1. Introduction

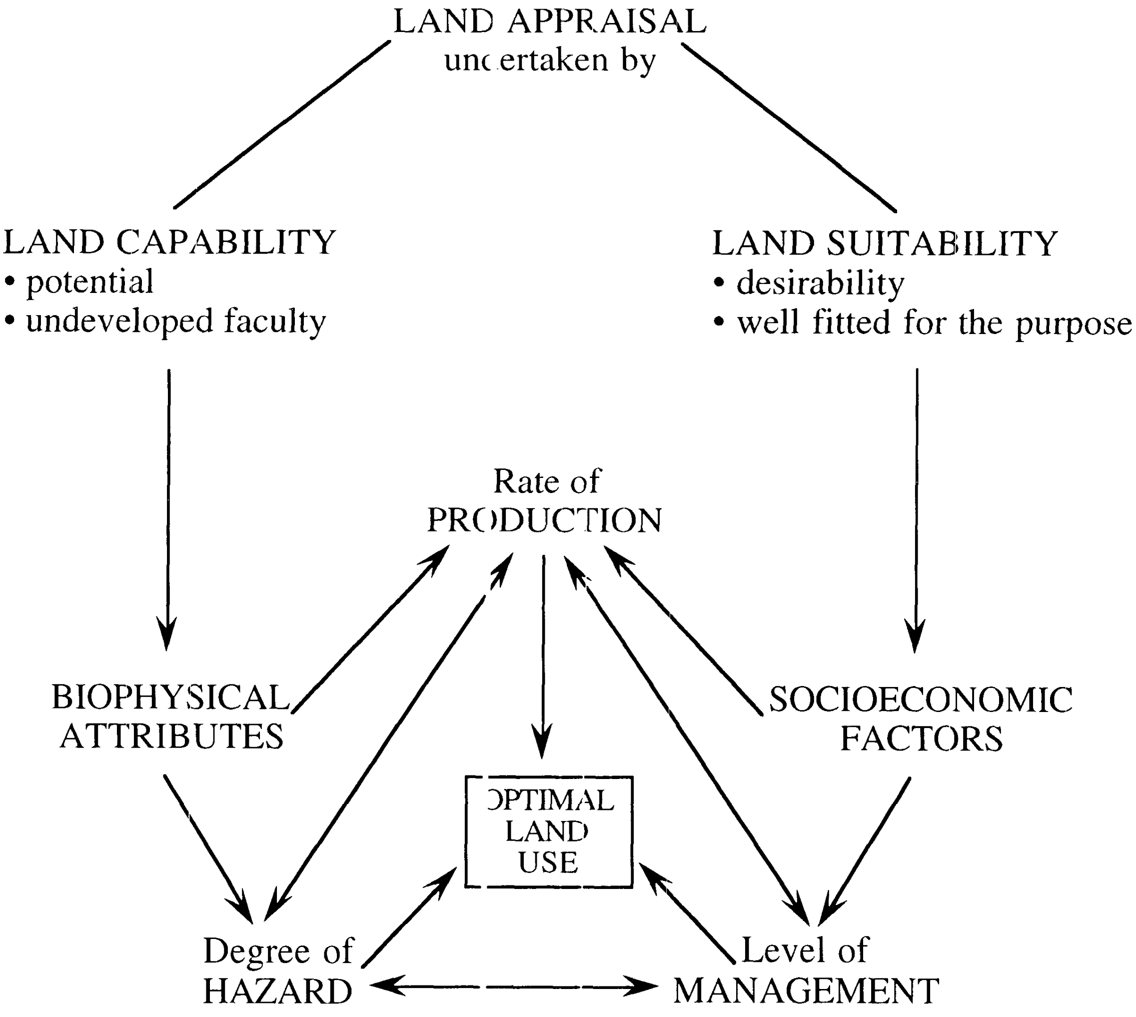
1.1 Background: the problem of land degradation

Land degradation is a prevalent feature of the Australian agricultural environment. Land degradation is defined for the purposes of this study as the decline in condition or quality of land as a consequence of human use. It is a natural process that has been accelerated through human action, and it may result in a decline in productivity in relation to the use to which the land is put. Degradation is considered to have occurred when there has been a measurable decline in the quality of the land.

Land degradation generally results from the combination of inadequate land management and land being used beyond its capability. We need to know the relationship between land degradation and causal factors in order to understand how land degradation issues develop and progress. Land degradation may be overcome by modifying existing land-management practices through the application of technological advancements, improving management practices and undertaking of structural works, or changing land use to a more appropriate form after the land has been rehabilitated. Land degradation is just one of the components in the interaction between the rates of production from an area of land, the degree of hazard generated in achieving that rate of production and the level of management required to keep the degree of hazard within acceptable bounds (Figure 1.1). The degree of hazard is determined by an examination of the interaction of fundamental facets of the physical environment (such as inherent erodibility, geomorphologic characteristics, climatic conditions and topographical characteristics), coupled with the particular land use undertaken. On this basis, the likelihood of a particular degradation event occurring can then be predicted.

Figure 1.1

The interaction of degrees of hazard, levels of management and rates of production for land-degradation research



Source: J. Duggin 1996, pers. comm

Changes in the condition of the land must be viewed in relation to the particular land use being considered. In order to assess the effects of land degradation on agriculture, the following problems and related degradation issues must be examined: (a) changes in soil condition such as soil loss, fertility decline and soil structure decline; (b) rising water tables resulting in salinisation and waterlogging; (c) changes in vegetation composition in pastures such as weed invasion; (d) loss of native vegetation/biodiversity through land clearance, and (e) invasion of feral animals leading to overgrazing and disturbance.

An ideal measure of the impact of land degradation will be objective, relevant to the concept of degradation as defined, capable of systematic application, and specific to the time and region (Warren 1984, cited in Bie 1990). Degradation can be measured in terms of bio-physical parameters such as tonnes of soil loss, length of gullies or loss of vegetation. An economic measure of land degradation can be the value of forgone output associated with reductions in land quality.

Management aspects relate to decisions on land use and land-degradation prevention and control. The management of land degradation requires different information at different scales. For example, at the national and State level, governments must allocate resources between a variety of competing uses such as health, education, law and order and the environment. At the regional or catchment level, the effective management of land degradation requires broad indicators of which types of land degradation are having a significant influence in particular areas. At the farm level, the individual landholder must incorporate the management of land degradation within a range of other farm-management decisions, as well as beyond his or her own farm boundary to consider neighbouring properties within a particular sub-catchment. At the paddock level, management decisions must be made on the basis of bio-physical and land-use attributes.

1.2 Extent of land degradation

It is generally in areas in which human land-use activity is greatest that the most severe cases of land degradation can be found. Reeve (1988), Moran, Chisholm and Porter (1991) and Barr and Cary (1992) have documented the effects of European settlement on the Australian environment, citing the use of inappropriate agricultural methods as a major catalyst for land degradation. Non-agricultural land uses such as mining and urban development have also caused significant, but limited, damage.

1.2.1 At the national level

An assessment of land degradation in agricultural and pastoral areas was made in 1975 by the Commonwealth and State governments in the Collaborative Soil Conservation Study. The main report from this study gives the first national view of the extent of land degradation (Department of Environment, Housing and Community Development 1978). The results for each State are summarised in Table 1.1.

The study estimated that of 5 million square kilometres of land used for agricultural and pastoral purposes in 1975, about 2.7 million square kilometres (or 51 percent) need treatment for land degradation. Twenty-two percent of the area requires treatment that involves modification of management practices, while 29 percent requires both land-management and soil-conservation works. The survey criteria and procedure of this study have been criticised because of problems with compatibility and uniformity in information collection between States (Musgrave and Pearse 1985; Conacher and Conacher 1995).

Table 1.1

Areas of land degradation requiring treatment at June 1975 (1000 km^2)

Form of degradation	Aust	NSW	Vic.	Qld	SA	WA	Tas.	NT	ACT
Area in use	1084	303	158	780	130	215	26	180	1.1
Area not requiring treatment	987	41	59	525	94	112	25	120	0.3
Water erosion	577	199	58	198	17	70	1	34	0.8
Wind erosion	57	-	26	-	18	13	*	-	-
Combined wind and water erosion	55	41	-	*	-	14	-	-	-
Vegetation degradation	92	8	-	57	-	3	-	24	-
Dryland salinity	10	-	7	a	*	3	-	-	-
Irrigation salinity	9	*	8	-	*	-	-	-	-
Other	14	13	*	*	*	1	-	-	-
Total areas requiring treatment	815	262	99	225	36	103	1	58	0.8

* Denotes small areas less than 1000 km^2

[a] Dryland salinity was reported, but the areas were not assessed

Source: Woods (1984).

The most recent documentation of the extent of land degradation was produced by the Australian Surveying and Land Information Group (AUSLIG), and published by the Australian Bureau of Statistics (ABS; 1992). On the basis of data supplied by State soil-conservation agencies, the extent of water erosion, wind erosion, soil acidification, salinity, soil structure decline, water-repellent soils and vegetation degradation are reported in mapped form according to categories of potential hazard. Although the survey results are only provided in mapped form, they indicate that large areas of agricultural land are subject to severe levels of degradation.

1.2.2 At the State level

The Land Degradation Survey of New South Wales (NSW) is the only comprehensive statewide survey available at present (Soil Conservation Service of NSW 1989; Graham 1989, 1992). The survey was restricted to forms of degradation that affected the productive capacity of the State's agricultural, pastoral and forested lands, and only land degraded as a consequence of European management was included. Measurements of decline in productivity associated with land degradation were not incorporated. Ten forms of degradation were assessed, and the presence of perennial bush and tree regrowth were also recorded. Table 1.2 is a summary of the main statistics for NSW. These measurements are not assessments of degradation as such but give an indication of past land use and the present stability or susceptibility of the area to degradation, thus providing a benchmark for future surveys. Like the national surveys, these results also show widespread occurrence of soil erosion, soil salinity, soil structure decline, mass movement, soil acidity and woody shrub invasion. The data from this survey are examined further in Chapter 5.

Other statewide land degradation data include the Victorian *State of the Environment Report* (Scott 1991). This survey indicates that 40 percent (2 334 000 ha) of cropping areas are subject to severe soil structure decline, while 52 percent (3 714 000 ha) of dryland-pasture areas have strongly acidic soils. It was also found that the area subject to dryland and irrigation salinity (275 000 ha) is small compared to the total area of agricultural land in Victoria (11 857 000 ha).

Table 1.2

Summary statistics from the NSW Land Degradation Survey

Form of Degradation	Occurrence (%)	Relative area (x1000 ha)
Sheet and rill erosion		
minor - moderate	11.07	8873
severe - very severe	0.84	677
Mass movement	2.69	N/A
presence		
Wind erosion	14.06	11 270
moderate	10.61	8501
severe - very severe		
Gully erosion		
minor - moderate	16.50	13 218
severe - extreme	5.54	4446
Dryland salinity		
moderate	0.54	N/A
severe	0.66	N/A
Irrigation salinity		
moderate	0.52	N/A
severe	0.25	N/A
Scalding		
moderate	9.18	N/A
severe	0.88	N/A
Soil acidity		
potential for acidity	6.65	5330
severe	3.38	2712
Soil structure decline		
severe	10.86	8701
Woody shrub infestation		
minor - moderate	25.87	20 734
severe	4.41	3533

Source: Soil Conservation Service of NSW (1989).

1.2.3 At the regional level

Junor, Marston and Donaldson (1979) report on increases in soil erosion in the Lower Namoi River area of NSW. Their results are based on soil-erosion surveys undertaken in 1945, 1967 and 1975 and indicate that over a thirty year period erosion increased from 39 percent of the total area to 69 percent (an increase of 920 400 ha). From the early 1960s there were significant changes in land use together with an overall increase in land-use intensity. The increases in soil erosion over the three time periods are shown in Table 1.3.

Table 1.3

Changes in soil erosion (% of total area) in the Lower Namoi region 1945-75

Erosion class	1945	1967	1975
Moderate - severe gully erosion	23	26	39
Sheet erosion	9	14	39
Wind erosion	7	7	7
No appreciable erosion	61	53	31

Source: Junor *et al.* (1979).

Ferdowsian, George, Lewis, McFarlane, Short and Speed (1996) reviewed and compared six different methods of assessing the extent of dryland salinity in Western Australia (WA). Based on results synthesised from the different methods of assessment, it was concluded that about 1.8 million ha of cleared land (9.4 percent of the state) are currently affected by dryland salinity, and it is predicted that this area could double in the next 15 to 25 years. A summary of the synthesised results for a number of hydrological regions in WA is given in Table 1.4.

Table 1.4

Estimated areas affected by salinity in WA in 1994 and 2010-20

Hydrological region	Area cleared (ha	Area affected 1994 (%)	Area affected 2010-20[a] (%)
Western and Central South Coast	2 440 960	11.2	18.3
Eastern South Coast	1 638 000	7.5	14.7
South West	3 310 000	8.3	18.0
Central and Eastern Wheatbelt	7 590 500	10.0	17.0
Northern Wheatbelt	4 251 900	8.8	17.0
Total	19 231 400	9.4	17.1

[a]Depending on rainfall

Source: Ferdowsian *et al.* (1996).

1.2.4 An acceptable level of land degradation?

Natural resource managers may regard any land degradation as undesirable when land use is judged against a goal of maintaining land condition. On the other hand, economists may regard a certain level of degradation as acceptable when net social benefits to society are maximised (Blyth and McCallum 1987), and undesirable when it imposes net costs on society (Quiggin 1986). In this sense, too much degradation or too much conservation may each impose net costs on society. The appropriate management of land degradation depends on finding a balance between conservation and degradation (Yapp, Sinden and Walpole 1992).

Some environmental organisations go so far as to argue that all land degradation must be eliminated to preserve land-use options for future generations. Bio-physical measures of land condition must, therefore, be fundamental measures of human well-being. According to the Australian Conservation Foundation, 'we must be able to continue to produce food without degrading the resource from which the food comes and upon which native ecosystems depend – the land' Cameron and Elix 1991, p.16). This view is supported by Pearce, Barbier and Markandya (1990) who state that a zero rate of degradation is preferred where the problem may be irreversible and no substitutes exist.

However, actions to rehabilitate degraded areas or to conserve soil are not costless. Recognising this, Edwards (1988) adopted a more pragmatic approach to the question of how much soil loss is acceptable. He notes the difficulty in convincing landholders to adopt practices to reduce erosion and suggests that the concept of zero degradation is untenable in a nation where the rate of soil formation is effectively zero[1] . A balanced approach is required whereby agricultural practices maintain the land resource yet are still economically viable on all but the most degraded areas.

1.3 The costs of land degradation

1.3.1 Lost agricultural production

There have been a number of attempts in Australia to estimate the amount of agricultural production forgone due to land degradation. According to Chisholm and Hone (1996), the figure most widely referred to is Australian Soil Conservation Council's (ASCC) $600 million per annum (1989 dollars) in lost production attributable to land degradation (ASCC 1989). The Department of Environment, Sport and Territories (DEST) recently estimated that lost production due to land degradation is $1.15 billion annually (DEST 1995). Price (1993) gives estimates for the per annum cost of lost income or for land-degradation treatment as being $180 million for waterlogging, $200 million for soil structure decline, $200 million for salinity, $300 million for acidity and $80 million for erosion.

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[1] Soil erosion that reduces the productive capability of the soil may be offset to some degree by deposition of material from elsewhere and by new soil formation. However, even limited data suggest that soil formation rates in Australia are very low. Edwards (1988) reports that the soil formation rate in Australia is approximately 0.4 t/ha/y.

Following on from an initial contribution by Sinden and Yapp (1987), the relationship between land-degradation data collected by the Soil Conservation Service of NSW and farm output for various agro-ecological zones in the state was explored by Walpole, Sinden and Yapp (1992, 1994, 1996). Their studies suggest that there is a link between levels of land degradation and farm output at the Local Government Area (LGA) level, with the results suggesting that land degradation is associated with the annual loss in NSW of $758 million in the gross value of production (1987-88 dollars).

Hall and Hyberg (1991) studied the effects of land degradation on farm output in the pastoral zone, the wheat-sheep zone, and the high rainfall zone of the coastal area and tablelands. Their data were obtained from the Australian Agricultural and Grazing Industries Surveys (AAGIS) of 1983-84. Their study showed that about 4.5 percent of annual output valued at $393 million was lost in 1983-84 due to land degradation. They also estimated that the production loss in NSW, outside the pastoral zone, was five percent.

The Environment Protection Authority of NSW (1993) sourced various research studies to report that the annual value of lost agricultural production in NSW was $100 million to soil acidity and $144 million to soil structure decline.

Gretton and Salma (1996) approach the analysis of land degradation on agricultural productivity on the basis of a production equivalent. They estimated the effects of four land-degradation types (dryland and irrigation salinity, soil structure decline and acidity) based on the profit-maximising behaviour of individual farmers. Their results indicate that a one percent increase in the level of soil structure decline or soil acidity would lead to a 0.29 and 0.13 percent reduction in agricultural profit, respectively. Conversely, a one percent increase in the level of dryland salinity or irrigation salinity would lead to a 1.22 and 0.44 percent increase in agricultural profit, respectively. They concluded from their analysis that it pays to let dryland and irrigation salinity continue due to the possibility of achieving higher levels of production, while there are positive incentives to avoid induced soil acidity and soil structure decline.

Several regional estimates of production losses due to land degradation have been made. For example, Young, Walker, Mallawaarachchi and Smyth (1995) and Mallawaarachchi, Walker, Young, Smyth, Lynch and Dudgeon (1996) estimate net agricultural income decline due to sheet and rill erosion in the Lachlan Valley to be $21 million (1989-90 dollars). Cameron and Elix (1991) summarise estimates of losses for the cropping region of the north-west slopes of New South Wales ($30 million of potential production lost in 1989 due to unseasonally heavy rains) and the pastoral areas of the Queensland mulga lands (up to a 50 percent reduction in pasture productivity due to woody weeds). Alcock (1979) estimated the decline in value of production due to soil erosion on the Darling Downs to be up to $40/ha, and Dumsday and Oram (1990) estimated the lost income due to salinity in northern Victoria. Molnar (1965) made the first attempt to quantitatively measure the impact of erosion on a regional basis. Wheat yields showed a 40 percent reduction between shires of high and low erosion, and changes in rainfall and fertiliser affected the size of the reduction.

Watt (1990) studied average soil-erosion rates in NSW using a modified Universal Soil Loss Equation developed by Rosewell and Edwards (1988). The erosion rates were estimated for a uniform type of soil (northern slopes and plains), a gradational soil (central western plains) and a duplex soil (southern slopes and plains). The study shows that for an unrestricted soil-loss system, a high-profit land use results in an average annual erosion rate of approximately four tonnes/ha/year (t/ha/year) for the northern and southern areas, and two t/ha/year for the central area. Furthermore, it is highlighted that the soil loss in the northern and southern areas is associated with a productivity loss of 4.3 percent after 50 years, and 8.6 percent after 100 years.

Most analyses of the costs of land degradation focus on areas of high agricultural productivity. However, the rangeland areas of Australia also suffer from losses in agricultural output due to various forms of land degradation. Passmore and Brown (1991) analysed rangeland degradation in south-west Queensland to examine the effects of property size, wool price, discount rate and risk attitudes on rangeland decisions and condition. They found that at low pasture biomass levels there is a higher risk of causing irreversible damage for an additional unit of resource use.

1.3.2 Restoration costs

The only broad-scale attempt at estimating restoration costs of land degradation in Australia is the Collaborative Soil Conservation Study, which determined the extent of land degradation in Australia and then made estimations of the land-treatment measures required for these areas (Woods 1983). It was found that 51 percent of rural land in Australia needed treatment for land degradation, at a total cost of $675 million dollars (1975 dollars).

Regional examples include Oram and Dumsday (1994), who examined the relationship between farming systems, recharge and groundwater discharge in the Campaspe Catchment of north-central Victoria. Information from a simulation model was combined with a benefit-cost analysis to estimate the benefits from the control of salinity and changes in land-use practices. At a regional level, the introduction of profit-maximising land-use systems would provide net social benefits of up to $2.3 million per annum. Using dynamic modelling, Dalziell and Poulter (1992) estimated the costs to landholders of curbing soil acidity through the application of lime in the Wagga Wagga district of NSW. It was found that it is profitable to lime soils so that productivity does not fall below a certain level, with a difference of $125/ha in the discounted value of gross margins between a pH of 4.2 and 5.2.

The Collaborative Soil Conservation Study appears to provide the only estimate of costs of restoration for more than one degradation type, with all other studies concentrating on one particular form of land degradation either at the regional or farm level. Cost of restoration estimates can only provide information on the economic importance of land degradation that has already occurred, so therefore have limited use in terms of future land-use decisions. Estimates of conservation works required to avoid land degradation provide a more dynamic and forward-looking approach to the economic measurement of land degradation (Sinden, Sutas and Yapp 1990).

1.4 Investment in management programs for land degradation

Private and government expenditure on Landcare grants for four kinds of conservation in NSW, Queensland and Victoria are summarised in Table 1.5. The distribution of private expenditure across degradation types is remarkably constant within States, yet the distribution of Landcare grants varies widely across degradation types and within States. In an *ex post* context, the following general questions must be asked. Have funds been spent in the right places and in the right ways? Should resources be allocated to areas with the worst erosion potential or would greater returns be obtained from these same resources if allocated to areas which are less prone to erosion?

There appears to be conflicting opinion on whether land-conserving management practices are actually profitable, particularly in the short term. Some branches of the

Table 1.5

Expenditure on land degradation control in 1991-92 for NSW, Victoria and Queensland

	Private expenditure[a] (%)				Landcare grants[b] (%)			
State	Weed growth	Water erosion	Salinity/ waterlogging	Tree establishment	Weed growth	Water erosion	Salinity/ waterlogging	Tree establishment
New South Wales	39.0	40.0	39.0	39.2	67.0	61.0	64.0	94.0
Queensland	26.6	25.7	26.5	26.6	33.0	27.0	0.0	0.0
Victoria	34.4	34.3	34.5	34.2	0.0	12.0	36.0	6.0
Total expenditure	$27.9m	$30.3m	$8.7m	$12.0m	$0.07m	$0.3m	$0.1m	$0.3m

[a] Nelson and Mues (1993).

[b] Department of Primary Industries and Energy (1993).

environment literature have an entrenched opinion that conservation practices are intrinsically unprofitable (Cary, Barr and Wilkinson 1993). Research by Walpole *et al.* (1996) concluded that there are many profitable opportunities for investment in soil conservation in NSW, but highlighted the need for careful assessment of potential costs and benefits prior to any individual or agency investing in particular projects. A number of Canadian studies cited by Fox and Dickson (1988) indicate that landholders may be financially worse off in the short and long term through the adoption of particular soil conservation techniques. While these results may not be applicable to Australian conditions, it highlights the need for adequate economic information to guide the allocation of scarce resources to various soil-conservation projects. Yapp and Sinden's (1992) review of land-conservation projects revealed that capital has not always been used to its greatest effect. Hyberg, Graham and Thorne (1993) highlighted the need for economic information to identify the types of land quality and land degradation most costly in terms of lost agricultural output and offsite effects, as well as the regions most seriously affected.

Davidson (1991) and Uren (1992) argue that farmers care about their future income and prosperity and that this will encourage them to manage their land appropriately. However, some argue that the stewardship ethic may not always be strong enough, particularly in times of economic hardship, where short-term survival will over-rule other long-term management priorities. Continual increases in Landcare membership during eastern Australia's recent drought contradicts this argument to some degree. Sinden and King (1990) maintain that despite all good intentions, the ultimate key in resolving a land-management problem will be economics. Cary *et al.* (1993) support this and suggest that the basic need for a simple, profitable system will often outweigh positive environmental beliefs.

The benefits from undertaking land-management practices are often hard to discern, particularly in the short term, and may not necessarily be reflected in direct economic terms. Bojö (1991) argues that physical estimates of a land degradation problem must be converted into units comparable with the cost of soil conservation to be of value to decision-makers. Musgrave and Pearse (1985) view the likely result of soil-conservation measures as being a decrease in current net income, and an increase in future net income and land values. Fletcher and Seitz (1986) highlight the lack of information available to the individual farmer regarding the costs of soil erosion and the benefits that might accrue from conservation investment, thus any remedial action taken will have inherent financial risks to the landholder (Quiggin 1987).

McDonald and Hundloe (1993) suggest that the land degradation that presently exists runs counter to the argument that all farmers are good conservationists. For the stewardship ethic to hold true, it must be assumed that (a) the better farmers treat their soil, the higher their income; (b) that farmers are willing to forgo short-term income for long-term stability, and (c) that farmers know for certain how present agronomic practices will affect their soils in the distant future (Roberts 1995). Subtle loss of soil and subsequent income loss is not easily detectible by landholders, and may be masked by fertiliser use. McDonald and Hundloe (1993) argue that markets are failing to give landholders the correct signals because of the gradual effect of land degradation.

Land degradation is a serious environmental problem that is having a significant impact on Australian agriculture in both physical and economic terms. However, opinions differ on the way incentives must be provided to farmers to invest in conservation. One line of reasoning (McDonald and Hundloe 1993; Davidson 1991; Epps and Crittenden 1992; Musgrave and Pearse 1985) maintains that short-term profitability is an essential proviso of investment. Sonter (1991) suggests that land management must be based on long-term capability rather than short-term economic gains. Given the financial constraints facing the majority of landholders at present, such as deregulation, relatively high inflation, fluctuating agricultural commodity prices, extremes in interest rates and a rapid appreciation of farmland values (Emery 1991), the latter viewpoint may be ideal, but not realistic. In setting out the principles for a national soil-conservation strategy, Cocks (1992) notes that while the cost to repair badly eroded soil may be prohibitive, landholders may be able to live with the expense of a slightly higher annual soil-protection cost while maintaining a profitable farming system.

1.5 Rationale for the research

Land degradation is a major problem in Australia, both in physical and economic terms. The causes of land degradation appear to be well understood, as are the management practices required to prevent or repair the problem (Roberts 1992, Conacher and Conacher 1995, McTanish and Boughton 1993). However, there appears to be conflicting opinion on whether land-conserving management practices are actually profitable, with little economic information available to guide investment decisions.

Concern about the current state of Australia's agricultural resource base has led to the development of policies and strategies that encourage more sustainable agricultural systems. Current Commonwealth and State policies and programs of this nature are outlined by the Prime Minister's Science and Engineering Council (1995). Sustainable agriculture is the use of farming practices and systems that maintain or enhance the economic viability of agricultural production, the natural resource base and other ecosystems that are influenced by agricultural activity (Standing Committee on Agriculture 1991). This definition is supported by principles that include the following.

(a) Farm productivity should be sustained or enhanced over the long term.
(b) Adverse impacts on the natural resource base of agriculture and associated ecosystems should be ameliorated minimised or avoided.
(c) The net social benefit from agriculture should be maximised.

By incorporating these principles into agricultural land-use policy, the importance of an integrated framework of management including economic, social and environmental factors becomes apparent (Ecologically Sustainable Development [ESD] Working Group 1991; Standing Committee on Agriculture [SCA] 1991). Agricultural land management undertaken within ESD philosophies requires a knowledge of the land-degradation process, the current status of land resources and the relationship between current management decisions and future levels of land degradation (Gretton and Salma 1996).

There is clearly a high degree of complexity in the type of information that must be analysed and understood. Agricultural landscapes are highly modified and simplified systems due to the tendency for agricultural practices to clear native vegetation, adopt monocultures, and replace naturally-occurring fauna with domesticated animals. However, most agricultural systems maintain some degree of structural and dynamic complexity, arising primarily from the interaction between socio-economic and ecological processes (Conway 1987). The effects of land degradation can be interpreted in relation to the relevant factors associated with its causes, how impacts of land degradation are measured, and how this information is represented and at what scale. These factors are outlined below for bio-physical, economic and social attributes, and the links between them developed.

1.5.1 The different factors

The direct causes of land degradation in agriculture associated with land-use factors are usually related to soil characteristics, topography, climate, hydrology and other bio-physical elements of the environment. In bio-physical terms, the impacts of land degradation may be measured as changes in resource quality, area of impact and degree of severity or hazard potential. The presentation of bio-physical information may take the form of maps, Geographic Information System (GIS) output or tabulated ground-survey data, and may be at a variety of scales.

Economic information relating to land degradation is usually associated with changes in agricultural production. The economic impact of land degradation is usually measured in terms of losses in agricultural output or changes in land value. The cost of repairing land degradation is an alternative way of measuring the impacts. When economic information relating to land degradation is presented, it tends to be in a form that corresponds to economic management units such as a paddock, farm or statistical local area rather than bio-physical management units such as catchments.

Social factors that have an influence on land degradation may be related to the individual landholder or the community as a whole. Relevant causal factors relating to the landholder include age and education levels and membership of a landcare group. These factors will influence the type of management decisions that the landholder makes, and will ultimately influence land-degradation levels to some degree. At the community level, peer pressure from groups such as Landcare may have an influence on how a landholder manages his or her land, and the community may ultimately benefit from these management decisions. These factors are difficult to quantify and represent in terms of specific levels of land degradation that may occur as a result of these management decisions, but are closely related to the bio-physical and economic factors.

1.5.2 The need for links between factors

Clearly there are links between the bio-physical and economic interpretation of the impacts from land degradation at each scale. For example, a physical impact of loss in crop yield can also be represented as a dollar value. Predicted degradation hazard levels can also be interpreted as future loss of agricultural output. Estimates of costs of soil conservation can be linked to particular bio-physical factors. Other factors, such as the presence of key macro or microfauna elements in the soil profile, representing levels of soil health, are more difficult to link to an economic value. However, their benefits can be viewed as a sustainability indicator making up one component of a group of soil quality factors.

Land degradation is a major physical and economic problem in the Australian agricultural environment and moves are being made towards developing more sustainable land-use systems. Despite this, policy and management decisions continue to be made without the guidance of prescriptive information regarding the profitability of particular land-management programs and associated bio-physical factors. The results and information also need to be available in a form that is easy to interpret and understand by policy makers and landholders alike. A method of analysis also needs to be developed that can be applied at various levels of management, thus allowing the results to be compared at different scales and between areas.

1.6 Aims and objectives of the thesis

The broad aim of this study is to develop a method to enhance management decisions in relation to land degradation, based on the integration of bio-physical and economic information, at the regional, farm and paddock level. More specifically, the objectives of the thesis are:

(a) to develop a general procedure for estimating cost and benefit data to treat land degradation at the regional, farm and paddock level;
(b) to estimate net returns from treatment of a specific degradation problem at these different levels;
(c) to develop a general procedure to extrapolate and depict economic information beyond normal economic boundaries on the basis of bio-physical and management attributes; and
(d) to assess economic priorities for management programs and policies at these different levels.

1.7 Thesis outline

The remainder of the thesis is organised as follows. Chapter 2 examines the policy responses to land degradation, issues related to sustainability, and the role of information and Geographic Information Systems in improving land-management decisions. The economic nature of land degradation is explored in Chapter 3, with an economic framework for decisions being developed, and examination of how the economic impacts of land degradation can be measured at the community and farm level. The method is outlined in Chapter 4, consisting of specification of a production function , estimation of benefits and costs, prediction of benefit-cost ratios and analysis at different scales. Chapters 6, 7 and 8 presents the results of analysis at the regional, farm and paddock scales, respectively. Overall discussion and conclusions of the study are presented in Chapter 9. Publications arising from research work that was undertaken during the candidature of the degree are listed in Appendix 1.

2. Responses to Land Degradation

2.1 Introduction

The range of land degradation types and their impact on the environment, individuals and society means that a variety of responses to management of the problem are required. This chapter reviews policy responses to land degradation, and the success of policies to manage land degradation. Issues relating to land degradation and sustainability are considered, and the type of information required for effective land degradation management is explored. Finally, the role of geographic information systems in land management decisions is examined.

2.2 Policy responses to land degradation

Governments respond to the problem of land degradation by using a variety of policy instruments. Examples include direct funding of preventative or remedial works (direct subsidies), provision of incentives for private action (tax rebates or concessions), provision of information (research, extension services and public education), regulation of land use or land-management practices (clearing of steep land), and policies to 'correct' the 'market signals' to which landholders respond (water pricing). Kirby and Blyth (1987), McDonald and Hundloe (1993), Dovers (1995), Martin and Woodhill (1995) and Edwards, Dumsday and Chisholm (1996a, 1996b) review the range of Australian policies. The policy tools available to government to influence land-use practices are summarised in Table 2.1.

Table 2.1

The range of policy tools available to achieve sustainable land use

Policy tool	*Application to land degradation*
Provision of information	Research into better management practices Extension services Farm planning services
Moral suasion	Publicity campaigns Calls for a land ethic
Government influences	Taxation concessions for conservation works Direct grants for conservation activities Influences on the prices for inputs and outputs
Direct controls	Tree-clearing regulations Control over production methods Subdivision and land use zoning Land tenure conditions on public leasehold lands
Government planning	Co-ordination of land and water agencies Regional catchment management Management of public lands Purchase of degraded lands
Government expenditures	Public works to prevent and rehabilitate degraded land
Legal remedies	Court action for nuisance and offsite damages Establishing property rights

Source: McDonald and Hundloe (1993, p. 362)

2.2.1 Government responses

Land management has traditionally been the responsibility of the States, with each state having legislation pertaining to the management of land degradation. Since 1983 governments have given increased attention to land degradation issues. The focus on particular issues and the balance of policy instruments has also changed in this period. The key stimulus to these changes was the advent of the National Soil Conservation Program (NSCP). This signified the entry of the Federal Government as a major funder of public soil conservation programs -- previously the preserve of State government. From small beginnings ($600 000 in 1983-84) the NSCP became increasingly influential, particularly over the nature and delivery of soil conservation programs. Perhaps the most dramatic of these changes is reflected in the NSCPs key role in facilitating local Landcare groups. In New South Wales, in particular, this involved a major shift toward greater participation of landholders and other community groups in defining their needs and designing participatory programs to address those needs. However, a mixture of policies remains in place. For example, Section 75D of the *Income Tax Assessment Act 1936* provides tax deductions for capital expenditure on farm improvements which treat land degradation. In addition, Section 75B allows accelerated deduction of capital expenditure on plant, structural improvements, or on extensions of existing plant, for conserving water (Petersen 1996).

The growth of the Landcare movement in Australia has enabled individual landholders to take a more active role in initiating land-management programs to prevent and repair land degradation. This trend is encouraged by a heightened community awareness of the problem, and the increased availability of funding from both State and Federal sources. Landcare groups are generally formed at the sub-catchment level, and attempt to deal with land degradation issues affecting their particular area. The key to this participatory process is that it works from the bottom-up, with Landcare groups exerting significant control over the initiation and direction of land-management programs they wish to undertake. The NSCP has now been replaced by the National Landcare Program (NLP). The Federal Government administers the NLP and the Land and Water Resources Research and Development Program under the *Natural Resources Management (Financial Assistance) Act 1992.*

State land-management agencies attempt to reduce land degradation through the provision of information and programs of incentives including advice, technical assistance, concessional credit and subsidised inputs. The agencies appear reluctant to use regulation, despite the fact that there is potential for substantial intervention in some cases. Bradsen (1987, 1988) argued that since Australian agencies adopted the US approach to soil conservation there has been little historical evidence to illustrate its effectiveness. Bradsen felt that enforcement should be the last resort, while Schapper (1990) insisted that rehabilitation and conservation should be an enforceable legal responsibility of landholders, because land misuse is a public issue.

Management of land degradation at the catchment or watershed level has also received greater attention in the past decade, with the recognition that catchment boundaries provide a useful natural-resource management unit. The concept of Total Catchment Management (TCM) aims to provide a coordinated approach of natural-resource management for both individuals, community groups and management bodies at the catchment level. Catchment management may also provide an important role in dealing with issues that are too large for an individual landcare group to address. In the context of soil and water conservation, Hurni (1995) argued that the catchment management approach is not necessary in all cases, with each issue requiring individual examination, with an appropriate unit of management then being defined.

2.2.2 *Individual responses*

Individual landholders make decisions at the farm and site-specific level in relation to the management of land degradation. The adoption of conservation practices are made in relation to many other farm-management priorities including; how much land to use for agricultural production, choosing a balance between enterprises and the methods of production (Edwards *et al.* 1996a). However, surveys by ABARE (Nelson and Mues 1993; Mues, Roper and Ockerby 1994) indicate that despite the financial difficulties facing many farmers at present they are still prepared to make private investments for conservation. Many farmers still lack basic information regarding existing and potential levels of degradation, and the likely effect on production and the potential benefits associated with treating or preventing the problem. However, society may view that it is in their best interest that a thorough assessment of the problem be made in order that the optimal solution be reached, whether it be in the interests of the individual farmer or not.

At the paddock level, management decisions are generally made on the basis of the land use undertaken. The occurrence of a particular land-degradation problem within a paddock may bring about the adoption of certain management practices which complement the current land use. For example, particular cultivation practices may be employed to lessen the risk of soil erosion. Bio-physical and seasonal variations must also be taken into consideration in the land-use decision-making process.

2.2.3 Has policy succeeded?

Levels of land degradation in Australia continue to be of concern (Epps and Crittenden 1992), despite increased recognition of the problem and perceived improvements in management. However, Davidson (1989, 1991) remains optimistic about Australia's ability to continue to increase agricultural output, despite the present levels of land degradation, due to technological advancements. Uren (1992) criticises the land-degradation debate as being disproportionate to the actual land-degradation problem. Chisholm (1990, 1992) also questions the seriousness of the land degradation problem, highlighting increases in agricultural output in the past 30 years. However, in more recent work (Chisholm 1994, Chisholm and Hone 1996), there is recognition that the decline in the natural resource base over time is a cause for concern for the broadacre agriculture sector.

Much of the seriousness of land degradation derives from how it is perceived. According to Edwards (1988, p. 136) 'erosion becomes apparent to the untrained eye at average annual rates of approximately 30 t/ha/year'. Conacher and Conacher (1995) suggest that despite the causes of land degradation appearing to be self-evident, the continued mis-use of rural land in Australia relates to people's attitude and perception of the environment. Public perception appears to be very important in dictating how a government will react to a particular environmental problem. For example, salinity is perceived by many at present as being a serious threat to agricultural productivity and has received a significant amount of attention. This is certainly true for some areas. However, soil erosion, soil acidity and soil structure decline are far more widespread in their impact, and are costing more in terms of lost agricultural output (Eckersley 1989; Walpole *et al.* 1992, 1996).

Critics of land use in Australia argue that past policies have been insufficient, and current policies remain insufficient, to combat degradation. Bradsen (1987), for example, argues that community awareness and support, together with government awareness, education and extension programs, will never achieve wise land use. Bradsen claims that as long as conservation is optional, natural resources will continue to be degraded. Epps and Crittenden (1992) also document the continuing community concern about the productivity of agricultural land. Greater emphasis, they say, must now be placed on the user-pays approach to conservation. Schapper (1990) goes even further to argue that ownership of land be conditional on maintaining the capacity of the soil to renew its fertility, and the capacity of the vegetation to regenerate. Campbell (1992, 1994) suggests that land-conservation activities have been directed towards rehabilitation rather than prevention, due to the present emphasis on policy that deals with land degradation rather than sustainability.

Indicators to measure policy success, or even to record land-management activity, are difficult to define, compile and apply. For example, improved economic welfare is an obvious indicator, and trends in agricultural output are a partial measure of this. According to Chisholm (1992) farm output in Australia has increased two and a half times over the last four decades. The NSW 1987-88 Land Degradation Survey (Soil Conservation Service of NSW 1989; Graham 1989, 1992) indicated that 25 percent of New South Wales was affected by moderate to very severe levels of wind erosion, 11.9 percent of the State was affected by moderate to extreme levels of gully erosion, and 18.3 percent of the State had moderate to severe levels of soil structure decline. So has degradation had an insignificant effect or has its effect been masked by improved practices or improved technology?

Around 30 percent of Australian broadacre farmers are now Landcare group members (Prime Minister's Science and Engineering Council 1995), indicating the willingness of many landholders to attempt to combat land-degradation problems. However, a critical point in the process has been reached by many Landcare groups who have gone through the recognition and planning stage and now require significant levels of funding to undertake specific conservation programs, which are far beyond the resources available from State and Federal sources.

The issue of tree planting remains very contentious. The wider community perceives tree planting as a very positive means of combating land degradation, with this perception being supported by Federal Government initiatives such as the One Billion Trees Program. Eckersley (1989) argues that a program of reafforestation will help to halt and reverse land degradation; however, Edwards (1990) and Barr and Cary (1992) question the rationale of such a simple prescription of management for what is a complex problem. Davidson (1991) is also critical of legislation in South Australia and Victoria prohibiting further land clearing, and of projects to plant large numbers of trees, arguing that these decisions were made without any assessment of the benefits and costs.

Whether land degradation is treated at an on-farm or off-farm level is also an issue for debate in resource management, that is who should pay for past management practices — farmers were guided by certain past policies such as land clearance tax incentives, drought subsidies, and water pricing, so can not be held entirely to blame for their actions. The growth of the Landcare movement. the information available to farmers, and the level of financial support provided by the state and federal governments, suggests that there is less excuse for farmers to misuse their land. In 1992-93 up to half of Australian broadacre farmers made expenditure eligible to be claimed under Sections 75B or 75D of the Income Tax Assessment Act 1936, spending on average $4828 each on a range of land conservation activities (Mues *et al.* 1994). Edwards *et al.* (1996b) note the bias in these deductions towards structural, rather than preventative works.

2.3 Sustainability and land degradation

Land managers must view utilisation of soil resources in terms of both present and future generations through the maintenance of natural capital. Soil, as a conditionally renewable resource, can be renewed following removal. According to Young (1992), conditionally renewable resources have the following functions:

(a) to produce assets that can be harvested and consumed by man;
(b) assimilate waste from human and other activity and provide a host of environmental services that are essential for the maintenance of environmental integrity; and
(c) provide a wide array of amenity, historical and cultural values.

These resources are 'conditional' because they are renewable if certain management conditions are met. The maintenance of the stock of natural capital and per-capita wealth depends on investment in the form of technological improvements, rehabilitation, reclamation and improved human capital (Young 1993). This notion, known as the 'Hartwick-Solow rule', was originally put forward by Solow (1974, 1986, 1993) and Hartwick (1977, 1978) in relation to non-renewable resources. A requirement of this rule is that each generation must reinvest the economic rent embodied in a non-renewable resource, but Young (1993) suggests that this concept may also be applied to conditionally renewable resources such as soil. However, the concept has been criticised by Barbier (1993) and Randall (1994) as not being applicable to real world situations and as being tautological. More recent economic theories have stressed the limits to substitution between many forms of natural and man-made capital (Randall 1994, Norton 1995).

Any offset in per-capita wealth due to these types of investments must be balanced by increases in production opportunities from various forms of natural capital, so that the present generation is not made worse off by guaranteeing the welfare of future generations. In the example of the prevention or restoration of soil degradation this issue is particularly relevant, given the present financial constraints of many agricultural landholders and the marginal condition of some land presently in production. Society as a whole will generally benefit from onsite amelioration of land degradation, so it must be prepared to contribute towards the investments required to maintain this particular resource, particularly in the more productive areas.

Ideally, an assessment of the impacts of land degradation on both present and future generations will be an incorporation of both bio-physical and economic factors. Issues relating to the appropriate choice of discount rate, the economic instrument to be used (eg valuation methodologies), property rights and the use of conventional markets must be carefully addressed when dealing with decisions relating to inter-generational equity.

The representation and measurement of land quality according to spatial distribution and temporal changes is also important (Fresco and Kroonenberg 1992). Incorporating both these factors and scale, Lefroy, Salerian and Hobbs (1993) have developed a means of examining agricultural systems as a series of levels in a hierarchy (Table 2.2).

This table highlights the inherent difficulties of trying to integrate values and constraints that apply at different levels. Lefroy *et al.* (1993) argue that prior to their study, farm planning models had almost exclusively considered the economic features of altered management, and had no systematic way of accounting for ecological parameters. They imply that only with the full integration of ecological, economic and social values can truly sustainable agriculture exist. Johnson, Cramb and McAlpine (1994) and Johnson and Cramb (1996) also argue for systems that include socio-economic variables in addition to bio-physical elements. Moxey, White, Sanderson, and Rushton (1995) suggest that the potential to identify management prescriptions necessary to induce an ecological change will only be of use if they are integrated with economic models that identify the associated financial incentives to farmers.

Table 2.2

A hierarchy of agricultural systems[a]

Level	Constraint	Goal	Time scale
Regional/national	Macroeconomic	Domestic food supply, generation of export income, support of rural population	Determined by planning horizon of politics and economics
Landscape	Ecological	Maintenance of the life-supporting capacity of unit	Considerably longer than units of several human generations
Farm	Micro-economic	Business survival	Several generations
Paddock	Agronomic	Crop productivity	Several seasons

[a]Adapted from Lefroy *et al.* (1993).

Recognising the differences between mainstream neoclassical economic paradigms and emerging ecological economic theory in relation to the valuation of natural resources over time, Norton (1995) proposes a means of analysis that combines current economic reasoning with other sources of information. This two-tier or hybrid approach to environmental decision-making makes distinctions in relation to a 'decision space' on the basis of irreversibility and risk. In areas of the decision space where there are likely to be major negative outcomes, moral structures are applied. In areas where reversibility is high, economic models are accepted as a means for analysis. Norton (1995) argues that mainstream economists recognise that changes in ecosystem-level functioning may have an impact on welfare, and are prepared to devise methods and means to describe and quantify this connection.

Any type of land use revolves around a process of decision-making, whereby bio-physical, social and economic factors are taken into consideration. The level of emphasis on these factors may vary according to the ultimate goal of the land use. Land evaluation assesses the requirements of a particular land use against land qualities and characteristics, and then relates the performance or output of the land to these assessments (van de Graaff 1988). The level of degradation hazard likely to be generated from a particular land use, and the amount of management needed to keep hazards to 'acceptable' levels must also be identified.

The concept of sustainability in relation to land evaluation attempts to provide a more holistic approach to land-use planning, such as the lengthening of the time frame upon which land-use planning decisions are made. However, the concept is more difficult to define. Pickup and Stafford-Smith (1993) define a sustainable management system, which, given a defined set of climatic and economic conditions, is able to produce the same amount of output over a particular time frame, without having changed the system's ability to produce in the future. Lefroy *et al.* (1993) claim that sustainable agriculture will truly exist only by fully integrating ecological, economic and social values, while Reid (1992) suggests that land use that does not accelerate erosion can be considered sustainable.

The theme of land quality is inherent in all of these concepts, with the need to maintain or improve land quality clearly important in the process of land-use planning for sustainable development. Land quality is a complex attribute that acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use (Food and Agriculture Organisation [FAO] 1983). The process of defining specific land qualities, such as levels of particular land-degradation types or their potential hazard, will assist in the development of land-management tools aimed at reducing the risks involved in making particular land-use decisions. Effective land management, according to defined aims such as maximising production or of conservation, is only possible with the knowledge of the state of the land qualities and the demands of land-utilisation types (Burrough 1989).

2.4 Information to improve land management decisions

The type of information required to make effective land-use decisions for land-degradation management is dependent on the scale of the problem being dealt with. The type of data provided and its usefulness to the end user clearly depends upon who this will be. Also the need for information at differing scales and how temporal and spatial information are dealt with are important issues. The integration of ecological and economic values and the level of balance achieved between these management objectives in an agricultural system must also be explored. Many of these problems arise due to inconsistencies in the way information is defined, collected, analysed and presented.

2.4.1 Usefulness to the end users

The ultimate aim of land management is to provide useful information to a particular end-user to aid them in making improved decisions. The goals and aspirations of the end user may vary according to his or her particular situation. In some cases the end user may be happy to make decisions independent of any outside sources. Stocking (1993) argues that in some cases, due to a lack of time and resources, an all-embracing thorough study of natural resources may not be appropriate. Chambers (1983) introduces the concept of Rapid Rural Appraisal whereby models are used that are more simple and flexible using proxy measures and variables that subsume many more complicated functions, and questions the view that measurement in science is completely objective and unbiased. This study implies that rapid, simple measurements may be more appropriate and take into account local knowledge. Mellerowicz, Rees, Chow and Ghanem (1994) argue that more informed decision-making in agricultural land management is possible regardless of the degree of completeness of individual data, as long as the relevant information available is compiled, analysed and presented in a format that end users can utilise. Kessell (1990, p. 356) states that

> results of research are frequently presented in a form that is not interpretable by managers. Instead of being incorporated into the decision-making process, research results are seen as novel curiosities of academic interest but quite useless to managers.

Johnson, Cramb and McAlpine (1994) suggest that societal goals will not necessarily be met in the absence of adequate data relating to bio-physical and economic factors that influence resource use.

The case for a rapid appraisal approach has merits in examples where some information is better than none. Basic information regarding existing and potential levels of degradation, and the likely effect on production and the potential benefits associated with treating or preventing the problem is still lacking. However, it may be in the best interest of society that a thorough assessment of the problem be made in order that the optimal solution be reached, whether it be in the interests of the individual farmer or not.

2.4.2 Scale

When collecting information required for land-use decisions, it must be taken into account that there will be significant variation in type, scale, depth of knowledge and information, and variations in space and time (Lowes and Bellamy 1994).

Scale is clearly an important issue. Land-use decisions will be made at the various scales of management, with governments and agencies making broad policy decisions, while landcare groups and individual landholders would make more specific management decisions. Therefore, there appears to be a case for developing a hierarchy of information at different scales, and Burrough (1989) argues that data should only be used to support decisions at the level for which they were collected. Pickup and Stafford-Smith (1993) argue that practical implementation of land use policy decisions must be made at the individual land management unit, such as the property or even paddock level, in order to determine the best combination of sustainable land uses. Alternatively, Rossiter (1990) sees a place for land-use planning at the national, regional, local and farm level.

2.5 Land management and geographic information systems

2.5.1 What is a geographic information system?

Geographic information systems (GIS) are useful tools for the collection, organisation, management and visualisation of large volumes of spatially referenced data (Burrough 1986, 1989), that is, data that are described in terms of their geographic location (Turner 1994). Burrough (1986) explains that a general formulation of a GIS envisages space as being covered by a cartesian coordinate system, with each separate attribute of space being described by a separate overlay. GIS allows for a vast amount of information on different themes and from different sources to be integrated and displayed in a format that end users can utilise (Mellerowicz *et al.* 1994). It therefore provides a framework for people's recognition skills to supplement sophisticated quantitative methods in the evaluation of various land-management options (Brown, Schreier, Thompson, and Vertinsky 1994).

2.5.2 *What can a GIS do?*

According to Johnson (1990), one of the most powerful operations a GIS can perform is the overlay of spatially-distributed data, eliminating what was a tedious and time-consuming manual operation. Geographic information systems can be used to:

(a) analyse temporal change;
(b) determine the spatial coincidence of physical and biological features;
(c) determine spatial characteristics;
(d) analyse the direction and magnitude of changes;
(e) produce graphic output; and
(f) interface with simulation models to generate new spatial data (Johnson 1990).

2.5.3 *Applications of GIS to land management*

GIS clearly has great potential as a powerful tool to assist in land-management decisions. Examples of applications are becoming more prevalent as software applications become more user-friendly and are more feasible for personal computers. Pure resource-management applications are, understandably, quite varied. For example, GIS has been used by Kessell (1990) as a decision support system for fire-prone rural land, providing capabilities for estimating and recording patterns of vegetation and fuel dynamics, analysing the behaviour of fire and its environmental effects, and reviewing strategies for fire control and related issues. Pressey and Ferrier (1994) used GIS as part of an interactive system to determine irreplaceability levels of pastoral holdings for conservation planning purposes, where irreplaceability is defined as the potential contribution of any site for reservation purposes.

Applications specifically relating to land degradation/soil erosion management include Turner and Ruffio (1993), who used GIS to identify agricultural land requiring improved management for non-point source pollution, and Hession and Shanholtz (1988), who estimated potential sediment loading to streams from agricultural land by developing a GIS for use with the Universal Soil Loss Equation (USLE). Best and Westin (1987) demonstrated the operational use of a GIS for the identification and management of cultivated sites susceptible to land degradation, while GIS was used by Hamlett, Miller, Day, Peterson, Baumer, and Russo (1992) to identify and rank pollution source areas on a regional (catchment) basis. GIS was used by Mellerowicz *et al.* (1994) to aid in soil and water conservation planning at the catchment level by integrating information on soils, climate and land use. Logan, Urban, Adams, and Yaksich (1987) evaluated different management scenarios for reducing soil loss using a Land Resources Information System GIS.

There have been a number of GIS applications to resource management that have gone beyond purely physical estimates such as erosion hazard and sediment loading, by incorporating some form of economic indicators in their estimates of land suitability. Lowes and Bellamy (1994) have incorporated a GIS of land units and property infrastructure with a knowledge-based system of management and ecological knowledge, a database system, and scientific and economic models to develop the Landassess Decision Support System (DSS). Landassess DSS can be applied to alternative management scenarios to assess risks of vegetation change from grazing management and other factors, and evaluate economic consequences (changes in gross margins) of the expected changes in yield and animal production. The Automated Land Evaluation System (Rossiter 1990) provides a computerised application of the FAO framework for land evaluation (FAO 1976), by allowing knowledge-based systems to be built by land evaluators to compute the physical and economic suitability of land map units.

Johnson, Cramb and McAlpine (1994) recognise that objective relationships between bio-physical criteria, crop productivity and management costs are not modelled in existing land-evaluation methodology, and developed a framework to include bio-physical and economic factors in the same assessment. Their economic approach to land evaluation is also outlined in Johnson and Cramb (1991, 1992) and Johnson, Cramb and Wegener (1994).

Moxey (1996) reviewed GIS in the context of agricultural economics and concluded that

> given the spatially extensive, land-based nature of agriculture, and the existence of both environmental and socio-economic networks within the sector, there is an opportunity for agricultural economists to simultaneously exploit the advantages offered by GIS and to draw upon traditional theoretical and empirical modelling strengths (Moxey 1996, p. 116).

Clearly the ability of GIS to handle and manipulate bio-physical and management data at various scales is useful in itself. However, to be able to add economic variables to the GIS as new layers, and thus relate the layers to one another, is invaluable. The representation of the final information in mapped form only adds to this value.

2.5.4 Sources of GIS error

As with all forms of data collection, assimilation and manipulation, there are some common sources of GIS error (Burrough 1986, Goodchild 1988, Openshaw 1989, Campbell, Radke, Gless, and Wirtshafter 1992, Hall and Burgin 1996).

(a) Categorical error is the most common form of error, and is committed during the raw data interpretation stage. Data can be misinterpreted and mistakenly placed in the wrong class.

(b) Temporal error occurs when two or more types of data are being assembled for input to a common information system, but were not collected during a common time period.

(c) Spatial error relates to the positional accuracy of digitised points, lines and polygons central to the outcome of any higher-level spatial analytic manipulation.

Fischer (1991, 1994) and Fisher and Langford (1995) discuss means of testing for and dealing with error in GIS databases.

2.6 Summary

In Chapter 1, land degradation was highlighted as a major environmental and economic problem, which incurs significant costs in lost agricultural output and conservation practices to prevent or repair the damage. Given that there has been recognition of the problem for some time, the effectiveness of past and present management and policy strategies must be questioned.

Despite land management traditionally being the responsibility of the States, Federal government involvement in land-degradation issues has gradually increased over the past decade. Current policy instruments used by government include direct subsidies, tax rebates or concessions, provision of information and regulation. The success of voluntary conservation groups such as Landcare indicates an acknowledgment of the problem by individual landholders and a desire to implement management strategies to prevent and control land degradation. However, there is some suggestion that regulations should be enforced upon those landholders reluctant to undertake rehabilitation and conservation.

A major part of the problem appears to be related to the perception of land degradation in relation to current and future impacts on agricultural productivity and income. Technological improvements and inputs such as fertilisers may have masked the impact of land degradation on output levels. However, it has been argued that there are limits to substitution between natural and man-made capital.

Ideally, an assessment of the impacts of land degradation on present and future generations will incorporate both environmental and economic factors. The type of information requirements and the level of emphasis on these factors may vary according to the ultimate goal of the land use and the scale. The type of data provided and its usefulness to the end user must also be considered. The theme of land quality is inherent in all of these concepts.

Geographic information systems are a useful tool to assist with the information and modelling requirements outlined above. The ability of GIS to handle and manipulate bio-physical and management data at various scales is useful. However, to be able to add economic variables into the GIS as new layers, and thus relate the layers to one another invaluable. The representation of the final information in mapped form only adds to this value.

The nature of land degradation in an economic context will be developed in Chapter 3.

3. The Economic Nature of Land Degradation

3.1 Introduction

An important aspect of the management of land degradation is an understanding of its relationship with current and future levels of agricultural output, as well as its influence on the broader community. In this chapter[2] the nature of land degradation is examined in an economic context. Firstly, land as a factor of production is considered in terms of declining returns and land quality. The measurement of the economic impact of land degradation at the community level is examined in the context of welfare loss, market failure and onsite and offsite implications, and changes in land values. An economic model of soil conservation is then developed at the farm level. Finally, the economic nature of land degradation is put into context in relation to the present study.

3.2 An economic framework for decisions

Land is a traditional input to production, and the influence of both land area and land quality have long been the subject of debate. In Australia the influence of land quality on agricultural output has assumed major proportions due to the extent of land degradation and the concern for land conservation. Land quality is defined by FAO (1976) as a complex attribute of land that acts in a distinct manner in its influence on the function of land for a specific kind of use, based on simpler, directly measurable characteristics of the landscape. For example, erosion hazard is assessed from land attributes that can be measured or estimated.

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[2] The author's contribution to Walpole, Sinden and Yapp (1996) forms the basis for part of this chapter.

3.2.1 Land as a factor of production

The treatment of land as a factor of production has received attention in the literature at least since Malthus and Ricardo dealt with the issue some two centuries ago. While Malthus (1798) was concerned mainly with the total area of land, Ricardo (1817) introduced the effect of differences in the quality of land. Since then the treatment of land quality in agricultural production has been the subject of an expanding literature, particularly in the areas of soil conservation and land degradation. The basic underlying issues may be summarised as three questions. Does the quality of given land decline with use? Does such a decline decrease production, and if so by how much? Is restoration economically beneficial? These issues are, in fact, a restatement of Ricardo's concerns about economic scarcity due to declining returns per hectare as more land and less fertile land is brought into use. The literature has addressed other issues more recently, including the external effects of land use and the reversibility of land-use changes. Land quality concerns all these issues but this chapter focuses on the three basic issues in order to present the general analytical approach.

3.2.2 The debate over declining returns

Land has traditionally been conceived as all those free gifts of nature that yield income (Marshall 1890). In this sense, land has no cost of production and sells at a price only because the output can be sold and rent can be earned. Rents for land differ partly because land quality differs, although quality characteristics recognised in these early writings included distance to market as well as inherent quality and fertility. In this way, debate over land has always rested as much on its quality characteristics as on the quantity of land of given characteristics.

The issue of generally-declining production from land was originally raised by Malthus and Ricardo in terms of population and food. Malthus (1798) contended that if land were homogenous in nature and finite in quantity, output would remain constant until all productive land was in use. Population growth would mean that more pressure would be placed upon the given land area to increase production, hence fertility would decrease and declining returns per hectare would follow. While Malthus may have formally introduced the idea that economic growth is limited by natural-resource scarcity, his failure to acknowledge variations in the quality of agricultural land was a significant omission.

Other omissions included the specification of time horizons, availability of other resources, and improvements in technology and production processes.

Ricardo (1817) recognised that not all land is homogenous, and suggested that declining returns per hectare was a temporary phenomenon because marginal land was being put into use for food production. Technical innovation would offset but not completely eliminate the trends of declining returns. The classical economist John Stuart Mill (1848), for example, recognised the existence of declining production and diminishing returns in agriculture, but felt that future limits to population growth would be countered by technical change. A survey of the literature reveals three versions of this optimistic viewpoint, namely declining returns (a) are just a temporary phenomenon, (b) won't occur soon but may occur at some time in the future, or (c) will never occur. The latter viewpoint rests, primarily, on the belief that technological advance will outstrip declining returns.

The optimistic opinions regarding the contribution of technology are based partly on the observation that land has an increasingly reduced role as an input, while labour and capital have greater and greater influences (Schultz 1953). Barnett and Morse (1963) predicted increasing returns through improved technology and knowledge, and Lewis (1967) also dismissed classical theory in favour of a shift away from the importance of land as a factor of production. However, these arguments have been countered by Barlowe (1986), who concluded that the prospect of declining returns must eventually become a reality, despite increased applications of labour and capital.

The debate continues to oscillate. The limits to growth movement in the early 1970s renewed argument about the availability of land as a restriction to agricultural production (Upton 1976), and caused optimism to falter regarding the ability of technology to maintain output. Turner and Pearce (1993) categorise currently competing viewpoints under the broader context of global environmental change. These are discussed under neo-Malthusian and neo-Ricardian headings, and the authors note that technocentrist views continue to counter the 'limits' debate. Young (1992) feels that, despite pessimistic views that have underestimated the possibilities of technological innovation, there is a limit to the earth's capacity to continue to support a growing population. Conventional faith in the management of technology to nullify resource depletion is being challenged in the sustainable-development debate. Batie (1989), for example, has highlighted the importance of maintenance of the land resource to sustain food production.

According to Upton (1976) and Heady and Dillon (1961), increasing returns from poor land through larger outlays of labour and capital may be more economic than intensifying production on good land. But current indicators are conflicting. For example, African agricultural production, which is greatly influenced by land degradation (Zhao, Hitzhusen and Chern, 1991; Hitzhusen 1993; Bojö 1996), has suffered from declining returns since the early 1970s, with a declining per capita food output of one percent per annum (World Commission on Environment and Development [WCED] 1987). WCED (1987) estimates that 10 million hectares of irrigated agricultural land are being abandoned each year due to degradation. However, on a global scale the increases in crop yields in the last 40 years suggest that land quality has not deteriorated due to soil erosion (Crosson 1993). Furthermore, not all forms of land degradation may be reversible.

While Malthus's theory of population growth has been largely discredited by economists (Edgmand 1979), ecologists still use it to justify their attempts for sustainable resource use (Young 1992). Thampapillai and Anderson (1994) cite cases in developing countries where Malthusian theory is still central to the analysis of the effects of land degradation. The current concern in Australia, with loss of agricultural production due to degradation of the land, also rests on declining returns. But the issues now concern the allocation of resources and the ability of conservation to restore the situation rather than the ability of land to feed a nation.

3.2.3 The influence of land quality on output

Declining returns can occur in several ways. In the Ricardian sense, average output per hectare decreases as land of poorer quality is used (that is, as the quantity and quality of land changes). The average quantity of output per unit of input decreases as the quality of inputs is increased on a given hectare at a given time, and with all other inputs held constant. Also, output for a given hectare may decrease over time as the characteristics of the land change — with all other inputs constant. While all three kinds of change are addressed in the debates on land use, we are concerned with the last concept. This concept has been the basis of economists' attempts to define a concept of soil conservation in the context of resource degradation. Heady (1952 p.782) defines soil conservation over time as the

> prevention of diminution in future production on a given area of soil and from a given input of labour and capital with the technique of production otherwise constant. Thus conservation refers only to the retention of a given production function over time.

In this sense, soil conservation attempts to prevent or reverse declining returns due to degradation.

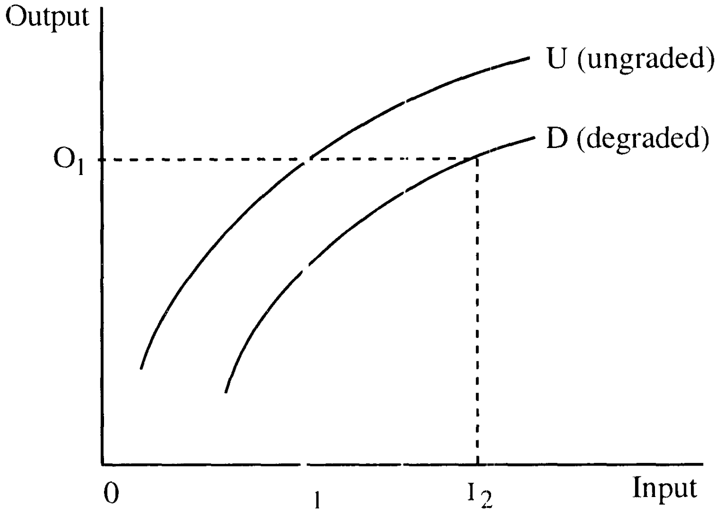
MacCallum (1967) views the economic significance of soil erosion, and soil quality, in terms of soil depletion (where the loss in production can be restored) or deterioration (where the loss in production is permanent). Losses due to soil depletion can be restored by substitution of additional inputs such as fertiliser and by conservation measures (Figure 3.1 (a)). But original levels of output cannot be achieved again if soil deterioration has resulted in permanent damage to the soil matrix, whereby necessary functions such as the provision of an environment for plant roots and micro-organisms, nutrient and water storage no longer exist and cannot be replaced (Figure 3.1 (b)). The original output therefore cannot be restored at any level of investment. MacCallum (1967) suggests that the occurrence of soil depletion and soil deterioration depends partly on soil type, implying that declining returns may not occur in every case of soil erosion. Heady's (1952) definition of soil conservation fits neatly into the production framework of Figure 3.1. Soil conservation ensures the retention of the current 'undegraded' function (U) over time, and prevents the 'fall' to degraded functions (D).

Chisholm and Hone (1996) suggest that estimates of changes in Total Factor Productivity (TFP) may be a useful way to determine the influence of land quality on agricultural output. Total Factor Productivity is a means of expressing the rate of productivity growth, and changes in TFP are an indication of technological change, with any changes in land quality being reflected in the input/output ratio that TFP measures. According to Chisholm and Hone, a sustained upward trend in TFP may be a reflection of one of the following: (a) non-depreciating land stock, (b) land degradation that has little impact on the marginal product of land , or (c) land degradation that is outweighed by continuing technological change. Total Factor Productivity growth may be increased by the presence of land degradation in the short term, however in the longer term TFP growth is likely to be depressed by sustained levels of land degradation that adversely affect the marginal productivity of land (Chisholm and Hone 1996).

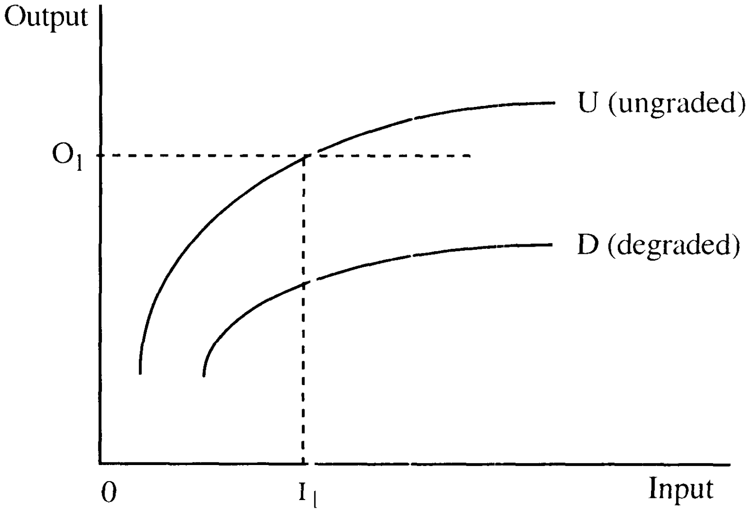
The analysis of the influence of land quality on agricultural output may also be based on a production equivalent, which is the potential production using agricultural land, without

Figure 3.1

Production functions to model the change in output due to change in land quality (following MacCallum 1967)



(a) Depletion (original output O$_1$ can be restored by increasing input from I$_1$ to I$_2$).



(b) Deterioration (original output O$_1$ cannot be restored).

Source: Walpole *et al.* (1996).

degradation, in its current use (Gretton and Salma 1996). This allows the measurement of the incidence of land degradation to be translated into a standard figure such as dollars of production or revenue. Such measures give a clear indication that degradation may reduce the usefulness of some elements of the landscape (Gretton and Salma 1996).

3.3 Measuring economic impacts at the community level

Having developed a framework for understanding land degradation in a production context, it is necessary to quantify the effects at the community level. Community well-being can be examined by determining loss of economic welfare due to changes in production costs. Welfare losses may also be felt because of externalities. This situation can be represented by a net social benefit model, where a divergence in the optimal use of land from a private and social perspective is regarded as a form of market failure caused by individual management decisions that do not take external costs into account. The economic importance of land degradation to the community may also be reflected in land prices.

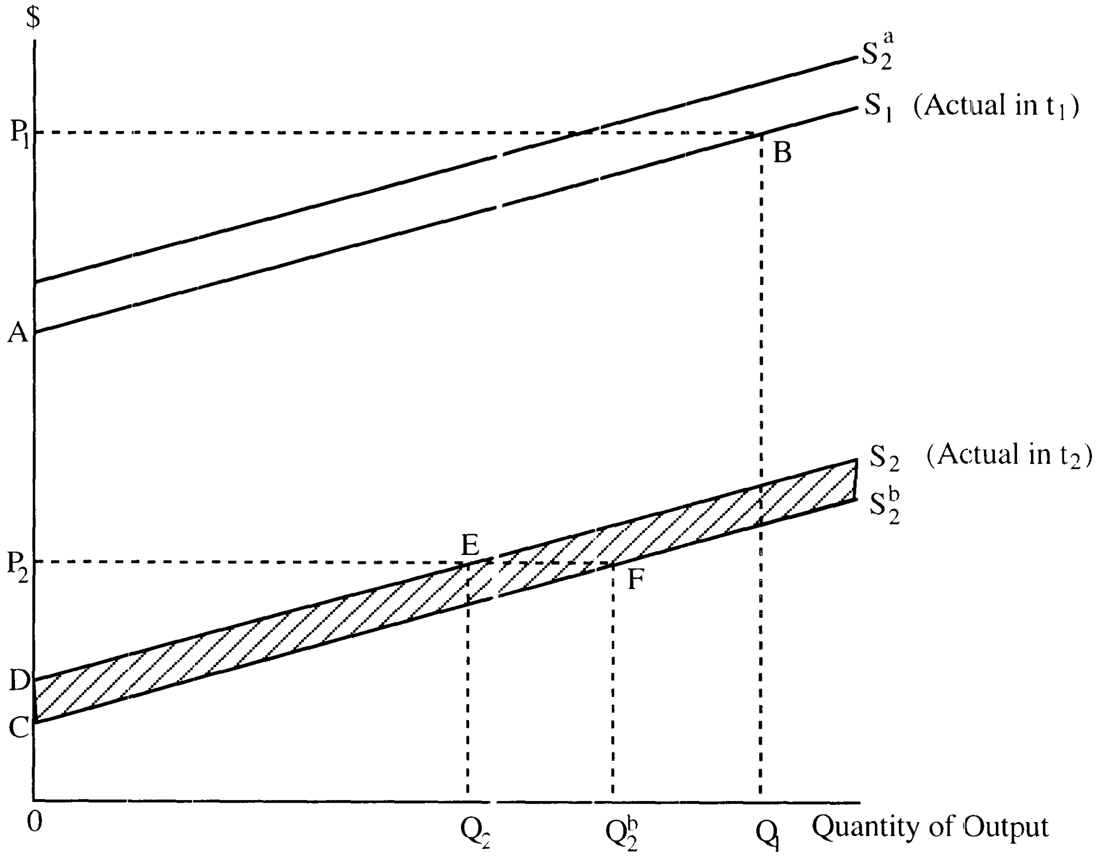
3.3.1 Welfare loss due to land degradation

Changes in agricultural output are caused by several factors even when land area, labour and management are held constant. Following Crosson and Stout (1983), supply curve S_1 in Figure 3.2 implies the actual marginal costs of production in time 1, and S_2 represents the lower actual costs in time 2. The changes between these times include technological advance, and changes in input and activity mix, as well as degradation–induced increases in cost. If there were no technological advance but degradation occurred, the supply curve would have risen from S_1 in time 1 to S_2^a in time 2. If there were no degradation but the actual technological advance occurred, the supply curve would have fallen from S_1 to S_2^b. The effect of degradation is therefore captured as the difference between curve S_2^b (actual technological change and no degradation) and curve S_2 (actual technological change and actual degradation). The loss in economic welfare derives from this difference, which is shaded in the figure.

The welfare loss, for an export product, can be defined as the change in producers' surplus and can be calculated by introducing product prices of P_1 in time 1 and P_2 in time 2. Price P_2 is lower, indicating a decline in real price over the time period. In time 1,

Figure 3.2

Welfare loss due to degradation



actual output is Q_1 and the producers surplus is area A P_1 B. In time 2, actual output is Q_2 and so producers' surplus is D P_2 E. Thus

$$\text{actual change in surplus} \quad = \quad AP_1B - DP_2E \qquad (3.1)$$

In time 2, the potential output without degradation would have been Q_2^b with a potential surplus of CP_2F. Thus

$$\text{potential change in surplus} \quad = \quad AP_1B - CP_2F \qquad (3.2)$$

The welfare loss, or opportunity cost, due to degradation alone is therefore the difference between the actual and potential change.

$$\begin{aligned} \text{Welfare loss} &= (AP_1B - DP_2E) - (AP_1B - CP_2F) \qquad (3.3) \\ &= CP_2F - DP_2E \\ &= \underline{CDEF} \end{aligned}$$

An estimate of this loss requires data on *inter alia*, the shift in quantity Q_2^b to Q_2, and an estimate of this shift requires an analysis of production and the effects of degradation on production.

Shifts in the supply curve described in this section capture the effect of land degradation due to increased production costs and subsequent losses in economic welfare to society. There are many other costs associated with land degradation that society must bear, because of the action of individual landholders. These costs will be examined in the following section.

3.3.2 Welfare loss due to market failure

A classic case of potential market failure, whereby individual decision-making results in inefficient use of resources for the whole community, occurs when decisions have external consequences. The use of land resources for agriculture can generate both onsite and offsite, or internal and external, effects respectively. The rational land user does not take into account the external costs generated by his or her activities, and this causes a divergence between private and socially optimal use of land.

Private costs are defined as those borne by the individual decision-makers. They are frequently identified as onsite costs, resulting from impacts at the source of degradation. Onsite costs include loss in production now and in the future, increase in farm damage and lower farm values.

Social costs include all the costs of degradation regardless of who bears them. Social costs include damage to water courses, roads and other infrastructure, and loss of native vegetation and wildlife (Upstill and Yapp 1988; Sfeir-Younis and Dragun 1993; Conacher and Conacher 1995).

External costs are the difference between private and social costs. These costs are borne by persons other than the individual onsite decision maker. The kinds of costs associated with land degradation are presented in Table 3.1.

Table 3.1

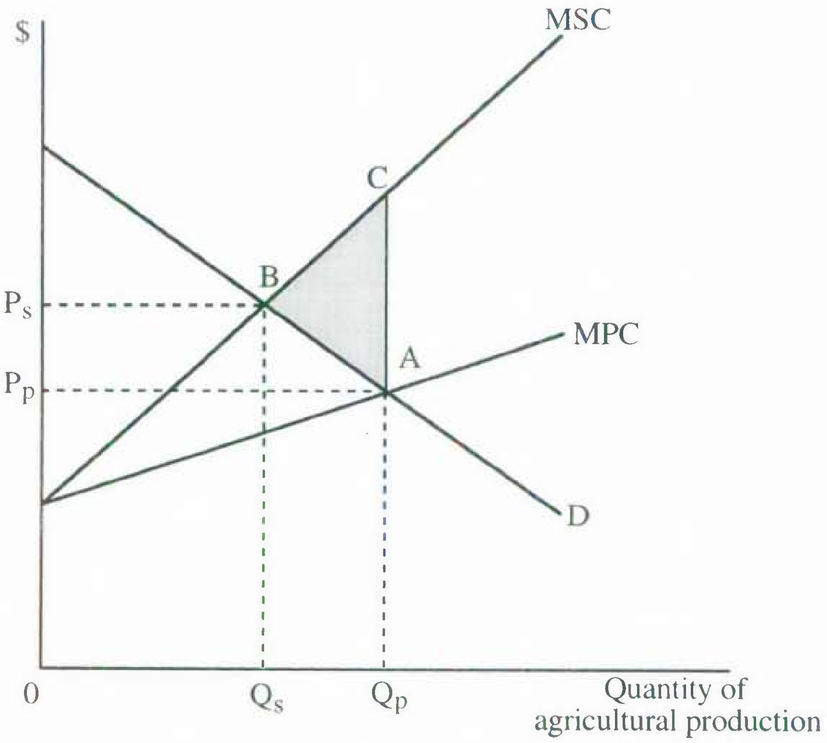
Costs of land degradation

Onsite (internal)	Offsite (external)
Current loss of production	Damage to water courses
Future loss of production	Damage to infrastructure (roads, bridges)
Increased farm damage	Changes to downstream water quality
Lower land value	Lost production on other farms
	Lower land values on other farms
	Changes to aesthetics
	Loss of wildlife and wildlife habitat

The external effects of soil erosion on agricultural activities, in the context of market failure, are illustrated in Figure 3.3. The figure shows the difference between private and social costs for a particular agricultural production activity. The demand curve (D) represents marginal benefits gained from consuming additional units of the product. Marginal private cost (MPC) represents the cost of producing additional units of a particular product, while marginal social cost (MSC) represents the cost to society for additional units of production. The difference between MPC and MSC is the external

Figure 3.3

The optimal quantity of resource use with land degradation



cost due to land degradation, which is assumed to increase slightly with output. If land degradation has no effects on any other individuals' properties, then MPC = MSC. The land user's private decision would then be socially optimal. In this situation, the equilibrium level of production and consumption are at A, with total quantity of output produced Q_P and price P_P.

On the other hand, if production results in soil erosion that generates costs to others beyond the farm boundary, then social costs would exceed private costs since external costs now exist. If landholders do not take into account the external costs generated from their activities, the private and socially optimal levels will diverge. In this case, the equilibrium level is at B, with quantity of output Q_S and price P_S. When an external cost exists, the socially optimal output is lower (Q_S rather than Q_P) and the socially optimal price is higher (P_S rather than P_P). The net welfare loss due to the divergence caused by externalities is the shaded area ABC. These externalities are likely to be an important source of market failure and a cause of excessive land degradation levels in Australia (Kirby and Blyth 1987; Freebairn 1991).

From an economic viewpoint, land degradation is only a problem when the externality is Pareto relevant, that is, when it is possible to modify the action so that some members of society can be made better off without others being made worse off (Kirby and Blyth 1987). This represents a classic case of market failure, whereby individual decision making results in an inefficient use of society's resources, due to the consequences of some action or decision that causes off-site or external damage.

3.3.3 Loss in land values

An examination of the formation and roles of agricultural land values provides a means of determining whether the land market is sensitive to the presence of land degradation, and whether investment in conservation practices are capitalised into land prices. Ervin and Mill (1985) suggest that potential purchasers may underestimate the effect of erosion on future productivity due to the difficulty of perceiving erosion levels, thus the land market is failing to recognise adequately the soil productivity consequences of soil erosion. This may lead to purchasers paying too much for poor land relative to higher quality land, due to not recognising the potential erosivity of the land or the costs necessary to prevent future productivity declines due to erosion (Miranowski and Hammes 1984).

The economic importance of land degradation on agricultural output may be reflected in land prices. A buyer will normally consider the level of land degradation and soil-conservation works on a property in relation to their possible effects on productivity and income. In addition to the quality of the land-resource base, there are likely to be several factors involved in the determination of land values. These include location, institutional and policy factors, as well as personal factors associated with particular purchasers and/or sellers. This highlights the difficulty of isolating the general effects of land degradation in influencing the value of a unit of land. Despite this apparent difficulty, attempts have been made to account for the effects of land degradation on land values.

Using a hedonic-price model, King and Sinden (1988) investigated the relationships between land condition and farm values for the Manilla Shire in NSW to explore whether the benefits of land improvement exceeded the costs. They concluded that land condition was clearly recognised by the market, with better-conserved land selling for higher prices. Land condition influences price in ways additional to expectations of immediate crop yields. These influences reflect expectations of longer-term yields, a desire to obtain and maintain a fully productive soil resource by purchasing better land, and a desire to avoid the unpriced costs of improving land in poor condition (King and Sinden 1988). Further models of the land market incorporating search and bargaining concepts were developed by King and Sinden (1994) in order to improve their original interpretation and understanding of land prices and market operation. They found that buyers valued the presence of soil conservation on the land they were intending to buy more than the sellers.

In an earlier Australian study, Molnar (1955) assessed the effects of land degradation on farm values and found that land prices varied significantly with erosion class, which largely reflected variations in soil fertility.

Other applications of the hedonic-price approach to studying the effects of soil quality and erosion on land values have met with mixed results. Miranowski and Hammes (1984) analysed land values in Iowa based on the hedonic-price approach. They found that prices for land reflected differences in soil characteristics, but were less confident in determining whether the market was discounting the value of farm land enough to account for loss of productive capacity (Miranowski and Hammes 1984). Gardner and Barrows (1985) and Barrows and Gardner (1987) investigated the relationship between investment in soil-conservation practices and land price in south-western Wisconsin. They argued that soil productivity is an important determinant of farm-land prices; however, their study concluded that investment in soil conservation was only capitalised into land values in the presence of severe, readily visible erosion problems. Ervin and Mill (1985) cite the lack of availability and high cost of information relating erosion to yield impacts and associated production costs to explain why land prices may not fully incorporate erosion effects. Palmquist and Danielson (1989) used the hedonic technique to value drainage and reductions in the erosion potential of the land, and found that land values were significantly affected by both potential erosivity and drainage requirements.

Despite the findings which indicate that land prices are significantly influenced by land degradation or soil conservation, Simmons (1992) suggests that producers may still not be fully aware of the economic implications of soil-management practices in terms of land prices. Morris, Wilks and Wonder (1992) also allude that not all land-degradation costs may be incorporated into land values.

3.4 Measuring economic impacts at the farm level

The control of land degradation represents a classic problem of balancing the immediate gains of a land-use action with associated long-term losses due to decreases in land quality. For example, there may be short-term production gains from intensive soil cultivation, but this will ultimately lead to a depletion of the soil stock and a decrease in output. On the other hand, soil-conservation projects will result in a decrease in profit due to initial capital outlays and reductions in short run output, with extended productivity in the long run. The application of an optimal control model (Chiang 1992) is a useful way of representing this particular problem in an economic context.

Rational farmers will maximise profits from their farm activities over the period of their working lives. Two things are considered in achieving this objective, namely the present value of expected farm net income over the planning period and the present value of the change in value of the farm over the planning horizon. In brief, the economically rational farmer will choose a plan that maximises his or her total net present value (NPV). Thus:

$$\text{Total NPV}_i = (\text{PVA} + \text{PVC}) \qquad (3.4)$$

where PVA represents the present value of annual expected net income, PVC represents present value of change in the farm land at the end of planning horizon T, and i represents any possible farm plan.

The length of the planning horizon and the discount rate used by the farmer are critical factors in determining total NPV. These factors may be unique to each farmer. If land and capital markets were perfectly competitive, farmers could exchange units of land (at the margin) for capital investment or present consumption.

Decisions whether to adopt the soil-conserving practices depend on the effects of such practices on the total NPV. If a soil-conserving practice raises both the present value of net income and the present value of the farm, it would be rational for the farmer to adopt it.

McConnell (1983) developed an optimal control model to apply these concepts and to analyse the theory of optimal private and social use of land. The focus of the model is the intertemporal path of soil use, and the identification of circumstances when the private path of erosion differs from the socially optimal path. In the absence of externalities, the two model solutions suggest that the social and private rates of erosion would generally converge under most institutional arrangements (McConnell 1983; Anderson and Thampapillai 1989).

It is assumed that the private landholder will aim to maximise the present value of profits plus the value of farm land at the end of the planning period. This can be expressed as follows:

$$\text{Max } J = \int_0^T e^{-rt}\,[pg(t)\,f(s,x,z) - cz]\,dt + R\,[x(T)]\,e^{-rT} \tag{3.5}$$

subject to: $x(t) = k - s(t)$ (3.6)

$x(0) = x_0,$ (3.7)

where J is the present value of the stream of profits for T years, r is the discount rate, p is the price of output, g is neutral technical change, s is soil loss, x is soil depth, z is the level of variable inputs, and c is index of marginal cost of inputs. Further, R[x(T)] is market value of land at terminal time T and k is the natural rate of soil regeneration. In the optimal control model, production of a single crop is assumed.

Maximisation of the objective (3.5) subject to (3.6) and (3.7) is the problem of optimal-control theory. The model implies that decision-makers would use the input z until the value of its marginal product matches its cost. This implies that soil loss will occur until the value of returns resulting from additional soil loss equals the cost of foregone future output due to soil loss. Additional output may be associated with a practice such as cultivation, which will also lead to higher levels of soil loss.

McConnell's model examines the potential resale value of the farm based on soil depth, R[x(T)]. If this value is high enough, farmers will act to conserve the soil. Thus, if the land market operates efficiently, it should be possible to determine the impact of land degradation by comparing land values among properties that are similar in all respects other than quality of the land resource. Such an analysis would provide an indication of the land purchaser's willingness to pay for reduced land degradation.

Based on McConnell's findings, there are several other implications of adoption of an objective function as described by (3.5). First, the profit-maximising farmer will use the soil until its returns are equivalent to returns from the use of each of the other assets. These returns represent the general opportunity cost of capital. Second, when additional soil depth has an impact on production, its value should be reflected in the capital gain of increased land value at the end of the planning horizon. Third, if the rate of soil formation is greater than the rate of soil loss, soil conservation may either reduce the rate of loss or increase the depth. If the soil depth increases, the associated rate of increase in land value must be greater than the farmer's own rate of time preference. Finally, if the farmer knows that resale values will be affected by the soil base, he or she will conserve that base.

McConnell (1983) has shown that, in the absence of externalities, farmer decisions on investment to reduce soil loss can be socially optimal. He concludes that farmers are not necessarily ignoring physical production relations by allowing increasing soil loss, and that they will conserve soil if they know the farm resale value will be affected by the soil base.

Pope, Bhide and Heady (1983) estimated optimal rates of soil depth and soil loss according to farmers' planning horizons. They found that the objectives and preferences of farmers were important factors influencing optimal rates of soil erosion. The level of soil erosion was found to be greatly affected by the planning horizons of individual farmers. Clarke (1992) and Barrett (1991, 1994) have also explored the relationship between prices and soil conservation at the farm level. Clarke (1992) examined the relationship between factor and product prices, land-conservation investment decisions and observed levels of land degradation. Clarke found that whenever economically-viable technology exists for soil conservation, farmers were encouraged to invest in such technology because of associated increases in profitability. When such technology does not exist, Clarke found that profitability increases were associated with a long-run deterioration in soil quality. Barrett (1991, 1994) examined the effect of macroeconomic pricing policy reforms on soil conservation by developing models of the optimal control of soil erosion and soil fertility. It was shown that the effect on soil conservation could be either positive or negative, with an accurate prediction requiring technical details of agricultural production.

These studies indicate that planning decisions by individual landholders in relation to land-degradation management are dependent on a number of factors related to profit maximisation. The need for adequate information in order to make these decisions is also apparent.

3.5 Summary

The preceding sections have highlighted how the impacts and management of land degradation can be viewed in an economic context. The importance of land quality as a factor of production can be examined from a historical perspective, with the issue of declining returns providing an important foundation for this research. Current debate centres on sustainability, and whether advances in agricultural technology can outstrip declining returns due to land degradation. The influence of land quality on agricultural output can also be viewed in the context of soil conservation, which attempts to prevent or reverse declining returns.

This study is confined to onsite costs of land degradation however it is important to highlight the costs incurred by the wider community as a result of the management decisions of individual landholders. A summary of the onsite and offsite costs was presented in Table 3.1. Measurement of the impact of loss of economic welfare on community well-being can be determined in terms of changes in production costs due to land degradation. A divergence in the optimal use of land from a private and social perspective is regarded as a form of market failure caused by individual management decisions that do not take external costs into account. The economic importance of land degradation to the community may also be reflected in land prices.

The management of land degradation represents a classic problem of balancing the immediate gains of a land-use action with associated long-term losses from decreases in land quality. For example, there may be short-term gains in production from more intensive cultivation of soil, but this will ultimately lead to a depletion of the soil stock and a decrease in output. On the other hand, soil-conservation projects will result in a decrease in profit due to initial capital outlays and reductions in short run output, with extended productivity in the long run.

This study will consider and apply the quantifiable attributes of agricultural production and land quality in an analytical model. The analytical framework proposed for this study is cast around a method to quantify economic losses due to land degradation, and the viability of conservation projects. In order to model the economic relationship between agricultural production and land degradation, the estimation of a production function that includes a land-quality input appears to be appropriate. A benefit-cost analysis will be undertaken to estimate the profitability of soil-conservation projects. The method of analysis is developed in Chapter 4.