Targeting Gully Erosion at a Catchment Scale

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Abstract: Gully erosion is a significant problem in many areas of Australia and other parts of the world. Erosion from gullies can transfer considerable quantities of sediment and associated pollutants, reducing the water quality of streams and water storages of many catchments. This study has used the Ben Chifley Dam Catchment on the Central Tablelands of NSW as a case study to identify catchment scale factors influencing gully erosion and to predict areas at risk of gully erosion. Available spatial data including a Digital Elevation Model (DEM), soil landscape, geological and landuse maps as well as a digitised map of the gullies in the catchment were used to analyse gully presence and density. This analysis indicated that specific soil, geological, elevation and landuse classes were highly significant in the prediction of areas with a high risk of gully erosion. The analysis allowed areas of the catchment at high risk of gully erosion to be identified. These high risk erosion areas should be targeted for preventative management schemes to reduce gully erosion in the catchment and improve water quality outcomes. This work will be used to refine modelling work being undertaken in the catchment. Further development may allow the targeting of gully erosion prevention to be adapted to catchments beyond the Ben Chifley Dam Catchment.

Keywords: *Gully erosion, Catchment management, Central Tablelands NSW, Spatial analysis.*

1. INTRODUCTION

Gully erosion is a significant problem throughout agricultural areas of Australia and many other parts of the world. It results in a loss of soil, loss of productive land and sedimentation of waterways. A study for the National Land and Water Resource Audit (Hughes et al., 2001) investigated gully erosion in river basins containing intensive agriculture. The study estimates that there is 325,000 km of gullies in areas which have been intensively farmed in Australia, which have delivered 4.4 billion tonnes of sediment into rivers over the last 100 years.

Limiting sediment attached nutrient delivery through improved gully erosion management is an important control option to reduce sediment and nutrient concentration in receiving waters. The identification of specific, readily discernable catchment characteristics is required to identify and predict those areas at high risk of active gully erosion. Active gullies are those gullies that are supplying sediment to streams. Greater efficiency and effective targeting of management resources for the prevention of active gully erosion will improve water quality.

2. PREVIOUS STUDIES

Past studies into gully erosion have predominantly focused on historical erosional events and gully initiation (Eyles, 1977 and Prosser and Winchester, 1996). Other studies have focused on gully head migration and factors that influence the extent of gully heads, such as Prosser and Abernathy (1996). They have concluded that there are topographical limits to gully head migration up slope and that many existing gullies are at this limit and will not substantially continue to erode head-ward. A study by Crouch (1987) has indicated that a considerable proportion of gully erosion activity is not related to gully head extension but to sidewall erosion.

However, little to no research has been reported on readily available catchment scale data that may provide useful information on the distribution and management of gully erosion. There is a need to develop methods to understand both the distribution and underlying processes influencing gully erosion at a catchment scale so that resources can be used efficiently and effectively prevent further gully erosion.

This work is part of a larger project that has devised an integrated hydrologic sediment and nutrient export model (CatchMODS) for the Ben Chifley Dam Catchment. The model is designed to simulate catchment-scale land and water management scenarios to reduce nutrient and sediment export from the Ben Chifley Dam Catchment (Newham et al., 2002). This paper describes work focused on identifying catchment scale factors that have influenced the distribution of existing gullied landscapes in the Ben Chifley Dam Catchment. This analysis has facilitated the identification of high risk areas of gully erosion. This will allow catchment managers to prioritise work for gully erosion prevention in these areas.

3. STUDY SITE

The study site considered in this paper is the Ben Chifley Dam Catchment located on the Central Tablelands of New South Wales (NSW) (see Figure 1). The Ben Chifley Dam Catchment is a 986 km^2 catchment in which gully erosion has been identified as the most significant type of erosion and as a major contributor of sediments affecting the water quality of the catchment (Rogers, 1997).

The average annual rainfall is approximately 650-950mm, which varies with elevation (Tooth, 1997). Elevation in the catchment ranges from 690 to 1340m. The slopes of the catchment are steeper in the lower elevations surrounding the rivers and streams while gentler slopes are found at higher elevations.

The landuse of the catchment is dominated by pasture (85% of the catchment area) and grazing of livestock. There are some areas of plantation and native forestry (14% of the catchment). Cropping only occurs around the alluvial flats of the main river channel (1% of the catchment).

The Ben Chifley Dam Catchment lies within the Lachlan Fold Belt, a highly folded and faulted sequence of Paleozoic marine sediments (Pogson and Watkins, 1998). The main geological units are sandstone, granite and basalt with occasional pockets of ultra-mafic rocks. Quaternary alluvium occurs along the main drainage channels.

The soils in the catchment are highly related to the geology (Taylor, 1994). Nineteen different soil landscapes have been identified in the Ben Chifley Dam Catchment by Kovac *et al*. (1990). Most of these contain duplex soils such as Red and Yellow Podzolics (Chromosols) on the high to mid slopes and Soloths (Sodosols) in the lower drainage lines. The basalt geological units underlie Krasnozem (Ferrosols) and Chocolate Soils (Dermosols) while the granitic geology types contain Siliceous Sands (Rudosols).

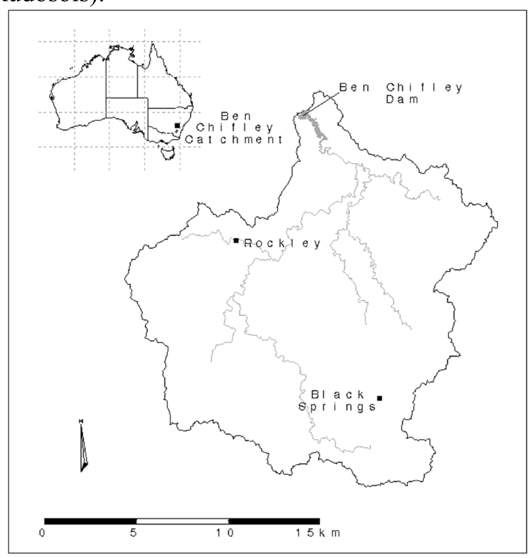

Figure 1: Map of the Ben Chifley Dam Catchment.

4. ANALYSIS APPROACH

The approach used in this paper to determine the factors influencing the distribution of gullies at a catchment scale entails a two-part process using several landscape factors. The factors considered included elevation, slope, landuse, soil landscape and geology.

The first part of the analysis involved reclassifying and combining the digital data for the catchment into individual polygons with unique classes. The digital data consisted of a DEM from which both slope and elevation patterns for the case study catchment were determined. A broad geology (Geoscience Australia, 2000) and soil landscape map (Kovac et al., 1989) were used, as well as a local landuse map, to determine the characteristics influencing the distribution of gullies in the catchment. The gullies of the catchment had been previously mapped by aerial photo interpretation and transferred to a spatial digital form (Rogers, 1997). The digitised map of the gullies was then related to each unique polygon so that gully presence and density could be determined. The relationship between the gully presence and density with the landscape factors were then statistically analysed.

A summary of the methods involved in this study is as follows:

- reclassification of spatial data to ensure compatible data classes between the factors;
- formation of unique polygons that contain different class combinations of elevation, slope, landuse, geology and soil landscape classes;
- identification of the area of each unique polygon and the corresponding gully length in each polygon;
- calculation of gully density for each polygon where gully density = log(length (m)/ area (m^2) x 10^6) - the log of the density was used for a numerical scale of gully erosion density;
- calculation of the probability of gully presence using a binomial generalised linear model - the probability of a unique combination of two factor classes containing a length of gully was used to determine gully presence probability.

5. RESULTS

The statistical analysis of the catchment factors of landuse, slope, elevation, soil landscape and geology demonstrated that all factors are highly statistically significant in predicting gully presence and density. Because the analysis could not be used to differentiate between the factors the results were considered in combinations of two catchment factors (for example, elevation and soils). The combination of the two factors allowed a comparison of the influence of individual combinations of classes to be analysed. This enabled specific classes that contained a high presence and density of gully erosion to be identified.

The analysis of a combination of landuse and elevation revealed that the most gullies occurred in a landuse class of pasture (85% of the catchment area) and at an elevation range of 700 to 1000m. This result was apparent in all landscape factor combinations. Because of the dominance of the elevation range of 700 to 1000m and a landuse of pasture on gully presence and density it was difficult to attribute specific classes to the process of gully erosion and so these factors could only be used to reduce the targeted areas.

Slope classes did not seem to significantly influence gully presence and density when considered in combination with other factors. This may be due to the calculation and distribution of slope classes in the process of the spatial analysis reclassification.

Table 1 shows the results for the combination of soil landscape and geology classes. The table also indicates the probability of presence (p), the percentage of catchment area for all combinations that exists in the catchment (a) and density of gully erosion if gullies exist in the class combination (d).

A category of risk was determined by grouping unique combinations of soil and geology classes into risk categories of high, medium and low gully erosion, as seen in Figure 2. These categories were determined by assessing both the gully presence probability and gully erosion density. A high risk of gully erosion was determined by those soil and geology class combinations with a high gully erosion presence probability of ≥0.5 and a gully erosion density of $\geq 5.9\times10^{-6}$m/m^2.

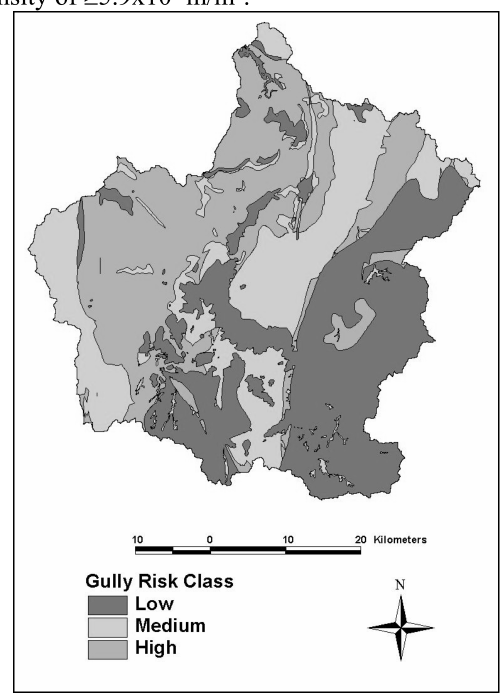

Figure 2: Gully risk map determined by gully presence probability and density for combined soil landscape and geology classes.

The medium risk category was determined by a mid ranged presence probability of between 0.5 and 0.3, inclusively. A medium ranged gully erosion density was determined by mid ranged a density of between 5.9 and 4.0×10^{-6}m/m^2, exclusively. Some soil and geology class combinations contained either a high presence probability and a low gully erosion density or a low presence probability with a high gully erosion density. These combinations were judged as a medium gully erosion risk and so are assigned a medium risk category.

The low risk of gully erosion region was determined by a low gully presence probability of ≤0.3 and a low gully density of ≤$4.0x10^{-6}m/m^2$. Two class combinations were placed in this low risk category because the probability was ≤ 0.3. However the density was in the mid range between 5.3 and $4.0x10^{-6}m/m^2$.

The soil and geology class combinations for the high risk region included: Alluvial soil landscape class combined with both intermediate volcanic and alluvium geology classes; Red Podzolic soil landscape class with intermediate volcanic, alluvium and sediment geology classes; Siliceous Sands soil landscape class with intermediate volcanic and granodiorite geology classes; and Yellow Podzolic soil landscape class with intermediate volcanic and granodiorite geology classes.

The medium risk regions contained soil landscape and geology class combinations which included: Non-Calcic Brown soil landscape with both granite and alluvium geology classes; Red Podzolic soil landscape in combination with granite, sandstone and granodiorite geology classes; Skeletal Soils soil landscape with intermediate volcanics, alluvium and sediment geology classes, and the Yellow Podzolic soil landscape class with sandstone, alluvium and sediment geology classes.

The low risk regions included all soil landscape classes when combined with basalt, mafic intrusions and shale geology classes; and all geology classes when combined with Krasnozem, Chocolate Soil and Red Earth soil landscape classes. Most of the Yellow Earth soil landscape class was in the low risk region, and some soil landscape classes when combined with granite geology class were also in the low risk region.

Table 1: The probability of gully presence, the density of gully erosion and percentage of area given for the combination of geology and soil landscape classes.

Soil Lanscape Class	**Geology Class**								
	granite	sandstone	shale	intermediate volcanics	mafic intrusions	alluvium	Sediments	grano diorite	basalt
Alluvial				p=0.7 a=0.2% d=6.9		p=0.6 a=0.2% d=7.0	p=0 a=<0.01%		p=0 a=<0.01%
Krasnozems		p=0 a=0.3%	p=0 a=0.2%	p=0.1 a=1.9% d=1.0		p=0 a=0.3%	p=0 a=1.0%		p=0.1 a=5.3% d=0.3
Chocolate Soils				p=0.2 a=0.2% d=5.2		p=0 a=0.2%	p=0 a=0.01%		
Non-Calcic Brown	p=0.4 a=0.6% d=6.8					p=0.2 a=0.04% d=6.8			
Red Earth	p=0 a=0.6%		p=0 a=0.7%	p=0.3 a=12.0% d=4.0	p=0 a=0.08%	p=0.2 a=0.9% d=4.2	p=0 a=0.5%		p=0 a=0.4%
Red Podzolic	p=0.2 a=0.5% d=6.3	p=0.1 a=0.4% d=5.8	p=0 a=0.2%	p=0.5 a=16.8% d=6.4		p=0.5 a=0.8% d=6.9	p=0.5 a=3.3% d=6.0	p=0.4 a=0.3% d=6.5	p=0 a=0.2%
Shallow Soils		p=0.5 a=2.3% d=5.2		p=0 a=0.3%		p=0 a=<0.01%	p=0.4 a=0.3% d=5.5		
Skeletal Soils	p=0 a=0.2%	p=0 a=0.2%		p=0.4 a=1.9% d=6.1		p=0.4 a=0.01% d=7.5	p=0.4 a=2.8% d=4.8	p=0.2 a=0.9% d=4.3	p=0.1 a=0.3% d=0.4
Siliceous Sands	p=0 a=0.01%			p=0.8 a=0.4% d=7.1				p=0.5 a=2.0% d=7.0	
Yellow Earth	p=0 a=0.2%		p=0.3 a=1.9% d=2.7	p=0.2 a=2.3% d=3.8	p=0 a=0.5%	p=0.2 a=0.3% d=6.2	p=0 a=0.01%	p=0 a=0.4%	p=0 a=0.1%
Yellow Podzolic	p=0.1 a=1.6% d=3.8	p=0.3 a=4.5% d=4.9	p=0 a=1.5%	p=0.6 a=10.9% d=5.9		p=0.4 a=1.1% d=5.4	p=0.7 a=13.2% d=4.7	p=0.7 a=0.1% d=7.2	p=0 a=1.4%

Key: p = probability of presence, a = percentage of catchment area, d = density of erosion log(density (m/m^2) $x10^6$).

Further spatial analysis of the regions was undertaken to ascertain if the probability of presence, density and the formation of risk regions from this data actually reflected the distribution of gully erosion in the catchment. The result of this analysis is shown in Table 2, depicting the percentage of area of each risk region and the density (m/km^2) of gully erosion which occurs in each region.

Table 2: Percentage of area and the density of gullies in each region.

Risk Class	Area (%)	Density (m/km^2)
High	35	847
Medium	28	407
Low	37	68

It was found that the high risk region contained the highest gully density. The medium risk region contains a mid-ranged gully erosion density, however this region accounts for the least catchment area. The low risk region covers the largest proportion of the catchment and contains a significantly lower gully erosion density.

6. DISCUSSION

The statistical analysis of gully erosion presence and density indicates that there are distinct areas of the catchment which can be considered as either a high, medium or low risk area of gully erosion, as seen in Figure 2. Subsequent spatial analyses of gully densities in these risk regions indicate that particular combinations of soil and geology classes (determined by a high gully presence probability and a high gully erosion density) does allow areas at a greater risk of gully erosion to be identified. The identification of these regions allows resources to be targeted by catchment managers in the prevention of further gully erosion and also allows some insight to be gained from the types of soil landscape and geology classes that are more prone to gullying from existing gully distribution data.

The geology classes and the soil landscape classes in the high risk region contain geology types that are high in silica and low in basic minerals. These rock types produce soils that have a weak structure and are low in plant nutrients (Gray and Murphy, 1999). An example of a nutrient poor and weak structured soil is contained in the Siliceous Sands soil landscape. The Siliceous Sand soil landscape when combined with intermediate volcanics and granodiorite geology classes are present in the high risk region. A poor soil structure and low plant nutrient content will cause the soil to be more prone to gully erosion which may be the reason behind the present distribution of gully erosion in this case study. However, the Siliceous Sand soil landscape when combined with the granite (high in silica and quartz) geology class contained no gullies. This may be due to the very small area covered by this soil and geology combination, an area which therefore is unlikely to contain a gully.

Soil and geological characteristics may affect gully presence but the particular soil attributes and geological mineralogy can reduce the risk of gully erosion, which is just as important. The low risk category contained rock types with low silica content, such as basalt and mafic intrusions. These rocks formed soils that are well structured and are high in plant nutrients, for example the Krasnozems soil landscape. The presence of a well structured soil and good vegetation cover will allow the soil to be more resistant to erosion and therefore contain a lower density of gully erosion.

The decisions made in which each combined class was categorised into high, medium and low risk regions were, at times, arbitrary, especially with respect to the medium range region. The occasionally arbitrary decisions may alter some of the class combination categorisation but the overwhelming density of the high risk region would not change considerably.

The use of either gully presence probability or gully erosion density gave a slightly different spatial distribution of the risk regions when compared to the use of both presence and density. However high densities of gully erosion were found in each high risk region identified by all three methods. The use of both presence probability and gully erosion density gave a greater resilience to the outcome of the risk regions, as presented in Figure 2, for gully erosion management. This work has identified that the factor combination of soil landscape and geology in the Ben Chifley Dam Catchment can be used to determine areas at high, medium and low risk of gully erosion.

7. CONCLUSION

One key outcome of this research has been the development of a gully erosion risk map of the Ben Chifley Dam Catchment (Figure 2). This map could be important in the targeting of resources, at a catchment scale, in the prevention of further gully erosion in the catchment. The targeting of resources will not only reduce the cost of erosion prevention in the catchment but also help to improve water quality.

This paper has shown that readily available data, such as broad scale soil and geology maps, can be used to determine areas that are at a greater risk of gully erosion. Soil and geological characteristics such as structure, plant nutrients and silica content may be important aspects that are effecting gully erosion distribution in this case study catchment.

The gully erosion risk map is a product for the Ben Chifley Dam Catchment. This map can be used in future modelling work and possibly in the management of erosion currently being undertaken in the catchment. Further application of these techniques to a wider range of catchments should allow an extension of these types of results to other areas where primary data on landscape factors such as soil and geology exist, but where limited information on the distribution of gully erosion is available.

8. ACKNOWLEDGMENTS

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