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Early landscape evolution — A field and modelling assessment for a post-mining landform

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ABSTRACT

Data from field plots describing how new surfaces evolve in the first few years post-construction are scarce in the literature. Here we examine sediment output from four similar 30 m by 30 m plots on a rehabilitated mine site over a six year period. Field measurements from the trial plots found that there is an initial high pulse of sediment over the first three years which rapidly reduces to rates similar to that expected for a natural or undisturbed surface. At 6 years the sediment output is equivalent to that expected from the surrounding undisturbed landscape. This plot data was compared to predictions from a calibrated landscape evolution model. The landscape evolution model used two sets of parameters, one derived from bare waste rock and one derived from an older vegetated surface. The simulations using bare waste parameters produced sediment output that matched the plot data in the first few years while the vegetated parameters produced sediment output which compared well with the field plot data at times > 3 years. The results demonstrate that when correctly calibrated the landscape evolution model is able to reliably predict sediment output from these field plots. These results suggest that there is the potential to employ the bare waste rock dump parameters for the first 3–4 years then switch to vegetated parameters for the longer term modelling. Both the field plots and landscape evolution model simulations displayed considerable annual variability in total load. This variability is the result of different surface structure from imposed surface roughness (ripping by a bulldozer) and their unique topographic structure. Both initial DEM and model parameters have a large influence on predicted sediment load. The results here support the reliability of the model at the sub-metre grid scale.

1. Introduction

Landform Evolution Models (LEMs) were initially developed to examine landscape evolution and dynamics at geological time scales (see Tucker and Hancock, 2010 for a review). In recent years landscape evolution models have been employed across a wide range of both natural and anthropogenic landscape systems Temme and Verburg (2011a), (Temme et al., 2011b; Baartman et al., 2013a, b). They have been used for both long-term geological assessments, short-term process studies such as rill and gully assessment and erosion modelling. While considerable effort is made to test and evaluate these models, there is a surprising lack of field data with which to evaluate LEM predictions at both the short and longer time scales (Tucker and Hancock, 2010).

Evaluating LEMs, particularly for their predictive ability in the early stages of evolution is vitally important (see Wilcock and Iverson (2003) for a review of model testing) (Temme et al., 2011b). It is this initial period which sets up the long-term landscape trajectory (Moreno-de las Heras et al., 2009). If LEMs perform poorly over the short-term it is unlikely that their predictions will be reliable at longer time scales. This issue is particularly important for disturbed systems such as post-mining landscapes. These initial surfaces, or transient landscapes, are also important from a human management perspective as it is this period where change occurs rapidly. If problems arise, such as the development of gully features, these problems may be managed by engineering earth works.

Small scale and experimental plots have been extensively used to examine geomorphic behaviour (Schumm et al., 1987). There have been a number of small scale and plot studies that have examined the ability of LEMs to predict the hydrology and sediment output. Using experimental model landforms, Hancock and Willgoose, 2002 assessed the ability of the SIBERIA model to predict landscape evolution and sediment output Hancock et al. (2000) demonstrated that the SIBERIA model could predict gully erosion on small scale plots over a 50 year time period as well as mining landscapes (Hancock et al., 2007). The CAESAR model was successfully employed at the trial plot examined here (Coulthard et al., 2012).

Here we examine the erosional behaviour of four plots on a rehabilitated mine surface over a six year period. We also examine the ability of

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a LEM to predict the erosion from these plots. Landform evolution modelling was first employed on post-mining landforms by Willgoose and Riley (1998) using the SIBERIA landform evolution model (Willgoose et al., 1989). Since then LEMs have been employed across a range of post-mining environments at both short (annual) and millennial time scales (i.e.; Evans et al., 1999; Hancock et al., 2000, 2002; Moliere et al., 2002). SIBERIA has also been successfully employed at the Nabarlek uranium mine following an assessment using the Revised Universal Soil Loss Equation (RUSLE) (Hancock et al., 2006, 2008). In more recent years the CAESAR (Cellular Automaton Evolutionary Slope And River) (Coulthard et al., 2002) and subsequent CAESAR-Lisflood model (Coulthard et al., 2013) have been used to assess rehabilitation designs on mine sites (Coulthard et al., 2012; Lowry et al., 2013, 2014).

The successful rehabilitation of a mine site is dependent on many factors, including the short- and long-term stability of the rehabilitated landform (Willgoose and Riley, 1998; Hancock et al., 2000; Evans et al., 2000; Hancock et al., 2002; Coulthard et al., 2012) in 7conjunction with vegetation establishment (Moreno-de las Heras et al., 2009). In the short-term, disturbance arising from the construction of the landform, will produce increased erosion, elevated sediment loads and transport of contaminants (Evans et al., 2000). Initial erosion establishes the patterns (i.e. rills) which may lead to gullies. Long-term landform erosional stability is important, particularly for uranium mines given the period of containment required for the products such as mill tailings. Given the Alligator Rivers Region (the focus of this study) has the second highest erosivity index in Australia (after Cape York Peninsula), long term erosional stability is a significant issue for any disturbed landscape system in the region (Williams, 1976; Duggan, 1988).

An important issue with understanding disturbed landscape systems is the availability of field data with which to quantify the processes as well as calibrate and or validate any model or model predictions and develop a long-term physical understanding (Moreno-de las Heras et al., 2009; Żołnierz et al., 2016). Data for total loads from field plots are difficult to obtain as it requires the measurement of both suspended sediment as well as bedload. Generally, there is little short term data available which could be used to evaluate LEMs. Importantly, this paper forms part of a long-term research project to evaluate landscape evolution models and their parameterisation.

The goals of this paper are to

(1) Assess field plot data to develop qualitative and quantitative understandings of landscape behaviour in the initial years of development (6 years); and
(2) Evaluate a numerically-based LEM for its ability to qualitatively and quantitatively predict the behaviour and sediment output from these plots.

2. Site description

A trial rehabilitated landform (TLF) containing 4 instrumented erosion plots has been built on the lease of the Ranger Uranium Mine (RUM). The RUM is surrounded by the World Heritage-listed Kakadu National Park in the Northern Territory of Australia (Fig. 1). The mine, is immediately adjacent to Magela Creek and tributaries to the east (Fig. 1) and the large catchment of Gulungul Creek to the west. These creeks could provide a conduit for erosion products (potentially contaminated) to be moved off the RUM. Magela Creek connects to the East Alligator River through wetlands listed as “Wetlands of International Importance” under the Ramsar Convention http://www.ramsar.org.

The RUM lies in the wet–dry tropics and receives high-intensity storms and tropical monsoons between October and April, with little rain falling for the remainder of the year. Average rainfall is approximately 1578 mm yr^{-1} (Jabiru Airport) www.bom.gov.au.

The mine operates under a set of specific Environment Requirements that are some of the most stringent in Australia. These stipulate that following mine closure, a new landform will be constructed which will need to resemble the surrounding undisturbed landscape. Further, the rehabilitated landform should have erosion characteristics similar to the surrounding environment and act as a functional containment structure for the mine tailings, which must be physically isolated from the environment for 10,000 years post-closure (Supervising

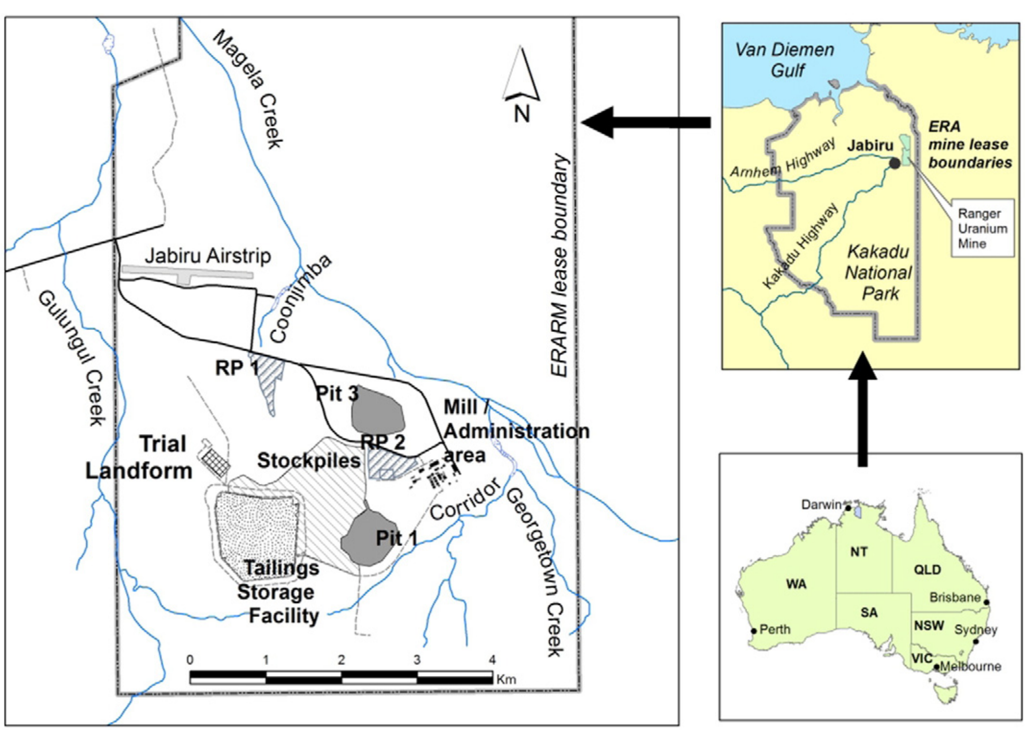

Fig. 1. Location of the Ranger mine and trial landform.