4. Method

4.1 Introduction

This chapter[3] details the method of analysis that is used to determine the economic impact of land degradation on agricultural output, at several scales. First, production functions are reviewed by comparing conventional and frontier production functions and different functional forms. The method of analysis is then developed. This consists of production function specification to relate changes in land quality to changes in agricultural output, estimation of an empirical model, and the calculation of costs of degradation and benefits of conservation in the form of a benefit-cost ratio. A means of predicting site-specific benefit cost ratios is then outlined. Finally, the different scales of analysis are discussed.

4.2 A general approach

The general approach consists of specifying the production function to relate changes in land quality to changes in output, estimating the empirical models, and then calculating the costs of degradation and benefits of conservation from the empirical results.

A production function depicts the relationship between output and inputs. If all land was homogenous, the production function would be symbolically represented as

$$y = f(a, l, k), \tag{4.1}$$

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

where y represents quantity of output, a quantity of land under production, l quantity of labour and k quantity of capital. The analyst, presumably, would apply this function to different types of land quality. A specific variable could be used for land quality when there are significant differences in quality between land units. This formulation of the production function would be

$$y = f(a, l, k, q), \tag{4.2}$$

where q is a measure of the land quality.

Expanding k to include the likely inputs of fertiliser and chemicals, the formulation of the production function in any year would be

$$y = f(a, l, f, c, q), \tag{4.3}$$

where f represents quantity of fertiliser and c quantity of chemicals.

4.2.1 Specification of the production function

This section will briefly review production functions by comparing conventional and frontier production functions and different functional forms.

(a) Conventional and frontier production functions

The conventional production function

$$y = a + bx_n + u \tag{4.4}$$

implies that output (y) is a function only of the specified input variables (x_n), and all other possible variables are fixed or unimportant. The single disturbance term u is assumed to be normally distributed, and the model estimated by ordinary least squares regression is a best-fit trend through the 'individual' observations.

Alternatively, models of production functions could characterise a frontier that defines the maximum possible (or frontier) output that can be produced from the given inputs. The random disturbances would then be presumed to follow a one-sided distribution ($u \leq 0$), and to be independently and identically distributed. Frontier functions have been the subject of considerable research over the last decade, particularly in the context of technical and economic efficiency (Aigner *et al.* 1977; Meeusen and van den Broeck 1977; Sengupta 1989). They have been estimated in a deterministic manner using corrected ordinary least squares, or in a stochastic manner.

Corrected ordinary least squares regression is a convenient deterministic means to estimate the production function. In the first step, ordinary least squares procedures are used to estimate a conventional function. In the second, the estimate of the intercept is corrected by shifting the function until no residual is positive. To do this, the largest positive residual is added to the intercept.

A stochastic frontier regression, from which production functions can be derived, was developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). In the basic equation,

$$y = a + bx_n + e \qquad (4.5)$$

the term e is assumed to comprise two independent disturbances. One disturbance is non-positive and allows for output to be on or below the frontier. Any deviation here is under the entrepreneur's control and so is attributable to differences in technical efficiency. The other disturbance allows for things the entrepreneur cannot control such as climate and topography. The former disturbance, due to differences in technical efficiency, is assumed to be asymmetric, following a one-side distribution. The latter is assumed to be symmetric. This stochastic formulation permits an improved ability to model actual situations while assessing technical efficiency. A comprehensive review of recent developments in frontier modelling and efficiency measurement is given by Coelli (1995), while Battese (1992) surveyed empirical applications of frontier production functions in agricultural economics.

The estimation a frontier production function aims to depict the maximum output that can be produced from a given set of inputs, while a conventional production function gives an average output response to a given set of inputs (Battese 1992). Therefore, frontier production functions will make soil conservation appear more profitable and therefore more likely to be adopted. While the determination of technical efficiency in agriculture is a useful exercise, Edwards *et al.* (1996) make the important observation that it is neither possible nor desirable for all landholders to achieve maximum performance levels in production, with the range of productivity levels not necessarily being a reflection of inefficiency. The estimation of an 'average' production function seems to be appropriate for this study. However, both conventional and frontier production functions will be estimated in the analysis.

(b) Choice of functional form

The choice of a functional form to accurately represent a given production relationship depends upon the nature of that relationship (Griffiths, Hill and Judge 1993). The model depicted in Equation 4.3 incorporates inputs that will have a positive impact on output (a, l, f and c), as well as an input with a potentially negative influence (q). The relationship should display declining marginal returns to each conventional unit of input (land area, labour and capital), so a linear form would be inappropriate, whereas a log-linear form such as the Cobb-Douglas may be appropriate. For n inputs, this function has the form

$$\ln y = \beta + \sum_{k=1}^{n} \beta_i \ln x_i + e, \qquad (4.6)$$

where x_i represents the different inputs, with $i = 1, \ldots, n$.

The translog function is a flexible functional form that does not assume constant or equal elasticities of substitution, thus allowing tests for specific characteristics of technology. According to Greene (1990), it is the flexible function most frequently used in empirical work. The translog production function for a single output y and two inputs (x_1 and x_2) can be represented as

$$\ln y = \beta_1 + \beta_2 \ln x_1 + \beta_3 \ln x_2 + \beta_4 \cdot \frac{\ln^2 x_1}{2} + \beta_5 \frac{\ln^2 x_2}{2} + \beta_6 \ln x_1 \ln x_2 + e. \qquad (4.7)$$

The second-order terms (β_4 *to* β_6) are described by Binswanger (1974) as amendments to the Cobb-Douglas function which allow arbitrary and variable elasticities of substitution among factors. The translog function (4.7) reduces to the Cobb-Douglas function (4.6) if $\beta_k = 0$ for $k = 4, 5, 6$.

The Cobb-Douglas model is used widely in economic analysis. The properties, benefits and limitations of the functional form have been discussed in detail by Heady and Dillon (1961), Upton (1979) and Dawson and Lingard (1982). The most appealing feature of the Cobb-Douglas functional form is its simplicity, as it lends itself easily to econometric estimation. However, this simplicity results in restrictive properties: the returns to scale have the same value across all firms in the sample, and the assumption exists that the elasticity of substitution is equal to one (Coelli 1995). Turvey and Lowenberg-DeBoer (1988) observe that the Cobb-Douglas production function has been used in a large number of studies, thus allowing for more direct comparison between past and present research. Just (1993) argues that despite improvements in the fit of estimated translog equations, increases in functional flexibility result in degrees of freedom problems and high levels of collinearity between the second-order terms containing common variables. This multicollinearity decreases the predictive ability of the estimated models.

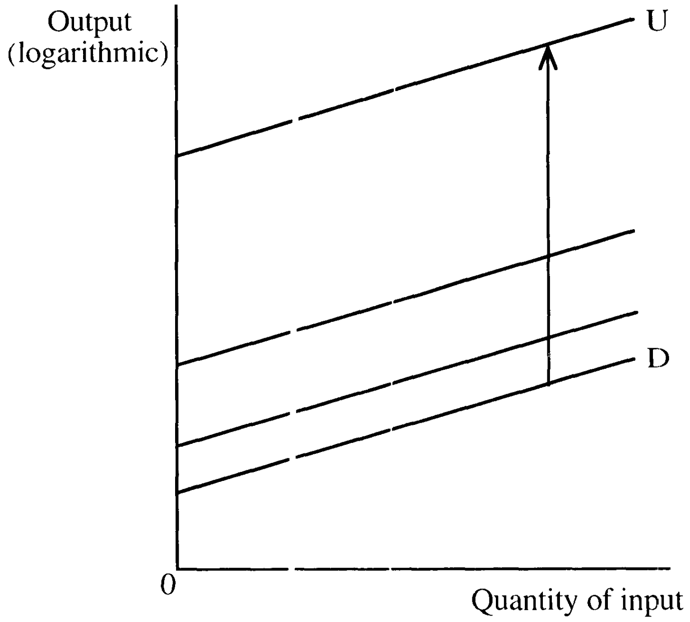
In order to choose an appropriate functional form, an F-test can be undertaken to validate this Cobb-Douglas restriction. This test will be used to help make the choice between the Cobb-Douglas and translog functions. Thus, both will be estimated and compared for a basic region and set of data, and one chosen for analysis.

4.2.2 A production function to estimate the benefits of ameliorating land degradation

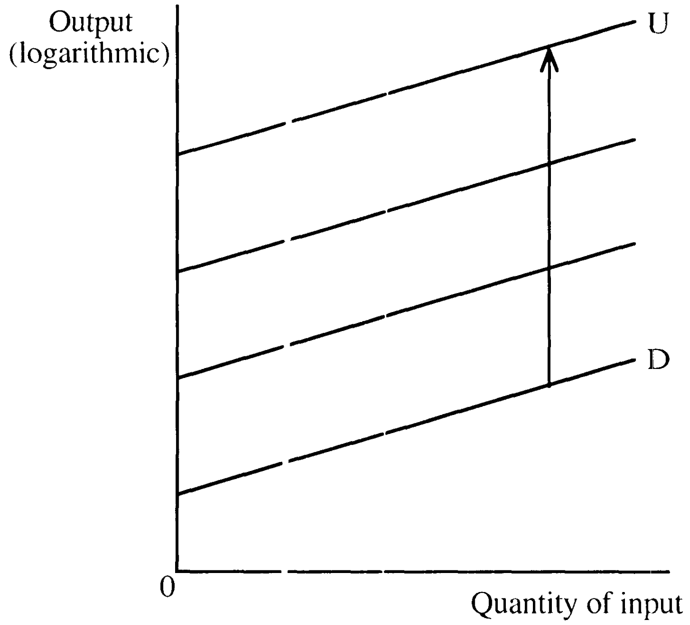
The production function provides the means to specify the relationship between land quality and output, and degradation can be represented as a change in land quality. The inclusion of a separate degradation variable in this model has important implications for the shift of the production function due to degradation and to soil conservation (= the treatment of degradation). We are concerned with the benefits of restoring degradation and so moving from a degraded situation (such as curve D in Figure 4.1) to an undegraded situation (such as curve U). Degradation, represented as an input in the logarithmic form, would exhibit increasing returns to given decreases in degradation and so reflect increasing returns to given investments in conservation works (Figure 4.1 (a)). This situation seems unlikely because of the relatively fixed nature of the required conservation works within a homogeneous region. Degradation represented as a linear or arithmetic variable (Figure 4.1 (b)) implies constant returns to conservation works. The latter situation is more likely, and so the linear form is to be preferred. Following

Figure 4.1

Production functions to model the change from a degraded (D) to an undegraded (U) situation



(a) Logarithmic degradation variable (LSUMGUL)



(b) Arithmetic degradation variable (SUMGUL)

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

Equation 4.6, this type of function could be represented in the following semi-logarithmic model.

$$\ln y = \beta + \sum_{k=1}^{n} \beta_k \ln x_i + \beta_k x_j + e, \qquad (4.8)$$

where x_i represents the conventional production inputs, with i = 1, ... n, and xj represents the land degradation input(s), with j = 1, . . . , m. The form of Equation 4.8 is preferred because it most closely represents the actual situation (Walpole *et al.* 1996).

4.2.3 Other specification considerations

The form of the degradation variable for the production function must first be specified. For example, should the variable for gully erosion be specified as the sum of gully length per unit of measurement? Or should it be the sum of gully length per 100 ha expressed as an average value? The former specification measures total degradation, while the latter measures the intensity of degradation. The basic units of analysis are the Local Government Area (LGA), farm and paddock, and output in the production function is defined in terms of total value of production for these units. Similarly, the other inputs are defined as total area, total labour and total quantity of fertiliser per management unit. The degradation variable should therefore also be specified as a total amount, where it has been measured in this way. The production function does not directly recognise different accumulated quantities of past degradation, rather it is measuring the benefits of halting degradation in the year of the calculation.

Soil resources possess some characteristics for which changes are technically reversible, and some which are non-reversible. The regeneration potential of soil resources is likely to differ depending on the prevailing condition of the land, with the regeneration process being slow with highly degraded land. As land conditions improve, the potential for further improvements in condition and fertility as natural processes begin to replace nutrients and chemicals, repair soil structure would also improve. Gullies occurring on deep and uniform soils and gently sloping land, for example, can generally be restored even though the cost may sometimes be high. Nutrients lost through sheet and rill erosion can be replaced with fertiliser. Acidity can be corrected by regular applications of lime and changes in land-management practices. Dryland salinity in its early stages can be treated by establishing pasture and tree crops that increase water transpiration and lower the water table. Therefore these forms of land degradation may be considered as fully reversible (or effectively so), such that a production function in position D could shift back to U (Figure 4.1). The time for this shift to take place will also vary according to the type of degradation. The Ecologically Sustainable Development Working Group (1991) reported natural regeneration periods ranging from five years for degradation relating to soil nutrient exhaustion and soil acidity, to periods approaching 100 years for waterlogging and salinity.

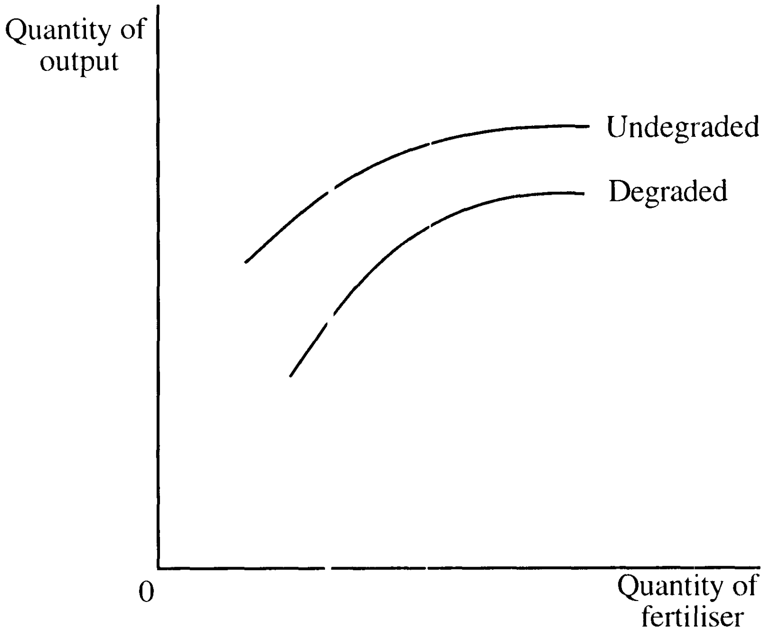
Even though regeneration can occur on highly degraded land, there would be some level of degradation beyond which regeneration will not occur. For example, the cost to repair gullies on shallow, dispersable soils on steep slopes may be prohibitive, thus a shift back to U is not likely to be achieved in this case. This study assumes that degradation can be returned to 'negligible' levels, rather than expecting a complete reversal of current levels.

The form of the degradation variable may well reflect total degradation, and returns to degradation effort may be reversible, but is the shift in the production function parallel, convergent, or divergent? A non-parallel shift may be caused by non-neutral technology, as MacCallum (1967) argued in the case of application of inputs to eroded land. For example, response to fertiliser may be greater in more degraded units than less degraded ones (Figure 4.2 (a)). The possibility of a non-parallel shift could also be indicated, in part, if the range of observed responses of output to, say, fertiliser is greater in more-degraded units than undegraded ones (Figure 4.2 (b)). In this latter situation, heteroskedasticity is present in the data, and it can be detected by examining the residuals and applying an appropriate test. Griffiths *et al.* (1993) discuss the forms of heteroskedasticity and the tests for it, and note that a major difficulty in testing is the need to know which form of heteroskedasticity is present. The variance of output is likely to depend on several variables in addition to degradation, and these variables cannot be expected to always move in the same direction. Griffiths *et al.* (1993) suggest that the Breusch-Pagan Test is useful in this situation. Accordingly, the Breusch-Pagan-Godfrey (BPG) test can be computed by SHAZAM (White 1993).

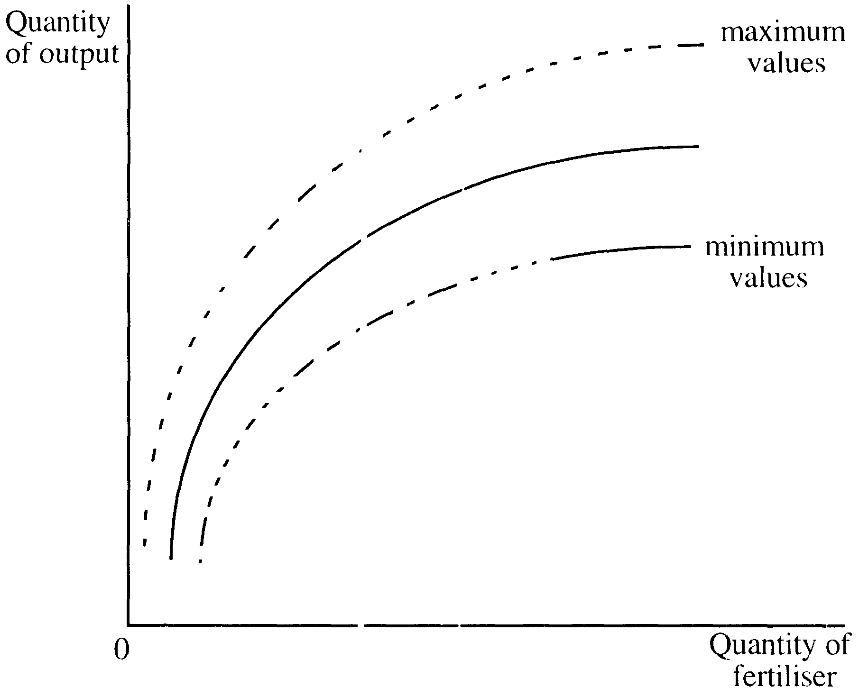
Another important issue concerns the possibility that errors corresponding to neighbouring areas of measurement (i.e. LGAs, farms, paddocks) are correlated. Because the estimated models may not include all the important variables, the residuals corresponding to neighbouring units may be correlated. This spatial correlation in cross-sectional data is analogous to autocorrelation in time series data, with corresponding effects. To detect the presence of spatial correlation, the areas can be ordered first by

Figure 4.2

Possible shifts in a production function



(a) Response to fertiliser



(b) Variation to output is greater in degraded areas that receive more fertiliser

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

northing, then by easting and the residuals plotted and observed. To test further, the Durbin-Watson test can be applied to the ordered areas using SHAZAM. Application of the test in this way explicitly tests for the most likely spatial correlation — eastward (or westward) for a given northing. If the estimated Durbin-Watson (DW) statistic is close to 2.0, then no autocorrelation exists (Doran and Guise 1984).

The consequence of using least squares estimators when the standard errors are heteroskedastic or autocorrelated is that the hypothesis tests that use these standard errors may be misleading. If either heteroskedasticity or autocorrelation are detected, alternative inference and estimation procedures need to be developed (Griffiths *et al.* 1993).

4.3 Estimation of the benefits and costs

4.3.1 Estimates of benefits

Using Equation (4.8), estimates of the increase in agricultural production, if all degradation is reduced to negligible levels, can be derived for a particular region with specific options. This gives an estimate of increased revenue from treatment in the form of a benefit value. Examples of such regional estimates are given in Walpole *et al.* (1992) and Walpole *et al.* (1996). The benefit per hectare from treatment, for a given management unit, can be derived from Equation (4.8) as follows, where the dependent variable is GVAP (gross value of annual agricultural production) and DEG represents the degradation variable.

(1) The mean value of the DEG variable is calculated.
(2) A 'negligible' level of degradation is determined.
(3) The reduction in degradation from mean to negligible levels is calculated.
(4) If the levels of all other inputs in Equation (4.8) are held constant, the change in GVAP is given by the change in DEG. The value of the change is determined by multiplying the reduction in degradation and the coefficient on DEG in the estimated equation.
(5) The increase in GVAP is calculated by adding the value of the change in GVAP to the mean GVAP value.
(6) The increase in GVAP represents the potential benefit if all degradation is restored to negligible levels. The per-hectare value of the increase in output

(BENPH) is obtained by dividing the increase in GVAP by the area of the unit.

(7) The present value of a sustained flow of benefits per hectare in perpetuity for a given management unit is now called PVB. It was calculated by discounting with a social rate of discount of 5 percent, which is the real risk-free rate recommended for use by the Department of Finance (1991), and falls within the range of values recommended by Sinden and Thampapillai (1995).

$$PVB = BENPH/0.05 \tag{4.9}$$

These benefits are used to calculate the benefit-cost ratio in Section 4.4.

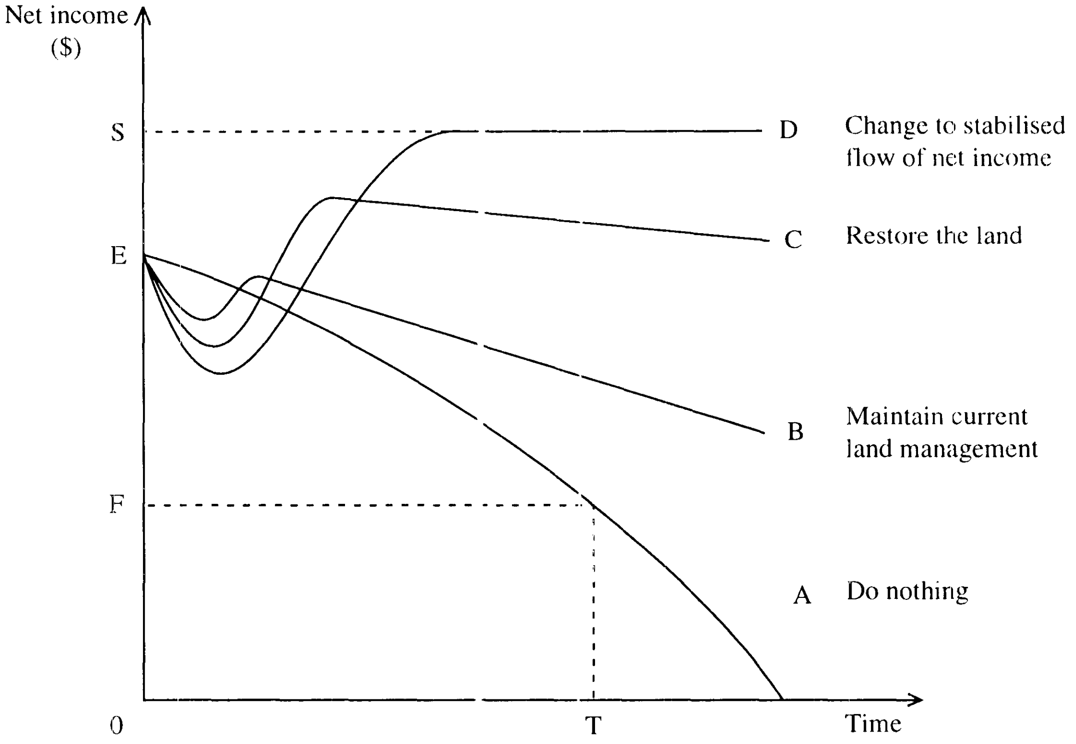
4.3.2 *Estimates of costs of soil conservation*

Estimates are required for the costs of conservation measures for each management unit specific to a particular region. Costs incurred with treatment may include those due to installation of works, operation and maintenance, and change in management practices. These estimates reflect particular land-management scenarios, and a theoretical representation of the flows of net income over time under alternative management scenarios is illustrated in Figure 4.3. The net income OS represents the income per unit area from undegraded land or land where all degradation has been treated using current technologies and at current prices. The net income OE represents income at present from degraded land. Thus, the opportunity cost of degradation in year 0 is represented by the decrease in net income ES.

(1) In the do-nothing situation (Scenario A), no maintenance or conservation of the land is undertaken and there is a decline in net income, as shown by EA. The curve EA shows income decreasing at an increasing rate with respect to time. For example, in time T the opportunity cost of degradation would be the net income FS, if the present degradation trends continue and no hing is done. However, there is some evidence to suggest that income may decline at a decreasing rate as erosion proceeds (van Vuuren and Fox 1989). Rather than net income continuing to fall to zero, the curve EA could flatten out as the land becomes more resilient to further productivity loss. This might occur where the years following initial cultivation show relatively steep declines in organic

Figure 4.3

Flows of net income over time under alternative land-management scenarios



Source: Walpole (1994).

matter and certain nutrients in the root zone. Continued cultivation, however, may result in these characteristics stabilising at a lower level.

(2) Areas with soil conservation works such as contour banks, but requiring additional maintenance, exhibit a declining level of net income due to the decreasing effectiveness of the earthworks constructed in the past. The curve EB reflects this situation (Scenario B), with an initial decrease in net income due to the outlay for earthworks, followed by an increase above EA and a lesser decline in net income. The scenario, and C and D, assume costs are paid as they are incurred.

(3) Areas with soil conservation works not requiring any significant additional work reflect a more stable level of net income. However, over time there will be a gradual decrease in net income as further land restoration becomes necessary due to land use practices such as cultivation that will continue to degrade the soil (Scenario C; curve EC).

(4) To reach the stable higher level of net income OS, all degradation is treated and management changes are undertaken to ensure a stabilised net income flow (Scenario D; curve ED). The curve of net income now moves from EA to ED. The stable level assumes that prices, yields and costs are constant, and in this study that a change to pasture land use will provide a stable flow of net income. There is some doubt whether the curve ED would ever be achievable in areas where the land is highly degraded; however, this study assumes that a 100 percent achievement of soil-conservation targets is possible.

4.3.3 Estimates of costs of treatment

The costs of treatment are estimated in the following series of steps.

(a) Collect the basic cost data

Cost data for the management units were obtained from staff of the New South Wales Department of Land and Water Conservation. The costs were provided for different soil, slope and land-use categories. They were provided for scenarios B, C and D (maintaining current land management, restoring the land, and changing land use to achieve a stable level of net income), and expressed as dollars per hectare. These data are discussed in further detail in Chapter 5.

The benefits were calculated on the basis of reducing all degradation to negligible levels, and then achieving a stable level of net income, as in scenario D. Thus, the costs must be calculated for the same situation, and so must include maintenance, restoration and changes in land use. A five percent discount rate is used to convert these to present values. This is close to the 'real' private rate of discount for farmers borrowing money for soil-conservation works through the Rural Assistance Authority (Flavel, N. 1996, pers. comm.). These calculations are now explained.

(b) Estimate costs to maintain current position

These are the costs ($MAINT) to maintain the current management position of scenario B, even though this position involves continuing degradation. They consist of the costs of establishing and maintaining contour banks and other earthworks, and they vary with soil type, land use and slope. However. they remain constant with varying degrees of gullying, because they are not a specific form of gully repair, but rather an overall form of treatment. Table 4.1 illustrates how different land categories affect the cost of maintenance for a pasture or continuous cropping land-use system in the northern part of the wheat-sheep zone. The monetary values ($/ha/yr) represents the average annual cost over the life of the earthworks. The present value (PVCMAINT) can be determined for a perpetual flow of these maintenance costs, using a five percent discount rate.

$$PVCMAINT = \$MAINT/0.05 \qquad (4.10)$$

(c) Estimate costs to restore the land

Restoration involves filling and stabilising the gullies and requires a one-off cost for the necessary earthworks ($REST). These costs, in addition to those for maintenance for scenario B, will restore net income from the land above the existing level $OE for a period of time. Then, following curve C in Figure 4.3, net incomes will eventually decline again. The cost varies with soil type, slope and severity of gully erosion, but is constant over all land-use types. The present value of the restoration costs (PVCREST)

Table 4.1

Comparison of maintenance costs ($MAINT) for different land attributes for pasture or continuous cropping in the northern part of the wheat-sheep zone ($/ha/year)

Land use	Slope(%)	Red soil ($/ha/year)	Black soil ($/ha/year)
Pasture	0 - < 2	4.24	12.70
	2 - < 5	5.20	15.60
Continuous cropping	0 - < 2	10.60	25.40
	2 - < 5	13.00	31.20

was derived by discounting, where 1.05 implies payment for the works occurs after one year.

$$PVCREST = \$REST/1.05 \qquad (4.11)$$

(d) Estimate costs to achieve a stable flow of net income

These costs ($CHANGE) are incurred to move to a system with a stable, higher flow of net income and include any loss in gross-margin returns due to changing from cropping to either a rotational or pasture land use. They may also include additional capital costs ($CAPITAL). It is assumed that prices, yields and costs would remain constant. Once these land uses were established, and once all maintenance, restoration and capital costs had been invested, it is assumed that net income would settle to a stable level as if all existing degradation were restored.

The loss in gross margin would be greatest in the first three years due to the cost of management changes: pasture establishment, the reduction in cropping income and the expenditure to increase stock numbers. However, enterprise budgets determined by Turvey (1988) indicate that the gross margin may not necessarily be lower after cropping is changed to grazing, and this is reflected in Figure 4.3, which shows a higher level of output after the change. An additional one-off capital cost would also be incurred in the flatter cropping and rotational areas due to fencing and watering requirements. These additional capital costs must be discounted to a present value. The present value of all the costs (PVCCHANGE) of moving from current to sustainable practice were determined by discounting.

The discounted value of all these costs (PVCCHANGE) is now calculated from its two parts, namely the present value of the three-year change costs and the present value of capital costs (PVCC).

$$PVCC = \$CHANGE \times 2.7232$$

where 2.7232 is the discount factor to calculate the present value of an annuity of $1 per year for a term of three years at a compound rate of interest of five percent.

$$PVCCAP = \$CAPITAL/1.05$$

The present value of all the costs (PVCCHANGE) is then calculated:

$$PVCCHANGE = PVCC + PVCCAP \tag{4.12}$$

(e) Calculate the total costs

A number of management options may be chosen from, each with different costs. The present level of degradation may be maintained (PVCMAINT), resulting in a gradual loss of net income over time as depicted in scenario B. Alternatively, restoration may also be undertaken (PVCREST), incurring an initial one-off cost but bringing previously degraded land back into production and reducing levels of degradation. The net income flow of scenario C is now obtained. In the case of rotation and cropping land use, further costs may be incurred to move to a system which achieves stable flows of net income. These costs are PVCCHANGE, and scenario D is achieved. These land-management changes may cause an immediate reduction in income, which recovers once a stable system has been established. It is assumed that for pasture land use, PVCCHANGE will be zero, indicating that if maintenance and restoration have been undertaken, no further change to the system is required to achieve stability.

The total treatment costs (PVC) for a land category to move from a do-nothing scenario A to the stable scenario D are calculated in the following way:

$$PVC = (PVCMAINT + PVCREST + PVCCHANGE) \tag{4.13}$$

Alternatively, PVC values can be calculated to only include PVCMAINT for scenario B, or only PVCMAINT + PVCREST for scenario C. In doing this, it is recognised that the idea of a stable flow of net income (PVCCHANGE) would not be achieved in all cases.

4.3.4 Estimates of benefit-cost ratios

The benefit-cost ratio (BCR) for each farm is calculated as follows:

$$BCR = PVB/PVC. \tag{4.14}$$

Given that a BCR other than 1.0 at the margin suggests that farmers are acting irrationally, it is important to be able to justify any variation that occurs in the estimated ratios (assuming that there are no other constraints such as limited inputs where the BCR may be greater than one and still rational). A major reason for departure of these marginal ratios from 1.0 may well be uncertainty of the actual benefits and costs associated with degradation. For example, a landholder may perceive some change in overall output levels due to degradation, but may not be aware of the actual extent of the change. A stochastic simulation is undertaken to estimate the level of uncertainty in the BCR values, using @RISK (Palisade Corporation 1992). The object of risk analysis is to determine the distribution of outcomes (BCRs) associated with each alternative. This is done by determining the value of each variable in a simulation, chosen randomly from its probability distribution by monte carlo sampling for each year of the planning horizon. This gives a set of values for each variable (benefit or cost) for each year of an enterprise. The BCR from this set of values is then calculated. This process is repeated many times to generate a distribution of the many outcomes. The results are a distribution of many BCRs.

4.4 Estimation of site-specific benefit-cost ratios

To increase the resolution of the BCRs, the bio-physical and management factors that are the most influential in changing the BCR levels are determined. The following model, developed by Walpole (1994), describes this relationship:

$$BCR = f(m, b), \qquad (4.15)$$

where BCR is the benefit-cost ratio, m represents land use and management factors, and b represents bio-physical factors, such as soil and slope. This equation is the basis of a procedure, where the BCR can be predicted for a region, farm or paddock with a particular combination of the defined attributes. The profitability of site-specific land-management proposals can then be predicted. This allows the BCR results from the conventional management level to be disaggregated below these levels, and therefore provides economic information at a scale that is useful for both policy makers and landholders in a decision-making process. The disaggregation of BCRs is undertaken either through a manual process of estimation or using predictive modelling in the GIS.

4.5 Predicting benefit-cost ratios

4.5.1 Model predictions

Having estimated models using Equation 4.15, it is then possible to use them to derive predicted benefit-cost ratios for different levels of the regressor variables. Variables with significant relationships with estimated BCRs are likely to provide the most useful BCR predictions. Thus, for a particular estimated equation, all but the two most significant variables are set at their mean values, and BCRs can be generated given particular values of these remaining variables.

4.5.2 GIS predictions

The availability of GIS data for map sheets at the 1:25 000 scale (see Chapter 5) enables predictive modelling of the BCRs to be undertaken in a GIS at the farm and paddock scale. The GIS package used for this analysis is the Environmental Resource Mapping

System (E-RMS). This package contains tools for data analysis, model building and extrapolation (Ferrier 1988). In order for predictive modelling to be undertaken in the GIS, the estimated BCR values for each farm must first be entered into the database as a new overlay.

(a) Adding BCR values as a new variable to the GIS database

In GIS terminology, the BCR values estimated in Equation (4.14) are known as ground surveyed data. These data can be incorporated into the GIS database as a new layer in the following way.

(1) A variable called 'farm' already exists in the GIS database. This consists of the boundaries of each property on the map sheet, with a number assigned to each.
(2) Each farm's estimated BCR value is categorised into one of the following groups: <1, 1-<2, 2-<5, and 5 and over.
(3) On the basis of the present 'farm' variable, new categories are created. The farms that have a corresponding category defined in (2) are grouped together.
(4) With the categories defined, a new variable called 'BCR', which contains the farms numbers grouped according to the four categories, is created.
(5) This variable is added to the database and can now be stored, mapped and modelled in the same way as the other bio-physical variables already present in the database.

A map of the estimated BCRs for each surveyed farm can then be produced, corresponding to the 1:25 000 map sheet. These results give an indication of the profitability of land-management programs at the farm level.

(b) Predictive modelling

The GIS being used for this analysis contains a predictive modelling module. This module enables models to be built, stored and used in a database. These models are decision-tree models, and can be thought of as a collection of 'if-then-else' rules in the form of a tree. Ground-surveyed BCR data do not have complete geographical coverage of the map sheet. Decision-tree models can be derived to extend or interpolate these data across unsurveyed areas and other map sheets based on correlations between these data and remotely mapped predictor variables with complete geographical coverage of the map sheet. The decision-tree models are derived automatically using a technique called machine learning or induction. In this case, the induction process relates the ground-surveyed BCR data to bio-physical and management variables (predictor variables) determined from Equation 4.15. An example of a decision tree model is shown in Figure 4.4, where the BCRs are predicted on the basis of slope, soil type and the presence of soil conservation works.

The induction algorithm uses the predictor variables to progressively partition the BCR data into increasingly homogenous subsets. The algorithms used in the predictive modelling module to derive decision-tree models are described by Ferrier (1988). The decision tree is constructed in a top down manner, with the G (likelihood ratio) statistic used as the measure to select and test branching variables, when the automatic splitting mode is set. The general algorithm for constructing the decision tree recursively splits the training data into subsets. The algorithm used to split each node is as follows.

1. The best available split for each predictor is derived heuristically by starting with a branch for every predictor category then repeatedly merging the least significantly different pair of categories until all resultant categories are significantly different according to the stopping criterion. The exact nature of the G-test comparing categories is tailored to the type of training data.

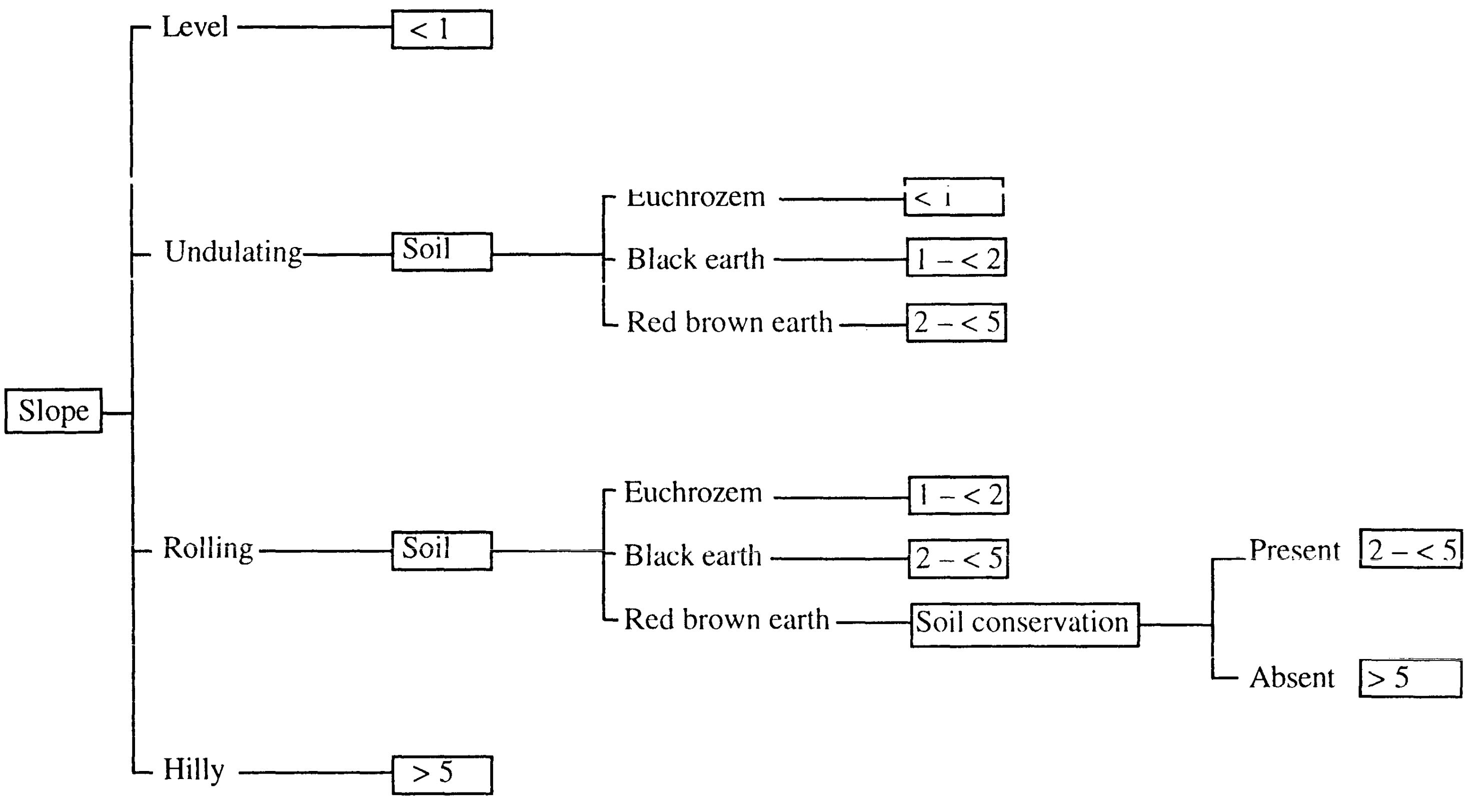
2. The overall significance of the best available split for each predictor is tested.

3. The predictor offering the most significant split is selected. If this split is significant according to the stopping criterion, the training data associated with the node are split into two or more subsets and the above process is repeated for each subset.

Once the decision-tree model has been built in the GIS, the predictive modelling module is instructed to run the model, and thus applies the model to every 20 m x 20 m grid cell in the database corresponding to the 1:25 000 map sheet. The mapped predictions are stored in a special grid cell variable, called a modelled variable. The difference between a modelled variable and other database variables is that a modelled variable does not contain 'hard' data, but rather predictions generated by a decision-tree model. This provides the information at a higher level of resolution, thus allowing landholders to make decisions at a more relevant management level.

Figure 4.4

An example of a decision tree model



4.6 Analysis at different scales

The importance of scale in decisions related to agricultural land management is highlighted by the Prime Minister's Science and Engineering Council (1995). The Council suggests that the scale at which land quality is monitored should match the scale of decision making and the bio-physical boundaries of the landscape. The general method developed in the previous sections can be applied at various scales, depending on the availability of appropriate data. In this study, the general method is applied at the regional, farm and paddock level.

At the regional level, the LGA is the basic unit of analysis. Appendix 3 shows the location of and list of rural LGAs in rural New South Wales (Figure A 3.1). Local Government Areas can be aggregated to represent particular regions of the state. Costs and benefits associated with land degradation are likely to vary on a regional basis according to topographical, bio-physical and land-use factors. An important consideration is therefore the definition of the regions in terms of homogenous ecological areas or homogenous land-use areas.

A classification of LGAs on the basis of agro-ecological zones was originally proposed by SCA (1991) and endorsed by the ESD Working Group on Sustainable Agriculture (1991). Using the *Provisional Environmental Regions of Australia* (Laut, Firth and Paine 1980) as a starting point, LGAs were aggregated according to common agricultural practice, within relatively homogenous regions of climate and geography. Three of the defined regions fall within New South Wales: region 6 is the Sub-tropical Highlands, region 7 is the Temperate Semi-arid Slopes and Plains, and region 10 is the Temperate Highlands. Another useful aggregation of LGAs would be into the three major topographic-climatic zones of the State, namely the Coastal and Tablelands zone, Wheat-sheep zone and Western zone (as defined by Walpole *et al.* 1992). The Wheat-sheep zone defined by ABARE (1993) for their annual farm surveys, extends further into the Western zone.

On the basis of the aggregations described above, and to provide relatively homogeneous regions, the zones to be analysed will be defined in the following way.

Zone 1. Temperate Semi-arid Slopes and Plains (36 LGAs).
Zone 2. Temperate Highlands (16 LGAs).
Zone 3. Sub-tropical Highlands (24 LGAs).

Zone 4. Coastal and Tablelands zone (44 LGAs).
Zone 5. Wheat-sheep zone (45 LGAs).
Zone 6. Western zone (16 LGAs).
Zone 7. Extended Wheat-Sheep zone (51 LGAs).

The location of these regions are shown in Figure 4.5a, 4.5b and 4.5c. A description of the three agro-ecological zones is given in Appendix 4. Thus, information on the benefits and costs associated with different land-degradation types in specific NSW regions can be determined.

The farm is the basic management unit for agricultural landholders. On the basis of the results at the regional level, an area will be chosen to apply the method at the farm level, concentrating on a single land-degradation type. Analysis at this scale will provide information that is useful to individual landholders who must deal with land degradation within the scope of their whole-farm management decisions. The information provided from the analysis may also be aggregated to a sub-catchment or catchment level, depending on the area chosen and the requirements of the landholders in the area (for example, Landcare groups).

The paddock can also be treated as an agricultural management unit. Management decisions, based on the specific attributes of a particular paddock, are likely to be aided by the provision of information at this level. It will also be useful to compare the results produced at this level with the farm level, in order to validate the accuracy of the predictions at each scale.

4.7 Summary

In this chapter, a general method of analysis has been developed for estimating the benefits and costs associated with land degradation at several scales. The steps undertaken in the analysis are outlined in Figure 4.6. In Chapter 3 it was established that a production function would be an appropriate means of determining the relationship between agricultural productivity and land degradation. A brief review of conventional and frontier production functions is given, as well as a comparison of functional forms. A Cobb-Douglas estimation is chosen for the analysis.

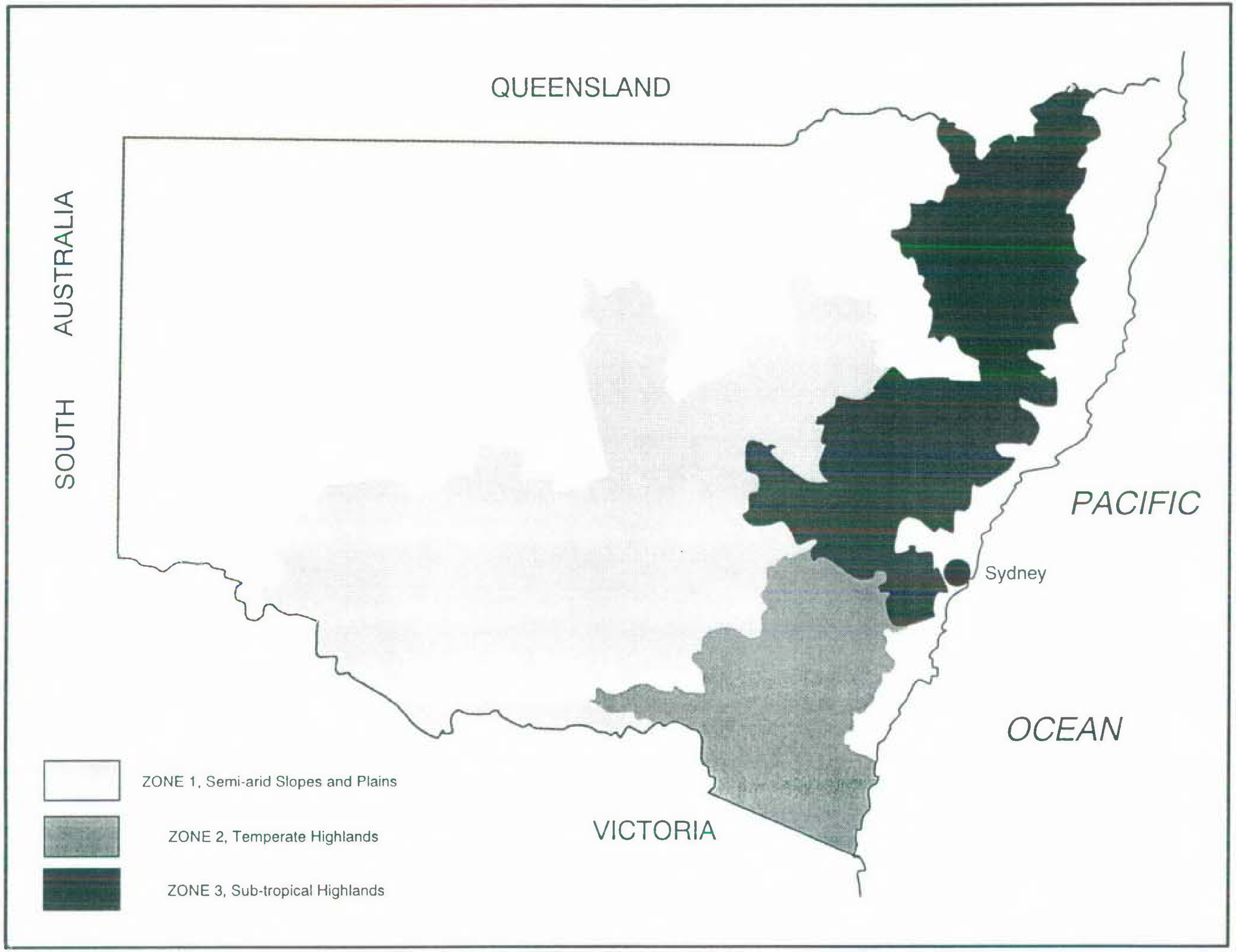


Figure 4.5a

Regional zones 1, 2 and 3

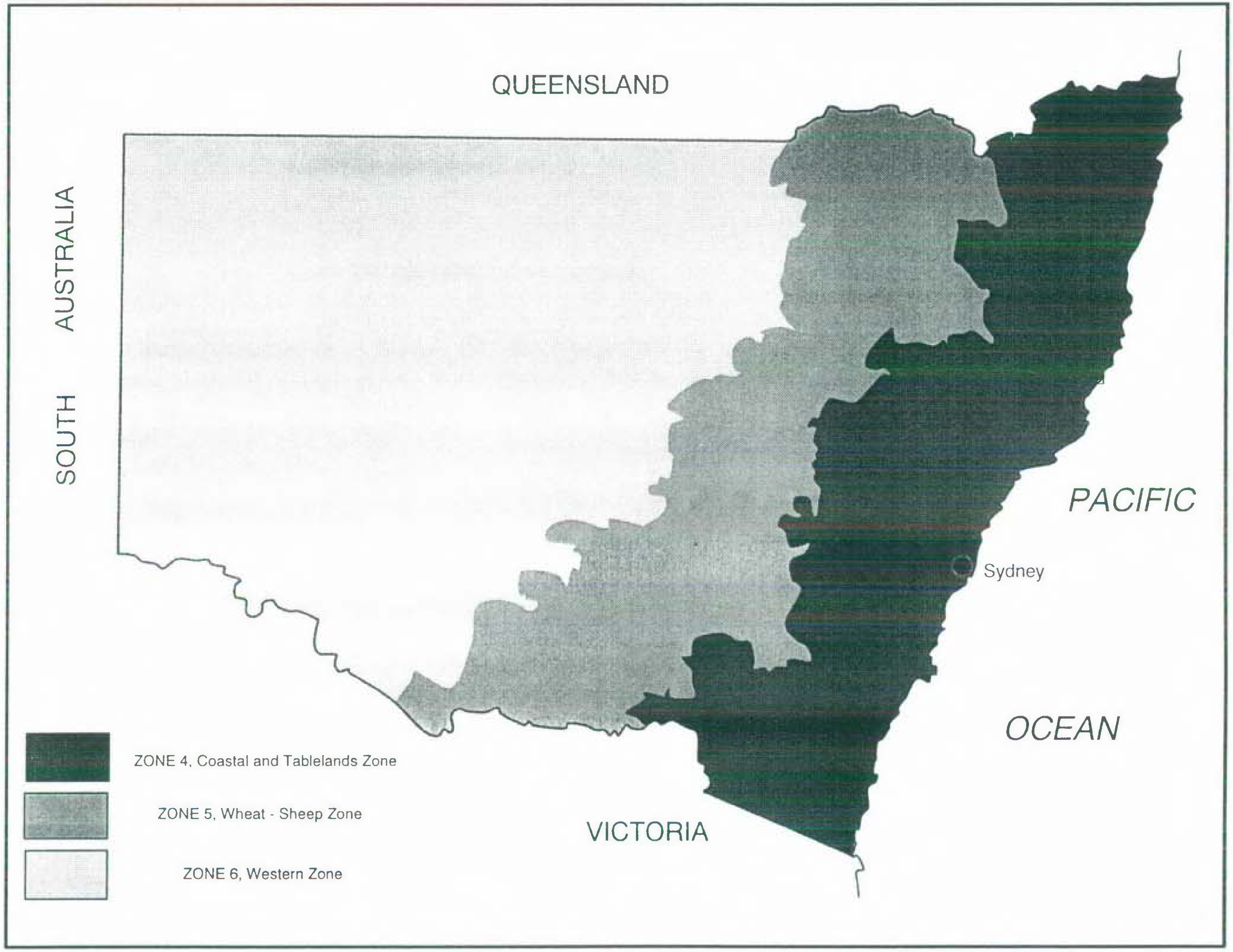


Figure 4.5b

Regional zones 4, 5 and 6

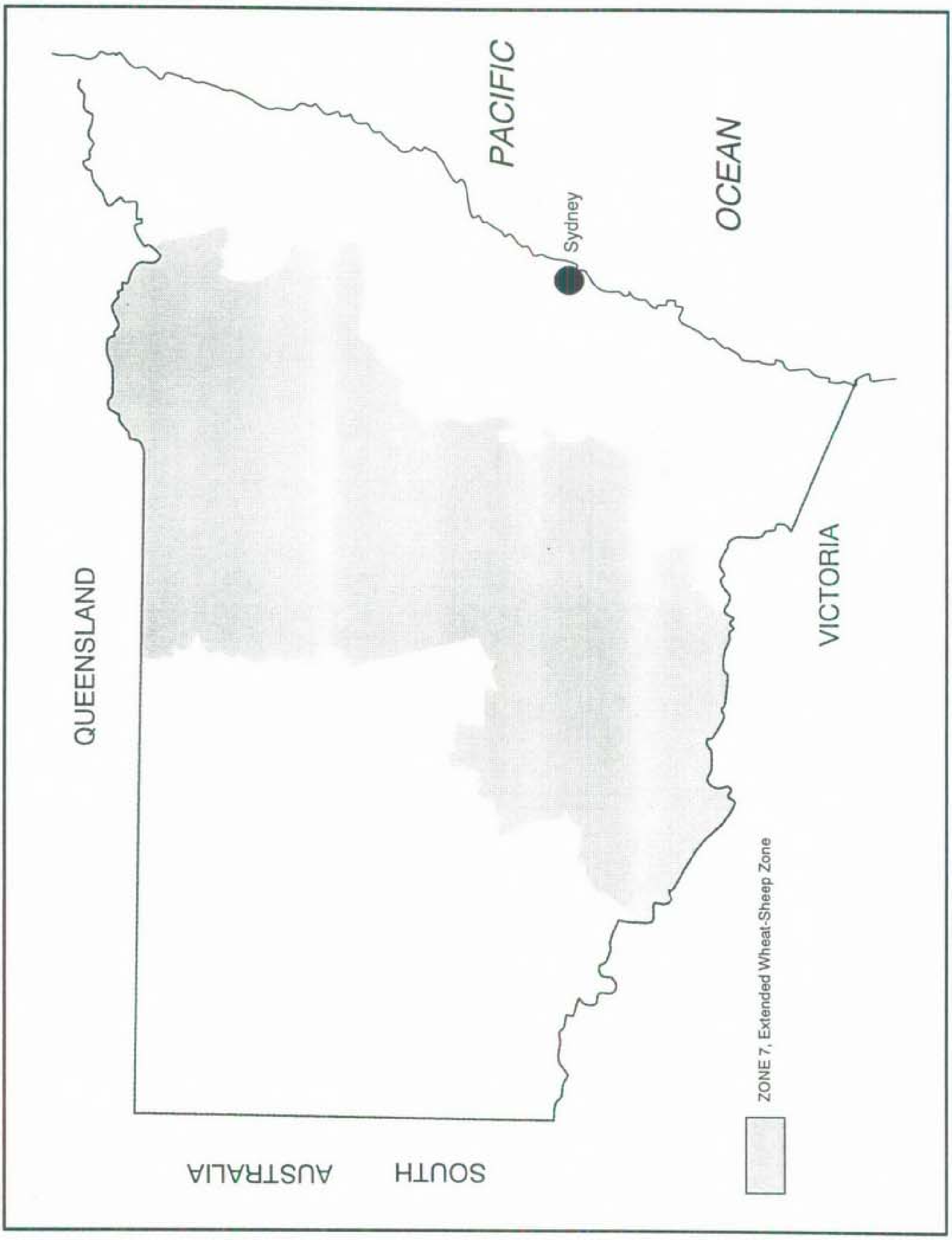
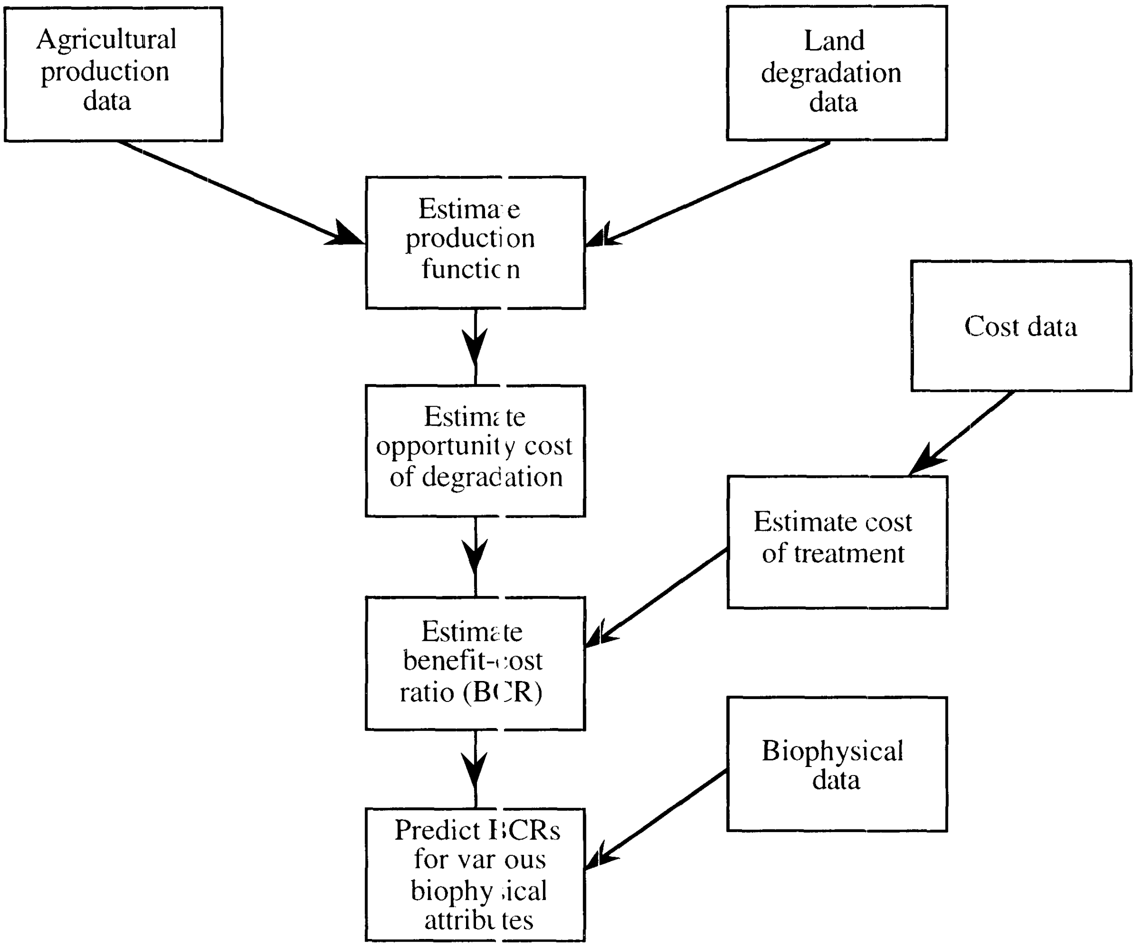


Figure 4.5c

Regional zone 7

Figure 4.6
Steps in the analysis



The general approach developed consists of estimating a production function that includes a land degradation variable in the equation, thus relating changes in land quality to changes in output. The inclusion of a separate degradation variable in the model has important implications for the shift of the production function due to degradation and conservation. Specification of the model must include consideration of the form of the land-degradation variable. Degradation represented as a linear or arithmetic variable, implying constant returns to conservation, is preferred. Other considerations in the estimation of the model include reversibility of degradation, non-parallel shifts in the production function, and spatial correlation. The application of appropriate statistical tests to detect these problems must also be considered.

Once the production function has been estimated, and any statistical problems eliminated, values of the increase in agricultural production if all degradation is reduced to negligible levels can be calculated. This is an estimate of potential benefit. The costs of undertaking conservation programs according to a number of land-management scenarios (ranging from do nothing to changes in land use) are then determined. A conventional benefit-cost ratio (BCR) can then be calculated from these estimates.

To increase the resolution of the BCRs beyond conventional economic management units, the bio-physical and management factors that are the most influential in changing the BCR levels are determined. The BCR can be predicted for a region, farm or paddock with a particular combination of the defined attributes. The profitability of site-specific land-management proposals can then be predicted. This allows the BCR results from the region, farm or paddock to be disaggregated below these levels and extrapolated to other areas. This, therefore, provides economic information at a scale that is useful for both policy makers and landholders in a decision-making process. The disaggregation of BCRs is undertaken either through a manual process of estimation or using predictive modelling in the GIS.

The data required for the analysis will be outlined in Chapter 5.