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# A Review of Erosion and Hydrology Research at *eriss*

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by

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ENVIRONMENTAL RESEARCH INSTITUTE OF THE SUPERVISING SCIENTIST

## Executive Summary

A major issue that has been the subject of research at ***eriss*** for a number of years has been the fate and subsequent environmental impact of material that will be eroded from the landform at ERA Ranger Mine (ERARM) following rehabilitation. There are three readily identifiable stages in the dispersal of eroded material from the rehabilitated site at ERARM: erosion of the rehabilitated landform itself; dispersion and deposition in the tributaries that link the mine site to Magela Creek; and dispersal and deposition in the Magela Creek and floodplain.

Past research has focused on sediment distribution in downstream areas of Magela Creek and the Magela Plain. The proportion of tailings from the mine reaching the Plain with a constant sediment delivery ratio is a function of time of total erosion of tailings. At the natural denudation rate (25±19 t/km²/y) tailings would take $1.4 \times 10^5$ y to erode with tailings being 1% of the annual load of 5000t reaching the Plain from Magela Creek. If the time is ≤1800 y tailings would comprise 50% or more of the load reaching the Plain. The proportion of tailings at any northing can be calculated for a wide range of erosion times. These calculations are reliable only if assumptions underlying the sediment routing model used are valid. It is likely that turbidity would increase as a result of sediment transport from the mine. The environmental impact of this should be investigated. If erosion of the tailings impoundment occurs at the natural rate it is probable that there will be minimal effect on biota of the Magela Plain. If erosion occurs at ≥4 times the natural rate increases in the bio-available concentration of metals will occur. The biological and radiological impact of this should be investigated.

Present research is addressing the refinement and validation of a landform evolution model SIBERIA. This model can be used to predict the long term geomorphic development of a proposed rehabilitated landform. A calibrated empirical erosion loss model has predicted a sediment loss rate of approximately 3100 t/km²/y from an unvegetated, unripped cap site on the waste rock dump and approximately 140 t/km²/y from a ripped and vegetated site. These values were calculated for slopes of approximately 3%. The erosion rates are orders of magnitude greater than the natural rate. SIBERIA simulations showed that for the unvegetated and unripped case, the landform at 1000 y would be dissected by localised erosion valleys (maximum depth = 7.6 m) with deposited fans (maximum depth = 14.8 m) at the outlet of the valleys. For the vegetated and ripped case reduced valley development (maximum 1000 y depth = 2.4 m) and deposition (maximum 1000 y depth = 4.8 m) occurred. For the vegetated and ripped condition simulated maximum valley depth in the capping over the tailing containment structure was about 2.2 m. Incision was approximately 5 m for unripped and unvegetated conditions. By modelling valley incision decisions can be made on the minimum depth of tailings cover required to prevent tailings from being exposed to the environment within a certain time frame. Validation of SIBERIA aims to test the long term erosion predictions of SIBERIA against natural processes in the field to strengthen confidence in the modelling process.

SIBERIA modelling to date has used present day parameters which assumes that the initial surface conditions of the waste rock dump will remain constant throughout the simulation period and there is no temporal change in parameters due to soil formation or ecosystem development. Simulations also assume there is no spatial variation in parameter values over the simulated area. Spatial variation results from surface treatments on the waste rock dump or the undisturbed land surface being included in the simulations. Temporal changes in parameter values are being addressed in current research.

Future research will continue the refinement of SIBERIA by incorporating spatial variation in input parameter values for the model. Sediment storage and transport in the small catchments between the mine site and Magela Creek will be investigated and this information will provide the link between the mine site and downstream areas of Magela Creek. This should strengthen the predicted sediment budget previously based on limited data. The impact of sediment and solute loads on the biota of Magela Creek should be investigated so that this can be related to the predicted sediment budget. Little is currently known of extreme flood events on Magela Creek and its tributaries. Floods at least 10 times greater than the mean annual flood have totally destroyed many channels and floodplains in Australia. It is essential that the probability of extreme storm events and floods is more accurately defined because of their significance for soil erosion, sediment transport, channel changes and landform evolution modelling by SIBERIA. The palaeoflood record should be analysed so that the effect of catastrophic events can be incorporated in modelling.

The research program is total catchment management orientated. Completion of the program will provide modelling techniques which can be used to assess sediment movement from a proposed rehabilitated landform through the mine site catchment to Magela Creek and assess the impact of this sediment on the ecosystem.

The need for, and the extent of, future research on erosion of rehabilitated sites in the ARR is considered in the light of possible decisions that may be made in the near future on the final repository for tailings arising from the processing of ore from the ERARM and Jabiluka mine. Recommendations are given for the priorities that should be attributed to future research proposals.

## Acknowledgements

Dr W Erskine (University of New South Wales) contributed sub-section 4.3 "Determination of the magnitude of catastrophic rainfall-runoff and erosion events in the Alligator Rivers Region". Mr D Moliere (***eriss***) contributed sub-section 3.3 "Temporal trends in SIBERIA input parameter values". Mr M Saynor, Dr D Klessa, Dr B Prendergast (***eriss***), Dr W Erskine and Dr G Willgoose (University of Newcastle) provided helpful discussion regarding future research projects.

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## 1.0 Introduction

A major issue that has been the subject of research at ***eriss*** for a number of years has been the fate and subsequent environmental impact of material that will be eroded from the landform at ERARM following rehabilitation. This material includes particulate matter from the waste rock dumps and, in the long term, erosion products from tailings if the tailings dam is rehabilitated *in situ*. The ***eriss*** program in this field is now nearing the end of a major phase and it is appropriate to review the status of our knowledge in the field before making decisions on future research.

There are three readily identifiable stages in the dispersal of eroded material from the rehabilitated site at ERARM:

- erosion of the rehabilitated landform itself,
- dispersion and deposition in the tributaries that link the mine site to Magela Creek, and
- dispersal and deposition in the Magela Creek and floodplain.

The third of these stages was the subject of an extensive study by Wasson and others in the 1980s (Wasson 1992). The first stage has been the subject of ***eriss*** research over the past seven years and is nearing completion. While some work has been carried out on dispersion in the nearby tributaries, the need for further work needs to be assessed.

This paper is a review of past research on erosion of the rehabilitated landform at ERARM and the subsequent dispersal of erosion products in the Magela Creek system. Issues that could be the subject of future research are identified and discussed to enable the Alligator Rivers Region Technical Committee to provide advice on priorities for future research.

## 2.0 Past research

Past research results are presented in Wasson (1992), part of which addresses the past, present and future sedimentation on the Magela Plain and in its catchment. The aims of that study were;

(1) To determine if sedimentation rates have been approximately constant over various time periods during the last 2 ka, and

(2) To determine the pattern of contemporary sedimentation as a guide to where sediment arising from erosion of the rehabilitated landform at the ERA Ranger Mine (ERARM) might be deposited.

Much of the following is taken directly from Wasson (1992) and issues are addressed under similar headings as used by Wasson (1992).

### 2.1 Sediment yields

The suspended sediment loads in Magela Creek were determined using the sediment rating curve (SCR) method. Wasson (1992) considered that measurements of discharge and probably sediment concentration were subject to considerable errors and that the SCR method for determining loads was not adequate but was the only method applicable in the case of the Magela Creek data.

Suspended sediment loads data from the NT Water Division were available from three sites: Jabiru gauging station (009); Jabiluka gauging station (017) and Outflow gauging station (019). At other sites, ratings were limited and discharge data not adequate. Only a small number of years of data were available.

Other workers (Williams, 1973, 1976; Woodroffe *et al.*, 1986; Duggan, 1988) presented sediment load data but Wasson (1992) considered that the uncertainties related to these data were underestimated. An inverse relationship between specific sediment yield and catchment area was developed which indicated that over a short period of time only a small fraction of eroded sediment reaches the outlet of the catchment. The ratio of total erosion to the catchment output is sediment delivery ratio (SDR) and Duggan (1983) showed that the SDR was <1 for small catchments near ERARM. Therefore, in a period of a few years, not all of the sediment from the mine would leave the immediate vicinity of the mine (at least under conditions not affected by tropical cyclones).

The specific sediment yield/catchment area ratio is not sustained over geologic time. The mean medium-term denudation from above ERARM One ore body is estimated as 230±330 $t/km^2/y$ (Airey *et al.*, 1982-83). The estimated grand mean medium-term denudation rate of the area over the last 59 000±6 700y is 25±19 $t/km^2/y$.

Wasson (1992) concluded that sediment fluxes have remained constant for periods of 2000 y and 10 y in the Upstream Basin and Mudginberri Corridor of Magela Creek. Large uncertainties attached to flux estimates made it difficult to resolve a sediment budget so that a firm statement could be made about distribution on the Plain of sediment from Magela Creek.

### 2.2 Sediment sources and sinks based on radionuclide studies

The use of $^{137}Cs$ as a tracer of sedimentation was confounded by unexpected spatial variability in data and uncertainties in the atmospherically derived component due to variable tree cover and unknown rates of organic matter export. The upper limit of overall sedimentation rate based on the analysis was <0.9 mm/y.

Peaks in U and Th series radionuclide concentrations were identified during floods (Martin and Hancock, 1987) but it was considered that this was due to increased suspended solids concentration and not to significant variation in the concentration of radium in suspended material.

The study indicated that particulate matter from Magela Creek appears to contribute to sedimentation on only a small fraction of the Plain. That is, 90% of Magela Creek sediment is deposited upstream of Jabiluka Billabong in an area which is about 15% of the Plain.

Radionuclide study results implied little loss of suspended sediment from the Plain in the last 100 y. There was evidence of a significant lag between release of suspended solids from ERARM Site and their deposition on the Plain.

## 2.3 Particle size of modern alluvia

### *2.3.1 Upstream of Mudginberri Billabong*

Limited sampling of surface sediments (number not given) undertaken in Gulungul Creek (Fig. 1) and the lower reaches of the sand tract of Magela Creek provided an indication of where fine sediment is stored on its way to the Magela Plain. Similar locations are likely to be preferred by suspended solids from the mine site. Channelled reaches of Gulungul Creek store less than 2% fine sediment (rapid transit zone). In unchannelled valley floors near the mine site surface sediment comprises up to 20% silt and clay.

At Sandy Crossing on Magela Creek <6% of sediments are silt and clay. A small quantity of fines is stored but is rapidly buried. When all storage areas, including levees and channel-side depressions, are considered there is ≤10% fines stored in the sand tract.

The tailings at ERARM comprise 32±9% sand, 52±8% silt and 16±11% clay (Pickup *et al.* 1987). They are more silty than sediments outside the Gulungul Creek channel. The sandy fraction of the tailings would be stored in the channel for short periods. If tailings get to Magela Creek the fines would be transported to the Plain.

The above applies only if the transport capacity of flow is greater than the supplied load of tailings or other sediment from the mine (Higgins *et al.*, 1987). If the transport capacity is overwhelmed deposition would occur but subsequent flows would move the finest sediment down stream. ***It is not known what quantities of sediment would overwhelm the transport capacity or what the subsequent rate of removal of the deposited sediment would be.***

### *2.3.2 Downstream of Mudginberri Billabong*

In this area the upper 2 cm of Plain sediments were sampled at 107 locations for particle size analysis (PSA). Sediment distribution in Magela Creek is similar to an alluvial fan. Coarse particles are deposited upstream with an increasing percentage of fine particles downstream. Longitudinal distribution of sediments allows an interpretation, consistent with radionuclide analysis that the influence of sediment from Magela Creek does not extend beyond the Central High.

## 2.4 A preliminary sediment budget for the catchments of the mine site tributaries

Pickup *et al.* (1987) considered that a proper evaluation of potential transport, deposition and storage of tailings and sediment from the mine site in small catchments between the mine and Magela Creek should involve sediment transport models and an account of the alluvial history as well as sediment budgeting. ***The modelling has not been done and the alluvial history of small catchments is not well known.*** Any attempt to assess the potential pattern of sediments derived from the mine site presently depends on a rudimentary sediment budget.

It is estimated that 42% of tailings would go to the Gulungul catchment; 24% to the Coonjimba catchment; 18% to the Georgetown catchment and 15% to the Djalkmarra catchment (Fig. 1). The Gulungul catchment has a major role in containing tailings and little detailed studies have been done on this catchment.

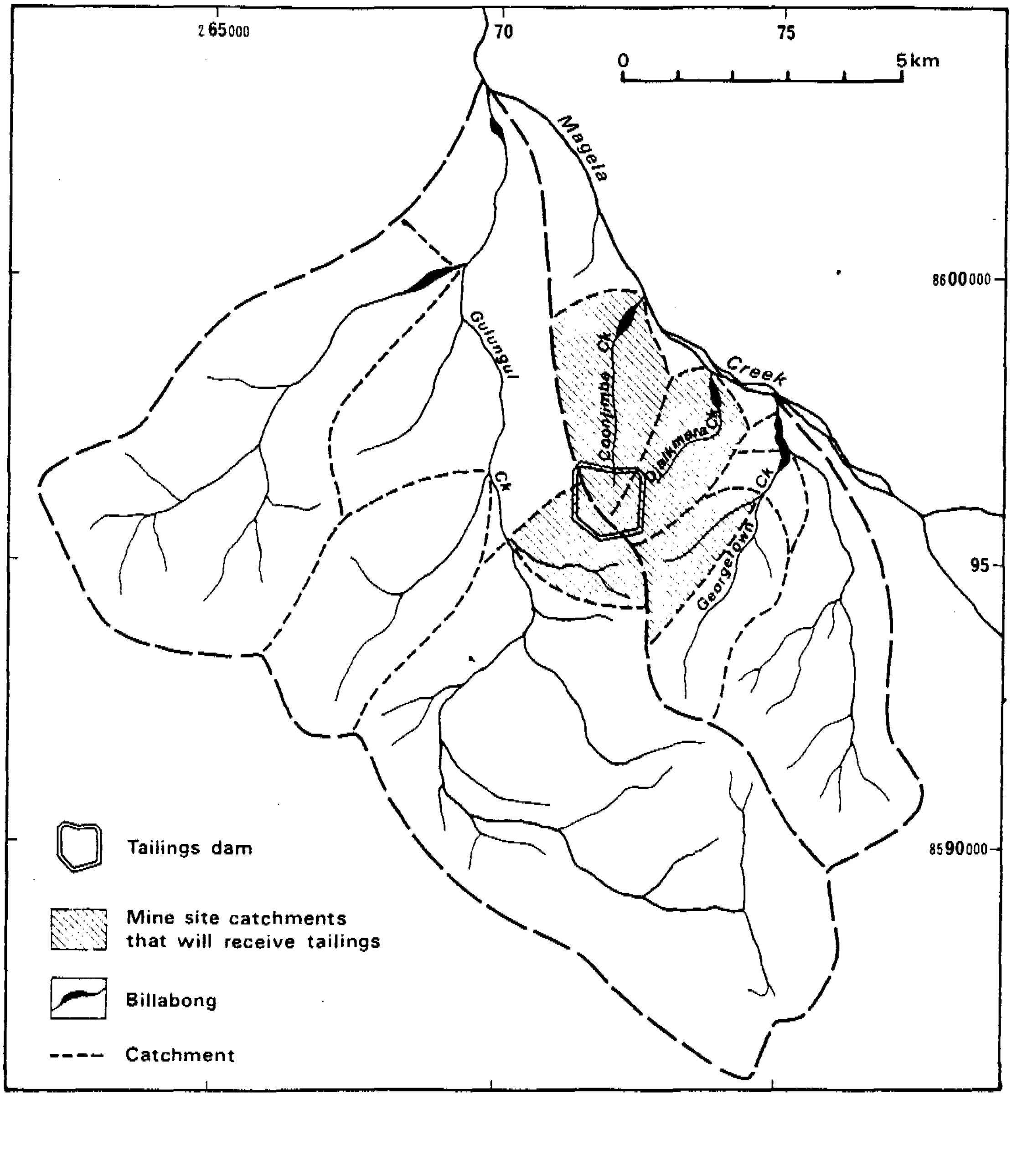


**Figure 1.** Stream catchments adjacent to ERARM. The shaded catchments are those most likely to initially receive tailings. Taken from Wasson (1992).

### 2.4.1 *Routing of tailings through the mine site catchments*

Unlike other mine site catchments Gulungul is considered an incised catchment. The estimated mean yield from the 62 $km^2$ catchment is 25.8 $t/km^2/y$ with channel sources being 70% of total yield. The calculations, however, neglect sediment storage derived from channel erosion. This component cannot be estimated from currently available data. Should a breach occur, the tailings dam will feed sediment through a 1.6 $km^2$ subcatchment on the right bank of Gulungul Creek. Assuming a tailings erosion rate of 17 $t/km^2/y$ (natural rate), 30 t/y enters the 1.6 $km^2$ catchment (yield from the catchment is 20 $t/km^2/y$) which is 0.2% of annual load leaving Gulungul Creek. Therefore, if 42% of tailings enter Gulungul Creek at 30 t/y it would take $1.4x10^5$ y to erode all the tailings. Tailings would dominate mine site catchments if tailings eroded in less than 100 y and Coonjimba and Djalkmarra catchments would be dominated if total erosion time was less than 1000 y.

The influence of a changing sediment delivery ratio (SDR), changing base level due to sea level change, and the effect of sediment control structures was not considered in the above calculations. A deterministic model is required to cope with a changing SDR but data for such a model are not available.

## 2.5 Tailings distribution on the Magela Plain

Estimates of the quantities of tailings reaching the Plain were based on a steady state sediment budget and the routing of tailings and natural erosion products through the mine site catchments. If there is total erosion of tailings in one year by catastrophic cyclone activity in one or two wet seasons, $8.53x10^6$ t of sediment would pass Mudginberri in one year with $1.47x10^6$ t of sediment remaining stored in the catchment for erosion over subsequent years. If erosion occurs at the natural long term rate, 70 t/y of sediment reaches the Plain. Each year the rate of movement downstream would decrease as the catchment area increased (SDR). The model used for estimates was crude and the data base for calculated values of the SDR had large uncertainties. The SDR may not apply if a catastrophic event occurs. If the natural erosion rate applies tailings will be 1% of current annual load of 5000 t. If total erosion occurs in one year tailings would be $1.7x10^3$ times the current load. Tailings would be greater than natural sediment for a total erosion period less than 1800 y.

The percent of tailings in sediment deposited at various points along Magela Creek varies with the time taken to erode tailings. The current natural load in Magela Creek is 5000 t/y (elevated if tailings are eroded quickly). If tailings erode in 1000 y then the tailings would be approximately 70% of surface Plain sediment deposited at an arbitrary datum point which is approximately 11-12 km downstream from the mine site. These predictions are most useful if conditions remain like they are today. Predictions would change if sea level changes. If other sources of sediment from the mine were considered in the study this would increase the load. Tailings will dominate the sediment delivery system if eroded at a rate substantially above the natural rate.

## 2.6 Summary

- *Sedimentation Rates*

  If sea level and climate remain constant then, for the next 1 ky, 20±13 cm of sediment will be deposited in the Upstream Basin and Mudginberri Corridor of Magela Creek.

- *Pattern of sedimentation on the Plain*

  Assuming Magela has had no significant influence beyond Jabiluka Billabong for the last 3-4 ky and assuming constant sea level and climate, an equation has been derived that can be used to estimate the Magela Creek derived fraction of sediment deposited on the Plain at any northing.

- *Pattern of sedimentation in mine site catchments*

  Little data are available because this area was originally considered not a task of the Wasson (1992) study. Based on particle sizes of sediment, mine site valley floors and small parts of hillslopes could store some of the sediment from the mine. Storage in overbank sites could be for long periods of time.

- *Routing of tailings to the Magela Plain*

  For a constant SDR the proportion of tailings reaching the Plain is a function of time for total erosion of tailings. At the mean medium-term natural denudation rate ($25\pm19$ t/km$^2$/y) tailings would take $1.4\times10^5$ y to erode with tailings being 1% of the annual load of 5000t reaching the Plain from Magela Creek. If the time is $\leq1800$ y tailings would comprise 50% or more of the load reaching the Plain.

- *Turbidity*

  Tubidity was not investigated and has not been mentioned above but, in summarising, Wasson (1992) considered that it was likely that turbidity would increase as a result of sediment transport from the mine. He considered that because of the balancing between turbidity, vegetation and light penetration there was a need to investigate the effect of an increased sediment load on biota.

- *Principle conclusion of Wasson (1992)*

  If erosion of the tailings impoundment occurs at a natural rate it is probable that there will be minimal effect on biota of the Magela Plain. If erosion occurs at $\geq4$ times the natural rate, increases in the bio-available concentration of metals will occur. The biological and radiological impact of this should be investigated.

## 3.0 Present research

A landform evolution model, SIBERIA, is being refined for use in the assessment of any specified engineered landform, for example the rehabilitation option proposed by ERARM. The model can also be used as an engineering tool to enable optimisation of the design to reduce erosion and increase the stability of landforms. It is important that testing and validation of SIBERIA be conducted so that there is confidence that predictions are reliable. Refining and validation of SIBERIA is the focus of present research.

### 3.1 Application of SIBERIA to the prediction of long term erosion on the spoil heap at ERA Ranger Mine.

SIBERIA is new technology. ***eriss***, in collaboration with the University of Newcastle, is at the forefront of this research worldwide. It is considered that the first research into the application of landform evolution modelling to post-mining rehabilitated landform design was conducted at ***eriss*** by Willgoose and Riley (1993). Willgoose and Riley used SIBERIA to model the ERARM "above-grade" landform using parameters derived from data collected from areas of the waste rock dump (WRD) with no vegetation or surface amelioration, such as ripping or rock-mulching. Data were collected from erosion and runoff plots (1 $m^2$ to 120 $m^2$) on the cap area of the WRD using techniques of rainfall simulation and monitoring of natural storm events. Their study showed that after 1000 y the landform would be dissected by deeply incised erosion valleys.

Evans and Willgoose (1994) hypothesised that vegetation and surface amelioration may affect the input parameters for SIBERIA. Willgoose (1995) conducted a sensitivity study on the evolution of the ERARM post-mining landform using data from Willgoose and Riley (1993) which showed significant effects of vegetation on simulated results. If SIBERIA input parameter values are affected by vegetation and surface amelioration then the long-term erosional stability of the post-mining landform can be reassessed and the design adjusted accordingly. Recent research by the Erosion and Hydrology Group (EHG) at ***eriss*** has advanced the knowledge gained from the Willgoose and Riley (1993) study and used mine site data to assess the effects of surface treatments on SIBERIA input parameter values and erosion rates.

***eriss*** collected data from four 600 $m^2$ sites on the waste rock dump at ERARM - (1) the cap site - surface slope 2.8%, unvegetated, unripped; (2) the batter site - surface slope 20.7%, unvegetated, unripped, covering of coarse rock material; (3) the soil site - surface slope 1.2%, ≈90% vegetation cover of low shrubs and grasses, topsoiled, surface ripped; and (4) the fire site - surface slope 2.3%, topsoiled, ripped, vegetated with well established trees, grasses and shrubs.

Rainfall simulation experiments on the cap, batter and soil sites and again on the soil site after vegetation was burnt and removed to ground surface level showed that, with respect to dependence of total sediment loss on discharge, there were no significant differences between the cap and batter sites or the vegetated soil and burnt soil sites. However, there was a significant difference between the cap and burnt soil sites with respect to dependence of total sediment loss on discharge. There was a significant difference between all sites with respect to infiltration which indicates a significant difference in runoff from the plots. Total sediment transport was controlled by discharge which was controlled by treatments such as vegetation, ripping and rock-mulching.

Natural rainfall event data from the cap, batter and soil site were used to parameterise SIBERIA. Low frequency, high intensity rainfall events resulted in the greatest soil loss. To ensure that sediment loss during high intensity events was predicted accurately, storms with a range of intensities were selected to derive the sediment transport model used in SIBERIA parameterisation. A calibrated empirical erosion model predicted a total sediment loss rate of approximately 3100 $t/km^2/y$ from the unvegetated unripped cap site and approximately 140 $t/km^2/y$ from the ripped and vegetated site. These values were calculated for slopes of approximately 3%. These erosion rates are orders of magnitude greater than the natural rate given in Wasson (1992).

SIBERIA simulations of post-mining rehabilitated landform evolution showed that for the unvegetated and unripped case, the landform at 1000 y would be dissected by localised erosion valleys (maximum depth = 7.6 m) with deposited fans (maximum depth = 14.8 m) at the outlet of the valleys. Simulated valley form has been recognised in nature which indicates that SIBERIA models natural processes efficiently. For the vegetated and ripped case reduced valley development (maximum 1000 y depth = 2.4 m) and deposition (maximum 1000 y depth = 4.8 m) occurred in similar locations as for the unvegetated and unripped case (ie. on steep batter slopes and in the central depression areas of the landform).

For the vegetated and ripped condition simulated maximum valley depth in the capping over the tailings containment structure was about 2.2 m after 1000 years. Valley incision was approximately 5 m for unripped and unvegetated conditions. By modelling valley incision, decisions can be made on the minimum depth of tailings cover required to prevent tailings from being exposed to the environment within a certain time frame.

### 3.2 Validation of SIBERIA

Some validation has been conducted by the University of Newcastle where predictions of SIBERIA have been compared with observed field catchments. These comparisons have shown the model yields realistic results if realistic parameters are used, but have not shown how well the actual form of a catchment is predicted and further testing is currently underway. The project reported here aims to test the long term erosion predictions of SIBERIA. Field studies have commenced at three sites where SIBERIA predictions can be compared with actual erosion.

#### *3.2.1 Study 1: Scinto 6 mine site*

This study will test SIBERIA's ability to predict erosion over a time period of about 50 years. The Scinto 6 mine, in the South Alligator River valley, was abandoned about 40 years ago and the WRD has subsequently eroded resulting in a flat topped WRD with angle of repose batter slopes. Qualitatively, erosion features at Scinto 6 are similar to that predicted at ERARM by SIBERIA.

A study site was established in association with Parks Australia and the Jawoyn Association, the traditional aboriginal owners of the land. During the 1996-97 wet season runoff and erosion from the WRD were monitored. Data were collected on rainfall intensity, runoff rate and total sediment loss. These data were used to calibrate a hydrology model and a sediment transport model which are used to derive input parameter values for SIBERIA.

In the next phase of this study, the calibrated sediment transport model and hydrology model will be used to test SIBERIA's ability to predict landform development of the Scinto 6 WRD.

#### *3.2.2 Study 2: ERARM waste rock dump gully*

Deep gullies on the batters are one of the major predictions of SIBERIA for unvegetated conditions. These gullies may breach the tailings dam. This part of the study will allow quantitative testing of gully development rates and the ultimate size that they attain using data on gully development on a batter slope on the WRD at ERARM.

Prior to the 1996-97 wet season ERARM staff constructed bunds on the top of the WRD creating a 7200 $m^2$ catchment with the outlet at the top of a batter slope. Runoff from this catchment onto the batter slope created a large gully. The slope was surveyed before the gully developed, during the wet season and at the completion of the wet season to determine the volume of sediment movement in the gully. Rainfall on the catchment was recorded throughout the wet season. Input parameters for an hydrology model for the catchment area have been derived and these will be used with the rainfall record to determine the discharge from the catchment. Once reduced, these data will be used to derive a soil loss/discharge relationship for the gully.

This study has provided an excellent opportunity to collect gully growth data from the time of initiation of the gully, and is possibly the first of its type conducted at this scale. Initial analysis conducted at the University of Newcastle has shown that there is good correlation between the measured properties of the gully and the properties simulated by SIBERIA. This analysis is not yet finalised.

#### *3.2.3 Study 3: Tin Camp Creek natural site*

Tin Camp Creek is a natural site in Arnhem Land and is a good site for testing the ability of SIBERIA to correctly model the longitudinal concavity of the landforms and thus the depths of erosion predicted for the cap layer of the rehabilitation structure.

This is also an important test site for SIBERIA to simulate natural landscapes as it is one of the few sites worldwide where the management regime has not changed in recent history. The historical hydrology and erosion that shaped the landform can reasonably be assumed to be as it is today.

The development of the valley network at Tin Camp Creek is a chaotic process and small changes in initial conditions or historical climate result in a dramatic change in the exact predicted valley network but not the statistics of the valley network. SIBERIA will be used to simulate geomorphic statistics to compare those measured in the field. A digital terrain map of the Tin Camp Creek area has been prepared and will be used to determine the geomorphic statistics of the area. Initial analysis showed that the simulated geomorphic statistics of two catchments at Tin Camp Creek compare well to the natural geomorphic statistics. These simulations were conducted using theoretical input parameter values. The next phase involves simulations using site specific input parameters derived using monitoring data.

Completion of these three studies will test aspects of the model that previous studies with SIBERIA at ERARM have highlighted as being important in order to achieve confident predictions of the long-term stability of the landform. This project will provide confidence in the predictions for the specific failure mechanisms that might occur at the mine site.

### 3.3 Temporal trends in SIBERIA input parameters values

To date, landform evolution modelling using SIBERIA has been based on input parameters derived from experimental data for the current WRD at ERARM. Since the period considered by the model is about 1000 years, it is necessary to take into account the change in erosion that will take place as a result of soil and vegetation development over that time period. The effect of temporal trends on the evolution as a result of erosion of the ERARM post mining landform was assessed using the SIBERIA landform evolution model.

An analogue site with soil, hydrological and erosion characteristics that may develop on the ERARM landform in the long term was selected at Tin Camp Creek. Monitoring data were collected from two sites at Tin Camp Creek (Riley 1994) and a batter site on the WRD at ERARM. Deriving SIBERIA input parameters for each site using the collected data showed that there were significant differences between the Tin Camp Creek analogue sites and the batter site in terms of runoff and sediment loss characteristics. The fitted value for long term infiltration rate on the batter site was significantly higher than the value fitted for the Tin Camp Creek sites, a major factor in the differences in the runoff and erosion characteristics between the sites.

The gully development and deposition occurs at similar locations for both Tin Camp Creek soil and batter site soil. It is difficult to interpret a temporal trend from the current results of SIBERIA simulations.

## 4.0 Future research

There are a number of issues which require further investigation. These issues are discussed in the following sections.

### 4.1 Further refinement of the SIBERIA landform evolution model - Spatial changes in input parameter values and sediment transport in streams

The data collected in the study by ***eriss*** outlined in sub-section 3.1 above were for a landform with surfaces that were (1) unvegetated and unripped, (2) unvegetated "rock-mulched" and (3) vegetated and ripped. These data reflected the condition of the landform at zero years. The SIBERIA simulations conducted were based on constant parameter values reflecting these initial conditions with no change during the simulation period or any spatial variation of surface conditions, such as vegetation, ripping or rock-mulching, of the landform. For example, it has been recognised that rip lines only maintain their integrity for periods of approximately five years, but this effect was not incorporated in the simulations. Temporal (addressed in sub-section 3.3 above) and spatial changes in parameter values resulting from weathering, soil forming processes, ecosystem development and varying rehabilitation strategies were also not incorporated in the modelling process. Further research is needed that can identify the spatial effect of these processes on input parameters values so that SIBERIA can be run incorporating temporal and spatial changes.

Present research results (sub-section 3.1 above) can be used to estimate deposition in creeks adjacent to the mine site. These estimates should be treated with caution as the mode in which SIBERIA was run did not model fluvial transport in the streams within the landform digital terrain model (DTM). Those estimates represent what is deposited during the simulated time period without further transport in the streams or flushing during high flow events. It should be investigated how stream transport and flushing can be incorporated in SIBERIA.

### 4.2 Characterisation of sediment transport and storage in small catchments adjacent to the ERA Ranger Mine

The study by Wasson (1992) has provided information on the transport and distribution of sediment in downstream areas of Magela Creek and on the Magela Plain. When completed, the present research and the research proposed in sub-section 4.1 above on landform evolution modelling will provide information on sediment transport from the mine site.

As stated above, Pickup *et al.* (1987) considered that a proper evaluation of potential transport, deposition and storage of tailings and sediments from the mine site in small catchments between the mine and Magela Creek should involve sediment transport models and an account of alluvial history as well as sediment budgeting. The modelling has not been done and the alluvial history of small catchments is not well known. Any attempt to assess potential pattern of sediments derived from the mine site presently depends on a rudimentary sediment budget. Gulungul Creek will be a major conduit for sediment from the mine site to the lower reaches of Magela Creek. Currently little is known about sediment storage or transport in the small streams adjacent to the mine site. This project aims to remedy that lack of data.

It is anticipated that one of the outcomes of this project will be the incorporation of the results in a GIS. Completion of this project is important as the information gained will provide the link between the mine site and the downstream areas of Magela Creek with respect to sediment movement.

### 4.3 Determination of the magnitude of catastrophic rainfall-runoff and erosion events in the Alligator Rivers Region

Little is currently known of extreme flood events on Magela Creek and its tributaries. According to Roberts (1991), the maximum flood recorded at gauging station GS8210009 had a peak discharge of $1580 m^3/s$, which is only 3.51 times greater than the mean annual flood (herein called the **flood peak ratio**). These data are, however, derived from a very short period of observations (about 20 years). Roberts (1991) also cites a probable maximum flood discharge of $6150\ m^3/s$, which has a flood peak ratio of 13.7. Floods at least 10 times greater than the mean annual flood have totally destroyed many channels and floodplains in Australia (Erskine, 1993; 1994; 1996; Erskine and White, 1996; Erskine and Saynor, 1996a; Erskine and Livingstone, 1997). Erskine (1994) reported floods with peak discharges up to 43.4 times the mean annual flood and Erskine and Saynor (1996b) reported floods with peaks up to 45.0 times the mean.

SIBERIA simulations of the landform, run during present research used an average rainfall pattern. Extreme events such as large cyclones were not incorporated. It has been shown that 90% of erosion can result from 10% of rainfall events. It is essential that the probability of extreme storm events and floods is more accurately defined because of their significance for soil erosion, sediment transport, channel changes and landform evolution modelling by SIBERIA. This can be achieved by extending the only previous palaeoflood analyses on the Katherine Gorge by Baker and Pickup (1987). Preliminary aerial reconnaissance of the East Alligator River upstream of the area mapped in detail by Pickup *et al.* (1983; 1987) and investigated by Murray *et al.* (1992) and Wohl *et al.* (1994) revealed better sites for palaeoflood interpretation than previously analysed. These sites should be analysed for their palaeoflood record so that the effect of catastrophic events can be incorporated in modelling of sediment movement.

### 4.4 Impact of sediment and solute loads from ERARM on the biota of Magela Creek

The plots at ERARM which were used to collect sediment loss data used in the above studies can also be used to collect information on solutes leaving the mine site. This information along with sediment transport predictions gained from the above modelling project could be used to assess the likely impact of elevated sediment and solute loads on Magela Creek biota. This project would require input from the Environmental Chemistry Group and biologists. The Environmental Chemistry Group would take a leading role in this project.

## 5.0 Impact of operational decisions on future research

Assessment of the priorities for future research cannot be carried out effectively without taking into account decisions that have been made or may shortly be made on the operation of the ERARM and on the development of the Jabiluka mine.

The principal driving force for the research program on erosion and hydrology has been the need to provide scientific information to assess the two options for rehabilitation of tailings at the ERARM; (1) *in situ* rehabilitation of the existing tailings dam (which would result in dispersion of tailings in the long-term) and (2) deposition of all tailings in the mined-out pits (which would effectively contain tailings for the indefinite future). Even if a decision is made to adopt the second option, rehabilitation will need to be carried out in accordance with Best Practicable Technology (BPT). The use of a fully calibrated and validated landform evolution model to design the final landscape will be an essential part of the adoption of BPT.

It needs also to be borne in mind that the radioactive content of waste rock is about five times that of surface rocks in the ARR and low grade ore, which will be rehabilitated under a shallow protective layer of waste rock, contains radioactive elements at significantly higher concentrations. Thus, even if tailings are rehabilitated below grade, it will be necessary to ensure that sufficient knowledge is available on probable erosion rates, and methods to minimise erosion, to ensure that steps are taken to protect the off-site environment from the effects of dispersal of erosion products from the waste rock dumps.

Possible major decisions that would have an impact on the need for, and priorities that would be allocated to, future erosion research in the ARR include:

- any decision by ERA to return all tailings from processing of the ERARM ore bodies to the mined-out pits, and
- a decision to develop a mill and tailings pond at Jabiluka rather than mill Jabiluka ore at ERARM.

Decisions on these issues are likely to be made in the near future and are, to some extent, linked. If the ERA preferred option (milling Jabiluka ore at ERARM) is implemented at Jabiluka, all tailings from ERARM and Jabiluka will be deposited below grade. If, however, a tailings dam is constructed at Jabiluka, ERA may wish to retain the option of *in situ* rehabilitation of the ERARM tailings dam through an assessment under Environmental Requirement 29(b). It should also be noted that even if the ERA preferred option is adopted there will still remain the possibility that the Jabiluka ore body is greater in extent than is currently known and future development of an extended ore-body may require an assessment, in advance of development, of the long-term consequences of above grade disposal of tailings.

For the purposes of considering the development of the erosion and hydrology program at ***eriss*** in the short term, two scenarios are considered; (a) a decision that no tailings will be rehabilitated above grade at either ERARM or Jabiliuka and (b) the option of above grade disposal of tailings at ERARM is retained or the Jabiluka Mill Alternative is adopted in the development of Jabiluka. In the latter case, research that is specific to tailings dispersal should continue with high priority. In the former case, research that is specific to tailings dispersal should be terminated as soon as is reasonable and emphasis should be given to the development of BPT for rehabilitation of the waste rock dumps. Resumption of research related to tailings dispersal could be resumed at a later stage if drilling confirms a significant extension of the Jabiluka ore-body.

## 6.0 Recommendations on future research priorities

Based upon consideration of the above issues, it is the view of ***eriss*** management that the following research should proceed irrespective of any decision on long-term tailings disposal. Projects are listed in order of proposed priority.

- Complete the current program on the validation of the predictions of the landform evolution model and the inclusion of temporal and spatial trends
- Determination of the magnitude and frequency of very high rainfall events and the subsequent modelling of the consequences of such events on erosion of the rehabilitated site
- Estimate, for various landform options proposed by ERA, the expected annual loads of particulate material leaving the rehabilitated site and entering adjacent streams
- Estimate the potential environmental impact arising from the dispersion of erosion products from waste rock under the various landform options
- Depending on the outcome of the above environmental impact assessment, determine whether or not further work on dispersion of erosion products in local tributaries is necessary; if so, design and conduct the research project
- Perform a BPT assessment of various landform options proposed by ERA.

If above grade disposal of tailings is retained as a long-term option at either site, priority should be allocated as follows:

- Completion of the current program on the validation of the predictions of the landform evolution model and the inclusion of temporal and spatial trends
- Determination of the magnitude and frequency of very high rainfall events and subsequently model the consequences of such events on erosion of the rehabilitated site
- Estimate, for various landform options proposed by ERA, the expected annual loads of particulate material leaving the rehabilitated site and entering adjacent streams
- Determine the probable long-term dispersal and deposition of tailings in the vicinity of the above grade site
- Estimate of the potential environmental impact on people and ecosystems arising from the dispersion of tailings in the long-term under the various landform options
- Estimate of the potential environmental impact arising from the dispersion of erosion products from waste rock under the various landform options
- Depending on the outcome of the above environmental impact assessments, determine whether or not further work on dispersion of erosion products in local tributaries is necessary; if so, design and conduct the research project.
- Perform a BPT assessment of various landform options proposed by ERA.

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