MODELLING RUNOFF AND EROSION PROCESSES IN CENTRAL QUEENSLAND GRAZING LANDS

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Abstract

Erosion-induced land degradation is a major factor contributing to unsustainable use of grazing lands in Queensland. Onsite degradation aside, offsite impacts, such as the movement of sediment and nutrients from grazing lands into drainage systems, are gaining public awareness and criticism - demanding sustainable management practices. Results from a grazing trial in Central Queensland found that high stocking rates increased runoff and erosion. The pasture productivity and soil water balance model, GRASP, provides a framework for analysis of land management effects on runoff and erosion. This paper will discuss the effectiveness of existing runoff and erosion algorithms in GRASP and the development of new algorithms based on the results of this trial.

The 'calibrated' curve-number equation simulated daily runoff with reasonable accuracy, high stocking treatment- $r^2 = 0.81$, medium stocking treatment- $r^2 = 0.83$ and the exclosed- $r^2 = 0.73$. Runoff arising from storm rainfall accounted for the majority of runoff and erosion measured. At this site the major factors affecting runoff were surface cover and rainfall intensity in contrast to soil antecedent moisture effects on runoff. A storm rainfall-runoff algorithm was developed, based on the surface cover and rainfall intensity. An erosion algorithm was developed based on the percentage of runoff calculated by the storm rainfall-runoff algorithm.

Introduction

A resource assessment of Queensland's native pastures (Tothill and Gillies, 1992) concluded that 20% were degraded and 40% were in a deteriorating condition. At a regional scale such as Dalrymple shire, Rogers *et al.* (1999) assessed 2259 sites and found typically greater than 40% were eroded. Historically there have been significant degradation episodes on the grazing lands that have received government and public attention. McKeon *et al.* (2004) describes eight of the worst degradation events and draws on the similarity of the precursors to such episodes. These precursors often include high stock numbers, drought and market price slumps, which consequently led to overstocking. Better adapted cattle (Zebu) and the ability to feed supplements have potentially compounded the problem, by allowing too many cattle to be stocked during extended dry periods. These studies highlight the degradation of our grazing lands and should cause concern for their long-term sustainability and their downstream environmental impacts.

A number of government and industry funded grazing trials and monitoring schemes have been undertaken over the last 20 years to address both productivity and land degradation issues. These trials have added to the knowledge base of understanding of grazing land processes affecting land degradation (O'Reagain *et al.*, 2003). Concurrently the water balance and pasture productivity model, GRASP, has been developed (Rickert *et al.,* 2000). GRASP provides a framework for spatial and temporal analysis of land management effects on runoff and erosion.

The pasture production, runoff and erosion results from a Queensland Government grazing trial were used to calibrate existing runoff and erosion algorithms in the GRASP model. The results from this trial also provided an opportunity to derive new and improved runoff and erosion algorithms, which could be used in future GRASP simulations.

Materials and Methods

This trial was undertaken northwest of Emerald in central Queensland during 1995-2000. Average annual rainfall is 640 mm. However, rainfall is highly variable with less than 400 mm in 20% of years and between 850-1200 mm in 20% of years. The dominant pasture species were *Bothriochloa ewartiana, Heteropogon contortus* and *Aristida* spp. The silver leaved ironbark trees *Eucalyptus melanophloia* were cleared at the beginning of the trial.

The soil has been classified (Filet and Osten, 1996) as a Red Chromosol (Isbell, 1996), or as a Kanhaplustalf (Soil Survey Staff, 1998). The red-brown soil colour indicates a moderately well drained profile, however the surface soil has a loamy texture where coarse particles have angular surface fraction resulting in hard setting of the topsoil, in particular under degraded conditions. The parent material is granite and weathered granite was encountered at depths of 0.5 m.

There were three stocking rate treatments high, medium and zero pasture utilisation. The high utilisation treatment aimed to annually utilise 75% of the standing dry matter measured at the end of the growing season, the medium stocking rate aimed to annually utilise 50% of the standing dry matter measured at the end of the growing season and the exclosed plots had no stock. Standing dry matter yield estimates were taken annually at the end of the growing season using the Botanal methodology.

Runoff measurements were taken using Gerlach troughs with tipping buckets. The runoff plots were located within ~30m of each other, hence minimizing the effects of spatial variability from soil type and storm rainfall. The runoff plots were closed catchments and were quite small, being on average 140 m^2 with a length of 20 m and width of 7 m. The slope within the runoff plots was 5 %. Bedload soil loss was collected from the Gerlach troughs after runoff events. A single suspended sediment sample was collected for each event. However these measurements have not been included due to the sampling intensity. Soil moisture measurements were taken using a neutron probe located in the centre of each plot. Surface cover estimates were taken regularly throughout the trial.

Initial model runs focused on calibrating the pasture growth component of the model using the field measurements of standing dry matter yield, projected cover and soil moisture measurements. The GRASP model was then calibrated to the runoff measurements using the curve number technique (eg. Owens *et al.*, 2003). To derive new runoff and erosion algorithms for the model, relationships between surface cover, rainfall intensity, soil antecedent moisture and runoff and erosion were explored.

Results and Discussion

The calibrated curve-number technique produced reasonable runoff predictions- High stocking rate; CN- 88 and r^2 = 0.81, medium stocking rate; CN- 86 and r^2=0.83, exclosed; CN- 45 and r^2=0.73. However, antecedent moisture - the major component of the curve-number technique- had little influence on the majority of runoff events. Annual pan evaporation in the Emerald region of ~ 2400 mm far exceeds rainfall and consequently most of the large rainfall events were likely to have occurred on soil profiles with a high soil moisture deficit (Figure 1). Runoff was primarily influenced by surface cover and secondly by rainfall intensity (Figure 2). Storm rainfall accounted for the majority of the runoff measured, hence the interaction between rainfall intensity and the soil unsaturated hydraulic conductivity appeared to be dominating the runoff process. Scanlan *et al.* (1996) also found a stronger relationship with rainfall intensity effects on surface runoff compared to antecedent moisture in the Charters Towers region.

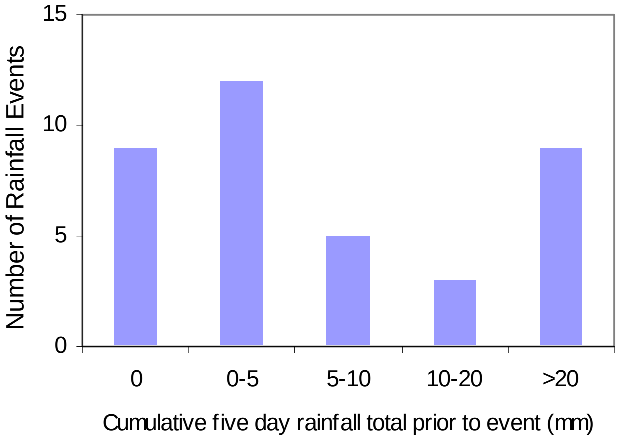


Figure 1. The five-day cumulative rainfall (mm) prior to daily rainfall events larger than 30 mm.

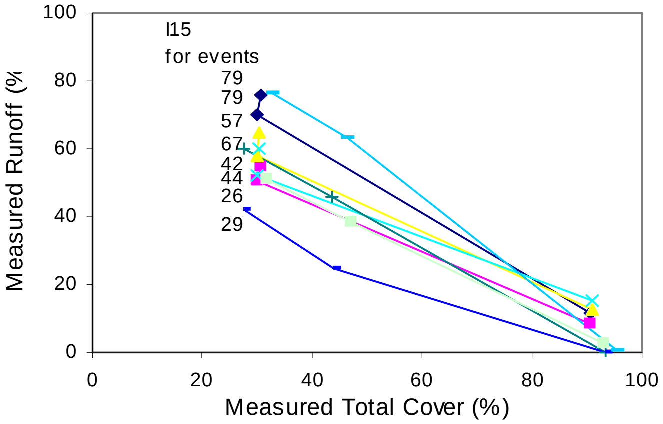
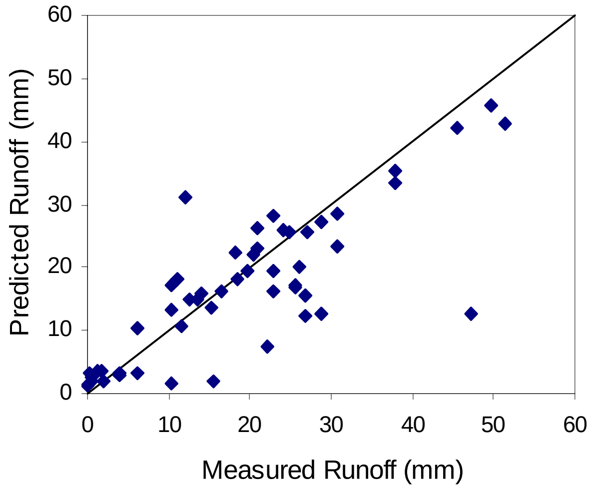


Figure 2. The effect of measured projected cover and measured rainfall intensity (I15 - maximum 15 minute rainfall intensity (mm/hr)) on measured surface runoff.

While the curve number method could be ‘calibrated’ to provide a reasonable prediction of surface runoff, there is little evidence from this trial that the technique adequately represents the physical processes taking place for the majority of runoff events. Two simple linear regressions were developed from the daily rainfall, projected cover and the maximum 15-minute rainfall intensity to provide a predictive runoff equation (Figure 3).
Equation- $\text{Runoff}\ (\%) = (-0.0082 \times I15 - 0.4108) \times \text{Cover} + (0.8074 \times I15 + 41.68)$, where I15 is the maximum 15 minute rainfall intensity (mm/hr) and Cover is the percentage surface cover (note the runoff (%) is limited to the upper boundary of 100% and lower boundary of 0%).



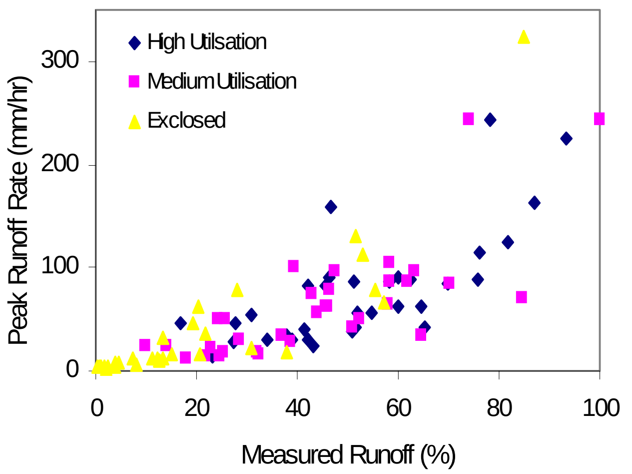


Figure 3 . Predicted runoff using the storm rainfall-runoff equation based on the 15-minute maximum intensity (I15 mm/hr) and cover (%), (Using modelled I15 and measured cover), and the measured event runoff.

Figure 4 . Measured percentage runoff and the measured peak runoff rate within a 1-minute period.

Although surface cover at this site was the major influence on runoff, cover is probably only an indicator of soil surface structural degradation. Rapid cover reductions due to burning in the exclosure did not increase surface runoff. Similar results have been found by McIvor *et al* (1995). Four years after the trial concluded and after resuming normal grazing management the surface soil in the high stocking treatments continues to visually display a larger proportion of bare areas with surface sealing characteristics, indicating that there may be a permanent change in the soil hydrological behaviour.

As in many other field-based trials, soil erosion at this site was episodic, with 5 events of 30 runoff events exceeding 10mm accounting for more than a half of the total bedload in the high utilisation treatment. The effects that surface cover has on erosion rates have been well documented and many predictive equations use the cover and total daily runoff as components in predictive equations. However, the rate of surface runoff is also important as this defines the transportation capacity of the event. There is a trend in Figure 4 indicating that the maximum runoff rates are correlated with the percentage runoff. As discussed above the surface cover and rainfall intensity were the two most important components influencing the percentage runoff and were used to form a predictive storm-runoff equation. The predicted storm-runoff equation can also be used to estimate bedload loss on an event basis (Figure 5), equation- $\text{Bedload (kg ha}^{-1}) = \text{Runoff}\ (\%) \times \exp\ (0.034 \times \text{Runoff}\ (\%))$, where Runoff (%) is calculated using the storm rainfall-runoff equation.

The high utilisation treatment had average event bedload concentrations consistently higher across cover classes indicating that there was another stocking rate effect apart from a reduction in surface cover (Figures 5 and 6). These effects could be due to stock trampling effects on surface soil infiltration properties or alternatively from a decline in infiltration during low cover periods, which did not recover as the surface cover improved.

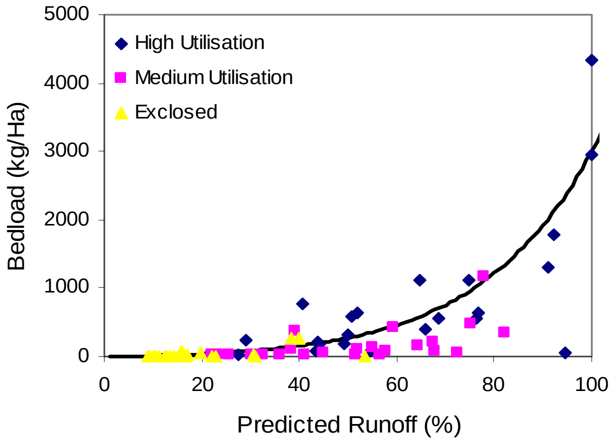


Figure 5. Predicted percentage runoff using the storm rainfall-runoff equation and the measured event bedload.

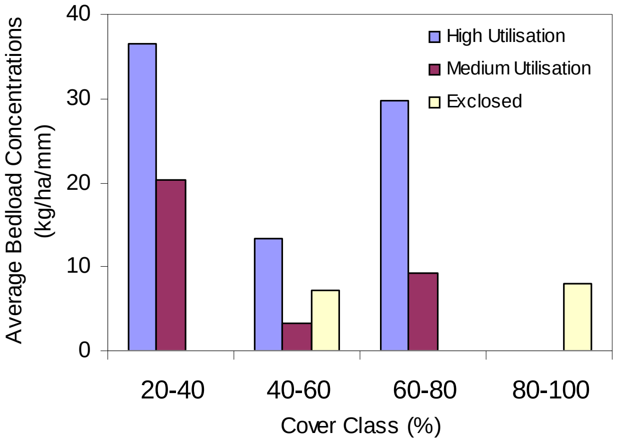


Figure 6. Average bedload concentrations for the three treatments and the cover class categories.

Conclusions

The results from this trial indicate the importance of both surface cover and rainfall intensity on runoff and the rates of soil erosion. The curve-number technique for modelling surface runoff did not represent the physical processes well, although, reasonable predictions were obtained through model calibration. Improvements to the model's representation of the physical environment required incorporating the effects of cover and rainfall intensity on runoff and erosion processes. However, the analysis also showed that cover alone could not explain the effects of different stocking rates on soil erosion.

The plots in this study were small and the effects of land management on runoff and erosion processes were obvious. At larger catchment scales, the effects of land management on runoff and erosion are likely to be less apparent. However, quantifying runoff and erosion processes at these small scales is valuable as it can indicate the effects that land management has on the redistribution of nutrients and water within the landscape. Maintaining surface cover is undoubtedly the best approach for graziers to minimise soil erosion. Extended periods of low ground cover resulting from over utilisation in this experiment led to a reduction in infiltration capacity due to surface soil structural decline. Further work needs to be undertaken to investigate the susceptibility of a range of soils to surface structure decline. Incorporating a soil susceptibility parameter into the model would improve the capacity to spatially model land management effects on soil erosion and productivity.

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References

Filet, P. and Osten, D. (1996). Ecology of a Grazed Woodland. *Technical Report*. Meat Research Corporation.

Isbell, R.F. (1996). The Australian Soil Classification. CSIRO Publishing. Melbourne.

McIvor, J.G., William, J. and Gardener, C.J. (1995). Pasture management influences runoff and soil movement in the semi-arid tropics. Australian Journal of Experimental Agriculture 35, 55-65.

McKeon, G.M., Hall, W.B., Henry, B.K., Stone, G.S. and Watson, I.W., (2004). Pasture Degradation and Recovery in Australia's Rangelands: Learning from History, (In press) Natural Resource Science Publications, Brisbane.

O'Reagain, P.J., McKeon, G.M., Day, K.A. and Ash, A. (2003). Managing for Temporal Variability in Extensive Rangelands – a Northern Australia Perspective. International Rangeland Congress, Durban.

Owens, J.S., Silburn, D.M., McKeon, G.M., Carroll, C., Wilcocks, J and deVoil, R. (2003). Cover-runoff equations to improve simulation of runoff in pasture growth models. *Australian Journal of Soil Research* 41, 1467-1488.

Rickert, K.G., Stuth, J.W. and McKeon, G.M. (2000). Modelling Pasture and Animal Production. In "Field and Laboratory Methods for Grassland and Animal Production Research" pp 29-66. CAB International, Wallingford.

Rogers, L.G., Cannon, M.G., Barry, E.V. (1999). Land Resources of the Dalrymple Shire. Queensland Department of Natural Resources.

Scanlan, J. C., Pressland, A. J. and Myles, D. J. (1996). Run-off and soil movement on mid-slopes in north-east Queensland grazed woodlands. *Rangeland Journal* 18, 33-46.

Soil Survey Staff. (1998). Keys to Soil Taxonomy. 8th Edition. United States Department of Agriculture.

Tothill, J.C. and Gillies, C. (1992). The pasture lands of northern Australia: Their condition, productivity and sustainability. *Tropical Grasslands Society of Australia Occasional Publication* No. 5.