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ECONOMIC COSTS OF CROPLAND EROSION: AN APPLICATION OF GIS-BASED NATURAL RESOURCE ACCOUNTING APPROACH[*]

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Rapid technological advancements and genetic improvements have masked the consequences of soil erosion for Australia's croplands. Tightening economic pressures and growing environmental awareness demand greater focus on changes in productive potential and off-site consequences of degradation. Lack of reliable quantitative data on the rate and extent of erosion in different ecological environments, land-use systems and geographical regions increases the risk that policy initiatives will be inefficient and even counter-productive.

This paper presents a GIS-based natural resource accounting framework for the assessment of the economic costs of land degradation over extensive geographical areas and its use for policy analysis. A framework for the estimation of NAIL (net agricultural income loss) and EVIL (external value of income loss) across space and through time is presented. Preliminary results of an application to assess the costs of sheet and rill erosion over an area of NSW are discussed.

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1. Introduction

Land degradation is a major threat to terrestrial environment and sustainability of an efficient sedentary agriculture. Development of commercial agriculture upon European settlement has often been blamed for high rate of degradation over Australian croplands. Often domestic livestock are accused of having a similar effect on our rangelands but increasingly wildlife and feral animals are being attributed similar status.

Land degradation is a complex phenomenon. It leads to changes in resource productivity at the point of origin (on-farm) as well as in localities further away (off-farm). Its implications are therefore different for primary producers and other Australians and vary from region to region. From the view point of the farmers, advances in technology and changes in land use patterns have led to rising farm yields. Technological progress conceals the effects of degradation. Often the effects are cumulative, lagged and only economically significant beyond a certain threshold. Occurrence of degradation may therefore, not become a problem to a farmer until the state of degradation causes significant losses in profitability. This has, in the past led some analysts to consider land degradation as primarily a 'private' economic issue not warranting public intervention (Kirby and Blyth, 1987). However, Chisholm (1987,1988) and Sinden (1988) have argued that the existence of off-site effects and the lost welfare of the non-farm members of the society as sufficient reasons for government involvement in abatement and restorative action.

More recently this view has gained popularity with the growing awareness of the potentially irreversible nature of the degradation process and its effects on the wider community by way of declining environmental quality. Pressure is also mounting on farmers to increase productivity due to falling commodity prices and weakening demand. These and the increasing concerns over future sustainability of present agricultural systems have made land degradation an important public policy issue in the 1990s.

Land is a finite resource that is conditionally renewable in nature (Young 1992). It is the primary medium for food production and an essential element of the environmental support system. The challenge for today's agriculture is therefore to break the nexus between production and degradation—both within and beyond the perimeter of the farm. Meeting this challenge requires wider community participation, effective policy support and efficient program development. A broader understanding of the associated costs of soil degradation to the private landholder and the community at-large is a vital prerequisite in this process.

However, there is a general lack of information on the severity and extent of the problem. Its economic costs to the society are not clear. Available national estimates rely heavily on two studies conducted in the seventies employing objective assessment criteria (Standing Committee on Soil Conservation, 1971; DEHC, 1978).

Given the vastness of the Australian territory and the fragile nature of its environment, data for policy analysis need to be obtained with reference to different ecological environments, land use systems and geographical regions. This paper describes a project that intends to meet this demand by collecting, storing and analysing the existing information to derive estimates of the magnitude of soil degradation costs across major parts of Australia. Geographical Information System (GIS) methodology is employed to collate, store and digitise the spatial information. Various estimates are derived based on process models and mathematical programming techniques. Policy analyses are conducted and presented in a natural resource accounting (NRA) framework. A methodology to assess the economic costs of land degradation and an application of that methodology to the assessment of costs of soil erosion from farm-lands over statistical local area (SLA) Orange in NSW is presented. The data was obtained mainly from the Australian Bureau of Statistics (ABS) and the NSW Land Information Centre and supplemented with data from various CSIRO and ABARE sources. Progressively the analysis will be extended to cover the other forms of land degradation by applying the methodology developed in this paper with appropriate variations over NSW.

2 Land degradation Processes

Land degradation is a natural resource depletion problem. Therefore it is associated with the reduction of benefits enjoyed by the use of that resource. Different definitions of land degradation have reflected this view (Charters 1987, Barrow 1991). The essence of these definitions are that; it occurs as a result of several forces including human activity and the process is not totally reversible, and therefore involves potential loss of social benefits. Human interference can be positive in terms of restorative and conservative management or negative—as believed in most cases—through acceleration of natural forces. Also considering the spatial and temporal dimensions of the problem, land degradation may be defined as follows;

> Land degradation can result from any causative factor that changes the physical, chemical or biological status of the land in a manner that either reduces its value or the value of related resources located on other sites.

Values that can be affected both 'on' and 'off' farm include the present and future worth of both tangible and intangible goods and services. Decline in production potential, habitat value, lost storage of reservoirs and recreation and aesthetic values are some such examples. They can also be characterised by increased water treatment and infrastructure maintenance costs.

Land degradation is considered to be the most serious environmental problem confronting Australia. It stems from the fact that nearly half the arable land is considered to be degraded to some extent in a country where around 90 per cent of the land cannot support viable commercial cropping systems (Woods, 1984; DAHE, 1986). Furthermore, Australia's major rivers indicate increasing trends in salinity, heavy sediment loads and buildup of nutrient levels leading to increased incidences of algal blooms and disruption of aquatic habitats.

The physical processes of land degradation are well understood. The various forms of degradation and the factors limiting its geographical spread are reasonably well studied particularly in the US (Lal, Hall and Miller, 1989; Barrow, 1991). Information under Australian conditions however is broad based and often lack the level of details required for effective policy analysis (Charters, 1987; Yapp and Gibbons, 1987; and Freebairn et al, 1989). Most of the available knowledge is limited to subjective assessments based on ad hoc criteria (Woods, 1984). There is a dearth of models that enable predictions of annual rates of degradation and their effects on the economy. This not only acts as an important deterrent for policy development (Commonwealth of Australia, 1989), it also increases the risk that policy initiatives will be inefficient and even counter productive.

Various forms of land degradation occur throughout the country. Soil erosion, salinisation, acidification, structural depletion and degradation of vegetation are the generally identified forms of degradation commonly occurring over arable lands. Summarised in Figure 1 are the various processes of land degradation, factors affecting their distribution and their association with the economic well-being of the farm.

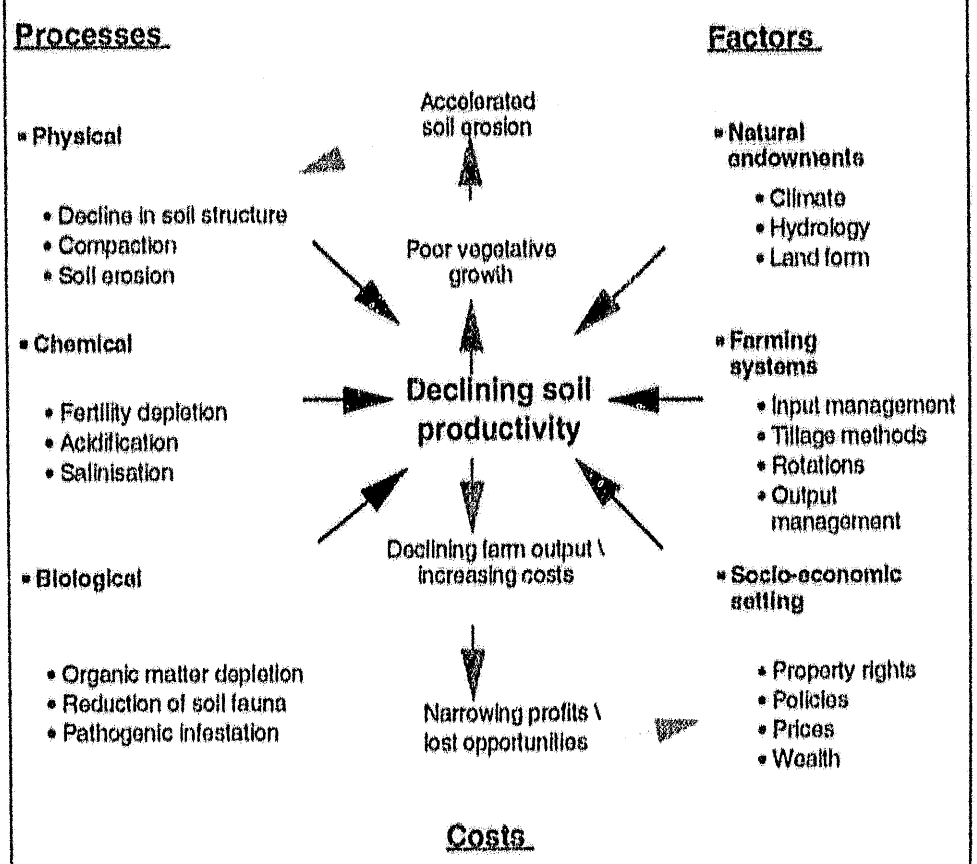

Figure 1: Causes and consequences of land degradation

The following discussion provides a brief introduction to the different forms of degradation and examines their relationships to each other.

Any land use option that exposes land to elements of weather increases the risk of erosion in proportion to the duration and the degree of exposure. *Water erosion* is widely prevalent in the undulating cropping and grazing lands of the non-arid areas of eastern Australia, whereas, *wind erosion* is a major problem in the drier regions. As the term implies the principal force behind water erosion is the kinetic energy of water, carried by falling raindrops. Erosion rates vary closely with rainfall erosivity and generally increase northwards in Australia. Rates vary from around 0.02-0.2 t/ha in Wagga Wagga in the South, to around 80-300 t/ha in Innisfail in the north (Freebairn 1992). Similarly, wind erosion results from the removal of finer soil particles by the forces of wind. Essentially most forms of erosion are irreversible.

Dryland Salinity is a condition caused by an excess of salt or alkaline material in the root zone. It occurs in the southern regions where past land clearing has contributed to rising water tables. Capillary rise brings moisture with dissolved salts to the surface and when the soil dries out through evaporation it leaves dissolved salts behind in large concentrations sufficient to impair crop productivity. This leads to partial abandonment of land only to be infested with highly salt tolerant scrub vegetation, thus further depleting the land's productive capacity. Often these lands become vulnerable to wind erosion during drought seasons due to top soil exposure through overgrazing induced by the salt-lick available to grazing stock. In some areas this leads to the exposure of saline subsoil and the formation of salt scalds.

Besides this, saline seepage also occurs on footslopes and in drainage depressions during wet seasons. This paves the way for the formation of salt pans during dry seasons and salination of surface streams. Therefore, dryland salinity, wind erosion, and scrub invasion could occur in tandem over certain areas of southern Australia.

Irrigation salinity occurs primarily in association with major irrigation schemes such as those along the Murray-Darling (MD) Basin. Seriously affected areas include the Kerang, Wakool and Shepparton districts. Inefficient irrigation management, inadequate drainage, leakage from delivery systems and naturally occurring sub-surface water movement are believed to be the principal causes. Apart from agricultural losses, this is also leading to significant external costs as the MD river system also serves a large urban community in the south, where progressive salt built up has led to serious water quality problems. This is also associated with lost recreational opportunities.

Acidification is a recently recognised problem in the wheat-sheep belt of southern Australia with annual rainfall exceeding 500mm. This is believed to be caused by acceleration of the natural leaching process of soils due to certain agronomic practices. Repeated cultivation of legume-based pastures or grain legumes, continued removal of alkaline plant and animal produce, organic acid build up from increased level of soil organic matter and the excessive uses of acidifying nitrogenous fertilisers are found to be the major causes. There is a non-linear relationship between crop yields and soil acidity. As crop yields decline farmers either change crops or apply lime to restore soil pH to profitable levels. Some acidity is irreversible. Productivity losses result through acidity by directly reducing the crop yields, as well as, due to treatment costs and its associated impact on increased erodibility of farmland.

Structural depletion is also a by-product of certain agronomic management causing soils to become harder, and impair plant growth via restricting the entry of air, water and plant roots into the soil. It also restricts the activities of soil organisms, diminish soil assimilation processes, and as a result, crop and pasture yield decreases leading eventually to increased runoff and water erosion losses. Compaction by heavy cultivation equipment under bad moisture regimes, continued trampling by stock, and excessive cultivation of soils are considered to contribute to this condition. Reversal requires deep ripping and management to restore organic matter.

Fertility depletion is a complex phenomenon arising as a consequence of one or more processes discussed above. It is often associated with nutrient leaching from top soils, loss of organic matter affecting the physical properties of soil that regulates the availability of plant nutrients, such as the soil pH and the cation exchange capacity. It could lead to significant productivity losses by constraining the crop growth and altering the soil microbial activity and making crops vulnerable to *pathogenic infestations*. Reclamation costs vary mainly depending on the cause.

Degradation of vegetation and encroachment by woody weeds is generally a culmination of a series of other degradational processes that alter the bio-diversity through changes in plant density, species composition, plant vigour and the ability of vegetation to compete with each other and naturally occurring pests and predators. Woody weeds are seriously depleting the productivity of Australia's rangelands but weeds are also a problem elsewhere for native vegetation. Eucalypt decline in farmlands is a common example. As also noted earlier, the degraded vegetative cover allows the erosive energy of wind and water to act directly on the soil thus enhancing the rate of soil erosion.

3. Analytical framework

Having briefly defined land degradation and identified its effects on farm productivity and management costs, the following discussion aims at developing a framework to analyse and assess these impacts.

3.1 Social welfare analysis

Effects of soil erosion are inevitably long term in nature and are potentially irreversible. Therefore it deals with social welfare of future generations. Supply of land in the economy is fixed but supply of products from it varies with its quality. Individual farmers are largely price takers and hence the demand curve they face is nearly perfectly elastic (line D_0 in Figure 2).

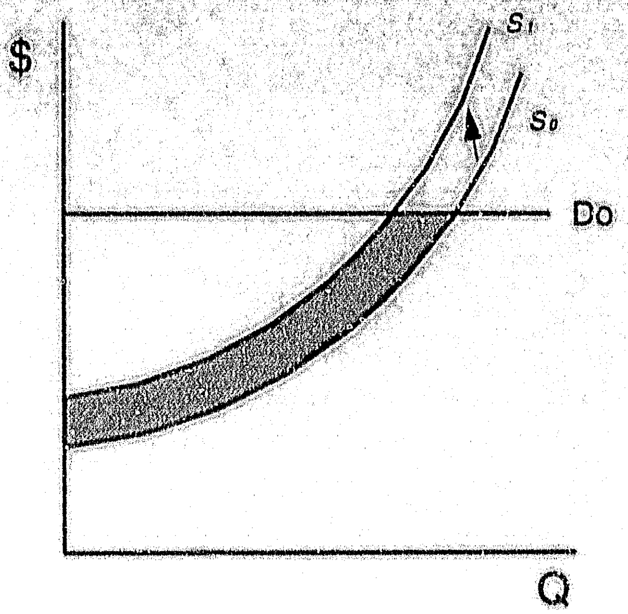

Figure 2: Economic cost of land degradation

Thus one way of measuring the costs of degradation is to estimate the loss in economic rent associated with the shifts in the supply curve (adjusted for changes in relative prices and costs and also technological change). This, however, requires knowledge of individual supply curves on a product by product basis. The alternative approach is to estimate the capitalised present value of the reduction in future income from the asset. Conventionally, this is done under current prices but given the conditionally renewable nature of the asset, there seems to be a good case for assuming increased scarcity.

3.2 Measures of economic costs of soil erosion

3.2.1 Concept of opportunity cost

The concept of opportunity cost offers a means of imputing values to the use of resources where markets do not provide a meaningful estimate of costs. The intricacies involved in the definition of opportunity cost for soil erosion are best documented in the exchange between van Kooten, Weissensel and de Jong (1989) and van Vuuren and Fox (1989).

Opportunity costs arise due to alternative management regimes and/or uses of resources and defined as the benefits forgone in the profit maximising alternative. Economic theory tells us that profits will be maximised when the value of Marginal Physical Product (MPP) equals its market price. Alternatively we can define this as the minimum income the farmer would forgo by losing one unit of the resource, which in turn is the private opportunity cost of the resource depletion.

3.2.2 Incidence of private and social opportunity costs

Yapp(1989) states that the "cost of farm erosion (on-site) can be measured as lost income from lower production or as the cost of restoring former productivity levels through increasing fertiliser applications". But these two approaches lead to two different estimates and in itself none of the approaches capture the total costs involved. As observed from the earlier discussion, one needs to consider the net effects of the two approaches, in order to include all the costs. Moreover, the economic theory tells us that application of inputs may not be efficient beyond the profit maximising combination, and imposes extra opportunity costs with such use.

Budget constraints and income pressure

The realities in farming business of budget constraints and lack of knowledge coupled with the associated risks due to both natural and market factors often do not allow the farmers to profit maximise in an unconstrained manner. For instance, farmers' commitments to lenders and the nature of their other fixed costs may require them to ensure a higher return on their business than can be achieved without endangering potential future income—as often is the case particularly in poor crop years. The practical inability of farmers to diagnose economically sound input levels may also contribute to this situation. Use of extra doses of fertiliser to offset loss of top soil is taken as such an example in this analysis.

As fertiliser used in production increases, the marginal product per unit of fertiliser diminishes, perhaps beyond its actual cost. In the same way the value (imputed) of output lost through erosion must increase. Therefore the total opportunity cost of soil erosion (on-site) is the sum of the losses in MPP of fertiliser due to over application of fertiliser beyond its economic optimal level, plus the net value of crop losses forgone due to eroded top soil. This is identical to the economic cost of on-site effects of soil erosion we have defined earlier.

This illustrates that the opportunity costs of soil erosion include both increased operating costs and reduced benefits. Some of these costs are also associated with degradation induced changes to crop mixes and rotation practices. Ultimately, however, it all translates through to income and overall farm profitability.

It would also yield costs to the wider economy as that portion of inputs used on inefficient activities could be used on more productive activities elsewhere, as the economic optimum allocation is found when the value of the marginal product is equal in all uses. As such, both in private economic sense as well as society's point of view, one needs to consider both extra costs on production due to soil erosion, as well as, the value of forgone benefits to measure the decline in profit-maximising income stream due to lost productivity of the natural endowment.

We also need to consider at this stage, the repetitive value of the land resource that brings time into our analytical framework. Although valuation of private and social time preference is an area of some debate in economics, at this stage we can clearly assume that at least there are distinct differences between the two. Time preference is generally measured in terms of the discount rate. Divergence in social and private time preference leads to a divergence between social and private opportunity costs of resources and in-turn lead to social welfare losses, through its effect on resource use decisions.

We can therefore summarise different sources and measures of opportunity costs created on and off farm due to soil erosion as given in Table 1.

Table 1: Sources and measures of different cost streams

Net Agricultural Income Loss (NAIL[1])		External Value of Income Loss (EVIL)	
Private	*Community*	*Private*	*Community*
lost net income at farm-gate price discounted at market interest rates	lost net income at market price discounted at social interest rates	external private opportunity costs and market opportunity loss at market price discounted @ market i	external social opportunity loss and market opportunity loss at social price discounted @ social i

These definitions do not capture the natural fluctuations in crop productivity arising through climatic variability, etc., and the changes in economic variables that affect farmer behaviour. In reality however, these variables are significant and cannot be ignored. The actual estimation procedure discussed later on would accommodate such variability within the availability of data. For example, effect of soil erosion is mainly felt when other environmental factors are least conducive (Lal 1987). Therefore, erosion increases the income risk due to uncontrollable weather conditions.

4. Natural Resource Accounting (NRA)

Why NRA?

The aim of any accounting system is to provide management information suitable for analysing the past performance and to plan for the future. That is why all business enterprises, big and small, construct their annual accounts. The same principle applies to a national economy. The only difference is that there is a standard practice of 'writing off' investment costs in business accounts, at least as an exercise of tax minimisation. As we do not pay explicit taxes for the use of natural endowments—other than in the form of deteriorating environment and lost income opportunities—depreciation of natural assets is neither included in national accounts nor in most models used for much policy assessment. This approach, however, only makes sense if "natural resources are so abundant that they have no marginal value" and can be regarded as "free gifts of nature" (Repetto 1992).

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[1] After (Grohs, 1992). However NAIL is used here with a different definition.

4.1 An accounting framework

Natural Resource Accounting offers a framework to present information on natural resources, the environment and the economy. Essentially natural resource accounting systems begin with a conventional accounting framework and then deduct the cost of resource degradation and depletion.

To do this, however, it is necessary to have access to large amounts of environment, resource and production data organised into a coherent, temporal and spatial framework.

Geographic Information Systems (GIS) provides an excellent platform to organise such data and then construct a GIS-based resource accounting system (Young 1992). On completion, such accounts will show useful information such as the annual costs of soil erosion, cost of build up of soil acidity, annual cost of deforestation, etc.

The procedure for the construction of a set of GIS-based accounts capable of estimating the annual cost of land degradation involves several steps.

i. Development of soil and climatic database

ii. Development of the agricultural landuse and production database

iii. Computation of estimates of annual degradation rates and their effects on productivity and income.

4.1.1. Development of the soil and climatic database

Detailed soil and slope maps of the study region are available from the Murray-Darling Basin Commission and the CSIRO Division of Soils, with varying degrees of accuracy for different soil parameters. A map overlay process was employed using GIS software to extract the best available information from these two sources. These information were supplemented by data from Yapp and Gibbons (1987) to develop new maps delineating spatial distribution of different soil types and slope categories for the study area.

4.1.2. Development of the agricultural landuse database

Data on agricultural landuse and production was obtained from the 1989-90 agricultural census of the Australian Bureau of Statistics(ABS) and corrected for spatial inconsistencies. There are three categories of principal landuse recorded by the ABS. They are a cropping area, sown pasture area and a residual which contains unimproved pasture, trees, etc. The distribution of these three categories vary over different farms, but are related to the overall farm size. The average farm size generally increases westerly from the coast, and so does the magnitude of residual farm area.

ABS data however, are neither organised by soil types nor do they contain information that can be used to estimate the distribution of crops across them. Therefore a combination of techniques involving GIS-based map overlay process, satellite image analysis and mathematical programming was employed for the reallocation of observed cropping areas over various soil classifications[2]. Essentially the process involves the identification of a "greenness" profile for crops and pastures on a month by month basis and the use of this information with a set of constraints about the nature of land use to identify where each crop type is located.

The result is a mosaic of pixcels each approximately 1km^2 and tagged according to what they grew and what this production was worth.

4.1.3 Assessment of costs of land degradation

The land degradation assessment problem involves two major steps; developing physical estimates of the extent of soil degradation, and imputing values to derive economic estimates based on degradation-productivity criteria.

There are two common approaches to the physical assessment of land degradation:

- Current status assessment based on visual observation of existing degradation and;
- computation of potential degradation hazard through process-based predictive models.

Each of these approaches has its own strengths and weaknesses. Direct measurements provide a broader overview and are useful for setting up benchmarks for future comparisons. However, being objective oriented they are more likely to estimate the extent of degradation with little emphasis on the degree of occurrence of a particular problem. Process based estimates on the other hand provides a basis for estimating degree of impact and can be employed as a cost-effective tool for developing time series estimates. They are particularly powerful when good benchmark estimates are available. For the present purpose of deriving annual estimates for natural resource accounting purposes the process-based modelling approach was considered more relevant, as it provides a useful way of interpolating between benchmark data which is only available at course scale and for scattered time periods.

4.2. Estimating soil erosion - the physical account

The physical assessment of soil erosion is based on the process model Universal Soil Loss Equation (USLE) developed in the US (Wischmeier and Smith 1978). Modified versions of the equation adopted to Australian conditions are also available (Rosewell and Edwards, 1988). A revised computerised version of USLE, RUSLE has recently been released in the US (Renard 1992).

Application of this equation is not uncommon under Australian conditions (Freebairn et al. 1989, Yapp 1989, Watt 1990). However, the availability of data to run USLE under

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[2] Methodological advances made in these areas will be reported in Walker and Young 1992 and other forthcoming publications from the project.

Australian conditions is very limited and various parameters need to be derived through interpolation and extrapolation based on available research evidence (Freebairn et al, 1989).

4.2.1 Computation of USLE estimates

The USLE computes soil loss through sheet and rill erosion based on the four major factors affecting soil erosion. They are represented by:

- R, climate erosivity;
- K, soil erodibility;
- LS, topography; and
- CP, landuse or crop management.

The USLE incorporates these factors to give $A=RKLSCP$, where, A is the computed soil loss, R is the rainfall-runoff erosivity factor, K is a soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is a cover management factor, and P is a supporting practice factor. A is generally estimated as a longtime average annual soil loss under climatic, soil, topographical and crop management practices represented by the data. However, with appropriate selection of its factor values and some controversy, USLE can be used to estimate the average soil loss for a particular cropping practice under given rainfall-soil management regimes. The ideal solution to this problem is to run USLE through PERFECT[3](Littleboy et. al. 1989) but this requires much more information and is seen as a refinement best left until a pilot accounting system is operational for a large area.

Based on the data gathered in the GIS soil erosion estimates were computed over pixels with uniform attributes. These were later aggregated over the entire SLA. In the pilot study USLE factors C and P were combined to form a single factor CP, based on Yapp and Gibbons (1987).

4.3 Estimation of productivity losses - the lost agricultural output

4.3.1 Erosion-productivity relationships

Effect of erosion on crop yields results from complex interactions among soil properties, crop characteristics, and the prevailing climate. As indicated earlier, management practices that reflect technological progress can mask the effects of erosion on crop productivity to a large extent. It is, therefore, difficult to establish direct causal relationships between rates of soil erosion and reduction in crop yields due to erosion-induced soil degradation (Lal 1988).

This is reflected in the paucity of available quantitative research evidence on erosion's impact on crop production around the globe despite vast literature dealing with the subject. Research reported in two recent reviews firmly establish that erosion lowers the productivity of the

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[3] PERFECT is a process based model that simulates plant-soil-water-management dynamics in an agricultural system.

soils through soil removal or sediment deposition[4] (Stocking 1984, Lal 1987). However, results are difficult to generalise as numerous techniques have been employed under varying ecological conditions. These include, direct measurement of field productivity losses, desurfacing or scalping experiments, laboratory and greenhouse studies, and computer simulation models .

Research in Australia on erosion-productivity relationships is also rather limited. Available information for some soils and crops do not offer enough evidence to generalise these results over various crops, soils, climates, management practices and the diversity of experimental approaches employed. On the other hand, the inherently low fertility level of most Australian soils and their very poor comparison with those of Europe and North America render extrapolations based on experiences overseas even harder to justify. Therefore, this study relies heavily on the scant information available from the limited Australian sources. Whenever data was found to be inconclusive or conflicting decisions were made on the basis of collective knowledge of several informed sources.

Aveyard (1983) reported that grain yield reductions attributed to erosion are around 0.52 percent per tonne/ha as observed on small plots of a red duplex soils of NSW. White (1986), in his review of soil erosion and agricultural productivity stated that duplex soils appeared to be more prone to productivity losses due to erosion.

4.4 Estimation of economic costs - the value account

4.4.1 Net Agricultural Income Loss (NAIL)

In the analysis that follows it is assumed that, erosion results in productivity losses, and that the future landuse practices would not significantly improve the productivity of land. The costs of any restoration activities are separated from normal farm costs as they have their own opportunity costs. For example, development of land-substituting technology is expected to reduce the costs of soil loss —greenhouse production. However, technological developments and applications are not socially costless as resources employed have opportunity costs elsewhere.

The following model is used to compute NAIL. The model treats farm's fixed and variable costs separately. Fixed costs (CF_i) are not expected to change with loss in productivity. Declines in soil productivity, however, are assumed to change variable costs (CV_i) like harvest labour, processing and selling expenses which are a function of final output level. Reduction in variable cost is a saving to the farmer, while it is an income loss to the sellers of those inputs.

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[4] Although sediment deposition has contributed to high fertility in most of the alluvial soils in Australia and overseas, selective deposition associated with cropland erosion causes significant damage to agricultural lands.

For a given productivity loss of x% per tonne of soil loss per ha for each crop i in a given pixcel a, the value of on-farm income losses AIL_{ia} [\$/tonne(of soil)/ha] may be computed as follows:

$$AIL_{ia} = AI_i^* - AI_i \qquad (1)$$

$$AI_i = Y_i \times (LV_i - CV_i) - CF_i \qquad (2)$$

$$AI_i^* = Y_i \times (1 + \tfrac{x}{100}) \times (LV_i - CV_i) - CF_i \qquad (3)$$

AI_i and AI_i^* denotes the agricultural income per ha for a crop with and without soil erosion respectively.

Assuming that the effect of the farm income losses at the pixcel level depend on the level of output Y_i (tonnes/ha) local value of output LV_i (farm-gate price, \$/tonne), the observed erosion rate D_{ia} (tonnes/ha), and the assumed productivity losses x (per cent). Therefore, when the area of crop i in pixcel a A_{ia}(ha) is known, the net agricultural income loss *(NAIL)* can be computed by the following equation.

$$NAIL_a = \sum_i AIL_{ia} \times A_{ia} \times D_{ia} \qquad (4)$$

Although this income is measured for a given crop year, there is a perpetual loss of that income as there is a permanent loss of endowment. Therefore given the market rate of interest (i), the private value of NAIL, $NAIL_p$ can be obtained by dividing equation(4) by i to obtain the discounted value on perpetuity[5].

Similarly the value of NAIL to the community, $NAIL_c$ can be obtained by dividing equation(4) by i^*, which represents the social interest rate.

4.4.2 *External Value of Income Loss (EVIL)*

The external value of income loss *(EVIL)* is different to *NAIL* in that *EVIL* measures non-farm income losses as a direct consequence of NAIL. This represents the value of income losses to the individuals beyond the farm gate where the erosion originates. It also varies depending on whether the effects are seen as a private individual or as a community but includes lost marketing, transport and processing opportunities.

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[5] Discounting over perpetuity is assumed here due to the perpetual nature of the asset loss, although farmers are assumed to have a short run planning horizon in terms of capital allocation.

EVIL can be defined as a function of the level of output Y_i, value added on farm output VA_i ($/tonne), the observed erosion rate D_{ia}, and the assumed productivity losses x.

$$EVIL_{ia} = f(Y_i, VA_i, D_{ia}, x) \tag{5}$$

Using the comparable notations and units for NAIL and for a given productivity loss of $x\%$ per unit of soil loss for each crop i in a given pixcel a, the value of external income losses EIL_{ia} may be computed as follows:

$$EIL_{ia} = EI_i^* - EI_i \tag{6}$$

$$EI_i = Y_i \times VA_i \tag{7}$$

$$EI_i^* = Y_i \times VA_i \times (1 + \tfrac{x}{100}) \tag{8}$$

Therefore, when the area of crop i in the pixcel a, A_{ia}(ha) is known, the EVIL can be computed by the following equation.

$$EVIL_a = \sum_i EIL_{ia} \times A_{ia} \times D_{ia} \tag{9}$$

Although this income loss is measured for a given crop year, there is a perpetual loss of that income as there is a permanent loss of endowment. Therefore given the market rate of interest (i), the private EVIL, $EVIL_p$ can be obtained by dividing equation(8) by i to obtain the discounted value on perpetuity. Similarly the value of EVIL to the community, $EVIL_c$ can be obtained by dividing equation(4) by i^*, which represents the social interest rate.

Once NAIL and EVIL have been computed for each pixcel it is a relatively easy GIS exercise to run these for any region, resource type or policy constraint. The two entities can be added to obtain the Net Income Loss (NIL) by the society due to land degradation.

$$NAIL + EVIL = NIL \tag{10}$$

In order to obtain a pre-flavour of the difference in magnitude between *NAIL* and *EVIL*, value added in crop commodities, VA_i, was approximated by the difference between the farm gate price and the unit Gross Value of Production (GVP) of commodities for this pilot study. This may not be a realistic assumption as the value added includes not only marketing and service opportunities included in the GVP but also a myriad of other processing opportunities as well.

These are difficult to measure in a static framework and truly represent dynamic relationships with temporal effects. Full appreciation of such effects warrants a complete input-output analysis with sectoral linkages in a general equilibrium framework. Such an analysis would capture the full multiplier effects of the forgone on-farm income opportunities on the wider economy. It will also enable analysis of the effects on the economy of the use of input substitution in agriculture for partial abatement of erosion effects. However, due to the very nature of the exercise and its resource requirements it will only be conducted at a later stage of the project.

5. Water Erosion in NSW: The case of Orange

In this section the physical extent and the economic costs in terms of NAIL and EVIL arising through water erosion for the statistical local area Orange is computed and discussed.

5.1 General overview

Orange is a relatively small SLA in the Central Tablelands of NSW and covers an area of 28,645 ha out of which 24,443 ha were under agricultural uses in 1989/90 (ABS 1991). The soil is predominantly of duplex group with relatively small areas of structured clay. The main land use practices of the area are grazing, horticulture and to a limited extent cereal and other annual cropping. More than 50 per cent of the area is in slope class above 10 per cent, although much of the cultivation is restricted to lower slopes.

5.2 Estimated erosion hazard

In this analysis the physical extent of erosion was computed only over the agricultural areas and thus exclude those areas considered as residual in the ABS statistics. Nonetheless most of those residual areas are also under native pasture and are in fact occasionally used for grazing.

The annual average soil erosion estimate over four main agricultural land uses are given in Table 2. Given the very high proportion of grazing properties over higher slopes and the high erodibility of duplex soils relatively high erosion figure for grazing areas is expected.

Table 2:—Estimated soil erosion for different crop industries

Land Use	Estimated soil loss (Tonnes/ha/year)	Annual total soil movement (Tonnes)
Grazing	11.30	411,831
Cereals	2.94	4,846
Other annuals	2.54	488
Horticulture	1.58	5,366

5.3 Net Agricultural Income Loss—NAIL

The economic costs of soil erosion on agricultural properties in terms of NAIL is presented in Table 3 with the private discount. It is noteworthy that despite the low levels of estimated soil erosion over horticultural industries, the estimated economic impact of erosion upon them is substantially higher per unit area due to the high value of crop they produce.

Given the estimated gross value of agricultural production (GVP) of $16.1m in 1989-90 from Orange, on farm costs of soil erosion amount to around 2.5 per cent of the GVP. This figure is compatible with around 4 per cent loss in agricultural output estimated for soil erosion in Canada by Smit et. al. (1988). Similarly, Sinden and Yapp (1992) using an econometric model estimated that yield losses associated with a tonne of soil loss per ha through sheet and rill erosion are around 3.8 per cent over NSW.

Each of 129 agricultural enterprises in Orange has thus forgone around $3,192 in 1989-90, due to soil erosion. This has implications on the acceptable levels of erosion, as well as on planning ameliorative measures over different land use categories.

Table 3:—Net Agricultural Income Loss 1989/90

Land Use	*NAIL ($/ha)*	*NAIL ($)*
Grazing	0.62	22,512
Cereals	1.31	2,159
Other annuals	86.72	16,657
Horticulture	109.09	370,441
All uses	5.64	411,769

5.4 *External Value of Income Loss—EVIL*

The external value of on farm income loss due to soil erosion reflects the lost income opportunities to non-farm individuals. Accordingly the largest impact is seen on those industries which produce output with high level of off-farm inputs—both goods and services—such as horticulture (Table 4).

Table 4:—Gross External Value of Income Loss *(EVIL)*

Land Use	*EVIL ($/ha)*	*EVIL ($)*
Grazing	0.63	23,077
Cereals	1.74	2,863
Other annuals	11.56	2,220
Horticulture	36.96	125,507
All uses	2.11	153,666

Given the permanent nature of the income opportunities forgone due to soil erosion, the total cost to the producer as well as the non-farm individuals were computed at a private discount rate of 0.155 and a real discount rate of 0.075 prevailed in 1989-90 (ABARE, 1991). Resultant estimates of private and community costs of soil degradation are given in Table 5.

Table 5:—Total value of lost income opportunities due to soil erosion in 1989/90 for Orange

Cost measure	Private ($)	Community($)
NAIL	2 656,575	5,490,254
EVIL	991,400	2,048,892

The next and final step is to add the off–farm costs of soil erosion due to water turbidity, loss of water storage capacity, impacts on other farms and so forth. This obvious step however, must await a subsequent paper.

6. Conclusions

This paper presents an integrated approach for evaluating and presenting the economic costs of land degradation at local levels over large geographical areas such as the entire state of NSW. The GIS approach provides an effective tool for policy analysis at a lower level of disaggregation than possible with pure econometric applications. The NRA framework allows meaningful incorporation of natural resource data into an accounting system in a way that enables policy analysis to examine the likely effects of policies affecting natural resource management on the overall economic performance.

However, the best use of this tool cannot be made unless reliable information on the complex interrelationships involved between natural resource use options and the behavioural impacts on other economic agents are also available. Therefore it is intended to extend the scope of this research to link the present GIS-based NRA approach to a general equilibrium framework. This extension will be used not only for a thorough investigation of EVIL, but also to evaluate the off-site impacts of various forms of land degradation across the state.

The pilot application indicates that, while considerable variation in erosion rates could be expected among different crop industries, the economic impact varies considerably depending on the profitability of the enterprises. This presents an important dilemma in developing conservation policies, as cost–benefit of targeting conservation effort on more vulnerable areas may not be satisfactory. On the other hand as much of the soil loss is recorded in low income industries, their impact on off-site costs not considered in this analysis would be substantial. This highlights the importance of considering total catchment management criteria in developing such policies.

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