Mine-Erosion: An Integrated Erosion and Landscape Design Package for Monitoring and Modeling Erosion from Steep Hillslopes on Minespoils

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Abstract: Rapid modern open cut coal mining results in minespoils or overburden landscapes that have slopes at the angle of repose (37°) which are highly erodible and are generally very saline. These landscapes pose a significant threat of pollution to the surrounding environment through the release of fine sediments and salt. Therefore, it is essential that these slopes be reduced and stabilized before any other effort in rehabilitation can be commenced. However, the necessary slope gradient that will result in acceptable rates of erosion is not known for the different soils or spoils. The current guidelines used by regulatory authorities in Australia were derived from low slope agricultural lands and are not suitable for minesites.

A user-friendly multi-purpose Integrated Erosion and Landscape Design Package was developed with the MINErosion model as the central component that links laboratory derived parameters to field erosion processes. The MINErosion package can be used (1) to determine the design criteria for hillslopes that will meet the requirement of acceptable erosion rates, such that it can be incorporated into the landscape design packages at the mines, (2) to monitor erosion rates from new and rehabilitated landscapes, (3) to determine the natural rates of erosion from undisturbed landscapes, and (4) to analyze data derived from field erosion plots.

The central component of the package is the MINErosion model, which allows the use of laboratory based parameters or parameters collected using a portable field rainfall simulator, for the predictions of field scale erosion. MINErosion is a steady state erosion process model that combines the processes of inter-rill/sheet erosion with rill erosion. MINErosion assumes a simple straight hillslope and hence the steady state is adequate to represent the net erosion losses (entrainment - deposition) from that slope, and is adequate to represent slopes on rehabilitated landscapes.

The erodibility K (susceptibility to erosion) is an inherent soil property and should therefore be related to properties that can be measured during routine soil analysis. These relationships are highly significant and are as follows:

Soil: Interill erodibility $(K_i) = 3.72–0.8891\ (OC)\ (r^2 = 0.59)$

Rill erodibility $(K_{r3}) = 63.96 + 0.00008797(0.02\% – 1mm)^3–3.20(pH) – 30.47(BD)$ $(r^2 = 0.71)$

Overburdens:

Interill erodibility $(K_i) = –2.8307 + 0.11089(CLAY) + 4.13(D20)\ (r^2 = 0.82)$

Rill erodibility $(K_{r3}) = 25.02 – 30.55(D20) – 0.18(ESP) + 4.80(EC)\ (r^2 = 0.61)$

The validity of the package and the accuracy of some of the predictions have been verified and shown to be accurate. Further testing and validation are underway.

The MINErosion package should be equally applicable for steep cultivated hillslopes in developing countries and can be employed to assist in the development of suitable management practices that will arrest or minimize erosion from these hillslopes.

Keywords: MINErosion, minesite erosion, landscape design, interrill erosion, rill erosion, hillslope erosion

1 Introduction

Modern open cut coal mining in Australia uses draglines which remove overburden with great efficiency and results in minespoils or overburden landscapes with steep slopes at the angle of repose

(37°). These slopes are highly erodible and are generally very saline. These landscapes pose a significant threat of pollution to the surrounding environment through the release of fine sediments and salt. Therefore, it is essential that these slopes be reduced and stabilized against erosion before any other effort in rehabilitation can be commenced. However, the slope gradients that will result in acceptable rates of erosion for the different materials are not known.

Existing erosion models were not suitable for designing landscapes, due to the high degree of inaccuracy in their predictions. The USLE and its derivatives and other erosion models (WEPP, etc) were designed as a land management tool to provide guidance in making decisions on agricultural land management and were not designed for accuracy of predictions on mined lands. They were developed to deal with fixed low slope gradients on soils with a relatively narrow range of limitations compared to disturbed mined land. For agricultural planning purposes, it was acceptable to derive generalized functional relationships using data from a few soils and assume they will apply to all soils. Hence errors in predictions were large and could not be tolerated for mined land rehabilitation planning as failures of rehabilitated landscapes will result in large economic cost and may render some mines unprofitable. Other process-based models (GUESS, EROSION 2D/3D) are excellent models but are difficult to parameterize and are therefore limited in their usefulness for mine landscape design.

The criteria for acceptable erosion rates was not known and was tentatively derived from criteria for the low slope agricultural situation, which was 12.5 t/(ha • y). A more suitable criteria for acceptable erosion rates would be the level of natural rates of erosion from surrounding unmined sites, however there is no information available on such rates. Difficulties associated with measuring natural rates of erosion have resulted in an almost total absence of such data globally. Hence a starting point adopted by the regulatory authorities was those derived from agricultural slopes. Landscapes were required to be reduced to less than 15 % with maximum erosion rates of 12.5 t/(ha • y). However, observations on natural rates of erosion in the semi-arid regions of Australia indicates that they can be much larger than 12.5 t/(ha • y) It was also clear from the range of material from minesites that there is a wide range of susceptibility to erosion which, if known, would lead to different slope gradient requirements to meet the criteria of acceptable erosion rates. And if natural rates of erosion can be estimated with reasonable reliability, it will provide a more realistic criteria of acceptable erosion rates. Hence the Australian opencut coal mining industry have a strong interest in the development of better erosion monitoring methodology and modeling as it may represents significant cost savings if steeper slopes are acceptable. At present the average cost of rehabilitation is $ 25,000/ha which is largely the cost of earthworks for lowering the slope gradient. In Queensland alone, there are more than 50,000/ha of disturbed landscapes from opencut coalmining that requires rehabilitation. A research project was initiated to develop cost-effective methodologies for erosion measurements and predictions and was funded between 1992—1998 by the Australian Coal Association Research Program and the Coal Mining Industry. The outcomes at the completion of this project was a database of 33 soils and spoils from field rainfall simulations and field erosion plots, and a series of erosion models that are useful to the mines for the design of their post-mining landforms.

One important outcome was that we were also successful in using laboratory based soil properties and erosion parameters from laboratory rainfall simulations, for the predictions of erosion rates from field erosion plots with good accuracy and reliability. A simple robust model was developed for this purpose called MINErosion as the interface between laboratory and field processes. However, the models derived were not easy to use and require considerable experience to apply them to the needs of the mining industry. A user friendly integrated set of models is needed by the industry.

The objective of this paper is to report on the development of a user-friendly multi-purpose integrated package that links laboratory based parameters through the MINErosion model to the RUSLE and the MUSLE (Onstadt and Foster, 1975) models. This package (referred to as the MINErosion package) can be used (1) to determine the design criteria for hillslopes that will meet the requirement of acceptable erosion rates, such that it can be incorporated into the landscape design packages at the mines, (2) to monitor erosion rates from new and rehabilitated landscapes, (3) to determine the natural rates of erosion from undisturbed landscapes, (4) to be used to analyze data derived from field erosion plots and (5) to rapidly parameterize new soil or spoil.

2 The MINErosion package and validations of its components

A schematic overview of the package is given in Fig.1. The central component of the package is the MINErosion model which allows the use of parameters collected using a portable field rainfall simulator or laboratory based soil physical-chemical parameters, for the predictions of field scale erosion. MINErosion is a steady state erosion process model that combines the processes of inter-rill/sheet erosion with rill erosion similar to the basic WEPP model. A default assumption of 1 (one) rill per m width of hillslope was adopted which applies to many minesites. However when necessary, it can be modified to any rill density. MINErosion assumes a simple straight hillslope and hence the steady state is adequate to represent the net erosion losses (entrainment-deposition) from that slope, and is adequate to represent slopes on rehabilitated landscapes. MINErosion requires 5 input parameters of interrill and rill erodibilities, infiltration rates, surface cover factor and rock content. The first four can be derived using the laboratory or field rainfall simulator.

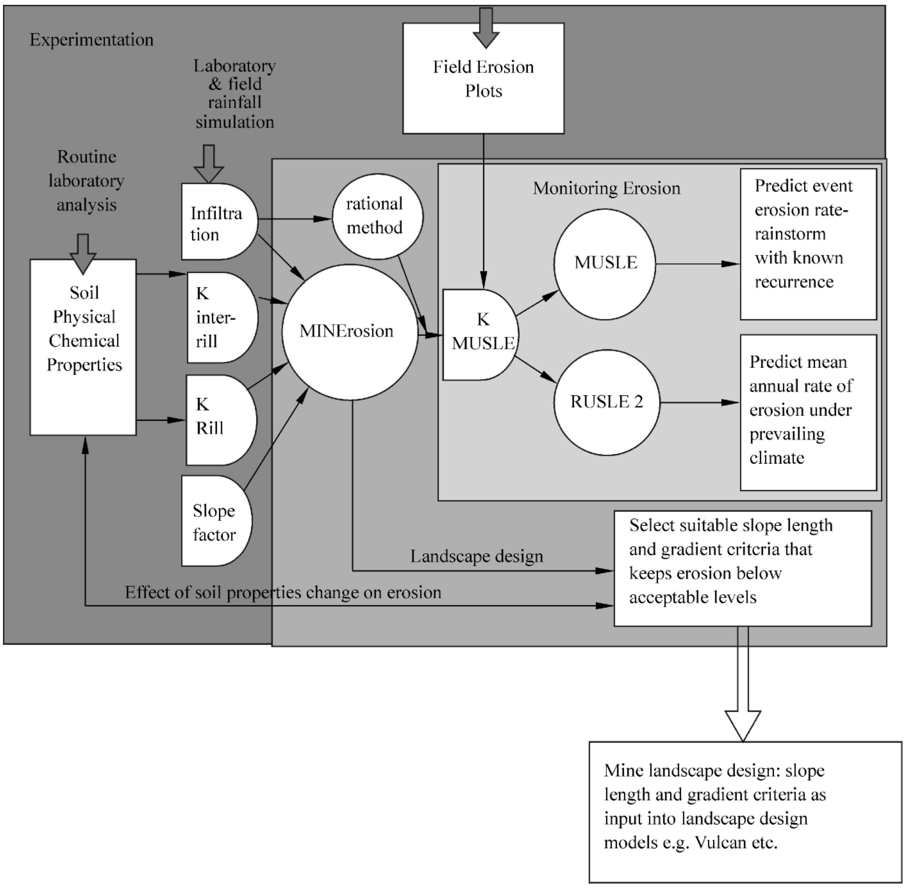

Fig.1 Schematic diagram of the MINErosion Package and how it can be linked to the mine landscape design packages.Red arrow indicate possible entry points into the package

MINErosion can also link routine laboratory based measurement of soil physical and chemical properties with field processes. The erodibility K or the susceptibility to erosion is conceptually an inherent soil property and should therefore be related to properties that can be measured during routine soil analysis. The following relationships are highly significant:

Soils: Interill erodibility $(K_i) = 3.72 - 0.8891(\mathrm{OC})$ $(r^2 = 0.59)$

Rill erodibility $(K_{r3}) = 63.96 + 0.00008797(0.02\%\text{–}1\mathrm{mm})^3 - 3.20(\mathrm{pH}) - 30.47(\mathrm{BD})$ $(r^2 = 0.71)$

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The link between the laboratory flume derived parameters and the field is shown by the excellent agreement between predicted sediment delivery and the actual measured sediment delivery from a 12 m rainfall simulator in the field (Fig.2), and the good agreement between predicted soil loss and measured soil loss from a 130 m slope at Kidston Gold Mine (20º slope) shown in Table 1.

Therefore, it is clear that soil loss can be predicted for any length of slope when subjected to a rainstorm with an intensity and duration similar to that of the rainfall simulator. Essentially we can use the laboratory flume to simulate the processes in a large field erosion plot.

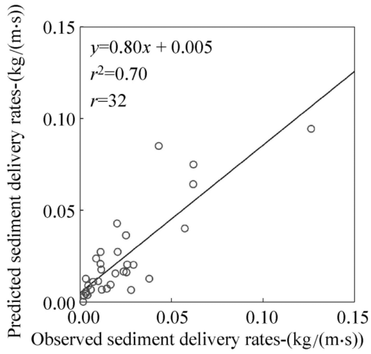

Fig.2 Predicted and measured sediment delivery for a 12 m field rainfall simulator plot

Table 1 Predicted and measured soil loss (t/ha) from a 130 m long slope at 20º slope and 70 m slope at 37º slope. Prediction were made with the MINErosion model and subjected to a 30 min 100 mm/h rainstorm

	Plot 6 20º slope, bare soil 130 m slope	Plot 4 20º slope, vegetated 130 m slope	Plot 9 37º slope, vegetated 70 m slope
Calculated soil loss (t/ha)	374	186	79
Predicted soil loss (t/ha)	251	190	62

As rainfall simulations also provide basic information on run-off generation, the use of the well known rational method can be used to estimate the total run-off and peak run-off rate for that storm-slope combination. This allows the estimation of the combined rill and interrill erodibility (K_{MUSLE}) using the Modified Universal Soil Loss Equation-MUSLE (Onstadt & Foster, 1975) which otherwise have to be measured using field plots which is an expensive exercise. Successful estimation of K_{MUSLE} provides the link to the most widely used erosion models (RUSLE and MUSLE). MUSLE can be used to predict the potential rate of erosion from rainstorm with known recurrence intervals, which provides information on the risk from erosion damage. Validations on the accuracy of these predictions are currently underway. RUSLE can be used with the appropriate K_{MUSLE} to predict the mean annual rate of erosion subject to the prevailing climatic conditions. Rainfall erosivity of tropical rainstorms are derived modified EI30 using the method of Yu (1998). The agreement between predicted mean annual soil loss at Kidston and measured annual soil loss are excellent. (Table 2).

Table 2 Predicted (using RUSLE 2) and measured annual soil loss from a 130 m long 20º slope and a 70 m long 37º slope at Kidston Gold Mine

Year plots established and age of plots	Treatments	Predicted mean annual soil loss (t/ha)	Measured mean annual soil loss (t/ha)
1996 — 3 years	20º slope, bare	421	425
1996 — 3 years	20º slope, grassed	86	68
1991 — 9 years	17º slope, grassed	14.5	11.3
1991 — 9 years	37º slope, grassed	24	9.6

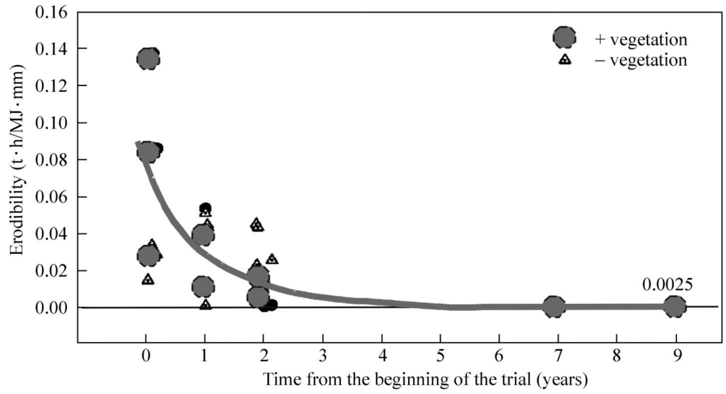

Fig.3 Changes in K_{MUSLE} with time of rehabilitation as measured on field erosion plots at Kidston Gold Mine in North Queensland

The portability of the field rainfall simulators implies that it is possible to conduct simulations on rehabilitated landscapes and examine the changes that has occurred during the early years of rehabilitation to assess the risk of erosion damage. Fig.3 clearly show that K_{MUSLE} tends to decrease exponentially with age of rehabilitation, indicating that 90 % of maximum stability is achieved after 4 to 5 years. This is useful information for planning rehabilitation programs as it provides the window of risk that needs to be considered within a rehabilitation program. Similarly, the MINErosion package can be used with data collected from field plots.

3 Potential use of the MINErosion package

Erosion is the main human induced form of degradation and is estimated to affect 1,000 Mha globally. It is considered as the main problem threatening sustainability of agricultural production. As the global population increased rapidly over the last 50 years, farming activities has progressively moved from the lower slopes to the steeper portions of the landscapes resulting in very high rates of erosion from these steep lands. This is a major problem in the developing countries and in many regions the degree of degradation on these lands is rapidly reaching a critical point beyond which productivity will decrease very rapidly. In many regions the regional hydrology has been altered resulting in increased flooding (associated with decreased infiltration into the soil) and reduced groundwater flow and storage. To arrest or minimize degradation from erosion on these lands, improved management practices needs to be developed for each region. To do this, it is necessary that we can readily and cost effectively parameterize, monitor and predict erosion rates from these steep lands. The MINErosion package can be used for that purpose and national or international database of erosion parameters can be developed rapidly and cost effectively. For this reason, the MINErosion package will be released into the public domain arena at the appropriate time.

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