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**BCA AND GIS: INTEGRATION OF
ECONOMIC AND ENVIRONMENTAL
INDICATORS TO AID LAND
MANAGEMENT DECISIONS**

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BCA AND GIS: INTEGRATION OF ECONOMIC AND ENVIRONMENTAL INDICATORS TO AID LAND MANAGEMENT DECISIONS

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Benefit-cost analysis (BCA) and geographic information systems (GIS) are both useful tools for aiding land management decisions. In this study, benefit-cost ratios (BCRs) for treatment of sheet and rill erosion are derived at farm level. The biophysical and management factors that most influence these BCRs are then determined. Using GIS predictive modelling, these farm-level BCRs are disaggregated according to slope, land use and presence of soil conservation works, for a higher resolution of information in the form of mapped output. This economic information relates directly to important biophysical and management attributes, at a scale useful for landholders to make improved land management decisions.

Keywords: Benefit-Cost Analysis, GIS, Land Management

1 INTRODUCTION

At the farm level, maintenance of land quality is just one of a number of management issues requiring attention from the landholder. Each farm may be faced with a variety of land degradation types of different intensity and scale. Most landholders now have access to information from various management agencies about the types of programs that may be undertaken to combat a particular land degradation problem, and the emergence of Landcare has assisted in the dissemination of this information. Certainly there appears to be an increasing will amongst the agricultural community, encouraged by increased government funding, to undertake land management programs such as tree planting, gully stabilisation and conservation tillage. However, is this conservation work

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warranted on a financial basis? Does information exist at the farm or sub-catchment level on the profitability of particular land management projects?

Estimates of the benefits of land management programs at the farm level are important for the landholder both for short and long-term management decisions. If a landholder is able to undertake a whole-farm planning program, the knowledge that specific forms of land management activities on particular land types will generate a certain levels of benefit is certain to be of assistance. Alternatively, if a group of landholders within a sub-catchment are able to identify areas of greatest agricultural loss and potential benefit from conservation programs, this information should assist their claims for funding from government agencies.

The area chosen to examine these issues is located in north-western NSW, and is based on a 1:25 000 map sheet, south-west of Gunnedah. This area falls within the wheat-sheep zone of NSW. There is a documented history of serious sheet and rill erosion in the area (Junor, Marston and Donaldson 1979, Anonymous 1991). Many landholders in the area have implemented major soil conservation earthworks in the past, although some of these are now in need of further maintenance.

In this context, the objectives of this paper are to

- (a) derive farm-level information about the benefit-cost ratios for treatment of sheet and rill erosion for particular land management situations,
- (b) determine the biophysical and management factors that most influence these benefit-cost ratios,
- (c) using predictive modelling in a geographic information system, disaggregate farm-level benefit-cost ratios according biophysical and land management factors, to give a higher resolution of information and a useful planning tool for landholders.

1.1 GIS as a Tool for Land Management

Geographic Information Systems (GIS) are computer-based systems for the manipulation and analysis of spatially-distributed data (Johnson 1990), 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), by providing a framework for people's recognition skills to supplement sophisticated quantitative methods in the evaluation of various land management options (Brown *et al.* 1994).

GIS clearly has great potential as a powerful tool to assist in land management decisions. Examples of resource management applications are becoming more prevalent as software applications become more user-friendly and are more amenable to personal computers. For the purposes of this study, the Environmental-Resource Mapping System (E-RMS; Ferrier 1988) will be the GIS used.

2 METHOD

The impact of land degradation on agricultural production, and the profitability of land management programs, have been estimated at the state and regional level (Yapp, Sinden and Walpole 1992; Walpole, Sinden and Yapp 1995). The issues facing individual landholders are somewhat different, however it is possible to apply a general method of analysis at this scale. The general method consists of specifying a 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.

2.1 Estimation of Benefits of Treatment

A production function depicts the relationship between output and inputs. If all land were homogenous, the production function would be

$$y = f(a, l, k) \quad (1a)$$

where y represents quantity of output, a quantity of land under production, l quantity of labour, and k quantity of capital (Heady and Dillon 1961). The analyst, presumably, would apply this function to different types of land quality. The test for the occurrence and extent of degradation would involve comparisons of coefficients on the variables between the functions for each land quality, or for a given quality over time. Heady and

Dillon (1961) suggest that 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

$$y = f(a, l, k, q) \quad (1b)$$

where q is a measure of the land quality.

Using a Cobb-Douglas specification of Equation 1b, estimates of the increase in agricultural production, if all sheet and rill erosion were reduced to negligible levels, can be derived for the study area. We are concerned with the benefits of restoring degradation and so moving from a degraded situation to an undegraded situation. The inclusion of a separate degradation variable in this model has important implications for the shift of the production function due to degradation and soil conservation. When degradation is represented in logarithmic form, there would be increasing returns to given decreases in degradation. That is, there would be increasing returns to given investments in conservation works. This situation seems unlikely because of the relatively fixed nature of the required conservation works within the homogenous region of the study area. For example, the type of treatment recommended from paddock to paddock and farm to farm is unlikely to vary much — there are standard types of earthworks and management practices prescribed by Soil Conservation Officers. When degradation is represented in linear form, there would be constant returns to given investments in conservation works. The latter situation is more likely, and so the linear form is to be preferred.

This method gives a farm-level estimate of increased revenue from conservation works in the form of a net benefit value per hectare (BENPH), which can then be discounted to a present value (PVB). It is assumed that a 'negligible' level of sheet and rill erosion is 0.5t/ha/year. Soil conservation measures to control sheet and rill erosion are rarely 100 percent effective, so sensitivity tests to consider the impacts of lower levels of effectiveness can be undertaken.

2.2 Estimation of Costs of Treatment

Estimates are required for the costs of conservation measures for each farm. 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 are illustrated in Figure 1. The net income \$OS represents the income at present 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, 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, at time T the opportunity cost of degradation would be the net income \$FS, if the present degradation trends continue and nothing is done.
- (2) Areas with soil conservation work, but requiring additional maintenance, reflect areas with a declining level of net income due to the decreasing effectiveness of the earthworks constructed in the past. The curve EB reflects this situation, with an initial decrease in net income due to the outlay for earthworks, and then an increase above EA, with a lesser decline in net income.
- (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 (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 (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 case study that a change to pasture land use will provide a stable flow of net income.

However, it should be noted that there is some evidence to suggest that income may decline at a decreasing rate as erosion proceeds (Fox, *pers. comm.* 1995). This might occur where the years following initial cultivation show relatively steep declines in organic matter and certain nutrients in the root zone. Continued cultivation, however, may result in these characteristics stabilising at a lower level.

The procedure for estimating the costs of treatment are as follows.

Figure 1 Flows of net income over time under alternative land management scenarios

(a) Maintain current land management

These costs (SMAINT) are those required to maintain the current management position. They consist of the costs of establishing and maintaining contour banks and other earthworks, and they vary with soil type, land use and slope.

(b) Change in land use

These costs (\$CHANGE) are those required to change the land use of the management system to achieve a stable higher flow of net income. They include any loss in gross margin due to changing from cropping to either rotational or pasture land use. It is assumed that prices, yields and costs will remain constant. Once these land uses are established, and once all maintenance and capital costs have been invested, it is assumed that the net income will settle to a stable level as if all existing degradation were restored.

Both of these cost estimates are discounted to present values and added together to represent the costs of conservation for the entire farm (PVC).

2.3 Estimation of the Benefit-Cost Ratio

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

$$BCR = PVB/PVC. \quad (2)$$

where PVB is calculated as in Section 2.1, and PVC is calculated as in Section 2.2.

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. 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).

2.4 Estimation of Site-Specific Benefit-Cost Ratios

To increase the resolution of the BCRs, the biophysical 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:

$$BCR = f(m, b), \quad (3)$$

where *BCR* is the benefit-cost ratio, *m* represents land use and management factors, and *b* represents biophysical factors such as soil and slope. This equation is the basis of a procedure, where the BCR can be predicted for a farm 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 farm level to be disaggregated below the farm level, and therefore provides economic information at a scale that is useful for landholders in a decision-making process. The disaggregation of BCRs is undertaken using predictive modelling in the GIS.

3 DATA

An area south-west of Gunnedah was chosen for the study due to the availability of GIS data collected for 1:25 000 map sheets by the NSW Department of Land and Water Conservation, and its relatively close proximity to Armidale. Following consultation with staff from the Department of Land and Water Conservation Research Station at Gunnedah, a map sheet was chosen that had a large range of land use, topography, vegetation, soil, and land management types. Using a map of property names and boundaries from the Gunnedah Shire Council, it was possible to identify which farms occurred within the boundaries of the chosen map sheet. Landholders were then contacted by phone to arrange a time for an interview. At the time of the survey (early 1995), drought was having a significant effect on the area, and some landholders were reluctant to co-operate due to the major difficulties associated with the prevailing conditions. Due to these constraints, selection of properties was based on the first 31 landholders with whom appointments could be made. The data collected from these landholders are considered to be representative of properties in the area, providing a good coverage of the map sheet.

The variables used in the analysis are now discussed.

3.1 Property Characteristics

Estimates collected through the survey were based on the 92/93 season, as this is when the GIS data were collected. The total area of the farm (AREA) was measured in hectares. Productivity was measured in terms of gross value of agricultural output (GVAP), with the number of stock (STOCK), and tonnes of grain (TGRAIN) also recorded. The number of farm workers (LABOUR) was estimated, as was the tonnes of fertiliser (FERT) and litres of chemicals applied (CHEM). Membership of a landcare group (LCARE), whether the owner intended to sell the property in the future (SELL), and intention to undertake soil conservation (CONS) were also recorded (1=yes/0=no).

Using an overlay of property boundaries on the GIS data, detailed biophysical information could be determined for each farm on the map sheet. Measured attributes include slope, terrain, land use, timber, erosion, rock, soil and soil erosion control earthworks. The erosion classifications range from no appreciable to very severe for sheet, wind, rill, gully and streambank erosion. Mass movement and saline indications were also recorded. However, for this particular study area, only sheet and rill erosion

and salinity were recorded as present. The following data were extracted from the GIS, in terms of average values per farm: slope (SLOPE) in degrees, area under cropping (CROP), pasture (PAST), lucerne (ALUC), and trees (TREES) in hectares, total amount of sheet and rill erosion per farm (EROSION) in tonnes, area of sheet and rill erosion (AEROS) in hectares, presence or absence of red brown earth (RBE), skeletal soil (SKEL), and euchrozem (EUCH) (1=present/0=absent).

3.2 Cost Estimates

Cost can be estimated according to areas requiring some form of soil conservation treatment. At the farm level, the following information was extracted from the GIS database; area treated with soil conservation works, but requiring additional works to complete erosion control (AREA SC). Using an overlay in the GIS, it is also possible to determine on which soil type, degree of slope and land use that additional soil conservation is required. Cost data were obtained from DLWC staff at Gunnedah. The costs were provided for different soil, slope and land use categories. Therefore cost estimates can be made to reflect more closely the true condition of the land.

The economic information available at the farm level from the survey, coupled with the detailed biophysical data from the GIS, allows for a more detailed examination of the factors influencing the benefits and costs associated with land degradation.

4 ANALYSIS AND RESULTS

4.1 Estimation of Models

The preferred Cobb-Douglas models are shown in Table 1. The estimated equations show the influence of degradation on the value of agricultural production, and a significant negative coefficient indicates that increases in degradation are associated with decreases in production.

The dependent variable is; LGVAP = the gross value of agricultural output (\$), in logarithms. The independent variables are; LAREA = the total area in agricultural production (ha), in logarithms; LALUC = the total area of lucerne in agricultural production (ha), in logarithms; LFERT = the total amount of any kind of artificial fertiliser applied (tonnes), in logarithms; LCHEM = the total amount of any kind of chemical applied (litres), in logarithms; LSLOPE = average slope across the farm, in

Table 1

Preferred models for the relationship between agricultural inputs and gross value of agricultural production

Regressors variable	Equation (4)	Equation (5)
LAREA	0.79 (4.0)***	0.59 (3.7)***
LALUC	0.07 (1.7)*	
LFERT	0.11 (2.1)**	0.15 (3.1)***
LCHEM	0.12 (4.2)***	0.13 (4.2)***
LSLOPE	-0.24 (1.8)**	
EUCH		0.28 (1.4)*
EROSION	-0.74E-04 (2.3)**	-0.92E-04 (2.9)***
n	31	31
Constant	5.78	6.81
R ²	0.80	0.77
Adj R ²	0.74	0.72
D-W Statistic	1.75	1.68
B-P-G Statistic	10.13	11.97

^a The levels of significance on the t-statistics in parentheses are as follows:

* = 10 percent or better, ** = 5 per cent or better, *** = 1 per cent or better.

logarithms; EUCH = presence or absence of euchorozem soil (1=present/0=absent);

EROSION = sheet and rill erosion, as the total amount of soil loss per year (tonnes).

Sheet and rill erosion was found to have a significant, negative effect on LGVAP in Equation 4, and 5. The area of lucerne and the degree of slope were found to be

significantly related to LGVAP in Equation 4, while soil type had a moderate influence in Equation 5.

The process of model estimation must include consideration of the form of the degradation variable in the model, the problem of reversibility, the nature of the shift in the production function, spatial correlation and multicollinearity.

This analysis assumes that land degradation is technically reversible, thus allowing for an upwards shift in the production function from its present (degraded) level to some future (undegraded) level. The degree of the reversibility of this shift is examined in the following Section. But is the shift parallel, convergent or divergent? A non-parallel shift may be caused by non-neutral technology. For example, the response of output to fertiliser application may vary between farms with different erosion levels. A non-parallel shift of the production function reflects the presence of heteroscedasticity in the data. Griffiths *et al.* (1993) discuss the forms of heteroscedasticity and the tests for it, and note that a major difficulty in testing is the need to know which form of heteroscedasticity is present. The variance of LGVAP 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 test was applied to Equation 4 and 5 using Shazam (White 1992), and the B-P-G statistics are shown in Table 1. These results indicate that heteroscedasticity is not present.

Spatial correlation may be present between errors corresponding to neighbouring properties, which may be quite similar in terms of geographical and climatic features. This may occur when important variables are excluded from the model, causing the residuals corresponding to neighbouring properties to be correlated. To detect the presence of spatial correlation, the farms were ordered first by northing, then by easting, and the residuals plotted and examined for any trends. No obvious trends could be detected, but for completeness the Durbin-Watson test was applied to the ordered farms. Durbin-Watson statistics for the estimated models are shown in Table 1 and are inconclusive in that H_0 (no autocorrelation) is neither rejected or accepted. However, the estimated values are closer to 2 than 0, indicating that autocorrelation is negligible (Doran and Guise 1984).

The problem of multicollinearity must also be examined. In Equation 4, the highest correlations were between LAREA and LSLOPE (0.57) and (0.46) between LSLOPE

and EROSION. There were no correlations above 0.35 in Equation 5. Klein (1962) argues that multicollinearity between variables is only a problem when it is high relative to the overall multiple correlation among all regressor variables together. The multiple correlation (R) of the regression should therefore be compared to R values when all regressor variables are regressed against all other regressor variables. The multiple correlation of Equation (4) is (0.89). The other R values are as follows.

Model			R
LAREA	=	r(LALUC, LFERT, LCHEM, LSLOPE, EROSION)	(0.73)
LALUC	=	r(LAREA, LFERT, LCHEM, LSLOPE, EROSION)	(0.38)
LFERT	=	r(LAREA, LALUC, LCHEM, LSLOPE, EROSION)	(0.52)
LCHEM	=	r(LAREA, LALUC, LFERT, LSLOPE, EROSION)	(0.50)
LSLOPE	=	r(LAREA, LALUC, LFERT, LCHEM, EROSION)	(0.74)
EROSION	=	r(LAREA, LALUC, LFERT, LCHEM, LSLOPE)	(0.54)

The highest R value in these four 'regressor' models is (0.74), which is 15 percent less than the R value in Equation (4). This suggests that there appear to be no harmful collinear relationships between any of the independent variables.

For the purposes of further analysis, Equation 4 appears to be the preferred model, reflecting more favourable results from the statistical tests undertaken.

4.2 Farm-Level Benefits, Costs and Benefit-Cost Ratios

The benefits and costs for each farm are calculated according to the procedures outlined in Section 3. A five percent discount rate is used to convert these to present values. Benefit-cost ratios are then calculated for each farm according to Equation 2. Summary results of these calculations are given for each farm in Table 2. The area, amount of erosion, and additional soil conservation works required are given to provide a profile of each farm in the study area. Farm areas range from 178 to 1246 ha, with an average of 726 ha. The annual soil loss from sheet and rill erosion per farm ranges from 282 to 4876 tonnes, with an average of 1992 tonnes per farm, or 2.65 tonnes/ha/year. Areas of additional soil conservation required range from 0 ha to 891 ha, with an average of 164 ha. The values of PVB, PVCMAINT, PVCCHANGE, PVC, and BCR for each farm in the study area are recorded in Table 2.

**TABLE 2 COMPARISON OF BENEFITS AND COSTS FOR TREATING
SHEET AND RILL EROSION**

Farm No.	Area (ha)	Soil loss (tonnes/vr)	PVB (\$/ha)	Add soil cons(ha)	PVC MAINT(\$/ha)	PVC CHGE(\$/ha)	PVC (\$/ha)	BCR
1	1003	2319.43	177.25	19.7	2.44	14.92	18.42	9.62
2	752	2620.96	259.84	0	0.00	4.13	5.24	49.63
3	178	1434.64	691.69	36.3	28.80	101.96	127.27	5.43
4	486	343.38	16.99	47.3	13.74	61.47	82.37	.02
5	685	674.32	70.15	102.6	28.26	37.93	72.60	.10
6	834	805.26	47.78	0	0.00	0.00	0.00	-
7	1000	1227.84	55.18	198.2	32.21	8.82	44.51	1.24
8	1093	2340.59	159.50	79.5	9.29	8.37	25.28	6.31
9	450	3649.92	208.14	155.3	70.21	28.68	104.01	2.00
10	467	1311.88	94.84	205.3	156.37	116.86	289.15	0.33
11	1246	2318.00	429.29	556.6	43.98	87.20	155.65	2.76
12	405	1120.14	79.69	39.1	22.21	8.47	35.62	2.24
13	800	3353.70	652.68	0	0.00	32.47	40.85	15.98
14	1154	414.72	22.05	79.8	22.09	18.12	45.05	-
15	900	1049.68	120.50	0	0.00	52.10	75.76	1.59
16	335	3697.22	1167.16	7.4	4.68	64.87	90.58	12.89
17	520	3566.46	1335.35	8.9	1.94	194.76	109.87	12.15
18	1226	628.46	4.09	832.9	170.76	118.57	299.44	0.01
19	429	779.12	177.29	10.5	8.53	120.35	136.33	1.30
20	1113	1556.67	88.76	2.8	0.11	5.58	7.34	12.09
21	630	4876.28	2054.94	454.1	161.82	122.15	284.17	7.23
22	643	3845.00	1188.84	95.9	22.41	109.78	132.02	9.01
23	417	282.00	12.04	33.3	16.93	53.29	73.47	0.16
24	1137	1330.19	91.41	198.8	27.50	25.29	56.19	1.63
25	1345	2143.84	402.28	433.2	85.86	73.37	170.06	2.37
26	364	2542.59	1126.85	145.6	57.97	154.75	177.32	6.36
27	607	815.40	36.23	192.6	13.56	0.00	13.56	2.67
28	1200	661.60	15.42	891.1	109.57	121.73	231.50	0.07
29	291	2149.72	196.92	112.2	89.65	83.10	172.47	1.14
30	312	4849.73	459.24	23.1	1.43	61.80	77.94	5.89
31	500	881.52	144.86	130.8	38.57	27.45	71.33	2.03
Ave	726	1922.27	372.36	164.3	40.03	61.88	104.04	5.62

The BCRs across the 31 farms range between 0.01 and 49.63, with an average of 5.62. Some of the results from individual farms require further explanation before discussing the overall results. According to the GIS data, Farm 6 does not require any additional soil conservation works, and has no cropping land use. Therefore PVCMAINT and PVCCHANGE are both zero, leading to an infinite BCR value. Farm 14 had soil loss levels that are already lower than the 'negligible' rate, therefore a BCR cannot be estimated.

A number of farms have very high PVB and BCR estimates, suggesting that the potential benefits of undertaking soil conservation are very high. Their estimated costs of soil conservation are sometimes quite low according to the areas of additional soil conservation required. The costs of maintenance and land use changes are made by local soil conservation experts, and are based on purely biophysical grounds. On the basis of the results from Table 2, soil conservation works and changes in land use are highly profitable options for the majority of farms in this area.

Landholders in this area generally perceive heavy rainfall events as being the only times of high levels of erosion damage, and thus may only manage for these events. The high levels of potential benefit suggest that low yet regular levels of erosion damage, which are less evident, may also have a significant effect on agricultural output. Also, some soil conservation works undertaken in the past may now require significant maintenance work. Therefore, the full costs of land management in both biophysical and economic terms are being under-estimated. Therefore, the BCRs were re-estimated to include a maintenance cost for the entire farm area under agricultural production. These results are shown in Table 3. The PVCMAINT estimates are considerably higher, thus reducing the BCR values. Only 13 out of the 31 farms now have BCRs higher than 1.0, in comparison to Table 2 with 23 farms. The BCR estimates in Table 3 are considered to be a more realistic reflection of the true benefits and costs associated with sheet and rill erosion in the study area.

The BCR (100%) estimates in Table 3 are based on the assumption that a reduction in soil erosion from present levels to a level of 0.5 t/ha/year reflects a 100 percent achievement of soil conservation targets. Sensitivity analyses were also undertaken on these data to reflect a 95, 85 and 75 percent achievement of soil conservation targets. These results are also shown in Table 3.

**TABLE 3 COMPARISON OF BENEFITS AND COSTS FOR TREATING
SHEET AND RILL EROSION, WITH BCR ESTIMATES FOR ACHIEVING 100, 95,
85, AND 75 % OF SOIL CONSERVATION TARGETS**

Farm No	PVB (\$/ha)	PVC MAINT(\$/ha)	PVC CHGE(\$/ha)	PVC (\$/ha)	BCR (100%)	BCR (95%)	BCR (85%)	BCR (75%)
1	177.25	122.88	14.92	137.80	1.29	1.20	1.05	0.88
2	259.84	115.36	4.13	119.49	2.17	2.09	1.92	1.75
3	691.69	142.25	101.96	244.21	2.83	2.79	2.71	2.62
4	16.99	131.32	61.47	192.78	0.09	0.04	0.00	0.00
5	70.15	139.05	37.93	176.98	0.40	0.31	0.13	0.00
6	47.78	99.03	0.00	99.03	0.48	0.37	0.15	0.00
7	55.18	134.48	8.82	143.30	0.39	0.33	0.21	0.10
8	159.50	89.63	8.37	98.01	1.63	1.51	1.29	1.07
9	208.14	201.25	28.68	229.94	0.91	0.89	0.86	0.83
10	94.84	246.81	116.86	363.67	0.26	0.25	0.22	0.20
11	429.29	71.79	87.20	158.99	2.70	2.47	2.03	1.59
12	79.69	112.12	8.47	120.59	0.66	0.63	0.56	0.50
13	652.68	124.58	32.47	157.05	4.16	4.02	3.76	3.49
14	22.05	134.03	18.12	152.15				
15	120.50	127.00	52.10	179.10	0.67	0.56	0.35	0.13
16	1167.16	132.42	64.87	197.29	5.92	5.85	5.71	5.57
17	1335.35	77.74	194.76	272.49	4.90	4.81	4.62	4.44
18	4.09	207.36	118.57	325.93	0.01	0.00	0.00	0.00
19	177.29	234.33	120.35	354.68	0.50	0.46	0.38	0.29
20	88.76	94.64	5.58	100.22	0.89	0.77	0.56	0.35
21	2054.94	226.05	122.15	348.21	5.90	5.80	5.60	5.39
22	1188.84	177.50	109.78	287.27	4.14	4.04	3.84	3.68
23	12.04	126.27	53.29	179.56	0.07	0.03	0.00	0.00
24	91.41	139.03	25.29	164.32	0.56	0.46	0.29	0.11
25	402.28	177.90	73.37	251.28	1.60	1.43	1.11	0.79
26	1126.85	158.21	154.75	312.96	3.60	3.53	3.41	3.28
27	36.23	88.41	0.00	88.41	0.41	0.36	0.25	0.15
28	15.42	218.69	121.73	340.42	0.05	0.00	0.00	0.00
29	196.92	179.22	83.10	262.32	0.75	0.74	0.71	0.69
30	459.24	32.01	61.80	93.81	4.90	4.85	4.77	4.69
31	144.86	841.85	27.45	869.30	0.17	0.15	0.12	0.09
Ave	372.36	164.62	61.88	226.50	1.71	1.64	1.51	1.38

4.3 Site-specific benefit-cost ratios

The preferred BCRs (100%) can now be regressed against land use and biophysical factors, as illustrated in Equation 3, in order to determine which of these factors are most influential in changing the BCR levels. The estimated models at the farm level are shown in Table 4.

Table 4

Preferred models for the relationship between benefit cost ratios and land use and biophysical factors

Regressor variable	Equation (6)	Equation (7)
EROSION	0.001 (10.2)***	0.001 (10.6)***
SLOPE	-0.065 (1.9)**	-0.15 (2.1)**
EUCH	0.91 (2.2)**	0.079 (2.0)**
AREA SC	-0.0009 (1.4)*	
TREES		0.004 (1.4)*
n	31	31
Constant	0.098	0.077
R ²	0.84	0.84
Adj R ²	0.81	0.81

^a The levels of significance on the t-statistics in parentheses are as follows:

* = 10 percent or better, ** = 5 per cent or better, *** = 1 per cent or better.

The dependent variable BCR = the benefit-cost ratio. The independent variables are: EROSION = sheet and rill erosion, as the total amount of soil loss per year (tonnes) SLOPE = average slope across the farm; EUCH = presence or absence of euchorozem soils (1=present/0=absent); AREA SC = area treated with soil conservation works, but

requiring additional works to complete erosion control, or works at end of lifespan;
TREES = the total area of trees (ha).

As in Section 4.1, the problem of multicollinearity can be examined using a Klein test. In Equation (6), there are no correlations above (0.26). In Equation (7), the highest correlation is (0.88) between SLOPE and TREES. The multiple correlation (R) of the regression should therefore be compared to R values when all regressor variables are regressed against all other regressor variables. The multiple correlation (R) of Equation (7) is (0.92). The other R values are as follows.

Model				R
EROSION	=	$\hat{r}(\text{SLOPE, EUCH, TREES})$		0.18
SLOPE	=	$\hat{r}(\text{EROSION, EUCH, TREES})$		0.88
EUCH	=	$\hat{r}(\text{EROSION, SLOPE, TREES})$		0.23
TREES	=	$\hat{r}(\text{EROSION, SLOPE EUCH})$		0.88

The highest multiple correlation in these four 'regressor' models is (0.88), which is 4 percent less than the R value for Equation 7 (0.92). This suggests that this level of correlation between TREE AND SLOPE is tolerable, according to Klein (1962).

The results from Table 4 indicate that levels of erosion, slope, soil type, area of additional soil conservation required and area of trees are the important biophysical and land management predictors for BCRs. Each of these indicators were obtained from the GIS data, thus allowing further analysis of these results in the GIS, as described below.

4.4 GIS Predictions

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 Section 4.3 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. Each farm that has a corresponding category defined in (2) are grouped together.
- (4) With the categories defined, a new variable called 'BCR' is created, which contains the farms numbers grouped according to the four categories.
- (5) This variable is added to the database, and can now be stored, mapped and modelled in the same way as the other biophysical variables already present in the database.

A map of the estimated BCRs for each surveyed farm can then be produced (Figure 2), 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. Figure 2 shows that the 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 the predictor variables of erosion, slope, soil type and area of additional soil conservation (identified from Equation 7). 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).

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 20x20m 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

Figure 2. Predicted BCRs and ratios of vegetation cover and its relation to wildlife loads for the entire area.

variable and other database variables is that a modelled variable does not contain 'hard' data, but rather predictions generated by a decision tree model. The modelled BCR variable is shown in Figure 3. This provides the information at a higher level of resolution than at the farm level (Figure 2), thus allowing landholders to make decisions at a more relevant management level.

It is also possible to test the predictive accuracy of the derived BCR models. This can be done by making a comparison between a 'training data set' and a 'validation data set', consisting of a random split of the farms into two sets. A model is then derived from the training data set, and the predictions compared with the modelled BCR variable. Results from this test indicate that the derived BCR models have a high level of predictive accuracy.

5 DISCUSSION

The results indicate that there are many profitable opportunities for managing sheet and rill erosion in the study area. Therefore, if these results are accurate, why are more farmers not recognising the financial advantages of undertaking land management programs?

The reason may lie with the calculation of the benefit-cost ratio, so further examination is warranted to see if there are some factors that are influencing the BCR values that have not been detected in the analysis thus far. Correlations between BCR values and the bio-factors of age, membership of landcare, whether the landholder intends to sell in the future, and whether trees have been planted did not reveal any significant relationships. However, correlations between BCR and present value cost and benefit estimates were more revealing. The correlation between BCR and PVB was (0.95), indicating the major influence of the benefit estimates on the BCR.

The benefit-cost ratios of Table 3 range from 0.01 to 5.92 for a 100 percent achievement of soil conservation targets. They show that further soil conservation measures on some farms are profitable (above 1.0), and greatly profitable (greatly above 1.0). They also show that further measures on some farms are unprofitable. The economically-rational farmer could be expected to have already undertaken the profitable measures, so why are there still profitable opportunities? One reason may be lack of information. Another, perhaps more relevant reason, is the uncertainty attached to the benefits and costs.

Accordingly, a risk analysis was undertaken to determine the sensitivity of the benefit-cost ratios to changes in the benefits and costs.

The representative farm, for the risk analysis was based on mean annual benefit and cost values for the 31 farms. The benefits and costs were assumed to follow a normal distribution, truncated to include observations within two standard deviations from the mean. This will, of course, include 95 percent of the observations of a normal distribution. The minimum values of benefits and costs were set at \$0. The time period was changed from perpetuity to 15 years to more properly reflect the farmers expectations that the measures will actually yield the given benefits that were modelled. The mean likelihood, that actual yield equals predicted yield, was set at 0.95 with minima and maxima of 0.75 and 1.00. A five percent discount rate was used, as this is considered to be close to the 'real' private rate of discount for farmers borrowing money for soil conservation works through the Rural Assistance Authority.

While the mean benefit-cost ratio was 2.00, the cumulative probability distribution of ratios gave the following results.

Ratio	Percentage of observations at or below the ratio
0.8	29.3
1.0	35.2
1.2	41.2
2.0	62.7

The high mean of 2.00 is therefore accompanied by a 35.2 percent chance that the measures will actually be marginal or unprofitable. A risk-averse farmer might well choose to invest elsewhere.

The potential benefit of increased agricultural production through the reduction of land degradation is clearly a difficult value for a landholder to estimate. Landholders often perceive a loss in output due to erosion, but find this difficult to quantify in dollar terms. The BCR estimates in Table 3 are based on the assumption that a reduction in soil erosion from present levels to a level of 0.5 t/ha/year reflects a 100 percent achievement of soil conservation targets. Sensitivity analyses were also undertaken on these data to reflect a 95, 85 and 75 percent achievement of soil conservation targets. The results reveal that

when the adjustments are made from 100 percent effectiveness to 75 percent effectiveness the change in average BCR values is from 1.71 to 1.38.

Other issues in relation to the estimation of Equation 1 require further examination. One is whether reductions in soil quality necessarily lead to a decline in output — that is, can non-land inputs such as fertiliser and other technologies be a substitute for land quality, and therefore maintain output while degradation continues to occur. Examination of the separate significance of the regressor variables in Table 1 indicate that the inputs of area, fertiliser, chemicals, slope, soil and degradation separately influence the value of output. Thus, while increases in land area, fertiliser, chemicals and soil type increase output, increases in degradation and slope decrease it. Therefore, non-land inputs may in some way be masking the negative effects of decreased land quality. Another issue is the omission of capital and labour variables from the estimated equations. Capital proved to be a difficult figure for landholders to determine, therefore fertiliser and chemicals were used as substitutes for capital. A labour variable was included in earlier estimations of the model, but did not display any levels of significance.

The models are based on a single production year, therefore it could be argued that other factors such as climate may be having an influence on output in that particular year. Examination of ABS farm survey figures for Gunnedah Shire for a number of years either side of the 92/93 period indicate that it was an 'average' year, and this is supported by landholder's remarks during the survey, indicating that it was a normal production year.

6 CONCLUSION

Economic information should not be the single guiding factor when estimating benefits and costs, as illustrated by the results in Table 4, where biophysical factors are also having an important influence on BCR levels. However, at present, decisions regarding land management at the farm scale have very little detailed economic/biophysical information to guide them. This research provides a consistent method of analysis, by giving information on where degradation is having the most significant effect on agricultural output, and relating the profitability of undertaking land management programs to various biophysical attributes and management attitudes. This process of data extrapolation using GIS technology allows the BCR results estimated at the farm level to be disaggregated below the farm level, including both surveyed and non-

surveyed areas. This therefore provides economic information at a scale that is useful for landholders in a decision-making process.

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