Preliminary assessment of erosion in the Williams River catchment using an empirical soil loss estimator and soil tracers

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Abstract The Revised Universal Soil Loss Equation (RUSLE), adapted for Australian conditions (SOILOSS), was applied to seven vegetated slope transects in and near the 1175km^2 Williams River catchment, NSW. Estimated average annual soil loss rates ranged from 0.07 t ha^{-1}yr^{-1} to 3.6 t ha^{-1}yr^{-1}. SOILOSS rates were also calculated for the lower Williams River catchment, using the ARC/INFO GIS raster structure at 100 m pixel resolution, from data sets of terrain, rainfall, vegetation density, landuse and soil-landscapes. The fallout environmental radionuclide caesium-137 (^{137}Cs) was used to assess the sheet and minor rill erosion status of the same seven vegetated slopes as used for the transect SOILOSS application. Soil sampling was performed along transects, with the net loss or gain of ^{137}Cs at each sampling point compared to the ^{137}Cs level at a reference site at the slope crest. An Australian regression model relating net soil loss from runoff-erosion plots to ^{137}Cs deficit in soils was used to calculate a weighted net surface and minor rill erosion rate for the entire slope. Results indicate low average net soil loss (0.002 t ha^{-1}yr^{-1} to 0.64 t ha^{-1}yr^{-1}) for the past 40 years. Preliminary results of a multi-parameter soil tracing study using ^{137}Cs and heavy metals are also presented for the determination of relative surface and subsurface sediment production rates from a 120 ha subcatchment. The potential for extrapolating subsoil erosion rates to other locations in the catchment is discussed. Surface erosion rates calculated by the two RUSLE-based approaches are compared to the ^{137}Cs derived erosion rates to assess the applicability of SOILOSS as a tool for estimating annual average surface erosion potential at the hillslope scale. The spatial integration of hillslope surface erosion rates and the incorporation of catchment subsurface sediment production rates into a regional scale sediment budget estimation procedure is considered.

1. INTRODUCTION

The Williams River catchment has undergone dramatic changes since European settlement began in the 1820's. The majority of native vegetation has been removed and replaced by pasture species suitable for grazing of sheep and cattle. Channel flow no longer occurs downstream of Seaham Weir (Figure 1), which now provides stilled conditions for potable water extraction to the Grahamstown Reservoir, supplying over 400 000 domestic consumers and close to 10 000 commercial and industrial users in the lower Hunter Valley. Concerns have developed about the quality of water derived from the Williams River, following recent blue-green algal outbreaks. It is believed that rising plant nutrient levels in the river are caused by soil erosion, cattle accessing riparian zones, dairy effluent, domestic wastewater and urban stormwater. The relative contribution from each source is, however, unknown. Long-term monitoring of sediment dynamics within the catchment has not been undertaken and little is known about sediment volumes transported to the stream system, let alone the nutrient concentrations associated with mobilised sediments. Any assessment of the catchment's erosion status will therefore require the use of techniques which do not rely on retrospective information.

Historically, water erosion prediction and conservation planning has been based on the empirically derived Universal Soil Loss Equation (USLE) [Wischmeier and Smith, 1978] developed for US conditions. Adaptation of the updated Revised USLE (RUSLE) [Renard *et al.*, 1997] to NSW conditions (SOILOSS) was conducted by Rosewell [1993b]. Given sufficient terrain, soil, vegetation and rainfall data, SOILOSS provides a simple tool for assessing the potential for sheet and rill erosion at the hillslope scale. However, validation is difficult, particularly in the absence of erosion measurements. Over the past two decades, sediment tracing techniques have emerged as viable estimators of sediment transport dynamics [Loughran, 1989]. The anthropogenically produced radionuclide caesium-137 (^{137}Cs) has been used for tracing and quantifying surface soil erosion and deposition. Numerous applications on both forest [cf. Elliott *et al.*, 1997] and pasture [cf. Walling and Quine, 1992] land uses indicate its potential applicability to the Williams River surface erosion assessment. In combination with other soil tracer properties, such as heavy metal concentrations, ^{137}Cs may also provide important information on the relative contribution of surface soil (pasture and unsealed roads) and subsoil (gully wall) sediment sources within the catchment [Walling *et al.,* 1993].

This paper presents an application of SOILOSS to selected hillslopes in the Williams River catchment to assess average annual sheet and minor rill erosion. Comparison to long-term surface erosion rates is undertaken using soil concentrations of ^{137}Cs. In an automated GIS procedure, SOILOSS is also applied to 234 km^2 of hillslopes in the catchment. The potential for using SOILOSS as a tool for extrapolating ^{137}Cs derived surface erosion rates to unsampled hillslopes is discussed. Preliminary results of sediment tracing in a small subcatchment are presented, and the potential of a composite tracer set to provide distinct, quantitative fingerprints for sediment derived from various depths in the soil profile is discussed.

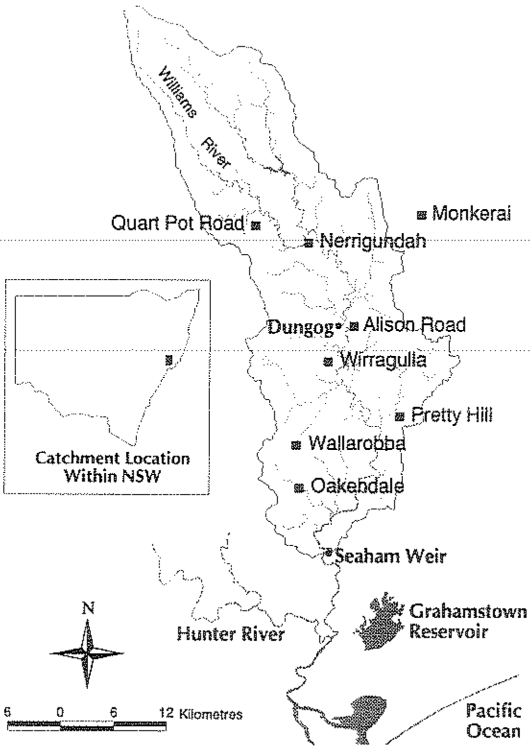

Figure 1 Locality map of the Williams River catchment and the eight ^{137}Cs hillslope sampling sites (solid squares)

2. STUDY AREA

The 1175 km^2 upstream of Seaham Weir (Figure 1) is the focus of this study. Most of the catchment geology comprises relatively uniform Carboniferous sediments and volcanics which have been folded and faulted. In the extreme north there is a remnant Tertiary basalt cap, and south of Clarence Town, Quaternary alluvium has been deposited adjacent to the main channel. Average annual rainfall is highest towards the northern end of the catchment (1600 mm), decreasing to 984 mm at Dungog and, under coastal influences, increasing to 1100 mm at Seaham. The predominant landuse is grazed pasture, accounting for 56% of the catchment area. Forest and related timber operations cover 42%, with less than one percent of the area used for cropping. A 120 ha subcatchment was selected for detailed sediment source analysis 4 km south of Dungog. This grazed catchment has several potential sediment sources; sheet erosion of slopes, gully sidewalls and unsealed road surface.

3. METHODS

3.1 SOILOSS Surface Erosion Rate Estimation

SOILOSS is a lumped sheet and rill erosion rate prediction technique developed to assess long term annual averages from specified land units under specified management systems [Rosewell, 1993b]. Rates are calculated as the multiple of six erosion related factors: rainfall erosivity (R), soil erodibility (K), cover management (C), support practice (P), overland flow path length (L) and slope steepness (S), the latter two being combined to form the length-slope factor (LS). The equation has several well documented shortcomings, the most significant being its inability to model the process of sediment deposition and therefore provide an estimate of net erosion rates [SWCS, 1993]. Despite this, its application in Australia continues with Rosewell [1997] applying SOILOSS in a national survey of potential sediment sources. However, the lack of high resolution information at the national scale is believed to have led to an over estimation of some parameter values in this study. Prior to publication of the Rosewell study, Wasson *et al.* [1996] used SOILOSS to assess nationally the contribution of sheet and rill erosion against gully and river channel sources. Loughran *et al.* [1999] applied the model at 22 locations in the Hunter Valley on vineyard, pasture and forest landuses.

In this study, SOILOSS was applied to six pasture and one forest hillslope (Figure 1). To facilitate calculation of the R-factor, the 1 and 12 hour log-Pearson Type III rainfall intensity contours for a two year recurrence interval were digitised from Australian Rainfall and Runoff [Pilgrim, 1987]. GIS interpolation within the ARC/INFO GRID module was conducted by the TOPOGRID tool and catchment-wide raster coverages were produced at 100 m resolution. The 2 year 6 hour log-Pearson Type III rainfall intensities were calculated using a raster overlay procedure and the estimated intensities were converted to R-factor values for the entire catchment [Rosewell, 1993a]. Particle size analysis of soil core information collected at each site provided average texture classes from which K-factor values were inferred using the SOILOSS handbook. The LS-factor was determined by field surveying on each slope transect. However, as SOILOSS is only calibrated from limited soil plot information, the program controls the overland flow path length (L) as a function of slope steepness (S) [Rosewell, 1993b]. Steep slope transects, for which L was reduced to less than half the surveyed slope length, were split into two equal portions and their rates summed. For the C-factor, vegetation cover percentages were estimated from field inspection during the summer months, but no attempt was made to calculate average annual values. No support practices were evident at any site and therefore the P-factor was set to unity.

In the 234 km^2 raster GIS application of SOILOSS, all factors were estimated at 100 m pixel resolution. This was considered suitable for the available terrain, soil, vegetation and rainfall information sources. Department of Land and Water Conservation (DLWC) terrain and landuse maps were used initially to eliminate drainage channels, streams, waterbodies and urbanised areas. R-factor values were transferred directly from the full catchment raster map produced for the transect SOILOSS application. Soil K values were taken from soil landscape information [Matthei, 1995]. Each soil landscape polygon was initially given the A1-horizon K-factor value, converted to raster format and overlaid with the raster terrain map, producing combinations of A1-horizon K-factors and terrain features. The schematic cross-section provided with each landscape variant was then assessed and those features (e.g. sideslopes) for which subsurface layers of the profile are likely to be exposed, were given K-factor values associated with the A2-horizon. The combined LS-factor was automatically calculated with the LS-Module v3.2 [Desmet and Govers, 1996], using a 100 m depressionless DEM and the terrain map as a parcel file to restrict overestimation of the L factor. Despite this control, 16% of cells exceeded the maximum of 10 imposed on the LS-factor and had to be reset to this value. The DLWC landuse and cover density map were combined to estimate the C-factor, with values derived from the SOILOSS manual.

3.2 Erosion Rate Estimation with Soil Tracers

Quantification of long-term surface and minor rill erosion has proved to be problematic using traditional erosion estimation techniques [Loughran, 1989]. One non-traditional approach uses fallout of ^{137}Cs, derived mainly from above ground nuclear testing which began in the 1950s. The loss of ^{137}Cs adsorbed on soil has been shown to be directly related to measured soil loss [Rogowski and Tamura, 1965] due to the strong and rapid adsorption of ^{137}Cs onto soils and subsequent limited removal by chemical means. Ritchie *et al.* [1974] concluded that net sediment removal and deposition could be reliably determined from soil ^{137}Cs loss measurements and therefore the net result of long-term surface and minor rill erosion could be estimated.

Representative soil cores on five grazed slope transects and one steep forested slope transect (Figure 1) were sampled for ^{137}Cs concentrations. Field sampling and laboratory methods are described in Krause *et al.* [1999]. For individual transect samples, the percentage of net ^{137}Cs loss or gain was determined by comparison with a stable reference-site value. For uncultivated land, the magnitude of net soil loss at each hillslope sampling location was estimated by a regression equation derived from Australian data [Elliott *et al.*, 1990], as amended after observations made by Lang [1992]. The revised relationship [Loughran and Elliott, 1996] is:

$$SL = 17.49\,(1.0821)^{x} \qquad (n=34;\ r=+0.84) \qquad (1)$$

where SL is net soil loss (kg ha^{-1} yr^{-1}) and x is percentage ^{137}Cs loss. Net soil gain was calculated using the regression model in reverse mode. By weighting each individual sample by the proportion of total slope length it represents and then summing for all samples, a long term net sheet and minor rill erosion rate is established for the entire slope.

In the Williams River catchment the soil surface layer is unlikely to be the only source of sediment mobilised during storm events. The assumption however, that material transported from a distinct depth-range of the soil profile will maintain during transport and ultimately deposition, some unique and quantifiable chemical or physical property "fingerprint", provides an attractive alternative to traditional long term monitoring options. Assuming that clear differentiation is evident between the fingerprints of two potential sources, the resulting sediment mix at some downstream location should reflect the contributing proportions delivered from

Table 1 Rates of sheet and minor rill erosion and respective slope characteristics for hillslopes in and near the Williams River catchment, as estimated with SOILOSS and the ^{137}Cs transect technique.
(* [DeLapouge, 1995],** [Saynor, 1994], # rates not determined at this location)

Site	^{137}Cs Erosion Rate (t ha^{-1} yr^{-1})	SOILOSS Transect Rate (t ha^{-1} yr^{-1})	SOILOSS GIS-based Rate (t ha^{-1} yr^{-1})	Landuse	Slope Length (m)	Average Slope (%)
Wallarobba	0.64	1.1	315.9	Improved Pasture	130	21.9
Alison Road	0.31	3.7	#	Pasture	325	21.6
Oakendale	0.14	0.14	0.06	Forest	212	28.5
Quart Pot Road	0.04	7.4	#	Pasture	200	25.9
Nerrigundah	0.00	0.72	#	Improved Pasture	210	6.3
Pretty Hill *	0.10	2.7	183.7	Pasture	280	16.0
Monkerai **	0.12	2.7	#	Pasture	360	14.0

each area. Radionuclides [cf. Wallbrink and Murray, 1993] and sediment chemistry [cf. Walling *et al.*, 1993] have shown promise as soil tracers, however a single trace property of soil movement is yet to emerge. The use of composite properties has been proposed as the most reliable method of proportioning sediment sources, particularly when differentiation between several sources is required [Walling *et al.*, 1993]. Collins *et al.* [1997] advocate the use of parameters from a range of property subsets (e.g. chemical, radionuclides and organics) to improve the statistical reliability of results. Assuming a base line surface erosion rate can be established with the ^{137}Cs technique, a multiple source tracing study within the same subcatchment, involving the relative contribution of surface erosion, may allow for erosion rates to be inferred for the other sediment contributors.

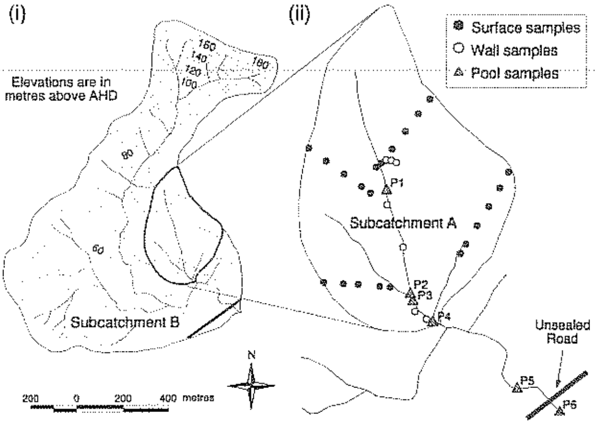

Figure 2 Maps of i) Wirragulla subcatchments A and B and ii) locations within subcatchment A of pasture (surface), subsurface (gully wall) and pool (suspended sediment) samples.

The Wirragulla subcatchments (Figure 2(i)) were selected to assess the relative contribution of sediment derived from exposed gully walls, vegetated pasture surfaces and unsealed roads. In the upper reaches of subcatchment B, where surface slope increases above 40%, evidence of accelerated sheet erosion exists. Minor gullies are present in the lower portion of subcatchment B surrounding the major drainage lines, but considerable vegetation cover indicates recent stability. Site inspection also revealed lengths of severely eroded, exposed gully walls within subcatchment A (Figure 2(ii)) adjacent to the main drainage line. Downstream of the junction between subcatchments A and B, approximately 200 m of unsealed road directs runoff towards the drainage channel. Within the 15 ha area of subcatchment A, a detailed soil sampling program was conducted to establish representative "fingerprints" of possible sediment sources. Reference is made to Krause et al [1999] for sampling methodology. In total, 21 pasture surface, 7 gully wall, 8 unsealed road and 6 deposited sediment samples were collected and analysed for ^{137}Cs and six heavy metals (Cu, Fe, K, Mn, Pb, Zn). For comparative purposes, additional soil core samples were collected to establish a surface erosion rate by the ^{137}Cs technique.

Catchment studies conducted by Walling *et al.* [1993] and Olley *et al.* [1995] are examples of mixing model applications in which surface and subsurface source contributions to the total sediment load are estimated. However, rigorous error analyses of the relative contribution estimates has proven to be problematic. An approach by Franks and Rowen [in prep.], which explicitly accounts for sampling uncertainty may provide contributing source areas with robustly derived confidence intervals.

4. RESULTS

4.1 SOILOSS Surface Erosion Prediction

The SOILOSS average annual sheet and rill erosion rate for each transect site is shown in Table 1. Values ranged from 0.72 t $ha^{-1}yr^{-1}$ to 7.4 t $ha^{-1}yr^{-1}$ for the pasture hillslopes, with an average of 3.05 t $ha^{-1}yr^{-1}$. The erosion rate of the forest hillslope at Oakendale was 0.14 t $ha^{-1}yr^{-1}$, which is a factor of five below the lowest pasture site. From the GIS-based SOILOSS application, surface and rill erosion rates ranged from 0.01 t ha^{-1}yr^{-1} to 591.6 t ha^{-1}yr^{-1}, with the majority of pixels having calculated rates less than 10 t ha^{-1}yr^{-1}. Direct comparison between the two methods was conducted at the three sites common to both approaches. Inspection of results in Table 1 reveals several magnitudes difference between predicted pasture rates at both Wallarobba and Pretty Hill, but closer agreement for the forest site at Oakendale.

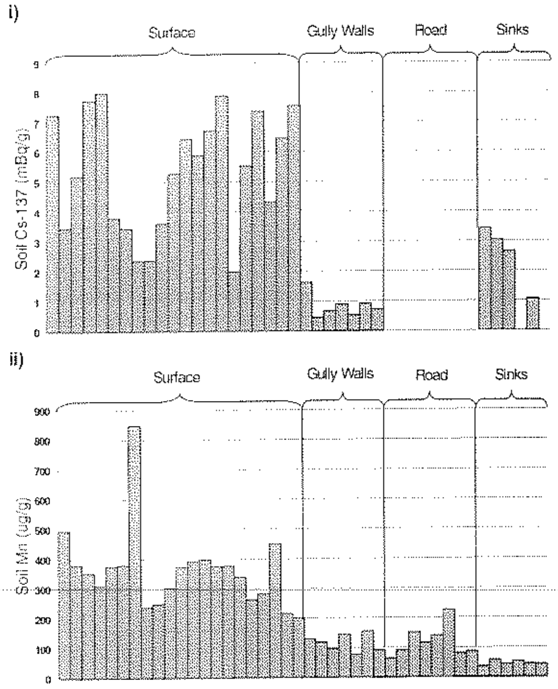

Figure 3 Soil concentrations of i) ^{137}Cs and ii) Mn in Wirragulla soil samples

4.2 Caesium-137 surface erosion prediction

Estimated net surface and minor rill erosion rates calculated from (1) for the five sampled hillslopes are presented in Table 1, along with two sites sampled prior to this study [DeLapouge, 1995; Saynor, 1994]. Wallarobba and Alison Road both had an estimated erosion rate above the overall average of 0.20 t ha^{-1} yr^{-1}. This value is below the average erosion rate of 0.42 t ha^{-1} yr^{-1} derived from 48 ^{137}Cs studies on uncultivated Australian hillslopes [Elliott *et al.*, 1997; Loughran and Elliott, 1996]. The low surface and minor rill erosion rates estimated in the present study suggest that slopes within the catchment are not major contributors to the sediment load of the Williams River. To provide a tool for extrapolating ^{137}Cs erosion rates to unsampled hillslopes within the catchment, correlation analyses were conducted between ^{137}Cs erosion rates, the two SOILOSS approaches and simple slope characteristics listed in Table 1. No significant relationships were detected.

4.3 Preliminary subcatchment sediment tracing

Soil tracer concentrations of ^{137}Cs and six heavy metals from various soil profile depths and stream deposits, indicate the potential for gaining relative sediment source information from the Wirragulla subcatchments. Figure 3 presents soil concentrations of ^{137}Cs and Mn measured from surface, subsurface, unsealed road and deposited sediments (sinks). From individual inspection of each tracer, they appear capable of discriminating between at least some of the potential sediment sources (surface, gully walls, road) in the catchment. In combination however, their value appears much greater. For example, an unsealed road sample tested for Mn is likely to have a value similar to a gully wall sample. If the same two samples are also tested for ^{137}Cs, it likely that the gully wall subsoil will contain a small concentration whereas the road will not, therefore identifying the origin of the samples.

5. DISCUSSION

Due to the inability of SOILOSS to incorporate soil deposition processes, calculated rates are considered an indication of the potential for erosion, rather than a net sediment flux through each individual pixel. In addition, the difficulty associated with ground truthing DLWC vegetation information and the relatively sparse soil core locations used for soil parameter extrapolation, is likely to lead to overestimation of both the C and K factors. Broad categorisation therefore of predicted rates may provide a useful tool for identifying areas of concern for management of large scale surface erosion, but is unlikely to provide the detailed quantitative information required for rigorous sediment budgeting appraisals. Due to the lack of correlation between the ^{137}Cs technique and both SOILOSS approaches, it is doubtful SOILOSS can be used as a simple means of extrapolating ^{137}Cs rates from representative slopes. If detailed retrospective vegetation cover information were available for SOILOSS C-factor parameterisation, correlation with the ^{137}Cs technique, which predicts average erosion rates for the last 40 years, may be improved. Surface erosion rates, calculated with the ^{137}Cs technique, still provide a reliable estimate of sediment removal from vegetated slopes in the catchment. If used in conjunction with subsoil and unsealed road production rates from the small subcatchment study, a method of estimating the magnitude and source of sediment to the Williams

River is still achievable. To facilitate this sediment budgeting approach, future investigations in the catchment will be directed towards establishing an inventory of gully features and unsealed roads.

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