MINEROSION 3: A USER FRIENDLY INTEGRATED PACKAGE FOR MONITORING AND PREDICTION OF POTENTIAL EROSION FROM STEEP MINESITES

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Abstract

Modern open cut mining results in landscapes with very steep slopes (37^o) which are generally very saline and highly erodible. They pose a threat of off-site pollution through the release of fine sediments and salt. These slopes must be reduced before rehabilitation can be commenced. A user-friendly integrated erosion and landscape design package, MINErosion 3, was developed (a) to accurately predict potential field scale erosion rates from laboratory derived parameters; (b) to derive suitable slope length and gradient parameters that result in acceptable erosion rates; (c) to monitor erosion rates at different stages of rehabilitation, (d) to provide an estimation of the potential range of erosion rates associated with variability of material properties, and (e) as an educational package.

The MINErosion package allows the use of laboratory based parameters or parameters collected using a laboratory or portable field rainfall simulator, for the predictions of potential field scale erosion. The package was validated against erosion rates from large field plots with excellent results. Predicted annual erosion rates are highly significantly correlated to measured annual soil loss with a slope of 0.9. The package includes a database of 34 soils and overburdens which should be useful for mine environmental planning. It is also useful for the processing of new experimental data, as well as an educational tool.

Additional Keywords: erodibility, landscape design, mine rehabilitation, rainfall simulation

Introduction

Modern open-cut mining and associated activities necessitate the disturbance of large areas of land, which must be stabilized and rehabilitated following mining operations. They give rise to landscapes with very steep slopes (37^o) which are generally very saline and highly erosive. Hence, they pose a threat of off-site pollution through the release of fine sediments and salt. These slopes must be reduced before rehabilitation can commence. In central Queensland, Australia, the area disturbed by open-cut coal operations exceeds 50000 ha (Welsh *et al*., 1994). The first step in mine-site rehabilitation is the design of the post-mining landform, which is also the most expensive component of the rehabilitation process as it involves extensive earthworks requiring heavy plant and equipment. A recent survey by the Australian Centre for Mining Environment Research puts the average cost of rehabilitation at around $22,000 per hectare .`The primary aim of the earthworks is to produce a post-mining landscape, which is resistant to geo-technical failure and to surface erosion processes from rainfall and runoff. The extent and cost of earthworks may be minimized, and rehabilitation failures avoided, if soil erosion from design landforms can be predicted prior to construction. The ability to predict erosion can also be used to design landforms that meet the criteria of acceptable erosion rates.

Soil erosion prediction models have been developed almost exclusively to solve erosion problems associated with agricultural land use. The surface media, topography, management practices and the economics of minesite operations are very different to those found in agricultural settings, so agriculturally based models may not work under these different conditions or they may not satisfy the requirements of the minesites. Long term field plots (Middleton, *et al.*, 1934; Barnett and Rogers, 1966; Wischmeier and Mannering, 1969; Elliot *et al.*, 1989) are generally used to derive the soil erodibility parameter. Data collection are expensive and time consuming as it depends on natural rainfall events. If parameterisation of the soil can be achieved using laboratory soil physical-chemical characteristics, or be conducted using a laboratory scale or small portable field rainfall simulator, it will be a very cost-effective methodology that is independent of rainfall patterns and can assist in the design of postmining landscapes that meets the requirement of acceptable erosion rates.

This paper describes a user friendly integrated package, MINErosion 3.01 (Figure 1), that can be used to:

- accurately predict potential field scale erosion rates from laboratory derived parameters;
- derive suitable slope length and gradient parameters that result in acceptable erosion rates;
- monitor erosion rates at different stages of rehabilitation;
- provide an estimation of the potential variability of erosion rates using the soil properties; and
- as an educational package.

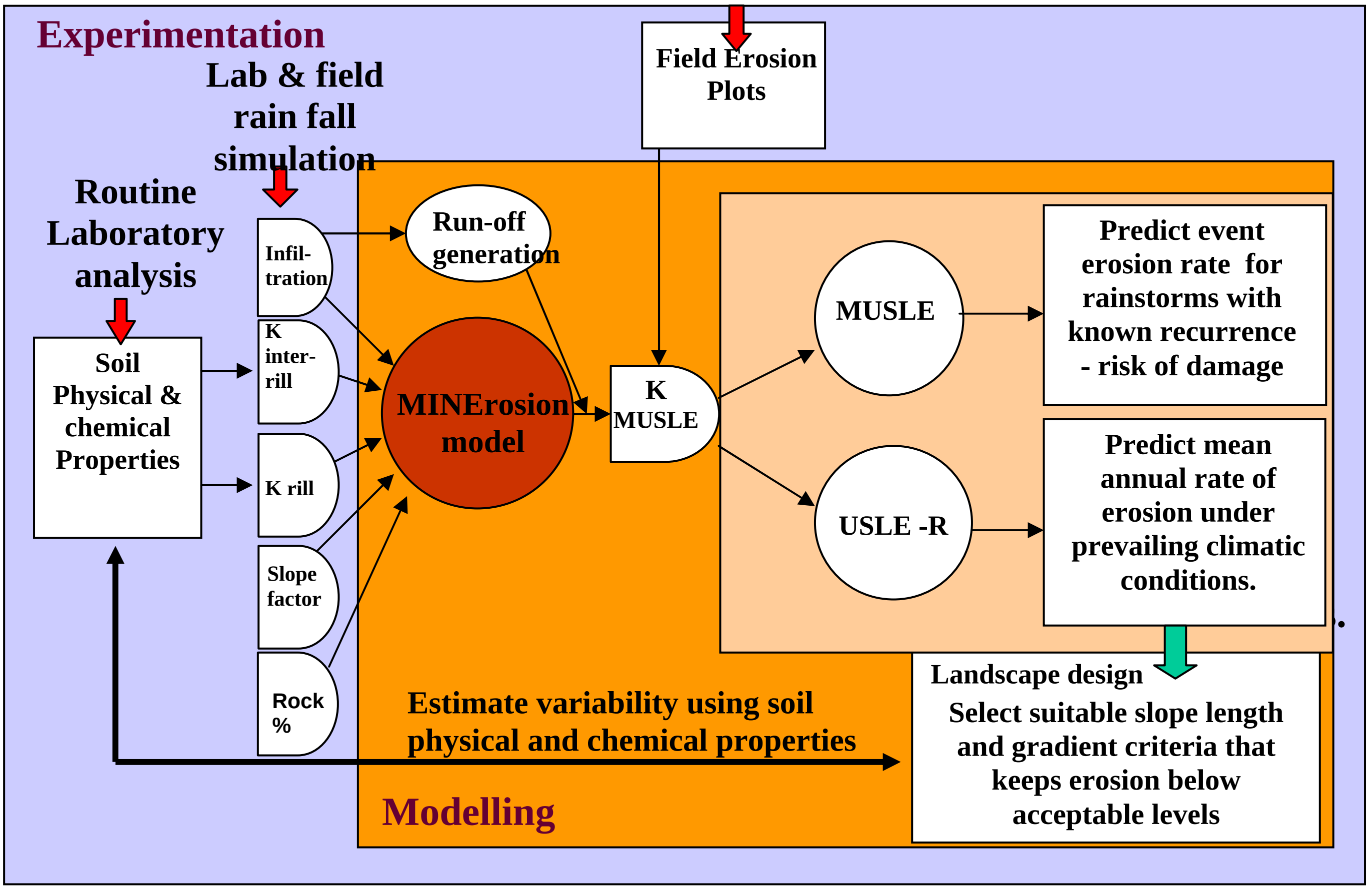


Figure 1. A schematic diagram of the structure of MINErosion 3.01 package. Experimentally, entry into the package can be made at 3 different levels: using estimation from laboratory derived soil properties, using data derived using lab or field rainfall simulation, or using data derived from field erosion plots which is the most common method for erosion measurements. Prediction of erosion rates is made using a modified USLE-R model for annual erosion rates, or the Modified USLE for erosion from rainstorm events.

The package covers details of various methods of data collection including the traditional field erosion plots (the experimental box in Figure 1) and the simulation of field plots and field slopes to derive mean annual soil loss and soil loss from individual rainstorm events (the modelling box in Figure 1). In this package, laboratory derived soil parameters are used for the reliable and accurate prediction of potential soil erosion based on a modified version of the widely used Universal Soil Loss Equation, the USLE-R. Contrary to the USLE which used general functions for some soil parameters, the simplicity of lab based data collection allows soils to be individually parameterised which leads to a high accuracy of predictions using this package.

Central to this package is the MINErosion model which simulates sediment delivery or erosion rates from plots with various combinations of slope length and gradient. Inputs into this model are infiltration rates, rill and inter-rill erodibilities, slope adjustment factor and a rock cover factor (Sheridan *et al.*, 2000a; Sheridan *et al.*, 2000b). These parameters are derived from small tilting flumes (3 m x 0.8 m) under rainfall simulations of 100 mm h^{-1} and conducted on at least 4 different slopes. All parameters can be derived using small field rainfall simulators except for the slope adjustment factor.

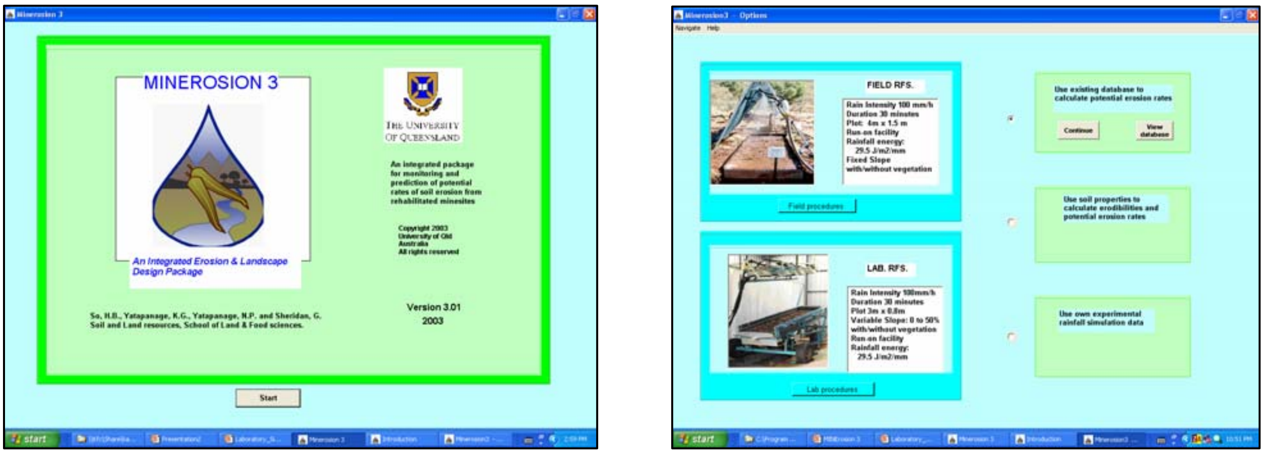
Since the USLE requires parameters appropriate for a standard plot of 22.1 m length and 9 % slope, the combined rill and interrill erodibility (K_{MUSLE}) was derived for the standard plot using the Modified USLE (Onstadt and Foster, 1975). Run-off characteristics were derived from rainfall, infiltration and plot characteristics using the run-off generator, which is a modified version of the Rational method. For convenience, the standard slope adopted was 10 % instead of 9 %. K_{MUSLE} was assumed to apply for both the MUSLE and the USLE-R. Unlike the USLE, K_{MUSLE} in this package can be modified by a soil consolidation factor to account for the effect of time (years) after rehabilitation, which is derived from field measurements. This consolidation factor accounts for the effect of repeated wetting and drying and the presence of plant roots.

The USLE-R is similar to the USLE or RUSLE in most respects. However, K_{MUSLE} was used as the erodibility parameter instead of the K_{RUSLE} estimation as described in the RUSLE-2 guidelines, which was predominantly a function of texture (RUSLE2, 2004). This erodibility factor K_{MUSLE} is used for both the MUSLE and USLE-R. Unlike the USLE where the vegetation cover factor represents the effect of above and below ground components of plants grown on the soil, in this package the vegetation cover factor only represents the protective effect of the above ground components. The effect of the below ground components is included in the consolidation effect on $K_{MUSLE.}$ This separation allows the simulation of erosion from freshly applied unconsolidated to consolidated sites where bushfires can reduce the amount of above ground cover.

An interesting feature of this package is the ability to derive rill and inter-rill erodibilities from soil or spoil physical and chemical properties. Therefore, it is possible to gain an estimate of the potential variability of erosion rates from readily accessible soil properties.

The Computer Application MINErosion 3.01.

The MINErosion 3.01 package is a user friendly visual basic (VB.NET) program and can be downloaded free from www.uq.edu.au/soils/. The program contains a database of 34 soils and overburdens from Queensland which is locked. The user can select one of three options to proceed (Figure 2). The first and main option is to use the existing database to estimate erosion rates on one or more of the soils or overburden material of interest, which is intended for the environmental officer or consultant. The second option is to use your own soil with known properties, while the third option is to enter your own set of data derived from lab or field rainfall simulation. Access to details of procedures for experimental measurements and explanation of the theoretical aspects are available through buttons in the appropriate pages. Where available, validation of predicted vs measured data is accessible as a menu item (Figure 3). The application's first and main option pages are shown in Fig 2.



An integrated package for monitoring and prediction of potential rates of soil erosion from rehabilitated minesites

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Rain Intensity 100 mm/h
Duration 30 minutes
Plot: 4m x 1.5 m
Run-on facility
Rainfall energy:
29.5 J/m2/mm
Fixed Slope
with/without vegetation

Rain Intensity 100mm/h
Duration 30 minutes
Plot 3m x 0.8m
Variable Slope: 0 to 50%
with/without vegetation
Run-on facility
Rainfall energy:
29.5 J/m2/mm

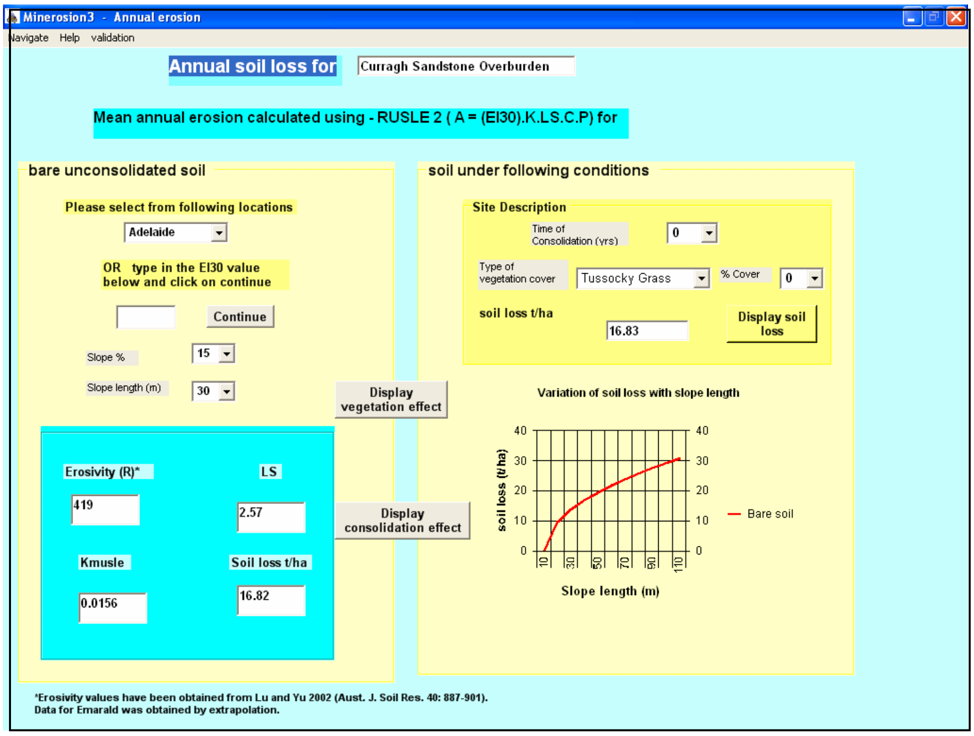
● Use existing database to calculate potential erosion rates

○ Use soil properties to calculate erodibilities and potential erosion rates

○ Use own experimental rainfall simulation data

Figure 2. Front page and the main option page of the MINErosion 3.01 application.

MINErosion predicts mean annual soil loss and erosion events for two possible conditions on the same page (Figure 3). On the left is the soil loss from a freshly exposed unconsolidated material subject to the selected conditions. Erosivity EI30 is calculated from the Australian climatic database using the method by Lu and Yu (2002) for tropical climates. On the right side soil loss is calculated for similar slopes that are consolidated and where vegetation cover is established. The consolidation and vegetation cover effects can be displayed by clicking the appropriate buttons. The graph shows the annual soil loss as a function of slope length. A reference graph for the unconsolidated material is shown as a default. Two other graphs can be displayed and compared. MINErosion can also be used to predict erosion from different storm events with known probability of occurrence. Clicking the 'validation' menu at the annual soil loss screen will display a comparison of predicted vs measured annual soil loss (Figure 4). Fig 4 shows that MINErosion 3.01 predicts 90 % of the measured annual soil loss with an r^2 of 0.84 despite the presence of an outlier from the Curragh minesite.



Annual soil loss for: Curragh Sandstone Overburden

Mean annual erosion calculated using - RUSLE 2 (A = (EI30).K.LS.C.P) for

bare unconsolidated soil

Please select from following locations: Adelaide

OR type in the EI30 value below and click on continue

Slope %: 15

Slope length (m): 30

Erosivity (R)*: 419

LS: 2.57

Kmusle: 0.0156

Soil loss t/ha: 16.82

soil under following conditions

Site Description

Time of Consolidation (yrs): 0

Type of vegetation cover: Tussocky Grass

% Cover: 0

soil loss t/ha: 16.83

*Erosivity values have been obtained from Lu and Yu 2002 (Aust. J. Soil Res. 40: 887-901).
Data for Emarald was obtained by extrapolation.

Figure 3. The page in MINErosion 3.01 showing the calculations for mean annual soil loss on unconsolidated (left) and consolidated (right) material.

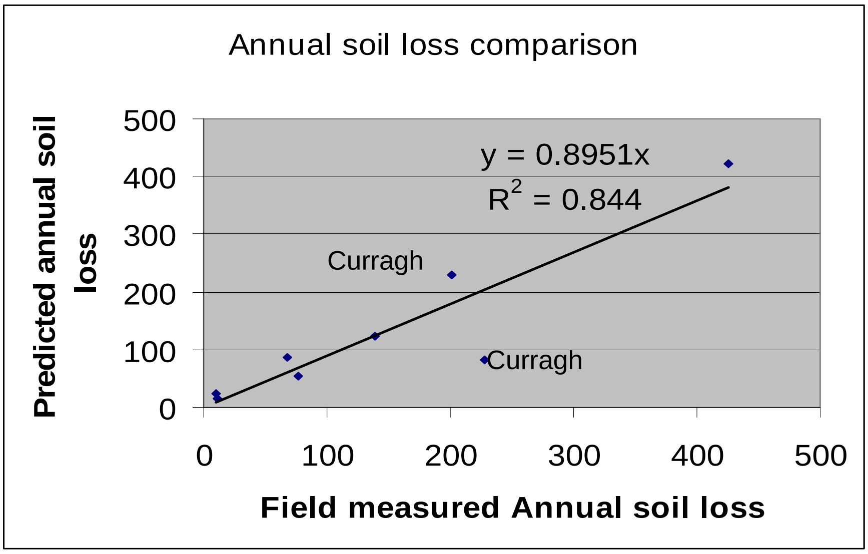


Figure 4. Predicted and measured annual soil loss for Curragh and Oakey creek mines (av of 4 years) and for Kidston Gold Mine (one year data) shown as white squares.

Conclusions

The MINErosion 3.01 package can be used to make accurate predictions of potential field erosion rates using laboratory based input parameters. The adoption of this package will contribute to reducing the cost and efficiency of erosion research and erosion monitoring programs.

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