

FINAL REPORT

**Sustainability Indicators
for Coal Mine Rehabilitation**

**C7006
April 2001**

ACARP

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Sustainability Indicators for Coal Mine Rehabilitation

ACARP C7006 Report



Queensland Department of Natural Resources and Mines

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ACARP

Australian Coal Association Research Program



Queensland Government
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Executive Summary

This field study assessed runoff, erosion and water quality from rehabilitated land at two scales: plot (0.01 ha) and catchment (0.4 to 0.9 ha).

The plot study measured runoff and sediment loss from three slope gradients (10, 20 and 30%), where pasture and tree vegetation treatments were imposed on topsoil and spoil materials. A topsoil and a spoil plot on the 20% slope were left bare for comparison with the vegetative treatments. A total of 14 plots at each mine site were monitored from 1993 to 1999.

Three contoured catchments at Curragh and at Goonyella Riverside, along with two angle of repose spoil catchments at Oaky Creek were monitored from 1994 to 2000.

The study highlighted that pasture cover is the preferred indicator of rehabilitation sustainability and stability, and that topsoil is the more suitable material for vegetation establishment on rehabilitated land. The use of topsoil and pasture cover produced the least runoff, sediment and soluble salt transport. A level of 50% was found to be the minimum ground cover that should be attained for erosion management.

Pasture establishment on spoil was poor at all mine sites, especially where the spoil was hard setting and dispersive. Annual erosion rates from spoil remained unacceptably high throughout the study. Where spoil was high in *in situ* soluble salts, the resulting runoff electrical conductivity levels were also high.

By the final year of the study, soluble salt levels in runoff from all topsoil pasture slopes had reduced to $<200 \mu\text{S}/\text{cm}$, which is comparable to the water quality found in local creeks.

Runoff and erosion rates from the rehabilitated contoured catchments progressively declined during the study, with a corresponding improvement in water quality.

Introduction

There is little information in Australia on erosion rates from open-cut coal mine 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 had not been studied, particularly on steeper slopes found on mine sites.

In 1992 a field study was established at Curragh, Goonyella Riverside 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 (0.1 ha) at 10, 20 and 30% gradient slopes, and small catchments (0.4 to 1.0 ha).

The project's objectives were to:

1. monitor the long-term impact of open-cut coal mine rehabilitation on erosion and water quality, under natural rainfall conditions.
2. evaluate physical and biophysical indicators for sustainable rehabilitation.
3. use the monitoring sites as an educational resource and promote outcomes from the study to the industry and the wider community.

This report describes objectives 1 and 2, and identifies topsoil and surface vegetative cover as important indicators of sustainable mine rehabilitation. The educational requirements of objective 3 were addressed through Landcare and Central Queensland Mine Rehabilitation Group (CQMRG) field days, in which mine environmental staff, government agencies, landholders and consultants were shown the field sites and project findings. Photographs from these field days are supplied in this report and in the project CD. Comprehensive final and supplementary data reports for Curragh , Goonyella Riverside and Oaky Creek coal mines, are also supplied on the project CD.

The study was jointly funded by the Australian Coal Association Research Program (ACARP) and 6 major local mining companies; BHP Coal Pty Ltd, MIM Holdings Ltd, Pacific Coal, Callide Coalfields, Capricorn Coal and Curragh Queensland Mining.

Materials and methods

Experimental gradient plots and catchment field sites were located at the Curragh Coal Mine (23.29°S, 148.50°E), Goonyella Riverside Coal Mine (21.51°S, 148.58°E) and Oaky Creek Coal Mine (23.04°S, 148.28°E) in Central Queensland.

Gradient Plot Field Study

Three slope gradients (approximately 10, 20 and 30%) were formed using a D9 size dozer (Figure 1). A depth of soil (10-30cm) was then laid over the spoil and ripped at 1m intervals across each slope. Pasture and tree treatments were imposed on topsoil and spoil material, and on the 20% slope, single topsoil 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.

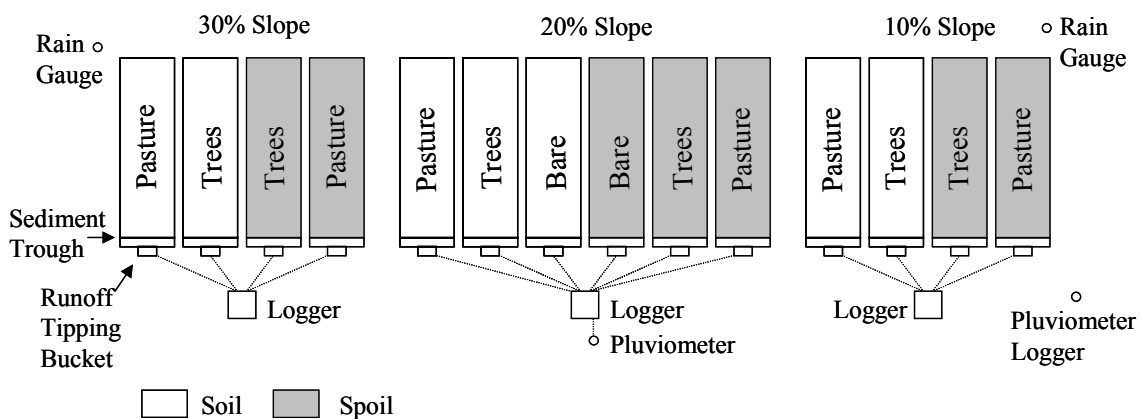


Figure 1. Gradient plot layout.

Catchment Field Study

Rehabilitated catchment areas (0.3 – 1.0 ha) were used to measure the runoff, erosion and water quality. Three contoured catchments with slopes between 5-10%, were used at Curragh and Goonyella Riverside, and two angle of repose catchments of spoil with slopes up to 70% were used at Oaky Creek. The catchments at Goonyella Riverside were covered with topsoil, while the Curragh catchments were covered with topsoil and spoil strips, with pasture species sown in the topsoil and tree species in the spoil. Rainfall was recorded in the same manner as for the gradient plots.

A concrete trapezoidal flume (45 degrees) with a 30cm throat was constructed at the exit of each catchment to measure runoff and erosion (Figures 2 and 3). 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 5m³ 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 determined suspended sediment concentrations, electrical conductivity and pH of the runoff.



equipment



equipment

Results and Discussion

Rainfall

In the first 2 years of the study, all mine sites experienced lower monthly and annual rainfall than the long-term median (approx. 600mm). Most of the rainfall during the study was from rainstorms, with several monthly totals larger than the median.

Gradient Plot Field Study

Impact of topsoil and spoil on runoff and sediment loss

Bare plots on the 20% slopes at all mine sites were used to compare the inherent differences in hydrology and erodibility of the topsoil and spoil material.

Where material was hard setting and dispersive such as Curragh spoil, Oaky Creek topsoil and both Goonyella Riverside topsoil and spoil materials, infiltration was poor and runoff losses were high. The hard setting and dispersive nature of these materials caused low hydraulic conductivity, high runoff losses and restricted the initial establishment of pasture species. On dispersive material, infiltration was often via pipes and cracks, which led to tunnel erosion, poor grass establishment and slope instability.

Differences in topsoil and spoil chemical and physical properties influenced surface strength characteristics and rates of infiltration. However, when bare, both topsoil and spoil materials on all slopes are at risk of high runoff and sediment losses. Without vegetative cover, annual erosion rates ranged from 47 to 443 t/ha from bare topsoil and 23 to 489 t/ha from bare spoil. These erosion rates are unacceptably high and will remain excessive until vegetation establishment.

Window-of-erosion risk

The establishment of pasture cover and biomass was the greatest influencing factor that reduced total runoff and sediment movement from slope gradients up to 30%. Any small within soil and spoil differences, had a lesser effect on runoff and erosion.

Topsoil was found to be the more suitable medium for rapid and sustainable pasture establishment on rehabilitation.

Rehabilitated land is at greatest risk of high runoff and erosion losses immediately after land reshaping, when there is low grass cover and a large proportion of soil is exposed to the erosive forces of rainfall and runoff. This period is referred to as the “window-of-erosion risk”.

The window-of-erosion risk began to decline once pasture and grass covered 50% of rehabilitated land surface area.

Figures 4 and 5 show the reduction in cumulative sediment loss from the 10, 20 and 30% slopes at the respective Curragh and Oaky Creek plot field sites. Before pasture levels reached 50% cover, annual erosion rates were extremely high from all slopes, ranging from 22 to >110 t/ha/yr. Once a minimum 50% cover of pasture had established, erosion rates began to decline.

Negligible annual erosion rates of <1 t/ha/yr were maintained on Curragh 10 and 20% slopes once pasture growth exceeded 50% surface cover. Although annual sediment losses were reduced to manageable levels on all other slopes once 50% cover had established, similar negligible erosion rates of <1 t/ha/yr were only achieved and maintained, once pasture exceeded 80% cover (Figures 4 and 5).

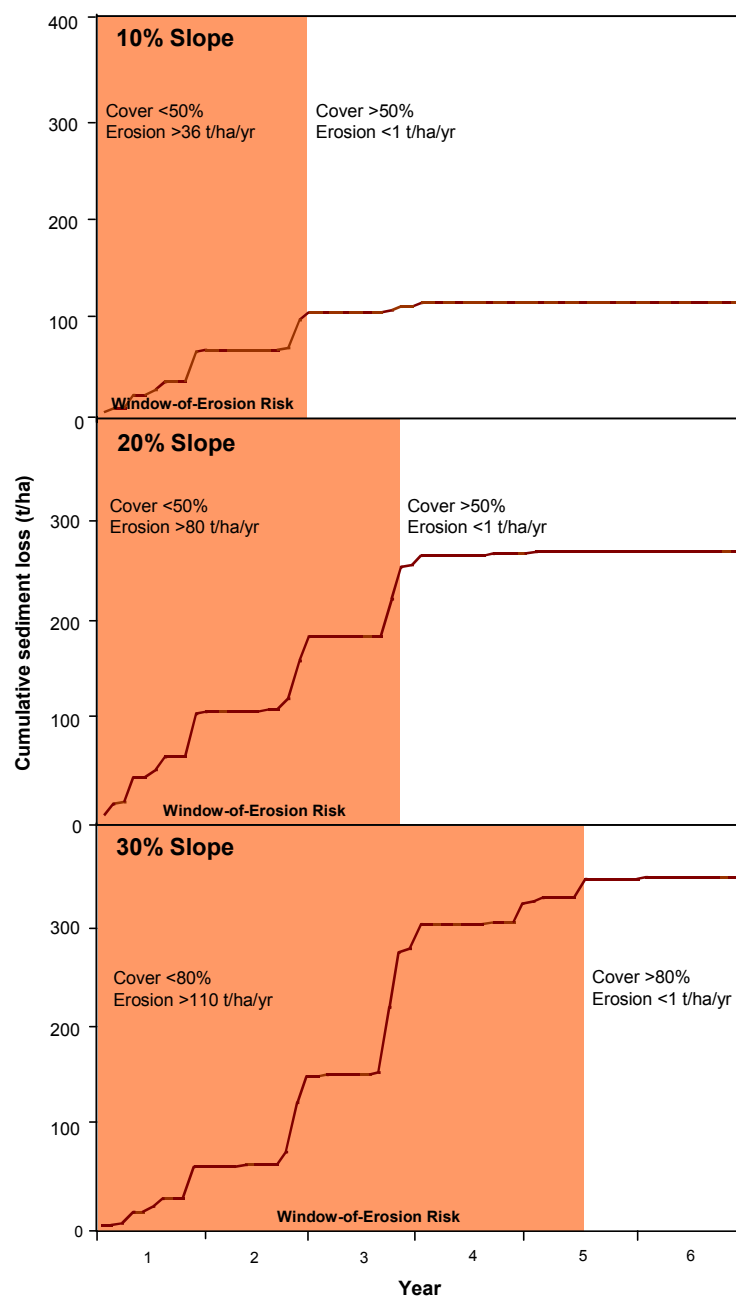


Figure 4. Window-of-erosion risk and cumulative sediment loss for 10, 20 and 30% topsoil slopes at Curragh coal mine

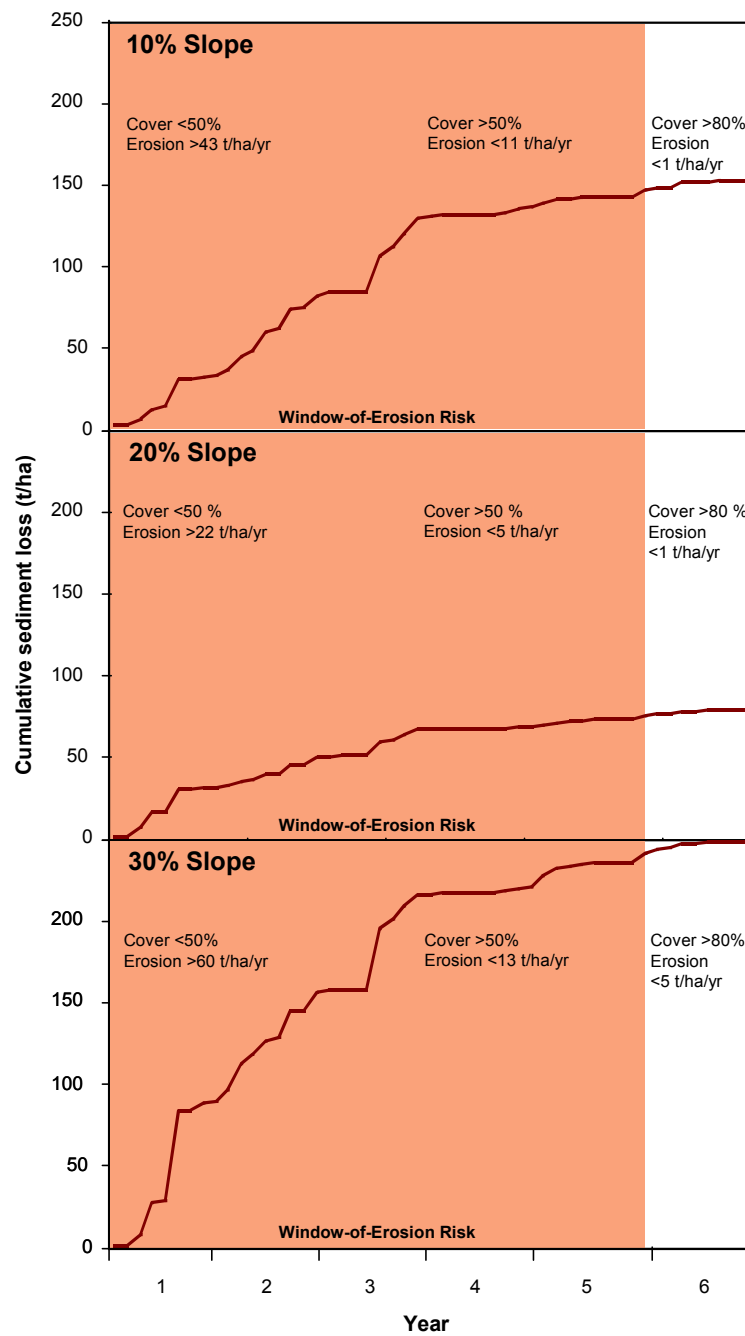


Figure 5. Window-of-erosion risk and cumulative sediment loss for 10, 20 and 30% topsoil slopes at Oaky Creek coal mine

Similar erosion and pasture relationships occurred on the Goonyella Riverside topsoil, however the site could not be maintained for the duration of the field study, due to slumping and piping within the plots.

Pasture establishment on spoil material was generally sparse and slow. Although increases in pasture cover on spoil did reduce sediment movement, the period at which the spoil surface was exposed to rainfall and runoff was far greater than topsoil rehabilitation. Consequently, when vegetative surface cover remained low, erosion rates from the spoil material were high even in the final year of the study (Figure 6).

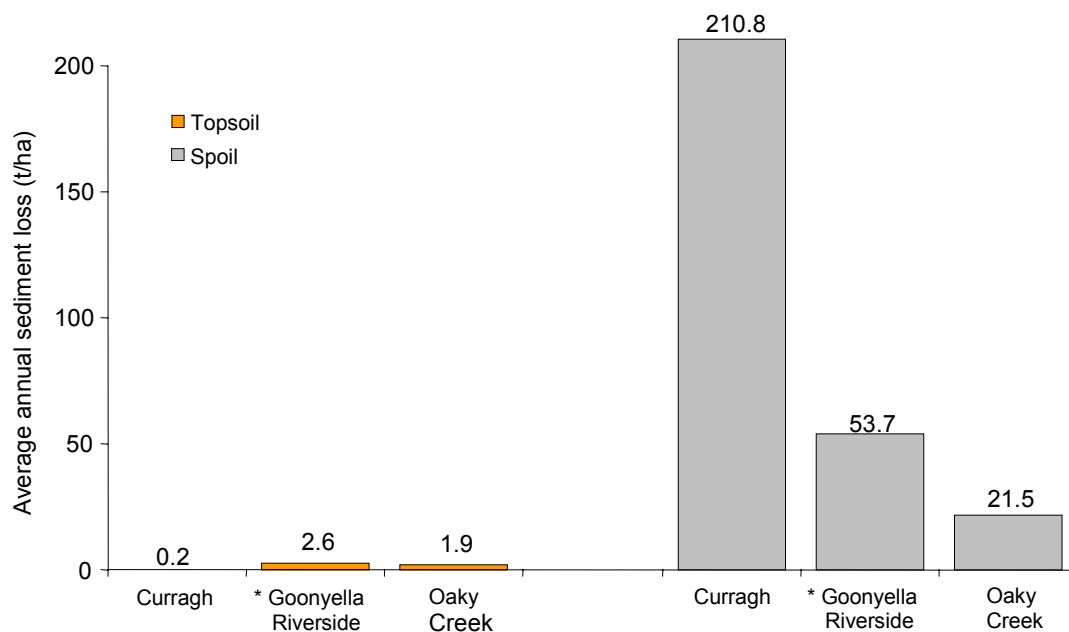


Figure 6. Average annual sediment loss from topsoil and spoil pasture plots in the final year of the study (* Goonyella Riverside plot study finished in Year 4).

Without the rapid and successful establishment of pasture surface cover, ongoing erosion rates from both topsoil and spoil material can be expected to exceed 100t/ha each year.

Impact of pasture cover on water quality

Pasture establishment had a similar effect on water quality (EC) from both topsoil and spoil materials, with reductions in runoff soluble salt levels corresponding with increases in pasture surface cover and biomass.

Runoff soluble salt levels were larger from spoil material on all mine sites, due to higher *in situ* EC and greater proportions of the spoil plot being exposed to rainfall and runoff forces. Where pasture established to >50% cover, EC declined to background levels, even on highly saline spoil material.

Soluble salt levels were lower on the topsoil plots due to lower *in situ* EC and greater levels of pasture cover. Runoff EC levels reduced from approximately 300 $\mu\text{S}/\text{cm}$ in Year 1, to <200 $\mu\text{S}/\text{cm}$ by the end of the study (Figure 7). These quantities are comparable to water quality levels found in local creeks (approx. 300 $\mu\text{S}/\text{cm}$).

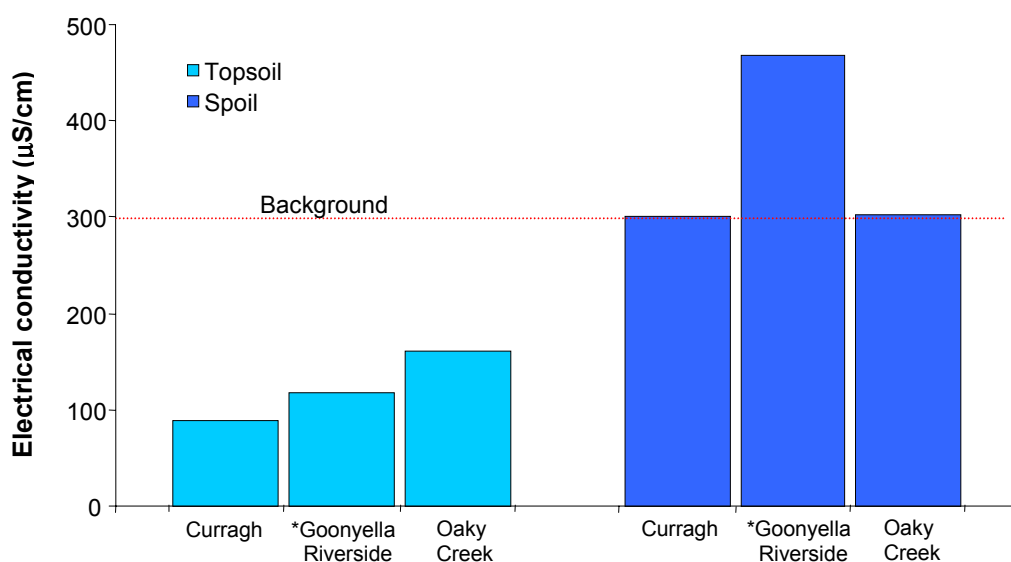


Figure 7. Average annual runoff electrical conductivity from topsoil and spoil pasture plots in the final year of the study (* Goonyella Riverside plot study finished in Year 4).

Impact of tree cover on erosion

Tree establishment was poor on the topsoil plots, due initially to low seasonal rainfall and the low infiltration rates caused by the hard setting nature of the material. Later in the study, competition from grass species that invaded the plots led to poor tree growth and survival.

In contrast, tree growth and survival was more successful on the Goonyella Riverside and Oaky Creek spoil plots, due to greater surface roughness improving infiltration and water availability within the profile. Successful tree species included Poplar Box (*Eucalyptus populnea*), Lemon-scented Gum (*Eucalyptus citriodora*), Blue Gum (*Eucalyptus tereticornis*), Sheoak (*Casuarina glauca*) and several Acacia species.

Although many tree species were successful, trees provided little or no surface cover on the spoil material, consequently erosion rates from the spoil tree plots tended to be higher than the pasture plots throughout the study.

Impact of tree cover on water quality

Water quality from the spoil tree plots was more variable with higher average runoff EC, due to salt *in situ* levels within the spoil profile and low levels of surface cover. The large fluctuations in runoff EC from Goonyella Riverside and Oaky Creek spoil material, suggests that a cycle of stripping, replenishment and stripping of the salt enriched layer is occurring on the spoil surface.

Runoff EC from the bare topsoil and spoil plots also decreased suggesting that the salt transport was becoming supply limited in the final years of the study.

Impact of slope on erosion and runoff

The relationship between slope and sediment loss varies depending on differences in surface roughness and infiltration. Generally, prior to pasture establishing to at least 50% surface cover, the steeper slopes of 20 and 30% gradient are at greater risk of high runoff and sediment losses.

Ripping of the soil surface was shown to reduce runoff and erosion, and improve infiltration rates during the early stages of rehabilitation when vegetative cover is low and risk of erosion was high. The effectiveness of ripping and the degree of surface roughness tended to be greater on steeper gradients and lasted until rills formed.

Catchment Field Study

Impact of vegetative cover on rehabilitated catchment erosion

The greatest impact from increasing pasture cover and dry matter yields, was the continual reduction in sediment concentrations within runoff.

Sediment movement from the contoured catchments at Curragh and Goonyella Riverside mine sites has been very low throughout the study. The rapid establishment of buffel and rhodes grass to >50% surface cover in the first two years of the study, began reducing runoff sediment concentrations and total erosion rates. By Year 6, the high levels of pasture cover (>80%) and biomass (Table 1), had decreased annual erosion to <1t/ha from all contoured topsoil catchments (Figure 8).

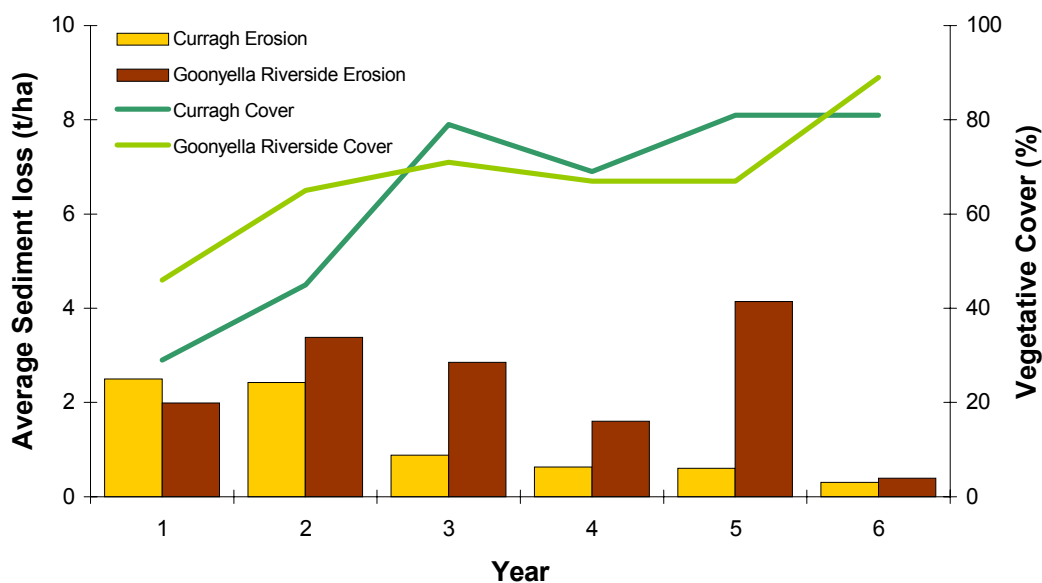


Figure 8. Average annual sediment loss and average annual vegetative cover from contoured catchments at Curragh and Goonyella Riverside mine sites. Years 1 to 6.

Table 1. Pasture biomass from the contoured catchments at Curragh and Goonyella Riverside mine sites, Year 6.

Catchment	Curragh Dry matter (t/ha)	Goonyella Riverside Dry Matter (t/ha)
A	10.6	7.2
B	8.6	3.6
C	7	11.8

Although total sediment loss was low from the contoured catchments, the proportion of suspended sediment remained large throughout the study, ranging from 66 to 94% of cumulative erosion (Figure 9). It is the suspended sediment component that has the greatest potential off site impact, and highlights the importance of vegetative cover in protecting soil particles from rainfall detachment and overland flow.

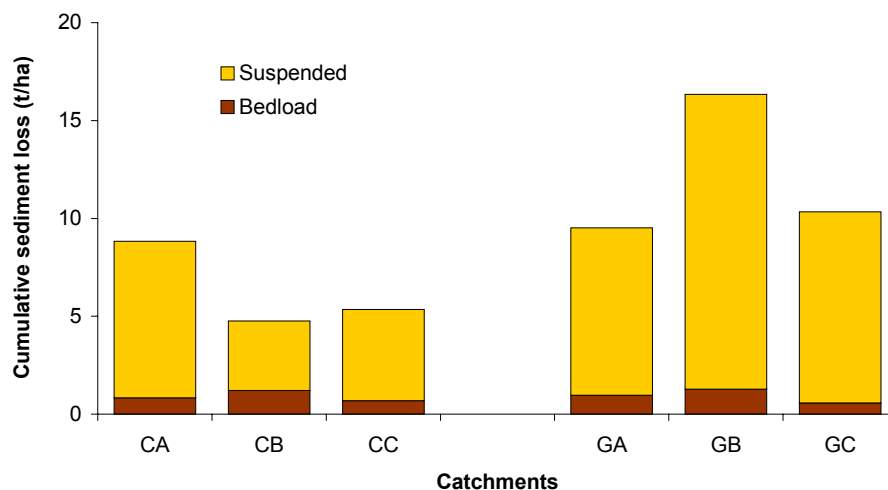


Figure 9. Suspended and bedload proportions within cumulative sediment loss from contoured catchments at Curragh and Goonyella Riverside mine sites. Years 1 to 6.

The establishment of pasture species on the angle of repose catchments was not as rapid or successful as the contoured catchments. Although a dramatic reduction in sediment concentration occurred during the study, pasture establishment never exceeded 42% surface cover. Consequently, annual runoff and sediment loss totals remained variable depending on rainfall amount and intensity.

However, approximately 80% of the total sediment loss was bedload material, which settled and deposited in the valleys of the internally drained landscape, minimising the risk of off-site impact.

Impact of pasture cover on rehabilitated catchment water quality

There was a corresponding improvement in water quality (EC) with increases in pasture cover and biomass. The surface protection provided by buffel and rhodes grass reduced the detachment and transport of sediments and soluble salts from the rehabilitated catchments. With the rapid establishment of vegetative cover, runoff water quality from the contoured catchments was <300 $\mu\text{S}/\text{cm}$ from the first year of the study onwards. The lower *in situ* soluble salt levels in topsoil and increasing pasture yields, have maintained average runoff EC levels below 200 $\mu\text{S}/\text{cm}$ (Figure 10).

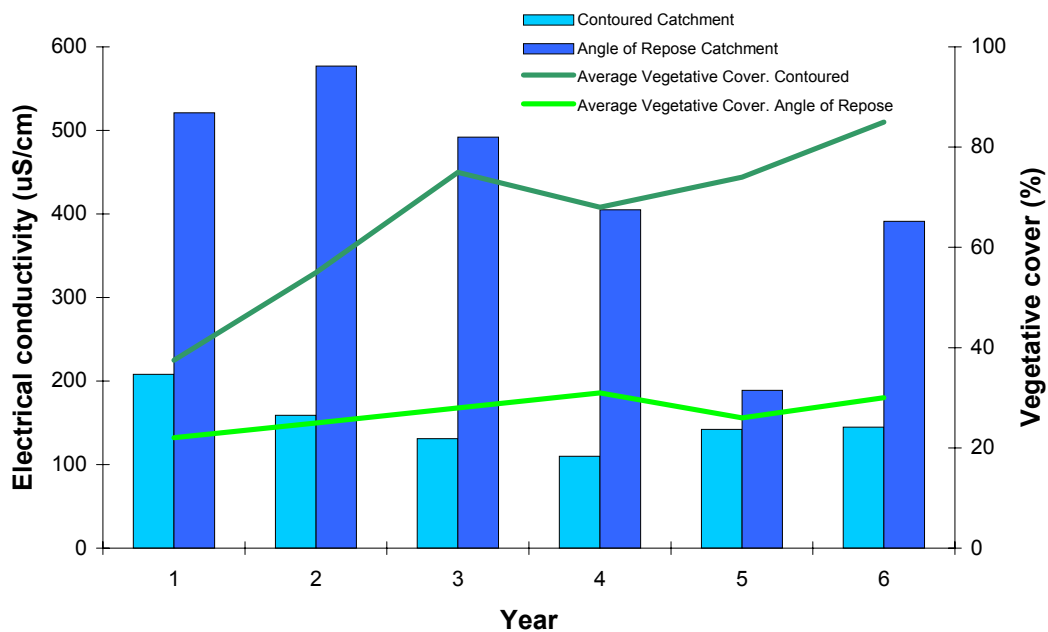


Figure 10. Impact of increasing pasture cover on average annual electrical conductivity from the contoured topsoil and angle of repose spoil catchments. Years 1 to 6.

Conclusion

The window-of-erosion risk on rehabilitated land occurs before pasture establishment reaches 50% ground cover. During this period rills formed, particularly on steeper slopes (>20%), until a dense sward of grass colonised and stabilised the topsoil surface. Pasture growth also reduced soluble salt concentrations at the surface of the topsoil and spoil material, and reduced the risk of salt movement on-site and off-site.

The study showed there was little difference in topsoil erosion rates between slope gradients, once a dense sward of buffel grass established on topsoil 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.

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 topsoil and spoil material determine how much rainfall infiltrates and how successful and quickly vegetation establishes. Where spoil crusted there was poor seedling establishment and vegetative growth, resulting in unacceptably large runoff and erosion rates throughout the study.

The rapid and successful establishment of pasture cover on the catchment areas, has been the greatest contributing factor to the results achieved during the 6 year field study. The rehabilitation methods used for the contoured catchment areas, have so far reduced erosion to negligible levels and improved runoff water quality.

Conclusion Summary

- Rainfall is the major limiting factor associated with successful rehabilitation. It is critical that pasture cover is established rapidly in order to maximise rainfall infiltration.
- A rehabilitated landscape is at greatest risk of erosion before grass cover is established. The window-of-erosion risk occurs before vegetative growth reaches 50% ground cover.
- Pasture establishment to 50% cover should be a minimum target indicator for coal mine rehabilitation. Further increases in pasture cover (>80%) and biomass are required to reduce erosion rates on 30% slopes to negligible levels.
- Topsoil erosion rates declined between slopes once a dense sward of grass cover established (>80% cover).
- Vegetative cover reduces the risk of salt movement on-site and off-site through runoff.
- The development of a hard dispersive crust on the spoil material reduced infiltration, produced very poor pasture and tree establishment and resulted in unacceptably high runoff and erosion.
- Surface ripping of slopes >20% should be used to improve infiltration and reduce runoff and erosion losses.
- Supplementary irrigation should be used to assist rapid pasture establishment during periods of low rainfall.

List of References

Carroll, C., Halpin, M., Burger, P., Bell, K., Sallaway, M.M. and Yule, D.F. (1997) The effect of crop type, crop rotation, and tillage practice on runoff and soil loss on a Vertisol in central Queensland. *Australian Journal of Soil Research* **35**, 925 -939.

Curragh Coal Mine

Pasture on 30% Topsoil Gradient

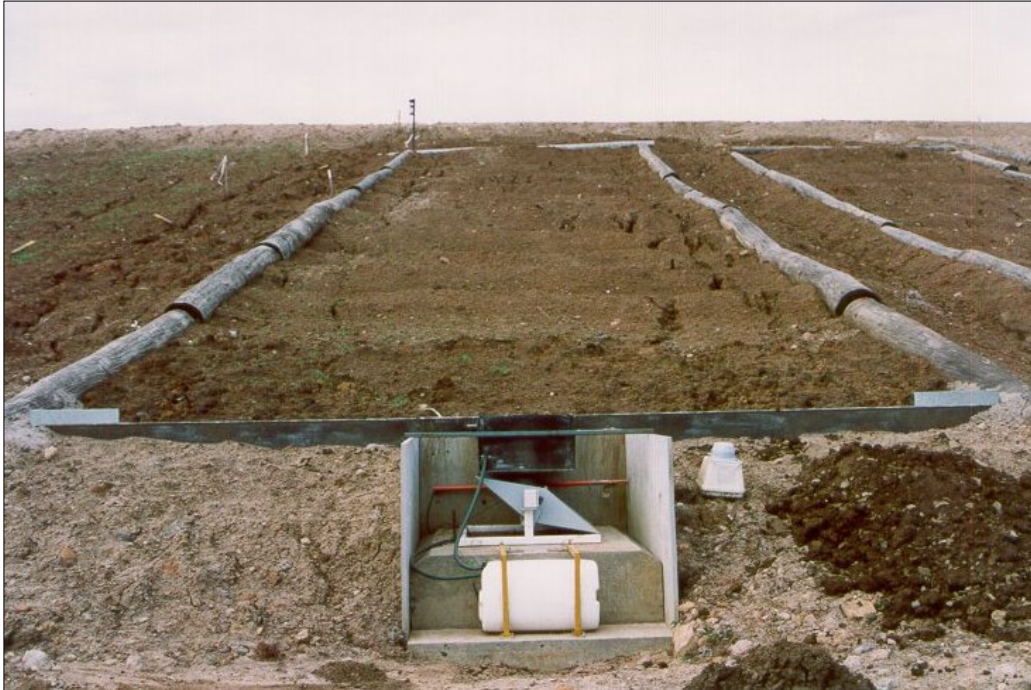


Photo 1. Year 1993. 0% Vegetative Cover



Photo 2. Year 2000. 100% Vegetative Cover

Curragh Coal Mine

Effects of no Vegetative Cover on 30% Spoil Gradient



Photo 3. Year 1993. 0% Vegetative Cover



Photo 4. Year 2000. 0% Vegetative Cover

Curragh Coal Mine

Catchment B



Photo 5. Year 1995



Photo 6. Year 2000

Goonyella Riverside Coal Mine

Pasture On 20% Topsoil Gradient



Photo 7. Year 1993. 5% vegetative cover



Photo 8. Year 2000. 100% vegetative cover

Goonyella Riverside Coal Mine

Effects Of No Vegetative Cover On 20% Spoil Gradient



Photo 9. Year 1993. 0% vegetative cover



Photo 10. Year 2000. 0% vegetative cover

Goonyella Riverside Coal Mine

Catchment A



Photo 11. Year 1993. 44% vegetative cover.



Photo 12. Year 2000. 83% vegetative cover.

Oaky Creek Coal Mine

Tree Growth On 10% Spoil Gradient



Photo 13. Year 1993. 0% Vegetative Cover



Photo 14. Year 2000. 7% Vegetative Cover

Oaky Creek Coal Mine

Catchment A



Photo 15. Year 1995.



Photo 16. Year 2000

Field Day Photos

Landcare field day at Oaky Creek, 1993



Photo 17.



Photo 18.

Landcare field day at Curragh, 1998



Photo 19.



Photo 20.

Landcare field day at Oaky Creek, 1999



Photo 21.



Photo 22.

Central Queensland Mine Rehabilitation Group at Curragh, 2000



Photo 23.

Sustainability Indicators for Coal Mine Rehabilitation

URRAGH



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Executive Summary

This field study assessed runoff, erosion and water quality from rehabilitated land at two scales: plot (0.01 ha) and contoured catchment (0.4 to 0.9 ha).

The plot study measured runoff and sediment from three slope gradients (10, 20 and 30%), where pasture and tree vegetation treatments were imposed on topsoil and spoil materials. A topsoil and spoil plot on the 20% slope, were left bare for comparison with the vegetative treatments. A total of 14 plots were monitored from 1993 to 1999.

Three contoured catchments, which represent current rehabilitation practices at Curragh mine, were monitored from 1994 to 2000.

The use of topsoil and pasture cover produced the least runoff, sediment and soluble salt transport. In the final year of the study, annual sediment loss was just 0.07, 0.14 and 0.5 t/ha, from 10, 20 and 30% gradients respectively. By year 6 buffel grass had produced >10 t/ha biomass on all three slopes, totally covering the topsoil plots.

In contrast, sediment movement from spoil pasture plots on the 10, 20 and 30% gradients was 63, 268 and 271 t/ha respectively, where there was no pasture cover (10% slope was the exception with <30% cover). The high erosion and runoff rates were a result of a hard dispersive crust that formed on the spoil material, which caused poor pasture establishment and low infiltration rates. Runoff and erosion rates from the rehabilitated catchments at Curragh have progressively declined during the study, with a corresponding improvement in water quality.

Introduction

There is little information in Australia on erosion rates from open-cut coal mine 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 land has not been studied, particularly on steeper slopes found on mine sites.

In 1992 a field study was established at Curragh, Goonyella Riverside and Oaky Creek open-cut 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 (0.1 ha) at 10, 20 and 30% gradient slopes, and small catchments (0.4 to 1.0 ha).

The project's objectives were:

1. monitor the long-term impact of open-cut coalmine rehabilitation on erosion and water quality, under natural rainfall conditions.
2. evaluate physical and biophysical indicators for sustainable rehabilitation.
3. use the monitoring sites as an educational resource and promote outcomes from the study to the industry and the wider community.

This report describes objectives 1 and 2, of which vegetative cover is the major biological indicator of sustainability. The educational requirements of objective 3 were addressed through Landcare and Central Queensland Mine Rehabilitation Group (CQMRG) field days, in which mine environmental staff, government agencies, landholders and consultants were shown the field sites and project findings. Photos from these field days are supplied in this report and in the project report CD.

The study was jointly funded by the Australian Coal Association Research Program (ACARP) and 6 major local mining companies; BHP Coal Pty Ltd, MIM Holdings Ltd, Pacific Coal, Callide Coalfields, Capricorn Coal and Curragh Queensland Mining.

Materials and methods

Experimental gradient plot and catchment field sites were located at the Curragh Coal Mine (23.29°S, 148.50°E) in Central Queensland.

Gradient Plot Field Study

Three slope gradients (approximately 10, 20, 30%) were formed using a D9 size dozer (Figure 1). A depth of soil (20-30cm) was then laid over the spoil and ripped at 1m intervals across each slope. 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.

Figure 1. Gradient plot layout.

Catchment Field Study

Rehabilitated catchment areas of approximately 0.5ha were used to measure the runoff, erosion and water quality. Three contoured catchments with slopes between 5-10%, were used at Curragh mine. They were covered with soil and spoil strips in which pasture species were sown in the soil and tree species in the spoil. Rainfall is recorded in the same manner as for the gradient plots.

A concrete trapezoidal flume (45 degrees), with a 30cm throat was constructed at the exit of each catchment to measure runoff and erosion (Figure 2). 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 5m³ 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 determined suspended sediment concentrations, electrical conductivity and pH of the runoff.



Figure 2. Catchment flume and sampling equipment.

Results and Discussion

Rainfall

In the first 2 years of the study all 3 sites experienced 50% less rainfall than the long-term median (Table 1). Most of the rainfall during the study was from rainstorms, with many monthly rainfalls larger than the median (Figure 3).

Table 1. Annual rainfall (mm) and year number for Curragh sites long-term median rainfall.

Year	Year No	Annual Rainfall
1993/94	1	345
1994/95	2	377
1995/96	3	352
1996/97	4	703
1997/98	5	619
1988/99	6	757
Annual median		567
Long-term median		565

Figure 3. Monthly and median rainfall for Curragh (1993 – 2000).

Impact of soil and spoil on runoff and sediment loss

Bare plots on the 20% slopes were used to compare the inherent differences in hydrology and erodibility of the soil and spoil material.

Curragh soil was a highly erodible material, with more sediment transported per unit volume of runoff than spoil. Curragh spoil had lower sediment concentration than soil however runoff was more than double, which resulted in spoil having an overall greater sediment loss than soil (Table 2).

Table 2: Curragh total runoff, sediment loss, average annual sediment loss and sediment concentration from bare soil and spoil, 20% slope (Years 1 to 6).

Material	Site	Total runoff (mm)	Total sed loss (t/ha)	Ave. annual sed loss (t/ha/yr)	Sediment Conc. (kg/m ³)
Soil	Curragh	1048	1552	259	148
Spoil	Curragh	1921	1807	301	96

When dry, the Curragh spoil formed a hard dispersive crust (Figure 4), which resulted in low infiltration and large runoff losses, with a runoff coefficient (c) of 0.62 (Figure 5). The hard setting and dispersive properties of Curragh spoil, were factors limiting the initial establishment of pasture species. Without the protective layer of pasture cover, 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 runoff coefficient (0.34), but this decreased once vegetation established. The protective cover of pasture reduces overland flow velocity and rilling potential, and thus the ability of water to detach and transport sediment.

Figure 4: Surface strengths for soil and spoil.

Figure 5: Cumulative rainfall, runoff and runoff coefficient (C) for soil and spoil .

Impact of pasture cover on erosion and water quality

Vegetative cover, was the most important factor that reduced sediment loss from soil and spoil materials on 10, 20 and 30% gradients. 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 (>200t/ha) throughout the study.

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 the spoil material. By Year 6, buffel growth had produced >10 t/ha dry matter (Table 3), and a 5 to 10 cm thick mulch layer which covered the entire plot and protected the soil from the erosive forces of rainfall and runoff.

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

Slope (%)	Dry matter (t/ha)
30	13.4
20	10.8
10	10.3

At Curragh, soil erosion rates rapidly declined once buffel grass covered more than half the plot. For example, on the 20% soil pasture plot, the annual sediment loss decreased from 115 t/ha to just 0.1 t/ha between Year 1 and 6 (Figure 10) when a sward of buffel grass covered the plot. (Figures 6 and 7). In contrast on the spoil, there was a linear increase in cumulative sediment loss during the study on both the 20% bare and pasture plots (Figure 11) due to poor pasture establishment on the spoil material (Figures 8 and 9). The greatest erosion on the soil pasture plots 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 (Figure 6).



Figure 6. Soil Pasture Plot Year 1.

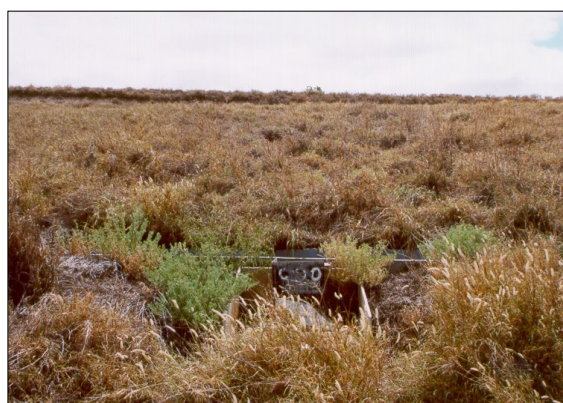


Figure 7. Soil Pasture Plot Year 6.



Figure 8. Spoil Pasture Plot Year 1.



Figure 9. Spoil Pasture Plot Year 5.

Figure 10. Soil Sediment loss from Bare and Pasture plots on 20% slope.

Figure 11. Spoil Sediment Loss from Bare and Pasture plots on 20% slope.

Drought and later competition from buffel grass caused poor tree establishment on topsoil, whereas on the spoil the hard setting and dispersive crust that formed was the cause of poor establishment.

Later in the study buffel grass established across all soil plots, out competing the tree seedlings for space. Consequently, soil erosion rates from the 10, 20 and 30% tree plots were very similar to the soil pasture treatments.

Impact of slope on erosion and water quality

Soil loss peaked with 154, 84, and 10 t/ha on the 30%, 20% and 10% slopes respectively. Runoff and erosion declined as buffel grass progressively colonised the soil plots, with negligible soil erosion (<0.5 t/ha) in years 5 and 6 from all 3 slopes (Figure 12). In contrast, on the bare soil plot soil loss doubled between year 1 and 6, with >280 t/ha in the last two years of the study.

On the spoil, Rhodes grass only sparsely established (30% cover) on the 10% slope, and not at all on the 20% and 30% slopes. By year 6, the 10% slope had over 80% less sediment loss than the 20% slope due to a combination of low slope and greater vegetative cover. However, both runoff and sediment loss were still unacceptably high (369 mm, 63 t/ha) on the 10% slope after 6 years of rehabilitation (Figure 12).

On the 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). On the steeper slopes, rills formed and tended to cut progressively deeper rather than wider, with spoil's low cohesive strength being preferentially eroded by concentrated flow from the bottom of rills (refer Figure 4). This caused rills to become increasingly deeper, with the potential to eventually form gullies.

Average runoff EC levels from Curragh soil and spoil plots, were below or close to background levels measured in local creeks (300 μ S/cm) throughout the study (Figure 12). These levels decreased on all soil plots as pasture established.

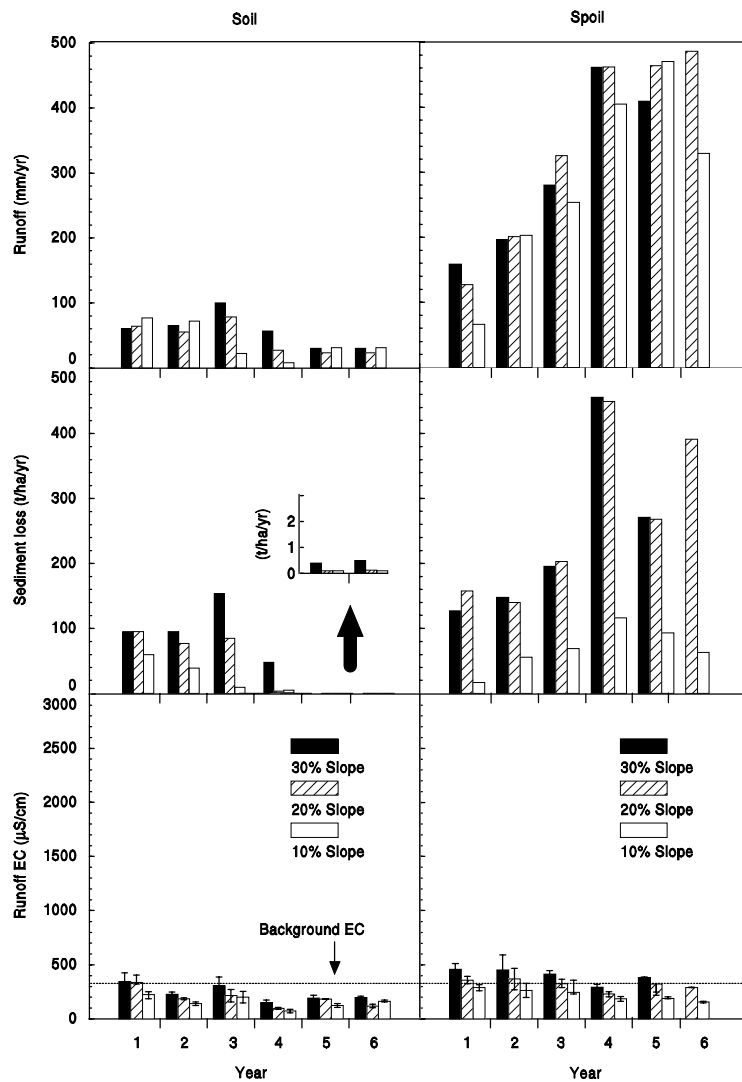


Figure 12. Curragh annual runoff, sediment loss and average runoff EC (with standard error) for soil and spoil pasture plots on 10, 20 and 30% slopes.

Impact of vegetative cover at a rehabilitated catchment scale

Sediment movement from the catchments followed a similar trend to that from the soil pasture plots. Between Years 2 and 3, sediment loss was reduced by more than half on all catchments, as vegetative cover increased (Figure 14). By year 6 there was 70% pasture cover in Catchment A and greater than 80% in Catchments B and C.

The weathering and breakdown of spoil laid down in strips for the sowing of tree seed, into finer materials, has enabled pasture species to spread from areas of topsoil. Although pasture competition prevented tree growth on the topsoil plots, the initial absence of Buffel and Rhodes from the spoil strips in the catchments, enabled tree seedlings such as Lemon-scented Gum and Sally Wattle to establish successfully (Figure 13 and 14).



Figure 13. Curragh Catchment C 1993.



Figure 14. Curragh Catchment C 2000.

The increase in standing pasture, tree leaf and detached litter over the 6 years, has contributed to the continual reduction in sediment detachment and transport, with an exponential decline in sediment concentration between year 1 and 6 (Figure 15).

The proportion bedload to suspended sediment loss has remained constant throughout the study, indicating little variation in particle size distribution (sand, silt, clay) within the eroded sediments. From Year 4 to Year 6, the annual sediment loss from catchments A, B and C, was <1 t/ha (Figure 16).



Figure 15. Soil Sediment Concentration on catchments A, B and C.

There has been a corresponding reduction in runoff EC from 300 $\mu\text{S}/\text{cm}$ in Year 1 , to approximately 100 $\mu\text{S}/\text{cm}$ in Year 6 (Figure 16) as cover increased. Standing pasture yields in year 6 were 10.6, 8.5 and 7.0 t/ha from catchment A, B and C respectively.



Figure 16. Annual runoff, sediment loss and average runoff EC for Curragh Catchments A, B and C.

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 once formed, persisted until a dense sward of grass colonised and stabilised rills. Pasture growth also reduced soluble salt concentrations at the surface of spoil material, and reduced 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.

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 successful and quickly vegetation establishes. Where spoil crusted there was poor seedling establishment and vegetative growth, with the result unacceptable large runoff and erosion rates occurred throughout the study.

The rapid and successful establishment of pasture cover on the catchment areas, has been the greatest contributing factor to the results achieved during the 6 year field study. The rehabilitation methods used for the Curragh catchment areas, have so far reduced erosion to negligible levels and improved runoff water quality.

Conclusion Summary

- Rainfall is the major limiting factor associated with successful rehabilitation. It is critical that pasture cover is established rapidly in order to maximise rainfall infiltration.
- A rehabilitated landscape is at greatest risk of erosion before grass cover is established. The window-of-erosion risk occurs before vegetative growth reaches 50% ground cover.
- Pasture establishment to 50% cover should be a minimum target indicator for coal mine rehabilitation. Further increases in pasture cover (>80%) and biomass will continue to improve rehabilitated land stability and land use sustainability.
- Soil erosion rates declined between slopes once a dense sward of grass cover established (>80% cover).
- Vegetative cover reduces the risk of salt movement on-site and off-site through runoff.
- The development of a hard dispersive crust on the spoil material reduced infiltration, and resulted in unacceptably high runoff and erosion, and very poor pasture and tree establishment..

List of References

- Carroll C, Halpin M, Burger P, Bell K, Sallaway MM, Yule DF (1997) The effect of crop type, crop rotation, and tillage practice on runoff and soil loss on a Vertisol in central Queensland. *Australian Journal of Soil Research* **35**, 925 -939.
- Gilley JE, Gee GW, Bauer A, Willis WO, Young RA (1977) Runoff and erosion characteristics of surface-mined sites in Western North Dakota. *Transactions of American Society of Agricultural Engineers* **20**(4), 697 - 700.
- Loch RJ, Orange DN (1997) Changes in some properties of topsoil at Tarong Coal - Meandu Mine coalmine with time since rehabilitation. *Australian Journal of Soil Research* **35**, 777 - 784.
- Schroeder SA (1987) Slope gradient effect on erosion of reshaped spoil. *Soil Society of America Journal* **51**, 405 - 409.

Curragh Mine Photo Plates

Pasture on 10% Topsoil Gradient



Photo 1: Year 1993. 3% Vegetative Cover



Photo 2: Year 2000. 100% buffel Cover on both tree and pasture plots.

Pasture on 20% Topsoil Gradient



Photo 3: Year 1993. 7% Vegetative Cover

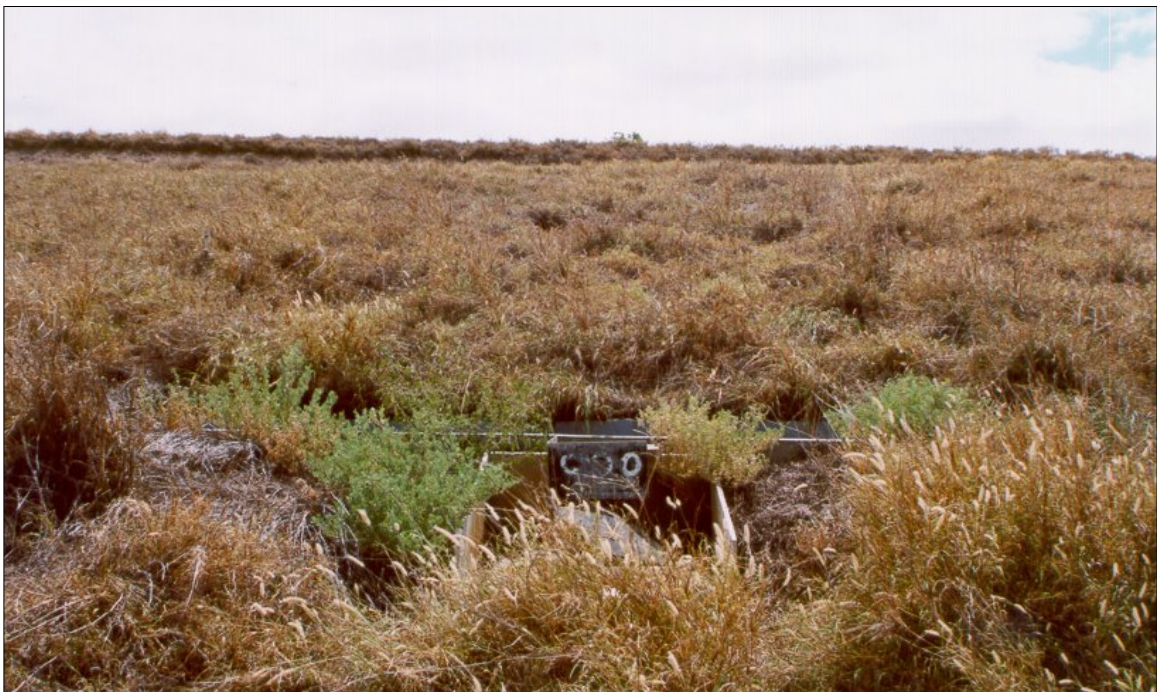


Photo 4: Year 2000. 100% buffel grass cover on both tree and pasture plots

Pasture on 30% Topsoil Gradient

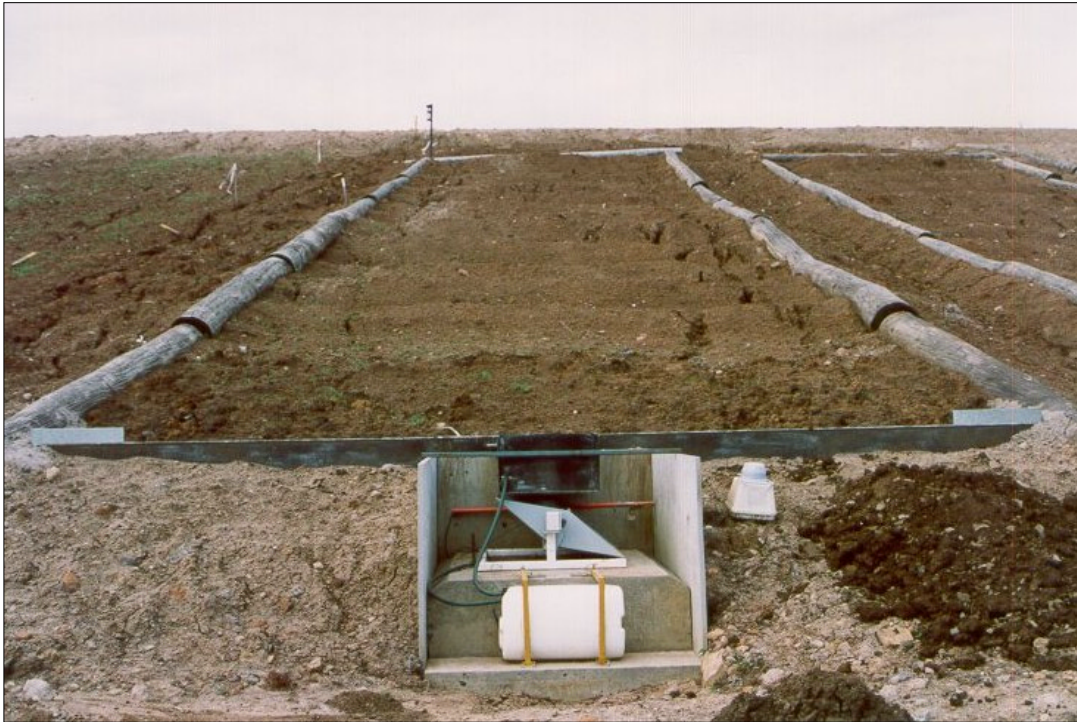


Photo 5: Year 1993. 0% Vegetative Cover



Photo 6: Year 2000. 100% Vegetative Cover

Effects of no Vegetative Cover on 30% Spoil Gradient



Photo 7: Year 1993. 0% Vegetative Cover



Photo 8: Year 2000. 0% Vegetative Cover

Catchment A



Photo 9: Year 1995.



Photo 10: Year 2000

Catchment B



Photo 11: Year 1995



Photo 12: Year 2000

Catchment C



Photo 13: Year 1995



Photo 14: Year 2000

Landcare field day at Curragh, 1998



Central Queensland Mine Rehabilitation Group at Curragh, 2000



Sustainability Indicators for Coal Mine Rehabilitation



Queensland Department of Natural Resources

C. Carroll, A. Tucker, L. Merton, P. Burger, L. Pink

ACARP

Australian Coal Association Research Program



Queensland Government
Natural Resources and Mines

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Executive Summary

This field study assessed runoff, erosion and water quality from rehabilitated land at two scales: gradient plot (0.01 ha) and angle of repose catchment (< 0.5 ha).

The plot study measured runoff and sediment from three slope gradients (10, 20 and 30%), where pasture and tree vegetation treatments were imposed on topsoil and spoil materials. A topsoil and spoil plot on the 20% slope, were left bare for comparison with the vegetative treatments. A total of 14 plots were monitored from 1993 to 1999.

In addition 2 catchments of predominately angle of repose spoil were monitored from 1994 to 2000.

Prior to pasture establishment, Oaky Creek topsoil formed a surface seal and caused higher runoff and sediment loss than spoil. The use of topsoil and pasture cover produced the least annual runoff, sediment loss and soluble salt transport by the completion of the study. In the final year, annual erosion was just 0.66, 0.92 and 4.25 t/ha from the 10, 20 and 30% slopes respectively. Pasture cover was >80% and pasture biomass ranged between 4.4 and 7.6 t/ha. In contrast, sediment movement from the spoil pasture plots was 34, 12 and 16 t/ha respectively, where pasture cover was <50% on the respective slope gradients. Soluble salt transport from spoil was higher than topsoil, however, electrical conductivity of runoff declined as pasture established on the plots.

Sediment movement from Catchment A (<5 t/ha) was consistently lower than Catchment B throughout the field study. Runoff and sediment loss totals remained variable depending on rainfall amount and intensity. Catchment B sediment concentrations decreased from 219 to 16 kg/m³ between Years 1 and 7. Runoff from the catchments had average electrical conductivity levels of 300 μ S/cm by the final year of the study.

Introduction

There is little information in Australia on erosion rates from open-cut coal mine rehabilitation, particularly under natural rainfall. Most erosion research has been conducted on agricultural soils and landuse, and on lower slope gradients. The 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 land has not been studied, particularly on steeper slopes found on mine sites.

In 1992 a field study was established at Oaky Creek, Curragh, and Goonyella Riverside 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 (0.1 ha) at 10, 20 and 30% gradient slopes, and small catchments (0.4 to 1.0 ha).

The project's objectives were:

1. monitor the long-term impact of open-cut coalmine rehabilitation on erosion and water quality, under natural rainfall conditions.
2. evaluate physical and biophysical indicators for sustainable rehabilitation.
3. use the monitoring sites as an educational resource and promote outcomes from the study to the industry and the wider community.

This report describes project objectives 1 and 2 at Oaky Creek Mine, of which vegetative cover is the major biological indicator of sustainability. The educational requirements of objective 3 were addressed through Landcare and Central Queensland Mine Rehabilitation Group (CQMRG) field days, in which mine environmental staff, government agencies, landholders and consultants were shown the field sites and project findings. Photos from these field days are supplied in this report and in the project CD.

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Gradient Plot Field Study

Three slope gradients (approximately 10, 20, 30%) were formed using a D9 size dozer (Figure 1). A depth of topsoil (10cm) was then laid over the spoil and ripped at 1m intervals across each slope. Pasture and tree treatments were imposed on soil and spoil material, and on the 20% slope, single topsoil 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.

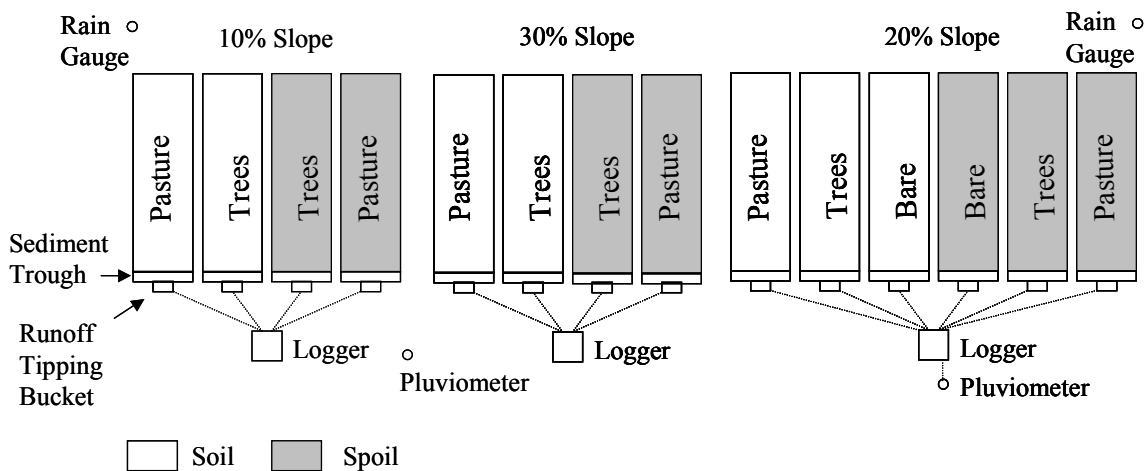


Figure 1. Experimental Plot Layout

Catchment Field Study

Runoff, sediment loss and water quality were measured from two spoil catchments with slopes up to 70%. These areas were designated Catchment A and B. A Pluviometer and rain gauge were installed at Catchment A.

A concrete trapezoidal flume (45 degrees), with a 30cm throat was constructed at the exit of each catchment to measure runoff and erosion (Figure 2). 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 5m³ 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 (Figure 2). These samples determined suspended sediment concentrations, electrical conductivity and pH of the runoff.



Figure 2. Catchment flume and sampling equipment.

Results and Discussion

Rainfall

In the first two years of the study, Oaky Creek experienced less than the long-term median rainfall (Table 1). Most of the rainfall during the study was from rainstorms, with many monthly rainfalls larger than the median (Figure 3).

Table 1. Annual rainfall (mm) and year number for Oaky Creek field sites long-term median rainfall.

Year	Year No	Annual Rainfall (mm)
1993/94	1	492
1994/95	2	527
1995/96	3	608
1996/97	4	612
1997/98	5	525
1998/99	6	930
1999/00	7	560
Annual median	1993-2000	584
Long-term median	100 Years	578

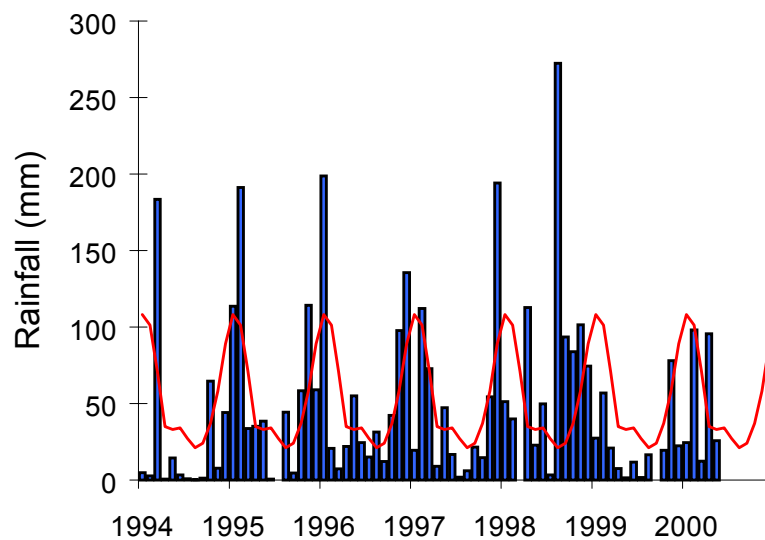


Figure 3. Monthly and median rainfall for Oaky Creek (1994 – 2000).

Gradient Plot Field Study

Impact of soil and spoil on runoff and sediment loss

Bare plots at the 3 minesites were used to compare the inherent differences in hydrology and erodibility of the topsoil and spoil material. On Oaky Creek soil, a thin surface seal formed and caused low hydraulic conductivity and a high runoff coefficient (0.44) than the spoil (0.27) (Figure 4). Oaky Creek topsoil and spoil had similar sediment concentrations, with soil having greater runoff and overall greater sediment loss than spoil (Table 2).

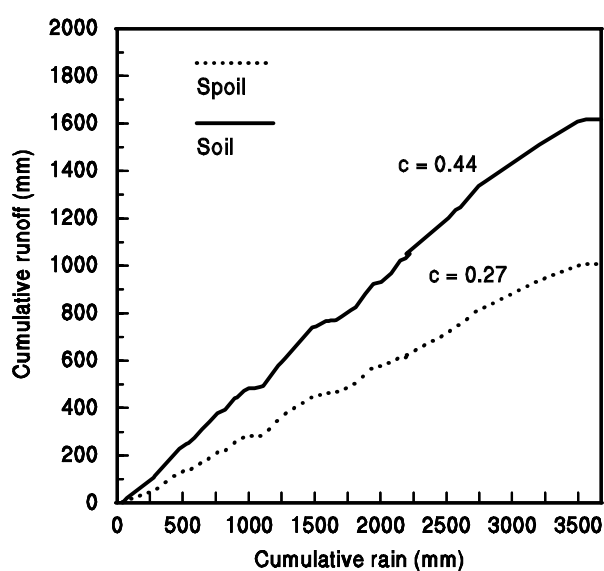


Figure 4. Cumulative rainfall, runoff and runoff coefficient (C) for soil and spoil.

Table 2. Oaky Creek total runoff, sediment concentration, total sediment loss and average annual sediment loss from bare topsoil and spoil 20% gradient plots (Years 1-6).

Material	Site	Total runoff (mm)	Sediment Conc. (kg/m ³)	Total sed loss (t/ha)	Ave. annual sed loss (t/ha/yr)
Topsoil	Oaky Creek	1608	43	695	115
Spoil	Oaky Creek	1000	46	462	77

Impact of pasture cover on erosion and water quality

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. The effect of pasture cover on erosion dominated across all sites despite large differences in topsoil and spoil properties. Vegetation, particularly grass cover, protects 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.

The establishment of vegetative cover and biomass on the pasture plots (Table 3) reduced total runoff, sediment detachment and transport, and total topsoil loss through the study. Loch and Orange (1997) observed that wetting patterns on rehabilitated areas were closely associated with root channels, which developed stable macropores and a gradual increase in aggregation. Any small within soil and spoil differences had a smaller effect on runoff and erosion.

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

Slope (%)	Dry matter (t/ha)
10	7.6
20	4.4
30	4.8

Vegetative cover was the most important factor that reduced sediment loss from soil and spoil materials on 10, 20 and 30% gradients. Soil erosion rates rapidly declined on all three slopes once Buffel and Rhodes grass exceeded 50% vegetative cover, which ameliorated the surface sealing nature of the Oaky Creek soil (Figure 5). Where grass cover was absent, soil loss remained consistently high throughout the study, with an overall cumulative soil loss of 695t/ha from the bare soil plot (Figure 5).

The greatest erosion rates from the topsoil pasture plots occurred in the first two years of the project, when there was low grass cover and a large proportion of soil was exposed to the erosive forces of rainfall and runoff. Within this period, rehabilitated areas are at the greatest risk of high runoff and sediment losses (Figure 5).

In Years 1 and 2 when vegetative cover was less than 50% (Figure 8 *photos*), sediment loss from the 30% topsoil pasture plots was very high, averaging 79 t/ha/yr. When Buffel and Rhodes grass exceeded 50% surface cover in Year 4, annual erosion was more than halved. By the final two years of the study, pasture cover had increased to around 90% (Figure 9) and had reduced sediment movement to 8 t/ha (Figure 7). Even greater reductions in erosion rates occurred on the 10 and 20% slopes, with <1 t/ha lost from each gradient in the final year, due to high pasture cover and biomass levels being achieved earlier in the study (Figure 12) *stacked graph*.

Pasture on the spoil plots never exceeded 50% surface cover, and as a result, sediment losses from the 10, 20 and 30% slopes in Year 6 were still high at 34, 12 and 17t/ha respectively. The 10% spoil plot had the greatest sediment loss of the pasture plots, and was greater than the bare spoil plot until Rhodes grass established in last 3 years of the study (Figure 6). The high erosion rate on the 10% spoil plot was due to the development of a salt crust. Following drying, the crust disintegrated leaving a layer of salt-enriched erodible sediment, which caused greater erosion, and higher runoff EC than the 20% and 30% pasture plots (Figure 11).

As Rhodes grass colonised all the spoil plots (Figure 9 and 10), sediment loss and runoff EC declined, particularly on the 10% slope where there was an 8-fold reduction in runoff EC from a peak of 2900 $\mu\text{S}/\text{cm}$ in Year 2 to 300 $\mu\text{S}/\text{cm}$ in Year 6 (Figure 11).

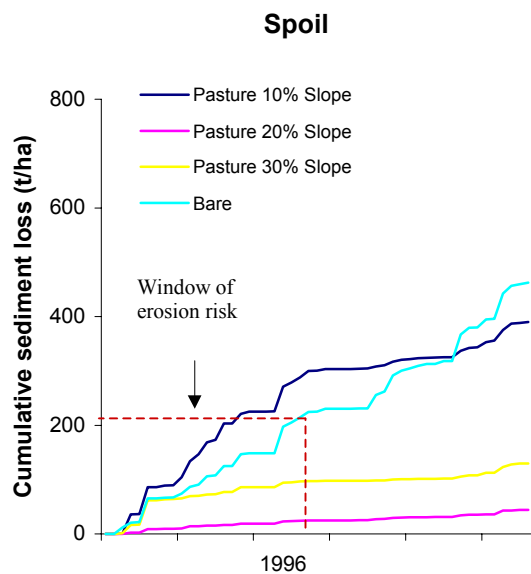


Figure 5: Cumulative sediment loss from the 10, 20, 30% pasture plots and the bare topsoil plot.

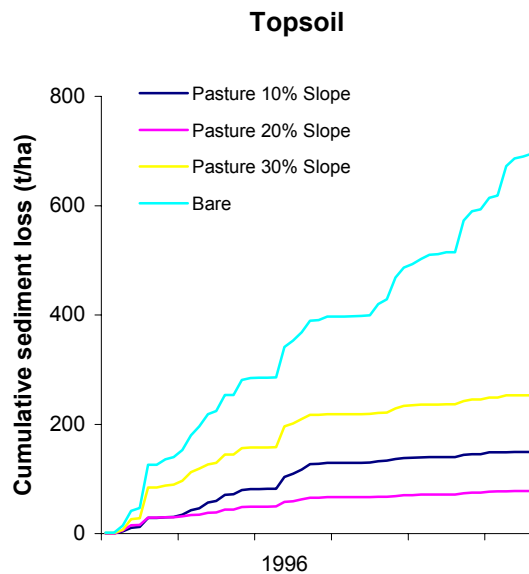


Figure 6: Cumulative sediment loss from 10, 20 30% pasture plots and the bare spoil plot.

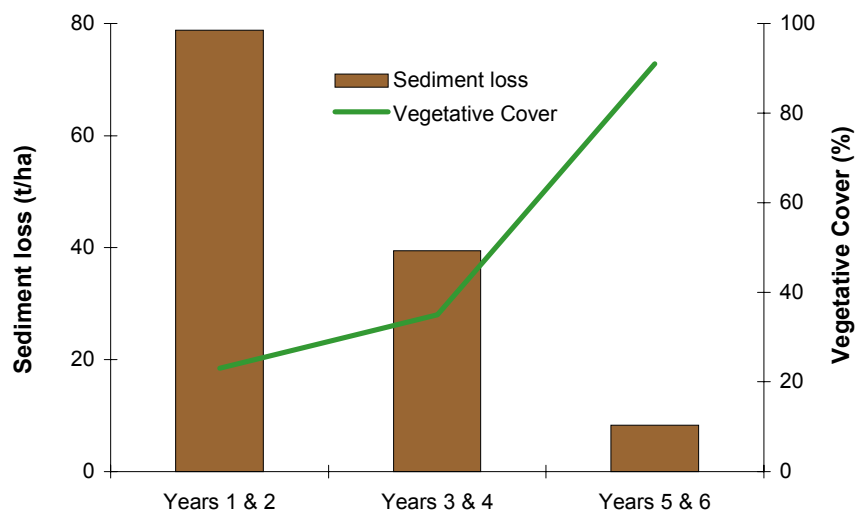


Figure 7. Average annual sediment loss for topsoil pasture plots on 30% slope.



Figure 8: Topsoil pasture plot



Figure 9: Topsoil bare plot



Figure 10: Spoil pasture plot.



Figure 11: Spoil bare plot

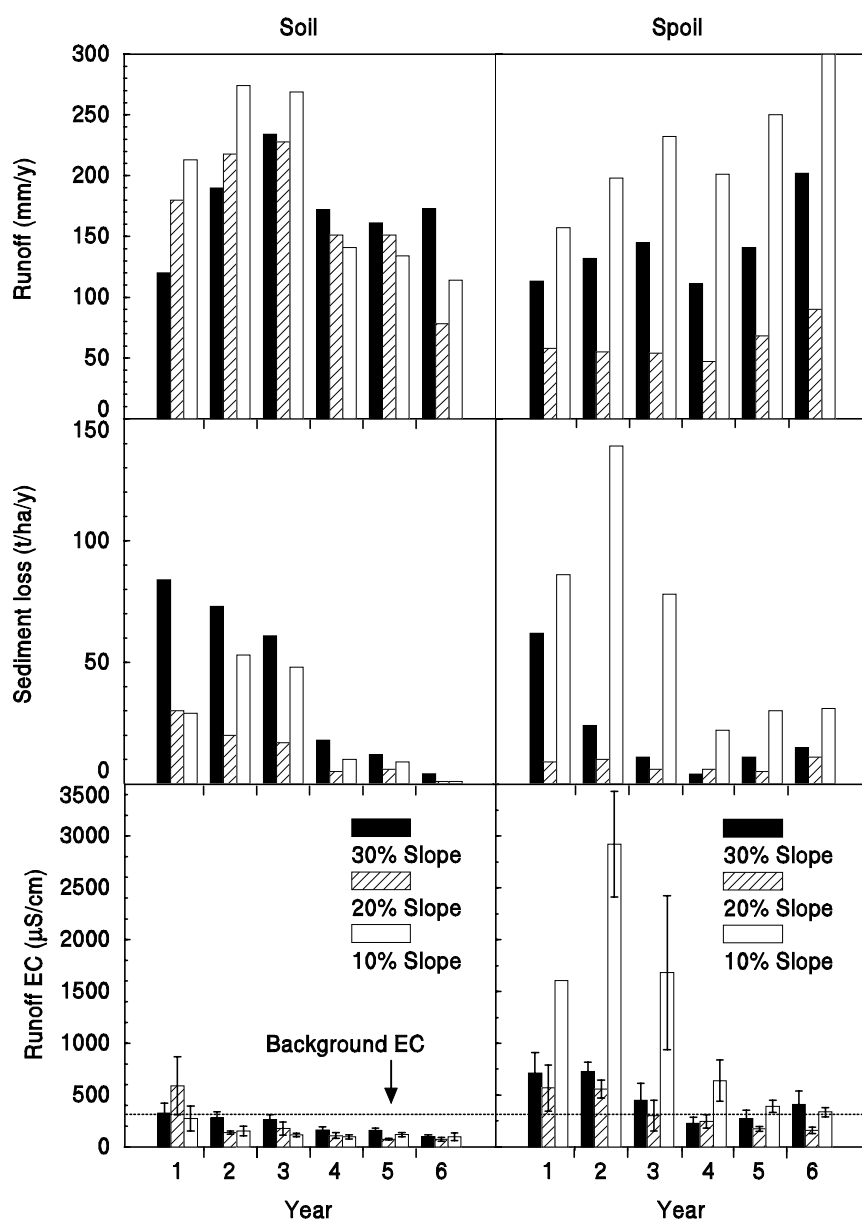


Figure 12: Oaky Creek annual runoff, sediment loss and average runoff electrical conductivity for topsoil and spoil material on 10, 20 and 30% slopes.

Electrical conductivity of runoff water from both soil and spoil materials declined during the study. By Year 2, electrical conductivity (EC) of runoff declined to $<150 \mu\text{S/cm}$ as pasture reached $>50\%$ cover on the 10 and 20% topsoil plots, and $<300 \mu\text{S/cm}$ on the 30% slope (Figure 12), which is comparable to water quality levels found in local creeks.

In contrast, spoil had higher runoff EC than soil throughout the study. However, as Rhodes grass established (>30% cover) runoff EC levels decreased to <300 $\mu\text{S}/\text{cm}$ on the 20 and 30% slopes (Figure 12). Soluble salt levels from the 10% slope remained high throughout the study, and peaked in year 2 at 2920 $\mu\text{S}/\text{cm}$. The large fluctuations in runoff EC in the first three years of the study suggest a cycle of stripping, replenishment, and stripping of the salt-enriched material. The cycle continued until Year 4 when Rhodes grass began to establish, causing runoff EC to decline to <300 $\mu\text{S}/\text{cm}$.

Impact of tree cover on erosion and water quality

At the start of the study, poor tree establishment was the result of low seasonal rainfall and low infiltration rates caused by the formation of a thin surface crust when the soil was bare. Later in the study competition from grass species that invaded the plots led to poor growth and tree survival. By the end of the study just 7 trees survived across the three tree plots on the soil material (Figure 13).

In contrast, Oaky Creek spoil had better tree establishment and survival than the soil material (Figure 14) due to less competition from grass species. Greater surface roughness on the spoil plots increased infiltration and enabled successful growth of Eucalypt and Acacia species on the 10, 20 and 30% gradient plots. Tree height data from Year 6 is shown in Figure 14.

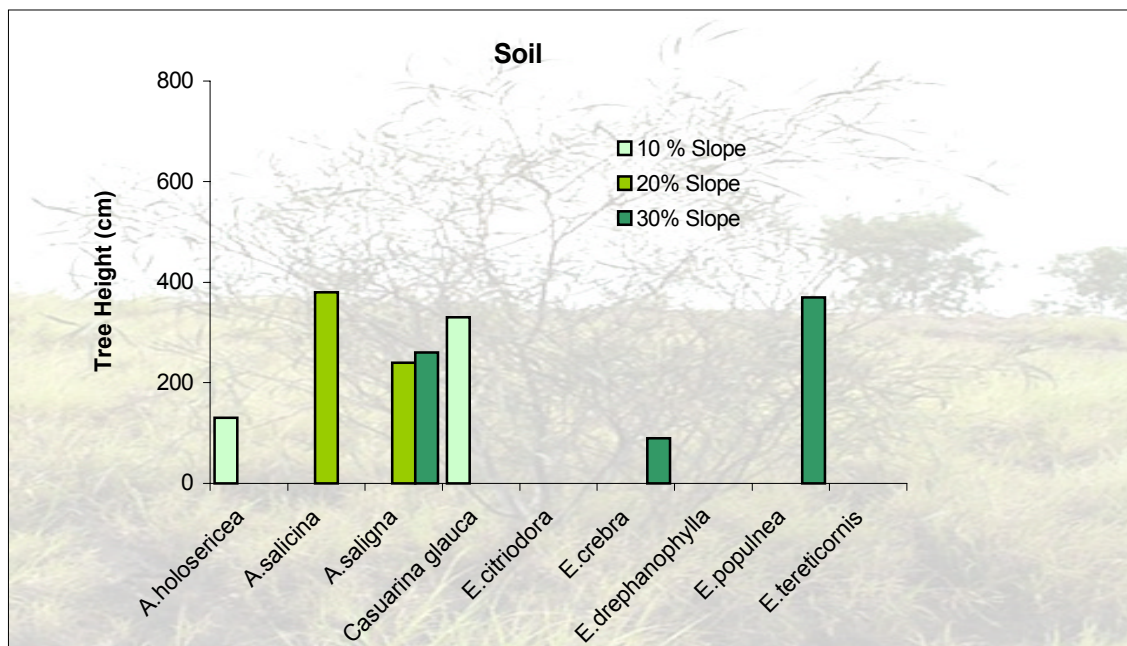


Figure 13: Surviving tree species height data from 10, 20 and 30% topsoil gradients

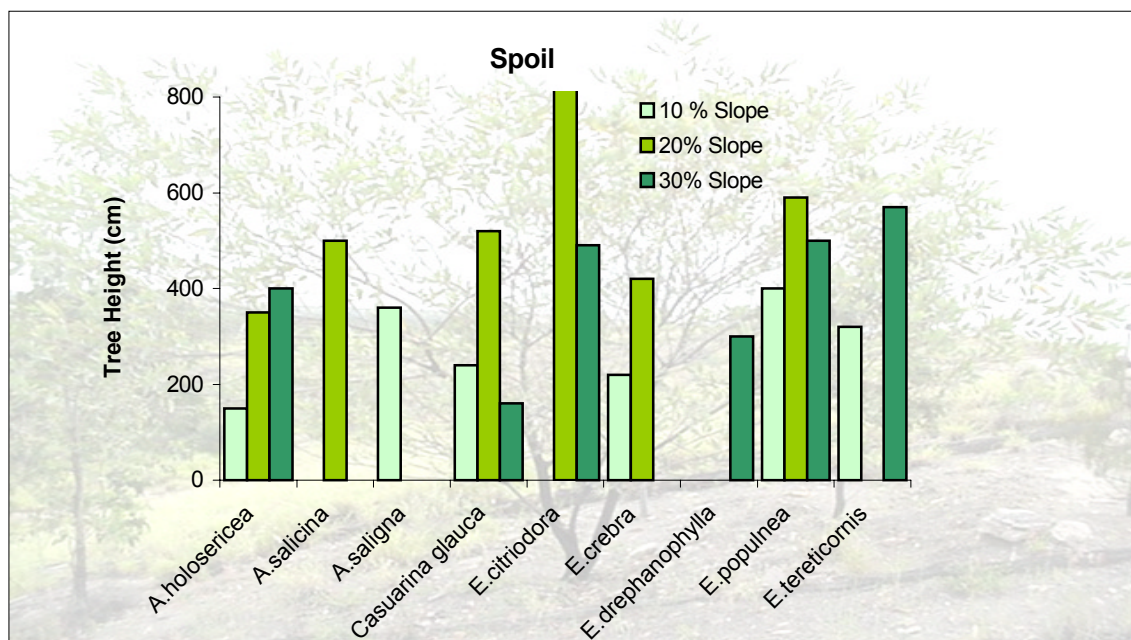


Figure 14: Surviving tree species height data from 10, 20 and 30% spoil gradient plots.

Trees provided little to no surface cover on spoil plots, consequently erosion rates from the spoil tree plots tended to be higher than the pasture plots. For example, in the final year of the study there was 29 t/ha sediment loss from the tree plot on the 20% slope, compared to 12 t/ha from the pasture plot.

Runoff water quality from the topsoil tree plots showed a similar trend as on the soil pasture plots, with a continual reduction in soluble salts throughout the study (Figure 15). Water quality from the spoil tree plots followed a similar trend. Although soluble salt levels in runoff from all slopes decreased throughout the study (Figure 16), average EC levels were higher due to the *in situ* salt levels within the spoil profile and low levels of vegetative cover. Runoff EC from the 10% spoil tree plot was higher due to the salt encrustation and higher erodibility than the 20% and 30% slopes.

Runoff EC from the bare soil and spoil plots, also decreased suggesting that salts are being leached down the profile and salt transport is becoming supply limited.

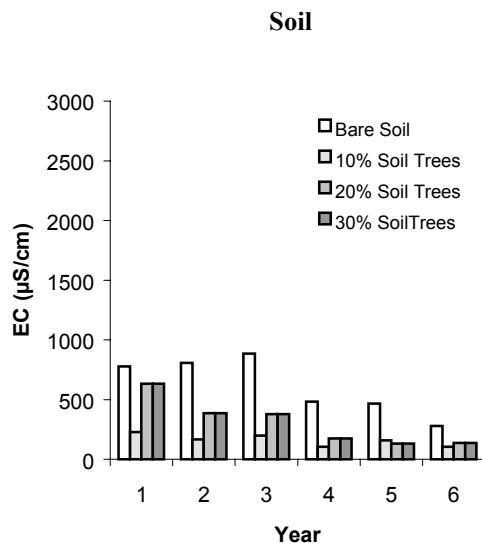


Figure 15: Runoff EC from tree topsoil plots.

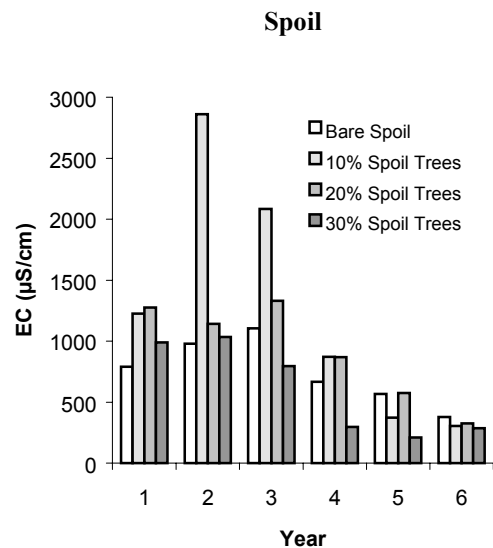


Figure 16: Runoff EC from tree spoil plots.

Impact of slope on erosion and runoff

At Oaky Creek there was not a clear impact of slope on runoff and erosion, due to differences in surface roughness and rate of establishment of pasture and trees. Ripping of plots to create a rough surface was shown to reduce runoff and erosion during the early stages of rehabilitation when vegetative growth was slow and risk of erosion was high. The effectiveness of ripping and the degree of surface roughness tended to be greater on steeper gradients (Figure 17), and lasted until rills formed. Surface roughness on Oaky Creek spoil plots had a pronounced impact on runoff in the first 2 years of the study, and was greatest on the 30% slope resulting in less runoff than the 20% and 10% slopes (Figure 12).

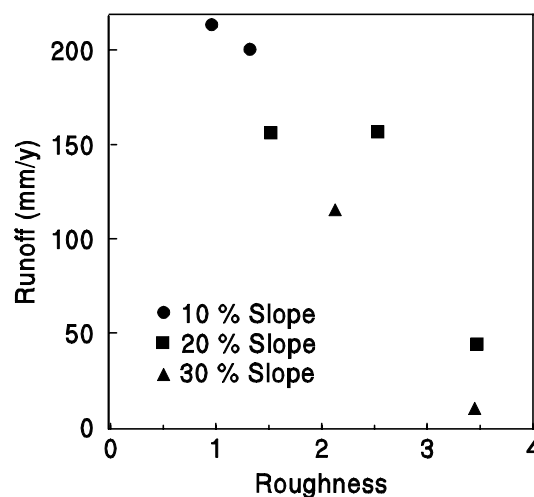


Figure 17: Effect of surface roughness and slope on total runoff, from spoil plots (Year 4).

The establishment of Buffel and Rhodes grass varied across the soil plots. Initially, Buffel grass established best on the 20% soil plot, and this, along with greater surface roughness, meant the 20% slopes had consistently lower runoff and sediment loss than the 10% slope. However, the difference in erosion rates between slopes declined (Figure 12) as Buffel and Rhodes grass colonised the soil plots. By Year 6, soil loss from the pasture plots was 0.6, 0.9 and 4.2 t/ha from the 10%, 20% and 30% slopes respectively. In comparison, the bare soil plot had 76 t/ha soil loss in Year 6.

Impact of vegetative cover on angle of repose catchments

Sediment movement from the catchments followed a similar trend as the pasture and tree plots, where the increase in vegetative cover resulted in the reduction of sediment concentration. Pasture establishment was most successful on the eastern aspects of the slopes, and more sparse on the western aspects (Figures 19 to 22). Although a dramatic reduction in sediment concentration occurred during the study (Figure 18), pasture establishment never exceeded 42% surface cover. Consequently, annual runoff and sediment loss totals remained variable depending on rainfall amount and intensity.

Sediment loss and concentrations from Catchment A were lower than Catchment B from the start of the study, with annual erosion rates <5 t/ha. By the final year of the study, sediment concentrations had reduced to 2.9 kg/m^3 (Figure 18). Catchment B sediment loads and concentrations were consistently higher than Catchment A due to a steeper slope leading into the flume. However, there was a 14-fold reduction in sediment concentration between the Years 1 and 7, with 219 kg/m^3 and 16 kg/m^3 in the respective years.

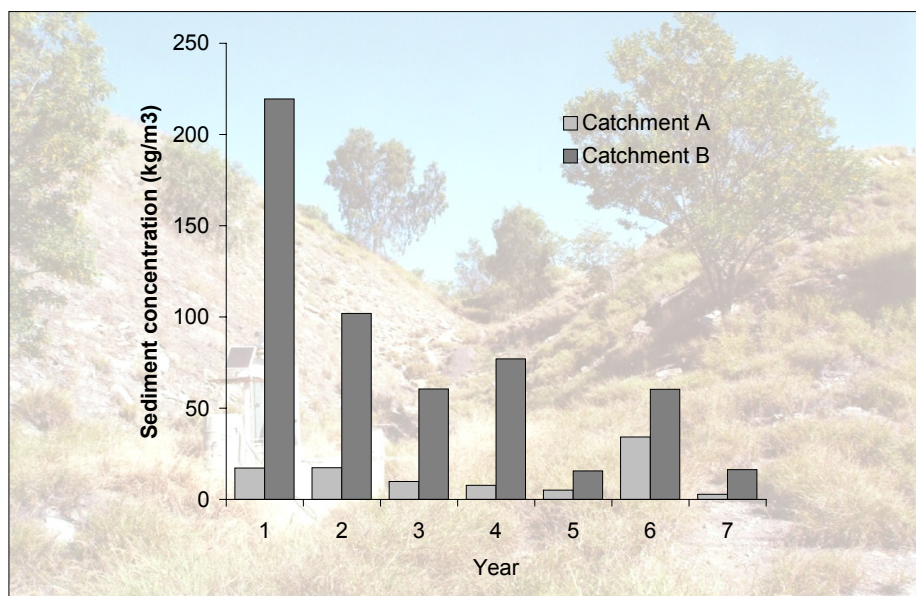


Figure 18: Sediment concentrations from Catchments A and B



Figure 19: Catchment A 1994



Figure 20: Catchment A 2000



Figure 21: Catchment B 1994



Figure 22: Catchment B 2000

Greater sediment concentrations led to greater runoff EC levels from Catchment B. By Year 6, average runoff EC had been reduced to 265 $\mu\text{S}/\text{cm}$ and 471 $\mu\text{S}/\text{cm}$ from Catchment A and B respectively (Figure 23). The reductions of sediment movement on Catchment A, also decreased runoff EC to levels comparable with local creeks (approx. 300 $\mu\text{S}/\text{cm}$).

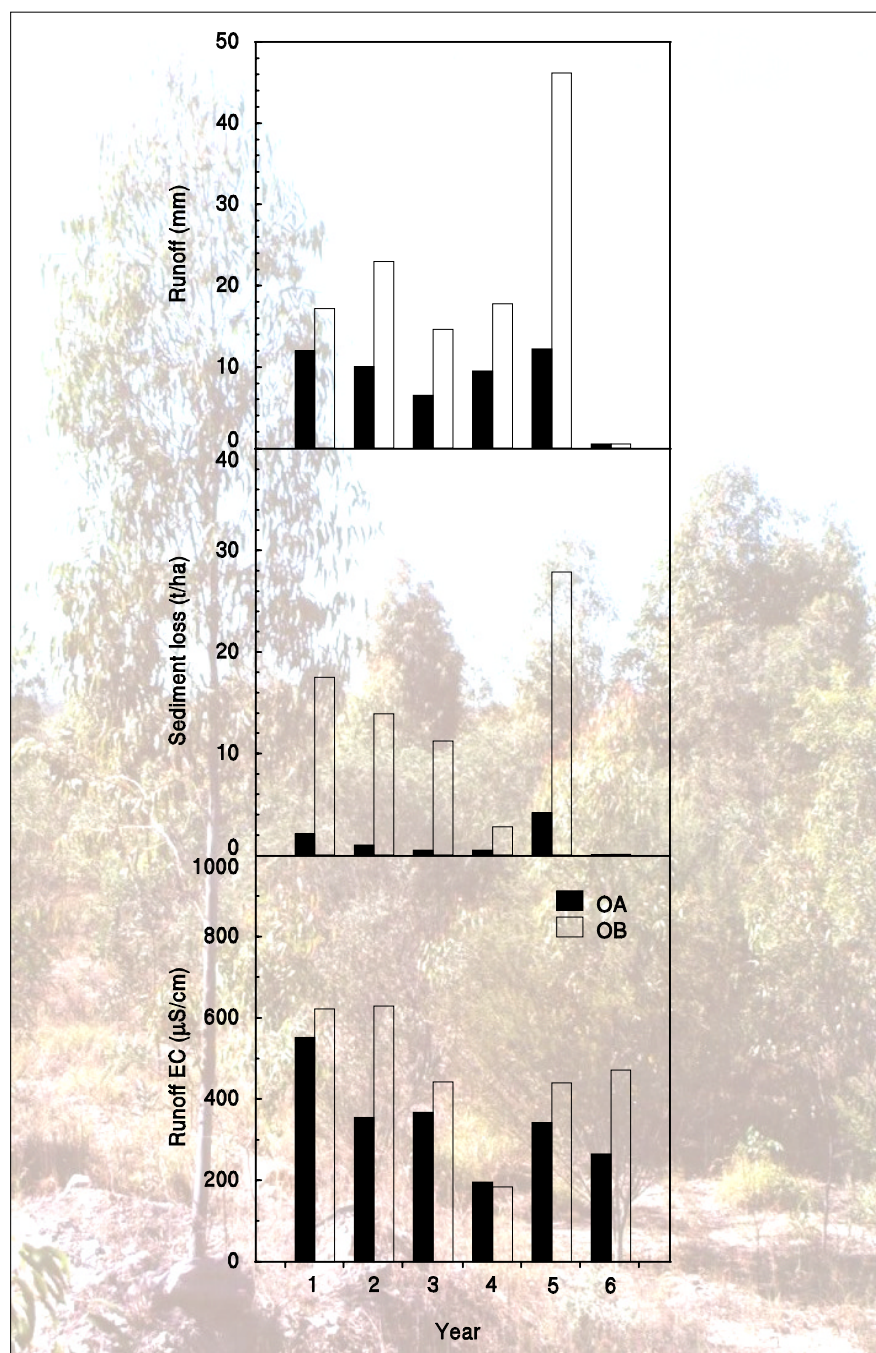


Figure 23: Annual runoff, sediment loss and average runoff EC from Catchments A and B.

Conclusion

The greatest window-of-erosion risk was before vegetation established, when a large proportion of soil and spoil surface area was exposed to the erosive forces of rain and runoff. During this period rills formed and persisted until a dense sward of grass cover colonised and stabilised rills. Pasture established best on topsoil with trees establishing best on spoil.

Vegetative growth also reduced soluble salt concentrations at the surface of spoil material, and reduced the risk of salt movement on-site and off-site.

A comparison of sediment loss from the different slope gradients was difficult at Oaky Creek, due to the differences in surface roughness (caused from different depth of ripping), differences in pasture and tree growth rate, and salt encrustation that occurred on the 10% slope.

However, the study did show that difference in soil erosion rates between slope gradients declined as pasture cover increased. 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.

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 successful and quickly vegetation establishes. At Oaky Creek where soils sealed and spoil developed a salt crust there was poor seedling establishment and vegetative growth, causing unacceptable large runoff, erosion rates, and runoff EC.

Conclusion Summary

- Rainfall is the major limiting factor associated with successful rehabilitation. It is critical that pasture cover is established rapidly in order to maximise rainfall infiltration.
- Topsoil and surface vegetative cover is the key to reducing erosion from slopes and minimising the off-site impacts of water quality.
- A rehabilitated landscape is at greatest risk of erosion before grass cover is established. The window-of-erosion risk occurs before vegetative growth reaches 50% ground cover.
- Pasture establishment to 50% cover should be a minimum target indicator for coal mine rehabilitation. Further increases in pasture cover (>80%) and biomass will continue to improve rehabilitated land stability and land use sustainability.
- When a surface seal and salt crust developed on soil and spoil material, infiltration was reduced and runoff, sediment movement and runoff EC increased.
- Vegetative cover reduced runoff EC and salt movement from the plot and catchment studies.
- Soil erosion rates declined between slopes once a dense sward of grass cover established (>50% cover).

List of References

Carroll C, Halpin M, Burger P, Bell K, Sallaway MM, Yule DF (1997) The effect of crop type, crop rotation, and tillage practice on runoff and soil loss on a Vertisol in central Queensland. *Australian Journal of Soil Research* **35**, 925 -939.

Loch RJ, Orange DN (1997) Changes in some properties of topsoil at Tarong Coal - Meandu Mine coalmine with time since rehabilitation. *Australian Journal of Soil Research* **35**, 777 - 784.

Oaky Creek Coal Mine Photo Plates

Pasture Growth On 10% Topsoil Gradient



Photo 1: Year 1993. 49% Vegetative Cover



Photo 2: Year 1999. 94% Vegetative Cover

Tree Growth On 10% Spoil Gradient



Photo 3: Year 1993. 0% Vegetative Cover



Photo 4: Year 2000. 7% Vegetative Cover.

Pasture Growth On 30% Topsoil Gradient



Photo 5: Year 1994. 12% Vegetative Cover



Photo 6: Year 1999. 92% Vegetative Cover

Pasture Growth On 30% Spoil Gradient



Photo 9: Year 1994. 8% Vegetative Cover



Photo 10: Year 1999. 47% Vegetative Cover

Tree Growth On 30% Spoil Gradient



Photo 7: Year 1994. 1% Vegetative Cover

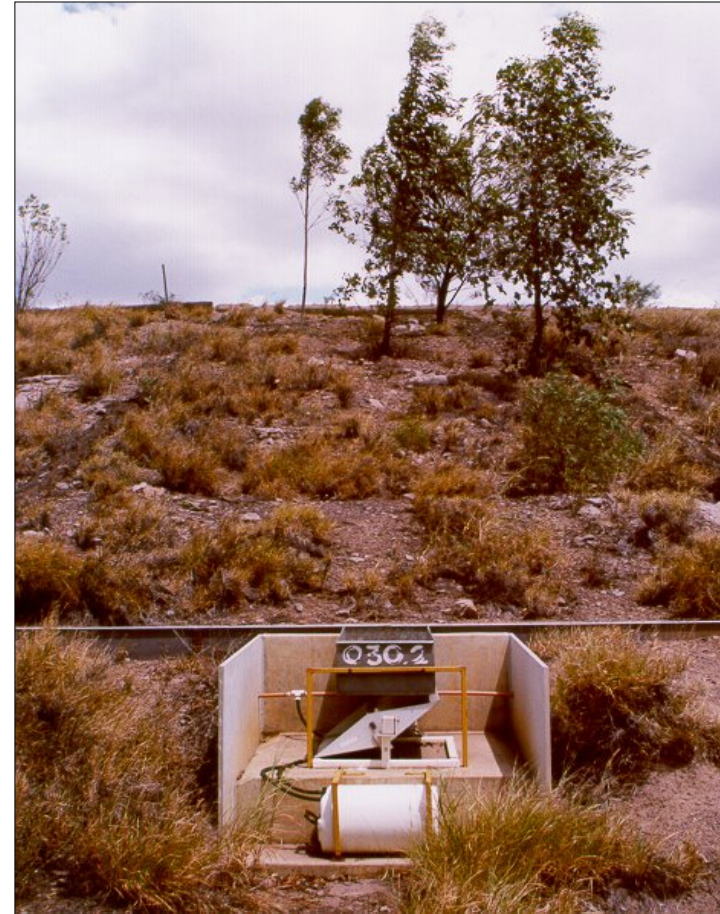


Photo 8: Year 1999. 34% Vegetative Cover

Pasture Growth On 30% Spoil Gradient



Photo 9: Year 1994. 8% Vegetative Cover



Photo 10: Year 1999. 47% Vegetative Cover

20% Gradient Plot Layout



Photo 11: 20% Gradient Plot Layout 1993



Photo 12: 20% Gradient Plot Layout 1999

Catchment A



Photo 13: Year 1995.



Photo 14: Year 2000

Catchment B



Photo 15: Year 1995



Photo 16: Year 2000

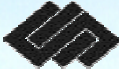
Landcare field day at Oaky Creek, 1993



Landcare field day at Oaky Creek, 1999



Sustainability Indicators for Coal Mine Rehabilitation

 **BHP**
Goonyella-Riverside



Queensland Department of Natural Resources

C. Carroll, A. Tucker, L. Merton, P. Burger, L. Pink

ACARP

Australian Coal Association Research Program



Queensland Government
Natural Resources and Mines

Sustainability Indicators of Coal Mine Rehabilitation

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Executive Summary

This field study assessed runoff, erosion and water quality from rehabilitated land on two scales: gradient plot (0.01 ha) and contoured catchment (0.4 to 1.0 ha).

The plot study measured runoff and sediment loss from three slope gradients (10, 20 and 30%), where pasture and tree vegetation treatments were imposed on topsoil and spoil materials. A topsoil and a spoil plot on the 20% slope, were left bare for comparison with the vegetative treatments. A total of 14 plots were monitored from 1993 to 1997. Three contoured catchments were monitored from 1994 to 2000.

The study highlighted that the spoil used for this field study is unsuitable for rehabilitation. Infiltration into the spoil was via pipes and cracks, leading to tunnel erosion and slope instability. Due to instability on the plots, no direct comparisons between slope gradients were able to be conducted at the site. However, the importance of topsoil and vegetative cover were highlighted by data collected from the 20% slope.

The use of topsoil and pasture cover produced the least runoff, sediment and soluble salt transport, with 50mm, <8 t/ha and 51µS/cm respectively from the 20% slope in the final year of the study. In contrast, on the same slope sediment movement was 6 times larger (48 t/ha) on the spoil pasture plot despite similar runoff. Accumulation of soluble salts caused a 3-fold increase in erodibility on the spoil material during the study and a corresponding increase in runoff EC.

Sediment movement from the rehabilitated catchments was consistently lower than the gradient plots, with <1 t/ha from all catchments in Year 6, with an 80% reduction in sediment concentration from the start of the study. Runoff EC averaged <200 µS/cm throughout the catchment study, highlighting the importance of topsoil and pasture cover on water quality from rehabilitated catchments.



Introduction

There is little information in Australia on erosion rates from open-cut coal mine 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 1992 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:

1. monitor the long-term impact of open-cut coalmine rehabilitation on erosion and water quality under natural rainfall conditions.
2. evaluate physical and biophysical indicators for sustainable rehabilitation.
3. use the monitoring sites as an educational resource and promote outcomes from the study to the industry and the wider community.

This report describes objectives 1 and 2, and identifies topsoil and surface vegetative cover as important indicators of sustainable mine rehabilitation. The educational requirements of objective 3 were addressed through Landcare and Central Queensland Mine Rehabilitation Group (CQMRG) field days, in which mine environmental staff, government agencies, landholders and consultants were shown results from the study. Photos from these field days are supplied in this report and in the project CD.

The study was jointly funded by the Australian Coal Association Research Program (ACARP) and 6 major local mining companies; BHP Coal Pty Ltd, MIM Holdings Ltd, Pacific Coal, Callide Coalfields, Capricorn Coal and Curragh Queensland Mining.

Materials and Methods

Experimental gradient plot and catchment field sites were located at the Goonyella Riverside Coal Mine (21.51°S, 148.58°E) in Central Queensland.

Gradient Plot Field Study

Three slope gradients (approximately 10, 20, and 30%) were formed using a D9 size dozer (Figure 1). Topsoil was laid over the spoil to a depth of 20-30 cm and ripped at 1m intervals across each slope. 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.

The field study terminated in Year 4 when increased slumping and cracking caused severe subsidence on the plots.

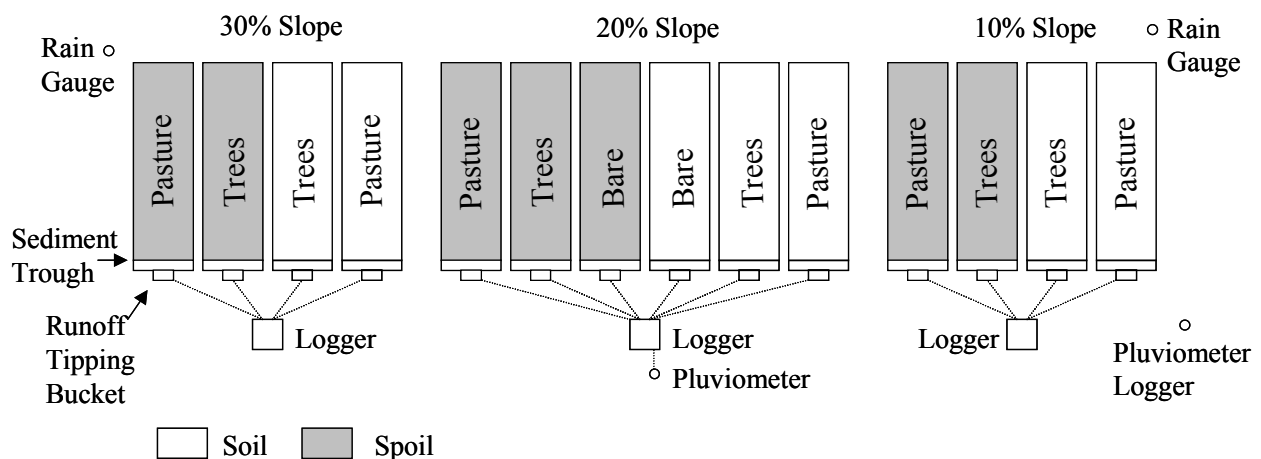


Figure 1. Experimental Plot Layout.

Irrigation

In 1994 (Year 2) a trickle irrigation system was installed (1 m spacings) on the 3 slope gradients to aid tree and pasture establishment due to low rainfall in the early part of the study. Five irrigations were conducted from 1994 to 1995, which aided tree and pasture establishment on the soil and spoil material.

Catchment Field Study

The catchments were located at the airport dam, and were monitored between 1994 and 2000. A 20 to 30 cm depth of topsoil was laid over the spoil material, ripped at 1 m intervals on the contour, and sown to buffel grass.

Runoff, sediment loss and water quality were measured from three rehabilitated contoured catchments (A, B, C) with slopes between 5-10%.

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 2). 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 m³ 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 (Figure 2). These samples were analysed for suspended sediment concentrations, electrical conductivity and pH of the runoff. A Pluviometer and rain gauge were installed at all three catchments.

In Year 6, a fire trial was conducted on Catchments B and C to assess the impacts on erosion and water quality. Catchment A was left as an unburnt control.

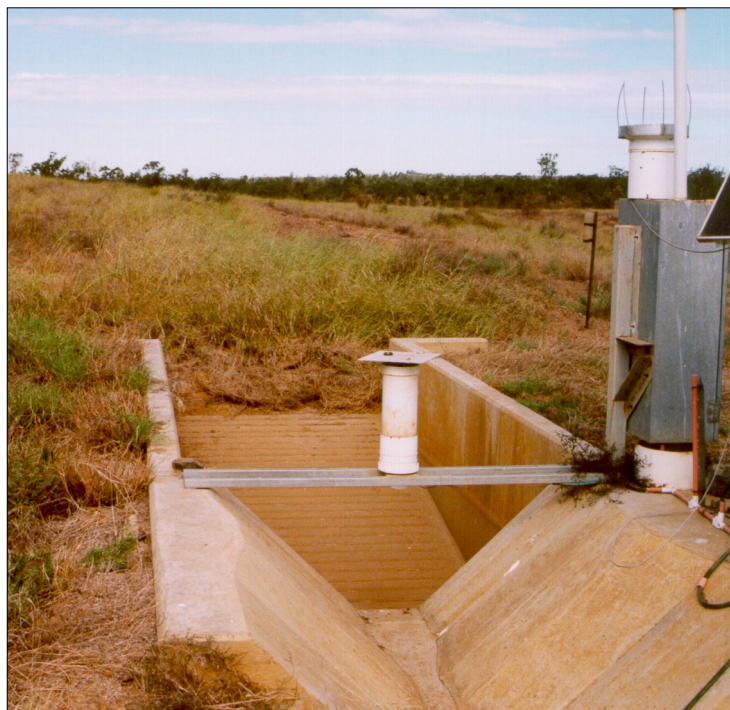


Figure 2. Catchment flume and sampling equipment.

Results and Discussion

Rainfall

In the first 3 years of the study, Goonyella Riverside experienced lower monthly and annual rainfall than the long-term median (Table 1). Most of the rainfall during the study was from rainstorms, with several monthly rainfalls larger than the median (Figure 3).

Table 1. Annual rainfall (mm) and year number for Goonyella Riverside sites, and long-term median rainfall.

Year	Year No	Annual Rainfall
1993/94	1	387
1994/95	2	332
1995/96	3	442
1996/97	4*	691
1997/98	5	404
1998/99	6	829
1999/00	7	473
Annual median (1993 – 2000)		472
Long-term median		613

* Plot study terminated.

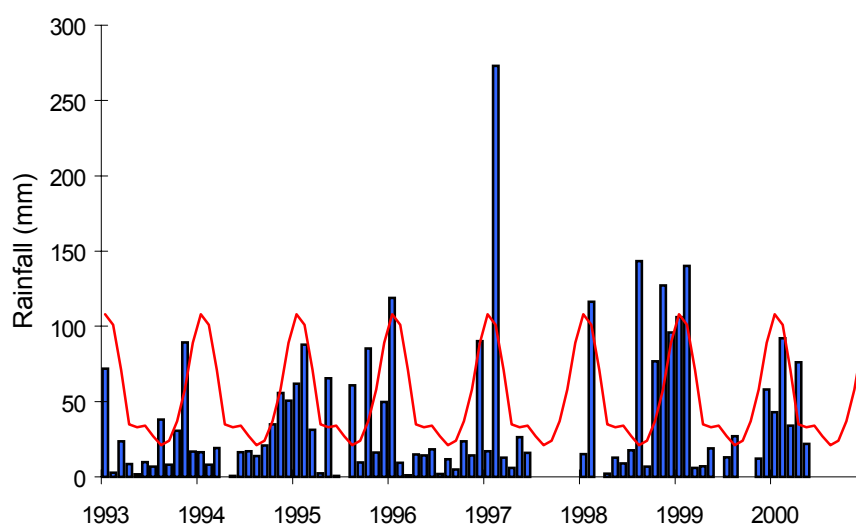


Figure 3. Monthly and median rainfall for Goonyella Riverside from 1993 to 2000.

Gradient Plot Study

Impact of soil and spoil on runoff and sediment loss

Bare plots on the 20% slopes were used to compare the inherent differences in hydrology and erodibility of the soil and spoil material.

Both soil and spoil at Goonyella Riverside were hardsetting (Figure 4). However, low runoff was generated on the spoil during the first two years of the study, giving a low runoff coefficient (Figure 5). Water entry was via small pipes that formed on the dispersive spoil (Figure 6), and once spoil water content increased, the runoff coefficient increased to 0.18. Topsoil had an overall runoff coefficient of 0.53, and reduced when cracks occurred on the plot.

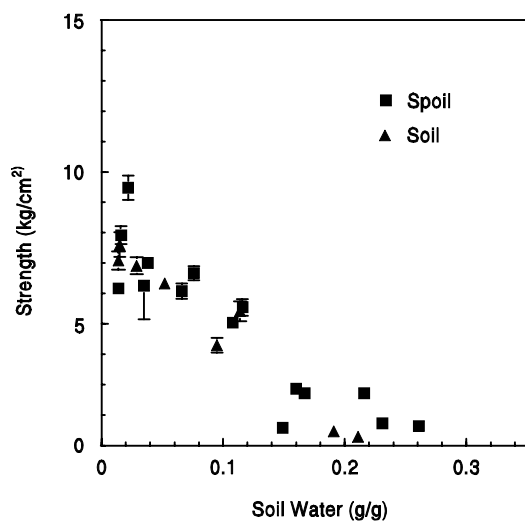


Figure 4. Surface strengths for soil and spoil.

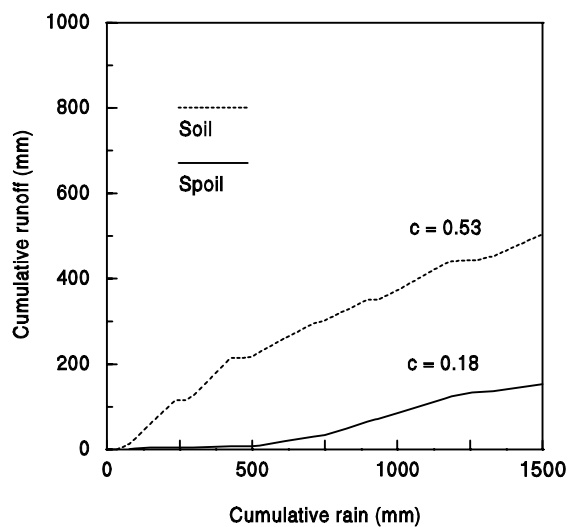


Figure 5. Cumulative rainfall, runoff and runoff coefficient (C) for soil and spoil.

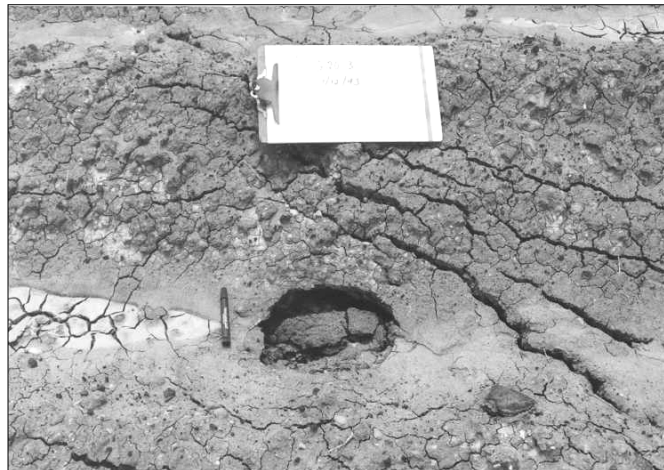


Figure 6. Piping that occurred on Goonyella Riverside spoil material.

The spoil material had a 3-fold increase in erodibility between Years 1 and 4, with 48 kg/m^3 sediment concentration in Year 1, compared with 128 kg/m^3 in Year 4. Along with an increase in runoff, there was a 66-fold increase in total sediment loss from the bare spoil material at Goonyella Riverside site (Table 2)(Figure 7). An increase in spoil erodibility corresponded with an increase in electrical conductivity causing the dispersive clay material to flocculate and become more erodible.

In contrast, runoff halved on the bare soil despite double the annual rainfall, this reduction in runoff was a result of cracking on the plot (Table 3).

Table 2. Comparison of total runoff, sediment concentration, sediment loss and average annual sediment loss from bare spoil 20% slope (Years 1 & 4).

Year	Total runoff (mm)	Sediment Conc. (kg/m^3)	Total sed loss (t/ha)
Year 1	7	48	3.4
Year 4	162	128	208

Table 3. Comparison of total runoff, sediment concentration, sediment loss and average annual sediment loss from bare soil 20% slope (Years 1 & 4).

Year	Total runoff (mm)	Sediment Conc. (kg/m ³)	Total sed loss (t/ha)
Year 1	180	47	85
Year 4	92	91	84

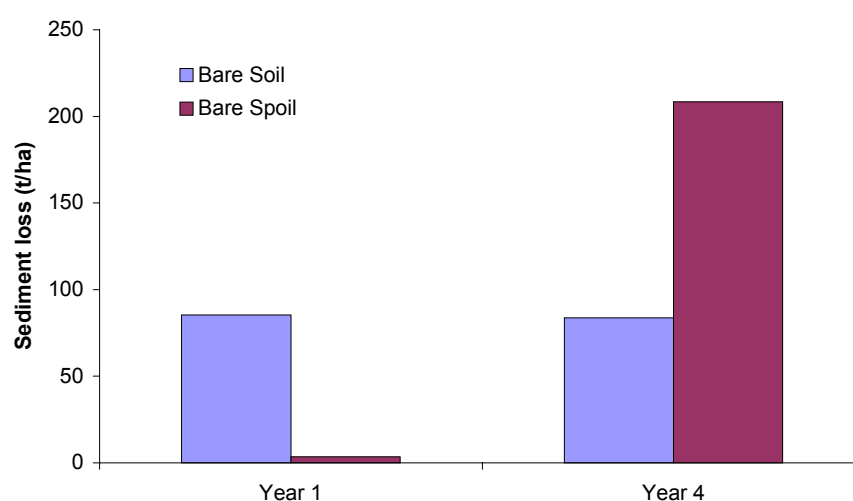


Figure 7. Sediment loss from bare soil and spoil, Years 1 and 4.

Impact of topsoil and pasture cover on erosion and water quality

Topsoil is essential in the successful establishment of pasture on rehabilitation at Goonyella Riverside.

Low and sporadic rainfall in the first two years of the study resulted in poor establishment of vegetation at the mine site. Supplementary irrigation was used in Year 2 to establish trees and pasture across the three slopes. Following irrigation, buffel grass (*Cenchrus ciliaris*) colonised soil plots, whereas the more salt tolerant rhodes grass (*Chloris gayana*) only sparsely established on the spoil material.

Soil erosion rates rapidly declined once buffel and rhodes grass covered more than half the plot (0.5 soil exposure) and ameliorated the hardsetting nature of Goonyella Riverside soil (Figure 8). The establishment of vegetative cover and detached litter on the pasture plots reduced total runoff, sediment detachment and transport, and total soil loss throughout the study (Figure 10).

The effects of vegetative cover on erosion dominated across all three mines sites, despite differences in soil and spoil properties. Where pasture cover was absent, soil loss remained consistently high throughout the study, with an overall cumulative soil loss of 296 t/ha from the bare soil plot (Figure 8). For example, in Year 4, there was 8 t/ha soil loss from the pasture plot on the 20% slope where there was a dense sward of buffel grass, compared with 84 t/ha soil loss from the bare soil plot (Figure 11).

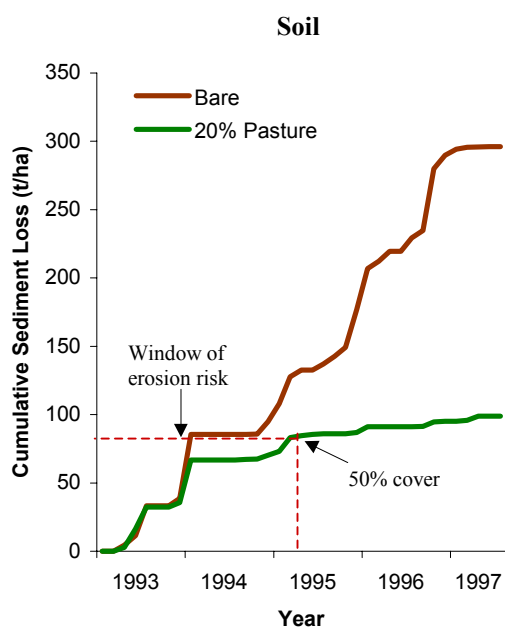


Figure 8. Cumulative sediment loss from the bare and 20% soil pasture plots.

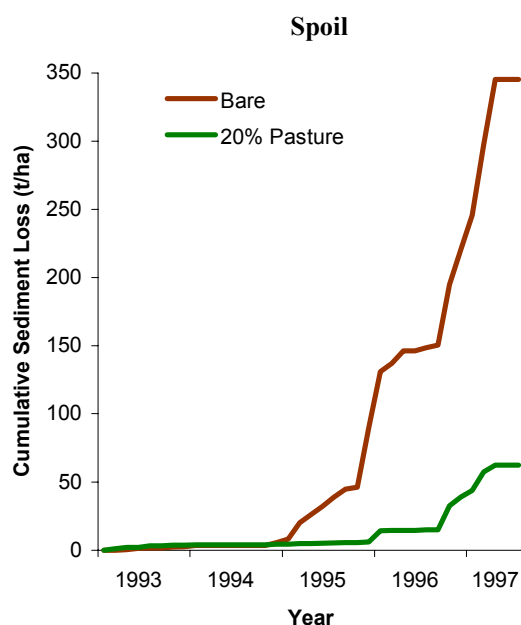


Figure 9. Cumulative sediment loss from the bare and 20% spoil pasture plots.

As previously mentioned, sediment loss was initially low from the bare spoil, and then increased rapidly producing 208 t/ha in final year of the study (Figure 13). Pasture cover fluctuated on the 20% slope when rhodes grass died back during dry conditions. Nevertheless, there was a 4-fold reduction in sediment loss (47 t/ha) from the 20% spoil pasture plot in the final year of the study, despite just 23% pasture cover (Figures 9 and 12).



Figure 10. Soil pasture plot, 20% slope.



Figure 11. Soil bare plot, 20% slope



Figure 12. Spoil pasture plot, 20% slope.



Figure 13. Spoil bare plot, 20% slope

Topsoil and pasture produced lower runoff EC (<300 $\mu\text{S}/\text{cm}$) than spoil from all slope gradients during the study (Figure 14), highlighting once again the importance of topsoil in reducing the impact of mine rehabilitation on off-site water quality.

In contrast, runoff EC from spoil material was consistently higher than background stream EC's, and peaked in Year 3. Runoff EC declined in Year 4 as rhodes grass colonised the spoil plots, particularly on the 10% slope (Figure 15). Analysis of surface *in situ* spoil samples show that electrical conductivity increased during the study. The large fluctuations in runoff EC from spoil material suggests that the increase in soluble salts at the surface caused the dispersive clay spoil to flocculate and produce a salt-enriched erodible layer. A cycle of stripping, replenishment and stripping of this salt-enriched layer is an explanation for the fluctuations in runoff EC from the spoil plots during the study.

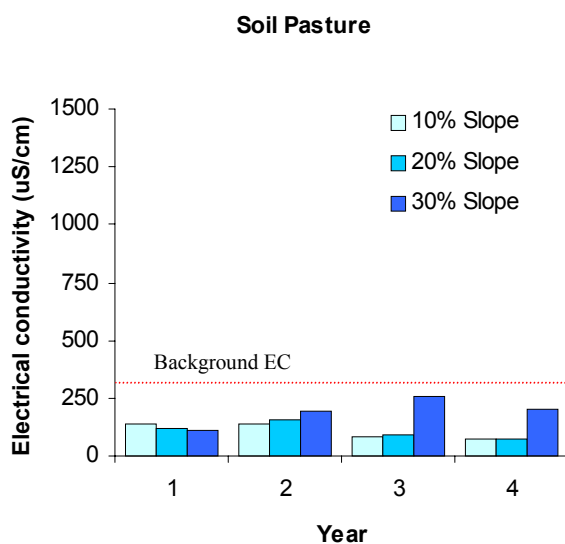


Figure 14. Runoff EC from soil pasture plots

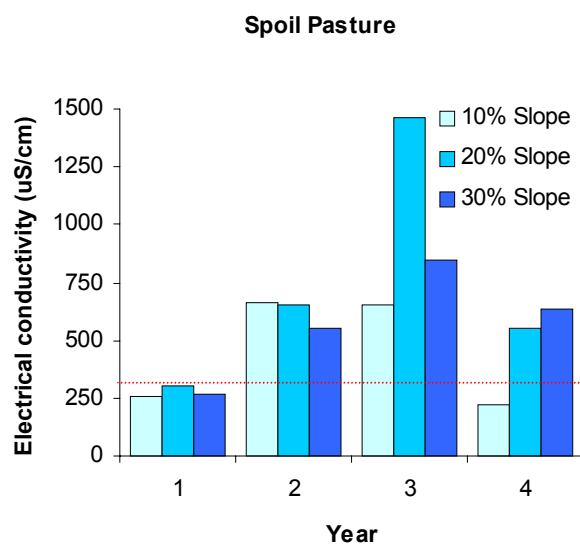


Figure 15. Runoff EC from spoil pasture plots

Impact of tree cover on erosion and water quality

Tree establishment was poor on the soil plots, due initially to low seasonal rainfall and the low infiltration rates caused by the hard setting nature of the material. Supplementary irrigation in Year 2

enabled trees to be established, however, just 6 trees survived once irrigations ceased on the topsoil plots (Figure 16).

In contrast, tree growth and survival was more successful on the spoil plots, and was most likely due to greater water availability at depth. Although, no water contents were measured, there was >250 mm more infiltration in the spoil than the topsoil plots in the first 2 years of the study, due to the small pipes that formed on the plots (refer to Figure 6). Poplar Box (*Eucalyptus populnea*), Blue Gum (*Eucalyptus tereticornis*) and Sheoak (*Casuarina glauca*) were the most successful tree species to establish on the spoil material (Figure 17).

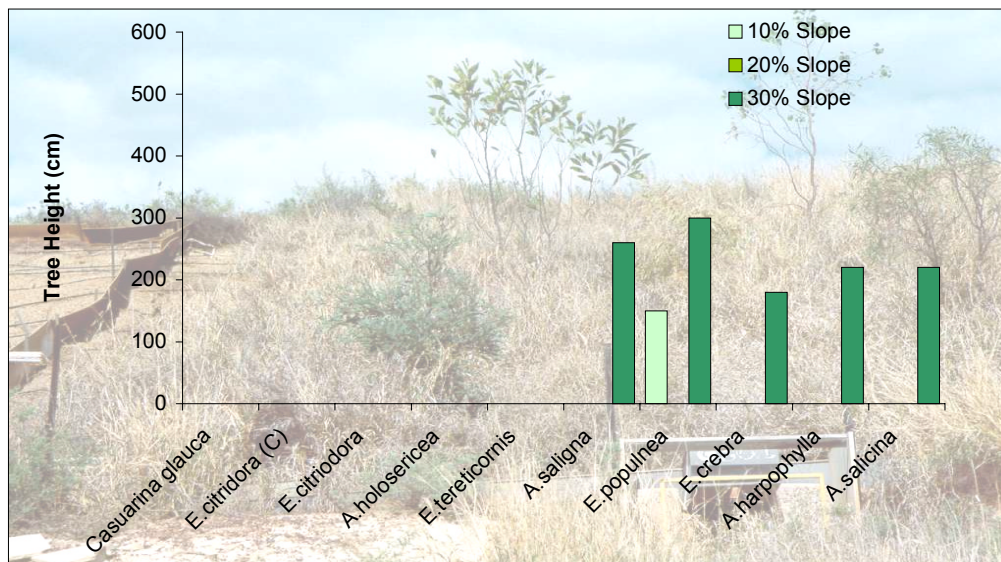


Figure 16. Surviving tree species height data from 10, 20 and 30% topsoil gradients.

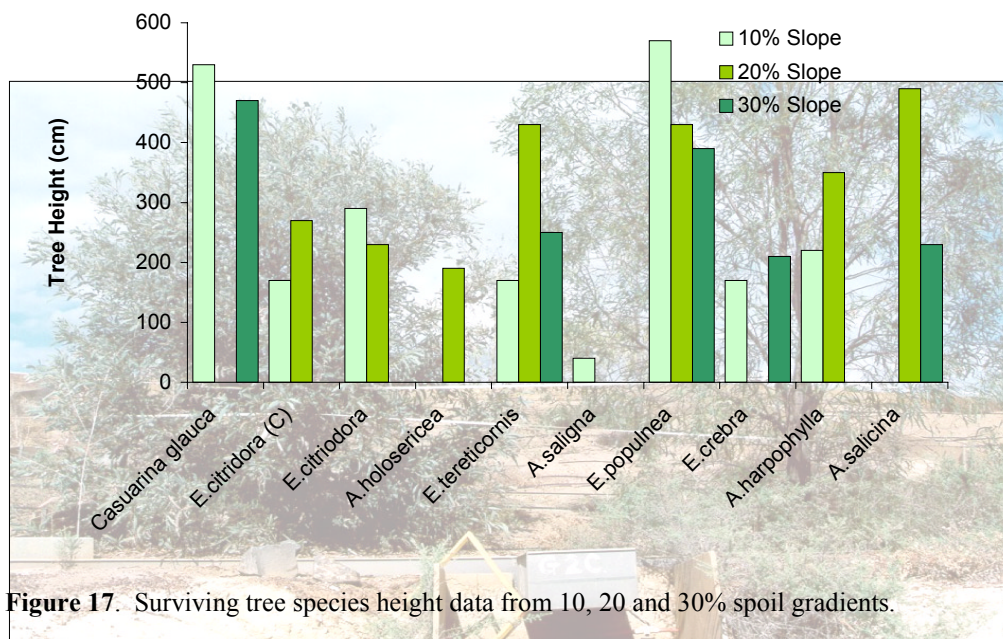


Figure 17. Surviving tree species height data from 10, 20 and 30% spoil gradients.

Trees provided little or no surface cover on the spoil material, consequently erosion from the spoil tree plots tended to be higher than the spoil pasture plots. However, trees had lower sediment loss than the bare spoil plot, with 45% less sediment movement in Year 4 of the study (Figure 18).

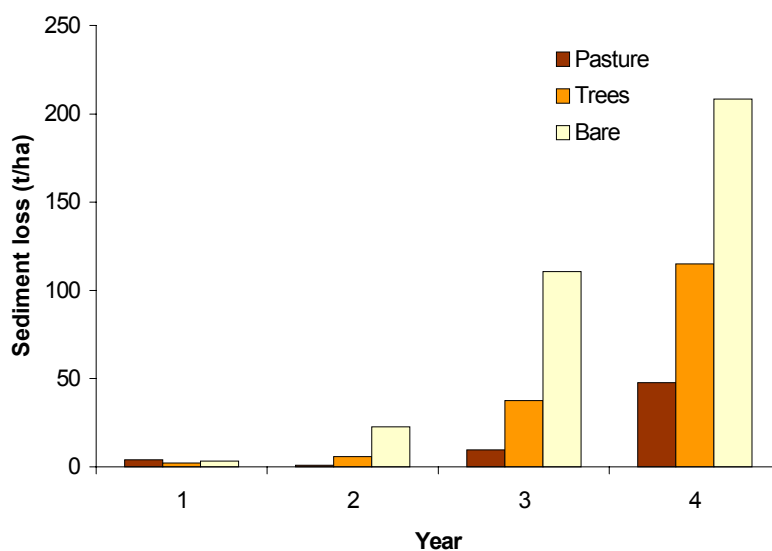


Figure 18. Annual sediment loss from pasture, tree and bare plots on 20% spoil slope.

Runoff water quality from the topsoil tree plots showed a similar trend to the topsoil pasture plots, with consistently low soluble salt levels than spoil throughout the study (Figure 19 & 20). Water quality from the spoil tree plots was more variable with higher average runoff EC levels.

An overall decline in runoff EC from all spoil plots in Year 4 including the bare plots suggests that salt transport was supply limited in the final year of the study.

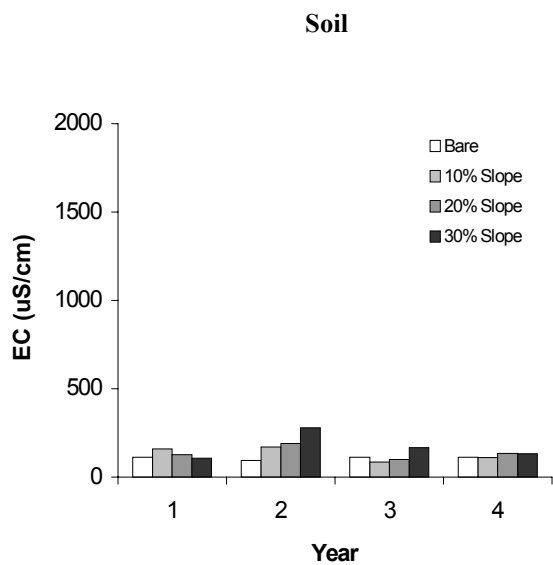


Figure 19. Runoff EC from soil tree plots

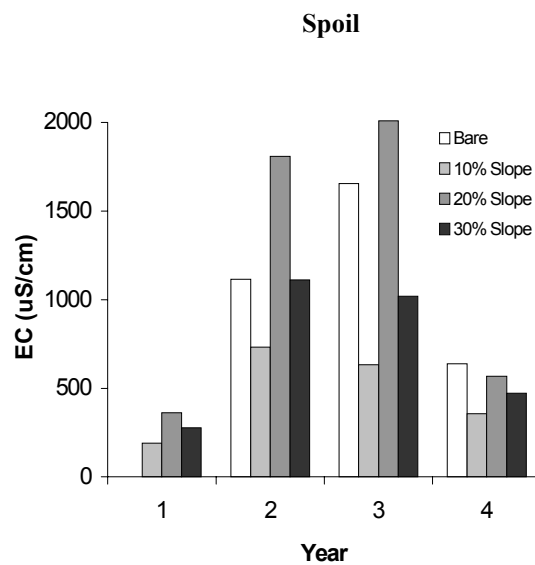


Figure 20. Runoff EC from spoil tree plots

Contoured Catchments

Impact of topsoil and vegetative cover on runoff, sediment, and water quality

The rapid establishment of buffel grass cover (>50% by Year 2), on all three catchments resulted in annual sediment losses of <5 t/ha/yr during the study (Figure 21). Annual runoff and sediment totals varied slightly depending on annual rainfall.

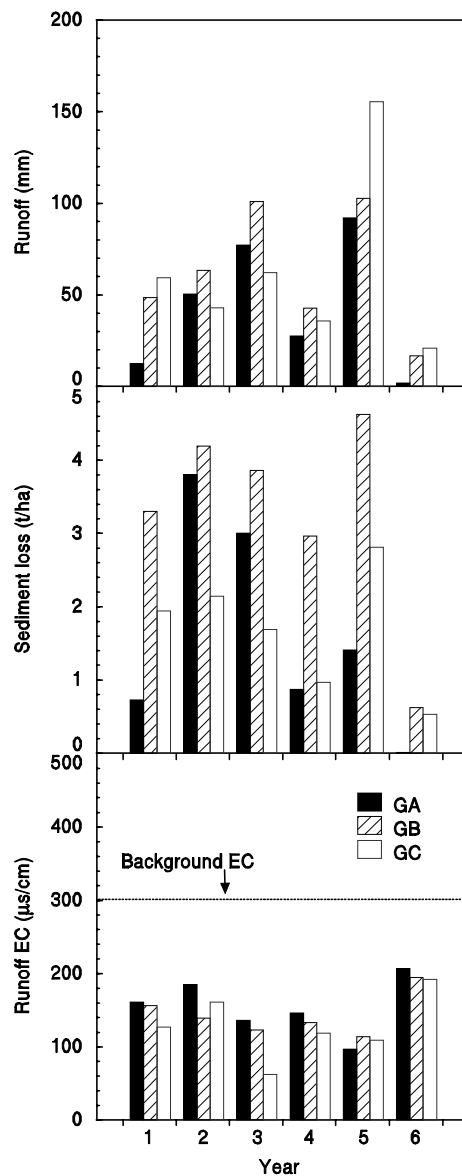


Figure 21. Annual runoff, sediment loss and average runoff EC for Goonyella Riverside Catchments A, B and C.

However, sediment concentration continued to decline as pasture dry matter and cover increased during the study (Figure 22). By Year 6, projected cover was 82, 83 and 100%, and standing pasture yields reached 7.2, 3.6 and 11.8 t/ha on Catchments A, B and C respectively (Figures 23 and 24).

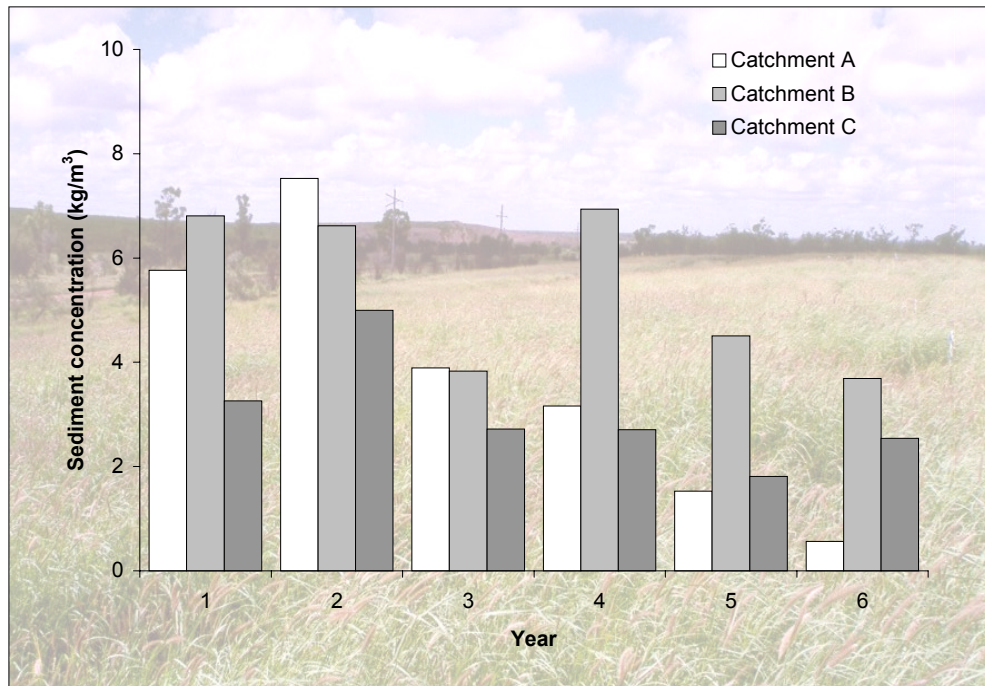


Figure 22. Sediment concentrations within runoff from Catchments A, B and C.



Figure 23. Goonyella Riverside Catchment A, 1994.



Figure 24. Goonyella Riverside Catchment A, 2000.

Although, total sediment loss was low from the catchments (<1 t/ha in Year 6) (Figure 22), the proportion of suspended sediment has remained high throughout the study, at approximately 90% of the total sediment loss (Figure 25). It was observed that pasture cover did not establish evenly over the catchments, and it is speculated that bare areas in the catchments are the sources of the suspended sediment, particularly areas where spoil material had become progressively exposed. The higher runoff EC's from the catchments compared with the topsoil plots would support this observation (Figure 26).

Once again it highlights the importance of achieving an even vegetative cover on rehabilitated catchments so that any potential off-site impacts are minimised.

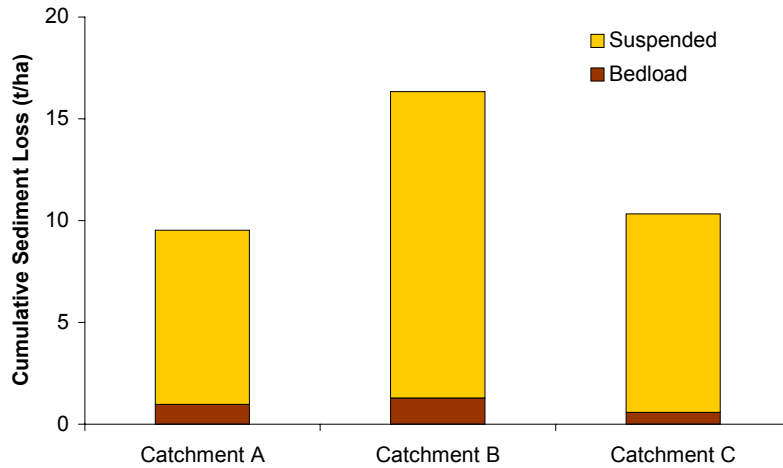


Figure 25. Suspended and bedload proportions within cumulative sediment loss from Catchments A, B and C. Years 1 to 6.

Although slightly higher than the topsoil plots, runoff water quality (EC) from the catchments have been low since the start of the study. The low *in situ* soluble salt levels in the topsoil and increasing pasture covers and yields, have maintained average runoff EC levels below 200 $\mu\text{S}/\text{cm}$ throughout the study (Figure 26).

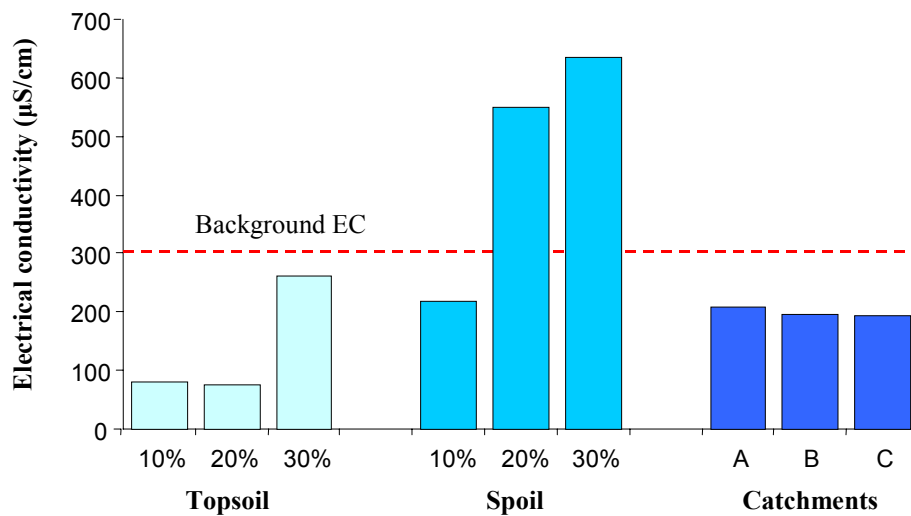


Figure 26. Runoff EC from soil and spoil plots, and catchments in the final year of the study.

Impact of fire on erosion and water quality at a rehabilitated catchment scale

To investigate the impact of fire as a catchment management tool, Catchments B and C were burnt in Year 6. Catchment A was left unburnt as a control. Prior to the burn, buffel grass was the dominant species with >80% cover and with standing pasture yields (i.e. excluding detached litter) of 7.2, 3.6 and 11.8 t/ha on Catchments A, B and C respectively.

After burning, pasture cover was <15% and dry matter yields <1 t/ha, and total runoff from Catchments B and C were greater than the unburnt control (Figure 27). Sediment concentration increased (<2 to >3 kg/m³) immediately after the burn, and began to decrease once pasture began to recolonise the burnt catchments (Figure 28). Although, runoff EC increased slightly after the burn, it was still <300 µS/cm.

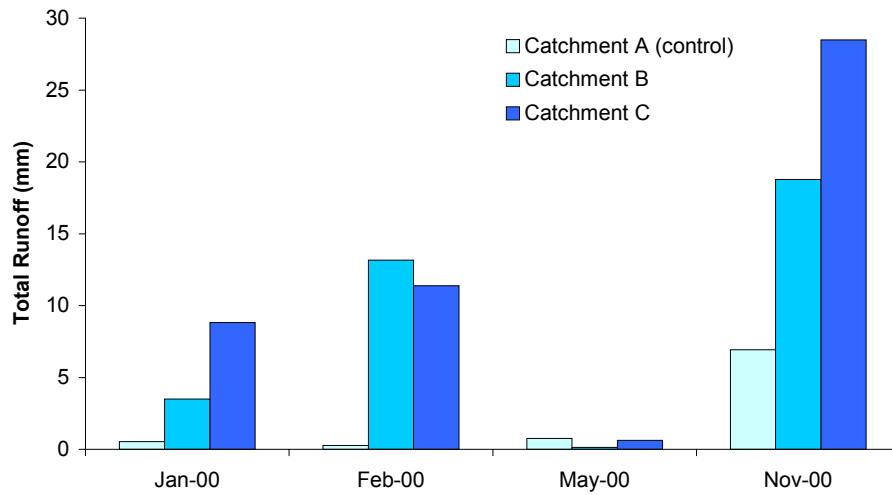


Figure 27. Runoff from Catchments A (unburnt control), B and C after the burn.

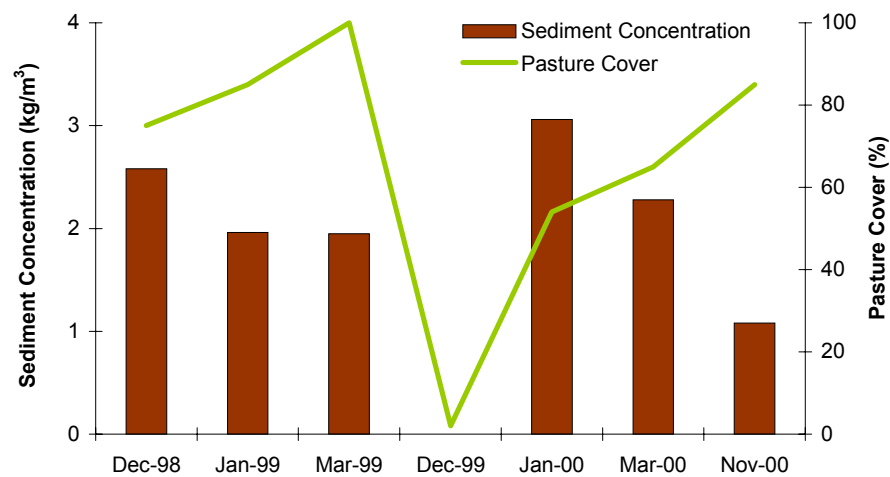


Figure 28. Changes to sediment concentration within runoff in response to pasture recovery on Catchment C.

Recovery of existing buffel tussocks was rapid following 200 mm rainfall immediately after the burn. Within 3 months of the burn, cover on Catchments B and C had reached 58 and 68% respectively. Standing dry matter also increased, with 3.5 and 4.7 t/ha on the respective catchments (Table 4). Photos of pasture recovery are shown in the Mine Photo Plates. However, in another scenario where rainfall is not received immediately after a burn, recovery of buffel will take longer, and therefore susceptibility to erosion will be longer following burning.

Table 4. Ground cover and pasture dry weights for Catchments A, B and C before and after the burn.

	Catchment A (unburnt control)		Catchment B		Catchment C	
	Cover %	Dry Weight (t/ha)	Cover %	Dry Weight (t/ha)	Cover %	Dry Weight (t/ha)
Nov 1999	83	7.2	83	3.6	100	11.8
Dec 1999 (Post Burn)	82	7.2	10	<1	13	<1
Jan 2000	83	8	38	1.1	53	1.8
March 2000	83	11.6	58	3.5	63	4.7

Conclusion

A comparison of runoff and sediment loss from the different slope gradients was difficult at Goonyella Riverside, due to slumping and cracking on the 10% and 30% gradient topsoil and spoil plots.

However, the importance of topsoil and surface vegetative cover was demonstrated once again at Goonyella Riverside. Like Curragh and Oaky Creek mine sites, 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 and persisted until a dense sward of grass cover colonised and stabilised the soil surface. Pasture established best on topsoil with trees establishing best on spoil due to preferential infiltration via small pipes.

Vegetative growth also reduced soluble salt concentrations on the surface of spoil material and reduced the risk of salt movement on-site and off-site.

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. 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. In a variable rainfall environment such as central Queensland, infiltration needs to be maximised and fully utilised, and unnecessary runoff losses minimised. Physical and chemical characteristics of topsoil and spoil material determine how much rainfall infiltrates and how successful and quickly vegetation establishes. At Goonyella Riverside where spoil was hardsetting, pasture establishment and growth was poor, resulting in unacceptable large runoff and erosion rates and high runoff EC levels.

The rapid and successful establishment of pasture cover on topsoiled catchment areas has been the greatest contributing factor to the results achieved during the field study. The rehabilitation methods used for the Goonyella Riverside catchment areas have so far reduced erosion to negligible levels and improved runoff water quality.

Preliminary results following burning showed rapid recovery of pasture species, and limited period of erosion risk. However, a more extensive data set covering a range of rainfall seasons is required to assess burning thoroughly.

Conclusion Summary

- Rainfall is the major limiting factor associated with successful rehabilitation. It is critical that pasture cover is established rapidly in order to maximise rainfall infiltration, minimise erosion and improve water quality.
- The Goonyella Riverside spoil used for this field study is unsuitable for rehabilitation. Infiltration into the spoil was via pipes and cracks, leading to tunnel erosion and slope instability.
- Topsoil and surface vegetative cover is the key to reducing erosion and minimizing the off-site impacts on water quality.
- Pasture establishment to 50% cover should be a minimum target indicator for coal mine rehabilitation. Further increases in pasture cover (>80%) and biomass will continue to improve rehabilitated land stability and land use sustainability.
- A rehabilitated landscape is at greatest risk before pasture cover is established. The window-of-erosion risk occurs before vegetative growth reaches 50% ground cover.
- Vegetative cover reduced runoff EC and salt movement from the plot and catchment studies.

List of References

Carroll C, Halpin M, Burger P, Bell K, Sallaway MM, Yule DF (1997) The effect of crop type, crop rotation, and tillage practice on runoff and soil loss on a Vertisol in central Queensland.
Australian Journal of Soil Research **35**, 925 -939.

GOONYELLA RIVERSIDE MINE PHOTO PLATES

Pasture On 10% Topsoil Gradient



Photo 1: Year 1993. 2% vegetative cover



Photo 2: Year 1997. 26% vegetative cover

Pasture On 20% Topsoil Gradient



Photo 3: Year 1993. 5% vegetative cover



Photo 4: Year 2000. 100% vegetative cover

Pasture On 30% Topsoil Gradient



Photo 5: Year 1993. 7% vegetative cover



Photo 6: Year 1997. 60% vegetative cover

Trees On 20% Spoil Gradient



Photo 7: Year 1993.



Photo 8: Year 1999.

Effects Of No Vegetative Cover On 20% Spoil Gradient



Photo 9: Year 1993. 0% vegetative cover



Photo 10: Year 2000. 0% vegetative cover

Slumping on the topsoil and spoil plots



Photo 11: Slumping on the 10% topsoil plot, 1994.



Photo 12: Slumping on the 30% spoil plot, 1994.

Catchment A



Photo 13: Year 1993. 44% vegetative cover.



Photo 14: Year 2000. 83% vegetative cover.

Catchment B



Photo 15: Year 1993. 32% vegetative cover.



Photo 16: Year 2000. 82% vegetative cover.

Catchment B



Photo 17: December 1999, 1 week after burn. 10% vegetative cover.

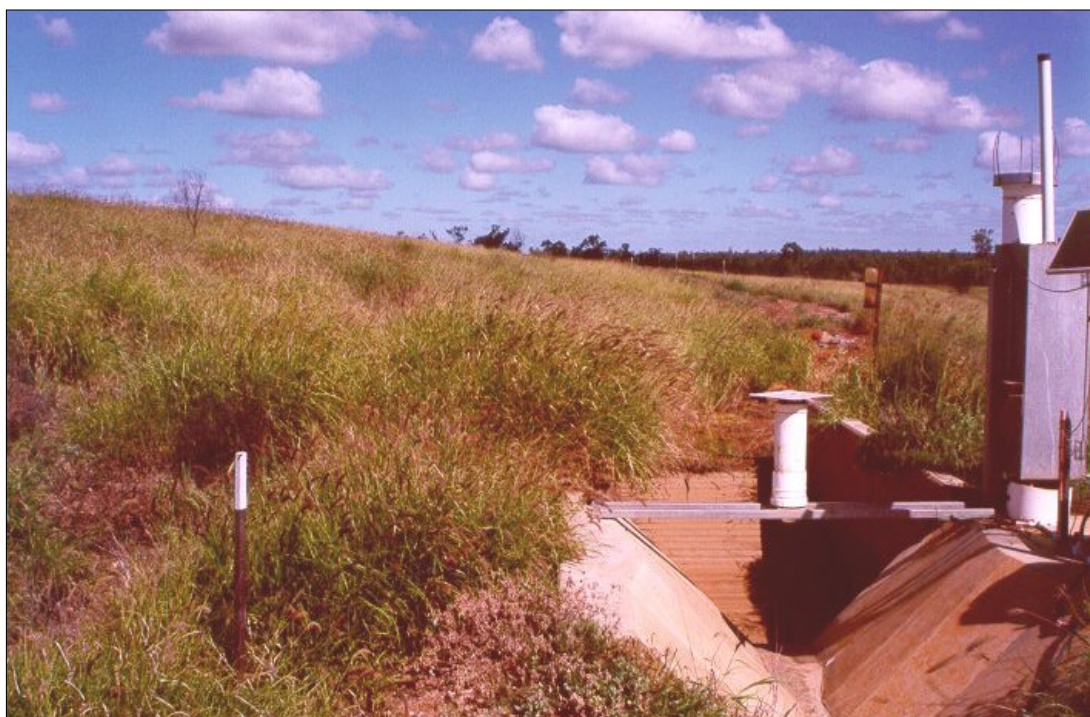


Photo 18: May 2000, 5 months after burn. 58% vegetative cover.

Catchment C



Photo 19: December 1999.

1 week after burn.

13% vegetative cover.



Photo 20: January 2000.

1 month after burn.

39% vegetative cover.

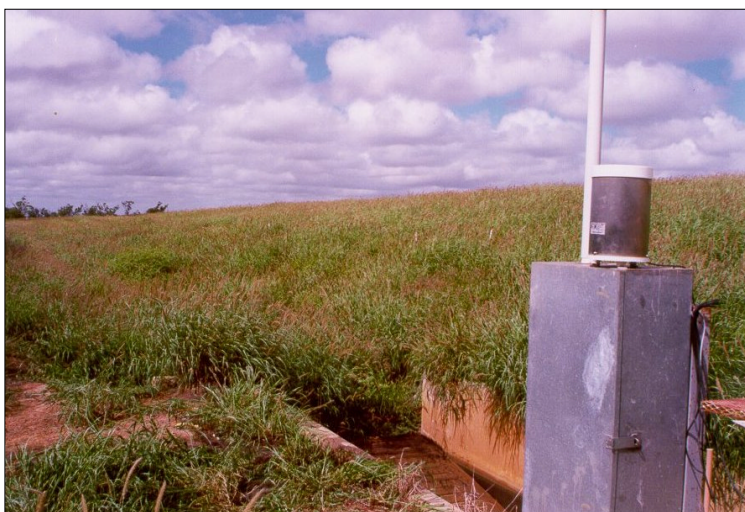


Photo 21: March 2000.

3 months after burn.

58% vegetative cover.

Catchment C



Photo 22: December 1999.

1 week after burn.

13% vegetative cover.



Photo 23: January 2000.

1 month after burn.

39% vegetative cover.



Photo 24: March 2000.

3 months after burn.

58% vegetative cover.