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Research papers

Sediment output from a post-mining catchment – Centennial impacts using stochastically generated rainfall

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ABSTRACT

Computer based landscape evolution models can provide insight into both erosion rates and processes (i.e. sheetwash, rill, gully erosion). One important data requirement of these models is long term, high quality, high-temporal resolution rainfall data (given that the physical nature of the erosion process is strongly related to rainfall). However, in many cases such data is limited - data is often short, incomplete or not of a sufficient temporal resolution. Therefore, the aim of this study was to test the sensitivity of modelled erosion rates to small changes in rainfall input. To achieve this we firstly assess the existing rainfall data from an established weather station and secondly, stochastically generate rainfall time series based on the longest and most reliable rainfall data. We then test the sensitivity of different rainfall sequences on sediment output using a well-tested landscape evolution and sediment transport model (CAESAR-Lisflood) over a simulated period of 100 y on a proposed rehabilitated mine landform. It was found that each rainfall scenario produces a unique pattern of erosion (i.e. the location and extent of the gullies is variable). Further, each rainfall scenario produces a unique pattern of sediment output that suggests non-linear processes. Importantly, this is the first time stochastically generated rainfall has been employed in landform evolution modeling and provides a statistical approach to quantify sediment transport and landform evolution. The method demonstrates a risk based approach and allows rainfall, runoff and sediment transport studies to be conducted in data poor environments. The findings clearly demonstrate that rainfall variability can greatly affect sediment transport and form of erosion as well as landscape evolution. This information is of particular importance for the design and testing of rehabilitated landscape systems such as post-mining landscapes.

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1. Introduction

For the majority of the world the rainfall record is relatively short (or in some cases non-existent). This is a significant issue for regions where the variability of rainfall (on inter-annual through to multi-decadal timescales) is large, as the rainfall record is unlikely to capture the full range of variability that can be expected. Northern Australia is a good example, where rainfall variability is markedly higher than most comparable climates in other continents (Dewar and Wallis, 1999) and rainfall records are both sparse and short. In the Northern Territory (NT) of Australia there are only three relatively complete (>85%) long-term (100 y) records of daily data, while sub-daily records are even scarcer, with only two stations recording at least 40 y of 6-min pluviograph data.

Sediment discharge is a product of the rainfall-runoff regime and resultant fluvial and diffusive erosion process. These processes in turn impact on the evolution of the landform. Therefore long-term high quality rainfall data is very important for an understanding of environmental processes (Baartman et al., 2013a,2013b). Given the issues with the length and quality of the rainfall record, how do we assess how a landscape will perform under different rainfall regimes? Also, given that climate is not static and rainfall varies spatially and temporally, how does this variability manifest itself in sediment transport and erosional stability? This information is extremely important not just for understanding natural catchments but also for agricultural landscapes, disturbed land and or reconstructed landscape systems (i.e. post mining) (Temme and Verburg, 2011). Mine sites may potentially disturb large areas of the land surface and post-mining the operators are usually required to return the landscape to a geomorphically stable system that integrates with its surrounds. Often these reconstructed landscapes contain uneconomic ore, mine processing waste and in the case of uranium mines, low grade uranium and

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associated fines from the mineral extraction process. These environmentally hostile materials are required to be encapsulated within the structure for millennia.

Models such as the RUSLE (Revised Universal Soil Loss Equation) and WEPP (Water Erosion Prediction Program) have always had the ability to assess the impact of different rainfall amounts and intensities. In recent years, computer based landform evolution models (LEMs) have been developed to the point where both spatially and temporally variable rainfall can be employed across a domain (see Tucker and Hancock, 2010 for a review of models). These models offer an unprecedented ability to assess landform evolution. However, at the core of these models are the data requirements, including reliable high-resolution rainfall data that captures the extent of variability that can be expected for the region, which as discussed is often limited. One solution to this (explored in this paper) is the use of a stochastic rainfall generator to enhance the existing rainfall record by producing rainfall replicates that are based on the historical record, yet provide rainfall events and sequences that have not necessarily been previously recorded. This can be used to then test the sensitivity of the landscape and the model to small variations in the rainfall regime.

A stochastic rainfall generator (also known as a weather generator) is a model that is designed to generate synthetic rainfall timeseries with the same statistical properties as observed data (Thyer and Kuczera, 2000). Rainfall generators can provide additional data when the historical record is insufficient to reliably estimate the probability of extreme events (Wilks and Wilby, 1999). The stochastic generation of daily rainfall data at a single site is a well-documented research area in both the hydrological and climatological sciences (e.g. Buishand, 1978; Chapman, 1998; Harrold et al., 2003a,b; Rajagopalan et al., 1996; Sharma and Lall, 1999; Srikanthan and McMahon, 1985; Srikanthan and McMahon, 2001) given that many hydrological models are run at a daily time step. However LEMs (such as CAESAR-Lisflood described below) require sub-daily (hourly) rainfall data, which necessitates the use of a particular set of rainfall generators. There are two main approaches to generating rainfall data at the subdaily level. The first method is to stochastically generate daily rainfall using either the Bartlett-Lewis Rectangular Pulse stochastic rainfall model or an Autoregressive 1 (AR1) model and then disaggregate to hourly rainfall (e.g. Engida and Esteves, 2011; Gyasi-Agyei, 2011; Gyasi-Agyei and Mahbub, 2007). The second method is to directly generate sub-daily (6 min/hourly) rainfall data using such models as the Disaggregated Rectangular Intensity Pulse (DRIP) model (Heneker et al., 2001) or the Neyman-Scott Rectangular Pulse (NSRP) process model (Frost et al., 2004).

This paper focuses on the first 100 y of landscape development of a proposed rehabilitated post-mining catchment located in the NT. This is the most dynamic period in the evolution of a landscape, where erosion rates are highest, the most easily eroded material is removed, gully development (if any) occurs and the drainage patterns are established and enforced. It is also a period that is within a human management time frame where any immediate sub-optimal landscape features or behavior can be identified and rectified.

This paper (1) demonstrates a new method for generating and employing synthetic rainfall data for areas where limited data exists; (2) employs this data in a landform evolution model to create a series of landscape predictions; and (3) examines the effect of enhanced rainfall variability on erosion rates and patterns generated from this rainfall.

2. Site description

The catchment of Corridor Creek is the focus of this study. Corridor Creek is one of the catchments that drain, and may be impacted by, the Energy Resources of Australia Ranger Mine that is located in the Northern Territory of Australia (Fig. 1). Corridor Creek is a tributary of Magela Creek, which flows into the East Alligator River through a broad expanse of floodplain and wetlands listed as "Wetlands of International Importance" under the Ramsar Convention (http://www.ramsar.org, 2003).

Processing of stockpiled ore at the mine site is scheduled to cease by 2021. Consequently, attention is increasingly focussing on the closure and the rehabilitation of the mine. Mine tailings are stored in a mined-out pit (Pit 1), which lies within the Corridor Creek catchment. Tailings containment structures, either above or below ground are required to have an engineered structural life of 10,000 y (Supervising Scientist Division, 1999), over which time the tailings should be isolated from the environment.

The requirements for the closure and rehabilitation of the Ranger mine have been documented in a series of published Environmental Requirements. These state, with respect to erosion and landform stability, that the landform should possess *"erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas"* (Supervising Scientist Division, 1999). Consequently, ERA will be required to rehabilitate disturbed areas of the lease to satisfy the above requirements. Implementing these requirements will require the landscape to be rehabilitated in a way that restores environmental functions supporting local ecosystem diversity. These environmental functions include landscape water, nutrient and energy balance, which can be represented through geomorphic properties such as relief (Ludwig and Tongway, 1995). The first stage in this process is to design and construct a landform that is erosionally stable.

2.1. Climate, vegetation and geology

The Ranger lease lies in the wet-dry tropics of Northern Australia and receives high-intensity storms and tropical monsoons between October and April (the 'wet season') with little rain falling for the remainder of the year (the 'dry season'). The annual average rainfall is 1584 mm with high interannual variability ranging between 1038 mm y^{-1} to 2623 mm y^{-1} (Bureau of Meteorology, 2014). Two main atmospheric pressure systems that drive the NT's climate are the sub-tropical ridge (STR) and the monsoon trough. The STR is weaker and located further south in summer but stronger and further north in winter (Drosdowsky, 2005). The monsoon affects northern Australia from November to March, bringing cloud, heavy rainfall, tropical depressions and cyclones to the north of the NT (Suppiah, 1992). The tropical cyclone (TC) season runs from November to April (Dowdy, 2014), with TCs producing heavy rainfall, damaging winds and storm surges. On average, two to three TCs form near the NT each season, however TC numbers have ranged from zero up to five in a season.

Vegetation on the lease consists of open Eucalypt forest dominated by *E. tetradonta*, *E. miniata*, *E. bleeseri* and *E. porrecta*. The understorey is characterised by *Acacia* spp., *Livistona humilis* and *Gardenia megasperma* with a variable grass cover of *Sorghum* spp., *Themada triandra* and *Eriachne triseta* (Chartres et al., 1991).

The geology of the site region is dominated by the mineralised metasediments and igneous rocks of the Pine Creek geosyncline (one of the richest uranium provinces in the world) and the younger sandstones of the Mamadawerre Formation (East, 1996; Needham, 1988). The geology of the Ranger mineral lease itself is composed of a superficial cover of Cainozoic soil, unconsolidated sands, ferruginous material and laterite over lower Proterozoic schists of the Cahill Formation (Chartres et al., 1991). Geomorphically, the Ranger lease is characterised as part of the deeply weathered Koolpinyah surface, which comprises plains, broad valleys and low gradient slopes, with isolated hills and ridges of resistant rock (East, 1996). The area of the lease has a mean elevation of 22 m above sea level.

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