Application of RUSLE for Erosion Management in a Coastal Catchment, Southern NSW

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Abstract: River catchments are dynamic and vulnerable systems that can change markedly when exposed to human impact. Changes induced since European settlement in Australia are of particular interest because impacts can be almost impossible to reverse. A measure of catchment degradation may be determined using accumulation in lakes. Along the east coast of New South Wales, both the rate of sediment infill and the stage of infill reached differ between coastal lagoons as a function of physical characteristics within their catchments, including the erosive power of rainfall, the intrinsic susceptibility of the soils to erosion, as well as the combined effect of slope angle and length. The amount of human development also plays a role in that the nature and extent to which the natural vegetation is disturbed, and practices that control erosion, may influence sediment loss.

Sediment accumulation rate in a lake has its own value, but when placed in the context of natural resource planning, it is retrospective and may not be the most efficient approach to land management in catchments. Thus, there is a need to forecast degradation; however, most research has tended to focus on "universal" applications that were designed to achieve exact values. Simulations using empirical, physical, and process-based techniques do offer another option. The effectiveness of the generated models can be tested by comparison with historic and prehistoric rates of sediment accumulation in coastal lagoons.

A small coastal catchment, Lake Wollumboola, located north of Jervis Bay, NSW, was selected for testing simulated soil erosion, using the Revised Universal Soil Loss Equation in combination with GIS, since it offers the opportunity for measurement of sediment accumulation in its terminal lagoon. This integrative approach allows the modelling of soil erosion in coastal catchments as a response to changes in land use. Using hypothetical scenarios, the nature and extent of catchment degradation and erosion can be predicted for past, present and future conditions.

Keywords: *Erosion, modelling, GIS, coastal catchment, sediment accumulation.*

1. INTRODUCTION

All parts of catchments are closely linked together by the behaviour of streams, land use and any disturbance in the hydrological and biotic environments. Therefore, river catchments are dynamic and vulnerable systems that can change markedly, especially when exposed to dramatic human impact, because the system must then adjust to accommodate this "unnatural" disturbance. Changes induced since European settlement in Australia are of particular interest since such impacts can be almost impossible to reverse. A measure of catchment degradation may be determined using sediment accumulation in lakes. Along the east coast of New South Wales, the rate of sedimentation differs between coastal lagoons. This difference is attributable to variations in physical characteristics within each catchment, including the erosive power of rainfall, the intrinsic susceptibility of the soils to erosion, as well as the combined effect of slope angle and length. Anthropogenic activities also play a role in that the extent to which the natural vegetation is disturbed, and practices that control erosion may influence sediment loss. An integrative approach allows the modelling of soil erosion in coastal catchments as a response to changes in land use. Using hypothetical scenarios, the nature and extent of catchment degradation and erosion can be predicted for past, present and future conditions.

This paper extends the studies previously undertaken by Simms *et al.* (2002) in which current soil loss was modelled. The focus of this paper, however, is to generate modelled estimates under different land use scenarios.

1.1. Traditional Methods of Estimating Catchment Soil Loss

Research undertaken during the last forty years has shown the value of estimating soil loss using accumulation rates in downstream dams, reservoirs and other areas of deposition (Walling, 1994). Estimation of soil loss is done by taking cores from the area of deposition and using methods of sediment dating to determine the rate at which the sediment was deposited. Walling (1994) suggested that there are 4 major requirements for reconstructing sediment yields. These include:

- a suitable downstream sediment trap, e.g. a lake, which has trapped sediment eroded from a catchment over a considerable period of time;
- dating methods capable of providing an absolute chronology for the sedimentation represented within the sediment cores;
- a method of inter-core correlation to enable estimation of the volumes of sediment stored between synchronous levels in the lake deposit;
- the possibility of distinguishing the allochthonous inputs of sediments eroded from within the surroundings of the catchment from autochthonous sediment originating from within the trap itself.

This approach continues to be adopted; however, since it is aimed at reconstructing past sedimentary activities it is not efficient at forecasting where soil erosion is currently active. Effective land management requires more precise determination of areas at risk of soil degradation.

1.2. Improvement in Technologies

Information on sediment yield at the outlet of catchments or downstream areas provides a useful perspective on the rate of erosion and soil loss in the watershed upstream. However, developments in computing technology, namely Geographical Information System (GIS) have conferred the advantage of estimating soil loss more quickly, less expensively and with greater automation (De Roo, 1996).

The Revised Universal Soil Loss Equation (RUSLE) is empirically based and was developed for detachment limiting erosion. The equation can be used to calculate soil loss, and then delivery ratio functions may be used to determine the amount of sediment delivered down slope (Renard *et al.*, 1994). This model requires values calculated for land use, slope, soil erodibility, erosivity and the flow paths though the catchment. The results of the calculations may then be used to derive estimates of the potential soil loss from the catchment and also to indicate "erosional hotspots" within it. According to De Roo (1996) run-off and soil erosion processes vary spatially, meaning that individual GIS grid cell-sizes should allow spatial variation within the catchment to be considered.

2. STUDY SITE

The catchment of Lake Wollumboola is located at 150°46'E and 34°57'S, approximately 172 km south of Sydney and just north of Jervis Bay on the New South Wales south coast (Figure 1). It has an area of approximately 35 km^2. A coastal saline lake at the mouth of the catchment is intermittently connected to the ocean (Shoalhaven City Council, 2000). When the entrance is closed, the lake level rises in response to catchment run-off. The highest point in the catchment is approximately 90 m, and the main drainage is the Coonemia Creek. The gradient of the land does not vary greatly and has a maximum slope of 20 degrees.

The catchment is relatively undisturbed, much of the vegetation consisting of tall open-forest. Of the total land catchment area, about 50% is included in the Jervis Bay National Park and 20% is forestry reserve (Currambene State Forest). The remainder of the catchment comprises urban residential areas (2%), disturbed areas that support grazing (11%) and the lake itself (17%). The Currambene State Forest undergoes minor disturbance from logging and forest management practices (Shoalhaven City Council, 2000).

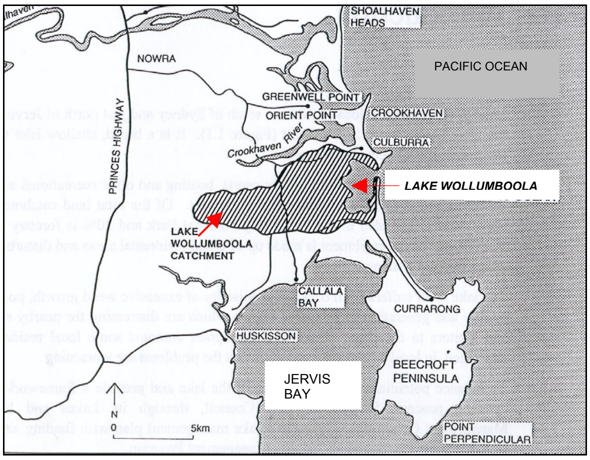

Figure 1: Location of the Lake Wollumboola catchment in NSW.

3. THE MODEL

3.1. The Empirical RUSLE

In 1985 the US Department of Agriculture (USDA) decided that the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1958) should be revised to incorporate additional research, resulting in a modified version called the Revised USLE - RULSE (Renard *et al.*, 1994).

The model takes the form:

$$A = R * K * (L * S) * C * P \quad (1)$$

Where:

A is the predicted long-term average soil loss (t ha^{-1} yr^{-1}). R, K, L, S, C and P are defined below.

It has been widely used as the leading tool for the prediction of erosion and conservation planning in the USA and elsewhere (Mitasova & Mitas, 1999).

3.2. Rainfall Erosivity (R factor)

R is a measure of erosivity of rainfall (product of storm kinetic energy and maximum 30-minute intensity EI_{30}). Within the RUSLE, rainfall erosivity is estimated using the EI_{30} measurement and the rainfall runoff R factor is the average of all computed EI_{30} values for a 1-year period. The intensity data may be derived from the Rainfall Erosivity values from maps of this factor. The Standard International (SI) unit for rainfall erosivity is MJ.mm / (ha.h.yr).

3.3. Soil Erodibility Index (K factor)

K is the measure of soil erodibility expressed as long-term average soil loss per unit of EI_{30} under standard conditions. Many variables influence the erodibility of a soil, including particle size, organic content and structure. In Australia soil erodibility has been classified as shown in Table 1 (Hazelton, 1992). Hazelton based erodibility on a series of field assessments of soil structure and permeability.

Table 1: Soil erodibility values; SI unit is t.ha.h / (ha.MJ.mm).

Erodibility	K Factor
Very Low	=< 0.01
Low	0.02
Moderate	0.03
High	0.05
Very high	=>0.06

3.4. The Crop and Land Management (C factor)

C is the crop or land cover management factor and measures the combined effect of all the interrelated vegetative cover and management variables. It is defined as the ratio of soil loss from land maintained under specified conditions to the corresponding loss from continuous tilled bare fallow.

The RUSLE and its predecessor (USLE) were developed for use in agricultural fields; however, it can be adapted for use in non-agricultural conditions. In this case the C factor measures the protection of the soil surface from raindrop impact by vegetative material at some height above the soil surface (canopy cover) and the additional protection from raindrop impact and overland flow by cover in contact with the soil surface (surface cover). Values can vary from 0 for very well protected soils to 1.5 for finely tilled, ridged surfaces that produce much runoff, leaving it susceptible to rill erosion.

3.5. The Support Practice (P Factor)

P is the support or land management practice factor. In RUSLE, the support practice factor is generally applied to disturbed lands and represents how surface and management practices such as contouring, terracing and strip cropping are used to reduce soil erosion. For areas where there is no support practice the P factor is set to 1.0.

3.6. The Topographic LS factor

L and **S** are factors representing the topography of the land and they define the effects of slope angle and slope length on sheet and rill erosion. More concerns are expressed over the L factor than any other of the RULSE factors, due to the fact that slope length involves human judgement. The slope length factor L is defined as the distance from the source of runoff to the point where deposition begins, or runoff becomes focussed into a defined channel.

The formula for calculating the computed LS factor is:

$$T = (A/ 22.13)^{0.6} \ (\sin B/0.0896)^{1.3} \quad (2)$$

where A is the upslope contributing factor, B is the slope angle.

Slope shape, the interaction of angle and length of slope, has an effect on the magnitude of erosion. For example, soil losses from plots on irregular slopes may be dependent on the slope immediately above the point of measurement. As a result of this interaction, the effect of slope length and degree of slope should always be considered together (Edwards, 1987).

However, with the incorporation of Digital Elevation Models (DEM) into GIS, the slope gradient (S) and slope length (L) may be determined accurately and combined to form a single factor known as the topographic factor LS. The precision with which it can be estimated depends on the resolution of the digital elevation model (DEM).

4. METHODOLOGY

The datasets for this project include digital representation of the soils landscapes mapping (Hazelton, 1992), a shape file of the Wollumboola catchment, and grids of the pre-1750 and current vegetation distribution, as well as grids of flow accumulation (corresponds to the drainage in the catchment) and a DEM. In this study, ArcGIS software (ESRI) was used to create the relevant thematic layers for the application of the RUSLE.

Raster Calculator was used to build the following expression:

R * [K] * [C] * [P] * [LS]

which, when applied to all cells in a raster coverage of the Wollumboola catchment, produced a map of soil loss in one year.

A summary of the steps used is as follows:

1. **R:** This value is a constant entered in the final equation, and a value 350 was used as indicated for this region of NSW by Rosewell (1993), which is 350 MJ.mm / (ha.h.yr).

2. **K:** The K Factor GIS layer was created along with its corresponding attribute table by adding the K values, displayed in Table 2 and derived from the Soil Landscapes mapped in the Kiama Soil Map (Hazelton 1992), to the soil landscapes theme. The K factor theme was then converted to a grid and named K Factor.

Table 2: Soil landscapes and their K factor values

Soil Landscape	K Factor
Greenwell Point (gp)	0.061
Seven Mile (sm)	0.01
Wollongong (wg)	0.01

3. **C:** A new C factor GIS layer was created along with its corresponding attribute table. A relational join was performed to append the values to the land use theme using Table 3 (adopting values recommended by Rosewell, 1993). This C factor GIS layer was then converted to a grid.

Table 3: Land use and C factor values

Land Use	C Factor
Natural Vegetation	0.003
Agriculture/Grazing	0.45
Complete Clearance	0.45
Logging	0.34

4. **P:** There are no effective erosion control measures in the Wollumboola catchment and as a result the catchment's P factor was set at 1.0.

5. **LS:** The combined topographic (LS) factor was computed rather than the individual slope length and slope angle, because the upstream contributing area is generally preferred instead of individual slope lengths.

The procedure for computation was as follows:

- using the Spatial Analyst Extension: **slope** was derived from DEM;
- using the Hydrological Extension: sinks in the DEM were identified and filled;
- the **filled DEM** was used as input to determine the **Flow Direction**;
- the Flow Direction was used as an input grid to derive the **Flow Accumulation**.

The LS factor was then computed using Raster Calculator from the menu to build an expression for estimating LS, based on flow accumulation and slope steepness (Mitasova and Mitas, 1999). The expression is:

Pow ([flow accumulation] * 25/22.13, 0.6) * Pow (Sin ([slope of DEM] * 0.01745/0.0896, 1.3)

Maps of potential soil loss were produced using Raster Calculator to build the expression:

350 * [K] * [C] * [LS]

5. RESULTS AND DISCUSSION

As seen in Figure 2, most of the catchment experiences moderate (1-10 t $ha^{-1}a^{-1}$) soil erosion. Preliminary GIS modelling suggests that even though the catchment is relatively unmodified, small disturbed areas, which account for only 14% of the catchment, have the potential to contribute 88% of the total soil erosion (Figure 2; Simms *et al.*, 2002).

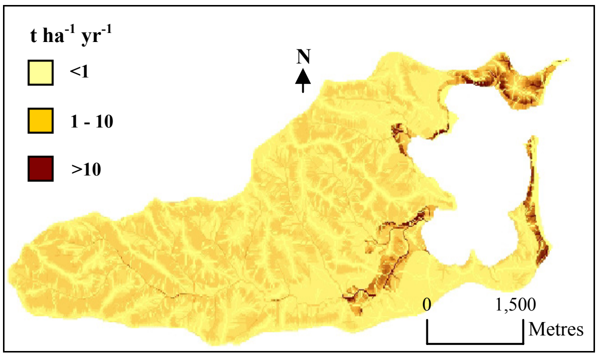

Figure 2: Current soil loss

Pre-1750 accumulation was simulated and compared with current sediment accumulation. Figure 3 shows the simulated soil loss under pre-historic conditions, where land cover was natural vegetation.

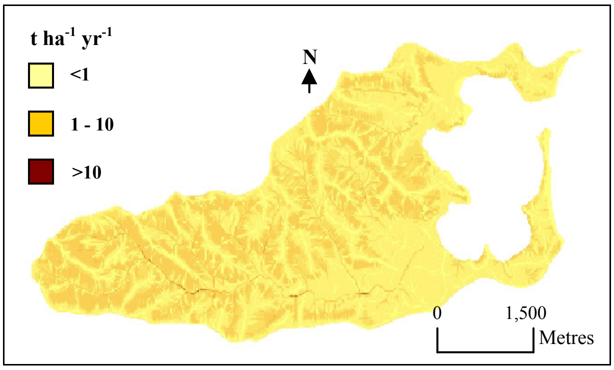

Figure 3: Pre-1750 soil loss

The sedimentary and stratigraphic histories of Lake Wollumboola suggest an accumulation rate of <1 mm/a (Baumber, 2001; Simms *et al.*, 2002).

Other simulations undertaken include scenarios of urban expansion (Figure 4), logging (Figure 5), and total clearance of the catchment (Figure 6).

The simulated urban soil loss (Figure 4) involved urban growth on 8,000 ha west of the current residential development. The proposed area of growth covers a less erodible soil landscape, Seven Mile. The soil loss simulated is only a very slight increase and may be attributed to the resistance conferred to the land by the Seven Mile soil landscape as well as the relatively low relief.

Simulating logging (Figure 5) involved a change in the land cover from natural vegetation (C factor = 0.003) to a land use, logging (C factor = 0.34).

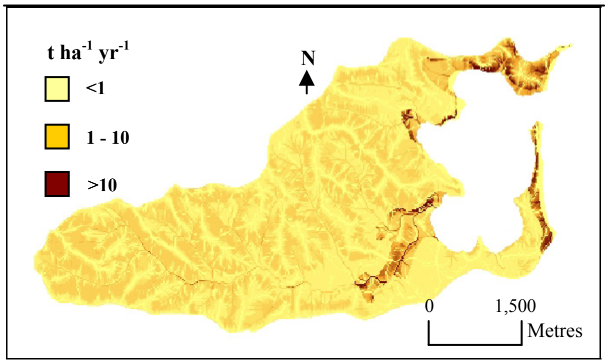

Figure 4: Soil loss under urban growth

This logging simulation yields appreciably more (6 times) soil loss than is currently experienced in the catchment.

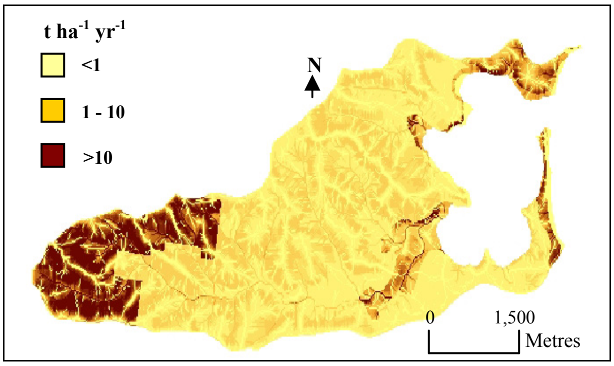

Figure 5: Soil loss under logging

Figure 6 shows the simulated soil loss for conditions of complete clearance in the catchment. The soil loss predicted would be 23 times that which is currently experienced in the catchment.

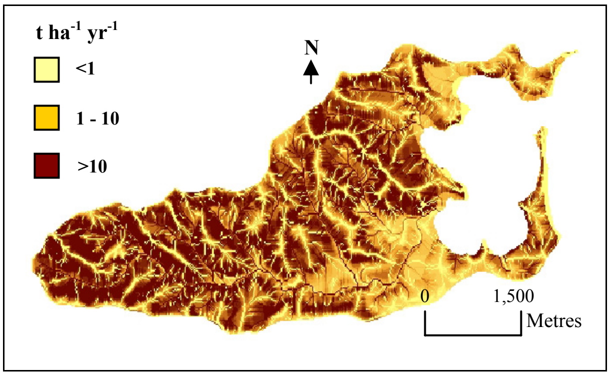

Figure 6: Soil loss under complete clearance

6. CONCLUSIONS

From the GIS simulations it appears that the catchment has the potential to be more sensitive to total clearance of vegetation than any other land use. Even though urban growth did not appear to contribute additional sediments because of the intrinsic resistance of the soil to erosion, it must be borne in mind that the area on which the development was simulated is a small one. Thus development would need to incorporate proper buffering to prevent erosion in neighbouring areas with less resistant soils. Also, this particular catchment contains mostly erodible soils (Greenwell Point: 0.061); thus any planning should consider the implications of development on erodible soils.

As cited by others (De Roo, 1996; Mitasova and Mitas, 1999; Lu *et al.*, 2001), there are several constraints to applying the RUSLE in Australia. A summary of the constraints is mentioned here, as they always need to be considered before decisions are made. The RUSLE is an empirical-based equation, which was developed for detachment limiting erosion under conditions with low slopes and no deposition and represents soil loss averaged over time and total area.

The RUSLE was first developed to simulate soil loss at plot level. Also, it does not equate to sediment delivery but rather to maximum potential soil loss that could occur; therefore, does not correspond to sedimentation in lakes if there is deposition at the base of slopes or in floodplains. However, the Lake Wollumboola catchment is small and lacks extensive floodplains; thus it is generally not a site of major alluvial deposition. There are also concerns about seasonal variation of erosivity in some parts of Australia; however, in this area rainfall and its associated erosivity are generally constant throughout the year.

While these limitations must be borne in mind and the particular values associated with particular parameters must be the subject of continuing reassessment, there is still scope for using the RUSLE combined with GIS, to aid in land management decisions, with respect to soil conservation. This is particularly useful because alternative strategies for land management may be simulated and evaluated quickly, especially in catchments where data are sparse. Modelling does offer the option to quickly identify potential areas of high or low erosion rates, as opposed to using only sediment accumulation rates. There is a greater chance of determining sources of erosion.

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