Mine landform cover design and environmental evaluation

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Abstract

Water balance processes critical to environmental restoration were measured for a reconstructed soil on a waste rock landform. This cover trial, involving four years of monitoring, identified temporal changes in water balance in the near surface and found that tree roots interacted with a drainage-limiting layer at one metre below the land surface in just over two years leading to altered hydraulic properties of the layer. Water balance simulations found that increasing the depth to, and thickness of, the drainage-limiting layer would reduce drainage flux and limit tree root penetration. A mine landform cover design based on soil profile properties and catchment hydrology of a natural analogue area is recommended to reconstruct the endemic natural ecosystems and restore environmental processes.

Key Words

Mine rehabilitation, cover design, ecosystem reconstruction, water balance.

Introduction

The objectives for designing landform cover systems can include control of dust and water erosion, chemical stabilisation of acid-forming mine drainage (through control of oxygen ingress), contaminant release control (through control of infiltration) and providing a growth medium for vegetation establishment (O'Kane and Wels 2003). The last objective is perhaps the most important one for addressing off-site impacts on water quality and catchment hydrology at closure (Croton and Reed 2007) although it is often overlooked.

Restoring the capacity of the soil zone to support natural ecosystems is an important aspect of ecosystem reconstruction. Consequently, this paper investigates aspects of landform cover design that are relevant to ecosystem reconstruction. A case study is made of a constructed cover at Ranger uranium mine and potential environmental performance issues at this site. Enhancing cover design by referring to soil profile and landform properties of natural analogue areas are suggested.

Objectives

Our objective was to assess the water balance of a waste rock cover that was constructed from barren mine waste at the Ranger uranium mine. The cover was intended to: (i) limit erosion and thereby contain mineralised waste rock; (ii) limit deep drainage through mineralised material; (iii) reduce water quality impact in the receiving environment; and (iv) support native woodland revegetation.

Methods

Climate and profile monitoring

A continuous logging system was installed to monitor the water balance (2001-2004) in a cover over mineralised waste rock constructed with a subsoil drainage limiting layer and a surface erosion resistant – ecosystem support layer. Two soil profiles were instrumented to measure soil water content (θ_v) and soil water potential (Ψ). One profile was in a bare area and the other in a revegetated area ten metres distant. The revegetated area had been ripped to 0.3 metres and planted in December 2000 with nursery grown plants.

Drainage flux estimate

Long-term drainage flux was predicted using a profile water balance model, SWIMv2.1 (Verburg *et al.* 1996) and the sensitivity of this parameter to variations in properties of the cover was assessed.

Results

Monitored rainfall and drainage in bare and vegetated plots are depicted in Figure 1. In the vegetated plot, enhanced infiltration through the land surface in the 2001 wet season and retention of moisture above the drainage limiting supported the high and sustained drainage flux during the 2002 dry season and into the following wet season. The surface ripping would have initially enhanced infiltration into the vegetated plot. This effect was lost in subsequent wet seasons as a surface crust developed and rainfall ingress decreased and root growth compromised the integrity of the drainage limiting layer.

However, plant growth and root water uptake in the vegetated plot appeared to reduce the drainage flux by the 2004 wet season. Further changes in the water balance are likely to occur as plant roots grow to depth and affect the control drainage into the underlying waste rock.

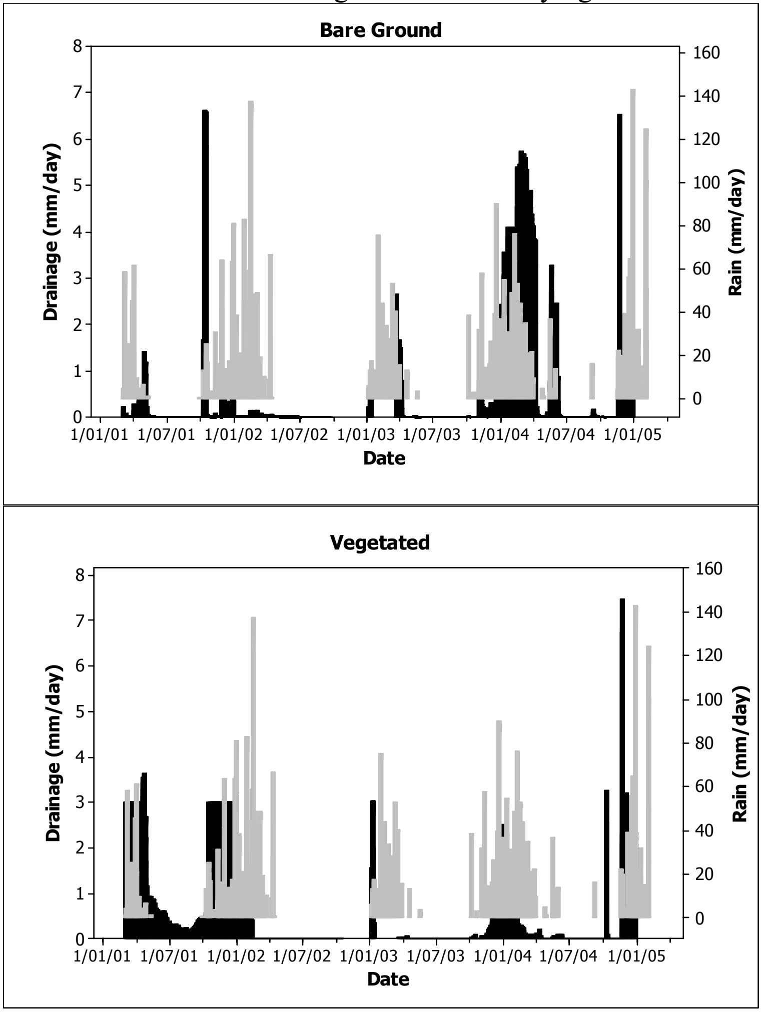

Figure 5. Daily drainage flux (black) and daily rainfall (grey) for bare and vegetated waste rock

Annual drainage and drainage as a proportion of rainfall (drainage: rainfall) are shown in Table 1 for bare and vegetated plots. Deep ripping and revegetation enhanced drainage as a proportion of rainfall compared with bare ground. However, the amount of drainage under revegetation declined (relatively) in subsequent years. In prolonged wet seasons, such as that in 2004, drainage as a proportion of rainfall was less in the vegetated plot compared with the bare plot. Evapotranspiration in the vegetated plot would account for this difference.

Table 4. Annual drainage as a proportion of rainfall for bare and vegetated plots

Rainfall	Rain	Vegetated		Bare ground	
year[1]	(mm)	drainage (mm)	drainage: rain (%)	drainage (mm)	drainage: rain (%)
2001	3912	281	7.2	20	5.0
2002	1590	300	19	98	6.0
2003	920	12	1.0	24	3.0
2004	1807	68	4.0	422	23
2005	1034	129	1.2	38	4.0

[1] measured between September and August

The proportion of rainfall occurring as either runoff or groundwater recharge has important effects on landscape ecology, determining how and where water is available to ecosystems. Evans (2000) used a runoff coefficient of 0.36, based on catchment measurements reported in Duggan (1991) for the natural land surface in the vicinity of Ranger mine to assess site rehabilitation impacts on stream water quality. Differences between bare and revegetated areas were associated with root growth and plant water use.

Significant changes in the soil water store of the constructed cover over a four year period were associated with plant water extraction and root growth down to two metres after two years. While better control over the construction of the sub-surface drainage limiting layer could improve drainage control the layer is unlikely to remain intact unless it is installed beyond the influence of tree roots. Similar interactions between tree roots and constructed covers have occurred at other sites (Taylor *et al.* 2003). Drainage limiting layers may need to be installed to five metres to be beyond the influence of tree roots in this environment (Kelley 2002; Kelley *et al.* 2007).

The design thickness of the drainage limiting layer needs to be increased if it is constructed by mining operations. Increasing the thickness of the drainage limiting layer to two metres could also halve the drainage flux according to water balance modelling estimates derived for the historical rainfall record. However, the effectiveness of the revegetation in establishing transpiring leaf area will be critical to achieving the predicted improvement in drainage control. Without effective evapotranspiration infiltration will still flux down, albeit at a slower rate.

The water balance for the ripped and revegetated monitoring plots showed enhanced drainage initially that declined over three years. Because the cover had not been thoroughly ripped and revegetated the general condition was of low infiltration through a compact and massive surface. Low infiltration through the surface acts as a throttle that limits the water available to plant growth, a critical factor in ecosystem function (Ludwig *et al.* 2000) particularly in water limited environments (Cook *et al.* 2002). This constraint over plant water supply will prevent comparable ecosystems becoming established to those in the surrounding natural landscape.

Conclusion

A basic cover design concept that uses oxidised and barren waste rock material and comprises erosion resistance and water retention for plant growth and drainage limitation could be refined to improve environmental performance. Surface treatment activities such as deep ripping also need to be combined with effective revegetation. Otherwise the stable soil porosity that is associated with biological activity and is essential for ecosystem function will not develop.

The design of the plant growth medium needs to demonstrate the capacity to support naturally occurring woodland ecosystems and restore a natural water balance to the mine landscape, as well as resist erosion. These critical issues affect landform integrity and will need to be resolved since the evapotranspiration capacity of the revegetation, and the protection it affords from rainfall erosion significantly influence drainage flux, runoff and long term integrity of the mine landform.

Demonstrating similarities in ecosystem support properties between the final landform cover and the soil zone in a natural analogue area will underpin an ecosystem restoration methodology. Long–term monitoring (5 to 10 years) of a final landform trial that is designed according to the environmental properties of the natural analogue area could improve cover design specifications and be used to develop a predictive capacity that ensures on-site and off-site environmental outcomes will be acceptable.

The capacity to predict ecosystem patterns and vegetation water use in the reconstructed terrain is needed to demonstrate an ecological design methodology and to assess whether a landform design will support similar vegetation patterns to surrounding natural landscapes.

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