3 Rapid erosion assessment

3.1 Introduction

Assessing the long-term impact of mining on catchment geomorphologic processes requires extensive in-depth research, monitoring and collection of data in the field, and sophisticated modelling techniques applied over a period of years. However, before these procedures are implemented it is necessary to quickly acquire and evaluate existing data to assist in the planning of the more detailed monitoring and modelling programs. Erosion hazard models provide a simple and efficient means for assembling available datasets to facilitate a rapid investigation into the physical processes and mechanisms governing soil erosion. Erosion hazard models therefore represent an important step in the risk assessment process. This chapter presents a rapid erosion assessment approach that should form an initial step in a complete erosion risk assessment. The approach is based on a simple erosion hazard model developed through the adaptation of the RUSLE (Renard et al 1994) and is applied here to assess erosion risk within the Ngarradj catchment. Recent data acquisition, including the interpretation of a detailed DEM and collection of sediment discharge data, has allowed the robustness and predictions made by the erosion hazard model to be validated. More precisely, the aims of this chapter are to:

- investigate the effects of elevation data resolution on erosion predictions derived through implementation of a simple erosion hazard model; and
- test the validity of erosion predictions made by the model against sediment discharge data collected from the field.

3.2 Erosion hazard model

The erosion hazard model developed for this project — a simplified form of the RUSLE — does not quantify erosion within a catchment, but rather provides a relative assessment of erosion risk. Rainfall erosivity (R) and the support practice (P) factors have been removed from the original RUSLE equation, such that the erosion hazard model is described by the equation:

$$A = K \times LS \times C \qquad (2)$$

where K is a soil erodibility factor, L is a slope length factor, S is a slope gradient factor and C is a cover-management factor. Rainfall erosivity has been removed from the original equation as, regardless of the actual value of R, this variable remains constant within an area of similar annual rainfall. R can therefore be ignored within an erosion hazard assessment, as it will not be responsible for any variation in erosion prediction within the Ngarradj catchment. The support practice factor, in a natural environment is 1. P can therefore also be removed from the RUSLE (P Puig pers comm 2000).

3.3 Data

A key issue associated with implementing the erosion hazard model is data availability. However, there is commonly a trade-off between data availability and data accuracy/resolution. The 1:50 000 land unit data of Wells (1978) and AUSLIG 1:250 000 elevation and hydrography datasets are widely available and have been shown to be suitable for medium scale erosion assessments. The land units map of Wells (1978) (fig 5) forms part of an increasingly widespread dataset that is being generated as part of a Northern Territory wide mapping program. The mapping program involves extensive field/ground truthing with remotely sensed information. Extra validation of the Wells (1978) land unit data for the Ngarradj catchment primarily consisted of checking the spatial accuracy of the mapped data against a detailed DEM of the catchment. The Wells land unit data were found to be of sufficient accuracy for application of a rapid erosion assessment. The land unit descriptions include information about the soil types, soil surface conditions and vegetation communities within the Ngarradj catchment that can be used to estimate the soil erodibility and cover management factors. A DEM has been interpolated from the AUSLIG elevation and hydrography datasets. Resolution is amongst the most important DEM attributes and will determine the usefulness and cost of a DEM. The DEM was interpolated at a 100 m grid cell resolution. The interpolation algorithm used to create the DEM is based on the ANUDEM program developed by Hutchinson (1989). This interpolation method is specifically designed for the creation of hydrologically correct DEMs from comparatively small, but well selected elevation and stream coverages (Hutchinson 1993). The DEM will provide topographic information for deriving the slope length and slope gradient factors at two different scales.

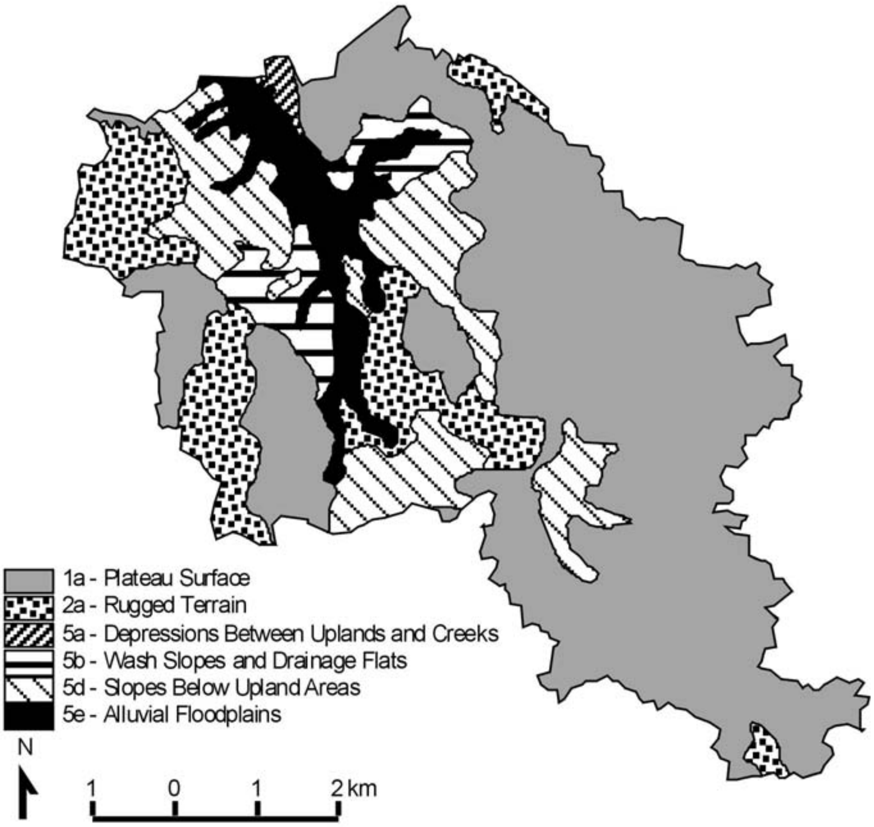

Figure 5 The land units of the Ngarradj catchment

3.4 Derivation of input factors

Implementation and verification of the rapid erosion assessment approach developed within this study was performed within a GIS (ArcView®) on a grid cell basis. The methods employed to prepare the input factors described in equation 3 are described below.

3.4.1 Soil erodibility factor

The dominant soils found within the Ngarradj catchment vary substantially from the shallow lithosol soils associated with areas of sandstone upland plateau to the deep sands of the floodplain alliance (Erskine et al 2001). The land unit descriptions of Wells (1978) provide comprehensive accounts of the soils associated with each land unit. The soil erodibility factor (K) can be derived through analysis of a soil's texture and percentage organic matter. A table produced by Mitchell and Bubenzer (1980) was used to relate the soil texture and organic matter content description for each land unit to soil erodibility values (table 4). The final soil erodibility grids were produced by clipping the soil erodibility coverage using the catchment boundary derived from the DEM of the same resolution, before being converted to a grid.

Table 4 Soil properties of the land units of the Ngarradj catchment

Land unit	Dominant soil	Texture	% Organic matter	K
1a	Shallow lithosols	Sand	<0.5%	0.05
2a	Shallow lithosols	Sand	<0.5%	0.05
5a	Deep earthy sands	Loamy Sand	4%	0.08
5b	Moderately deep siliceous sands	Fine Sand	<0.5%	0.16
5d	Moderately deep siliceous sands	Fine Sand	<0.5%	0.16
5e	Alluvial soils or sands	Sandy Clay	2%	0.13

3.4.2 Slope angle factor

The slope angle factor was calculated from the DEM. The function utilised in the production of the slope grids identifies the maximum rate of change in value from each grid cell to the neighbouring cells using the average maximum technique (Burrough 1986). The slope was calculated as the percent rise, and expressed as a decimal in order to provide comparative values to those provided by the K and C factors. The DEM used in the slope angle calculation covered an area greater than that of the Ngarradj catchment to allow for the flattening effect which occurs when the slope function is applied to cells at the edge of a grid. The slope statistics for the final slope angle factor grid are shown in table 5.

Table 5 Slope statistics for the Ngarradj catchment using a 100 m resolution DEM

Slope (%)	Maximum	Minimum	Mean	Standard deviation
100 m DEM	48.0	0.1	10.6	7.9

3.4.3 Slope length factor

The slope length factor was approximated using two methods. The first, the AF slope length method, attempted to capture the impact of surface runoff on the spatial distribution of erosion risk. This was approximated by calculating a grid that depicts the accumulation of runoff through a digital elevation model. Within the rapid erosion assessment model presented here it is not possible to consider fluvial erosion processes. A threshold was therefore applied to the accumulated flow, with cells having an accumulated flow area of greater than 10 cells considered to be operating under fluvial conditions and masked out of the final analysis. As with the K, S and C factors, the slope length factor grid was normalised to values between 0 and 1.

The second method applied in this rapid erosion assessment, IC slope length, attempted to approximate the length over which water flowed within an individual cell. This method firstly considers the horizontal distance over which the water will move through a cell by examining the direction of the flow, before incorporating the impact of the cell slope on the distance travelled. The function used to incorporate the cell slope is:

$$l = x / \cos \theta \qquad (3)$$

where l is the slope length, x is the horizontal flow distance and θ is the slope angle in degrees. The slope lengths were normalised to values between 0 and 1 to provide values of a similar magnitude to the other factors.

3.4.4 Cover management factor

The cover management factor, which accounts for the protection given by canopy cover, gravel lag and ground cover, is an important factor to be considered when attempting to model soil erosion. The land unit descriptions of Wells (1978) provide qualitative descriptions of both the soil's surface condition and vegetation cover. A cover index (CI), which represents a simple rank from the least protective against erosion (1) to the most protective (5), was then derived for all land units by intuitively comparing the protection against erosion offered either by canopy cover or gravel lag within the different environments. A first approximation of C (C_a) was obtained by calculating the inverse of the cover index (table 6). This relative estimation of the cover management factor was found to be sufficient when providing a rapid, relative assessment of soil loss.

Table 6 The qualitative descriptions of soil and vegetation cover provided by Wells (1978) and the corresponding cover management factor (C_a) value derived for this project

Unit	Soil cover	Vegetation	CI	C_a (1/CI)
1a	Abundant quartz sandstone	Scattered scrub	4	0.25
2a	Frequently stony/gravelly	Grassland to low open woodland	4	0.25
5a	Some coarse quartz sand veneer	Woodland to low open woodland	3	0.33
5b		Woodland with grassland	3	0.33
5d		Variable tall open wood to scrubland	3	0.33
5e		Grassland with areas of woodland	2	0.5

3.5 Results and validation

3.5.1 Elevation data resolution

The erosion hazard model was applied by simply multiplying the input factor grids on a cell-by-cell basis to derive grids of soil loss (A). The resultant soil loss grids were classified into areas of relatively low, moderate and high erosion risk. The thresholds used in the definition of these erosion risk classes were defined by examining the distribution of each dataset. The erosion risk grids were all log-normally distributed. As such, the categories were defined as -1 to 0 standard deviation (low), 0 to +3 standard deviations (moderate) and >+3 standard deviations (high).

DEMs are widely recognised as being highly useful in studies of earth surface processes as they allow the extraction of terrain and drainage features to be fully automated (Wharton 1994). Within this study, the inclusion of a DEM in the rapid erosion assessment approach allowed a more spatially distributed analysis of slope and the calculation of slope length. However, the scale and accuracy of the DEM play an important role in determining its efficacy. The erosion hazard grid produced by applying equation 3 using data derived from the 100 m grid cell resolution is shown in figure 6. The proportion of each land unit occupied by the predicted relative erosion risk classes calculated using the IC slope length and AF slope length methods is shown in table 7.

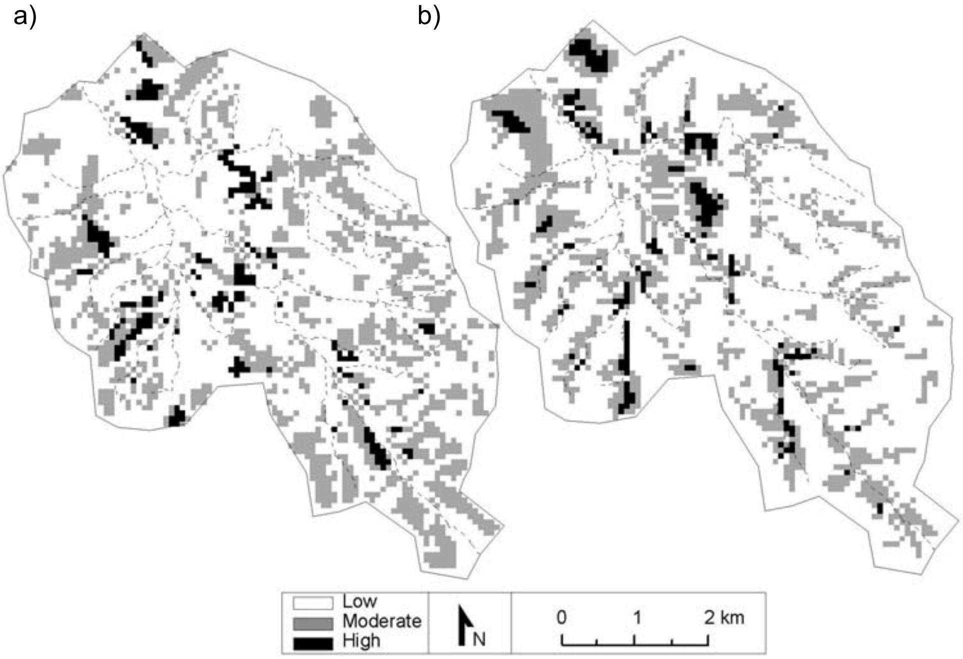

Figure 6 The relative soil erosion risk distribution for the Ngarradj catchment calculated using the 100 m DEM and a) the IC slope length method and b) the AF slope length method

Table 7 Cross-tabulated frequency data (in ha) for the land units grid and 100 m DEM predicted relative erosion risk classes

AF Slope L	**1a**	**2a**	**5a**	**5b**	**5d**	**5e**
Low	214	25	529	344	2429	102
Moderate	111	28	178	322	694	69
High	40	7	4	105	36	32
IC Slope L						
Low	306	23	534	547	2027	159
Moderate	32	13	156	151	1055	31
High	27	24	21	73	77	13

The erosion risk values obtained using both slope length calculation methods appear to correlate well with the land unit descriptions of Wells (1978). That is, the high erosion risk areas tend to be concentrated within the land unit 5d, which contains areas that are highly susceptible to erosion. The upland plateau, primarily composed of highly resistant sandstone, contains the majority of the low erosion potential class. However, the IC slope length method produces results that tend to overestimate the probability of erosion in the upland plateau region and underestimate erosion in the 5d land unit relative to the AF slope length method. When directly compared, the IC slope length method and AF slope length method are shown to produce significantly different results, with the greatest agreement occurring within the low erosion risk class (table 8). Comparison of figure 6a with the slope grid reveals that the rapid erosion model becomes very sensitive to slope when applied using the IC slope length method and high resolution DEM. The AF method, however, provides a more realistic distribution of erosion within the Ngarradj catchment.

Table 8 A contingency table for the IC slope length and AF slope length 100 m erosion grids

		IC Slope L		
		Low (ha)	Moderate (ha)	High (ha)
AF Slope L	Low (ha)	2487	1056	83
	Moderate (ha)	1156	406	18
	High (ha)	34	48	15

3.5.2 Field data validation

The Erosion and Hydrology program at ***eriss*** has established a field project to collect baseline geomorphological data on catchment geomorphology, channel stability, sediment movement and hydrology of the Ngarradj catchment (Erskine et al 2001). These data can be used to assess possible geomorphological impacts arising from the recently established ERA Jabiluka Mine. This mine is adjacent to the World Heritage listed Kakadu National Park and comprises underground mining, contaminant and runoff storage and related surface infrastructure. As part of this project, three gauging stations were established within the catchment (fig 1). Two stations are located upstream of all mine influences, the first on the main right bank tributary of the Ngarradj ('East Tributary') and the second on the main Ngarradj channel ('Upper Main'). The third station ('Swift Creek') is downstream of the mine site. Amongst the data collected at or by these stations are stage height and suspended sediment concentrations. Analysis of these datasets allows the total sediment yield to be calculated for each site.

In order to compare the measured sediment yields with the erosion risk predicted using the rapid erosion assessment method, a series of ratios was established between the three monitored sub-catchments of Ngarradj. Dimensionless ratios between the predicted erosion risk values were calculated through the summation of the predicted risk values associated with each grid cell for each sub-catchment (table 9). In order to calculate ratios between the measured sediment yields for each sub-catchment, a sediment delivery ratio (SDR) had to be approximated, as only a fraction of the sediment eroded within a stream's catchment will be transported to the basin outlet (Walling 1983). This relationship can be quantified by calculating the percentage of the annual gross erosion in a catchment that is measured as the sediment yield at the basin outlet. Approximations of the SDRs for each of the Ngarradj sub-catchments were obtained using the relationship between SDR and drainage basin area developed by the US Soil Conservation Service (Walling 1984) and SDR values obtained for smaller catchments (0.15–0.78 km^2) within the Alligator Rivers Region by Duggan (1988) (table 9). These values were used to convert the measured sediment yield into estimations of gross erosion, thereby enabling comparison of these ratios with the ratios predicted using the rapid erosion assessment method (table 9).

Table 9 Sediment delivery ratios and measured (both unadjusted and SDR adjusted) and predicted soil loss ratios between the sampled sub-catchments

	East Tributary	Upper Main	Swift Creek
SDRs	18%	15%	12%
Measured yield	1	2.32	3.44
Adjusted for SDR	1	2.79	5.17
AF Slope L	1	2.56	6.22
IC Slope L	1	3.30	7.30
Catchment area	1	2.25	5.12

The ratio of sediment loss between the East Tributary, Upper Main and Swift Creek sub-catchments is shown in table 9 for both field measured and predicted values. Sediment yields, adjusted using approximations of each sub-catchment's SDR, indicate that there is a non-linear relationship between catchment area and sediment loss within the Ngarradj catchment. This non-linear relationship is also shown by applying the erosion hazard model to the 25 m Ngarradj DEM (fig 7). However, the slope of this line is much greater than that relating area to the adjusted sediment yield, with a significant under-prediction of erosion in the East Tributary sub-catchment relative to the Upper Main and Swift Creek sub-catchments. The most accurate prediction of the relationship between erosion in the Upper Main and East Tributary sub-catchments, relative to the measured soil loss, was made using the 100 m interpolated DEM and AF slope length method (table 9). However, the relative sediment loss is over predicted using this dataset for the Swift Creek – Upper Main relationship as the relationship continues a linear trend and does not flatten out between these two points. These results indicate that the rapid erosion assessment method tends to be increasingly influenced by area with decreasing data resolution, with a general under prediction of net erosion over smaller areas and over prediction in larger areas.

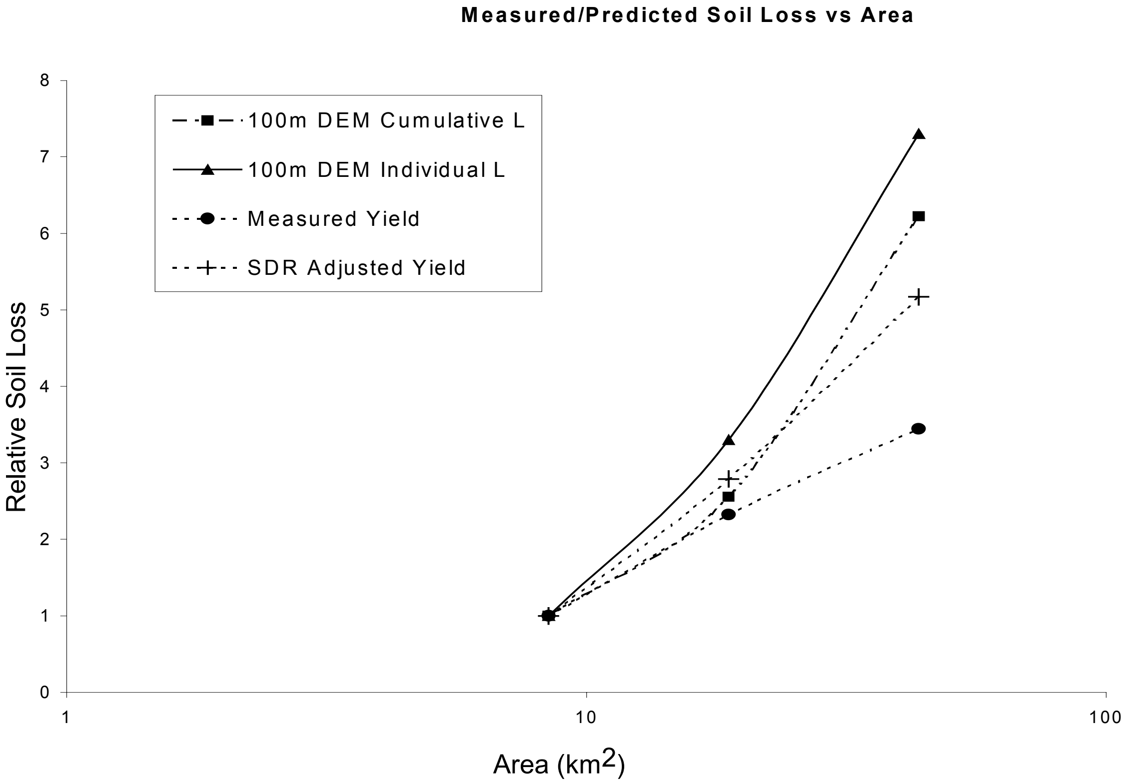

Figure 7 The relationship between relative soil loss and area for both the measured and predicted values