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Assessing mine site rehabilitation design for erosion impact

KG Evans

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supervising scientist

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K.G. Evans
Environmental Research Institute of the Supervising Scientist,
GPO Box 461 Darwin NT 0801 Australia

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Introduction

Without proper management and design, erosion of above-grade waste rock dumps (WRDs) resulting from surface mining has the potential to cause stream and river pollution through elevation of sediment loads. Quantifying sediment generation from a landform, through predictive modelling, takes the 'guess-work' out of landform design. This paper presents a modelling case study applied to the ERA Ranger Mine (ERARM) in the Northern Territory of Australia (Fig. 1). Three models are used: (*1*) SIBERIA (Willgoose *et al* 1989); (*2*) the Water Erosion Prediction Project (WEPP) (Flanagan and Livingston 1995); and (*3*) the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al* 1994).

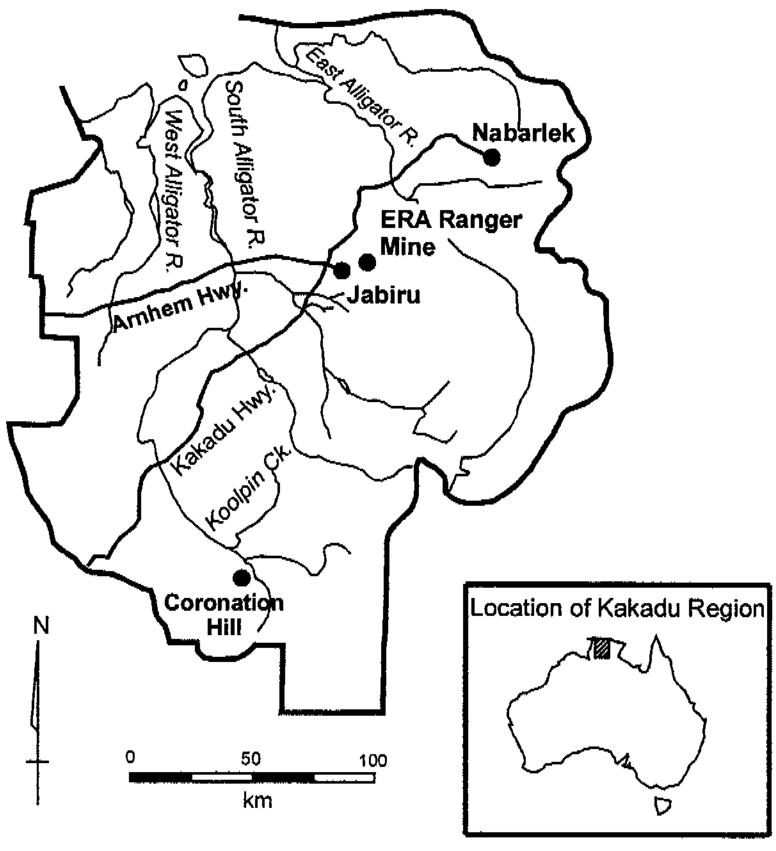

Figure 1 Location of ERA Ranger mine.

The ERARM (Fig. 1) is adjacent to the World Heritage-listed Kakadu National Park and is an open-pit uranium mining operation. The area receives high-intensity storms and rain depressions between October and April (wet season) with virtually no rain falling during the remainder of the year (dry season). The average annual rainfall is 1480 mm. At the conclusion of mining, ore will have been removed from two pits (No. 1 and No. 3) (Fig. 2).

Tailings will be stored in Pit 1 and Pit 3 below ground level and only low-grade mineralised waste will be contained above ground level. The rehabilitation design must provide for the long-term containment of contaminants (i.e. over a period of a thousand years) (Wasson 1992); it must also ensure that weathering and erosion of the containment structure, in an area which experiences high rainfall intensities, do not result in the release of contaminants that would degrade the environment or aesthetics of the surrounding Kakadu National Park.

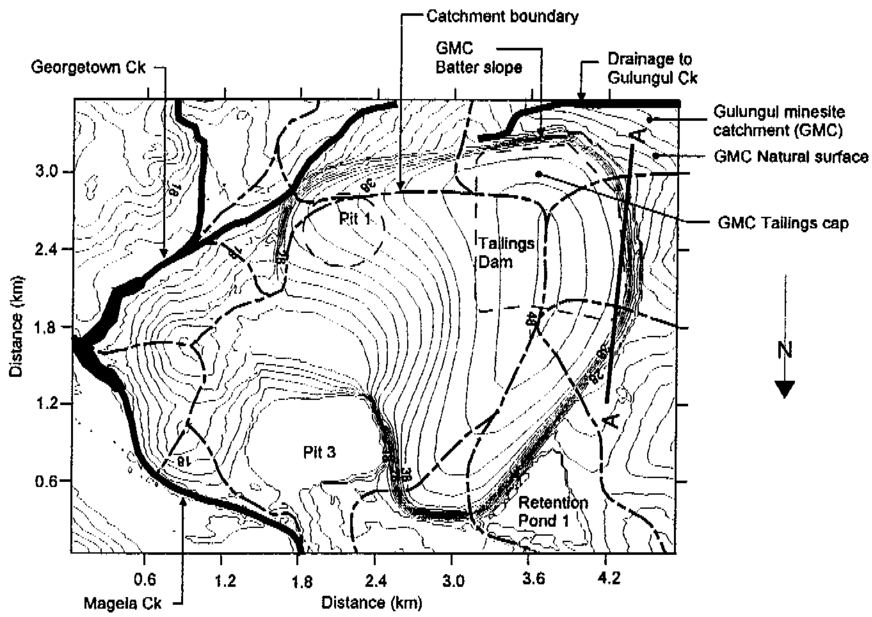

Figure 2 Contour plan of the above-grade landform rehabilitation option. Contour intervals are 2 m.

The final landform design is still being developed and decisions on batter slopes and revegetation techniques are still to be made. An earlier option, now disgarded by ERARM, was for the existing tailings dam to be rehabilitated *in situ*. The outcome of the modelling studies on this option, although no longer applicable at ERARM, illustrates how to assess mine site rehabilitation design for erosion impact and has relevance to sites where contaminants may need to be stored above ground. This case study uses the above-grade rehabilitated landform (Fig. 2) proposed by Unger and Milnes (1992) as an example of the application of modelling technology.

Landform assessment

The 3 stages of landform design assessment are: (*1*) landform stability; (*2*) sediment delivery; and (*3*) downstream water quality impact. An assessment of post-mining rehabilitated landform stability needs to quantify soil erosion rates and how well a structure encapsulates waste material. Oncc stability has been confirmed it is necessary to determine how much sediment could be delivered from the slopes of the WRD through natural catchments into downstream-receiving waterways. The final stage is to determine if resulting stream sediment concentrations are above accepted water quality guidelines.

Landform stability

The model used to assess the ability of the above-grade option to encapsulate contaminants was SIBERIA. This is a 3-dimensional (D) topographic evolution model simulating runoff, erosion, deposition and long-term evolution of channels and hillslopes in a catchment.

1000 years of erosion of a ripped and vegetated as-constructed landform was simulated. After a 1000-year simulation, sediment movement on the landform was not obvious and cannot be seen clearly on a 3-D representation (Fig. 3). There is minor valley development in the central depression and on the steep batter slopes. Minor deposition is visible above Pit 3 on the 1000-year output. Section A-A (Fig. 4; see Fig. 2 for section location) taken through the tailings dam shows that the max. depth of valley incision is 2.2 m at a max. width of≈60 m that would not incise the encapsulated contaminants if, for example, a 5 m deep capping layer of waste rock had been used.

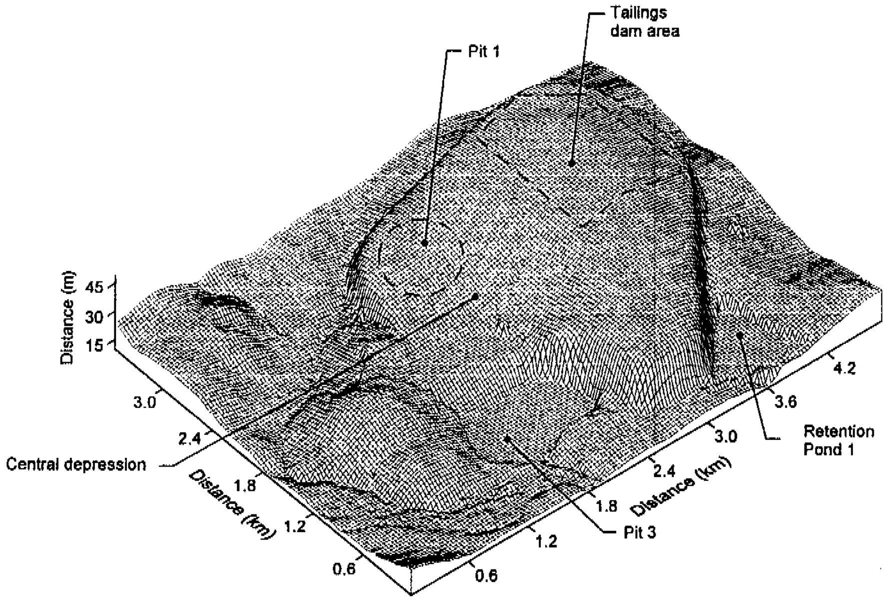

Figure 3 Three dimensional representation of the above-grade landform option for a ripped and vegetated condition after 1000 years of erosion simulation using SIBERIA

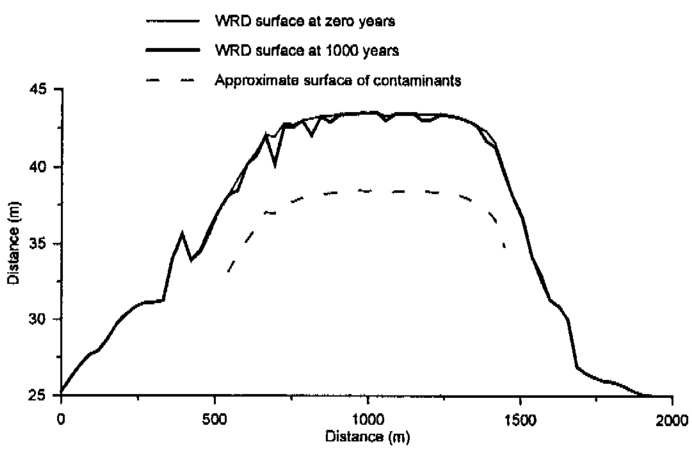

Figure 4 Section A-A through the landform for simulations at 1000 years. WRD, waste rock dump.

Sediment delivery

The next step in the design or assessment process is to determine how much sediment arising from erosion on the mine site is delivered through the catchments linking rehabilitated landforms and the stream systems. The fraction of the originally eroded sediment ultimately delivered to a stream from a catchment is the area-dependent sediment delivery ratio (SDR). The determination of sediment delivery for ERARM is demonstrated for 1 mine site catchment (Fig. 2, Fig. 5). The catchment combines part of the landform with part of the catchment of an upper branch of Gulungul Creek and is referred to as the Gulungul mine site catchment (GMC). The GMC has 3 different areas of erosion contribution (Table 1): (*1*) tailings cap, (*2*) batter slope and (*3*) natural surface linking the batter slope and creek. Gross erosion for the ERARM, was determined through erosion prediction modelling.

Table 1. Gulungul mine site catchment erosion rates and sediment delivery.

Catchment portion	Area (ha)	Model	Catchment erosion rate (t/year)	Sediment delivery (t/year)
Tailings cap	40	RUSLE	48[A]	
Batter slope	14	WEPP	34[B]	
Natural surface	62	Denudation rate (0.014 mm/y)	12[C]	
Total area (ha)	116		82[D] (A+B=D)	41[E] (0.35D+C=E)

Downstream water quality impact

The water quality impact at the confluence of the outlet of the GMC and the main Gulungul Creek channel was determined (Fig. 5) where the mine-derived sediment first enters the main stream channel. Mean annual discharge, Q (m^3/year), from a catchment of area A (m^2) and average annual rainfall R (m/year) is determined at the GMC outlet through: $Q = C_r RA$, where C_r is the runoff coefficient. For this case study, a mean C_r of 0.36 is used for the undisturbed natural Koolpinyah Surface. C_r for the vegetated and ripped tailings cap is 0.1 and for the batter slope is 0.41. For an average annual rainfall of 1480 mm and weighting the C_r values for each area (Table 1) the estimated mean annual discharge at the GMC outlet is 474 ML. Dividing the annual quantity of sediment delivered to the GMC outlet (41 t) by the estimated average annual discharge at the outlet (474 ML) gives an average annual sediment concentration (86 mg/L) in the stream at that point (Table 2). The estimated annual quantity of sediment delivered to the 116-ha GMC outlet for undisturbed conditions is 23 t. This is based on a denudation rate of 0.014 mm/year and a soil bulk density of 1.43 t/m. The discharge is 618 ML, using a C_r of 0.36 for the natural surface, giving a background annual sediment concentration at that point for the undisturbed catchment of 37mg/L (Table 2). The mine site disturbance in the GMC results in a 141% increase in the average annual sediment concentration above background at the GMC drainage channel outlet (Table 2). This increase is diluted considerably when the GMC drainage channel enters the main Gulungul Creek channel. An area of approximately 3000 ha drains through this point (Fig. 6). Based on a C_r of 0.36, the annual discharge at this point is 15 984 ML. Using the denudation rate of 0.014 mm/year and a soil bulk density of 1.43 t/m^3, the sediment delivery at this point is approximately 591 t. This gives a background average sediment concentration in Gulungul Creek of 37 mg/L (Table 2). The sediment delivered to this point as a result of the mining disturbance in the GMC is the sum of the gross erosion in the disturbed 54-ha GMC multiplied by an SDR of 18% (82 t) and sediment yield from the remaining undisturbed 2946 ha of the upper half of Gulungul Creek catchment resulting from denudation (580 t) with a SDR of 18.0% applied. Average annual sediment delivery to Gulungul Creek including the disturbance in the GMC is 595 t/y. Average annual discharge is the sum of 474 ML from the disturbed GMC and 15 366 ML from the undisturbed remaining 2884 ha using a C_r of 0.36. The average annual sediment concentration at this point as a result of mining disturbance in the GMC is 595 t ÷ 15 840 ML = 37.6 mg/L (Table 2). This is an estimated average increase of 1.6% per year in the sediment concentration in Gulungul Creek (Table 2).

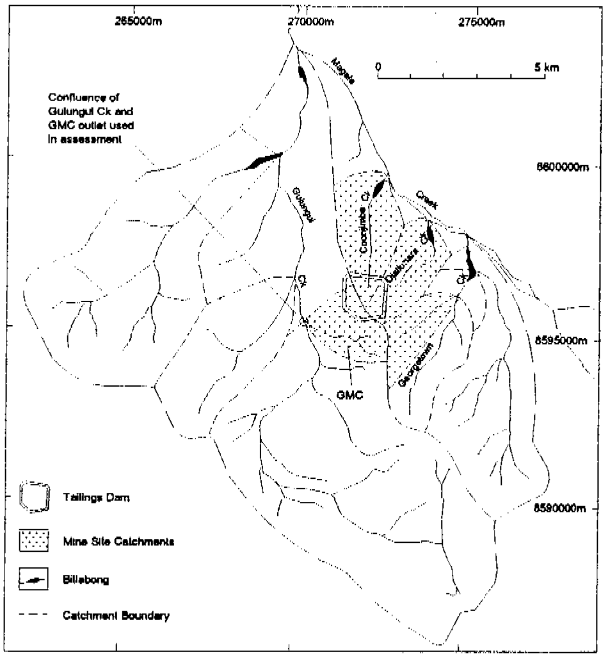

Figure 5 Mine site tributaries and catchments (from Wasson 1992).

Table 2. Impacts on sediment concentration in Gulungul Creek due to mine site disturbance in the GMC.

Catchment conditions	Catchment annual discharge (ML)	Catchment annual sediment delivery (t)	Average sediment concentration at catchment outlet. (mg/L)	Increase in sediment concentration above background (%)
GMC undisturbed – background condition	618	23	37	
GMC with mine site disturbance	474	41	86	141
Main Gulungul Creek channel at confluence with GMC undisturbed – background condition	15 984	591	37	
Main Gulungul Creek channel at confluence with GMC with mine site disturbance	15 840	595	37.6	1.6

Conclusions

The proposed landform, if well vegetated, will suffer little incision by erosion during the first 1000 year after rehabilitation and that contaminants should not be exposed to the environment. Modelling facilitates decisions on capping thickness. If cap thickness can be reduced, this would reduce the cost of earthworks while maintaining structural integrity.

There is an estimated increase of 141% in average annual sediment concentration in the GMC drainage channel as a result of erosion from the rehabilitated post-mining landform within the GMC. Current water quality guidelines (ANZECC 1992) recommend that water turbidity should not increase by > 10% through anthropogenic activities. If this is translated to sediment concentration, then the estimated increase of 141% is well above the recommended 10%, and the landform design should be reassessed. The increase of 1.6% in annual sediment concentration in the main Gulungul Creek channel as a result of the disturbance is within water quality guidelines.

Such an analysis needs to be done for all the mine site catchments shown in Fig. 2 and Fig. 5. For ERARM, there are at least 2 sites where impact on water quality should be assessed (Fig. 5). These sites are in: (*1*) Gulungul Creek, immediately downstream of the confluence of the GCM drainage channel and the main Gulungul Creek channel; and (*2*) Magela Creek, immediately downstream of Coonjimba Creek. Assessment of these sites is important because they are immediately downstream of where the small minesite catchments first enter the main Magela system. Of course, a thorough assessment could be made by deriving sediment concentrations downstream of the confluence of Magela Creek and Djalkmara and Georgetown Creeks.

Water quality is the key. Once effects on water quality have been determined, this knowledge can be used to reassess landform design, if necessary, to reduce erosion by reducing slope, installing sediment traps, or increasing vegetative cover until derived downstream sediment concentrations are acceptable. The technology is available to predict impact on downstream water quality and adjust rehabilitation accordingly. There is now a need for industry and regulators to decide how far downstream or what size catchment is assessed to determine the acceptability of an impact.

References

ANZECC (1992) Australian water quality guidelines for fresh and marine waters. National water quality management strategy. Australian and New Zealand Environment and Conservation Council.

Flanagan DC and Livingston SJ (1995)(Eds) 'WEPP user summary – NSERL Report no. 11' (USDA-ARS NSERL: West Lafayette, IN)

Goldman SJ, Jackson K, Bursztynsky TA (1986) 'Erosion and Sediment Control Handbook.' (McGraw-Hill Book Company: New York.)

Mitchell JK, Bubenzer GD (1980) Soil loss estimation. *In* 'Soil Erosion'. (Eds MJ Kirkby, RPC Morgan.) pp. 17-61. (John Wiley and Sons: Brisbane.)

Needham RS (1988) Geology of the Alligator Rivers uranium field, Northern Territory. Bureau of Mineral Resources, Bulletin 224. Canberra, Australia.

Renard KG, Laflen JM, Foster GR, McCool DK (1994) The revised universal soil loss equation. *In* 'Soil Erosion Research Methods'. 2nd Edn (Ed R Lal.) pp.105-24. (Soil and Water Conservation Society: Ankeny IA.)

Unger CJ, Milnes, AR (1992) Rehabilitation at Ranger Uranium Mines. *In* 'Conservation and Development issues in North Australia'. (Eds I Moffat, A Webb.) pp. 221-31 (North Australian Research Unit: Darwin.)

Wasson RJ (1992)(Ed) *Modern sedimentation and late quaternary evolution of the Magela Creek Plain.* Research Report 6, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

Willgoose GR, Bras RL, Rodriguez-Iturbe I, (1989) A physically based channel network and catchment evolution model. Ralph M. Parsons Laboratory, Department of Civil Engineering, MIT. Boston, MA. TR 322

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By

Ken Evans

Environmental Research Institute of the Supervising Scientist.

Environment Australia

Department of the Environment and Heritage

Supervising Scientist

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ERA Ranger Mine

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Introduction

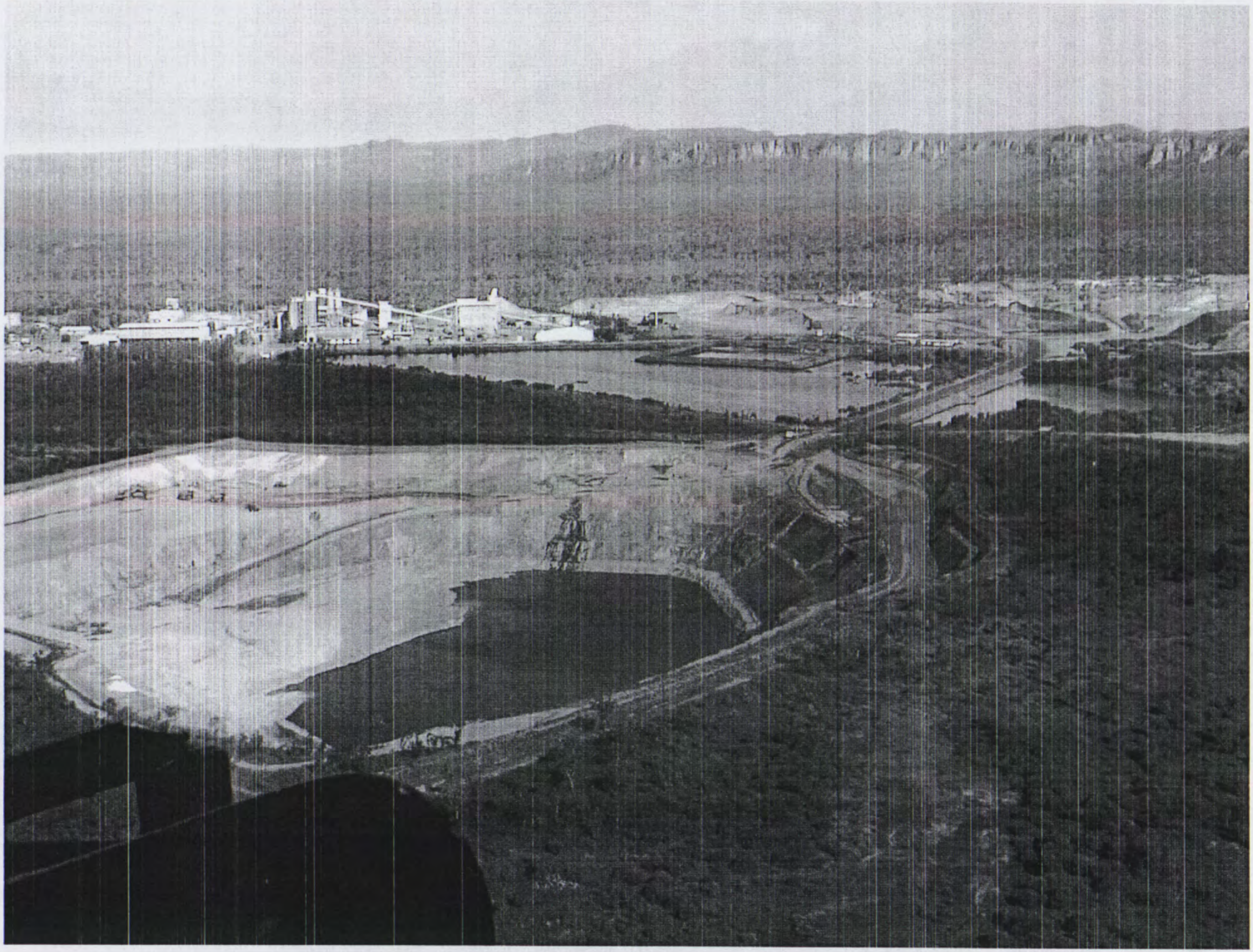
Poor management and design of above-grade waste rock dumps resulting from surface mining can result in:

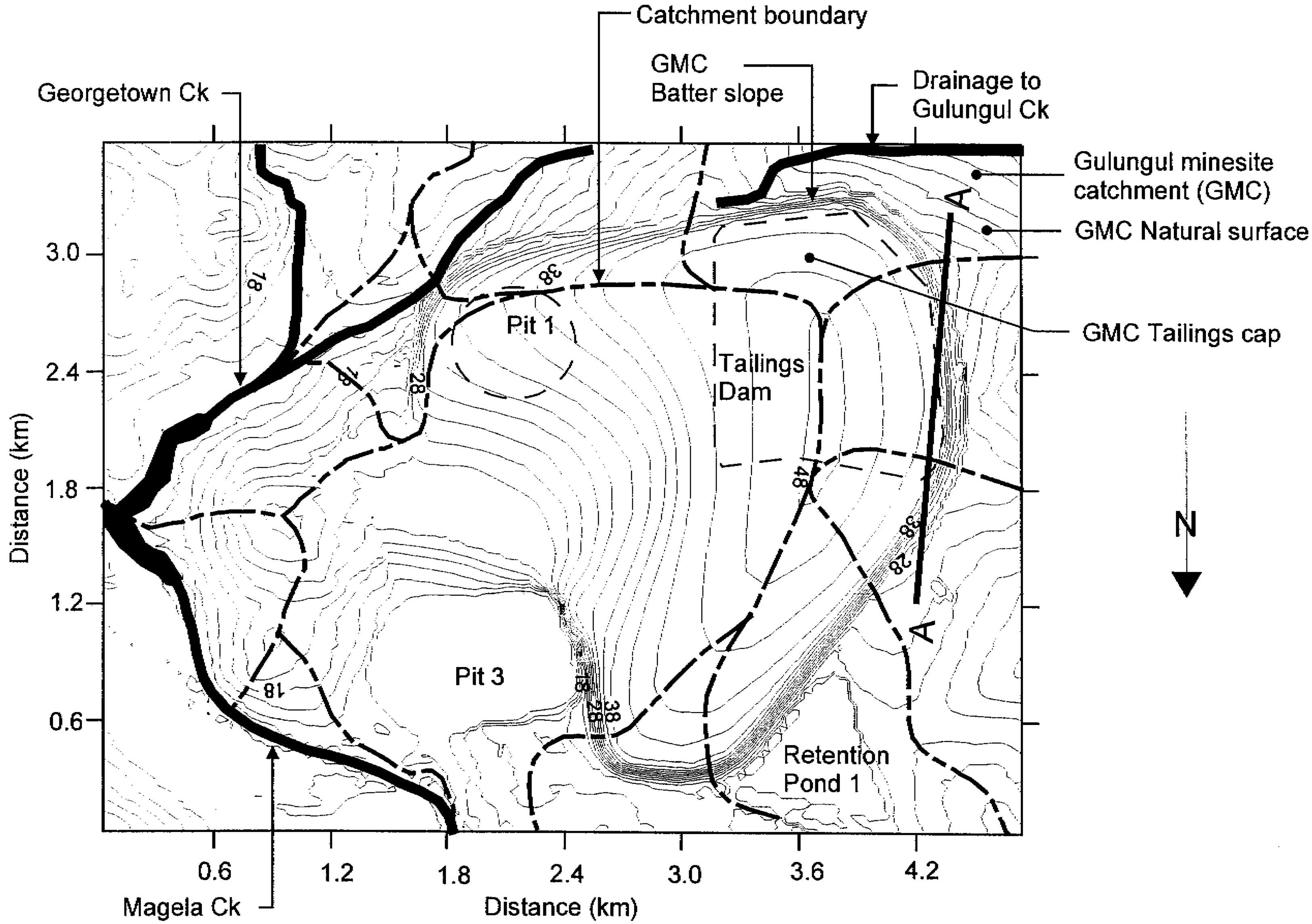
1. **Excessive erosion**
2. **Elevated stream sediment loads**
3. **Stream and river pollution.**

Predictive modelling can quantify sediment generation and assist with landform design and management.

Case study - ERA Ranger Mine

- ERARM - open pit uranium mining adjacent to WHL Kakadu National Park
- Wet Season October -April - 1480 mm
- Final landform still being developed - proposed all tailings returned to below-grade and only low-grade mineralised waste above-grade.
- Case study: earlier option with existing tailings dam rehabilitated *in-situ* as example of modelling application.





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Landform stability: encapsulation of contaminants for extended periods

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Sediment delivery from landform through catchments to stream systems

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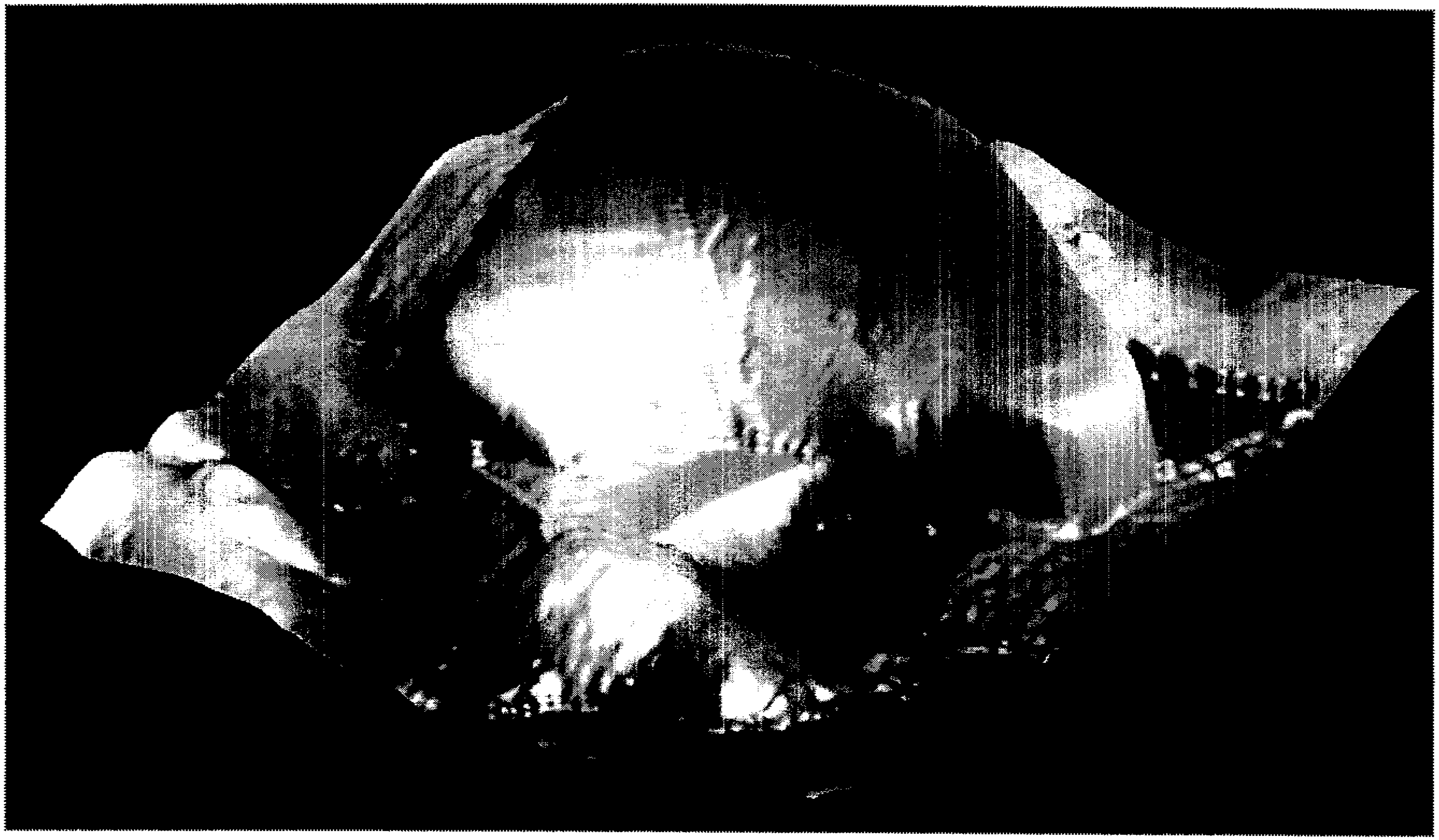
Impact on stream system water quality

Landform Stability

- SIBERIA
  - * 3-D topographic evolution
  - * simulates runoff, erosion, deposition
  - * predicts long-term channel and hillslope development
- 1000 y simulations - ripped and vegetated
  - * max. valley depth - 2.4 m
  - * max. deposition - 4.8 m

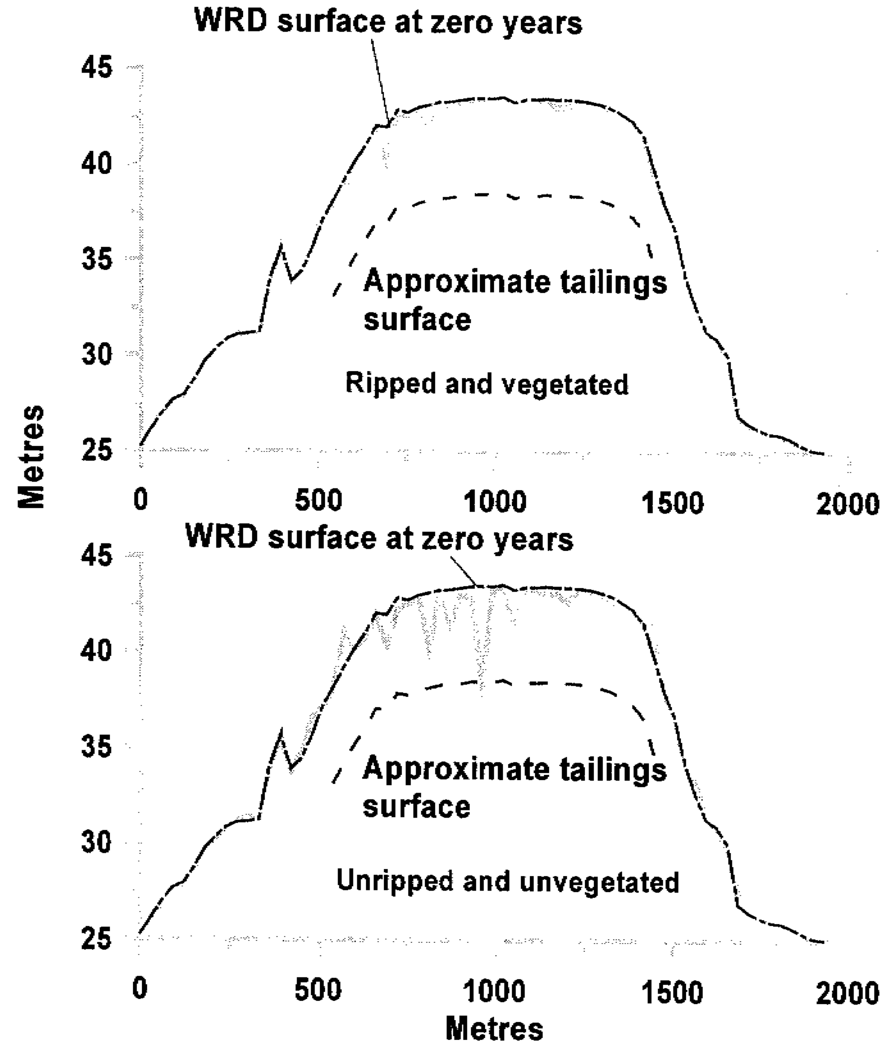


1000 year simulations vegetated, ripped surface

- **Minor valley development in central depression and on batters**
- **Minor deposition occurs above Pit #3**

Tailings Containment Implications - 1000 y erosion incision in tailings dam area

- Ripped and vegetated - max. incision ≈2.2 m
- Unripped and unvegetated - max. incision ≈5 m. Possible breach of tailings surface
- Modelling quantifies effect of surface treatment
- Reduction of 2 m depth of capping material



Sediment Delivery

- Eroded sediment goes through cycles of detachment, transport and deposition until entering the stream system.

- Sediment Delivery Ratio (SDR)
  * Ratio of gross erosion in a catchment to amount ultimately reaching the stream
  * $SDR = (8.33 - 0.51 \ln A)^2$ ($r^2 = 0.996$), where A is area (ha).

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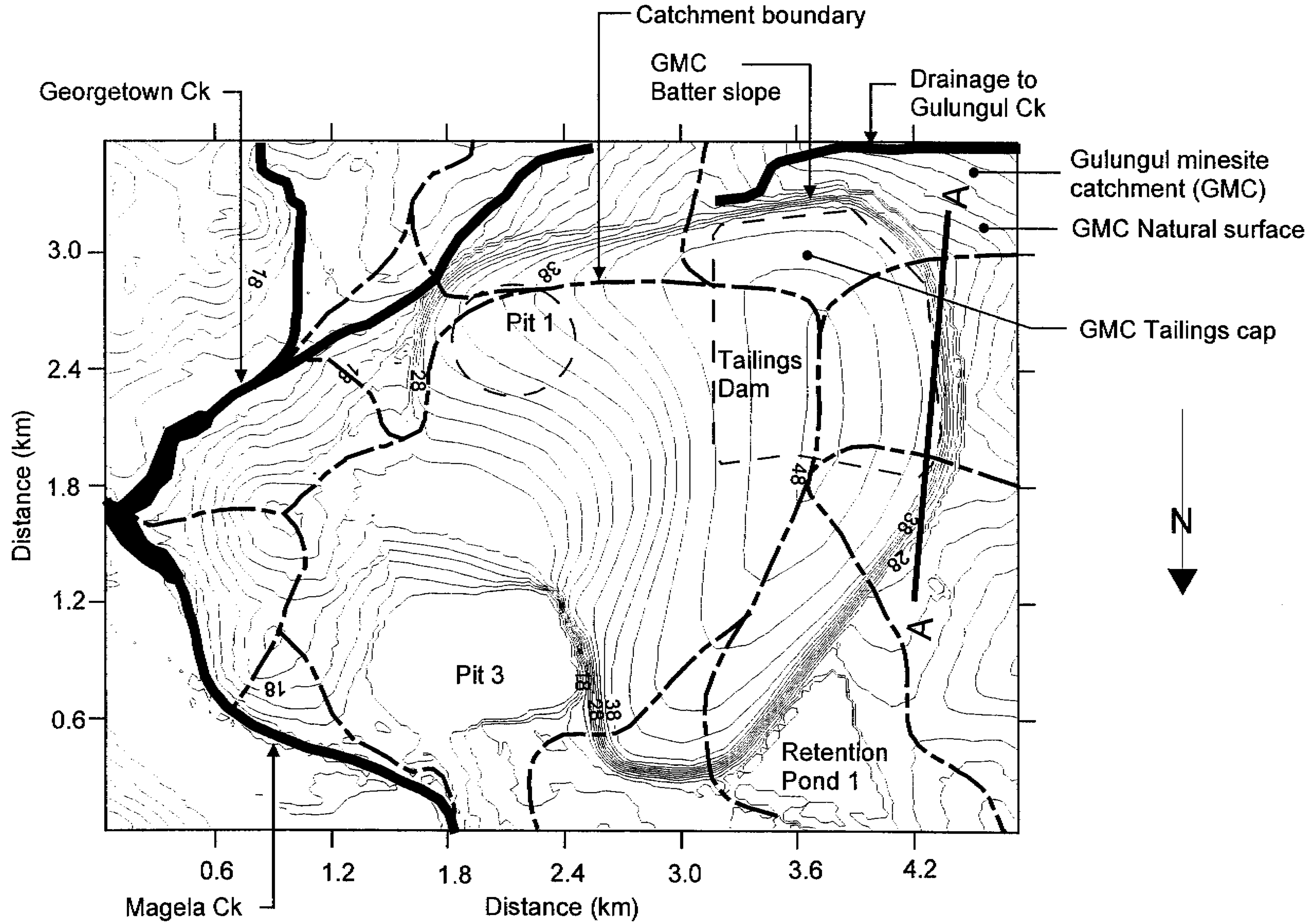

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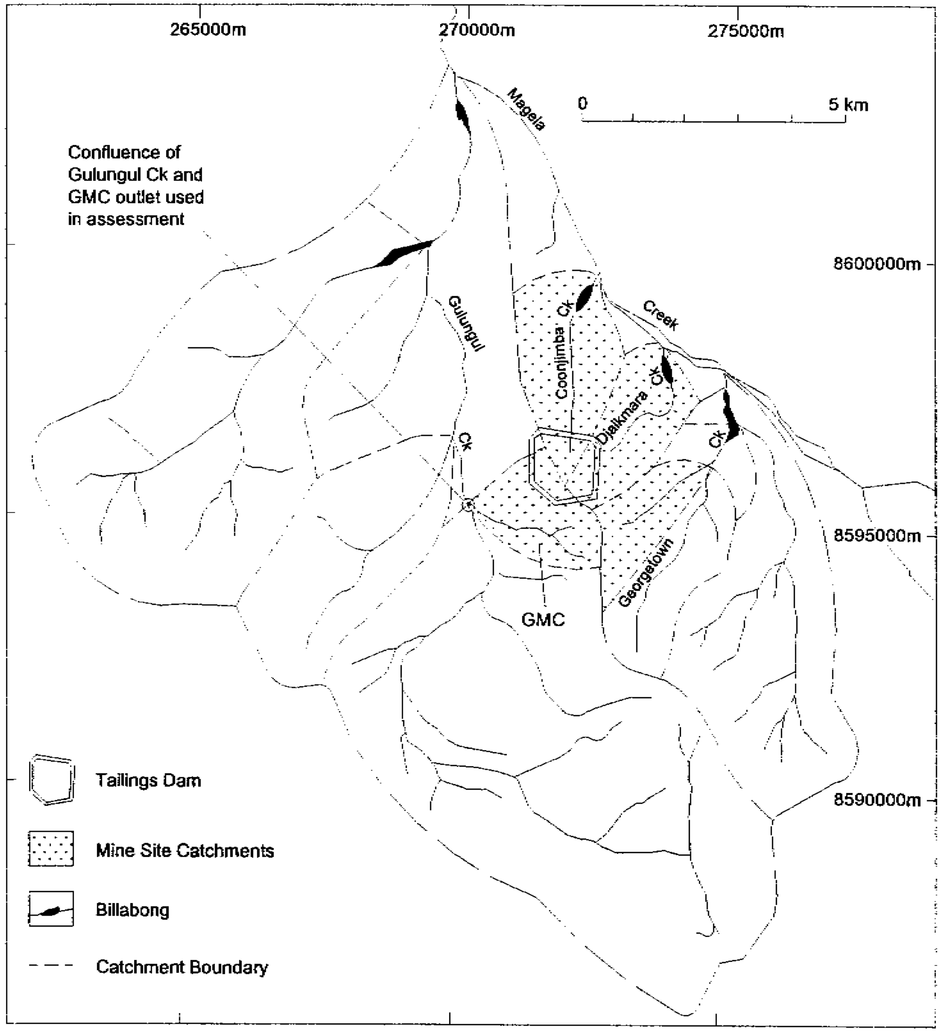
1 Values derived by Landloch Pty Ltd

Downstream Water Quality Impact

- Determine if sediment reaching the stream system elevates stream loads above accepted water quality guidelines

- If unacceptable redesign rehabilitation and assess with modelling until required standards are achieved.



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$$Q = c_r R A$$

where

Q = discharge per unit time
c_r = runoff coefficient
R = Rainfall per unit time
A = Area

$$\text{Sediment concentration} = \frac{\text{Total sediment discharge}}{\text{Total discharge}}$$

Catchment conditions	Catchment annual discharge (ML)	Catchment annual sediment delivery (t)	Average sediment concentration at catchment outlet. (mg/L)	Increase in sediment concentration above background (%)
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Conclusions

- Minor incision in well vegetated landform during first 1000 y after rehabilitation
- Modelling assists with decisions on capping thickness:
  * cost of earthworks
  * structural integrity
- Similar assessment needs to be done for all mine site catchments to assess quality in Magela system
- Technology is available to predict water quality impact
- Decisions are required on the location of impact assessment in the stream system

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