2 GIS establishment

2.1 Introduction

A geographic information system (GIS) is being developed for the storage, retrieval and analysis of information generated by an investigation into the long-term geomorphological impacts of the Energy Resources of Australia (ERA) Jabiluka Mine. GIS are commonly linked with erosion and hydrology models (eg De Roo 1998, Haan & Storm 1996) but not often used in geomorphological impact assessment (eg Patrono et al 1995, Verstappen 1995). This study adopts a GIS-centred approach to the management and manipulation of data generated by a geomorphological impact assessment. Benefits of this approach include the simplification of data maintenance, revision and update, as well as facilitating availability and access for users. The aims are to simplify data analysis and presentation, to increase individual and group productivity and cost-effectiveness, and to provide an information system that could be integrated with other specialised fields in use within ***eriss***.

The methods and processes required to store, retrieve and manipulate the datasets resulting from impact assessment, range from spreadsheets and statistical analysis to spatial databases and visual analysis. Data emanating from the impact assessment that will be used in this project can be grouped into four categories, based on these methods and processes: (1) High Temporal Resolution Spreadsheet Data; (2) Raster Data; (3) Vector Data; and (4) Model Data. This requires the customisation of the GIS software package (ArcView®) through the development of specific GIS tools that allow the end user to interact with this range of data successfully. The GIS therefore provides a focal point for these datasets, retaining the flexibility and functionality required to store and manipulate each dataset, whilst offering a central link for the projects data (fig 4).

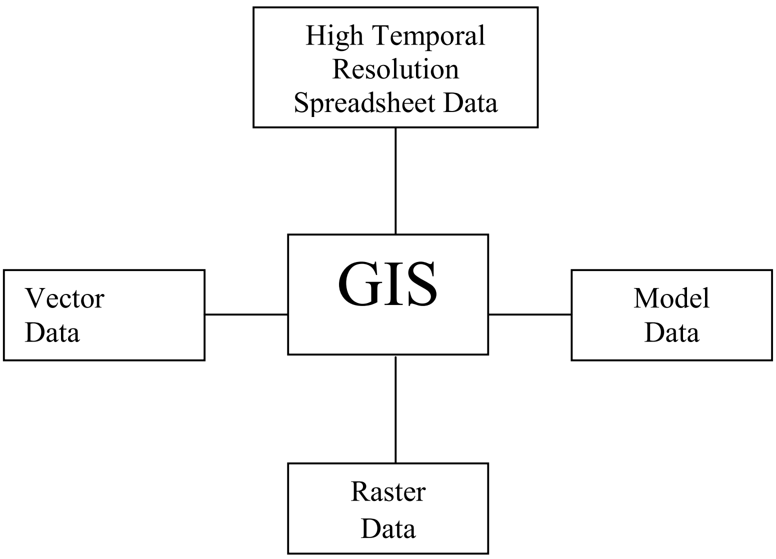

Figure 4 The approach used in the development of a GIS as a focal point for datasets generated during the geomorphologic impact assessment of the ERA Jabiluka Mine

2.2 High temporal resolution data

In November 1998 three stream gauging stations were established by ***eriss*** within the Ngarradj catchment (fig 1). Two stations are located upstream of all mine influences (on the main right bank tributary of Ngarradj ('East Tributary') and on the main Ngarradj channel ('Upper Main')). The third station ('Swift Creek') is located on the main Ngarradj channel downstream of the mine site and can be used to assess possible impacts from the mine site (fig 1). Data are collected from these stations at frequent intervals. Turbidity, rainfall and water level information is collected by each station at 6 minute intervals. Suspended sediment concentrations, electrical conductivity, pH and turbidity samples are collected by automatic samplers that are triggered by rises and falls in stream water levels, as predetermined for each station. It is possible to collect 24 samples at the upstream gauging stations East Tributary and Upper Main and up to 48 samples at the downstream Swift Creek site. In-stream velocity gaugings are conducted during each weekly site visit. Bedload movement information, collected using a Helley-Smith sampler according to the technique described by Emmett (1980), is also obtained during these visits. These data are used in this project to establish a discharge area relationship and to derive a sediment transport equation for the eventual calibration of the SIBERIA landform evolution model (see chapter 4).

The approach adopted to store, manage and retrieve these data involves customisation of the ArcView® GIS package to connect the GIS with relational database and spreadsheet software packages. Data collected during field visits or through laboratory analyses are entered as separate tables into a database through 'user-friendly' forms accessed through the GIS interface. All tables have a unique code that links them to a further table that contains descriptions of each gauging site and their geographic coordinates. A connection known as an Open Database Connectivity (ODBC) has been established between the GIS and database to enable data to be retrieved through customised dialog boxes embedded within the GIS interface using structured query language (SQL). Customisation of the GIS also allows the user to interactively select a site on the computer screen and interact with the associated databases, importing and graphing data for the selected site. This allows rapid assessment of temporal and spatial trends in the data. The data accessed by this more generalised toolbox include low temporal resolution spreadsheet data and image data, as well as high temporal resolution spreadsheet data. Much of the analysis of these data, however, involves complex statistical operations not offered within the standard GIS. An option within the data retrieval dialog box allows the user to export data directly from the database to a spreadsheet package, allowing further statistical analysis and more sophisticated graphing operations.

2.3 Raster data

Raster data obtained for the Ngarradj project comprise a DEM constructed from 1:30 000 pre-mining (1991), aerial photography and remotely sensed imagery (including aerial photography, Landsat TM and MSS imagery). Raster data sets are generally composed of large amounts of data and thus require large and well-organised databases as well as 'user-friendly' data processing hardware and software. A GIS offers a highly suitable approach for efficient storage, retrieval and analysis of large raster data sets (Schultz 1993).

One of the great advantages of using DEM and remotely sensed data in hydrological and geomorphological studies is that more spatially variable information can be obtained, as opposed to the more common point data (eg rain gauges) (Schultz 1993). The DEM constructed for this project covers the Ngarradj catchment. Raster processing of DEMs using functions that are often in-built in a GIS, allows the user to obtain many derivatives of DEMs such as slope, aspect, convexity/concavity etc (Delaney 1999). Remotely sensed imagery, on the other hand, is considered to be a rapid and flexible method for obtaining updated data, particularly as images are easily stored and interpreted in a GIS (Al-Ankary 1991). Maintaining a GIS as the central data management system allows DEM and remote sensing derived data to be directly linked to data emanating from the other four categories of data shown in figure 4. Raster data, therefore, are useful in the examination and explanation of the high temporal resolution spreadsheet data and provide direct inputs into the hydrology and landform evolution models. Further analysis, including detailed geomorphometric analysis of the modelled output DEM within the GIS, will enable temporal and spatial variations in mining impacts on landform evolution to be detected.

2.4 Vector (dGPS) data

The ability of GIS to store and analyse vector data represents one of the prime reasons for the high level of attention paid to GIS over the past 30 years (Lam & Swayne 1993). The vector database established for ***eriss*** chiefly consists of the Topo-250 k digital data product produced by the Australian Surveying and Land Information Group (AUSLIG), with some of the data available at 100 k scale. Additional data layers are related to individual projects and have been obtained in the field, from aerial photography or other imagery (Bull 2001). As much of these base vector data are too coarse for investigations at the Jabiluka project scale, the primary vector data source is from DEM/remote sensing derived products and differential global positioning system (dGPS) acquired data.

Many public and private agencies involved in the environmental impact assessment process are turning to GPS and GIS technologies to deliver precision at an acceptable cost and a refined database essential to the assessment of environmental impacts (Rodbell 1993). Differential GPS provide a cost effective, accurate source of raw geographical information valuable in the mapping, field data collection and GIS database construction phases of the geomorphological impact assessment process (Cornelius et al 1994). dGPS, along with aerial photography interpretation, has been successfully used in initial channel reach characterisation and geomorphic mapping of the Ngarradj catchment. Characterisation of the catchment will enable the identification of sites most likely to be affected by mining impact and should facilitate the detection of possible geomorphologic imbalances resulting from mining activities at Jabiluka. Differential GPS information has also been collected on knick-point migration rates. GIS analysis of these snapshot datasets will provide vital information on quantifying mining impact on gully formation and extension rates. The use of dGPS to geo-reference field sites is considered crucial to the GIS-centred data management approach as all data are linked to a spatial location, facilitating the incorporation of all field project data into the information management system.

2.5 Geomorphological modelling with GIS

GIS and environmental modelling are considered to be highly complementary with both technologies attempting to analyse spatially distributed and time dependent objects and processes (Fedra 1993). However, since GIS and environmental modelling have evolved separately they have different data structures, functions and methods for inputting and outputting spatial information (Maidment 1993). Over the past two decades there has been considerable research into the integration of these two technologies to the extent that the synthesis of spatial data representations and environmental models has been described as the new ‘Holy Grail’ (Raper & Livingstone 1996). Currently there exist many different approaches to linking environmental models with GIS, from the very simple, in which the GIS is used for writing model input and the analysis of model output, to closely integrated systems (Charnock et al 1996).

Currently three environmental models are employed by ***eriss*** in the assessment of mine site landform stability and off-site geomorphological and environmental impacts: 1) a basic sediment transport model, 2) the Distributed Field Williams (DistFW) hydrology model (Field & Williams 1987) and, 3) the SIBERIA landform evolution model (Willgoose et al 1991). The sediment transport model is an equation of the form:

$$T = K \int Q^{m_1}\, dt \;\eta \qquad (1)$$

where T = total sediment loss, $\int Q^{m_1}\, dt$ = cumulative runoff over the duration of the event (Q = discharge (l s^{-1})) and K and m_1 are fitted parameters. $\eta \approx N\,(1, \sigma)$ is an independent multiplicative log-normally distributed error with mean 1 and standard deviation σ.

This model does not have a spatial component and is therefore not appropriate for implementation within a GIS. However, the DistFW hydrology model is a distributed model that operates on a sub-catchment basis, whilst the SIBERIA landform evolution model is based on a DEM. The integration of these two models with the GIS has used the loose coupling and tight coupling methods respectively. The ArcView® GIS package has been customised to facilitate these levels of integration between the models and the GIS.

2.5.1 DistFW hydrology model

Hydrologic analysis has been integrated with computers to such an extent that computers often provide the primary source of information for decision-making by many hydrologic engineers (De Vantier & Feldman 1993). The use of GIS in hydrologic analysis provides an effective method for the construction of spatial data and the integration of spatial model layers (Singh & Fiorentino 1996). GIS are able to generate both the topographic and topologic inputs required to accurately model hydrologic systems. GIS can also assist in design, calibration, modification and comparison of models. However, the acquisition and compilation of information required by a GIS for hydrological modelling is often labour intensive and is an issue commonly encountered in hydrologic applications of GIS (Hill et al 1987). Linking the DistFW hydrology model with a GIS using a loose coupling approach primarily involves the development of a GIS toolbox that will allow the automatic generation of DistFW input requirements.

The DistFW hydrology model requires the input of a significant amount of topographic information. Catchments are represented within the model as being composed of a number of sub-catchments for which information must be derived describing their horizontal shape, vertical relief, conveyance and flow relationships existing between the sub-catchments (table 12). A significant challenge in this research project has been to develop a set of customised tools that automatically generates this information from a DEM. Six software tools have now been developed that extend the functionality of the ArcView® GIS to satisfy the topographic input requirements of the DistFW hydrology model. A description of the tools developed for the derivation of the required DistFW inputs is shown in table 1.

Table 1 Descriptions of the tools developed to facilitate the automatic generation of the topographic input requirements of the DistFW hydrology model

GIS tool	Function/DistFW topographic input requirement
Incidence	Calculates the flow relationships between sub-catchments. Directly determines ‘maximum number of upslope sub-catchments’ and ‘sub-catchment incidence’ for DistFWs.
Catchment width	Determines the average catchment width perpendicular to the central stream channel. Directly determines ‘sub-catchment conveyance’ values for DistFW.
Stream length	Computes the length of a catchment based on the central drainage channel. Directly determines ‘the sub-catchment length’ values for DistFW.
Min-max area	Calculates the minimum elevation, maximum elevation and area of each sub-catchment within the catchment being studied. Directly inputs ‘UpSlope Elevation’, ‘DownSlope Elevation’ and Sub-Catchment Area for DistFW.
Multi-point watershed	Generates a grid of multiple watersheds. Where one point is downstream of another, the intervening sub-catchment is automatically calculated.
Downstream	Reduces the area of a sub-catchment where one sub-catchment is downstream of another to the intervening area.

2.5.2 SIBERIA landform evolution model

SIBERIA models the evolution of a catchment through operations on a DEM for the determination of drainage areas and geomorphology. GIS offer a wide range of raster data processing capabilities and a clear means for organising and visualising data from a number of different formats (Rieger 1998). Linking the SIBERIA landform evolution model with GIS therefore provides benefits not available in one or other of these environments. The SIBERIA landform evolution model is computationally intensive and consequently does not lend itself to interactive use. Integration of this model with a GIS will therefore attempt to increase the ‘user-friendliness’ of the model, whilst also extending the functionality of the model. The complexity of the model means that integrating the two technologies using an ‘embedded’ approach is not feasible. However, by using a tightly coupled approach the two technologies will essentially remain separate but will share a user friendly front-end and database. Furthermore, by using this approach the powerful processing and analytical capabilities of the GIS will be available for the analysis of SIBERIA output.

The suite of tools developed to link SIBERIA with the ArcView® GIS package has been assembled into an ArcView® extension named ‘ArcEvolve’. Extensions are add-on programs that provide additional functionality to ArcView® through the addition of menu items, buttons and/or tools. The functionality associated with the added menus/button/tools is derived from scripts written in the ArcView® object-oriented programming language ‘Avenue’. ArcEvolve is currently still a prototype under development. As such, only a brief description of the functionality contained in ArcEvolve will be provided in this report, with more detailed descriptions and applications to be published in the future as ArcEvolve is fully tested.

ArcEvolve adds two menus to the ArcView® ‘View’ document graphical user interface (GUI). The first, ‘SIBERIA’, contains a number of items that: (i) allow SIBERIA native format files to be imported and exported; (ii) provide access to dialog boxes for the creation and management of a SIBERIA parameter database; and (iii) run the model. A description of the items contained in this menu is provided in table 2.

Table 2 Descriptions of the menu items added to the ArcView® 'View' GUI, under the menu 'Siberia', when using the ArcEvolve extension for interacting with the SIBERIA landform evolution model

Menu item	Function description
	'Siberia'
Export to RST2	Exports ArcView® grids, with relevant parameters from database, to SIBERIA RST2 File format
Import RST2 grid only	Imports the digital elevation data only from a SIBERIA RST2 file into an ArcView® grid
Import All RST2 File	Imports the digital elevation data and parameter values contained in a SIBERIA RST2 file into and ArcView® grid and database respectively
Create boundary file	Creates a SIBERIA boundary file from an ArcView® grid
Import boundary rile	Imports a SIBERIA boundary file into an ArcView® grid
Create database	Creates a SIBERIA parameter database. The database contains an item 'gridname' that links each record to a grid.
Edit database	Opens the first of a series of nine dialog boxes that provide a user-friendly front-end for updating the parameter database for a selected grid
Copy parameters	Copies the parameters associated with one grid to a record associated with the selected grid
Delete parameters	Deletes a record from the parameter database
Run Siberia	Runs the SIBERIA model, with output imported into ArcView® following the completion of the model run

The second menu, 'Geomorph', contains functionality for the geomorphometric analysis of digital elevation data (the primary input and output of SIBERIA). Geomorphometry provides an effective means for quantifying changes in basin morphology and has been used in previous studies to assess the ability of SIBERIA to model landform evolution. The standard geomorphic statistics used in these studies have been the width function, hypsometric curve, cumulative area diagram and area-slope relationship. These statistics have been adapted for implementation within the ArcView® GIS package and have been included in the Geomorph menu of ArcEvolve (table 3).

Table 3 Descriptions of the menu items added to the ArcView® 'View' GUI, under the menu 'Geomorph', when using the ArcEvolve extension for interacting with the SIBERIA landform evolution model

Menu item	Function description
	'Geomorph'
Width function	Calculates the width function from a DEM, Flow Direction or Flow Accumulation grid. The width function allows the user to define the minimum drainage area required to form a stream (ie allows for both traditional and simplified calculation of width function). The output is line graph. The table is also available for exporting to more advanced graphical packages.
Hypsometric curve	Calculates the hypsometric curve from a DEM. The table is also available for exporting to more advanced graphical packages. The output is a line graph showing the hypsometric curve. The table is also available for exporting to more advanced graphical packages.
Cumulative area diagram	Calculates the cumulative area diagram from a DEM, Flow Direction or Flow Accumulation grid. The output is a line graph. The table is also available for exporting to more advanced graphical packages.
Area-slope relationship	Calculates the area-slope relationship from a DEM grid. The output is displayed as a log-log scatter graph. The table is also available for exporting to more advanced graphical packages.
Cut-fill	Adapted from the standard ArcView® 3D-Analyst tool that calculates the volumetric difference between two surfaces. The output is a grid showing the net gain/net loss between two elevation grids.
Denudation rate	Calculates the denudation rate (mm/yr) between two elevation grids subjected to a landform evolution model.

2.6 Conclusions

Since their inception, GISs have evolved and are still evolving from simple graphical tools towards being fully developed 'intelligent' systems. A GIS is currently being used by ***eriss*** as a central management tool to coordinate the storage, manipulation and retrieval of information generated by an investigation into the geomorphological impacts of the ERA Jabiluka Mine, Northern Territory, Australia. Data useful to the project are disparate in terms of location, format and the original context in which it was collected. GISs have the unique ability to store, manage and manipulate these highly variable datasets, providing an environment that eliminates problems such as absence of metadata and multiple copies of the same datasets spread through an organisation.

However, although the range of functionality offered by GIS is continually expanding, standard GIS packages still lack the functionality for complex geomorphological modelling and analysis. An extension to the standard ArcView® GIS software package, 'ArcEvolve', has been developed to provide links between the GIS and SIBERIA landform evolution model. The extension consists of two menus. The first of which allows the user to interact with SIBERIA native format files and parameter database and run the model. The second provides a suite of tools for the geomorphometric analysis of SIBERIA output, allowing a quantitative approach to assessing landform evolution.