



Potential Sources of Sediments and Nutrients: Sheet and Rill Erosion and Phosphorus Sources

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Preface

Australia: State of the Environment 1996 (the first ever independent and comprehensive assessment of the state of Australia's environment) was presented to the Commonwealth Environment Minister in 1996. This landmark report, which draws upon the expertise of a broad section of the Australian scientific and technical community, was prepared by seven expert reference groups working under the broad direction of an independent State of the Environment Advisory Council. While preparing the report, the Department of the Environment, Sport and Territories, on behalf of the reference groups, commissioned a number of specialist technical papers. These have been refereed and are now being published as the State of the Environment Technical Paper Series. Reflecting the theme chapters of the report, the papers relate to human settlements, biodiversity, the atmosphere, land resources, inland waters, estuaries and the sea, and natural and cultural heritage. The topics covered range from air and water quality to sea grasses and historic shipwrecks.

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Abstract

Soil erosion is a key limitation to achieving sustainable land use in Australia and is the major source of sediment and phosphorus in Australian waterbodies. The major sediment source-types are : sheet and rill erosion, gully erosion and main channel erosion. This paper describes the method used to develop and map an Australia-wide indicator of sheet and rill erosion and to combine this with information on soil phosphorus status to provide an indicator of the potential for movement of particulate phosphorus.

1 Introduction

The Revised Universal Soil Loss Equation (RUSLE) was selected as the most appropriate method to calculate a sheet and rill erosion indicator. It was considered to be feasible to estimate the RUSLE factor values from the currently available natural resource data in digital form. The limitations of the existing data sets and the difficulties in estimating appropriate factor values are discussed. Maps are presented of the sheet and rill erosion index and the index of phosphorus movement potential.

2 Methods

A sheet and rill erosion index was calculated using the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) as adapted for NSW in the SOILOSS computer program (Rosewell 1993a).

The RUSLE is:

$$A = R \times K \times L \times S \times C \times P \quad (\text{Eqn 1})$$

where

A = average annual soil loss

R = rainfall erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = crop and cover management factor

P = support practice factor

In SOILOSS, the R and K factors are in SI units so that A has units of t/ha/y (tonnes per hectare per year). The calculated average annual soil loss is used as an index of sheet and rill erosion potential.

2.1 Rainfall erosivity factor (R)

The R factor, a measure of the erosive power of rainfall, was estimated from the 2 year 6 hour log-Pearson Type III rainfall intensities as calculated and supplied by the Bureau of Meteorology. The intensity data were derived from the Australian Rainfall and Runoff (Pilgrim 1987) database and were supplied as a grid at a spacing of 0.025 degrees. Appendix 1 shows a map of the R factor calculated for each grid intersection using Equation 2 (Rosewell 1993b)

$$R = 164.74 (1.1177)^{I_s} (I_s)^{0.6444} \text{ (MJ.mm/(ha.h.y))} \quad (\text{Eqn 2})$$

where I_s is the 2 year 6 hour log-Pearson Type III rainfall intensity (mm/h).

2.2 Soil erodibility factor (K)

The K factor is a measure of the resistance of the soil to sheet and rill erosion. K may be estimated from data on the soil's particle size distribution, organic matter content, surface structure and profile permeability using the soil erodibility nomograph (Wischmeier and Smith 1978; Rosewell 1993a). Alternatively K may be estimated from the surface soil texture using an assumed organic matter content (Rosewell 1993a). However, none of these soil data are available Australia-wide in digital form.

Table 1: Erodibility classes used for ranking soils

| Erodibility Class | Erodibility | K factor |
|-------------------|-------------|-------------|
| 1 | Very Low | ≤ 0.01 |
| 2 | Low | 0.02 |
| 3 | Moderate | 0.03 |
| 4 | High | 0.05 |
| 5 | Very High | ≥ 0.06 |

The Digital Soils Atlas created by the National Resource Information Centre (NRIC) from the *Atlas of Australian Soils* (Northcote et al. 1960–68) contains mapping units with landform attributes and dominant principle profile forms for the whole continent. A useful aggregation of these mapping units is shown in the *Atlas of Australian Resources—Soils* (Division of National Mapping, 1980). These mapping units were assigned an erodibility class on a scale of 1 to 5 based on an assessment of the surface soil texture, organic matter content, surface soil structure and profile permeability of the dominant soils. The classes and corresponding K factors are shown in Table 1 with the K factors assigned to each mapping unit shown in Table 2. No soil units were assigned to a class of 5 (very high erodibility) as this classification would only apply to soils with a silty surface texture which, although common on, for example, the NSW coastal plain (Morland 1994), are not mapped in the *Atlas of Australian Soils*.

The K factors for the units shown in Table 2 were used as a guide to the assignment of a K factor to all of the Principal Profile Classes (Principal Profile Forms at the Class level) found in the Digital Soil Atlas. It was not possible to perform a completely systematic reclassification of the Digital Soil Atlas and some manual reclassification was necessary to cover all of the units found. This reclassification included the subjective assignment of a K factor of 0.04 to some soils of moderate to high erodibility.

2.3 Slope length (L) and steepness (S) factors

The L and S factors are measures of the effect of slope length and slope steepness on sheet and rill erosion. The slope and an average slope length may be calculated from a digital elevation model (DEM) if it has sufficient resolution. The current Australian DEM

at a resolution of 0.025 degrees has been shown to give spurious results for large parts of the continent (Bullen and Thackway, pers. comm., 1994).

For this project, slope length and steepness were estimated from the landform attributes attached to map units on the Digital Soils Atlas. The landform keywords in the explanatory notes for each map unit were standardised into the twenty-one standard codes used by McDonald et al. (1990) in a previous ERIN/NIE project. The slope was set to the modal slope for each standard code. The slope was combined with the average relief for each standard code to calculate a theoretical maximum slope length. The actual slope length assigned to each standard code was between a minimum of 22 m (length of USLE unit plot) and an upper limit of the maximum slope length or 300m whichever was smaller. A 300 m slope length is the maximum recommended for use with the RUSLE. Within any relief class the slope length was assumed to decrease with increasing slope grade. Slope length was subjectively assigned, but within defined limits. The range of slope lengths were purposely kept narrow and the impact of errors in estimation is expected to be relatively minor as with the RUSLE soil loss is less sensitive to slope length than to any other factor. For typical slope conditions, a 10% error in the slope length results in a 5% error in computed soil loss.

The slope length and slope steepness factors shown in Table 3 were calculated from the following equations as used in the RUSLE (Renard et al. 1997) and in SOLOSS (Rosewell 1993a).

$$L = \left(\frac{X_h}{22.13} \right)^m \quad (\text{Eqn 3})$$

where X_h is the horizontal slope length in metres and m is a variable slope length exponent related to the ratio (β) of rill to interrill erosion.

For a moderate rill/interrill ratio,

$$m = \frac{\beta}{(1 + \beta)} \quad (\text{Eqn 4})$$

$$\beta = \frac{\sin \alpha / 0.0896}{[3.0 (\sin \alpha)^{0.8} + 0.56]} \quad (\text{Eqn 5})$$

where α is the slope angle.

L is, therefore, a function of both slope length and slope angle.

Table 2: Soil erodibility factor (K) for soil mapping units in *Atlas of Australian Resources—Soils*

| Mapping Unit | Profile Forms | Erodibility Class | K |
|--------------|--|-------------------|------|
| A1 | Um4.3; Um5.22; Um6.11; Um6.14; Um6.3 | 3 | 0.03 |
| A2 | Dr2.2; Dr2.6; Dr3.2; Dr4.1; Dr4.2; Db1.2; Db3.1; Dy2.2; Dy3.2 | 3 | 0.03 |
| Ba1 | Um4.4; Um6.12; Um6.13 | 2 | 0.02 |
| Ba2 | Uf5.2 | 2 | 0.02 |
| Ba3 | Gn3.0; Gn3.1; Gn3.2; Gn3.4; Gn3.5; Gn3.7; Gn3.9; Gn4.1; Gn4.3; Gn4.4 | 2 | 0.02 |
| Bb1 | Um5.52 | 3 | 0.03 |
| Bb2 | Um7.1 | 1 | 0.01 |
| Bb3 | Uf6.71 | 3 | 0.03 |
| Bb4 | Gn2.1; Gn2.2; Gn2.3; Gn2.4; Gn2.6; Gn2.7; Gn2.8; Gn2.9 | 3 | 0.03 |
| Bb5 | Dy2.6; Dy3.6; Dy3.8; Dy5.6 | 4 | 0.05 |
| Bc1 | Uc1.1 | 1 | 0.01 |
| Bc2 | Gc1.2; Gc2.2 | 3 | 0.03 |
| Bd1 | Um1.1; Um1.2 | 4 | 0.05 |
| Bd2 | Uf1.4; Uf6.5; Uf6.6; Ug5.17 | 4 | 0.05 |
| Bd3 | Dr1.1; Dr1.3; Dr1.4 | 4 | 0.05 |
| Ca1 | Uc1.43; Uc2.2; Deep Uc1.2; Uc4.2; Uc5.1 | 3 | 0.03 |
| Cb1 | Ug5.11–.16; Ug5.2; Ug5.3 | 4 | 0.05 |
| Cb2 | Ug5.4; Ug5.5 | 4 | 0.05 |
| Cc1 | Dr2.1; Dr2.3; Db1.1; Db1.3; Dy2.3; Dy3.3; Dd1.1; Dd1.3; Dd2.3 | 4 | 0.05 |
| Cd1 | Uc2.3 | 2 | 0.02 |
| Cd2 | Dr2.4; Dr2.8; Dr3.4; Dr4.4; Db1.4; Dy2.4; Dy3.4; Dy5.4; Dy5.8 | 3 | 0.03 |
| Ce1 | Uf6.42 | 3 | 0.03 |
| Ce2 | Dg2.4; Dg4.1 | 3 | 0.03 |
| Cf1 | Uc1.3; Uc1.4; Uc2.1; Uc5.2; Uc6.1; Shallow Uc1.2; Uc4.1; Uc4.2; Uc5.1 | 2 | 0.02 |
| Cf2 | KS–Uc4.1; KS–Uc4.2 | 2 | 0.02 |
| Cf3 | Um1.3; Um1.4; Um2.1; Um4.1; Um4.2; Um5.1; Um5.3; Um5.4; Um5.51; Um5.61; Um6.2 Shallow Um5.2 | 3 | 0.03 |
| Cf4 | Uf6.1; Uf6.2; Uf6.3 | 2 | 0.02 |
| Cf5 | Largely bare rock | 4 | 0.05 |
| O1 | O | 1 | 0.01 |

Table 3: L and S factors for simple landform patterns characterised by relief and modal slope

| Code | Relief (m) | Slope % | Maximum slope length (m) | Slope length (m) | L | S | LS |
|------|------------|---------|--------------------------|------------------|------|-------|------|
| RM | 500 | 20 | 2550 | 40 | 1.42 | 2.79 | 3.97 |
| SM | 500 | 40 | 1350 | 22 | 0.95 | 5.74 | 5.43 |
| VM | 500 | 70 | 870 | 22 | 0.86 | 9.13 | 7.88 |
| PM | 500 | 100 | 710 | 22 | 0.77 | 11.38 | 8.78 |
| UH | 150 | 6 | 2500 | 125 | 2.11 | 0.68 | 1.43 |
| RH | 150 | 20 | 760 | 70 | 2.00 | 2.79 | 5.60 |
| SH | 150 | 40 | 400 | 40 | 1.42 | 5.74 | 8.18 |
| VH | 150 | 70 | 260 | 22 | 0.86 | 9.13 | 7.88 |
| PH | 150 | 100 | 200 | 22 | 0.77 | 11.38 | 8.78 |
| UL | 50 | 6 | 835 | 300 | 3.09 | 0.68 | 2.09 |
| RL | 50 | 20 | 250 | 125 | 2.86 | 2.79 | 8.00 |
| SL | 50 | 40 | 140 | 40 | 1.42 | 5.74 | 8.18 |
| VL | 50 | 70 | 80 | 22 | 0.86 | 9.13 | 7.88 |
| GR | 15 | 2 | 750 | 300 | 1.89 | 0.25 | 0.46 |
| UR | 15 | 6 | 250 | 125 | 2.11 | 0.68 | 1.43 |
| RR | 15 | 20 | 80 | 40 | 1.42 | 2.79 | 3.97 |
| SR | 15 | 40 | 40 | 22 | 0.95 | 5.74 | 5.43 |
| LP | 5 | 0.5 | 1000 | 300 | 1.25 | 0.08 | 0.10 |
| GP | 5 | 2 | 250 | 125 | 1.53 | 0.25 | 0.38 |
| UP | 5 | 6 | 80 | 40 | 1.29 | 0.68 | 0.87 |
| RP | 5 | 20 | 25 | 22 | 0.98 | 2.79 | 2.75 |

The steepness factor (S) is derived as follows:

$$S = 10.8 \sin \alpha + 0.03 \quad s < 9\% \quad (\text{Eqn 6})$$

$$S = 16.8 \sin \alpha - 0.50 \quad s \geq 9\% \quad (\text{Eqn 7})$$

where s is the slope gradient in percent.

Separate data layers for L and S were prepared to facilitate review of the data and some manual adjustment of the slope classes was made to areas where local knowledge indicated that an error in interpretation had occurred. The changes were made by adjusting the Atlas landform attributes by one class up or down as appropriate.

2.4 Crop and cover management factor (C)

The *C* factor measures the combined effect of all the interrelated vegetative cover and crop 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.

For non-crop (non-disturbed) land 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). Surface cover includes living and dead vegetative material and non-transportable material such as stones and rocks. The *C* factor can be estimated from information on canopy cover and surface cover using the procedures described by Wischmeier and Smith (1978).

The vegetation of Australia has been mapped in the *Atlas of Australian Resources—Vegetation* (AUSLIG 1990) which shows the estimated growth form and foliage cover for the years 1788 and 1988. The map for 1988 also shows the area of crop land using symbols which represent 10 000 ha of either winter or summer crop. Only the 1988 data were used in this project.

The natural vegetation information is available in digital form as codes indicating the growth form (height) of the tallest stratum, the foliage cover and the growth form of any lower stratum. These codes were used to determine canopy cover and canopy height. It was assumed that foliage cover, ‘the proportion of the ground that would be shaded if sunshine came from directly overhead’, is the same as canopy cover ‘portion of total-area surface that would be hidden from view by canopy in a vertical projection’. The floristic codes and the descriptions of each unit in the Atlas were examined to estimate the average annual ground cover as grass and grass-like type and herbaceous type covers. No attempt was made to include rock cover in the assessment of surface cover. The derived data are shown in Table 4.

For each mapping unit the *C* factor was estimated using the equations based on the data in Table D5 of the *SOILOSS Handbook* (Rosewell 1993a). The *C* factor is calculated as the product of subfactors for canopy cover and surface cover.

$$C = \text{Can_Cov} * \text{Surf_Cov} \quad (\text{Eqn 8})$$

$$\text{Can_Cov} = 1 - (\text{CC}/100) * \text{EXP}(-.328 * \text{CH}) \quad (\text{Eqn 9})$$

$$\text{Surf_Cov} = \text{EXP}(a + b * \text{GC} + c * \text{GC}^2 + d * \text{GC}^3) \quad (\text{Eqn 10})$$

where:

- CC is canopy cover (%)
- CH is canopy height (m)
- GC is surface cover (%)
- *a*, *b*, *c* and *d* are coefficients.

For Grass (G) cover type:

- *a* is 0.7986
- *b* is 0.047384
- *c* is 0.0004488
- *d* is 5.2035E 06.

For Herbaceous (H) cover type:

- *a* is 0.7982
- *b* is 0.040083
- *c* is 0.0005212
- *d* is 4.9749E 06.

Equations 8 to 10 produce a *C* factor of 0.45 for bare undisturbed land compared to a maximum value for *C* of 1.0 for bare cultivated land.

For closed forests and rain forests the *C* factor was set to 0.001 and 0.0001 respectively as suggested in Table D4 of the *SOILOSS Handbook*.

For crop land the *C* factor is a measure of the additional erosion resulting from frequent soil disturbance by cultivation and the protection provided by crop canopy, crop residue, surface roots and tillage induced surface roughness. During a crop rotation the soil disturbance and proportion of each type of protection will vary as will the seasonal distribution of erosive rain and it is necessary to develop a weighted average annual *C* factor. Zones of assumed equal distribution of erosive rain have been developed for use in Australia (Rosewell 1993a). The *SOILOSS* computer program contains the procedures for calculating *C* factors for each zone and for a range of crops managed using different practices.

Table 4: Estimation of C factors for vegetation described in the *Atlas of Australian Resources—Vegetation*

| LEGEND: | | LS_GF Lower stratum growth form | |
|---|--|--|-------------------------------------|
| TS_GF Tallest stratum growth form | | F Other herbaceous plants | F Other herbaceous plants |
| | | G Tussocky or tufted grasses | G Tussocky or tufted grasses |
| | | H Hummock grasses | H Hummock grasses |
| | | L Low trees—8m | L Low trees—8m |
| | | M Medium trees—20m | M Medium trees—20m |
| | | S Tall shrubs—4m | S Tall shrubs—4m |
| | | T Tall trees—30m | T Tall trees—30m |
| | | Z Low shrubs—1m | Z Low shrubs—1m |
| TS_D Tallest stratum foliage cover | | CH Canopy height | |
| 1 5% | | CC Canopy cover —assumed equal to foliage cover | |
| 2 20% | | GC Ground cover — derived from vegetation description and assumed to be the cover in contact with the soil surface. | |
| 3 50% | | Typ Ground cover type | |
| 4 85% | | G Grass and grass-like plants | |
| | | H Herbaceous plants and litter | |
| | | C USLE C factor | |

| # | TS_GF | TS_D | LS_GF | CH | CC | GC | Typ | C | Notes |
|----|-------|------|-------|----|----|----|-----|-------|------------|
| 2 | F | 1 | | | | 5 | H | 0.373 | |
| 3 | F | 3 | | | | 50 | G | 0.067 | |
| 4 | F | 4 | | | | 85 | G | 0.008 | |
| 5 | G | 1 | | | | 5 | G | 0.359 | |
| 6 | G | 2 | | | | 20 | G | 0.200 | |
| 7 | G | 3 | | | | 50 | G | 0.067 | |
| 8 | G | 4 | | | | 85 | G | 0.008 | |
| 9 | H | 2 | | | | 20 | G | 0.200 | |
| 10 | L | 1 | | 8 | 5 | | | 0.003 | Rocky |
| 11 | L | 1 | F | 8 | 5 | 20 | H | 0.238 | |
| 12 | L | 1 | G | 8 | 5 | 20 | G | 0.199 | |
| 13 | L | 1 | H | 8 | 5 | 15 | G | 0.239 | |
| 14 | L | 1 | S | 8 | 5 | 15 | H | 0.272 | |
| 15 | L | 1 | Z | 8 | 5 | 20 | H | 0.238 | |
| 16 | L | 2 | | 8 | 20 | 5 | H | 0.368 | |
| 17 | L | 2 | F | 8 | 20 | 50 | H | 0.118 | eL2F in SA |
| 18 | L | 2 | G | 8 | 20 | 25 | G | 0.166 | |
| 19 | L | 2 | H | 8 | 20 | 20 | G | 0.197 | |

Table 4 (continued): Estimation of C factors for vegetation

| # | TS_GF | TS_D | LS_GF | CH | CC | GC | Typ | C | Notes |
|----|-------|------|-------|----|----|----|-----|-------|----------------|
| 20 | L | 2 | S | 8 | 20 | 15 | H | 0.269 | |
| 21 | L | 2 | Z | 8 | 20 | 15 | H | 0.269 | |
| 22 | L | 3 | | 8 | 50 | 5 | H | 0.359 | |
| 23 | L | 3 | G | 8 | 50 | 30 | G | 0.136 | |
| 24 | L | 3 | S | 8 | 50 | 25 | H | 0.204 | |
| 25 | L | 3 | Z | 8 | 50 | 20 | H | 0.230 | |
| 26 | L | 4 | | | | | | 0.001 | Closed forest |
| 27 | M | 1 | F | 20 | 5 | 50 | H | 0.120 | |
| 28 | M | 1 | G | 20 | 5 | 50 | H | 0.067 | |
| 29 | M | 1 | L | 20 | 5 | 20 | H | 0.141 | |
| 30 | M | 1 | L | 20 | 5 | 20 | H | 0.239 | |
| 31 | M | 1 | S | 20 | 5 | 20 | H | 0.239 | |
| 32 | M | 2 | G | 20 | 20 | 50 | G | 0.067 | Now cropped? |
| 33 | M | 2 | H | 20 | 20 | 40 | G | 0.099 | |
| 34 | M | 2 | L | 20 | 20 | 35 | H | 0.169 | Now cropped? |
| 35 | M | 2 | S | 20 | 20 | 35 | H | 0.169 | Now pasture? |
| 36 | M | 2 | Z | 20 | 20 | 25 | H | 0.212 | |
| 37 | M | 3 | | 20 | 50 | 5 | H | 0.373 | |
| 38 | M | 3 | G | 20 | 50 | 85 | G | 0.008 | |
| 39 | M | 3 | L | 20 | 50 | 85 | H | 0.030 | |
| 40 | M | 3 | S | 20 | 50 | 85 | H | 0.030 | |
| 41 | M | 3 | Z | 20 | 50 | 70 | H | 0.063 | |
| 42 | M | 4 | | 20 | 85 | | | 0.001 | Closed forest |
| 43 | S | 1 | | 4 | 5 | 5 | H | 0.368 | Degraded Mulga |
| 44 | S | 1 | F | 4 | 5 | 30 | H | 0.186 | |
| 45 | S | 1 | G | 4 | 5 | 25 | G | 0.166 | |
| 46 | S | 1 | H | 4 | 5 | 15 | G | 0.237 | |
| 47 | S | 1 | Z | 4 | 5 | 10 | H | 0.312 | |
| 48 | S | 2 | | 4 | 20 | 5 | H | 0.353 | |
| 49 | S | 2 | F | 4 | 20 | 20 | H | 0.226 | |
| 50 | S | 2 | G | 4 | 20 | 20 | G | 0.189 | |
| 51 | S | 2 | H | 4 | 20 | 20 | G | 0.189 | |

Table 4 (continued): Estimation of C factors for vegetation

| # | TS_GF | TS_D | LS_GF | CH | CC | GC | Typ | C | Notes |
|----|-------|------|-------|----|----|----|-----|--------|-------------|
| 52 | S | 2 | Z | 4 | 20 | 15 | H | 0.258 | |
| 53 | S | 3 | G | 4 | 50 | 15 | G | 0.208 | |
| 54 | S | 3 | H | 4 | 50 | 10 | G | 0.252 | |
| 55 | S | 3 | Z | 4 | 50 | 10 | H | 0.273 | |
| 56 | T | 3 | L | 30 | 50 | | | 0.0001 | Rain forest |
| 57 | T | 3 | M | 30 | 50 | | | 0.0001 | Rain forest |
| 58 | T | 3 | S | 30 | 50 | | | 0.0001 | Rain forest |
| 59 | Z | 1 | | 1 | 5 | 5 | H | 0.360 | |
| 60 | Z | 1 | F | 1 | 5 | 10 | H | 0.305 | |
| 61 | Z | 1 | G | 1 | 5 | 10 | G | 0.281 | |
| 62 | Z | 1 | H | 1 | 5 | 5 | G | 0.346 | |
| 63 | Z | 2 | | 1 | 20 | 5 | H | 0.319 | |
| 64 | Z | 2 | F | 1 | 20 | 20 | H | 0.205 | |
| 65 | Z | 2 | G | 1 | 20 | 20 | G | 0.171 | |
| 66 | Z | 3 | | 1 | 50 | 5 | H | 0.239 | |
| 67 | Z | 3 | G | 1 | 50 | 30 | G | 0.090 | |
| ? | T | 4 | | 30 | 85 | | | 0.0001 | Rain forest |

SOILOSS was used to calculate the *C* factors for crop monoculture managed using traditional tillage (maximum tillage and minimum residue retention) practices. The selected crops were sorghum in the summer dominant rainfall zones and wheat in the non-seasonal and winter dominant rainfall zones. The estimated *C* factors are shown in Table 5. The crop *C* factors were applied to the areas represented by the location symbols for summer or winter crops on the vegetation map.

2.5 Support practice factor (P)

In the RUSLE, the support practice factor (P) is generally applied to disturbed lands where contour cultivation, systems of banks and other support practices are used to reduce erosion. For this project all lands were assumed to have no erosion support practices and the factor was set to 1.

Table 5: Estimation of C factors for crop lands in ten rainfall erosivity zones

| Zone | Crop | Practice | C |
|------|-------------|-------------|------|
| 1 | Sorghum | Traditional | 0.47 |
| 2 | Sorghum | Traditional | 0.53 |
| 3 | Sorghum | Traditional | 0.46 |
| 3 | Wheat | Traditional | 0.16 |
| 4 | No cropping | No cropping | – |
| 5 | Sorghum | Traditional | 0.47 |
| 5 | Wheat | Traditional | 0.16 |
| 6 | Wheat | Traditional | 0.15 |
| 7 | Wheat | Traditional | 0.18 |
| 8 | Wheat | Traditional | 0.18 |
| 9 | Wheat | Traditional | 0.24 |
| 10 | Wheat | Traditional | 0.21 |

3. Sheet and rill erosion index

The data for each factor in the RUSLE was calculated for each grid cell to provide a data layer for that factor. Each of the input data layers were converted, by ERIN, into ARC/INFO Grid format. Each input datum was multiplied by the other RUSLE factors for each grid cell with the product placed in another grid cell with the same georeferencing. The sheet and rill erosion index value for each grid point was reclassified and mapped in three ranges of:

- Low (<1 tonnes/hectare/year)
- Moderate (1 to 10 tonnes/hectare/year)
- High (>10 tonnes/hectare/year).

The resulting map, Appendix 2, shows areas with low, moderate and high sheet and rill erosion index with drainage basins superimposed.

4. Phosphorus movement index

The potential movement of phosphorus in Australia was estimated by combining estimates of sheet and rill erosion with estimates of the phosphorus concentration in surface soils. The mapping units of the Digital Soils Atlas were assigned a total phosphorus content ranking of low (<200 ppm), moderate (200–400 ppm) and high (>400 ppm) using data provided by NRIC. This input data layer was multiplied by the sheet and rill erosion index layer to provide a grid coverage showing the potential for phosphorus movement. The final map, Appendix 3, was prepared showing three classes:

- Low movement potential (0–2000)
- Moderate movement potential (2000–10 000)
- High movement potential (>10 000)

and is shown with superimposed drainage basins.

5. Discussion

This project has provided a first approximation of continent-wide indices of sheet and rill erosion and potential phosphorus movement. The results appear reasonable and demonstrate the utility of the RUSLE approach in providing a broad scale view of sheet and rill erosion. However, there are many obvious anomalies which reflect the lack of high resolution

topographic, soil and vegetative cover data for Australia.

Of all the factor values, the rainfall erosivity factor was the easiest to estimate and appears to be reliable with a draft map being in good agreement with existing rainfall erosivity information, (Rosewell 1993a). However, an analysis of pluviograph data for South Australia (unpublished) shows that Equation 2 over-estimates the R factor by a factor of two for *I_s* values about 5 mm/h and smaller. Data from the tropical areas of Queensland (unpublished) indicates that Equation 2 slightly under-estimates R for very high values of *I_s*. Re-calculation of the R factor using modified equations would be warranted for future projects using rainfall erosivity in Australia.

Considerable difficulty and subjectivity were involved in the assignment of a *K* factor value to the Principal Profile Form of the dominant soil of a soil landscape which is used as a basis for mapping in the Digital Soil Atlas. In most cases the criteria used to classify the Principal Profile Form have little or no relevance to determining the soil erodibility. Due to the time constraints placed on the project it was not possible to explore alternative methods of estimating *K* factors for Australian soils. One useful suggestion has been made that individual State soil databases contain the information to allow correlations between Principle Profile Forms and surface soil texture which, in turn, can be used to estimate *K* factors. In particular, the NSW Soil Database contains a great deal of information on soil profile descriptions and associated *K* factors. Greater use should be made of the State soil databases for estimating *K* factors in the future.

The terrain slope class was objectively assigned to a landscape description contained in the Digital Soils Atlas. However, it is possible that the soil surveyors involved in the preparation of the *Atlas of Australian Soils* could have used different soil terrain descriptions for similar slopes. Also some of the terrain slope classes cover a wide range of slopes. For example, the moderately inclined slope class (McDonald et. al. 1990) has a slope range from 10 to 32% and the use of a modal slope of 20% would over-estimate the slope for a large area of soils. It is considered that slope should be estimated from an accurate DEM when available.

Table 6: Examples of extreme values of average annual soil loss

| Long. | Lat. | A | R | K | L | S | C |
|---------|---------|-----|-------|------|------|------|-------|
| 143.125 | -12.675 | 605 | 9202 | 0.03 | 1.42 | 5.74 | 0.269 |
| 143.45 | -12.950 | 449 | 11063 | 0.03 | 1.42 | 5.74 | 0.166 |

Examination of a preliminary sheet and rill erosion index map showed some areas of Australia with extremely high values ($A > 100$ tonnes/hectare/year) especially in the tropics and arid areas. It appears that such areas are generally associated with high R factors and relatively high C factors. For example, refer to Table 6.

The first example has a C factor of 0.269 which corresponds to Table 4 Units 20 or 21 with an estimated ground cover of 15%. The second example corresponds to Units 18 or 45 with a ground cover of 25%. It is considered that the C factors are much too high as there is no evidence that the tropics of Australia under natural vegetation are eroding at the rate of about 500 t/ha/y.

The most likely explanation for the high C factors is that no account was taken of the high rock cover that is often present on the soils of central and northern Australia. See, for example, the photographs of the soil surface in the *Atlas of Australian Resources—Vegetation* map for the low trees and shrub vegetation types. If it was assumed that a rock cover of 50% was present and the effect of the vegetation cover was additive (50% rock plus 15% vegetation = 65% ground cover) then the C factor for the first example would be 0.076 ($A = 171$ tonnes/hectare/year) and that for second would be 0.018 ($A = 48$ tonnes/hectare/year).

A second difficulty concerns the estimation of an average annual C factor where the rainfall is markedly seasonal. Northern Australia experiences a marked wet season with rain falling over a four to six month period. The C factors of Table 4 are calculated as an average annual value based on an estimate of the ground cover observed at some unknown time during the year but probably during the dry season. It is likely that this estimated ground cover would only apply for the first month of the wet season and that up to 80% of the erosive rain would be falling on soil with a cover exceeding the estimate. A seasonally weighted C factor calculated as for an annual crop from the

seasonal distribution of ground cover and erosive rain would be more realistic and much lower than that estimated for Table 4. Furthermore, C factors estimated from a seasonal greenness index (Bullen 1993) might be more useful than those estimated from the vegetation map.

6. Conclusions

The estimated level of sheet and rill erosion are in the anticipated range for most of the country. However, the sheet and rill erosion indices for much of semi-arid Australia are higher than expected from experience. The most likely explanations are:

- the R factor is too high for the southern parts of the arid zone
- the C factor is over-estimated as discussed above
- possible over-estimation of the land slope.

Some of the ‘dominant’ landforms of some arid landscape units are probably minor types such as residual hills in an otherwise flat or undulating landscape.

Any errors in the sheet and rill erosion estimates will carry through to the potential phosphorus movement index. There are additional errors which are introduced in estimating the phosphorus status of the soils particularly in the selection of the scale used for ranking. It might have been more appropriate to have broadened the medium range to provide more emphasis to the soils with a very high phosphorus status (Banks, pers. comm., 1995). In interpreting the map in Appendix 3, the reader is cautioned that only the contribution of sheet and rill erosion to the potential movement of phosphorus is considered. Contributions from gully and streambank erosion may be more significant in many parts of Australia. Furthermore, no attempt has been made to estimate the enrichment of sediments with particulate phosphorus which occurs in the sheet and rill erosion process. Such enrichment can range from a factor of 1 to 5, dependant on soil texture, soil aggregate

stability and scale of measurement (Hairsine, pers. comm., 1995).

Overall, the project has been successful in highlighting the significant erosion experienced on much of the land of Australia and the consequence of

this erosion on the potential for phosphorus to move on the landscape. The project has also emphasised the need for high resolution topographic, soils and ground cover estimates in Australia in order that the state of the environment can be monitored more closely.

Abbreviations

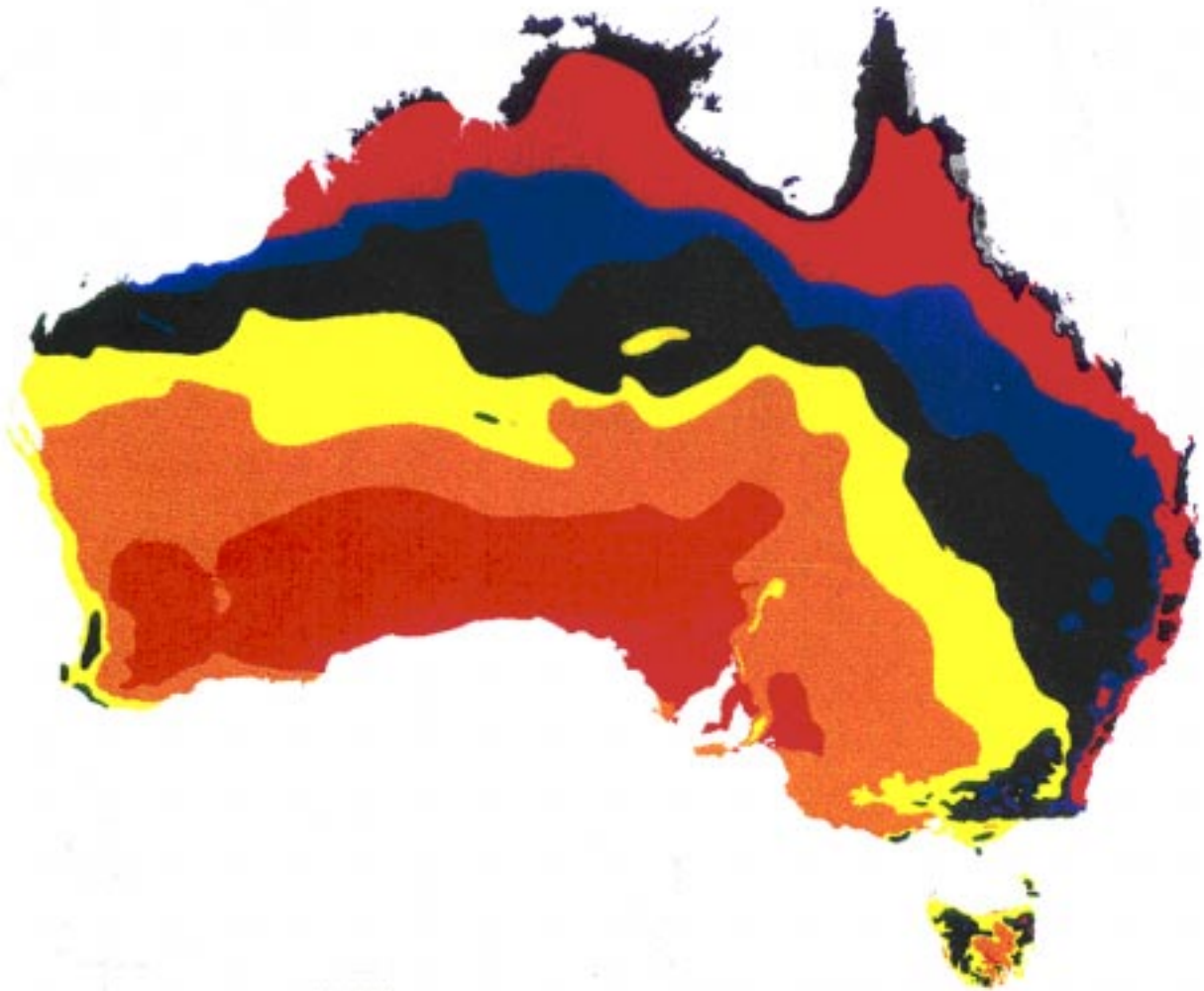
| | | | |
|--------|--|-------|--------------------------------------|
| AUSLIG | Australian Land Information Group | NIE | National Index of Ecosystems |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation | NRIC | National Resource Information Centre |
| DEM | Digital Elevation Model | RUSLE | Revised Universal Soil Loss Equation |
| DLWC | Department of Land and Water Conservation (NSW) | USLE | Universal Soil Loss Equation |
| ERIN | Environmental Resources Information Network | | |

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Appendix 1: Rainfall erosivity for Australia

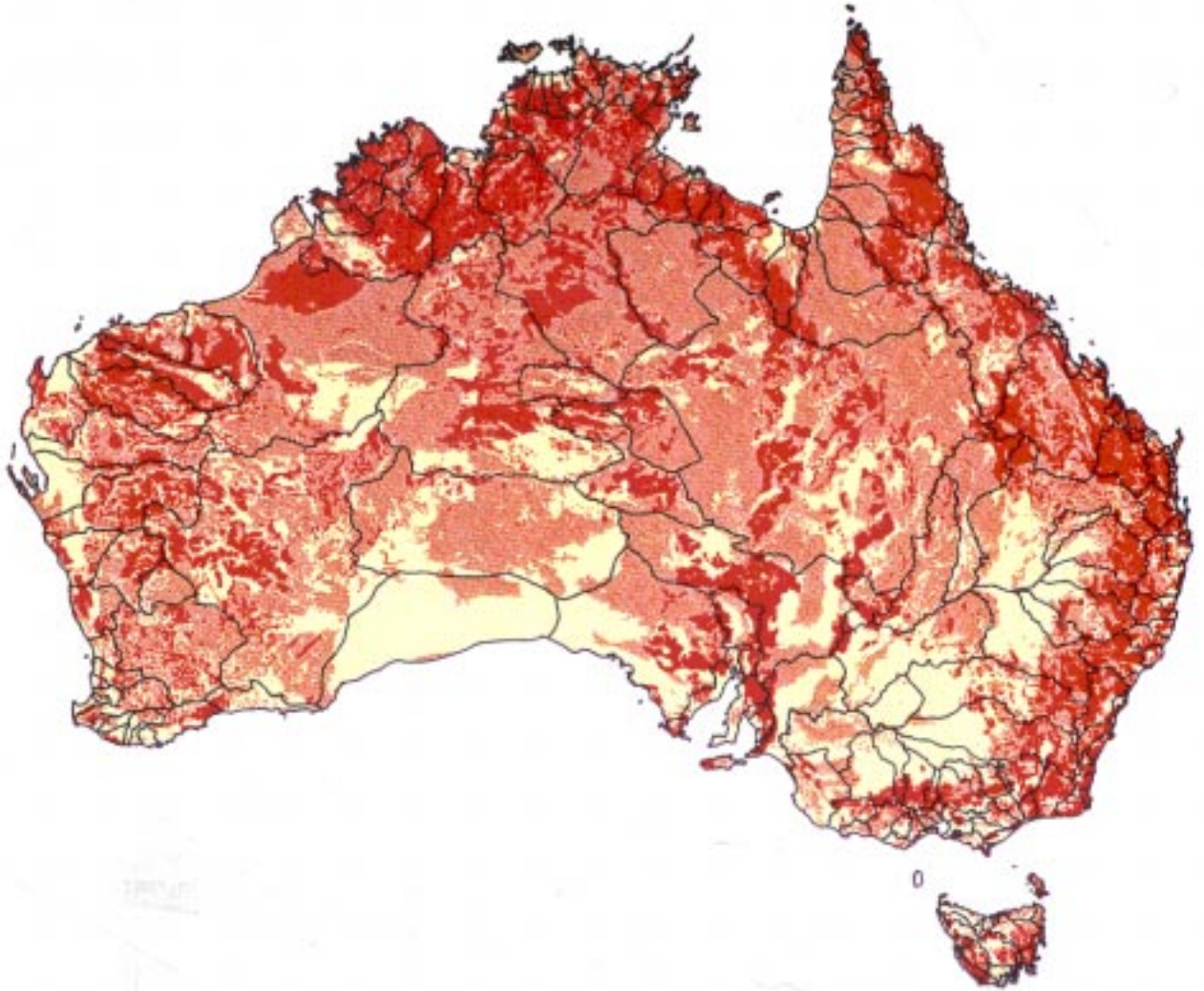
RUSLE factor R, MJ.mm/(ha.h.y)



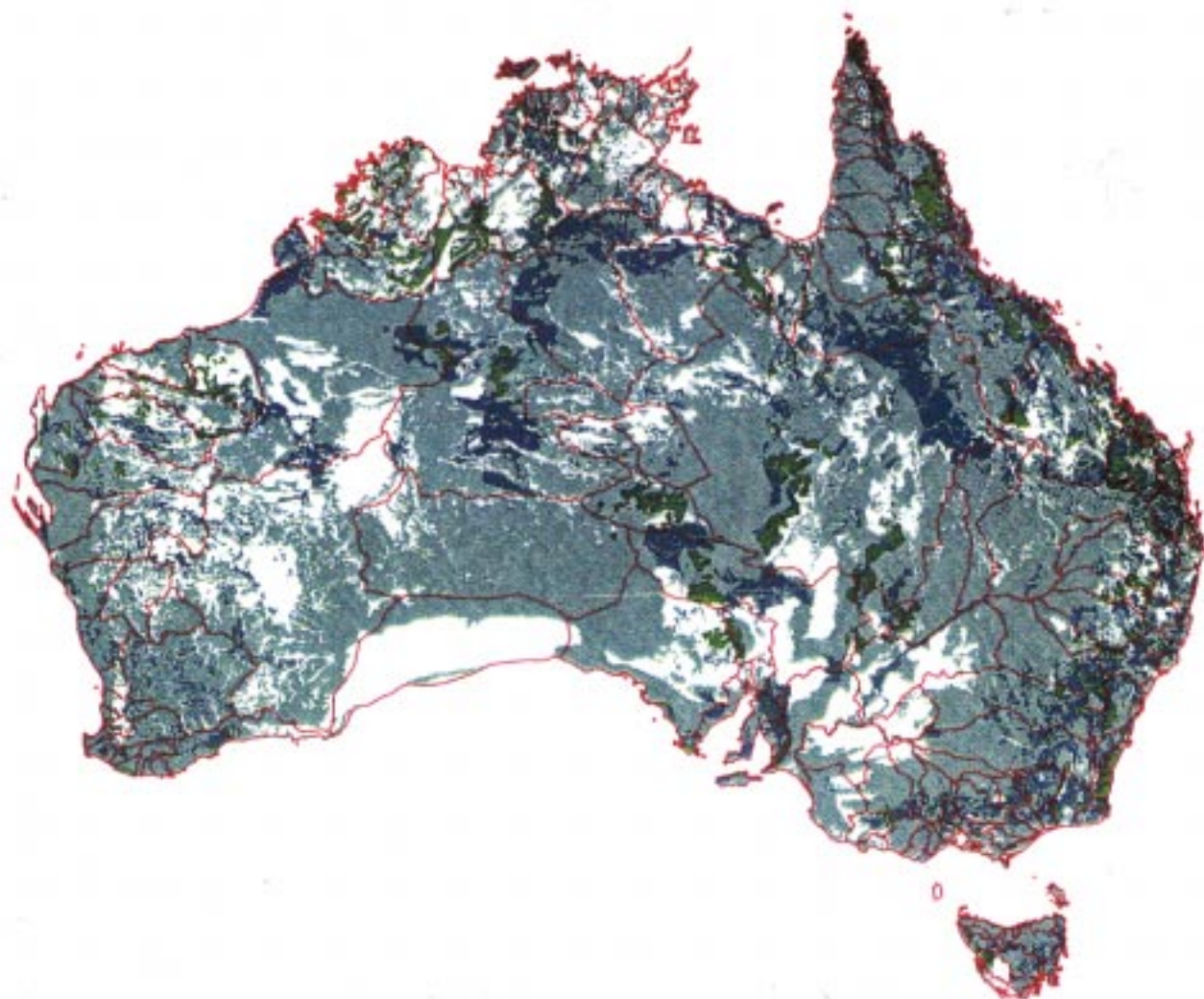
Legend

| | |
|---|---------------|
| ■ | 593 - 700 |
| ■ | 701 - 900 |
| ■ | 901 - 1200 |
| ■ | 1201 - 1800 |
| ■ | 1801 - 2500 |
| ■ | 2501 - 5000 |
| ■ | 5001 - 10000 |
| ■ | 10001 - 15000 |
| ■ | 15001 - 25000 |
| ■ | 25000 - 64673 |

Appendix 2: Sheet and rill erosion projection



Appendix 3: Phosphorus movement potential



- Legend
- No data
 - Low
 - Moderate
 - High