Lancaster, K. (1966). A new approach to consumer theory. *Political Economy, 74*, 132-157.

Lancaster, K. (1975). Socially Optimal product differentiation. *American Economic Review, 65*(4), 567-585.

Lancaster, K. (1991). *Modern Consumer Theory*. Brookfield, Vermont: Edward Elgar.

Leidreiter, G. (1996). *Getting Our Effluent in Order. A Review of Australian Dairy Effluent Management Using Case Studies*: The National Landcare Program.

Lerner, S., & Pool, W. (1999). The economic benefits of Parks and open spaces. How Land Conservation Helps Communities Grow Smart and Protect the Bottom Line. *The Trust for Public Land*(41), 48.

Lewis, S. R. (1969). *Economic Policy and Industrial Growth in Pakistan*. London: George Allen and Unwin.

Little, I. M. D., & Mirlees, J. A. (1976). *Project Appraisal and Planning for Developing Countries*. London: Heinemann Educational.

Liverpool Plains Management Committee. (2000). *Investment Programs and Institutional Arrangements for Effective Natural Resource Management:* (Draft Project Report final). Tamworth.

LMIAG. (1999). *The SWAMP irrigator's manual: a revision by CSIRO Land and Water for the Lower Murray Irrigation Action Group.* Unpublished manuscript, South Australia.

Louviere, J. J. (1988). Conjoint analysis of stated preferences: a review of methods, recent developments and external validity. *Transport Economics and Policy, 22*, 93 - 119.

Lynne, G., Conroy, P., & Prochaska, F. (1981). Economic valuation of marsh areas for marine production (Florida). *Environmental Economic Management, 8*, 175-186.

Mac Kenzie, W. R., Hoxie, N. J., & Proctor, M. E. (1994). A massive outbreak in Milwaukee of Cryptosporidium infection transmitted through the public water supply. *N Engl J Med, 331*, 161-167.

Mackay, N., & Eastburn, D. (1990). *The Murray.* Canberra: Murray Darling Basin Commission.

Maltby, E. (1991). Wetlands and their values. In M. Findlayson & M. Moser (Eds.), *Wetlands* (pp. 8-26). Oxford: Slimbridge: International Waterfowl and Wetland Research Bureau.

Manfrinato, E. S., Filho, E. S., & Salati, E. (1993). Water Supply System Utilizing the Edaphic-Phytodepuration Technique. In G. A. Moshiri (Ed.), *Constructed Wetlands for Water Quality and Improvement. Chapter 34*. Boca Raton, FL: CRC Press.

Markandya, A., & Pearce, D. (1988). *Environmental considerations and the Choice of the Discount Rate in Developing Countries* (Environment Department Working Paper 3). Washington: World Bank.

Marohasy, J. (2003). *Received Evidence for Deterioration in Water Quality in the River Murray.* Paper presented at the IPA Water Forum No. 2, Canberra, 25 July.

Marshall, G. (1998). *Economics of cost-Sharing for Agri-Environmental Conservation* (Paper prepared for the project LMP2 Investment Programs for Effective Natural Resource Management). Canberra: Land and Water Resources Research and Development Corporation.

McCrum, W. A. (1984). The use of second-order derivative spectroscopy in the investigation of sources of coloured pollutants in water. *Water Resources, 18*, 1249-1252.

Miller, S. (1996). The economic benefits of Open Spaces. *Association of New Jersey Environment Commission, 9.*

Mishan, E. (1975). *Cost benefit Analysis: An informal introduction* (Second ed.). London: George Allen & Unwin.

Mitch, W., & Wilson, R. (1996). Improving the success of wetland creation and restoration with know-how, time and self design. *Ecological Applications, 6*, 77-83.

Mitchell, D. (1995). *Constructed Wetlands in Australia: A Critical Appraisal of Future Perspectives.* Paper presented at the National Conference on Wetlands for Water Quality Control, 25-29 September, Townsville.

Mitsch, W. J., & Gosselink, J. (1993). *Wetlands* (2nd Edition ed.). NY: Van Nostrand Reinhold Co.

Moore, D. R. J., & Caux, P. Y. (1997). *Ambient Water Quality Criteria for Colour in British Columbia*. Victoria, BC: Water Quality Section, Water Management Branch.

Morrison, J. (1996). *The Economic Impact of Irrigated Agriculture in the Shepparton Irrigation Region*. Shepparton: Sustainable Regional Development Board.

Morrison, M. D., Bennett, J. W., & Blamey, R. K. (1998). *Valuing Improved Wetland Quality Using Choice Modelling* (Choice Modelling Research Report No 6). Canberra: University College, The University of New South Wales.

Mundy, K. (1997). Using Nature's Technology: Constructed Wetlands. *Horizons, 9*(5).

Mur, L. R., Skulberg, O. M., & Utkilen, H. (1999). Chapter 2 Cyanobacteria in the Environment. In C. I. a. B. J (Ed.), *Toxic Cyanobacteria in Water* (pp. 15-40): E& FN Spoon for WHO.

Murray Darling Basin Commission. (1996). *Cost sharing for on-ground works*. Canberra.

Murray Darling Basin Commission. (2001). *Assessing the costs and benefits of alternative actions* (Salinity information package Basin-wide Information sheets, Sheet E6).

Murray, P., & Philcox, M. (1995). *An assessment of irrigation runoff quality draining from flood irrigated dairy pastures of the Lower Murray* (NRMS Project S236 Final Report). Primary Industries South Australia: Murray Darling Basin Commission.

Naiman, R., Melillo, J. M., & Hobbie, J. E. (1986). Ecosystem alteration of a boreal forest stream by Beaver (Castor Canadensis). *Ecology, 67*, 1254-1269.

Native Vegetation Council. (2005). *Draft guidelines for a Native Vegetation Significant Environmental Benefit Policy for the clearance of scattered paddock trees.* Adelaide, South Australia: Department of Water Land and Biodiversity Conservation.

NCSU Water Quality Group. (2002). *Water, Soil and Hydrology Environmental Decision and Support system.* North Carolina State University Cooperative Extension: Department of Biological and Agricultural Engineering.

Nguyen, D. T., & Alamgir, M. (1976). A Social Cost-Benefit Analysis of Irrigation in Bangladesh. *Oxford Bulletin of Economics and Statistics, May.*

NH & MRC and AWRC. (1987). *Guidelines for Drinking Water Quality in Australia.* Canberra, Australia: Australian Government Publishing Service.

NSW Government. (1997). *Guidelines for Economic Appraisal.* Sydney: Treasury Policy and Guidelines Paper TPP 97-2.

NSW Treasury. (1990). *NSW Government guidelines for Economic Appraisal*. Sydney: NSW Treasury Technical Paper, revised edition.

OECD. (1975). *The polluter pays principle - Definitions, Analysis, Implementation.* Paris: Organisation for Economic Cooperation and Development.

Osmond, D. L., Line, D. E., Gale, J. A., Gannon, R. W., Knott, C. B., Bartenhagen, K. A., Turner, M. H., Coffey, S. W., Spooner, J., Wells, J., Walker, J. C., Hargrove, L. L., Foster, M. A., Robillard, P. D., & Lehning, D. W. (1995). *WATERSHEDS: Water, Soil and Hydro-Environmental Decision Support System.*

OTA. (1993). *Preparing for an Uncertain Climate* (Vol II OTA-O-568). Washington, DC: US Congress, Office of Technology Assessment.

Patto, P. M. (1988). *Laser landforming/grading and salinity*. Victoria: Irrigation Services Branch, Rural water Commission.

Pearce, D., Markandya, A., & Barbier, E. B. (1989). *Blueprint for a Green Economy*. London: Earthscan Publications.

Pearce, D., & Moran, D. (1994). *The economic value of biodiversity. The Biodiversity Programme of IUCN, the World Conservation Union*. London: Earthscan.

Pearce, D., & Ozdemiroglu, E. (2002). *Economic valuation with stated preference techniques.* (Summary Guide). London: Department for Transport, Local Government and the Regions.

Pearce, D., & Turner, K. (1992). *Benefit estimates and environmental decision-making* (Washington, D.C : OECD Publications and Information Centre). Paris, France: Organisation for Economic Co-operation and Development.

Pearce, D. W. (1983). *Cost-Benefit Analysis* (2nd ed.). London, New York, NY: Macmillan, St. Martin's.

Penny, A. (1993). *An analysis of the effectiveness of Greenfields wetlands for its pollutant removal efficiency of stormwater.* Unpublished Honours thesis, Adelaide University.

Perkins, F. (1994). *Practical Cost Benefit Analysis: Basic Concepts and Applications.* Hong Kong: Macmillion.

Petersen, E., & Bennett, J. (2003). *Gurra Gurra Wetland Rehabilitation project: Benefit cost analysis.* (Environmental Resource Economics): Wetland Care Australia.

Philcox, M. (1996). *Laser Levelling on the Lower Murray - A collection of articles and papers on laser levelling from research undertaken on reclaimed swamps* (Rehabilitation and restructuring Vol 1). Murray Bridge: Primary Industries South Australia.

Philcox, M. B. (1990). *Technology transfer to improve land and water Management on the Lower Murray Swamps in South Australia* (Unpublished). Murray Bridge: Primary Industries.

Philcox, M. B., & Douglas, T. A. (1990). *An assessment of plant available water in organic cracking clays of the Lower Murray Swamps* (Unpublished). Murray Bridge: Primary Industries.

Philcox, M. B., Eaves, D. D., & Scown, S. Q. (1992). *Financial planning packages for improved irrigation management on the lower Murray reclaimed swamps* (Final Report, Project 90/S04): National Irrigation Research Fund.

Philcox, M. B., & Scown, S. Q. (1991). *Scheduling irrigation for increased productivity of Lower Murray Dairy Farms* (Final Report, Project 90/S02): National Irrigation Research Fund.

PIRSA. (2001). *Consultancy for Lower Murray Reclaimed Areas Study: Stage 2 Vol 1*. Adelaide: PIRSA Rural Solutions.

Pitt, M. W. (1992). *The value of coastal land: an application of travel cost methodology on the north coast of NSW*. Paper presented at the 37th Annual Australian Agricultural Economic Society, February, Sydney.

Portney, P. R. (2002). *Benefit-Cost Analysis. The concise encyclopaedia of economics*. Liberty Fund, Inc. Available: www.econlib.org/library/Enc/BenefitCostAnalysis.html; [2003, 5 November].

Powell, R. (1991). *Impacts of the Dairy Industry on selected regional economies* (Report to DRDC, Phase one): Australian Dairy Products Federation.

Powell, R. (1992). *Impacts of the Dairy Industry on selected regional economies* (Report to DRDC, Phase two): Australian Dairy Products Federation.

Prelec, D., & Loewenstein, G. (1991). Decision Making Over Time and under Uncertainty: A Common Approach. *Management Science, 37*, 770-786.

Randall, A., & Peterson, G. (1984). The valuation of wildland benefits: an overview. In G. Peterson & A. Randall (Eds.), *Valuation of wildland resource benefits* (pp. 1-52). Boulder: Westview Press.

Ray, A. (1984). *Cost-Benefit Analysis: Issues and Methodologies*. Baltimore, Maryland: The World Bank by John Hopkins Univerisity Press.

Read Sturgess and Associates. (1994). *The economic significance of Grampians National Park.* Victoria: National Parks Service, Department of Conservation and Natural Resources.

Read Sturgess and Associates. (1996). *Rapid Appraisal Methodology In Economic Benefits of Nutrient reduction and algal management* (Water report): Goulburn Murray.

Reaves, R. P., DuBowy, P. J., Jones, D., & Sutton, A. L. (1994). *Design of an experimental constructed wetland for treatment of swine lagoon effluent.* Paper presented at the Constructed Wetlands for Animal Waste Management Conference, Purdue University.

Rellney Group. (2000). *Corowa Estate Wetland Treatment and Reuse System, Recycling wastewater the natural way*. Woodville, South Australia.

Resource Assessment Commission. (1992). *Forest and Timber Inquiry* (Final Report). Canberra: Australian Government Publishing Service.

Richardson, C., & McCarthy, E. J. (1994). Effect of Land Development and Forest Management on Hydrologic Response in South-eastern Coastal Wetlands: A Review. *Wetlands, 141*, 56-71.

Richardson, C. J. (1985). Mechanisms controlling phosphorus retention capacity in wetlands. *Science*(228), 1424-1427.

River Murray Catchment Water Management Board. (1997). *Water Allocation Plan for the River Murray prescribed water Course*. Berri SA.

River Murray Water Resources Committee. (1994). *Draft River Murray Regional Water Resources Management Plan*.

RMCWMB. (2003). *Catchment Water Management Plans for the River Murray in South Australia*: River Murray Catchment Water Management Board.

Roser, D., & Bavor, H. J. (1995). *Current Direction in Constructed Wetland Research in NSW.* Paper presented at the Practical Aspects of Constructed Wetlands Workshop, June 1994, Newcastle, NSW.

SA Water. (2001). *Water Filtration process*. Available: www.sawater.com.au [2002, January].

Sanders, L. D., Walsh, R. G., & McKean, J. R. (1991). Comparable Estimates of the Recreational Value of Rivers. *Water Resources Research, 27*(7), 1387-1394.

Sappideen, B. (1992). Valuing the Recreation Benefits of Sale Wetlands using Contingent Valuation. In M. Lockwood & T. DeLacy (Eds.), *Valuing natural areas: applications and problems of the contingent valuation method*. Albury: Johnstone Centre of Parks, Recreation and Heritage, Charles Sturt University.

Schrale, G. (1989). *Long Flat irrigation area - Pasture water allotment* (Discussion Paper). Adelaide: SAWRC.

Scoccimarro, M., Beare, S., & Brennan, D. (1997). *The opportunity cost of introducing environmental flows to the Snowy river.* Paper presented at the 41st conference of Australian Agricultural Economics Society, January, Gold Coast.

sCOWn Consulting. (2000). *DairySA - Farm Business Analysis Project: 2nd Milestone Report on SA004 to DairySA*. Adelaide: DairySA.

Scown, S. Q., & Hanscomb, B. (1996). *Indicators of costs and returns on farms in the South Australian Dairy industry.* (Report for SA Dairy Industry).

Senate Standing Committee on Environment Recreation and the Arts. (1993). *Water Resources - Toxic Algae*. Canberra: Commonwealth of Australia.

Simpson, J. S. (1995). *Interim Guidelines on the Planning, Design and Management of Artificial Wetlands in Queensland*: Queensland Department of Primary Industries, Water Resources.

Simpson, J. S., & Woolley, A. (1995). *The application of Artificial Wetlands for the Treatment of Municipal Effluent in Tropical and Sub-Tropical Climates.* Paper presented at the National Conference on Wetlands for Water Quality Control Conference, 25-29 September, James Cook University, Townsville.

Sinden, J. A. (1990). *Valuation of the Recreational Benefits of River Management: A case study in the Ovens and King Basin*. Victoria: Office of Water Resources, Department for Conservation and Environment.

Sinden, J. A. (1994). A Review of Environmental Evaluation in Australia. *Review of Marketing and Agricultural Economics, 623*, 337-368.

Sinden, J. A., & Thampapillai, D. J. (1995). *Introduction to Benefit-Cost Analysis*. Melbourne: Longman.

Sivonen, K., & Jones, G. (1999). Chapter 3, Cyanobacterial Toxins. In I. B. Chorus, J (Ed.), *Toxic Cyanobacteria in Water* (pp. 41-111): E& FN Spoon for WHO

Sloan, K. (1987). *Valuing Heron Island: Preliminary Report.* Paper presented at the 16th Conference of Economists, Surfers Paradise Queensland.

Slovic, P. (1987). Perception of Risk. *Science, 236*, 280-285.

SLWRMC. (1999). *Discussion Paper: Principles for Shared Investment to Achieve Sustainable Natural Resource Management Practices*. Canberra: Sustainable Land and Water Resource Management Committee.

Statistics New Zealand Te Tari Tatau. (2003). Statistics New Zealand. Available: www.stats.govt.nz [2004, 25 May].

Stone, A. (1991). *Valuing wetlands: a contingent valuation approach.* Paper presented at the 35th Annual Conference of the Australian Agricultural Economics Society, University of New England.

Stoneham, G., Crowe, M., Platt, S., V, C., Soligo, J., & Strappazzon, L. (2000). *Mechanisms for Biodiversity Conservation on Private Land.* Melbourne: Victorian Department of Natural Resources and Environment.

Tacconi, L. (2000). *Biodiversity and Ecological Economics. Participation, Values and Resource Management*. London and Sterling VA: Earthscan.

Taylor, J. K., & Poole, H. G. (1931). *A soil survey of the Swamps of the Lower Murray River* (Bulletin No 51): Council for Scientific and Industrial Research.

Thaller, R. H. (1981). Some Empirical Evidence of Dynamic Inconsistency. *Economic Letters, 8*, 201-207.

The Advertiser. (1999, 2 September). Tapping into the future. Unique water project for rural SA. *The Advertiser,* pp. 51-54 & 59-62.

The Economist. (2002). Science and technology - Restoration Drama. *The Economist, August 10,* 65-66.

Thibodeau, F. R., & Ostro, B. D. (1981). An Economic analysis of Wetland Protection. *Journal of Environmental Management, 12*, 19-30.

Thomas, R. C., Jessup, A. P., Wallent, K. M., & Hutchens, N. S. (1986). *South Australian Government Irrigation Areas Lower Murray Reclaimed Swamps, A Review of Operations and Maintenance Costs, Activities and Standards* (4586/85, Ref 86/8): EWS.

Tobey, J., & Smets, H. (1996). The 'polluter pays' principle in the context of agriculture and the environment. *World Economy, 19*(1), 63-87.

Tucker, P., Dominelli, S., Harper, M., Van der Weilen, M., & Siebentritt, M. (2002). *Hydrology Guidelines*. Renmark SA: Australian Landscape Trust.

Turner, R. K., Pearce, D., & Bateman, I. (1994). *Environmental economics: an elementary introduction*. New York; London: Harvester Wheatsheaf.

Urbonas, B., & Stahare, S. (1993). *Stormwater. Best management practices and detention for water quality, drainage and CSO management.* New Jersey: Prentice Hall.

US Congress. (1972). *Clean Water Act* (Title 33, Chapter 26, Sub chapter 1, Bill number 1251).

US Fish and Wildlife. (2003). *Water quality monitoring* (Fuel and Fire Effects Monitoring Guide).

USDA, APHIS, & VS. (1993). *Cryptosporidium is common in dairy calves.* National Dairy heifer evaluation project. Available: NAHMSweb@aphis.usda.gov [2003, October].

USEPA. (1993). *Natural Wetlands and Urban Stormwater: Potential Impacts and Management.* Washington DC: US Environmental Protection Agency.

USEPA. (1995). *Wetlands Fact sheet.* (EPA 843-F-95-001): USEPA.

Van Bueren, M., & Bennett, J. (2000). *Estimating community values for land and water degradation impacts* (Final report): The National Land and water Resources Audit Project 614.

Van den Bergh, J. C. J. M. (1999). *Handbook of Environmental and Resource Economics.* Cheltenham UK: Edward Elgar.

Walbridge, M. R., & Struthers, J. P. (1993). Phosphorus retention in non-tidal palustrine forested wetlands of the mid-Atlantic region. *Wetlands, 13*(2), 84-94.

Walker, C., & Greer, L. (1992). *The Economic Costs Associated with Lost Recreation Benefits Due to Blue-Green Algae in New South Wales: Three case studies* (Final Report, Appendix F): NSW Blue-Green Algae Task Force.

Walsh, R. G., Johnson, D. M., & McKean, J. R. (1992). Benefit transfer of outdoor recreation demand studies. *Water Resources Research, 28*(3), 707-713.

Watson, C. L., & Cole, P. J. (1972). *Matric Water Potential and Ground Water Levels on an Irrigated Pasture at Long Flat* (Experimental Record): South Australian Department of Agriculture.

Watson, J. T., & Hobson, J. A. (1989). Hydraulic Design Considerations and Control Structures for Constructed Wetlands for Wastewater Treatment. In H. DA (Ed.), *Constructed Wetlands for Wastewater Treatment* (pp. 379-391). Chelsea Michigan: Lewis.

Watson, K. (1998). *Benefit Cost Analysis Guide*: Treasury Board of Canada Secretariat.

White, G. (1995). *The Broader Aspects of Constructed Wetlands.* Paper presented at the Practical Aspects of Constructed Wetlands Workshop, June 1994, Newcastle.

White House Office on Environmental Policy. (1993). *Protecting America's Wetlands: A fair, flexible, and effective approach*. Washington, DC: Federal Government, US.

White, P. C. L., Bennett, A. C., & Hayes, E. J. V. (2001). The use of willingness-to-pay approaches to mammal conservation. *Mammal Review, 31*(2), 151-167.

Whitten, S. M., & Bennett, J. W. (2001). *Non-market values of wetlands: A choice modelling study of wetlands in the Upper South East of South Australia and the Murrumbidgee River floodplain in New South Wales* (Research report number 8). Canberra: School of Economics and Management, University College, University of New South Wales.

Whittle, J., & Philcox, M. (1996a). *Constructed Wetlands for Water Quality Control for the Lower Murray Reclaimed Swamps* (LMIAG). South Australia: Primary Industries.

Whittle, J., & Philcox, M. (1996b). *Drainage Management Options for the Lower Murray Dairy Swamps A feasibility Study Undertaken for the Lower Murray Irrigation Action Group*. South Australia: Primary Industries.

WHO. (1983). *Guidelines for Drinking Water*. Geneva, Switzerland: World Health Organization.

Winpenny, J. (1995). *The Economic Appraisal of Environmental Projects and Policies: A Practical guide*: OECD.

Withers, B. (1997). Alternative land Use, *Rehabilitation and Restructuring* (Vol. 9): Lower Murray Irrigation Action Group.

Wong, T., Breen, P. F., Somes, N., & Lloyd, S. (1999). *Managing urban stormwater using constructed wetlands* (98/7): Industry Report.

Wood, A. (1990). Constructed Wetlands for Waste Water Treatment - Engineering and Design Considerations. In P. F. Cooper & Findlater (Eds.), *Constructed Wetlands in water Pollution control* (pp. 605). Oxford; Sydney: Pergamon Press.

Wrigley, T., Farrell, P., & Griffiths, D. (1991). Ecologically sustainable water clarification at the clear water Lagoon, Mt Isa. *Water, Official Journal of the Australian Water and Wastewater Association, 18*(No 6), 32-34.

Yeates, J. S., Deeley, D. M., Clarke, M. F., & Allen, D. (1984). Modifying Fertiliser Practices. *Journal of Agriculture Western Australian, 3*, 87-91.

Young, R. (1991). The economic significance of environmental resources: a review of the evidence. *Review of Marketing and Agricultural Economics, 59*, 229-254.