IMPROVED INPUTS FOR PREDICTION OF REGIONAL-SCALE SOIL EROSION POTENTIAL FOR QUEENSLAND

D. Brough , P. Lawrence, G. Fraser, D. Rayner and J. Le Grand
Department of Natural Resources, Mines & Energy, Brisbane, Australia.

Abstract
Soil erosion is a major form of land degradation in Queensland, which impacts on both on-site costs as well as off-site infrastructure, conservation assets and adjacent farmlands. For some time, there has been an active program of experimental research on runoff and erosion processes at a farm scale. However, for catchment scale planning and use of natural resources, a broad-scale assessment of the potential for soil erosion is required to predict the spatial impacts of land-use and prioritise investments in solutions. A spatial version of the Universal Soil Loss Equation (USLE) has been developed for this purpose in Queensland. The USLE factors rainfall erosivity, soil erodibility, slope and length of slope have been derived from a range of spatial estimation approaches using the best available information for Queensland. When combined with a cover index, these factors will produce a spatial map of the inherent hazard to hillslope soil erosion based on the physical features of landscapes, land management and climate. The development of the soil erosion assessment map can then provide a framework for government and catchment community groups to focus their activities in areas where the risks of potential soil erosion are greatest.

Additional Keywords: soil, erosion, prediction, geographical information system

Introduction
Soil erosion is a major cause of land degradation throughout Queensland resulting in reduced land productivity as well as potentially reducing water quality in rivers and coastal deposition areas. Intensive field trials have indicated that soil erosion rates are highly variable, both spatially and temporally, highlighting the difficulties in extrapolating the results of these trials to all parts of the landscape. Ideally, mapping the high erosion hazard areas in a landscape can show the areas that require more attention in land management and can also focus government and community investment in the areas that contribute a disproportionate amount of sediment to drainage lines. Although there are many models for calculating soil erosion, perhaps the most enduring method is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) to estimate long-term average annual soil loss. For more than 40 years, the USLE has experienced an array of applications spanning research, resource planning, and engineering. Although an empirical model, the method continues to be applied as factors of rainfall erosivity, soil erodibility, slope and length of slope, and cover factor (assuming support land practice is a sub-factor), to capture the fundamental processes leading to hillslope erosion.

Part of the attraction of the USLE is its simplicity. The factors can be derived from handbook or measured values. In recent times, the use of Geographic Information Systems (GIS) has supported the on-going applications of the USLE where spatial coverages of the input factors are combined to produce maps of annual soil erosion to inform planning and management of natural resources.

In Australia, two major initiatives have brought a sharp focus to the need for broadscale resource condition information. In 1997, the National Land and Water Resources Audit (NLWRA) considered the status of resource condition and the availability of resource information. As part of this program, Lu et al. (2001) developed USLE factors at a national scale for rainfall, soil erodibility, cover and combined slope and length of slope. In more recent time, the National Action Plan for Salinity and Water Quality (NAPSWQ) has a commenced a program for Regional Community Bodies to develop resource plans that address the issues of salinity, water quality and biodiversity. In Queensland, considerable resources are being invested to support the regional bodies by providing science information and tools to assist the Regional Community Bodies make informed resource planning decisions.

This paper describes an activity to improve the input data for a soil erosion hazard map and communication kit to support resource planning and decision making at a State-level scale. The work supercedes a component of the original NLWRA work for Queensland for determining hillslope soil erosion in a number of ways and combines new analyses that are being funded under the NAPSWQ. The paper also demonstrates the value of undertaking a systems approach to deriving science information products that allow updated information to be incorporated into existing data models to increase the efficiency of delivering information.

Materials and Methods

In 2001, Lu et al. (2001) used a simplified version of the Revised Universal Soil Loss Equation (RUSLE) which was calibrated using New South Wales field data to map hillslope average monthly and average annual erosion rates. This work indicated that there are a number of advantages with using the RUSLE equation including the ability to combine it with a raster-based GIS to produce a cell-by-cell basis for mapping spatial patterns of soil erosion rates. The advantage of using a GIS raster based framework is that it allows one to quantify the impact of a single factor on the overall result and it can also easily be updated with improved datasets.

The Queensland Department of Natural Resources, Mines & Energy (NRM&E) commenced a project to develop a state-wide assessment of soil erosion, using the same methodology of Lu et al. (2001), however with improved datasets for Queensland. This work builds on past activities involving soil conservation research experiments (see Freebairn and Silburn, 2004), previous efforts to quantify soil erosion on cropping lands (Begbie and Sullivan, 1986) and a generation of soil conservation extension (B. Carey, pers. comm. 2004). At the time of preparing this paper, the practice and cover factor have not been included in this project and hence a complete map of soil erosion hazard for the State is not available. The following section summarises the preparation work undertaken to improve the R and K factors.

Derivation of Rainfall Erosivity Factor

The derivation of rainfall erosivity (R-factor) from daily rainfall data follows the procedure described in Lu et al. (2001). In the USLE formulation, the rainfall R-factor is defined as the mean annual sum of individual storm erosion index (EI30) values. Individual storm erosion index values are calculated from rainfall intensity (pluviograph) records. It is not currently possible, however, to derive State-wide EI30 data-series because of the sparse spatial and temporal coverage of the Bureau of Meteorology pluviograph network. Instead, the R-factor calculation uses the model of Yu (1998) which relates EI30 values to daily rainfall totals. The model of Yu (1998) was derived from 41 sites across tropical Australia, and includes a monthly seasonal dependence.

Interpolated daily rainfall surfaces from the NRM&E SILO database (2004) were used as the model inputs. The SILO surfaces are defined on a regular latitude/longitude grid with 0.05 degree resolution.

A description of the rainfall interpolation technique used to generate these surfaces can be found in Jeffrey et al. (2001). In summary:

- observed station monthly rainfall totals are first normalized using observational data raised to an appropriate fractional power;
- the normalized data are interpolated using ordinary kriging;
- the interpolated surfaces are de-normalized to produce monthly rainfall surfaces in units of rainfall; and
- the interpolated monthly rainfall is then redistributed into daily rainfall totals, according to the distribution of interpolated daily rainfall.

Using this technique, it was possible to update the rainfall erosivity factor using a longer record of data 1915 – 2001 compared to the data set used by Lu et al. (2001) which only considered the rainfall records between 1980 - 1999. The base rainfall datasets produced by SILO (2004) have also changed as the interpolation techniques have been improved since 2001. Consequently, the longer base data set and the improved techniques for developing the base data represents an improved estimation of the rainfall erosivity for Queensland.

Derivation of Soil Erodibility Factor

The soil erodibility factor (K-factor) is derived on soil physical characteristics of particle size, permeability and structure. At the time of the NLWRA, a national coverage of soils information was restricted to the Atlas of Australian Soils at a scale of 1:2 million. However, extensive soil and land resource surveys in Queensland provide a much richer source of soils information compared to that available to Lu et al. (2001). More than 115 current and historical land resource surveys were overlaid from the largest to the smallest scale (that is from the Atlas of Australian Soils (1:2,000,000 scale) to the detailed 1:25,000 scale studies of irrigation areas). A description of the compilation of the soil attribute surface can be found in Brough et al. (2004) and Brough (2003).

The K-factor was calculated using the pedotransfer function developed by Littleboy 1997 who applied an adjustment factor for sediment density to the K-factor. For each of the suitable sites stored within the Soil and Land Information (SALI) database (SALI 2004), a K-factor was calculated and then averaged based on the

Principal Profile Form (Northcote 1979) of the site. This averaged K-factor was then applied to a polygon mapping following the steps listed in Brough (2003).

The combination of the pedotransfer function analysis, in conjunction with the spatial coverage of soils information and more detailed polygon mapping, were used to derive a State-wide coverage of the K-factor. The higher spatial resolution available from the Queensland land resources surveys and the improved quality of data compared to the earlier NLWRA information provides a more accurate picture of hillslope erosion processes.

Topographic Factors
Length of slope (L- factor) and slope steepness (S-factor) attributes were derived from topographic information. For these factors, the base data sets for mean slope and slope length were acquired from the NLWRA data library as generated by Galant (2002). These basedata sets for mean slope and slope length were then used as inputs to generate the L and S factor for the USLE.

The L factor is defined as the ratio of soil loss from the field slope length to that from a 22.13 m length under otherwise identical conditions (Lu et al., 2001) and was derived using the equation:

$$L = (X_h / 22.13)^m \quad [1]$$

where X_h is the horizontal slope length and
m is a variable slope length exponent.

The S factor is defined as the ratio of soil loss from the field slope gradient to that of 9% slope under identical conditions and was derived using the equations:

$$S = 10.8 * \sin\theta + 0.03 \text{ where } \sigma \leq 9\% \quad [2a]$$
$$S = 16.8 * \sin\theta - 0.5 \text{ where } \sigma > 9\% \quad [2b]$$

where θ is the angle of slope and σ is the slope gradient in percentage.

Using these equations and baseline 1:250,000 scale topographic coverage, L and S factor layers were derived for Queensland.

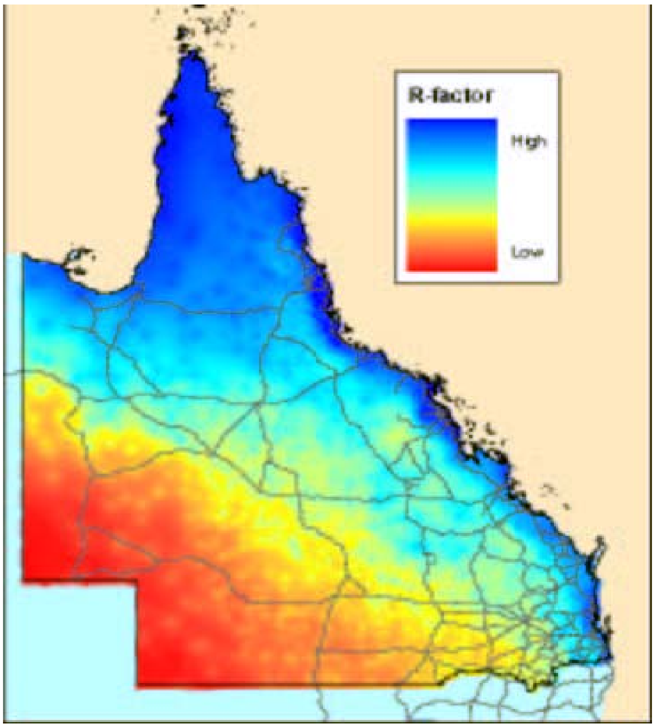
Information Management
All spatial factor coverages were stored on the dedicated Spatial Information Resource (SIR) information management platform called ENRII. The Department's Environment for Natural Resource Information Infrastructure (ENRII) establishes protocols and procedures for describing metadata tags for spatial and aspatial data. The benefits of this approach ensure consistency of data processing, a centralised, 'point-of-truth' repository to access spatial data, and significantly reduce the effort when these coverages are used for other applications. Further details on the ENRII are available on the NRM&E website (www.nrm.qld.gov.au).

Results and Discussion

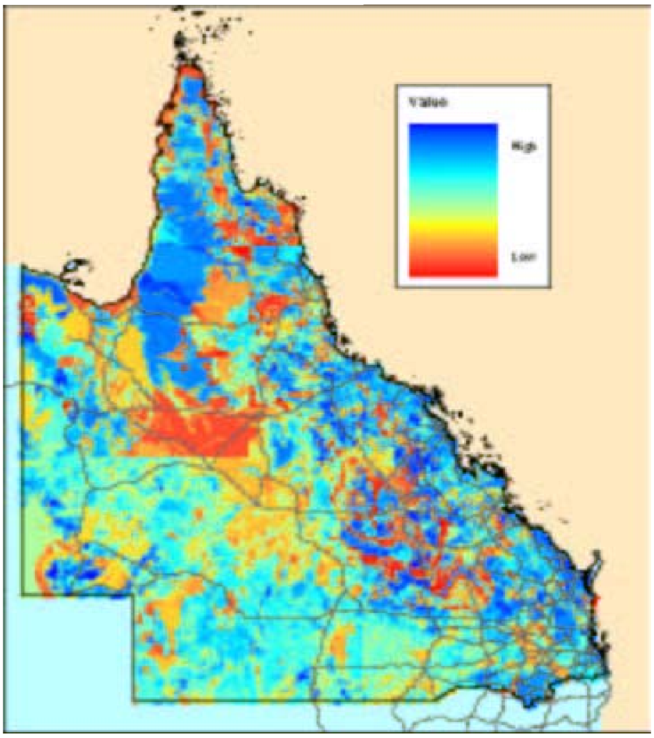
Input Factor Analysis
Queensland-wide maps of the rainfall erosivity factor, the soil erodibility factor, the length of slope and the slope steepness factors are shown in Figure 1. In presenting this information, a relative index system was used to spatially categorise the severity of each factor.

The rainfall erosivity (R-factor) shows generally high rainfall erosivity parallel to the coast, which declines in a westerly movement away from the coast (Figure 1a). This is similar to the outcomes from the NLWRA analysis and the analysis by Roseththal and White (1980), however the improved temporal resolution which was achieved using a longer daily rainfall record ensures a greater accuracy of the information to represent rainfall intensity and variability. A subset of longer term rainfall recording locations were reviewed and indicated that at these locations there was an average increase of 18% in the R-factor value using the longer term rainfall record compared to the previous analysis in the NLWRA. This outcome may not only be associated with the longer term records as the rainfall interpolation technique has also been revised.

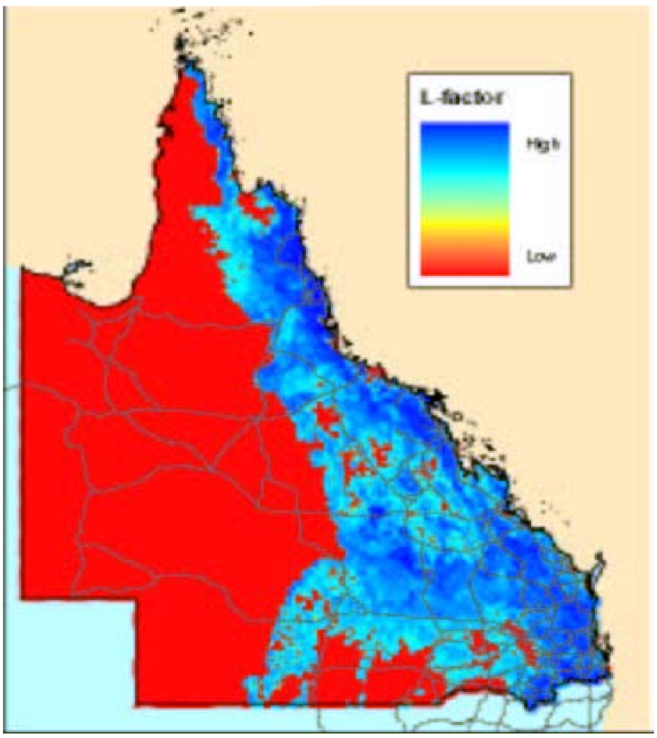
(a) Rainfall erosivity



(b) Soil erodibility



(c) Length of slope



(d) Slope steepness

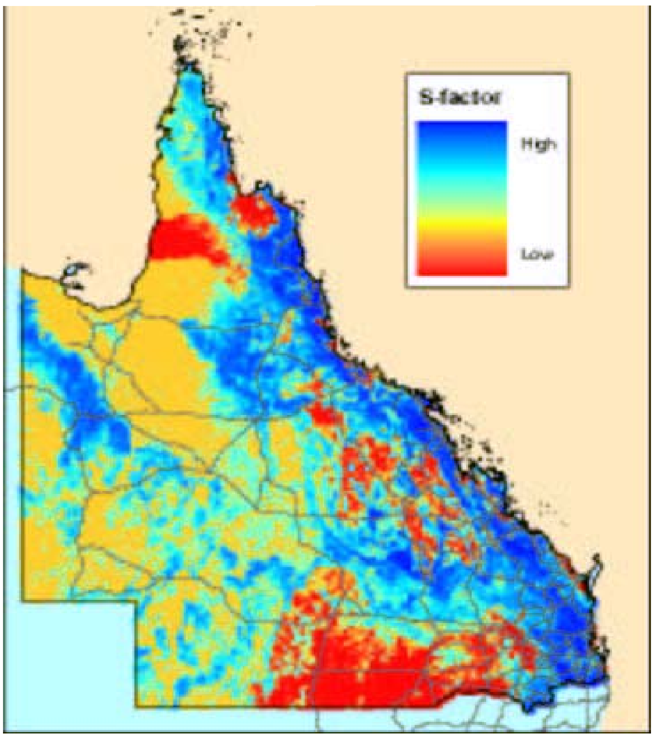


Figure 1. Spatial distribution of (a) rainfall erosivity factor, (b) soil erodibility, (c) length of slope and (d) slope steepness for Queensland.

The soil erodibility (K-factor) (Figure 1b) shows the locations where the soil physical properties provide an inherently higher hazard to water erosion. There are relatively higher soil erodibility ratings for coastal and inland areas in the south-east, central and western areas of northern Queensland, where these areas have clay and light textured soils. It can also be seen that some boundaries of K-factor analysis are straight lines. This is an artefact of the analysis process which used the best available soils and land resource information, and a straight-line boundary can occur when the analysis passes from one soil mapping sheet to another.

The length of slope (L-factor) and the Slope (S-factor) (Figures 1c and 1d) were derived from the 1:250,000 topographic information. The high hazard contributions from slope length and slope steepness correspond to the steeper slopes of the Great Dividing Range that runs parallel to the coastline. The extensive open plains of the central-western and inland areas of the State however pose relatively less impact from these physical features. When deriving LS factors for areas with less than 1 percent slope (when using a 9 sec DEM), then Lu et al. (2001) recommend that a value of 1 be used for the L factor.

The information presented should be regarded as preliminary, recognising that the current analysis does not include the cover factor of the USLE. The cover factor will identify locations where land use and management is conducive or detrimental to soil erosion and its potential to provide surface protection, particularly during the summer months when there is a greater incidence for high intensity storms. It is intended to use remote sensing methods to acquire land use and management information on a regular basis, so that erosion hazard information can be updated and used strategically in resource management planning. In addition, activities will be undertaken to validate the outcomes using local knowledge, site-specific ground-truthing and measurements from long term experimental sites, as well as provide regional training workshops to ensure agency and community groups are skilled to incorporate the information into their decision making. A communication kit will also be developed to ensure the information generated by the erosion hazard analysis is understood by resource planners in local government, industry and community groups and delivered in a way that supports their current activities.

Conclusions

An analysis of rainfall and land resource information has generated new and updated coverages for the R-factor and K-factor for Queensland as input layers for estimating long-term hillslope soil erosion. The analysis has used long-term rainfall records (> 80 yrs) and the best available soil and land resource information for Queensland. This has improved the accuracy for these two factors. These maps can now be adopted for current models that require estimates of hillslope erosion (e.g. EMSS). Apart from the improved accuracy of the inputs, the adoption of these maps as a standard will ensure greater consistency when interpreting the results from static or dynamic models that utilise the USLE approach to estimate soil erosion.

The current work should be regarded as preliminary and is somewhat limiting until a C-factor coverage can be incorporated and validated using on-ground checks, experimental sites and local knowledge. Incorporating a cover factor is currently in progress. Nonetheless, the work to date provides the foundation to prepare the necessary spatial data as well as the information protocols for further use of the spatial layers. This will improve the efficiency for delivering spatial information to external users as well as the standardising the spatial coverages related to these factors.

Acknowledgements

We wish to thank Mr Steve Huch, Department of Natural Resource, Mines and Energy for his assistance with spatial coverage databases and Mr Bruce Carey, Department of Natural Resource, Mines and Energy, for his advice on soil erosion mapping. We also acknowledge Dr Hua Lu and Dr John Galant, CSIRO Land and Water, for providing data and advice while undertaking this project.

References

Begbie, D.K. and Sullivan, D.J. (1986). Soil erosion. Qld Agricultural Journal 112(4): 158-160.
Brough, D.M. (2003). Creation of soil attribute surfaces for landscape salinity hazard assessment – Ver. 2. Enhanced Resource Assessment report 2003-02. Queensland Natural Resources & Mines, Brisbane.
Brough, D.M., Grundy, M.J. and Claridge, J (2004). Soil Attribute Surfaces for Regional Scale Assessment. In *Proceedings ISCO 2004*. International Soil Conservation Organisation. Brisbane.
Freebairn, D.M. and Silburn, D.M. (2004). Soil conservation in Australia's semi arid tropics; pathways to success, and new challenges. In *Proceedings ISCO 2004*. International Soil Conservation Organisation. Brisbane.

Galant, J. Topographic scaling for the NLWRA Sediment Project (CLW12). CSIRO Land and Water Technical Report 27/01: 18pp.
Jeffrey, S.J., Carter, J.O., Moodie, K.M and Beswick, A.R., 2001, "Using spatial interpolation to construct a comprehensive archive of Australian climate data", *Environmental Modelling and Software*, Vol 16/4, pp 309-330.
Littleboy, M. (1997). Spatial generalization of biophysical simulation models for quantitative land evaluation: a case study for dryland wheat growing areas of Queensland. PhD Thesis. University of Queensland.
Lu, H., Gallant, J., Prosser, I.P., Moran, C., Priestly, G. (2001). Prediction of Sheet and Rill Erosion Over the Australian Continent, Incorporating Monthly Soil Loss Distribution. CSIRO Land and Water Technical Report 13/01: 31pp.
Northcote, K.H. (1979). A factual key for the recognition of Australian soils. Rellim Technical Publications Pty Ltd, Adelaide.
Rosethnal, K.M. and White, B.J. (1980). Distribution of an erosion index in Queensland. Dept. Primary Industries, Div. Land Utilisation Report 80/8. 29pp.
SALI (2004). Soil and Land Information Database. Queensland Natural Resources, Mines and Energy.
SILO (2004). Queensland Natural Resources, Mines and Energy SILO database. http://www.nrm.qld.gov.au/silo/.
Wischmeier, W. H. and Smith, D.D. 1978. Predicting rainfall erosion losses, United States Department of Agriculture, Agricultural Handbook 537, Washington DC.
Yu, B. (1998). Rainfall erosivity and its estimation for Australia's tropics. Aust. J. Soil Research 36(1): 143 – 166.