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Vegetation and soil controls on water redistribution on recently constructed ecosystems in water-limited environments

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Achieve International Excellence

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PhD Thesis Abstract

Vegetated engineered covers are artificially constructed ecosystems designed to minimize the environmental risks posed by hazardous wastes. Covers serve multiple objectives, which include supporting a stable vegetation community resembling natural ecosystems, and minimizing deep drainage into buried wastes by enhancing soil moisture storage in the top layers, and subsequent water loss through evapotranspiration. Vegetation directly contributes to cover hydrology through transpiration, and conversely, hydrology influences transpiration and vegetation growth, forming a feedback loop. These vegetation-soil feedbacks may drive early ecosystem development, and control hydrology and vegetation patterns in water-limited ecosystems.

Until now, information on the ecohydrology of recently constructed ecosystems such as covers has been lacking. Available literature has a disciplinary bias towards field evaluation and predictive modelling of cover hydrology (**Chapter 1**), while a systems perspective integrating material hydraulic properties, vegetation characteristics and their interaction is still lacking. In particular, little was known about the spatial patterns of hydraulic properties and fine roots on covers, and their impacts on transpiration and plant water relations. Moreover, earlier studies lumped together bare soil evaporation and transpiration as evapotranspiration, thereby confounding our mechanistic understanding of the individual processes. Here, I took the next logical step to address these knowledge gaps through field experimentation on a vegetated cover in Western Australia (**Chapters 2-5**) and ecohydrological modelling (**Chapter 6**).

Spatial analysis of hydraulic properties revealed that mean saturated hydraulic conductivity K_s values for both field and laboratory measurements were very high (38.7-77.9 m day^{-1}), exceeding typical values for natural soils by several orders of magnitude (**Chapter 2**). Coefficients of variation (CV) were low (26-44%), resembling those of well-sorted sediments. These findings were attributed to well-sorted and a predominantly coarse-texture associated with mechanically separated material. Geostatistical analysis revealed surface patterns and vertical layering of K_s caused by construction procedures and particle segregation. These properties influence soil moisture storage, root water uptake and deep drainage.

Bare soil evaporation E_s measured following a soil wetting pulse revealed a two-stage process, characterized by a rapid decline phase and a low-rate stage (**Chapter 3**). The time-course of daily E_s reflected the low moisture retention and high evaporative demand during the study period. Vegetation cover reduced peak daily evaporation by more than 50% relative to open spaces, and muted diurnal variations caused by weather fluctuations. These findings stress the need to account for both soil moisture and vegetation cover when modelling E_s on such ecosystems.

Fine roots showed high spatial variability (CV: 50-236%) in both vertical and horizontal directions (**Chapter 4**). Approximately 90% of the fine roots were confined to the top 40-cm depth, declining exponentially to a maximum rooting depth of 150 cm. Comparison with a global root distribution model showed that the shallow root distribution resembled that of a grassland rather than a woodland. These findings were attributed to stand age and subsoil chemical constraints to root growth. The implications of the findings for root water uptake are discussed.

Transpiration was directly quantified at different temporal scales. Annual transpiration was low (147 mm), accounting for only 22% of the annual total rainfall (673 mm), which was about three-fold lower than 59-99% reported in natural Mediterranean vegetation ecosystems (**Chapter 5**). Overall, transpiration tracked soil moisture patterns rather than atmospheric conditions, with most of the transpiration confined to the wet winter season (108.1 mm), while the dry summer value was very low (39.1 mm). These findings reflected the collective impacts of low moisture retention of the material, shallow root distribution and low leaf area index on transpiration.

Chapter 6 presents an ecohydrological model to demonstrate how vegetation-soil feedbacks, and their interaction with climatic fluctuations impact on temporal patterns of vegetation. This was motivated by damped and overshooting behaviour of vegetation observed on highly disturbed ecosystems, whereby biomass productivity exceeded long-term sustainable levels after 1-2 decades. I hypothesized that these patterns are caused by vegetation-soil feedbacks. Under steady-state rainfall, I demonstrated that vegetation converged to equilibrium points or persistent oscillations (limit cycles). Cyclic climatic fluctuations amplified vegetation variability through period doubling and phase synchronization depending on rooting depth and climatic periodicity. These findings suggest that ecohydrological feedbacks may provide a unifying mechanism for diverse patterns of vegetation observed in water-limited environments. Overall, the insights gained from this study emphasize the need for a systems perspective to understand the behaviour of recently constructed ecosystems.

Thesis Papers:

(I): Field-scale Spatial Variability of Saturated Hydraulic Conductivity on a Recently Constructed Ecosystem

Willis Gwenzi, Christoph Hinz, Karen Holmes, Ian R. Phillips and Ian J. Mullins

Abstract

Saturated hydraulic conductivity K_s influences water storage and movement, and is a key parameter of water balance and solute transport models. In contrast to the substantial literature available on K_s for natural soils, systematic field evaluation of K_s and its spatial variability for recently constructed ecosystems such as engineered covers is still lacking. To address this knowledge gap, the specific objectives of the present study were; (1) to determine saturated hydraulic conductivity using a combination of in-situ field methods (Philip-Dunne, and Guelph permeameters) and compare their results to the well-established constant-head laboratory method; and (2) to evaluate the spatial variability of K_s using univariate and geostatistical analyses. Surface K_s was sampled on a nested grid, and vertical K_s was measured along a trench face on an engineered cover. Comparison of K_s methods revealed significant ($p<0.05$) differences between field and laboratory methods, but mean values and coefficients of variation (CV) were within the same orders of magnitude. Regardless of method of measurement, mean K_s values were very high (38.6-77.9 m day^{-1}), exceeding typical values for natural soils by several orders of magnitude. K_s for surface samples was normally distributed, while that for samples taken at depth was bimodal, reflecting layering caused by settling and self-filtration of fine particles. Measured K_s values were linearly and negatively correlated with dry soil bulk density (r^2=0.73), and to a lesser extent silt plus clay percentage (r^2=0.21). Combining both dry soil bulk density and silt plus clay percent significantly ($p<0.05$) improved the relationship and gave the best predictor of K_s (r^2=0.76) for the study site. Geostatistical analysis of surface K_s revealed a spatial pattern described by a spherical model with a correlation range of 8 m. A kriged map of K_s showed alternating bands of high and low values perpendicular to the slope, consistent with surface structures created by wheel tracks of construction equipment. A spatial structure was also observed in the vertical direction for the trench data, with a short correlation range of 40 cm presumably indicative of layering caused by post-construction mobilization and deposition of fine particles. Overall, the extremely high K_s, low variability and spatial patterns reflected the predominantly well-sorted coarse texture (96% sand) caused by mechanical separation, construction procedures and post-construction processes such as settling and self-filtration. These findings demonstrate that artificially constructed ecosystems can exhibit unique hydraulic properties beyond those expected for natural soils. The results have implications for soil moisture storage, plant water relations and water balance fluxes on vegetated engineered covers, particularly where such landforms are intended to restore pre-disturbance ecological and hydrological functions.

(II): Bare Soil Evaporation and Soil Moisture Patterns on a Vegetated Engineered Cover Following Soil Wetting

Willis Gwenzi, Ian R. Phillips, Timothy M. Bleby, Christoph Hinz, Erik J. Veneklaas and Stephen S.O. Burgess

Abstract

Evaporation from bare soil surfaces E_s is an important hydrological flux in water-limited environments. Its importance is potentially even greater on "evapotranspirative" engineered covers, as such covers often have limited vegetation cover. However, studies quantifying E_s on engineered covers, and its relationship with vegetation and the often unique soil properties are still lacking. A field study was conducted on a recently constructed cover with sparse woody vegetation. The material was predominantly (96%) sandy textured characterized by high saturated hydraulic conductivity (6.4 x 10^{-2} m s^{-1}) and low moisture retention (10.1% at 10 kPa and 2.8% at 1500 kPa suction). The objectives were; (1) to quantify the diurnal and daily patterns of E_s following wetting of the soil by a 100-mm irrigation pulse, and; (2) to investigate the effects of woody canopy cover, weather variables and soil moisture on E_s. A portable chamber was used to measure E_s on replicated points on four consecutive days, and three weeks after irrigation. Weather variables and soil moisture were monitored half-hourly using a data logger. Results showed that vegetation canopies suppressed peak bare soil evaporation by about 50% compared to open spaces. Maximum diurnal E_s on the first day was 0.35 and 0.55 mm hr^{-1} in the canopy and open spaces, respectively, and less that 0.03 mm hr^{-1} three weeks after irrigation. Diurnal E_s varied considerably in response to solar radiation (r^2=0.60-0.89), vapour pressure deficit (r^2=0.6-0.86) and soil moisture (r^2=0.47-0.56). On the first day of measurement, daily E_s was also higher in open spaces (7.3 mm day^{-1}) than canopy spaces (2.8 mm day^{-1}), but declined exponentially (r^2=0.96-0.98) to less than 0.3 mm day^{-1} in both cases three weeks after irrigation. This decline of E_s with time was attributed to rapid soil drying caused by high atmospheric water demand and low moisture retention of the material. Consequently, high E_s associated with first-stage evaporation did not persist, while the three stages of evaporation often observed on natural soils following a wetting event were not apparent. Evidently, daily E_s was a two-stage process consistent with the exponential decline of soil moisture (r^2=0.86-0.96). These findings stress the need to account for the effects of both vegetation canopies and soil moisture patterns when modelling bare soil evaporation. Further research based on portable chamber measurements should focus on quantifying the seasonal and annual patterns of bare soil evaporation on covers.

(III): Spatial Analysis of Root Distribution on a Recently Constructed Ecosystem in a Water-limited Environment

Willis Gwenzi, Erik J. Veneklaas, Karen Holmes, Timothy M. Bleby, Ian R. Phillips and Christoph Hinz

Abstract

Fine roots are crucial for plant water uptake, and are a key input in water balance and biogeochemical models. While literature exists on fine root spatial distribution in natural, forestry and cropping systems, such information is scarce for recently constructed ecosystems such as vegetated engineered covers. To address this knowledge gap, the specific objectives of the present study were; (1) to investigate the vertical and horizontal spatial patterns of fine roots on a recently constructed ecosystem, and their correlation with selected soil properties; and (2) to compare the root distribution to that predicted using a global model developed by Jackson et al. (1996) for natural ecosystems, hereafter JM96 (Jackson et al., 1996. A global analysis of root distributions for terrestrial biomes. *Oecologia*, 108: 389-411). Soil core samples were collected from a trench wall (6.2 m long and 1.4 m deep) using a 20 x 20-cm sampling grid. Root (≤5 mm) diameter distribution, root biomass density *RBD*, root length density *RLD*, soil pH, electrical conductivity (EC) and dry soil bulk density BD were measured for all samples. *RBD* and *RLD* averaged 0.27 kg m^{-3} and 1.57 cm cm^{-3}, respectively, with a predominance (90%) of roots of diameter $\phi \leq 1.0$ mm at all soil depths. Coefficients of variation were high in both vertical (88-200%) and lateral (50-236%) directions, and increased with root patchiness. About 90% of fine roots were in the top 40-cm depth, declining exponentially to a maximum rooting depth of 150 cm. Comparison of the computed root extinction parameter β (0.944) to the corresponding JM96 values for sclerophyllous (0.964), temperate deciduous (0.966) and coniferous (0.976) woodlands revealed a shallow fine root distribution resembling that of grasslands and boreal forests (β = 0.943). While a high concentration of roots in the top 40 cm enhances root water uptake in water-limited environments, where rainfall occurs as infrequent shallow pulses, the overall shallow root system could be indicative of subsoil constraints, particularly high soil pH. Lateral variability showed a quasi-periodic pattern, but peak root density was independent of location of individual plants, reflecting extensive lateral growth of fine roots. Geostatistical analysis revealed that root biomass density, soil pH and electrical conductivity were anisotropic, with a distinct spatial structure in the vertical direction, while horizontal variation was not spatially structured. Correlation analysis and cross-variograms revealed a spatial relationships between soil pH and root depth distribution (r=0.51). The implications of these findings are discussed in the context of root water uptake and water balance modelling.

(IV): Transpiration Patterns and Plant Water Relations on a Recently Constructed Ecosystem in a Seasonally Dry Environment

Willis Gwenzi, Erik J. Veneklaas, Timothy M. Bleby, Isa A.M. Yunusa and Christoph Hinz

Abstract

Vegetated engineered covers are a key strategy to minimize the environmental and public health risks associated with hazardous wastes. Revegetation is critical for restoring ecosystem functions, and vegetation plays an important role in cover hydrology. Root water uptake reduces soil moisture and minimizes the risk of deep drainage. While transpiration in natural Mediterranean vegetation ecosystems is known to persist as long as soil moisture is available in the root-zone, studies quantifying transpiration patterns and plant water relations for recently constructed ecosystems in a seasonally dry environment are still lacking. To address this knowledge gap, the present study investigated transpiration patterns and plant water relations on a 4-year-old constructed ecosystem planted with a mixture of evergreen native woody species. The specific objectives were; (1) to quantify diurnal, seasonal and annual patterns of transpiration, and their relationship with environmental variables and soil moisture, and (2) to investigate the seasonal patterns of plant water potential and stomatal conductance for the dominant species with contrasting root patterns. The results showed strong seasonality in plant water potential ψ_p, stomatal conductance g_s and stand transpiration E_t. Predawn water potential in wet winter (-0.6 MPa) was higher than dry summer values (-2 MPa), and a similar trend was observed for minimum water potential (winter: -1.5 MPa versus summer: -4.8 MPa). g_s was also low, ranging from 72.1 to 95.0 mmol m^{-2} s^{-1} in winter to less than 30 mmol m^{-2} s^{-1} in summer. For both species, there were significant correlations between g_s and ψ_p ($p<0.05$, $r^2=0.71$-0.75), indicating that species regulated excessive water loss through stomatal closure. Daily E_t was low, with an average of 0.7 mm day^{-1} in winter and 0.2 mm day^{-1} in summer, giving corresponding seasonal totals of 108.2 and 39.1 mm, respectively. Consequently, annual E_t (147.2 mm) accounted for only 22% of the total rainfall (673 mm). The relationship between vapour pressure deficit and winter diurnal transpiration ($r^2=0.75$) was characterized by hysteresis. However, daily and seasonal patterns of transpiration tracked soil moisture fluctuations in the top 90-cm depth ($r^2=0.75$). These findings were attributed to altered hydrology associated with a recently constructed ecosystem. First, material properties, and handling and construction procedures resulted in coarse-textured material with very high hydraulic conductivity and low moisture retention. Moreover, subsoil constraints particularly soil pH restricted root growth, resulting in a shallow root system. A combination of rainfall seasonality, low soil moisture retention and a shallow root system that led to low moisture storage in the root-zone and severe plant water stress in the dry summer season. Moreover, while the wet winter patterns were comparable to those for shallow-rooted natural ecosystems in seasonally dry environments, to our knowledge, the sharp drop and overall low transpiration observed in summer has not been reported before. The findings have implications for ecosystem functions and hydrology of recently constructed ecosystems such as engineered covers.

(V): Vegetation-soil feedbacks control early ecosystem development and temporal patterns of vegetation in water-limited environments

Willis Gwenzi, Christoph Hinz, Gavan S. McGrath and Erik J. Veneklaas

Abstract

Microscale vegetation-soil feedbacks account for self-organized spatial patterns of vegetation observed in semi-arid ecosystems, yet studies investigating temporal patterns of vegetation caused by such feedbacks are still lacking. Moreover, until now, there has been no unifying mechanism accounting for nonlinear temporal patterns of vegetation such as the damped behaviour observed on recently constructed ecosystems such as engineered covers, and cyclic patterns and abrupt shifts in vegetation revealed by palaeoecological studies. In this paper, we developed and applied a simple ecohydrological model to explore the hypothesis that these diverse temporal patterns can be explained by vegetation-soil feedbacks, and their interaction with climatic fluctuations.

Under uniform or steady state rainfall, the model predicted damped and periodic oscillation (limit cycles) of vegetation suggesting that vegetation-soil feedbacks may explain temporal patterns of vegetation observed in water-limited ecosystems. Aridity gradients caused by shifts in rainfall patterns triggered threshold-like vegetation transitions or bifurcations, leading to the emergence of alternative temporal patterns of vegetation. The effect of cyclic climatic forcing on vegetation patterns was dependent on rooting depth and rainfall periodicity. For a typical rooting depth of 1.5 m, we demonstrated that vegetation temporal patterns caused by vegetation-soil feedbacks persisted under low rainfall periodicity (T_p< 5 years) indicating that the response time of vegetation was slower than that of rainfall variability. At intermediate rainfall periodicity (T_p = 6-9 years), the interaction of vegetation-soil feedbacks and climatic fluctuations amplified vegetation oscillations through period doubling, whereby a new limit cycle emerges from an existing one. For rainfall periodicities in the order of decadal and multidecadal scales, vegetation temporal patterns were synchronized with climatic forcing, a phenomenon known as dynamic resonance or phase locking. The results are indicative of the potential response of vegetation to cyclic rainfall fluctuations caused by climatic phenomena such as El-Niño Southern Oscillation and Interdecadal Pacific Oscillation. Our findings suggest that El-Niño Southern Oscillation (T_p = 4-11 years) and North Atlantic Oscillations (T_p = 8years) may amplify vegetation oscillations or variability depending on rooting depth and periodicity. On the other hand, multidecadal climatic oscillations such as Interdecadal Pacific Oscillation and Atlantic Multidecadal Oscillation (T_p = 30-40 years) may control long-term temporal patterns of vegetation. Overall, the model captured the diverse temporal patterns of vegetation observed in water-limited environments, thus providing a simple unifying mechanism. Understanding these feedbacks may provide some crucial insights for ecological applications such as restoration of disturbed ecosystems.

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CMLR - University of Queensland

Anne Schneider, Thomas Baumgartl, David Doley, David Mulligan

Paper:

Schneider, A., Baumgartl, T., Doley, D., Mulligan, D. 2010. Evaluation of the heterogeneity of constructed landforms for rehabilitation using lysimeters. Vadose Zone Journal, *in press*.

Conference proceedings:

Schneider, A., Baumgartl, T., Mulligan, D., Doley, D. 2009. The effect of heavy rain events on the performance of a Store and Release cover in a semi-arid environment of Queensland, Australia. International Workshop Transregio 32, Patterns in Soil-Vegetation-Atmosphere Systems: Monitoring, Modelling and Data Assimilation, Aachen, 8-10 June 2009.

Schneider, A., Baumgartl, T., Doley, D., Mulligan, D. 2010. Store and Release Cover Systems: a suitable preventive for Acid Mine Drainage in semi-arid monsoonal Queensland? pg. 77 – 80. *In* 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, 1-6 August 2010.

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Store and Release Cover Systems: a suitable preventive for Acid Mine Drainage in semi-arid monsoonal Queensland?

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Abstract

Metalliferous mining operations are required to prevent contamination of the surrounding environment resulting from the discharge of leachates from waste repositories that may contain acid-forming sulfidic rocks or mine tailings. Waste rock cover systems are commonly used to isolate hazardous wastes from precipitation and thereby to prevent toxic or acidic mine drainage. Store and release cover systems are designed to retain all precipitated water within benign material overlying the waste, where the water is removed by evapotranspiration. Two cover designs were tested in semiarid monsoonal northwest Queensland: (1) 1.5 m of unconsolidated waste rock overlying 0.5 m of consolidated waste rock and (2) 2.0 m of unconsolidated benign waste rock. Cover performance was monitored with lysimeters, soil moisture and soil suction sensors. In a wet season with higher than usual precipitation (900 mm), water infiltration into underlying waste rock beneath bare covers varied from 3% to 76% of precipitation. Store and release cover systems may not always ensure sustainable mine closure in semi-arid areas with distinct wet and dry seasonality. It may be prudent for mining companies in those regions to supplement store and release covers with other water management systems.This study will support the optimisation of design of covers for the mining industry and affiliated stakeholders.

Key words

lysimeter, store and release cover, waste rock, drainage

Introduction

Mining activities often result in the production of hazardous or potentially hazardous wastes such as waste rock from the mining operation and fine-grained wastes from minerals processing (tailings). Weathering of sulfidic waste rock in contact with water and oxygen can produce acid and metalliferous drainage and tailings often also contain a high levels of heavy metals or are sulfidic (Lottermoser 2007). Infiltration of precipitation into the waste material can result in the leaching of hazardous substances into adjacent environments. For mine lease relinquishment, mining companies are required to prevent any potential contamination of the surrounding landscape.

In semi-arid environments, it is often proposed to use store and release cover systems (SRC) to enclose such hazardous wastes (Hauser et al. 2001; Fourie and Tibbett 2007). On mine sites, cover systems generally consist of benign (non-hazardous or non-acid-forming) waste rock which encapsulates waste rock dumps or tailings facilities. The thickness of the benign waste rock layer is designed according to site characteristics, climate (especially rainfall) and particle size distribution of the cover material. Other design features may include a compacted layer directly overlying the hazardous waste. The aim of a SRC system is to store precipitation in the benign waste rock and therefore prevent it from (deep) drainage and reacting with the hazardous waste. Stored rainwater is removed from the cover through evaporation and transpiration (O'Kane Consultants Inc. 2004). The theory of SRC systems is based on the water balance equation (Eq. 1)

$$L = P - Q - \Delta S - (EV + T) \quad (1)$$

Where L =seepage, P = precipitation, Q = runoff, ΔS = change in moisture content of the cover material, EV = evaporation and T = transpiration.

The objective of this paper is to investigate the feasibility of a bare SRC system for acid drainage prevention in a region with distinct wet and dry seasons in semi-arid monsoonal north-west Queensland, Australia.

Method

Field site

The mine site is located in a region classified as *BSh* (B = arid, S = steppe, h = hot arid) in the Köppen and Geiger Classification (Kottek *et al.* 2006). The mean monthly minimum and maximum temperatures are 11.6 and 37.3°C, respectively. The long-term annual rainfall of the area is 420 mm, but rainfall is highly erratic. Over 77 years of records, annual rainfall fluctuated between 104.9 mm in 1970 and 870.7 mm in 1950. Three-quarters of the annual precipitation occurs in the southern hemisphere summer, mainly between December and March but this is highly variable, from 78.0 mm in 1985/86 to 798.3 mm in 1996/1997, respectively. Most summer rainfall events are high intensity storms although the long-term data do not record these intensities (Bureau of Meteorology 2009).

Cover trials

Two cover trial areas (20 m x 60m) were constructed in October 2008 with a supplemental installation of sensors in December 2008. The cover designs were: (1) 0.5 m compacted benign waste rock on the potentially acid-forming waste rock, overlaid by 1.5 m uncompacted benign waste rock (Treatment 1V) and (2) 2.0 m uncompacted benign waste rock placed directly on potentially acid-forming waste rock (2V). Each cover trial area was subdivided into three subplots (20 m x 20 m) and instrumented identically. In each subplot, a lysimeter (3 m diameter and 3 m deep) was placed into to the hazardous waste material with its top being level with the surface of that material. Each lysimeter was connected to a tipping bucket gauge through a PVC pipe with a slope of ca. 2%. Furthermore, 16 soil matric potential sensors (229-L, Campbell Scientific, Logan UT USA) and 6 soil moisture sensors (Model CS616, Campbell Scientific, Logan UT USA) were installed in a single vertical line extending from the base of each lysimeter to the top of the cover system. A standard automatic weather station (Campbell Scientific, Logan UT USA) was mounted nearby.

Results

The data presented focuses on subplots 1Vb, 1Vc, 2Va and 2Vc based on integrity of the underlying data set.

Precipitation

The main period of precipitation in the wet season 2008/2009 began in the first week of December 2008 and ended in the second week of February 2009. No significant precipitation was received in March 2009. In total, 916 mm of rainfall was measured at the experimental site in an interval of 67 days. This rainfall was greater than that at the Bureau of Meteorology

(BoM) station in the vicinity of the trials, which recorded 668mm of rainfall for the same period. The BoM rainfall for January 2009 was the highest and the 2008/2009 wet season was the third wettest since measurements commenced at the site in 1932 (Bureau of Meteorology 2009).

Soil suction

The soil suction sensors responded quickly to rainfall events and the advance of the wetting front. The first major rain event on the 7th of December (27mm) triggered slightly different reactions on the subplots. Infiltration of rainfall proceeded approximately to the same depth on 2V (2Va: 1.02 m, 2Vc: 1.10 m) (Figure 1c, d). However, on Treatment 1V, infiltration was measured from 1.10 m (1Vc) to 1.99 m (1Vb), which indicates highly heterogeneous pore size distribution at this cover trial (Figure 1 a, b).

The suction values clearly show that in all four subplots, rainfall infiltrated into the hazardous waste. On Treatment 1Vb this occurred after 151 mm cumulative rainfall (Figure 1a), whereas on Treatment 1Vc infiltration into the potentially acid-forming material first occurred after only 99 mm of cumulative rainfall (Figure 1b). On 2V, water reached the hazardous material after 108 mm and 140 mm cumulative rainfall in Treatments 2Vc and 2Va, respectively (Figure 1c, d).

Beneficial influences of cover design, i.e. the compacted layer, on the hydrology of these cover systems cannot be claimed on the basis of the existing data.

Seepage

Seepage was recorded in all plots but the amount of seepage and time of occurrence varied between the subplots. No seepage was recorded from any plot between 13/01 and 24/01/2009. In these 10 days, a total of 253 mm of rainfall was recorded, with storm events of 37 mm, 48 mm and 50 mm on the

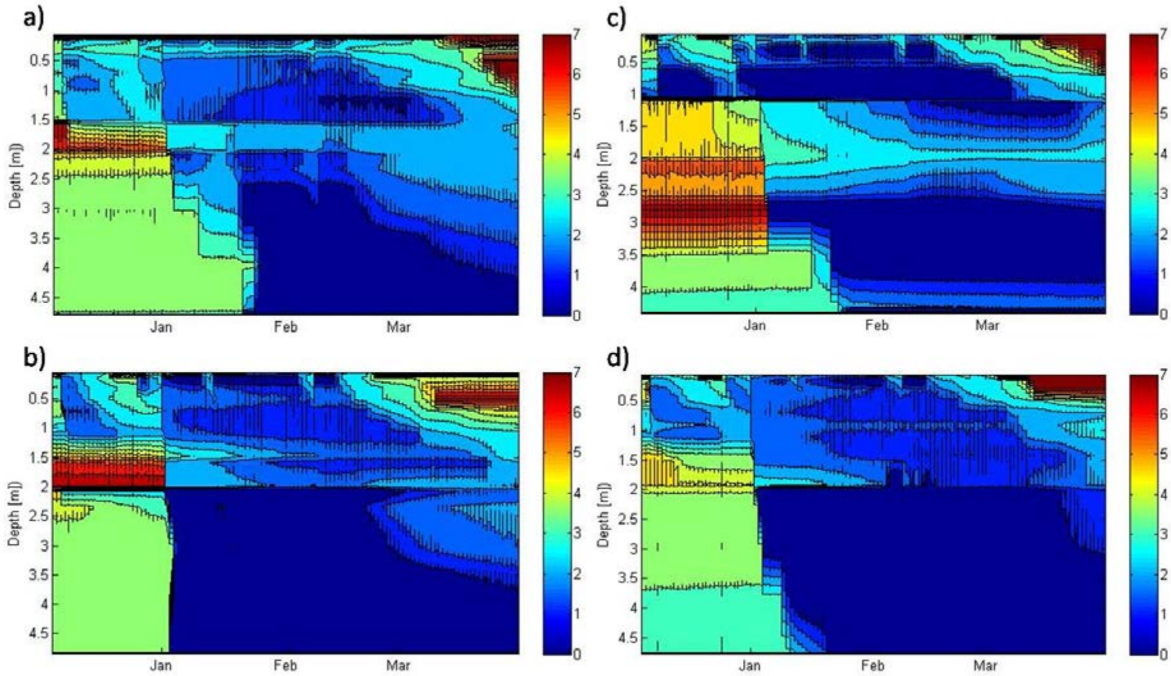

Figure 1. Logarithmic soil suction [hPa] over the course of the wet season 2008/2009 on subplots a) 1Vb, b) 1Vc, c) 2Va and d) 2Vc.

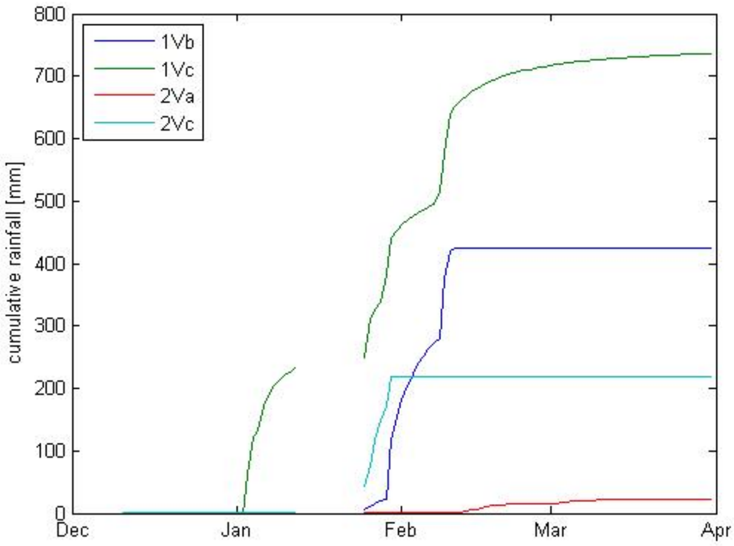

Figure 2. Cumulative seepage [mm] over the course of the wet season 2008/2009 on subplots 1Vb, 1Vc, 2Va and 2Vc.

20th, 21st and 22nd of January, respectively. As the soil suction and soil moisture sensors were operating satisfactorily during this period, it is likely that tipping buckets were not functioning correctly during that time. Cumulative seepage rates range from 21 mm (2Va) up to 736 mm (1Vc) (Figure 2). Generally seepage from the covers with a 0.5 m compacted layer was higher than from the plots without a compaction zone. However the differences within the cover designs themselves are very pronounced. Approximately 310 mm more drainage was recorded at 1Vc compared with 1Vb, and at 2V the difference in drainage from the two lysimeters was almost 200 mm. From the four subplots under consideration, only 2Va showed drainage from the lysimeter of less than 5% of rainfall. The amount of water seeping out of the remaining three plots exceeded this acceptable threshold by a large margin.

Conclusion

In a wetter than normal wet season in north-west Queensland, seepage under a bare (non-vegetated) 2 m cover system can reach up to 76% of the 916 mm of rainfall received during the period under consideration. The importance of vegetation for the mitigation of seepage amounts has been stressed by several authors (Hauser et al. 2001; O'Kane and Wels 2003; O'Kane Consultants Inc. 2004). The presence of vegetation can enhance the storage capacity of a cover as more water is removed from the cover through evapotranspiration than by evaporation alone. However, the frequency and intensity of storm events in areas with distinct wet and dry seasons remain a challenge for SRC systems. If the rain patterns and extreme events of a region and the hydraulic properties of potential cover material are known, as well as the potential for the plant community to remove water from the cover, the maximal seepage rates through a cover can be estimated and a decision made on the suitability of a SRC for the region.

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The effect of heavy rain events on the performance of a Store and Release cover in a semi-arid environment of Queensland, Australia

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Abstract

In many mining areas where annual evaporation far exceeds rainfall, Store and Release Cover (SRC) systems are often constructed to enclose hazardous (e.g. acid-forming) wastes and prevent leakage of contaminants into the environment. The concept of a SRC is to intercept and redistribute precipitation before it reaches the hazardous waste. The theory often compares a cover to a sponge; rainfall is absorbed and stored by the cover material; vegetation growing on the cover removes part of the water through transpiration, while another part is released into the atmosphere through evaporation.

In semi-arid north-west Queensland, two SRC trials instrumented with lysimeters, suction and moisture sensors, were built in October 2008. One of the trial covers on mineralised waste rock consists of 0.5 m compacted benign waste rock material underlying 1.5 m of uncompacted benign waste rock material. The other cover is formed out of 2 m uncompacted benign waste rock material directly over the minerlised waste.

In the wet season 2008/2009, over 900 mm of rain, more than twice the amount of the long-term annual average was received in 67 days. Due to their recent construction, the SRC trials were not vegetated at the time, and in this condition and under these rainfall intensities,neither of the two cover designs was able to prevent water penetration into the underlying potentially acid-forming waste rock. Heterogeneity within each cover design had a greater effect on the pattern of water penetration than did the design of the waste covers themselves.

Data gained from the lysimeters will be used in the future to model the role of vegetation in influencing the water balance. The lysimeter and other sensor data will also play important roles in determining the extent of heterogeneous flow through the cover systems, and the consequences for the prediction of flow patterns, given the degree of heterogeneity, will be derived.

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Comparison of engineering with ecophysiological models for predicting components of vadose zone water balance on two contrasting vegetation covers associated with waste management

Abstract

There is an increasing need for a detailed understanding of the hydrology of soil/vegetation covers established over hazardous materials in the mining and waste management industries. Sensitivity of these sites, in addition to their often difficult topography, limits applications of intrusive measurement techniques. Applications of simulation models therefore become the most viable alternative. In this study we compare the ecohydrological Soil-Plant-Atmosphere (SPA) model with the engineering Vadose model on vegetation covers over a bauxite residue at Pinjarra and a municipal waste site at Castlereagh, in western and eastern Australia, respectively. The SPA model was more precise than Vadose in predicting evapotranspiration (ET) at both sites. Vadose over-estimated ET at Pinjarra and underestimated it at Castlereagh, because of the seemingly large errors in its prediction of soil evaporation (Es). Under the sparse canopy developed on the sand at Pinjarra, Vadose predicted high rates of Es, which at the end of the 13-month period exceeded total rainfall. Under the dense canopy on the duplex soil (sandy topsoil over clay subsoil) at Castlereagh, Vadose predicted no occurrence of Es at all. This was because Vadose estimates Es as a function of radiant energy transmitted to the soil surface irrespective of the water status of the near-surface layers and it eliminates the process once the leaf area index exceeds 2.7 as was the case at Castlereagh. Despite the differences in their approaches, the two models were mostly in agreement in their predictions of transpiration from the canopy (Ec), except for the relatively higher values predicted by Vadose during extended dry periods in summer at Pinjarra. The relatively poor performance by Vadose was mostly due to its reliance on soil-water as the principal controller of Ec, while SPA takes additional account of transient micrometeorological influences on canopy conductance along with that of soil-water on the plant-water status. Predictions of drainage and of soil-water storage were affected by those of ET and its components. We propose ways by which both models can be improved to facilitate their wider application.