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Case study

Predicting uncertainty in sediment transport and landscape evolution – the influence of initial surface conditions

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ABSTRACT

Numerical landscape evolution models were initially developed to examine natural catchment hydrology and geomorphology and have become a common tool to examine geomorphic behaviour over a range of time and space scales. These models all use a digital elevation model (DEM) as a representation of the landscape surface and a significant issue is the quality and resolution of this surface. Here we focus on how subtle perturbations or roughness on the DEM surface can produce alternative model results. This study is carried out by randomly varying the elevations of the DEM surface and examining the effect on sediment transport rates and geomorphology for a proposed rehabilitation design for a post-mining landscape using multiple landscape realisations with increasing magnitudes of random changes. We show that an increasing magnitude of random surface variability does not appear to have any significant effect on sediment transport over millennial time scales. However, the random surface variability greatly changes the temporal pattern or delivery of sediment output. A significant finding is that all simulations at the end of the 10,000 year modelled period are geomorphologically similar and present a geomorphological equifinality. However, the individual patterns of erosion and deposition were different for repeat simulations with a different sequence of random perturbations. The alternative positions of random perturbations strongly influence local patterns of hillslope erosion and evolution together with the pattern and behaviour of deposition. The findings demonstrate the complex feedbacks that occur even within a simple modelled system.

1. Introduction

How landscapes evolve in response to the range of natural forcings is a basic scientific question that has long been examined by both qualitative and quantitative methods. Initially developed to examine natural catchment hydrology and geomorphology, numerical Landscape Evolution Models (LEMs) have become a common tool with which to examine geomorphic behaviour as well as geology, climate and the resultant soil and vegetation feedbacks. They can operate over time scales ranging from years to millennia and spatial scales from sub-hectare to entire regions (Dietrich et al., 2003; Tucker and Hancock, 2010).

A significant issue for both the short and long-term modelling of landscapes are model inputs, such as the initial landscape that is usually represented by a digital elevation model (DEM) (Perron and Fagherazzi, 2011). With the initial DEM there are two main causes for uncertainty. Firstly, a scenario uncertainty of what surface to represent: for example, if modelling a landscape several million years old how do you reconstruct this past surface? Secondly, a numerical uncertainty in how differences, errors or misrepresentations within the DEM surface can propagate during simulations to give alternative model results. For example, in landscape evolution there are a series of positive feedbacks that can lead to small surface perturbations generating significant changes as simulations progress (Ijjasz-Vasquez et al., 1992; Haff, 1996; Willgoose et al., 2003; Jerolmack and Paola, 2010).

The focus of this paper is on this second numerical uncertainty. A simple but often impracticable solution to this sensitivity is to use a very high spatial resolution for the DEM to capture surface heterogeneity. However, gaining accurate surface elevation data at a high spatial resolution can be difficult especially if we are dealing with highly variable surfaces. Additionally, modelling at a high resolution increases the number of data points or pixels in a modelled domain, increasing computational load and thus often leading to long run times (Tucker and Hancock, 2010). Therefore, LEMs use a compromise DEM resolution that is of sufficient

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detailed resolution to capture catchment and hillslope form, whilst retaining a low number of grid cells. For example, Hancock (2005) showed that a 10 m DEM is a good compromise for most catchment scale assessment where the hillslope is the feature of interest. If other features such as creeks, contour banks, roads or constructed benches on mine sites are present then the DEM must be at sufficient resolution that these features are captured.

These issues have come to the fore with the increased use of LEMs to assess rehabilitation designs for post-mining landforms. These landforms can be simply defined as man-made hills usually burying mine sites, spoil tips and other industrial architecture blended into the surrounding landscape. They are often built from materials different to that of the surrounding landscape. In the example studied here, low grade uranium ore, tailings, brines and other mine wastes will be buried at depth in the areas of the former pits.

Ideally, a rehabilitated landform is intended to (i) minimise the area of disturbance; (ii) visually and geomorphologically blend in with the surrounding landscape; and (iii) be erosionally stable over the long-term. How these landscapes evolve is of the utmost importance for the surrounding environment as any erosion in excess of that of the surrounding environment may cause pollution and sedimentation of the surrounding waterways as well as the exposure and release of harmful contaminants. Mining companies design these landscapes with these concepts in mind but with surprisingly little assessment as to how changes in the landscape design or errors in construction influence landscape behaviour in either the short or long term. Similarly, relatively little consideration appears to be placed as to whether the erosion from the landscape is tolerable for the surrounding receiving environment.

These are important issues as post mining landscapes are required to be functional geomorphological and ecological entities that re-engage sites with the surrounding non-mined landscape. It is vital therefore that the short and long-term behaviour of these landscapes be assessed and qualitatively and quantitatively understood.

This study will examine the effect of initial surface roughness and resultant differing initial conditions on sediment transport rates and geomorphology on a proposed rehabilitated landform. This initial roughness is in keeping with the surface perturbations that could be expected when a new landform is constructed including features such as 'rips' (ploughed furrows added to reduce overland flow). We investigate how sensitive landscapes are to initial conditions by assessing the temporal patterns of sediment transport as well as geomorphic form at the end of a prescribed modelling period. These issues are significant from both a basic science perspective as well as for the long term management and stewardship of post-mining environments.

2. Site description

The Energy Resources of Australia (ERA) Ranger mine is surrounded by the World Heritage-listed Kakadu National Park in the Northern Territory of Australia. The mine is immediately adjacent to Magela Creek (Fig. 1) and erosion products from the mine could potentially impact three tributaries of Magela Creek, – Corridor, Georgetown and Coonjimba Creeks, and the large catchment of Gulungul Creek to the west of the mine. Magela Creek connects to the East Alligator River through wetlands listed as "Wetlands of International Importance" under the Ramsar Convention (http://www.ramsar.org, 2003). The mine operates within some of the world's most stringent environmental requirements (http://www.environment.gov.au/science/supervising-scientist).

Mine tailings are currently stored in the above grade tailings dam and in a mined-out pit (Pit 1) and are required to be contained for 10,000 years. Mining at the site ceased in 2012, with milling and processing of ore due to cease in 2021. Consequently attention is increasingly focussing on the closure and the rehabilitation of the mine. The requirements for the closure and rehabilitation of the Ranger mine have been published as a series of 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). This will require the landscape to be rehabilitated in a way

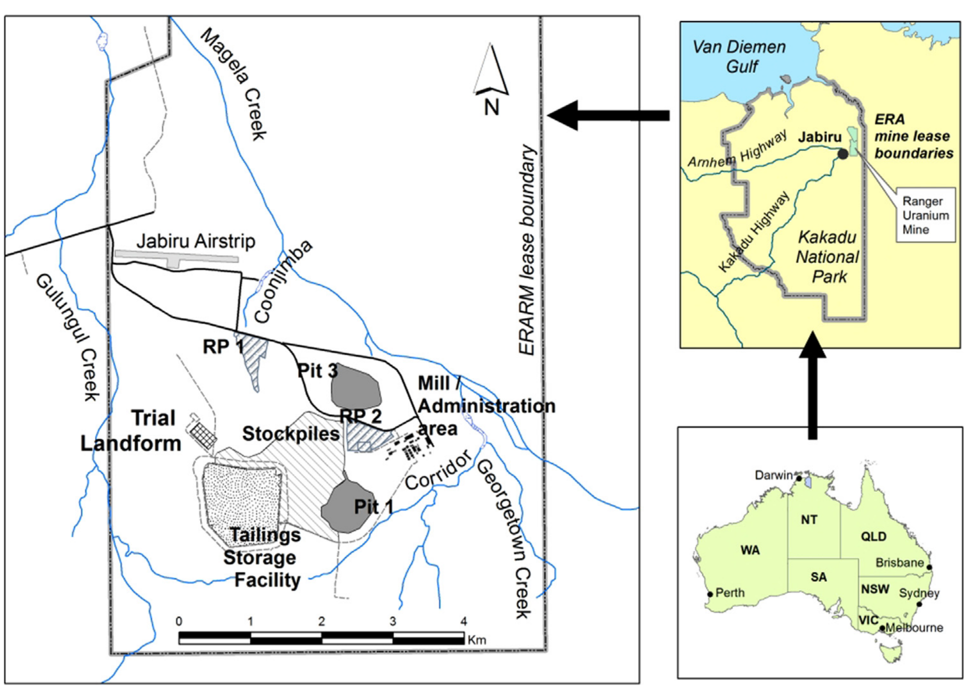

Fig. 1. Location of the ERA Range mine.