5 Future research

5.1 Introduction

This report discusses major progress in the research area of GIS application to the assessment and management of mining impact. Three areas have been identified as requiring further study in order to provide a more valuable approach to assessing mining impact: (i) the incorporation of spatial variation in SIBERIA input parameter values in the modelling process; (ii) an analysis of the sensitivity of the SIBERIA model to input parameter value variations or error; and (iii) the practical application of the developed technology to assessing the impact of the ERA Jabiluka Mine on landform evolution in the Ngarradj catchment.

5.2 Incorporation of spatial variation in parameters

5.2.1 Parameter value derivation

The landform evolution model, SIBERIA, has been used to investigate erosion and hydrological processes operating on post-mining landforms (Evans et al 1998, Willgoose & Riley 1998, Hancock et al 2000b) and small natural catchments (<55 ha) (Hancock et al 2000a). However, the majority of these studies have been conducted using constant parameter values reflecting the initial conditions of one area of the landform or catchment with no consideration of the spatial variation in surface conditions, such as vegetation cover, soil erodibility or management practices. A recent study by Ferguson (1999) is the first attempt to incorporate the spatial variation in parameter values into the SIBERIA landform evolution modelling process. The study by Ferguson investigated the effect of spatial variation in surface treatment parameters on SIBERIA simulations of the proposed ERA Ranger Mine above-grade rehabilitated landform. Through comparison of a spatially varied simulated landform with landforms derived through three single parameter simulations, it was found that the inclusion of spatial variability significantly altered the evolution of the landform. Further studies were found to be required to establish whether these differences were natural or consequences of the modelling process, caused by inaccuracies in the modelling of spatial variation or the use of an excessively coarse grid cell resolution.

This project, representing the first attempt to apply SIBERIA to the assessment of mining impact on a medium-sized catchment, will require the inclusion of the spatial variation in parameter values to accurately model landform evolution. The total Ngarradj catchment, covering an area of almost 67 square kilometres, includes 3 major geomorphic regions including the Ngarradj backwater floodplain adjacent to the Magela floodplain, the Ngarradj lowlands with deep sandy soils and an upland plateau region with highly dissected sandstone and shallow sandy soils. When modelling long-term landform evolution in a catchment of this size, it is necessary to consider the natural heterogeneity in landform surfaces. The derivation and spatial mapping of these natural catchment parameters will occur through analysis of the gauging station data as well as DEM and remotely sensed imagery classifications.

Research by Ferguson (1999) at the ERA Ranger Mine has also demonstrated the impact of including mine site heterogeneity in the modelling process. The assessment of landform evolution at Jabiluka and the wider Ngarradj catchment should include parameters for different surface treatments on the mine site. It is proposed to use a portable rainfall simulator to collect runoff, infiltration and sediment loss data from disturbed and undisturbed sites on the ERA Jabiluka Mine site. Three replicates will be conducted on sites such as the cap of the waste rock dump, the batter slopes of the waste rock dump and undisturbed natural sites. Rainfall simulations are to be used in this study as the current intense stream monitoring program conducted in Ngarradj during the Wet season makes it logistically difficult to conduct plot monitoring. The simulator has been calibrated and successfully used during a 6 year project covering 14 central Queensland coal mines (R Loch pers comm 2000).

5.2.2 Spatial variability in SIBERIA

SIBERIA considers the landform evolution of a catchment through two main components, elevation variation and channel network development (Willgoose & Riley 1998). The model considers the elevation change and potential for channel network development on each cell within the DEM on which it operates. Spatial variability is included in SIBERIA's assessment of landform evolution through the definition of regions within the DEM for which individual sets of erosion and runoff parameters are applied. Regions are defined as individual files consisting of the x and y coordinates of the boundary of the region. The region boundary files remain constant throughout the simulation period. Each region has an associated set of erosion and runoff input parameters (β_1, m_1, n_1, β_3, m_3). The erosion parameters are stored in a single generic 'erode' file which subsequently relates to each region file, applying the particular set of parameters when SIBERIA operates on the defined region in the DEM.

The SIBERIA landform evolution model is a complex model that not only considers the parameters associated with a single cell, but also examines changes in the surrounding cells. That is, the erosion and runoff properties associated with a cell influence its elevation variation, which subsequently influences the direction in the which the output mass (or elevation) is moved to. Therefore, including parameter spatial variability in a SIBERIA landform evolution simulation does not simply result in the same landform development in the area described by a region for a single parameter simulation using the parameters prescribed for that region, but actually results in elevation changes that are influenced by surrounding regions (ie the whole is greater than the sum of the parts) (Ferguson 1999). However, the application of regions results in distinct boundaries where parameter values change abruptly. This trend is generally not demonstrated in nature with most soil properties changing gradually through space. This study will examine the effect of incorporating transitional parameters to represent the areas that exist between distinct landforms in order to approximate the gradual transition.

5.3 Sensitivity analysis of SIBERIA

Many hydrological and erosion modelling studies employ sensitivity analyses to methodologically investigate the response of selected output variables to variations in parameters and/or driving variables (Veihe & Quinton 2000). Sensitivity analysis studies are of particular importance in complex models, such as SIBERIA, as the model complexity frequently induces uncertainties in model output due to the propagation and compounding of errors in input parameter estimation through the modelling process. Sensitivity analysis provides a method by which model parameters can be ranked based on their contribution to overall error in model predictions. It describes model uncertainty because it indicates the expected errors in model prediction which will be attributable to errors in model parameters (Tiscareno-Lopez et al 1993). Furthermore, a detailed evaluation of a model's response can yield a great deal of insight into the nature of the model. In fact, to the degree of accuracy with which a model simulates a physical system, sensitivity analysis can provide considerable information on the influence of individual factors on the response of the physical system (Nearing et al 1990).

Uncertainty in the modelling process can be derived from three sources including structural uncertainty, parameter uncertainty and input uncertainty. Structural uncertainty refers to the inadequacy and the incompleteness of the model in accurately representing the physical system being studied. Parameter uncertainty arises from the uncertainty associated with parameters that are generally fixed in the model and not normally adjusted by the user. The final source of uncertainty, input uncertainty, refers to errors associated with the measurement or derivation of input data for the model (Chaves & Nearing 1991). This study will investigate the impact of input uncertainty on the SIBERIA modelling process.

Several sensitivity analysis methods exist ranging from simple analysis, where individual input variables and parameters are changed and the model output examined (De Roo 1996), to methods based on the Monte Carlo simulation, where a number of random parameter selections are made based on the input variables' probability distributions (Veihe & Quinton 2000). The Monte Carlo simulation method is suitable for complex non-linear models where the input parameters' probability distributions can be described and for models that involve the use of time-dependent driving variables (Tiscareno-Lopez et al 1993, Samper & Carrera 1995, Veihe & Quinton 2000). Through repeated numerical sampling from the input variables' probability distribution, a large number of samples of finite size are created. Estimation techniques are then applied to the samples and the distributions of the estimates are studies in relation to the true parameter values and to theoretical expectations about asymptotic distributions (Veihe & Quinton 2000).

The SIBERIA landform evolution model is being developed by the model's author to support Monte Carlo simulations. When the software packages have been modified, a quantitative risk assessment (QRA) study of the ERA Jabiluka Mine is proposed (G Willgoose pers comm 2000). The risk assessment will involve (a) the input of the error data into the new version of SIBERIA, (b) the running of the Monte Carlo simulations and (c) the analysis of the simulation output to determine the probability distribution of the desired environmental assessment. The computational demands of the proposed Monte Carlo simulation will be large. To put these demands in perspective, a 1000 year simulation using SIBERIA V8.10 of a 20 000 cell DEM (Willgoose & Riley 1998) takes about 30 minutes on a 500 MHz Pentium III running Windows 2000. Thus a 10 000 realisation simulation would take approximately 200 days. It is proposed that the runs will be done on a Tornado workstation cluster, which is optimised for doing large Monte Carlo simulations. This will allow the elapsed time to be reduced to about 10 days.

SIBERIA will not be modified to provide statistical analysis of the simulations as this would limit the analysis to those described in detail by the user prior to the Monte Carlo simulations being performed. Rather, results from all the simulations will be stored for later analysis in order to provide the most flexible approach to the final error analysis. However, this will require the availability of a very large amount of disk space. A considerable section of the final analysis will be conducted within the Ngarradj GIS.

The current estimation of the minimum number of realisations that should be considered is 10 000. However, it may be possible to reduce that number slightly once experience has been gained with some smaller test runs of the modified code. This estimate is based on a simple calculation in which the probability of failure was assumed to be 1 in 1000.

Table 13 shows the probability of observing no failures whatsoever in any of the realisations (ie the simulations would indicate that the project is acceptable when in fact it is not). Only with 10 000 simulations will the probability of saying something is acceptable, when in fact it is not, be acceptably low.

Table 13 Probability of having no failures for a set number of realisations (G Willgoose pers comm 2000)

Number of realisations	Probability of no failures
100	0.90
1000	0.37
10 000	4.5 e-5
100 000	3.5 e-44

5.4 Application to the assessment of mining impact

One of the primary advantages of linking environmental models to a GIS is the possibility of rapidly producing modified input-maps with different management practices to simulate alternative scenarios (De Roo 1996). Desmet and Govers (1995) for example, were able to rapidly assess the impact of varying a length proportionality factor on landform evolution within an agricultural landscape by using a GIS based simple landscape evolution model. The final objective to be achieved by this project is to apply the interactive GIS to the long-term assessment and management of possible impacts associated with the ERA Jabiluka Mine. The first step in this phase is therefore to identify the various management scenarios that are possibly going to be applied to the ERA Jabiluka Mine. The draft Environmental Impact Statement (EIS) for the Jabiluka uranium mine project (Kinhill 1996) provides descriptions of mine development alternatives. These include the Ranger Mill Alternative (RMA), the Jabiluka Mill Alternative (JMA) and the Pancontinental proposal.

Once the GIS/modelling technology has been developed and elevation models for each of these management alternatives obtained, various scenarios of mine site design will be modelled to assess possible impacts of the ERA Jabiluka Mine on landform evolution within the Ngarradj catchment. It is expected that these model simulations will focus on the final development alternatives, for example JMA, addressing various design scenarios incorporated in the alternative such as waste rock dump and infrastructure design variation. Impacts of the alternative management scenarios on catchment evolution will be assessed over both long- and short-term time scales. Outcomes derived from these modelling scenarios can be used in the formation of management recommendations once final decisions on mine development and design are made. The application of the interactive GIS to real life problems will aid the identification of possible problems associated with the interactive GIS. This will allow the opportunity to refine the tool and will give an understanding of any potential application limitations.