Effects of pasture cover on soil erosion and water quality on central Queensland coal mine rehabilitation

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Abstract

To determine the impact of vegetative cover and slope on runoff, erosion and water quality, a field study was commenced in 1993 at 3 open-cut coal mine sites in the Bowen Basin. Field plots of 0.1ha with slope gradients of 10, 20 and 30%, along with catchments of 0.5ha, were used to measure runoff, sediment loss and water quality from rehabilitated land. Pasture and tree treatments were imposed on soil and spoil material, while 2 soil and spoil plots were left bare as the control for the study.

The greatest soil erosion risk occurred before pasture cover established, when a large surface area of the soil (>50%) was exposed to rainfall impact and overland flow. Once grass species, such as buffel (*Cenchrus ciliaris*), colonised soil plots, there were negligible differences in soil erosion between slope gradients. On spoil plots, rhodes grass (*Chloris gayana*) reduced *in situ* soluble salt content and runoff electrical conductivity levels. Where spoil crusted, there were poor vegetative growth and unacceptably high runoff and erosion rates throughout the study. Average electrical conductivity of water leaving the catchments also declined with the increase in vegetative cover. Where burning was conducted, runoff and erosion rates increased. After one month and following rainfall, buffel biomass had regenerated to 1.1 and 1.7 t/ha on the two catchments.

Introduction

Draglines are used in most open-cut coal mines in Australia, and landscapes after mining generally consist of a series of parallel spoil piles, with slope angles of approximately 75%. 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.

Zingg (1940) found erosion rates on agricultural soils increased with slope gradient, whereas Warrington *et al.* (1989) found a rapid increase in erosion as slope increased from 10 to 25%, but only a small increase between slopes of 25 and 30%. Gilley *et al.* (1977) found a similar response on disturbed mined land, and observed that increasing slope steepness caused only a small increase in erosion rates on sodic spoil material. Likewise, where spoils crusted, erosion rates from different slope gradients were similar (Schroeder 1987). Crusting can also cause poor seedling establishment and reduced plant water-use efficiency (Naidu 1992), leading to unsuccessful rehabilitation.

Other factors such as pasture and mulch cover also modify the effect of slope, preventing macropores from being sealed, enhancing infiltration, and reducing runoff and erosion and, hence, the impact on water quality (Wilcox and Wood 1989; Eldridge and Rothon 1992). On steeper slopes, more cover is required to control erosion, and rapid establishment of vegetation on reclaimed mine land is suggested as a way to reduce erosion and prevent both on-site and off-site transport of sediment (Meyer *et al.* 1970; Schroeder 1987).

Compared with pasture, trees have a slower growth rate and provide less surface cover to prevent erosion. Rehabilitated mine lands like agricultural soils in central Queensland, are most vulnerable to erosion when they are bare and have low vegetative cover, a scenario often caused by the variability of the region's rainfall (Carroll *et al.* 1997). For this reason, we focus on the role of pasture rather than trees in stabilising slopes on coal mine rehabilitation.

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There is little information in Australia on erosion rates from open-cut coal mine rehabilitation, particularly from natural rainfall events. Most erosion research has been conducted on agricultural soils and land use, and on lower slope gradients than are commonly found on mine rehabilitation. Undertaking erosion research under natural rainfall conditions is labour-intensive, time-consuming and costly. In this study, 3 coal mines were selected with a range of soil and spoil materials that are commonly encountered on central Queensland coal fields (Carroll *et al.* 2000).

In this paper, we describe a 6-year field study to determine the impact of pasture cover on runoff, sediment loss and salt transport from 3 slope gradients and rehabilitated catchments. A preliminary investigation into the impact of burning on runoff, erosion and water quality is also reported.

Materials and methods

Location and experimental layout

The experimental sites were at 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.

Three slope gradients (approximately 10, 20, 30%) were formed using a D9 bulldozer (Figure 1). Soil (20–30cm at Curragh and Goonyella/Riverside, 10cm at Oaky Creek) was then laid over the spoil and ripped at 1m intervals across 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 0.01 ha (20 m × 5 m) in size.

Soil and spoil

From each plot, 8 surface samples (0–50 mm) were randomly collected and bulked and a single sub-sample was taken for chemical and physical analysis (Table 1).

Pasture and trees

A mixture of species were sown on the pasture plots: *Chamaecrista rotundifolia* and *Stylosanthes*

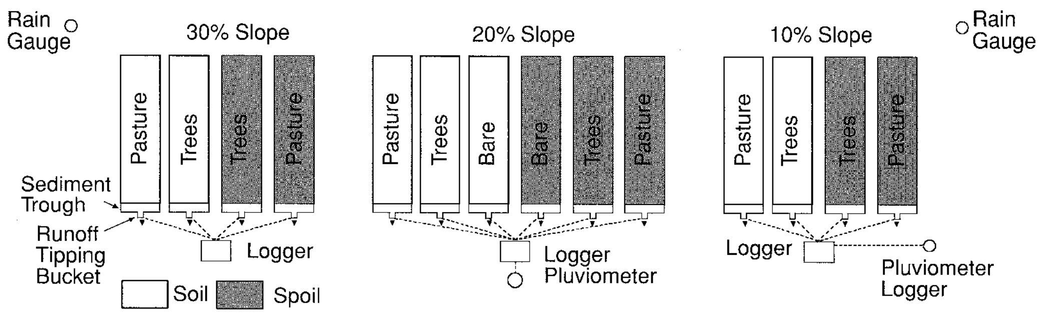

Figure 1. Experimental layout of plot study.

Table 1. Chemical and physical properties of soil and spoil material at Curragh, Oaky Creek and Goonyella/Riverside sites.

	Site	pH	EC	Cl	SO_4–S	Ca	Mg	CEC	ESP	CS[1]	FS[1]	S[1]	C[1]
			(mS/cm)	(mS/cm)	(mg/kg)	(meq %)	(meq %)	(meq %)	(%)	(%)	(%)	(%)	(%)
Soil	Curragh	8.6	0.43	219	31	26	9.2	38	7	5	22	16	59
	Oaky Ck	7.3	1.29	274	753	4.3	6.2	9	10	11	62	9	19
	Goonyella	7.6	0.32	394	11	6.2	4.8	15	11	19	22	9	51
Spoil	Curragh	9.6	0.61	519	39	2	8.4	20	28	19	31	19	33
	Oaky Ck	8.3	3.33	583	3371	3.7	11.9	8	15	24	46	14	15
	Goonyella	8.0	2.32	3299	2	7.4	9.1	20	38	11	16	13	61

[1]CS — Coarse sand (0.2–2.0mm); FS — Fine sand (0.02–0.2 mm); S — Silt (0.002–0.02 mm); C — Clay (<0.002 mm).

hamata (Amiga and Verano) at 3 kg/ha and *Bothriochloa insculpta*, *Cenchrus ciliaris* and *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* and *Eucalyptus tereticornis*.

Rainfall

At each site, rain was recorded at 1-min intervals by 2 pluviometers situated on the 20 and 10% gradients, and recorded on data loggers. Two rainfall gauges were installed on the 10 and 30% gradients to measure daily rainfall (Figure 1).

In the first 2 years of the study, rainfall at all 3 sites was 50% lower than the long-term median rainfall (Table 2). Most rainfall during this period was from rainstorms, with several monthly rainfalls larger than the median (Figure 2). Highest annual rainfall at Curragh and Oaky Creek was in Year 6 of the study.

Table 2. Annual rainfall (mm) and year number for Curragh, Oaky Creek and Goonyella/Riverside sites, and long-term median rainfall.

Year	Year no	Curragh	Oaky Creek	Goonyella/ Riverside
1993/94	1	369	407	279
1994/95	2	362	531	316
1995/96	3	479	608	507
1996/97	4	694	610	604
1997/98	5	596	568	TM[1]
1998/99	6	824	772	TM
Long-term median		567	584	530

[1]Terminated monitoring.

Runoff and sediment

Runoff was measured using a tipping bucket (7.47 L capacity). 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 2 components: bedload; and suspended sediment in runoff. Bedload was deposited in 5 m long troughs and was weighed after each rainstorm event and dry weight calculated. A 10 cm 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 it in a 20 L plastic drum. Suspended sediment, pH and EC were determined from a runoff subsample. Sediment in the bedload trough and in the runoff were used to determine total sediment movement.

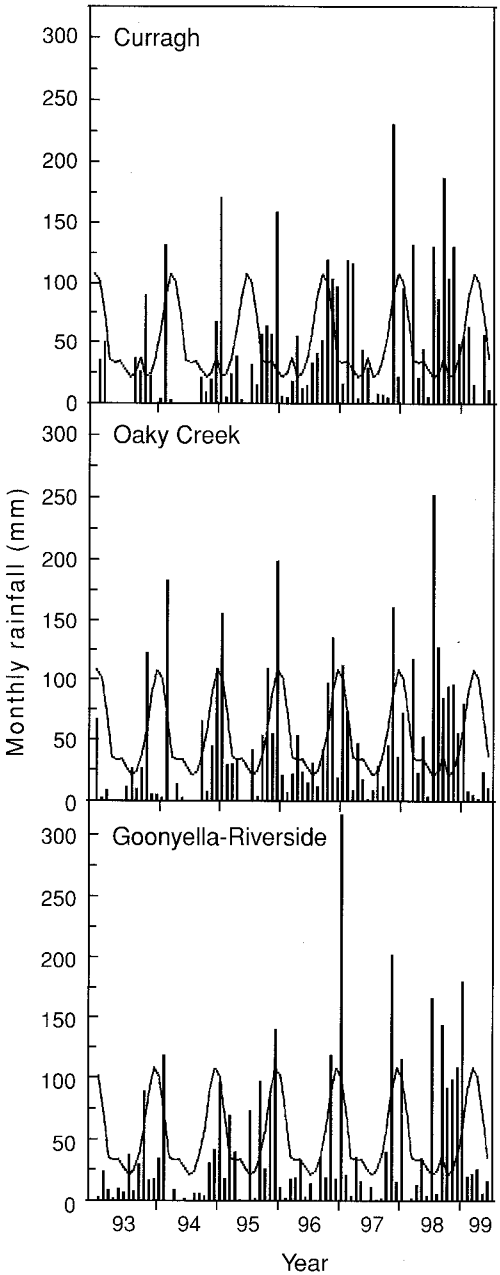

Figure 2. Monthly rainfall (bars) for Curragh, Oaky Creek and Goonyella/Riverside sites (1993–1999), and long-term median rainfall.

Vegetative cover

Sallaway *et al.* (1988) described the photographic technique used to quantify vegetative cover. Three photographs were taken at 5m intervals along each plot, and covered an area of 30 m^2. In Year 6, standing dry matter was determined on the soil plots at Curragh and Oaky Creek by cutting and drying samples taken from 5 quadrats (0.25 m^2).

Catchments

Rehabilitated catchment areas of 0.5ha were also used to measure runoff, erosion and water quality. Three contoured catchments with slopes of 5–10% were used at both Curragh and Goonyella/Riverside mine sites.

A concrete trapezoidal flume (45 degrees) with a 30cm throat was constructed at the exit of each catchment to measure runoff and erosion. Runoff was measured using a mechanical chart recorder, electronic and acoustic flow height sensors that recorded to a data logger. Bedload was deposited in a 5m^3 capacity silt trap in front of the flume. A sample of suspended sediment was collected at the outlet of the flume with an ISCO sampler. These samples were used to determine electrical conductivity and pH of the runoff.

Results and Discussion

Sediment loss from all soil and spoil material was large (>70 t/ha) when there was low surface cover. When pasture colonised plots, 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 (>200 t/ha) throughout the study.

Impact of vegetative cover and slope on erosion and water quality

Over the course of the study, the most significant factor in reducing sediment loss from soil and spoil materials on 10, 20 and 30% gradients was the increase in surface vegetative cover. Low and sporadic rainfall in the first 2 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 3 sites.

The effect of vegetative cover on erosion dominated across all sites, despite differences in soil and spoil properties. Vegetative growth ameliorated the hardsetting nature and surface sealing of Goonyella/Riverside and Oaky Creek soils, improved hydraulic conductivity, and reduced runoff and erosion rates. Runoff and sediment movement reduced dramatically on Curragh and Oaky Creek soils in particular once pasture established.

At Curragh, soil erosion rates declined rapidly once buffel grass covered more than half the plot (>50% cover) on the 20% slope (Figure 3), with annual sediment loss <1 t/ha in Years 5 and 6. In comparison, on the bare plot where pasture cover was 0%, erosion from Years 5 and 6 was 289 and 309 t/ha, respectively.

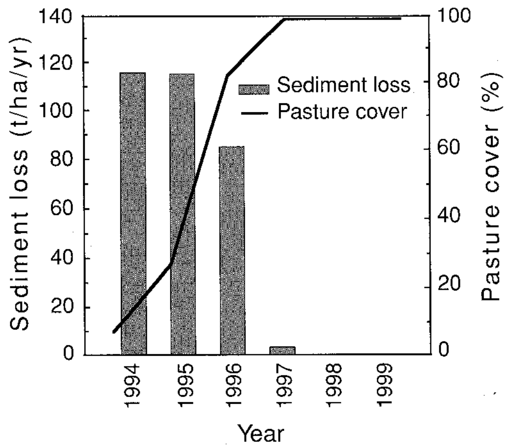

Figure 3. Impact of pasture cover on annual sediment loss from Curragh 20% soil plots, Years 1–6.

The greatest erosion on the pasture plot was in Years 1 and 2 when grass cover was low and a large proportion of the soil was exposed to the erosive forces of rainfall and runoff.

Pasture growth on Oaky Creek soil also reduced sediment loss during the study, with losses in Year 6 of 0.6, 0.9 and 4.2 t/ha from 10, 20 and 30% slopes, respectively, compared with 76 t/ha from the bare soil plot. Loch and Orange (1997) observed that infiltration on rehabilitated areas was closely associated with root channels, which developed stable macropores and a gradual increase in aggregation.

The impact of vegetative cover was also seen at Goonyella/Riverside and Oaky Creek sites where increasing vegetative cover progressively reduced erosion (Figure 4), a similar relationship to that found by Carroll *et al.* (1997) on an agricultural soil in central Queensland. Overland flow on bare soil and spoil or on areas with low vegetative cover (<30%) will form in directions of preferred flow causing rills that concentrate runoff. Vegetative cover reduces overland flow velocity and rilling potential, and thus the ability of water to detach and transport sediment.

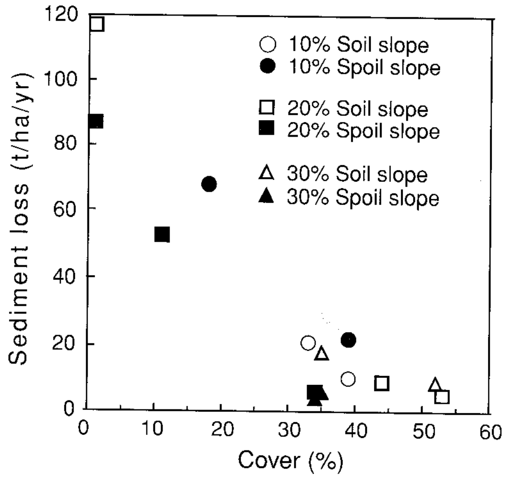

Figure 4. Year 4 annual sediment loss versus pasture cover, Oaky Creek soil and spoil.

Tree establishment was poor on soil material due initially to low and sporadic rainfall, then later to invasion by grass species, particularly buffel grass. Better tree growth occurred on Oaky Creek and Goonyella/Riverside spoils where there was less competition from weeds. However, tree seedlings provide little or no surface cover, and erosion rates on bare plots tended to be higher than on the pasture plots (Figure 5). Lemon-scented gum (*Eucalyptus citriodora*) and Sally wattle (*Acacia salicina*) were the most common tree species on the catchments.

At Curragh, sediment loss peaked in Year 3 on the 30% slope with 154 t/ha compared with 85t/ha and 10 t/ha on the 20 and 10% slopes, respectively. Runoff and sediment loss declined as buffel grass continued to colonise soil plots, until Years 5 and 6 when soil erosion was negligible (<0.5 t/ha) from all 3 slopes (Figure 6). The negligible erosion on the pasture plots is in direct contrast with the bare soil plot where sediment loss doubled between Years 1 and 6, with >280 t/ha in the last 2 years of the study (Figure 7). In Year 6, buffel growth had produced >10 t/ha DM (Table 3), and a 5–10 cm thick mulch layer.

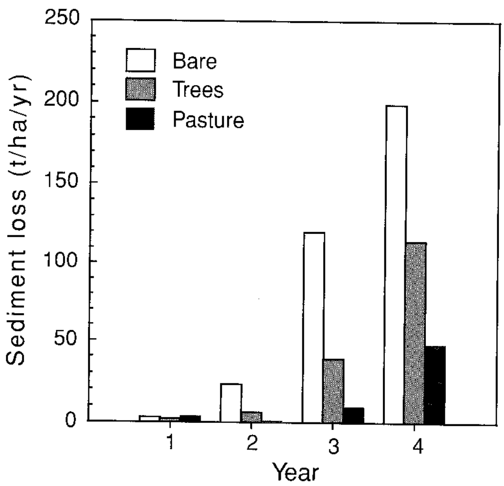

Figure 5. Annual sediment loss from bare, tree and pasture plots, Goonyella/Riverside spoil, 20% slope, Years 1–4.

Table 3. Standing dry matter for Curragh and Oaky Creek soil plots on 30, 20 and 10% slopes (Year 6).

Slope (%)	Curragh	Oaky Creek
	(t/ha)	
30	13.3	4.8
20	10.8	4.4
10	10.3	7.6

On Curragh spoil where a dispersive crust formed, there was little difference in runoff and sediment movement between the 20 and 30% slopes, a finding similar to that of Gilley *et al.* (1977) and Schroeder (1987).

Runoff EC from Curragh soil and spoil was below background levels commonly measured in local creeks (Figure 7). Erosion rates and runoff EC from the Curragh rehabilitated catchments were lower than from the erosion plots, and declined in a similar manner during the 6-year study (Figure 8). Pasture dry matter yields in Year 6 were 13.3, 10.8 and 10.3 t/ha, respectively, on catchments A, B, and C. Goonyella/Riverside catchments had similar pasture biomass and average runoff EC <200 μS/cm.

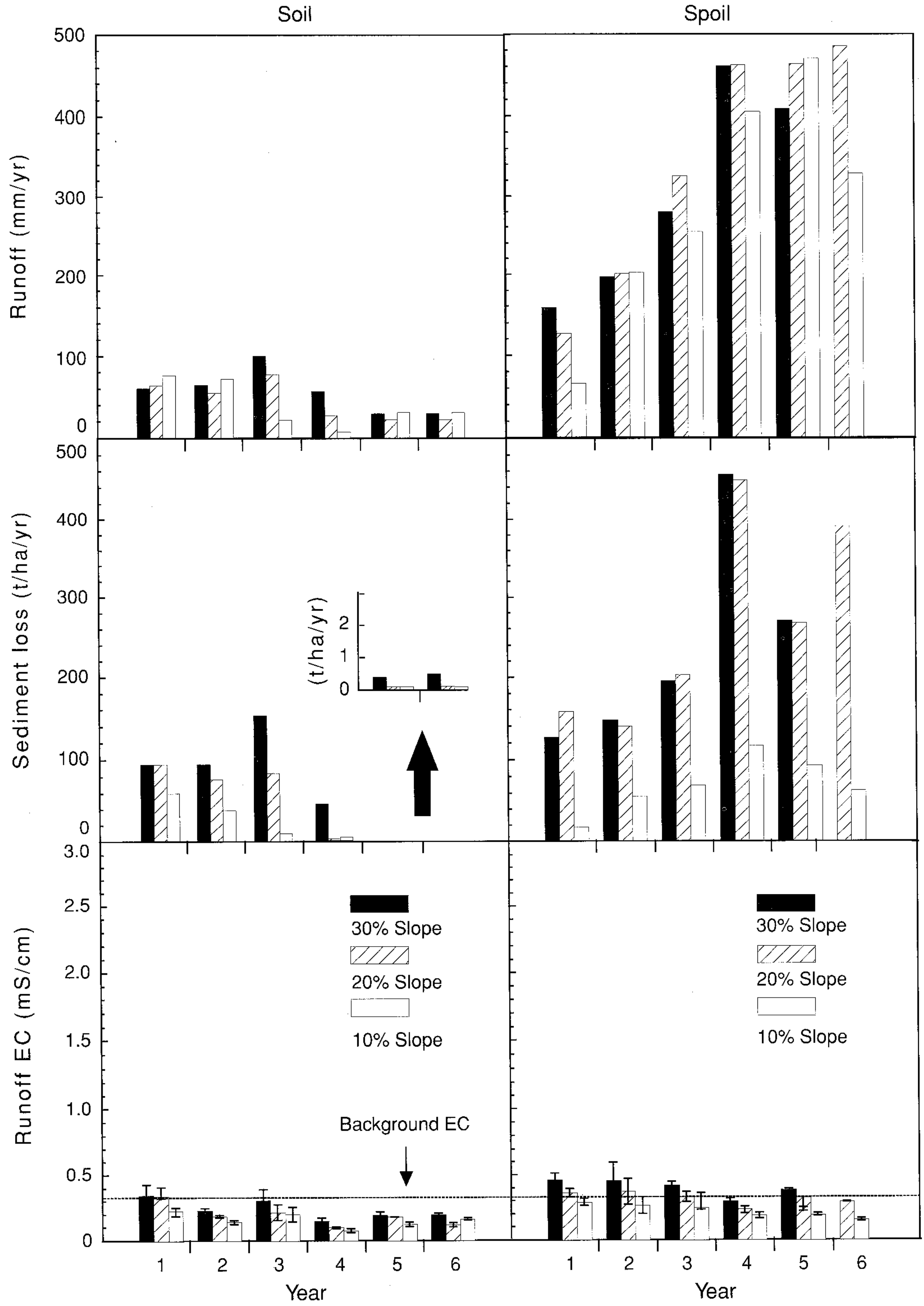

Figure 6. Curragh annual runoff, sediment loss and average runoff EC (with standard error) for soil and spoil material on 10, 20 and 30% slopes.

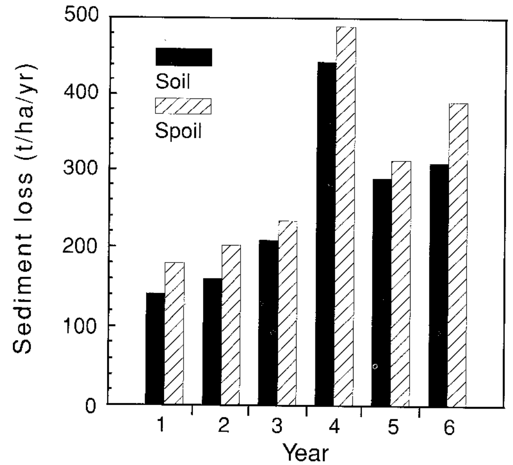

Figure 7. Annual sediment loss for Curragh bare soil and spoil, Years 1–6.

Temporal change to erosion and water quality

In situ soluble salt content of Oaky Creek spoil declined as pasture established during the study (Figure 9), with a similar trend on Goonyella/Riverside spoil. *In situ* soluble salt content peaked in Year 2 on the 10% spoil at Oaky Creek, and began to decline as rhodes grass colonised the plot, with an 8-fold reduction in average runoff EC between Year 2 and Year 6. A reduction in runoff EC coincided with a reduction in *in situ* soluble salt content (Figure 9). The large fluctuations in runoff EC in the first 3 years of the study suggest a cycle of stripping, replenishment and stripping of salt-enriched material. The cycle continued until the start of Year 4 when rhodes grass began to establish, causing runoff EC to decline to levels similar to those in surrounding creeks. Leaching and depletion of salt-enriched spoil material are other explanations for the reduction in runoff EC. Singer and Warrington (1992) and Zhang and Miller (1993) have observed similar salt-encrustation processes and wetting and drying effects on erosion rates.

Impact of fire on rehabilitated catchments

Catchments B and C at Goonyella/Riverside were burnt in December 1999. Immediately after the burn, 3 rainfall events provided an optimal start for seed emergence. However, there was a marked increase in sediment concentration, due to the reduction in vegetative cover (Figure 10). After one month, buffel regrowth was 1.1 and 1.75 t/ha (38 and 54% cover) on catchments B and C, respectively.

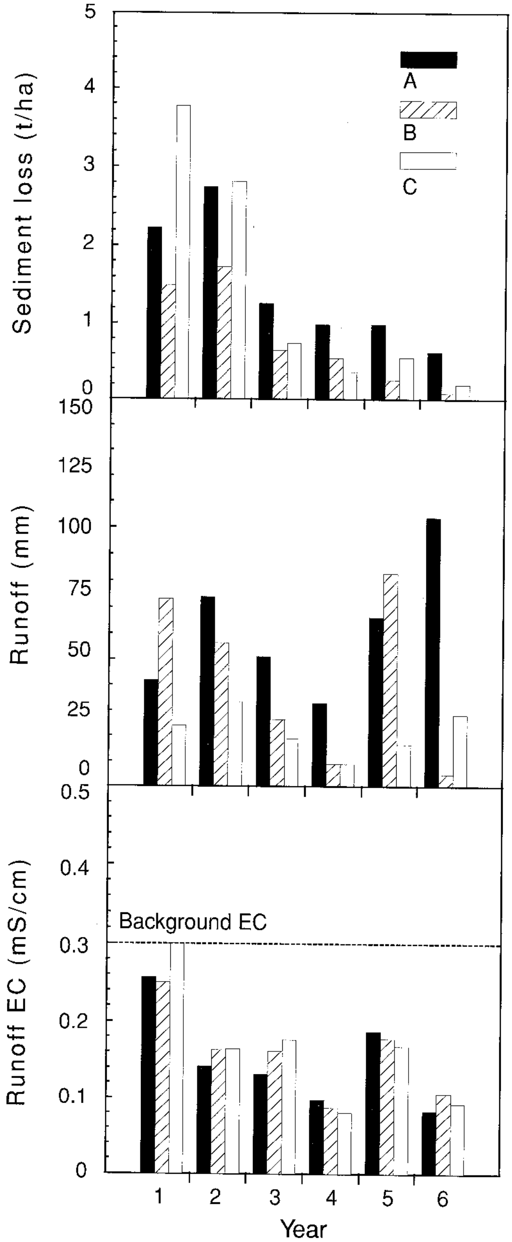

Figure 8. Annual runoff, sediment loss and average EC for Curragh catchments A, B and C.

Areas within the catchment that had greater pasture biomass produced the hottest part of the burn. Within these areas, a greater proportion of

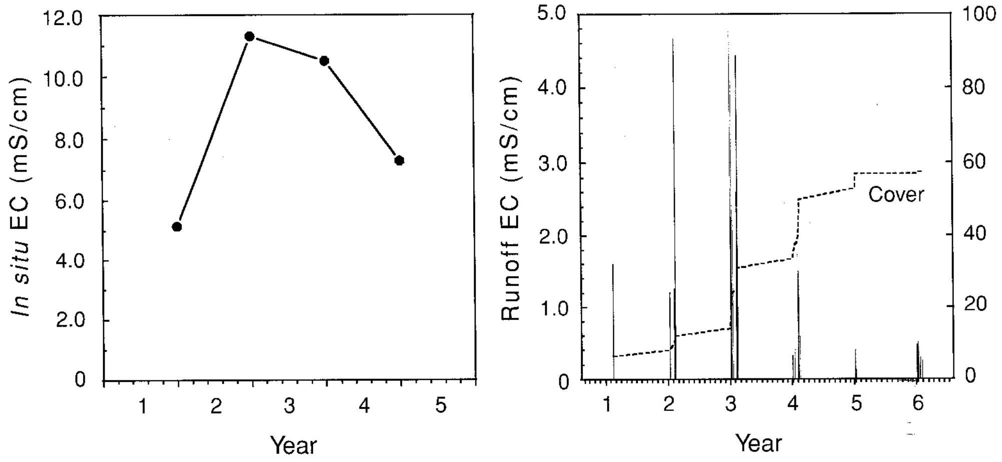

Figure 9. In situ electrical conductivity (EC) of Oaky Creek spoil pasture plot, and runoff EC, Years 1–6.

the existing buffel tussocks did not regenerate. This reduction in competition allowed a wider variety of grass and legume species to emerge. After one month, vegetative cover was already at 38 and 54% for catchments B and C, respectively.

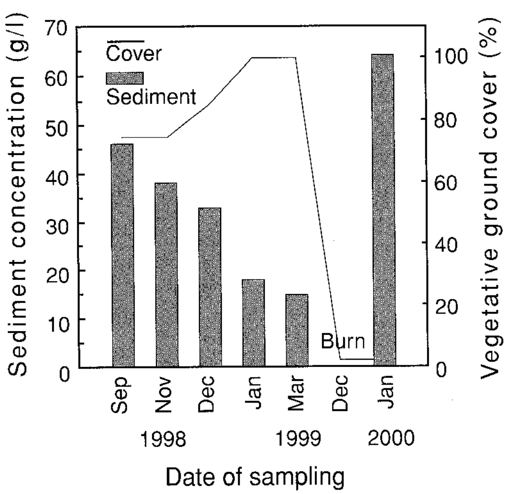

Figure 10. The effect of vegetative cover on sediment concentrations.

As well as providing trends in pasture revegetation and succession, the data collected from the catchments will assist in the future management of grazing pressures on rehabilitated land. Different grazing pressures will have varying impacts on vegetative cover, pasture dry matter yields and areas of high erosion risk. The post-burn phase of the study is designed to assess what impact reduced pasture cover and biomass yields will have on runoff, erosion and water quality, and subsequently on grazing management on rehabilitated lands.

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. During this period, rills formed, particularly on steeper gradients, and persisted until a dense sward of grass colonised and stabilised rills. Vegetative growth also reduced both soluble salt concentrations at the surface of spoil material, and the risk of salt movement on-site and off-site.

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. However, caution should be shown when rehabilitating steep slopes. Post-mining land use and management will determine the long-term success of erosion and water quality control from steep slopes. For example, should grazing be the preferred post-mining land use, the amount of pasture utilised by cattle should be strictly controlled. If overgrazing should occur resulting in insufficient vegetative cover, erosion rates and water quality would be likely to return to levels experienced before slopes were rehabilitated.

Successful establishment of vegetative cover is the key to reducing runoff and erosion, and improving water quality. 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. Physical and chemical characteristics of soil and spoil material determine how much rainfall infiltrates and how successfully and quickly vegetation establishes. Where spoil crusted, there was poor seedling establishment and vegetative growth, with the result that unacceptably large runoff and erosion rates occurred throughout the study.

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