1. Introductory Remarks

1.1 Introduction

The Gerangamete catchment is located approximately ten kilometres south east of Colac in south west Victoria. The total area of the catchment is approximately 2000 hectares. Groundwater monitoring in the catchment indicates that if the existing rate of recharge continues, dryland salinity could become a major problem, leading to the loss of productive agricultural land and increasing salinity levels in local streams. In order to minimise groundwater recharge and the spread of salinity in the Gerangamete catchment, the Department of Natural Resources and Environment modelled the hydrological processes occurring in the catchment and investigated the biophysical effects of various recharge control options. From the results obtained a catchment management plan was developed to ensure sustainable resource use. The purpose of this study is to evaluate this plan (and other alternative landuses for the catchment) to determine if it is economically viable.

In this chapter, the background to the salinity problem is discussed both in a general context and the more specific setting of the Gerangamete catchment. This is followed by the objectives and hypotheses to be tested. Finally, the organisation of the study is presented.

1.1.2 The Salinity Problem

Salinity is a major problem threatening both the agriculture and the environment of Victoria. Already in parts of the State, communities are facing income losses, a degraded landscape and social hardship brought about by this problem. If left uncontrolled, its extent and severity could continue to increase.

The salinity problem is largely related to groundwater behaviour. In most catchments a finely tuned balance exists between groundwater and surface water. However a small increase in the amount of water entering the ground from the surface (which is known as recharge), due to rainfall or irrigation or pended water, can cause a significant rise in groundwater pressure and consequently of the water table. As groundwater rises, naturally-occurring salts, which are dissolved in the water are brought to the surface where the salt is concentrated by evaporation (see Appendix A) (Hamilton and Lang, 1978). Once toxic concentrations of salt occur in the root zone of plants, their growth suffers resulting in a loss of agricultural productivity. Not only does salinity affect agricultural production, it also has a detrimental effect on local streams and wetlands, increasing soil erosion, damaging water using appliances and leading to the loss of wildlife habitat and recreational areas thus inflicting social costs to the community.

Dryland salinity is observed when groundwater reaches the surface of the land. In many parts of south west Victoria this is a natural occurrence. It is often evident in the form of saline lakes and wetlands. In these naturally occurring circumstances the salinity is described as primary salinity. The principal concern in this study is secondary salinity - salinity problems that have occurred as a result of human activity, such as extensive clearing of trees (Greig and Devonshire. 1981; Hamilton and Lang, 1978; Peck, 1978; Tisdell, 1985). Bennett and Thomas (1982), report that salinity is roughly linearly (rather than exponentially) related to forest cover. Dixon (1989) found that clearing native vegetation for agriculture changed the amount of annual recharge in a sub-catchment at Glenthompson from around five millimetres in pre-settlement times to an estimated ninety millimetres under the present agricultural systems. Similarly, Peck and Williamson (1987) investigating the effects of forest clearing on groundwater found that in areas fully cleared for agriculture, the groundwater moved upward at more than 2.6 meters per year averaged over several years (or a recharge estimate of 6 to 12 per cent of rainfall) compared to 0.9 meters per year on partially cleared areas.

Secondary salinity occurs when water tables rise, bringing dissolved salts to the surface of the land. Often, primary salinity sites are the first to be affected by secondary salinity, but new sites also develop as groundwatertables rise. Secondary salinity is often first noticed when deep rooted trees die. As groundwater tables rise the health and productivity of shallow rooted species, such as pasture grasses, are also affected (Hamilton and Lang, 1978). As the salinity of the soil rises, only salt tolerant vegetation species will grow. These are often unproductive for agricultural purposes. The diversity of native vegetation communities is also adversely affected. In its most severe form, dryland salinity prevents the growth of all but a few highly salt tolerant species. Thus agricultural production is almost eliminated from the affected area as bare ground develops, which is susceptible to erosion (Peck, 1978).

1.2 The Study Area

1.2.1 The Study Area and Dryland Salinity

The Gerangamete catchment is located approximately ten kilometres south-east of Colac in south west Victoria. The catchment is nestled between the East and West branches of the Barwon River that rises in the Otway Ranges. A map of the catchment is presented in Figure 1.1. The Gerangamete catchment is approximately 2000 hectares in size. Of this total area 1714 hectares has been cleared for agricultural production. Almost 80 hectares of the cleared land however is salt affected and no agricultural production is possible, leaving only 1643 hectares available for agricultural production. Of the 1643 hectares, 654 hectares (40 per cent) has unimproved native pasture, with the remaining (60 per cent) being improved pasture.

Due to the increasing problems of land salinisation, within the confines of the catchment, an extensive piezometer network was installed on a pilot trial sub-catchment of 180 hectares in 1993. Because the pilot trial was confined to a distinct sub-catchment, it was able to be described within a water balance context. The information collected from the pilot site, along with those collected on the rest of the catchment, were used to model groundwater trends using a hydrological model (known as Mike-SHE). The results of the hydrogeological modelling reveal that throughout the catchment groundwater pressures and levels are rising and that these pressures will not stabilise, in the foreseeable future. Without further remedial action water tables will continue to rise, resulting in extensive salinisation of land. It was predicted from the model that the current area of salt affected land could double in the next 30 years time.

Modelling the catchment hydrology enabled scenario analysis to be undertaken to assess the impact various vegetative options would have on the recharge rate. The most practical and feasible option to avoid irreversible resource loss was put forward as the catchment management plan. This was to plant half of the existing areas of unimproved pasture to trees (322 ha) and to improve the remaining half of unimproved pasture (322 ha).

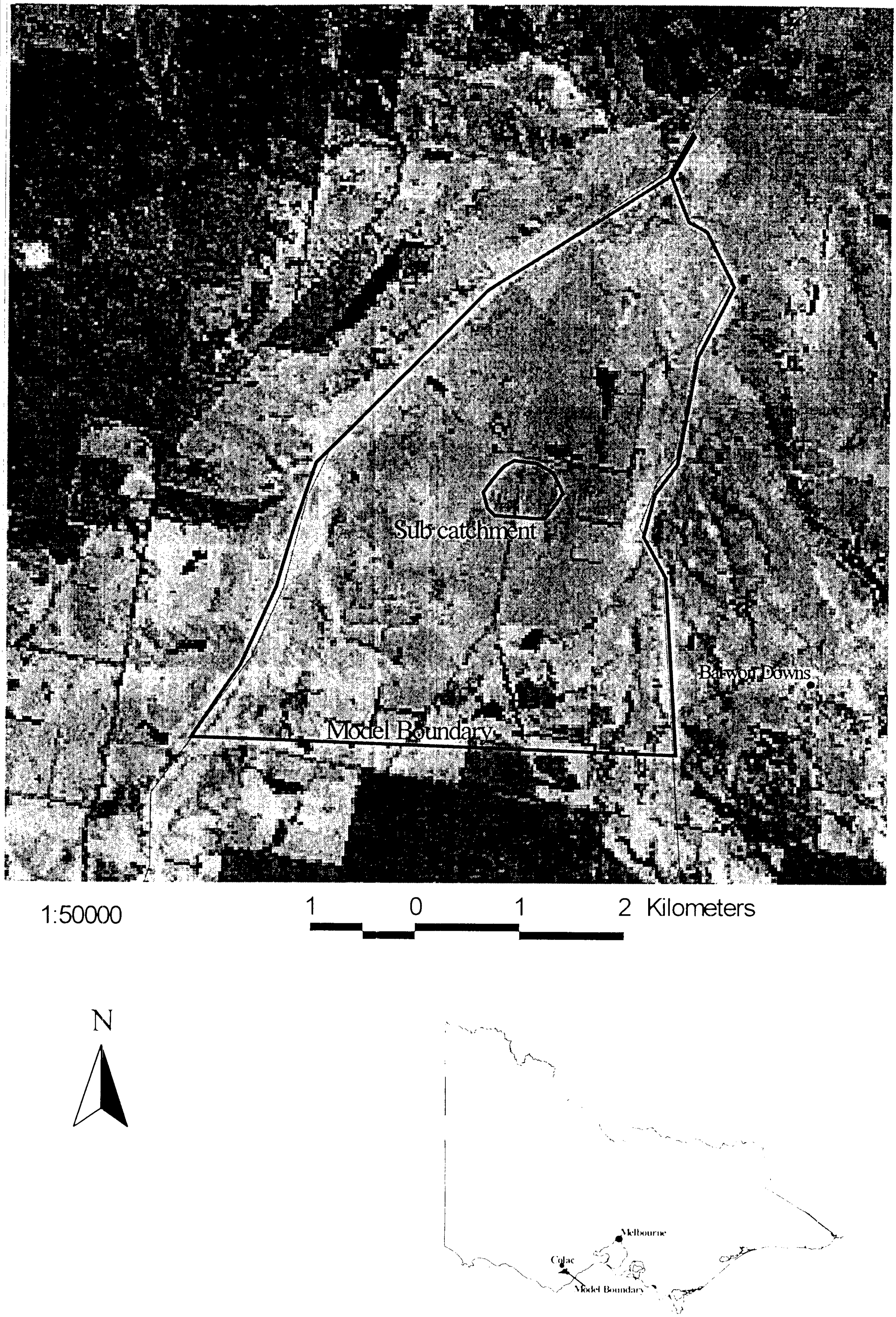

Fig. 1.1 Location of Gerangamete Catchment

1.2.2 Groundwater Trends

Groundwater systems are predominantly local in nature, with groundwater recharge being significant across the landscape as a whole. Groundwater levels, though dependent upon topography, are generally within 3-4 meters of the surface, even beneath moderately elevated crests. There is significant evidence of underlying long term rises in groundwater levels in general. Groundwater salinity generally varies between 2 000 and 9 000 EC (electrical conductivity), often , but not always, increasing down-slope (see Appendix C) (Heislers, 1997).

1.2.3 Historical Recharge Studies

Using seasonal hydrograph fluctuations Heislers (1996) calculated that groundwater recharge in the Barwon Downs district, of which the Gerangamete catchment is part, varies between 58 millimetres and 184 millimetres per year. This translates to 7 to 23 per cent of the annual rainfall. This wide range reflects considerable variation in soil permeability, lithological and perhaps the development of preferential soil water transmission pathways.

Despite the evidence of a "permeability cap", and even accepting only the more conservative recharge calculations, it is clear that significant recharge does enter the Barwon Downs landscape.

1.2.4 Soil Infiltration Results from the Pilot Site

Infiltration rates are categorized as whether they fall into the moderate (50-500 mm/day), slow (5-50 mm/day) or very slow (less than 5 mm/day) ranges. Soil infiltration distribution appears to reflect the surface topography and groundwater discharge pattern.

Over half of the sub-catchment lies in the moderate infiltration range. This encompasses both the southern and eastern slopes. Soils on the southern slopes have infiltration rates between 100-200 mm/day. One site on the eastern divide recorded the highest infiltration rate of 336 mm/day. In contrast, a site at the top end of the sub-catchment, recorded an average of only 6 mm/day. This aberration to the regional pattern is perhaps indicative of natural variability. The north eastern corner is typified by rates of 100 mm/day (Heislers, 1997).

The lowest infiltration rates, 1 to 4 mm/day, were recorded in and near the vicinity of the discharge area. Hydrograph fluctuation and corresponding recharge values generally drop along the slope, which corresponds to the infiltration rate pattern. Along the western divide groundwater fluctuations are of the order of 2.5 to 3 metres, corresponding to 90 millimetres of recharge and 15 per cent of annual rainfall (Heislers, 1997).

1.2.5 The Mike-SHE Model

The Mike-SHE Model is a "whole hydrologic cycle" model. While the model, can be used to simulate sub-surface processes, it can also be used to incorporate surface hydrology and crop effects, which enables management scenario testing. For use in dryland salinity modelling, Mike-SHE offers useful groundwater description, good information on recharge and river interaction and solute transport capability (not used in this study).

The Gerangamete catchment for the model was represented as a two layer aquifer system. Layer 1 represented the Gellibrand Marl and therefore the watertable aquifer, while Layer 2 represented the deeper tertiary confined aquifer systems. The area modelled for the sub-catchment is bounded by the East and West branches of the Barwon River and the Bambra fault to the south. The model grid is approximately six by six kilometres with a node spacing of 50 by 50 metres (Sinclaire Knight and Merz pers. comm.).

1.3 The Research Problem

It could be argued that dryland salinity in the Gerangamete catchment is largely a biophysical problem and as such does not solely constitute an economic problem. The problem however is not that straight forward because as well as impacting directly upon farm land, salinity is also likely to have an impact on local streams affecting downstream users who use the stream water for stock or for irrigation. Therefore market failure may exist, due to externalities, making the current set of circumstances a problem that warrants investigation.

In this study an attempt is made to identify and value the costs and benefits that will arise with the proposed catchment management plan and to compare them with the situation that would exist if the plan were not adopted. The difference is the incremental benefit arising from the project investment. The catchment management plan is considered the safe minimum standard to avoid irreversible resource loss and the minimax principle is posed as a decision criterion for evaluation of the proposed catchment management plan.

1.4 Approaches to Reducing Dryland Salinity

Poulter and Chaffer (1991, p361) state that '...in order to set an efficient policy, scientific information such as hydrological data must be fully integrated with economic information on the linkages between farm management practices, salinity and farm profitability'. Such linkages will provide a means of examining the long-term implications of salinity management for agriculture and also for the development of an optimal catchment management strategy.

In order to have a high chance of success, control measures need to be financially viable, environmentally acceptable and have a likelihood of widespread adoption by the farming community. Currently there are four major approaches to on-farm salinity control and management. These are:

- recharge management using vegetative controls;
- recharge management using engineering controls;
- management of salt affected land; and
- doing nothing.

The last two options of doing nothing and attempts to manage salt affected land, do not address the problem and can result in greater resource degradation. Engineering controls on the other hand are not suitable for all soil types, may be technically infeasible and tend to be very expensive.

Vegetative controls are considered to be the most feasible option to reduce salinity and groundwater recharge in the Gerangamete catchment. In much of the literature, the cause of salinity is the large scale clearing of land (of trees) and their replacement with current agricultural practices based on shallow root systems. It anticipated that the planting of trees and deep rooted perennial pasture will assist to redress the salt imbalance that occurs. In addition to the salinity benefits, trees have been shown to raise agricultural productivity through the provision of shelter, reduce water and wind erosion, provide a suitable habitat for wildlife and may have aesthetic appeal (Tisdell, 1985).

In this study the economic framework that can be used to evaluate the salinity problem in the Gerangamete catchment is outlined. In addition an economic assessment of a catchment management plan that has been proposed to halt the expansion of dryland salinity in the catchment will be undertaken.

The catchment management plan devised to halt the spread of salinity, was to plant half of the existing area of unimproved pasture to trees (322 ha) and to improve the remaining half of unimproved pasture. Production on the existing improved pasture is assumed to be the same as under the existing situation.

Although the principal objective in this study was to evaluate the net social benefit of implementing the proposed catchment management plan, it was also decided to examine the net social benefit of some possible variations to the catchment management plan. These are to:

- to plant the entire catchment to trees;
- to plant 50 per cent of the catchment to trees; and
- to plant none of the catchment to trees (i.e. only improving all existing unimproved pasture).

1.5 Research Objectives and Hypotheses

The objectives of this study are to:

1. estimate the priced and unpriced costs to landholders and society that result from dryland salinity under current land use practices and those that result following the implementation of the prescribed catchment management plan;

2. calculate the priced net social benefits of current landuse, and implementing the prescribed catchment management plan using deterministic discounted cash flow analysis and stochastic discounted cash flow analysis with risk analysis using Monte Carlo type simulation;

3. assess the usefulness of the safe minimum standard (SMS) approach of game theory as alternative or complementary decision criteria to the standard cost-benefit analysis; and

4. propose economic policy alternatives for successful implementation of management solutions.

In objective 1, the cost of dryland salinity and its control are assessed. Given the nature of this problem, there are no benefits from dryland salinity, thus only costs are assessed. The benefits from its control are assessed in objective 2. Objective 3 is aimed at assessing a methodological issue of how to assess the problem of dryland salinity. The aim of the final objective (4) is to evaluate the implications of the plan.

The guiding hypothesis tested in this study is:

Ho : That the net social benefit of implementing the prescribed catchment management plan is less than the net social benefits of current land use.

This hypothesis relates directly to objectives 1, and 2 specified above. To resolve this hypothesis stochastic dominance criteria will be used. The hypothesis will be rejected if the net present value (NPV) of the catchment management plan is greater than the NPV under current land use. The last two objectives (3 and 4) are assessed on subjective grounds.

1.6 Outline of the Study

In Chapter 2, a review of previous studies which are relevant to the study are presented. The focus is on the issue of unpriced values and external effects. Discounting is also discussed with reference to intergenerational equity.

The economic and modelling framework used in this study are developed in Chapter 3. In this chapter a procedure that does not require the measurement of unpriced values and externalities, and does consider intergenerational equity is defined. Sources of priced and unpriced effects of salinity and the catchment management plan are also identified. Deterministic and stochastic methods for estimating the priced benefits and costs of the catchment management plan are explained, as is the model that is used to undertake the quantitative analysis.

In Chapter 4, the data and methodology used to empirically investigate the problem are outlined. Data were obtained to describe the priced effects of the catchment management plan, and the impact of salinity.

The results and sensitivity analysis are presented and interpreted in Chapter 5. The results of the discounted cash flow analysis and risk analysis are presented. The opportunity cost of the catchment management plan is described by two parameters. Firstly, as the net difference between current land use and the catchment management plan, and secondly as the maximum cumulative loss that results with the catchment management plan. The results of an economic evaluation of variations in landuse from the prescribed catchment management plan are also presented in this chapter.

The results of the study are discussed in Chapter 6. The framework developed in this study is appraised on its ability to treat economic efficiency, equity and externality issues. Conclusions are also drawn from preceding discussions and limitations of the study and suggestions for future study are also discussed.

2. Background: Conventional Economic Measures and the Environment

2.1 Introduction

In this chapter the issues relating to sustainable resource use and those relevant to the economic problem framed in this study are presented. The wide and varying views on sustainability are presented, along with the causes of unsustainable resource use and the weaknesses of traditional methods appraising resource use which use the net present value technique. The Safe Minimum Standard concept, used for describing problems involving uncertainty and irreversibility, is used to evaluate the catchment management plan, within a minimax decision framework.

2.2 Sustainability

Sustainability can mean different things to different people. While there has been a gamut of definitions of sustainability many of which are simply a difference in emphasis and a difference in interpretation.

Lowrance, Hendrix and Ordum (1986) proposed a hierarchical approach to sustainability. Reeve (1990, p6) classified these hierarchies from lowest to highest as;

- agronomic sustainability - the ability of the field system to maintain acceptable levels of production over a long period of time (which must be evaluated over multiple growing seasons);
- microeconomic sustainability - the ability of the farm unit to maintain economic viability;
- ecological sustainability - the ability of the catchment or land system to maintain the services that ecosystems provide (e.g. clean air and water); and

- macroeconomic sustainability - the ability of regional or national economies and institutional frameworks to continue to meet regional and national goals.

Lowrance *et al.* point out that sustainability at any 'given' level is affected by the state of the system at the level above that of the 'given' level. Schaller (1989), in Reeve (1990, p8), defined low-input sustainable agriculture in terms of its goal as,

> .... 'an agriculture that is, and will continue to be, profitable for farmers, that will conserve soil and water resources and protect the environment, and that will assure adequate and safe food supplies'.

Perhaps the most widely quoted, and for that matter arguably the most famous, definition of sustainable development is that contained in *Our Common Future*, by the Word Commission on Environment and Development (1987). They defined sustainability as '... development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WECD, 1987, p43). The threat to future generations perceived in the report arise from potentially large scale and irreversible degradation of natural systems in the course of global economic development, particularly in poorer countries. As Barbier (1987, p103) points out '... poor people often have no choice but to opt for immediate economic benefits at the expense of the long-run sustainability of their livelihoods'.

Quiggin (1992) presents an alternative to the standard cost-benefit analysis approach which accounts for sustainability through the question of inter-generational equity. Quiggin interprets sustainability very broadly to encompass two main concerns:

- the interest of future generations should be given equal weight with the current generation in making decisions which affect the long term future; and

- it should not be assumed that capital (that is technology embodied in produced goods) can be substituted indefinitely to compensate for land (taken broadly to include all the contributions of the natural

> environment to human welfare, and agricultural production in particular).

Pearce, Barbier and Markandya (1990, p4) suggest that '... much of the sustainable development literature has confused definitions of sustainable development with the conditions for achieving sustainability'. They define development to be a vector of desirable social objectives whose elements include not only increases in real income, but also improvements in a range of 'quality of life' indicators, such as income distribution and basic freedoms.

James (1991) suggests that the key consideration when discussing sustainability from an economic point of view, is the level an management of the economy's capital stock which is made up of human, man-made and natural capital. He suggests that,

> '... as long as there is continuity in the supply of goods and services, as long as human wants are being met, as long as substitution of products and resources takes place, and as long as the economy's capital stock is appropriately maintained and modified welfare can be sustained' (James, 1991, p3).

In a similar vein, Pearce (1987) defines sustainability as maintaining the level of human well-being so that it might improve but at least never decline. This implies that sustainable development could include the replacement of natural capital by man-made capital, provided the increase in the latter compensated future generations for any fall in their welfare that might have been caused by the depletion of natural capital.

Batie (1989) suggests that two different general definitions encompass most interpretations of sustainable development. These are, the "constrained economic growth" definition and the "maintenance of the resource" definition. Constrained economic growth is defined as '... the pursuit of economic growth subject to environmental constraints...' (Batie 1989, p1084). This has two stages; first the establishment of rules based on ecological principles and environmental ethics, and second the economic maximisation within the rules established. Sustainable development within this context is seen as either maintaining productivity at relatively constant prices or productivity per capita or real wages per capita. With the resource maintenance approach the concept is to minimise the use of the natural environment (Tolba, 1987; Costanza, 1991; Cumberland, 1991; Common and Perrings, 1992). The preservationists view of this definition may vary from one that emphasises the need for severe constraints on economic growth to an extremist view that is dominated by concern for rights of non-human species (Batie, 1989).

> 'The disagreements about the definition of sustainability (or sustainable development) reflect the conceptual problems associated with the formulation of a rigorous definition to describe a complex phenomenon, as well as fundamental differences in moral and ethical values' (Jayasuriya, 1992).

Young observes that a precise definition may be too elusive, all that is really needed is to recognise the '... necessary conditions for...' and the '... opportunities to provide...' what is possible (functional perceptions) and what is not possible (constraints) (Young, 1992, p14). The definition of sustainability used in this study, is one which allows for development subject to environmental constraints that meets the needs of the present without compromising the ability of future generations to meet their own needs. This in effect, is a combination of Batie's constrained economic growth definition and the World Commission on Environment and Development's definition of sustainability.

2.3 Factors that Lead to Unsustainable Resource Use

The problems associated with the use of natural resources arise due to market failure. As perfect markets do not exist for natural resources many are used at rates above that which is socially desirable. The divergences between private and social rates of resource use has been one of the most important reasons for intervening in free markets. In the following section some common factors that contribute to market failure and the reasons for government intervention are outlined.

2.3.1 Market Failure Argument

Market imperfections (imperfect knowledge), collective consumption goods (or public goods), externalities, monopolies and common property are the factors that can cause market failure (Chisholm, 1987a). Imperfect information (uncertainty) is also a relevant factor in this study while the existence of monopolies is of little relevance. The reasoning provided in the preceding discussion and the divergence between public and private views has led to difficulty in optimising resource use to maximise social welfare.

The existence of salinity is an externality. The large scale clearing of native forests by landholders on recharge areas has the potential to increase groundwater infiltration (recharge) and discharge further down the landscape affecting the productivity of land. If uncontrolled, lateral flows of surface and sub-surface saline water discharge into local streams causing stream salinity levels to rise, resulting in a degradation of the marine ecosystem. Because streams, rivers and wetlands in most instances are shared by more than one person the salinity problem also becomes a public good and an open access problem (Quiggin, 1986).

When there is market failure government intervention may be needed to correct the problem. However, as Chisholm (1987a) points out even if there is market failure, it is not always possible for governments to correct it. Deficiencies in information on the part of government can result in the adoption of policies that are less effective, and therefore are worse, than the current situation (Kirby and Blyth, 1987).

2.3.2 Externalities

Mishan, (1976, p117) defines an externality as '... a direct effect on another's profit or welfare arising as an incidental by-product of some other person's or firm's legitimate activity'. An external cost is said to exist when the following conditions prevail, that:

- an activity by one agent causes a loss of welfare to another agent; and
- the loss of welfare is uncompensated.

For a external cost to exist both conditions need to be met. If the loss in welfare is accompanied by compensation by the agent causing the externality, the effect is said to be internalised (Pearce and Turner, 1990; Randall, 1972). A diagram depicting optimal externalities is presented in Figure 2.1.

In Figure 2.1, the optimal level of production is shown as Qm, where zero level of externality is at point O. Maximum social benefit are said to exist where the marginal net private benefit (MNPB) equals the marginal external cost (MEC). The MNPB for the firm is defined as price minus marginal cost, where price equals product price and marginal cost equals marginal private cost. Where MNPB equals MEC (point Y), price equals marginal social cost (MSC) (Chisholm, 1987a; Pearce and Turner, 1990; Pan, 1994).

While it is unlikely that all pollution will or should be eliminated, the level of pollution can be reduced to a socially optimum amount. The optimum level of economic activity is Q, in Figure 2.1 and therefore the area bound by the triangle OYQ (area B) is the optimum level of externality (Pearce and Turner, 1990).

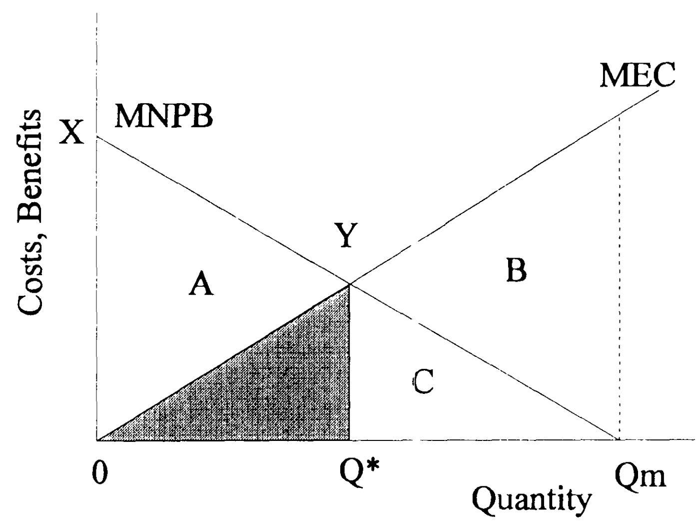

Figure 2.1 Optimal level of an Externality

In this study, land clearing on recharge areas of the landscape and the subsequent increase in dryland salinity and saline runoff have the potential to impact on other land users and the community at large. The costs incurred by downstream producers and clean-up costs are generally however not included in the net private benefit maximisation function of upstream producers. If left unchecked pollution above that which is socially acceptable will result. Finally, the existence of externalities provides some justification for intervention by government to reduce the divergence between private optimal rates of pollution and socially optimal rates through an appropriate policy measure (Quiggin, 1986; Chisholm, 1987b, 1992; Clark, 1991).

2.3.3 Irreversibility

Irreversibility occurs when the use of some natural resource is lost forever (i.e. it is non-renewable). It is argued that irreversibility should be avoided particular when a resource has unique significance and is used for giving preferential treatment to areas such as resource conservation (Arrow and Fisher, 1974). This means that if preventive measures are not taken now, and the costs of resource degradation turn out to be greater than are currently expected, it will be too late to do anything about it (Brennan, 1995; Randall, 1987).

The problem with this argument is that it is not clear which resources, and to what extent, current resource use is irreversible. For instance, an irreversible outcome may be said to occur when it is either technically impossible or prohibitively costly to restore a resource to its original condition (Dovers, 1995). This however assumes that in some cases no new non-renewable resources will ever be found. Second, also overlooked is the fact that in some cases it may be possible to substitute labour and capital for scarce non-renewable resources (van Pelt, 1995). Finally, it is assumed that technology does not change (Pearce and Turner, 1990). While it may be safe to assume that technological advances may not substitute for scarce resources the notion that no new resources will be found, nor that no new technology will ever evolve is unrealistic and is either implicitly or explicitly rejected by the neoclassical theory (Chisholm, 1987b; Clark, 1991).

Faced with this problem of uncertainty and irreversibility, decision makers should not be hasty to select development over the preservation option when it comes to giving up scarce natural resources. A safety-margin approach, based on the concept of the safe minimum standard has been recommended in this context (Pearce and Turner, 1990). When an outcome is irreversible and resource loss is permanent then the issue of intergenerational equity becomes a concern.

2.3.4 Intergenerational Equity

One of the main arguments put forward for the use of lower discount rates when evaluating resource use concerns inter-generational equity. With the intergenerational equity argument, it is asserted that the present generation has insufficient concern for its own future let alone for that of future generations (Howarth and Norgarrd, 1993; Tacconi and Bennett, 1995). Another variant of this argument for intergenerational equity is the assertion that it is 'unjust' that unborn generations are not represented in the decision-making processes of the present generation. According to the proponents of this view, existing members of society are 'guardians or trustees of future generations' (Pearce, 1987).

Pearce and Turner (1990) suggest that one way to satisfy both current and future generations is to separate projects that use resources into two categories. The first would consist of those with payoffs in the short-to-medium term (say the next ten years). Since these mostly benefit the present generation, they should be evaluated using current market interest rates. On the other hand, as the market interest rate takes little account of the needs of future generations, benefits occurring further into the future should be discounted at a rate below that yielded by market processes.

This intergeneration equity argument has however been criticised for a number of reasons. First, the alleged lack of concern for future generations is only asserted to exist. There is no evidence to suggest that current generations do not take into account the welfare of future generations when making resource use decisions. Second, no guidance is provided on the extent of divergence of the so-called social discount rate from private rates. Finally, the concern shown in this equity argument for the plight of future generations seems to be based on a Malthusian notion of resource depletion and a consequent inability of future generations to provide adequately for themselves. Thus, policies designed to decrease present consumption and increase investment activity by lowering discount rates may actually involve a transfer of income from relatively poor present generations to relatively rich future generations (Pearce and Turner, 1990; Solow, 1986).

Quiggin (1992) describes how the issue of discounting can be viewed with respect to the relationship between sustainability and the optimal growth path. He suggests that, under appropriate conditions, the growth path derived from the Ramsey rule of saving, where the marginal productivity of capital should be equal to the rate of growth of consumption, will converge to a "golden rule" path in which output, consumption and capital stock attain their maximum sustainable levels. This concept is presented in Figure 2.2.

The horizontal axis represents the stock of the resource and the vertical axis represents either the rate of return to capital or the renewal of a natural resource. Under the Ramsey solution, the optimal path leads to point C. By contrast, if the discount rate is positive the optimal solution will be either convergence to a tangency point such as B or, if the discount rate is sufficiently high, to a exhaustion of the stock and an equilibrium at zero (point A).

Quiggin extended the Ramsey analysis to incorporate human produced capital stock and a stock of renewable natural resources. Assuming no substitution between these stocks and in the absence of harvest costs, the optimal rule for the stock of renewable natural resources is a path leading to the maximum sustainable yield. If future consumption is lower than present consumption, the opportunity cost rate is negative. This means that project appraisals should be weighted to favour projects that yield high payoffs in adverse states of the world.

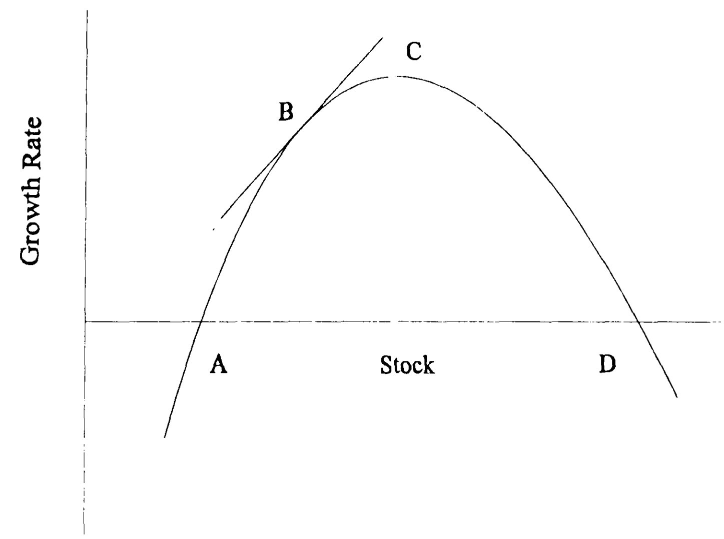

Figure 2.2: Growth of a renewable resource

2.4 Cost-Benefit Analysis

'Benefit-cost analysis is a procedure for comparing alternative courses of action by reference to the net social benefits that they produce' (Dept. of Finance 1991, p1). Unlike financial evaluation, which is conducted from the vantage point of the individual firm or agency, the aim of cost-benefit analysis is to identify the option which will maximise social welfare.

Cost-benefit analysis involves the appraisal of all costs and benefits which relate to a proposed course of action or investment project, from the viewpoint of society as a whole (Chisholm, 1987). The concept underlying cost-benefit analysis is to achieve a potential Pareto improvement or Pareto optimality.

A pareto optimum situation is one in which it is impossible to make any individual better off without making someone else worse off (Pearce and Tuner, 1990). But this action is not socially optimal if a Kaldor-Hicks approach to determining the social optimum is adopted. The Kaldor-Hicks principle states that when those individuals gaining from an economic reform could as a result of the reform, compensate those losing from it and be better off than before the reform, a Kaldor-Hicks gain is said to occur and Pareto improvement is said to exist (Tisdell, 1982).

Cost-benefit analysis is a widely used technique for project evaluation as it provides an acceptable framework for public decision making. The technique is used extensively in both the private and public sector for project evaluation and consideration of alternative uses of resources. The aim of cost-benefit analysis is to express social benefits and costs in money terms. When the stream of net social benefits (social benefits less social costs) is positive the project is said to provide society with a net gain in welfare and a pareto improvement exists. Invariably, projects are ranked on the magnitude of the net present value or on other criteria such as the cost-benefit ratio or an internal rate of return.

2.4.1 Problems with Cost-Benefit Analysis

Like any analytical approach, cost-benefit analyses does have its limitations. The major objection to the use of cost-benefit analysis is that many of the costs and benefits cannot be calculated in terms of market prices (Junger, 1979; Cocks, 1992; Boyce, 1994). Environmental effects in particular, are difficult to predict. This is because of the complexity involved with environmental effects. However, as Faeth (1993), points out, excluding environmental costs and benefits from funding decisions could mean that from society's point of view, the wrong research is funded.

The application of cost-benefit analysis to evaluating costs relating to the environment has been criticised on the grounds that it is anthropocentric. That is, values are defined only in terms of the experience of humans, and the value of the natural environment is derived only through satisfaction that it brings to humans (Harrison and Tisdell, 1994; Jones, 1992; Toman, 1994; Chisholm, 1992). As Quiggin (1992, p 243) states '... the discounting of future benefits has long been one of the most controversial, and in many ways, unsatisfactory, aspects of cost-benefit analysis'. Further, Norgaard and Howarth, (1991, p88) state that '... discounting is appropriate with respect to the efficient use of this generation's resources, but is inappropriate when this generation is primarily concerned with redistributing resource rights to future generations'.

Environmental problems that are seen in terms of market failure can be corrected by imposing charges on polluting and natural resource depleting activities (Hodge, 1982). Dietz and Van der Straaten, (1992) identify several missing links between mainstream economic theory and environmental policy. They are that:

- many benefits cannot be expressed in market prices, simply because there are no markets for public goods like ecosystems and landscapes;

- the preferences of future generations are unknown and the depletion of non-renewable natural resources, the over exploitation of renewable natural resources, and the irreversible pollution of ecosystems reduce the stock of natural resources available for future generations;

- processes in nature and hence, human interventions in these processes are difficult to predict and some effects are synergetic, other do not show until a threshold is reached and others have delayed effects;

- even where the economic benefits and costs are calculated, powerful economic interest groups can influence policy setting;

- politicians prefer policy measures that can be exactly predicted, which result in direct regulations and standards being more widely used than taxes and subsidies;

- individual firms prefer standards to levies and charges, yet regulations in the form of standards do not cost money once they are achieved while taxes on the otherhand will still be levied on emissions below the optimal level; and

- imbalances of power in society offer vested economic interests the opportunity to put their individual and short-term interests ahead of the collective and long-term interests of a sustainable society.

In short, as Lind (1988, p88), suggests '... benefit-cost analysis is not a precise tool but rather, is a crude tool that can identify projects that are clearly losers or winners'. Benefit cost analysis by itself has never been a tool for resolving issues of equity.

Despite the unresolved questions relating to the use of cost-benefit analysis, there is widespread acceptance of the usefulness of cost-benefit analysis for assessing efficiency in project evaluation (Young, 1992). Junger (1979) also concedes that despite some of the pitfalls of the technique in determining important issues of public policy, there seems to be no better technique available for making such evaluations.

2.4.2 Reconciling Sustainability and Cost-Benefit Analysis

The rationale embodied in cost-benefit analysis is that any course of action is judged acceptable if it confers a net advantage, namely that the benefits outweigh the costs. What constitutes a gain or a loss depends on the objective function chosen (Perace *et al.*, 1990). While most cost-benefit analysis operate with a function based on economic efficiency, Pearce *et al.* suggest that this is only one of many possible objective functions. In principle they suggest that any objective function can be chosen. Thus the sustainability objective can be integrated into any cost-benefit analysis leaving the basic structure of the technique intact.

Pearce *et al.* (1990) suggest that a way to introduce sustainability into cost-benefit analysis is by setting a constraint on the depletion and degradation of the stock of natural capital. Doing so would modify the economic efficiency objective and mean that all projects that yield net benefits should be undertaken subject to the requirement that environmental damage (i.e. natural capital depreciation) should also be zero or negative. Applying this criteria to individual projects would diminish the economic feasibility of projects.

2.5 Making Investment Decisions in an Uncertain Environment

Investment decisions often have to be made under circumstances when the available information is uncertain. This will increase the risk of taking those decisions. Risk means that the outcome of a particular decision depends on the circumstances ('states of nature') which might prevail and the probability of each of these circumstances is known. Uncertainty, on the contrary, relates to a context where probabilities cannot be assigned to events (Perrings, 1991).

From the point of view of cost-benefit analysis that use the net present value criterion, if the probability distribution for the returns from a risky investment can be estimated, decisions can be based on expected values or arithmetic mean (Dasgupta and Pearce, 1978). When events are uncertain (in general have more than one possible outcome, and probabilities cannot be assigned to events) an alternative decision framework using a pay-off matrix can be constructed based on the principles of game theory.

2.5.1 Uncertainty and Decision Criteria

Risky events, by their very nature, are uncertain and the ordering of alternatives requires both a probability of occurrences and preference information. In situations where the decision maker cannot assign any probabilities at all to the various events that could affect the results of their actions, the expected utility criterion for project choice cannot be applied. In such situations, the decision problem can be investigated using the principles of game theory, where a payoff matrix is constructed providing the decision makers know the possible actions, the possible states of nature and the payoff that result from their actions under each state (Hey, 1979).

On the horizontal axis of Table 2.1, four possible states of nature N are specified, for which the probability of these occurring are unknown. The net social benefits (the 'pay-offs') accruing from each state of nature are assumed to be known and these are given in the body of the matrix. They vary according to the strategy (S) chosen, which in this example there are four.

If the decision maker is optimistic, the decision with the highest payoff (maximax) might be chosen, such as S equals three, N equals two giving a net social benefit of four, see Table 2.2.

Alternatively, maximin utility criterion can be used. Using this criterion the decision maker looks for the minimum utility for each strategy and then maximises the minimum payoff (Hey, 1979). If the decision maker is cautious, the decision that minimises possible losses will be chosen. In Table 2.2, the project with the maximum minimum payoff (S2) is chosen. If the pay-offs are replaced by costs the rule becomes one of choosing the maximum losses and then minimising this loss. In this form it is known as the minimax loss criterion. This maximin criterion guards against the worst at the cost of ignoring decisions that might do very much better with only slightly less probable outcomes. From an equity point of view, avoiding the worst scenario will be particularly relevant if the investment in question impose costs on future generations.

Table 2.1 Decision Matrix for Choice under Four Possible States of Nature

Decision	States of Nature (N)			
(S)	**1**	**2**	**3**	**4**
1	2	2	0	1
2	1	1	1	1
3	0	4	0	0
4	1	3	0	0

Table 2.2 Maximax/Maximin Matrix

Decision (S)	States of Nature (N)				Maximum Gain	Maximum Loss
	1	**2**	**3**	**4**		
1	2	2	0	1	2	0
2	1	1	1	1	1	1
3	0	4	0	0	4	0
4	1	3	0	0	3	0

An alternative on the minimax loss matrix is the minimax regret criterion. The minimax regret or loss is defined as the difference between the actual payoff and what the payoff would have been had the correct decision been made. The regret matrix for shown in Table 2.3 uses the same payoff as in Table 2.1. If state 1 occurs, and strategy 1 is chosen, the actual gain is two and the maximum potential gain for that state of nature is also two giving a net potential gain of zero. As the aim is to minimise the maximum regrets (losses), strategy 4 is chosen. This criterion ignores the absolute magnitude of the returns and focuses only on the comparative consequences of the alternative decisions (Hey, 1979). It highlights the outcomes of each decision as compared with the maximum attainable in each state of nature.

Table 2.3 Minimax Regret Matrix

Decision (S)	States of Nature (N)				Maximum Regrets
	1	**2**	**3**	**4**	
1	0	2	1	0	2
2	1	3	0	0	3
3	2	0	1	1	2
4	1	1	1	1	1

2.5.2 Safe Minimum Standard (SMS)

The safe minimum standard was developed by Ciriacy-Wantrup in 1952, as an alternative decision rule for problems involving irreversibility and pure uncertainty (Ciriacy-Wantrup, 1968). Ciriacy-Wantrup defined the safe minimum standard as a standard of conservation practices that are designed to avoid the 'critical zone' of resource depletion. The critical zone comprises those physical conditions brought about by human action, which would make it uneconomical to halt and reverse depletion (Ciriacy-Wantrup, 1961, 1968).

The safe minimum standard approach has theoretical roots in game theory and calls for the avoidance of irreversible loss of natural capital unless the social costs of conservation are unacceptably large (Bishop, 1979; Toman, 1994). The safe minimum standard can therefore be best described as a choice problem, as one of choosing between the increased future uncertainty - a cost- that will result from irreversible loss, and the more obvious costs that may result from efforts to avoid irreversible loss (Bishop, 1979). Batie (1989, p1097) succinctly summarises the approach, stating that,

> 'The safe minimum standard is a risk-averse, conservative criterion that states society should assure the survival of species, habitats and ecosystems unless the costs of doing so are unacceptably large'.

Young (1992, p227) states that,

> 'Essentially, the safe minimum standard approach can be viewed as a constrained cost-benefit analysis approach in the sense that cost-benefit analysis in the context of the efficiency goal should be applied to preservation issues, subject to the constraint that the safe minimum standard level be maintained. An ethical judgement is required to resolve the equity question of whether the safe minimum standard will actually be adopted'.

The safe minimum standard approach therefore can provide some common ground between those who support the constrained economic growth definition and those advocating the maintenance of resource definition (Batie, 1989). Rogers and Sinden

(1993, p1) further suggest that '... the safe minimum standard is a criterion for environmental choice that bridges economic and environmental goals, and provides a characterisation that is common to both'.

The concept of the safe minimum standard is similar to the 'Precautionary Principle' discussed by Perrings (1991) as both are motivated as an approach for decision making under uncertainty. A precautionary principle implies '... the commitment of resources now to guard against potentially adverse outcomes of some decision' (Perrings, 1991, p154).

2.5.3 Game Theory and the Safe Minimum Standard Approach

Bishop (1979) developed the safe minimum standard as a two person game against nature using the minimax decision rule as the decision making criteria. However, in his attempts to formalise the relationship between the safe minimum standard and the minimax solution to a two person game, he incorrectly specified the loss matrix for the game he envisaged. Ready and Bishop (1991) in correcting the relationship extended the two person game theory developed by Bishop (1978) to suggest two plausible games that can be used to model decisions involving endangered species, the insurance game and the lottery game. The modification of previous work was an attempt to link the safe minimum standard to a theoretical model of social choice as cost-benefit analysis has theoretical foundation in the potential Pareto improvement criterion.

For a problem framed as an insurance game it is assumed that a species holds a cure for a disease, but the outbreak of the disease is unknown. The payoff matrix is illustrated in Table 2.4 where, the development benefits are symbolised as Bd, and are greater than zero. Extinction of species is assumed to entail the possibility of future losses, symbolised as L. These losses are assumed to be large, to the extent that L is greater than Bd. Uncertainty is modelled by two policy-independent future states of the world, where State 1 corresponds to an outbreak of disease and State 2 corresponds to no outbreak. It is assumed that L and Bd are known, but the probability of states 1 and 2 are unknown (Ready and Bishop, 1991).

The baseline for measurement of losses is chosen as no disease and no development. The loss matrix showing the relative gains and losses is presented in Table 2.4. Under the safe minimum standard, the maximum possible loss is zero. Under DEVELOP, the maximum possible loss is L-bd. As the objective is to minimise the maximum possible loss the safe minimum standard is chosen as the preferred strategy.

In the lottery game, the disease is assumed to occur with certainty, but there is uncertainty if preservation will lead to a cure. In state 1, the species holds the cure while in state 2 it does not. The base line for the lottery game is no development and no cure. The loss matrix for the lottery game is presented in Table 2.5. The maximum possible loss under the safe minimum standard is zero, while under DEVELOP it is -Bd which is less than zero. Hence, the strategy that minimises the maximum loss is DEVELOP, despite the fact that this can lead to extinction of the species and losses to society from the disease.

By modifying the motivation of the problem Ready and Bishop (1991) showed that completely different results can be obtained. Neither game captures the nature of the problem better than the other. While the use of the game theoretic framework gives structure to the problem, the safe minimum standard cannot be motivated as the minimax-loss solution to a two person game against nature. From this, Ready and Bishop (1991, p309) concluded that '...although the safe minimum standard is intuitively appealing, it cannot be motivated by game theory' . Rejection of game theory however does not necessarily mean rejection of the safe minimum standard as a decision making policy.

Table 2.4 Loss Matrix for the Insurance Game

Strategy	States of Nature		Maximum Loss
	1	2	
SMS	0	0	0
DEVELOP	L - Bd	-Bd	L - Bd

Table 2.5 Loss Matrix for the Lottery Game

Strategy	States of Nature		Maximum Loss
	1	2	
SMS	-L	0	0
DEVELOP	-Bd	-Bd	-Bd

2.6 Summary

There have been a plethora of definitions of sustainability with perhaps the most widely quoted, and for that matter the most famous, definition being the '...development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WECD, 1987).

Conservationists have maintained that one of the main weaknesses of conventional cost-benefit analysis is its inability to accurately account for sustainability issues. Neoclassical economic models based on optimisation and cost-benefit analysis need to be interpreted with caution because of the possible bias in favour of projects that have economic over environmental benefits.

In the face of uncertainty and irreversibility, conserving what there is could be a sound risk-averse strategy, providing rationale for conserving existing stock, at least until a clearer understanding of what the optimum stock is known.

In this study, the safe minimum standard has been proposed as an alternative decision making framework for problems of choice involving uncertainty and irreversible loss. By using the safe minimum standard approach some caution must be exercised about the alleged benefits of development, and the profile of the environmental benefits needs to be raised. Its use for decision making is largely based on the ethical judgement by the decision maker.