COALMINE REHABILITATION: A LONG TERM EROSION AND WATER QUALITY STUDY ON CENTRAL QUEENSLAND COALMINES

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Abstract
In 1993 a field study commenced to determine the impact of vegetative cover and slope on runoff, erosion, and water quality at 3 open-cut coal mine sites. Runoff, sediment, and water quality were measured at two scales: plot (0.01 ha) where 3 slope gradients (10, 20, 30%) with pasture and tree treatments were imposed on soil and spoil material, and on small catchments (0.4 to 1.0 ha).

The greatest soil erosion occurred before pasture cover established, when a large surface area of soil (>0.5 plot area) was exposed to rainfall and overland flow. Once buffel grass (*Cenchrus ciliaris*) colonised soil plots there were negligible differences in soil erosion between slope gradients. Where spoil crusted there was poor vegetative growth and unacceptable large runoff and erosion rates throughout the study

Additional Keywords: erosion, runoff, vegetation, natural rainfall.

Introduction
Draglines are used in most open-cut coal mines in Australia, with the result that landscapes after mining generally consist of a series of parallel overburden spoil piles, with slope angles of approximately 75%. The cost of recontouring these spoil piles represents a major cost in rehabilitation of mined land. A small change in the degree and length of slope can have a major impact on the cost of recontouring the landscape.

There is little information in Australia on erosion rates from open-cut coalmine rehabilitation, particularly under natural rainfall. Most erosion research has been conducted on agricultural soils and landuse, and on lower slope gradients. The region's variable rainfall is a major limitation to successful rehabilitation in Central Queensland. Annual rainfall can range from 200 mm to 1400 mm/year, with a long-term median of 604 mm. In this environment the challenge is to find and adopt suitable rehabilitation strategies that enhance infiltration, minimise runoff and erosion, and maximise vegetative growth.

Vegetative cover on agricultural and pastoral land has been shown to greatly reduce runoff and erosion (Carroll *et al*. 1997). However, the impact and role of vegetation on mine rehabilitation has not been studied, particularly on steeper slopes found on mine sites.

In 1993 a field study was established at Goonyella Riverside, Curragh and Oaky Creek coal mines in Central Queensland. The three sites were selected to represent a range of topsoil and spoil materials. Runoff, sediment loss, water quality and vegetative cover were measured at two scales: plots (0.01 ha) at 10, 20 and 30% gradient slopes, and contoured catchments (0.4 to 1.0 ha). The project's objectives were to monitor the long-term impact of open-cut coalmine rehabilitation on erosion and water quality under natural rainfall conditions.

Materials and Methods
Three coalmines were selected that represented the range of topsoil and spoils found in the Bowen basin. These were the Curragh (23.29'S, 148.50'E), Oaky Creek (23.04'S, 148.28'E), and Goonyella/Riverside (21.51'S, 148.58'E) coal mines in Central Queensland

Plot layout
Three slope gradients (approximately 10, 20, 30%) were formed using a D9 size dozer. A depth of soil (20-30cm at Curragh and Goonyella/Riverside, 10cm at Oaky Creek) was then laid over the spoil and ripped at 1m intervals across each of the slopes. Pasture and tree treatments were imposed on soil and spoil material, and on the 20% slope, single soil and spoil plots were left bare as a comparison with the vegetated treatments. Sediment and runoff were measured from 14 bounded plots, each 0.01ha (20m by 5m) in size. Rainfall was measured using pluviometers located on the 10% and 20% slopes. Runoff was measured using a tipping bucket (7.45 L capacity) (Figure 1). Total runoff and runoff rate were determined by recording the number of tips per minute on a data

logger. Total tips were also recorded on a mechanical counter. Sediment erosion was measured as two components: bedload and suspended sediment in runoff. Bedload was deposited in 5 m long troughs (two troughs were used on bare topsoil and spoil plots, and was weighed after each rainstorm event and dry weight calculated. A 10cm copper pipe with a 1mm vertical slot collected a small sample of runoff (0.01% flow) from one side of the tipping bucket, and stored in a 20 L plastic drum. Suspended sediment, pH, and EC were determined from a runoff sub sample. Data is reported for 6 years with the exception at Goonyella/Riverside where the field study terminated in year 4 when subsidence caused slumps and cracks to appear on the plots.

A mixture of species were sown on the pasture plots: *Chamaecrista rotundifolia*, *Stylosanthes hamata* (Amiga and Verano) at 3 kg/ha, and *Bothriochloa insculpta*, *Cenchrus ciliaris*, *Chloris gayana* at 4 kg/ha . Ten tree species were planted on the tree plots: *Acacia harpophylla*, *Acacia holosericea*, *Acacia salicina*, *Acacia saligna*, *Casuarina glauca*, *Eucalyptus citriodora*, *Eucalyptus crebra*, *Eucalyptus drephanophylla*, *Eucalyptus populnea*, *Eucalyptus tereticornis.* Low and sporadic rainfall early in the study resulted in poor establishment of vegetation at all sites.

Catchment study
Three rehabilitated catchments were monitored at Curragh and Goonyella/Riverside (1 ha), and at Oaky Creek two catchments were monitored where slopes had been left at angle-of-repose (approximately 75%). A concrete trapezoidal flume (45 degrees) with a 30 cm throat was constructed at the exit of each catchment to measure runoff and erosion (Figure 1). Runoff was measured using a mechanical chart recorder, as well as capacitance and acoustic flow sensors that recorded to a data logger at 2-minute intervals. Bedload was deposited in a 5 m^3 capacity silt trap in front of the flume. An ISCO 3700 automatic sampler (24 bottles) collected suspended sediment water samples at the outlet of the flume, using a 1m PVC sampling arm. These samples were analysed for suspended sediment concentrations, electrical conductivity and pH of the runoff. A Pluviometer and rain gauge were installed at each catchment.

Figure 1. Plot and catchment monitoring equipment.

Results and Discussion

During the six-year study there was two noticeable rainfall periods. In the first 3 years of the study all 3 sites experienced 50% less rainfall than the long-term median rainfall (565 mm). In contrast, the final 3 years had greater rainfall than the long-term annual median rainfall, with the highest annual rainfall at Curragh and Oaky Creek in Year 6 of the study (Table 1). Most of the rainfall during the study was from rainstorms, with several monthly rainfalls larger than the monthly medians. The variability of the rainfall early in the study resulted in poor pasture and tree growth at all 3 sites, and large initial runoff and erosion rates.

Table 1. Curragh, Goonyella and Oaky Creek annual rainfall.

Year	Year No	Annual Rainfall (mm) Curragh	Goonyella	Oaky
1993/94	1	345	387*	492
1994/95	2	377	332*	527
1995/96	3	352	442*	608
1996/97	4	703	691*	612
1997/98	5	619		525
1988/99	6	757		930
Long-term annual median		567	613	578

* Goonyella/Riverside plot study terminated after year 4.

Bare plots at the 3 sites are used to compare the inherent differences in hydrology and erodibility of the soil and spoil material. The field study highlights the important role surface crusting, sealing and hardsetting have on runoff, and soil and spoil erosion rates. However, the study shows there is not a simple relationship between soil or spoil strength, erodibility and sediment loss due to the interactions on infiltration and runoff. This is well illustrated with the Curragh soil and spoil.

Curragh soil was the most erodible of the 6 materials studied, with more sediment transported per unit volume of runoff. In contrast, Curragh spoil had lower sediment concentration, however runoff was more than double, which resulted in spoil having an overall greater sediment loss than soil at this site (Table 2). When dry, the Curragh spoil formed a hard dispersive crust, which resulted in low infiltration and large runoff losses, with a runoff coefficient (c) of 0.69 (Figure 2). Curragh spoil consistently had low infiltration and high runoff and erosion rates throughout the 6-year study. When bare, Curragh soil had a relatively high erodibility and runoff coefficient (0.43), but this was greatly reduced once vegetation established, as discussed later.

Table 2. Curragh, Oaky Creek and Goonyella/Riverside average sediment concentration, total runoff and sediment loss, and average annual sediment loss from bare soil and spoil, 20% slope (years 1 to 4).

Material	Site	Average sed conc (g/l)	Total runoff (mm)	Total sed loss (t/ha)	Ave. annual sed loss (t/ha/yr)
Soil					
	Curragh	192	495	954	238
	Goonyella/Riverside	58	598	345	86
	Oaky Creek	49	1050	514	128
Spoil					
	Curragh	107	1047	1119	280
	Goonyella/Riverside	123	255	314	78
	Oaky Creek	51	623	318	79

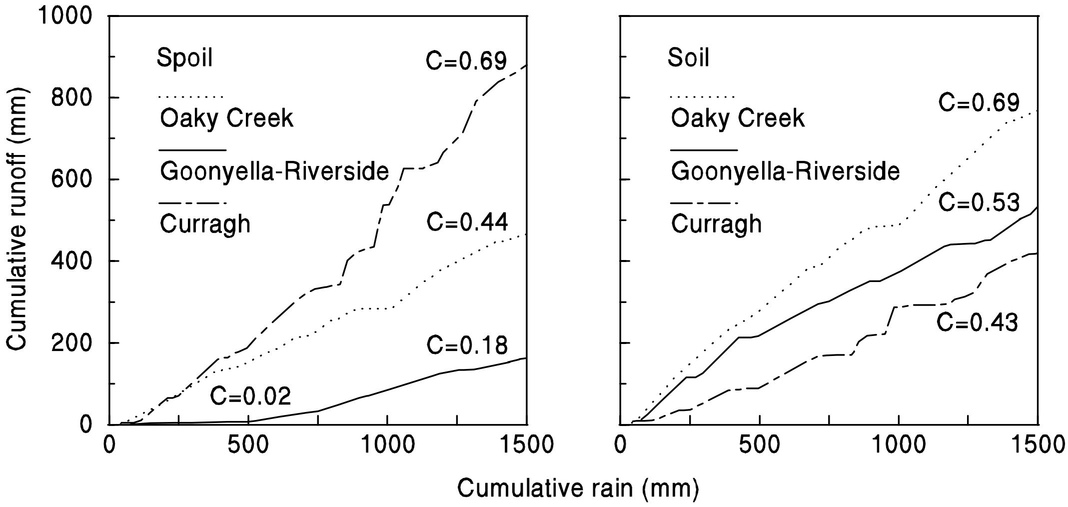

Figure 2. Curragh, Goonyella/Riverside and Oaky Creek soil and spoil runoff coefficiency (c).

4.2.3 Impact of vegetative cover on runoff and erosion

Plot Study

The presence of surface vegetative cover not only protects the soil and spoils from the erosive impacts of rainfall and overland flow it also dries, and in some incidences cracks the soil or spoil, increasing infiltration and reducing runoff. Low and sporadic rainfall in the first two years of the study resulted in poor establishment of vegetation at all sites. Buffel grass (*Cenchrus ciliaris*) colonised soil plots, whereas the more salt tolerant rhodes grass (*Chloris gayana*) only sparsely established on spoil material at the three sites. The effect of vegetative cover on erosion dominated across all sites, despite large differences in soil and spoil. Any small within soil and spoil differences had a smaller effect on runoff and erosion.

Sediment loss from all soil and spoil material was large (>70 t/ha) when there was low surface cover. When pasture colonised plots, runoff and erosion rates declined to negligible levels (<0.5 t/ha), even on steeper slopes. Where pasture did not establish, due to surface crusting, rates remained very large (>200t/ha) throughout the study (Figure 3).

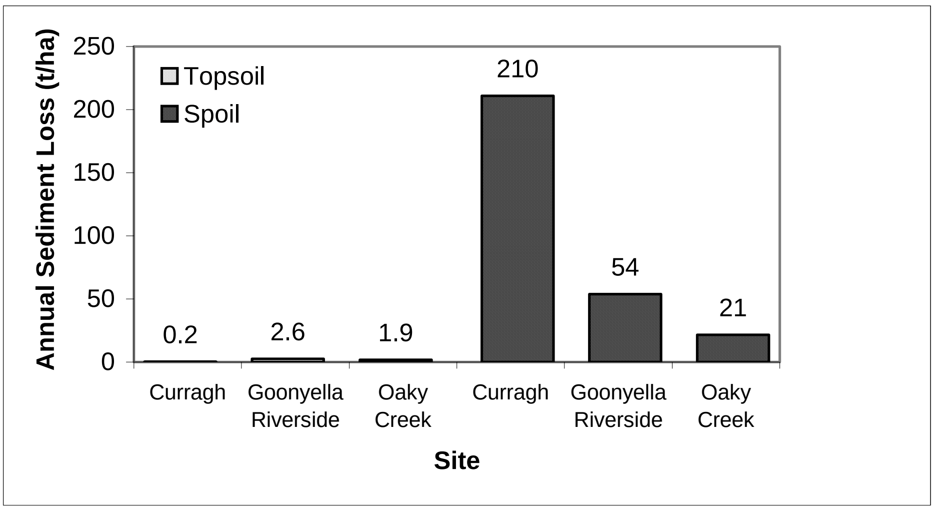

Figure 3. Annual sediment loss from soil and spoil pasture plots in final year of the study.

Vegetative growth ameliorated the hardsetting nature and surface sealing of Goonyella/Riverside and Oaky Creek soil, and improved hydraulic conductivity, and reduced runoff and erosion rates. Curragh and Oaky Creek soil in particular had a dramatic reduction in runoff and sediment movement once pasture established. At Curragh, soil erosion rates rapidly declined once buffel grass covered more than half the plot on the 20% slope, with >1200 t/ha more erosion from the bare plot by the end of the study (Figure 4). In contrast on the spoil there was a near linear increase in cumulative sediment loss during the study on both the 20% bare and pasture plots due to poor pasture establishment on the spoil material (Figures 5).

The greatest soil erosion on the pasture plot was in years 1 and 2 when grass cover was low and there was a large proportion of soil exposed to the erosive forces of rainfall and runoff. Vegetation, particularly grass cover, protected the soil from rainfall impact which disrupts and detaches soil aggregates and causes macropores to block, infiltration to decline and erosion and runoff to increase. Loch and Orange (1997) observed that wetting patterns on soil rehabilitated areas were closely associated with root channels, which developed stable macropores and a gradual increase in aggregation. Infiltration on the Curragh soil was further enhanced where buffel grass dried and cracked the soil. The impact of vegetative cover was also seen at Goonyella/Riverside and Oaky Creek sites where increasing vegetative cover progressively reduced erosion.

The field- plot study at Curragh showed soil and spoils were highly erosive with <50% cover (Figure12). Once surface vegetative cover exceeded this level erosion rates were negligible (<1/t/ha/year) on the 10% and 20% slopes. However, >80% cover was required on the 30% slope for similar levels of erosion.

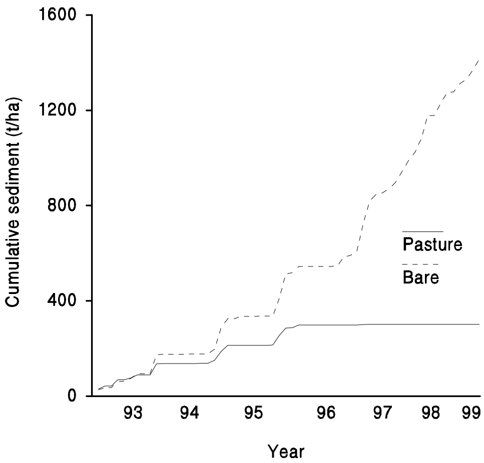

Figure 4. Curragh bare soil and pasture plots Cumulative sediment loss

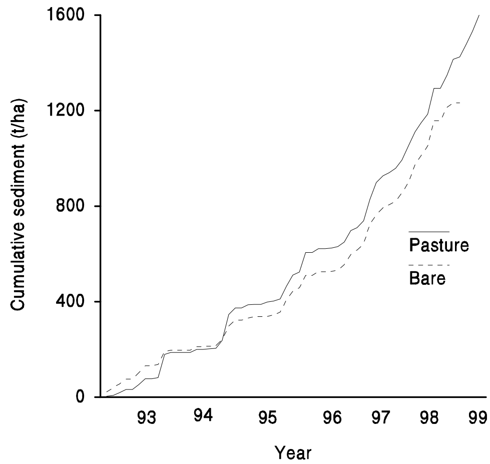

Figure 5. Curragh bare spoil and pasture plots cumulative sediment loss.

Catchment Study

On the Curragh catchments vegetative cover established more quickly than on the plots, due to a combination of lower slopes and rainfall soon after sowing. The catchments have now been monitored for 10 years, Figure 6 shows the runoff co-efficiencies from the catchments can be delineated every 1000 mm of rainfall. In the first 1000 mm, when vegetative cover was establishing, the runoff coefficient for the 3 catchments ranged between 0.08 and 0.16, and progressively declined to a value of just 0.001 (0.1% runoff) for the last 1000 mm rainfall received at the study. The lower runoff co efficiency for the last 1000 mm of rainfall is a result of increased evapotranspiration, and hence greater soil and spoil deficit and infiltration. In the final 3 years of the study average sediment yield was just 0.01 t/ha/year.

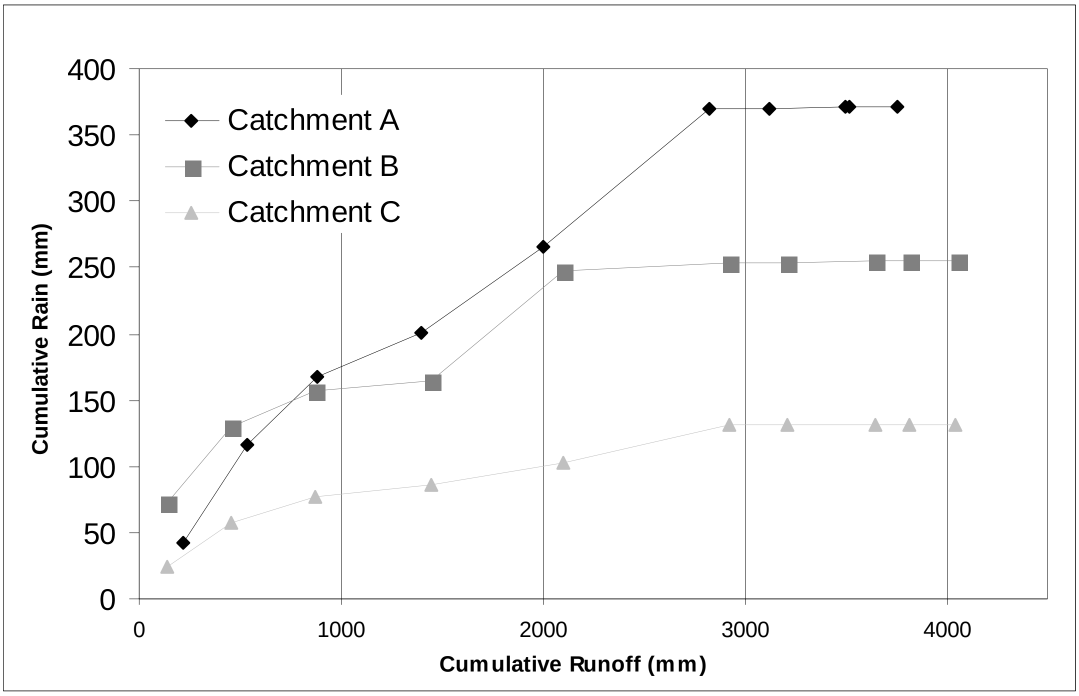

Figure 6. Cumulative rainfall and runoff from Curragh catchments, years 1 to 10.

Conclusions

The greatest window-of-erosion risk was before vegetation established, when a large proportion of surface area was exposed to the erosive forces of rain and runoff. Successful establishment of vegetative cover is the key to reducing runoff and erosion, and improving water quality. The study showed there was little difference in soil erosion rates between slope gradients once a dense sward of buffel grass established on soil plots. In a semi-arid environment, rainfall is a major limiting factor for successful rehabilitation. In such an environment rainfall needs to be fully utilised and unnecessary runoff losses minimised. The long-term catchment study has shown that as pasture progressively increased infiltration and pasture water use efficiency and decreased and runoff and erosion.

Acknowledgements

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