GOLDFIELDS ENVIRONMENTAL MANAGEMENT GROUP

2002 Workshop on Environmental Management in Arid and Semi-Arid Areas

PROCEEDINGS

The Boundary Fence and Beyond




AURIONGOLD

2002 Workshop on Environmental Management in Arid and Semi-Arid Areas

PROCEEDINGS

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The Boundary Fence and Beyond

FOREWORD

AurionGold, a major Australian based international gold producer, recognises that environmental excellence is an integral component of any efficient, successful and sustainable business. AurionGold is committed to the pursuit of 'best practice' in environmental performance that reflects the expectations and needs of the broader community.

With these objectives in mind, AurionGold is proud to be the major sponsor of the 2002 GLRG Workshop and commits to continued support of the GLRG.

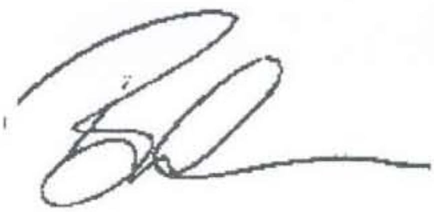
The GLRG is a technical and professional body of environmental practitioners striving toward best practice environmental outcomes in the WA Goldfields. Over the past fourteen years, the group has developed from concentrating on developing and promoting sound land rehabilitation practices to include a much broader spectrum of environmental issues facing the industry.

The biannual GLRG workshop is integral in the provision of expert information and promotion of environmental management and initiatives within the region. The workshop is designed to facilitate interaction between all stakeholders, resulting in implementation of improved environmental initiatives. Clear and frequent communication is imperative if all stakeholders are to be involved in the process.

This year's theme is "The Boundary Fence and Beyond". A knowledgeable and diverse range of speakers will present aspects of their work with this theme in mind. Topics such as community relations and consultation, impact of mining on fauna, sustainable development, tailings disposal and management, water management and monitoring, approaches to rehabilitation and completion criteria & closure will be explored. Tours to the Kundana, Mt Pleasant, Paddington and Kanowna Belle operations are also included in the workshop.

AurionGold is committed to achieving environmental excellence in its operations and exploration activities, and recognises stakeholder involvement as critical to this commitment. We see our environmental commitment and performance as vital to our success. We will know we are successful when the communities in which we operate openly value our presence.

Forums like this workshop are critical to the success of AurionGold in particular and to the mining industry in general and I wish you all the best of success in your deliberations over the next few days.



Brad Gordon

AurionGold
GENERAL MANAGER – KALGOORLIE WEST OPERATIONS

GOLDFIELDS ENVIRONMENTAL MANAGEMENT GROUP 2002 WORKSHOP ON ENVIRONMENTAL MANAGEMENT IN ARID AND SEMI-ARID AREAS - PROCEEDINGS

Session Four - Tailings Disposal & Management cont

Day Two Thursday May 30, 2002

Day Three Friday May 31, 2002

Session One - Water Management & Monitoring

Session Two - Approaches to Rehabilitation

Session Two - Approaches to Rehabilitation cont

Session Three - Completion Criteria & Closure

INTRODUCTION AND MEMBERSHIP TO THE GEMG

INTRODUCTION

The Goldfields Environmental Management Group (GEMG) is a technical and professional body of people working to achieve environmental best practice. The GEMG promotes good environmental management practices in arid and semi-arid areas by providing a source of expertise and resource for land rehabilitation and environmental management.

This is achieved through providing information and education to the public and industry on vegetation and environmental management and by identifying areas where rehabilitation knowledge is limited and research will be beneficial.

The group was formed in 1988 by a small number of individuals involved in land rehabilitation in the Eastern Goldfields region of Western Australia.

Today we have a solid membership from a broad range of backgrounds such as government organisations, consultants, rehabilitation contractors and minesite environmental personnel.

The aim of the GEMG is to promote sound environmental management practises throughout the region.

The GEMG has endeavoured to achieve these aims in several ways:

- Regular meetings with a guest speaker.
- Producing a plant identification handbook.
- Establishing the Goldfields Reference Herbarium.
- Conducting a biennial conference on relevant topics.

PROJECTS

This is the 6th environmental workshop that GEMG have held in Kalgoorlie. The workshops are among the projects GEMG has undertaken to forward the aim of promoting sound environmental management practices and information exchange.

Other projects past and current include:

- Publishing a series of guidelines on topics such as topsoil management, seed collecting, waste dump revegetation and hypersaline water management.
- Producing a plant identification handbook.
- Establishing the Goldfields Reference Herbarium in conjunction with the Kalgoorlie College (Curtin University) and the Western Australian Herbarium.
- Development of a website.

The upgrade of the Herbarium and the website to expand the services offered by both are among our current projects. Public outreach will remain a key goal of the GEMG.

AIMS

The overall aim of the Goldfields Environmental Management Group is to promote sound environmental management and awareness in the Goldfields region, particularly by:

1. Providing a source of expertise and resources for land rehabilitation in the Goldfields. This includes areas such as revegetation techniques, seed technology and site planning.
2. Providing information and education to the public on revegetation and environmental management in the Goldfields.
3. Identifying areas where rehabilitation knowledge is limited and research will be beneficial.
4. Provide a forum for discussion and dissemination of information and knowledge regarding environmental issues.

INTERESTED?

To apply for membership to the Goldfields Environmental Management Group, or to obtain further information about the group's activities, contact:

The Secretary
Goldfields Environmental Management Group
PO Box 2412
BOULDER WA 6432

www.gemg.org

The GEMG meets regularly to discuss environmental management issues.

2002 Workshop on Environmental Management in Arid and Semi-Arid Areas

PROCEEDINGS - DAY 1

SESSION 1 - COMMUNITY RELATIONS & CONSULTATION
SESSION 2 - IMPACT OF MINING OF FAUNA
SESSION 3 - SUSTAINABLE DEVELOPMENT
SESSION 4 - TAILINGS DISPOSAL & MANAGEMENT

The Boundary Fence and Beyond

REHABILITATION INDEX BASED ON REPTILE COMMUNITY STRUCTURE FOR MINE SITE MONITORING

Scott Thompson

CENTRE FOR ECOSYSTEM MANAGEMENT, EDITH COWAN UNIVERSITY

ABSTRACT

Biotic integrity is possessed by an ecosystem in which its composition, structure, and function appear not to have been adversely affected by human activities; perhaps a final objective for a rehabilitated mine site. Biotic integrity or functionality of an ecosystem is difficult to measure and efforts to restore the integrity of, or develop a functional ecosystem in a disturbed site have been dominated by non-biological measures such as chemical and physical parameters. The approach I have adopted is based on the presumption that the biological community will follow if the chemical and physical parameters in a rehabilitated area are appropriate.

A preliminary rehabilitation index based on the assemblage of small reptiles is presented as a method for measuring the progress towards rehabilitation success. The rehabilitation index uses a series of parameters of the reptile assemblage to provide an estimate of the biotic integrity or functionality of an ecosystem. Parameters used include: species richness, abundance, trophic composition, habitat preference and predatory strategy. Reptile community data comes from undisturbed and rehabilitated waste dumps in the area approximately 50 km north of Kalgoorlie.

INTRODUCTION

Currently in Western Australia (WA), the Department of Mineral and Petroleum Resources (DMP - formerly Department of Minerals and Energy) and the Department of the Environment (DoE) advise mining companies to use the guidelines outlined in the *Best Practice Environment Management in Mining* series when developing rehabilitation programs. The onus is on the mining company to describe what its rehabilitation program will be and when enough is enough in rehabilitating the mine site; completion criteria are ill defined. Mining companies negotiate with staff from the DMP to determine when they have done sufficient rehabilitation at a particular disturbed site for them to be released from their environmental obligations, but the absence of guidelines means that the decision to return environmental bonds for rehabilitated lands is subjective.

Restoring an ecosystem to its original condition is ideal, but often not achievable (Recher, 1993). Restoring ecosystem structure and function to approximate pre-undisturbed conditions, without perfect replication, is a more achievable goal. Rehabilitation programs put in place appropriate soils and vegetation, hoping that natural processes and the invasion of invertebrates and vertebrates from adjacent areas will progress toward the establishment of a functional ecosystem (Majer, 1989).

Succession

Natural development of the ecosystem, or succession, involves moving from a simple, low complexity biotic state, towards a more complex state (Majer, 1989). Mine site rehabilitation can be viewed as managing a succession from the surface produced by the mining activity to a self-sustaining ecosystem.

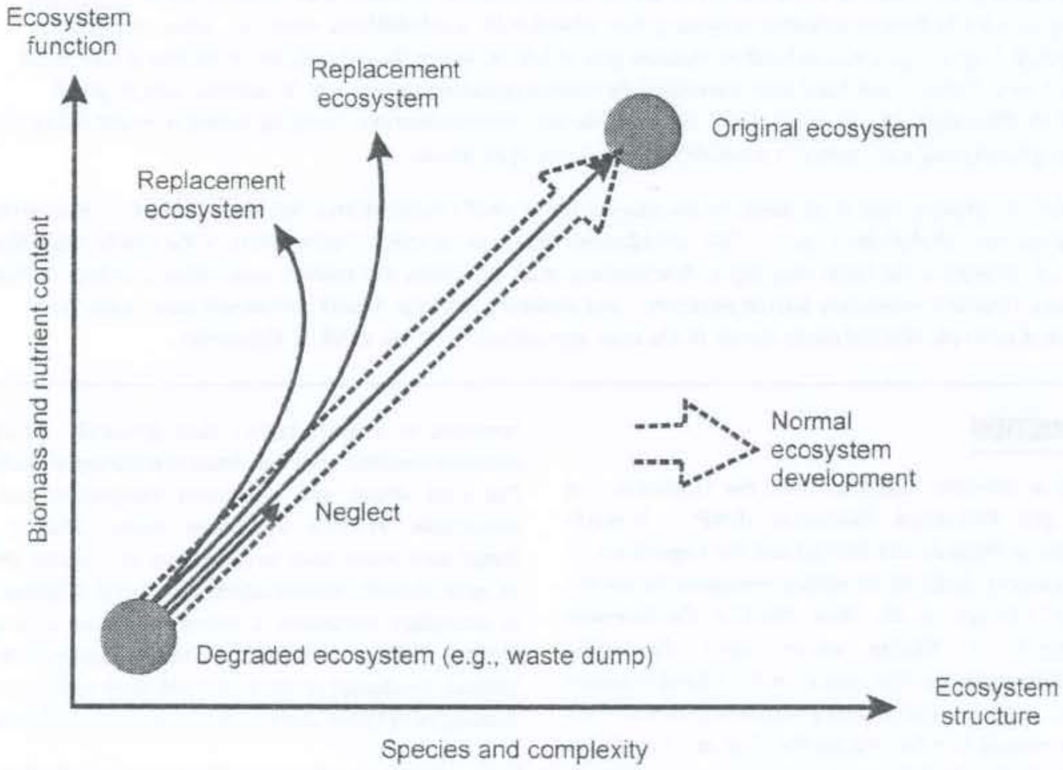
In primary succession, vegetation and associated animals colonise a bare inorganic surface, and once this 'pioneer community' is established, there are a series of replacement communities ('seral stages') that gradually modify the microenvironment until the climax community is established. The seral stages, and community composition are often predictable. Primary succession occurs after a major disturbance event, such as glaciation, or volcanic eruption or, more recently, mining activity (Werner & Wigston, 1989). In secondary succession, a disturbance such as fire, or a cyclone, modifies an existing climax community such that a residual community is left, which will then undergo a series of changes until the climax community is re-established.

Large mining operations are likely to initiate both primary and secondary successions. As far as biotic community development is concerned, it is of little consequence if the disturbance event initiating change is natural or anthropogenic. Thus, if we monitor and analyse the results of disturbance events in natural ecosystems, the information may be applied to the rehabilitation of an operation such as a mine-site (Werner & Wigston, 1989). Fauna respond to changes and succession in vegetation communities rather than just a change in time (Fox, 1997). Figure 1, developed from Bradshaw (1984), shows the process of rehabilitation from a completely degraded ecosystem towards the original ecosystem. The natural ecosystem development involves the movement from a simple state in the bottom left of the graph towards a more complex state in the top right (Bradshaw, 1984).

Closure and completion criteria

It is neither practical nor desirable to rigorously define a single comprehensive set of rehabilitation standards that will apply across all types of terrain and all manner of operations. It is necessary to look at the specific requirements of each individual operation and determine rehabilitation standards on a site-by-site basis (Hollands, 1993). Because mining operations tend to develop in unpredictable ways, planning for rehabilitation needs to be adaptable (Department of Mines and Energy, 1997).

Figure 1: Process of succession from a degraded ecosystem to the original ecosystem (Bradshaw, 1984)



Once the decommissioning phase of a mine has started, the difficulty faced by the owner or operator is when to finish the process. Without a clear understanding of the endpoints, which can determine effective closure, there will be considerable uncertainty.

A commonly accepted goal of rehabilitation of mined land is to restore the structure, diversity, function and dynamics equivalent to that in an undisturbed ecosystem (Bisevac & Majer, 1999). The need to carry out high-quality rehabilitation has become more acute in the industry with the phasing in of performance standards for assessing ongoing rehabilitation, and success indicators or completion criteria for assessing the end product (Bisevac & Majer, 1999).

Fauna as bio-indicators for rehabilitation progress and success

The goal of land rehabilitation programs has shifted from just revegetating an area, towards developing a functional ecosystem (Andersen, 1994). The aim of a bio-indicator based study is to use the living components of the environment under study, as the key to assess the transformations and their effects. In the case of landscape reclamation, they are used to monitor the remediation process in different parts of the landscape over time (Paoletti, 1999). This shift towards developing functional ecosystems in rehabilitated areas has lead to investigations that use invertebrates as indicators of ecosystem restoration programs (Andersen, 1993; Majer, 1989; Majer & Nichols, 1998). The use of vertebrates as bio-indicators is relatively new.

Indicator taxa are species or higher taxonomic groups whose parameters, such as diversity, presence or absence, or infant survivorship, are used as proxy measures of ecosystem conditions (Hilty & Merenlender, 2000). A *biological indicator* might be defined as "a species or group of species that readily reflects: the abiotic or biotic state of an environment; represents the impact of environmental change on a habitat, community or ecosystem; or is indicative of the diversity of a subset of taxa, or of wholesale diversity, within an area" (McGeoch, 1998, p. 185). Chase, *et al.*, (2000, p. 475) defined a *biodiversity indicator species* as "those whose presence is correlated with high species richness or with the presence of a threatened biological community or sub-association".

Since lower trophic levels must have appropriate representation before higher trophic levels can colonise rehabilitated areas, it follows that the presence of higher trophic levels indicates that lower trophic levels are functional. However, it cannot necessarily be assumed that because lower trophic levels appear functional that higher trophic levels will automatically evolve. If secondary and tertiary consumers are not present, it can be assumed that one or more of their requirements are lacking (Knight, 1998). Secondary and tertiary consumers may therefore be seen as an appropriate group to focus on, in the search for indicators of ecosystem functionality and rehabilitation success (Knight, 1998). Many small vertebrates, such as reptiles and small mammals are secondary or tertiary consumers and are also relatively easy to sample and identify (Knight, 1998).

Vertebrates can be herbivorous, omnivorous or carnivorous (including invertivorous) and are unlikely to recolonise rehabilitated areas unless the vegetation structure (food and shelter) and invertebrates (food) necessary for their survival are present. For example, the absence of decomposing logs will mean there will be few or no termites, so lizards that only eat termites are unlikely to colonise an area that has few decomposing logs. If the composition of lizard communities in undisturbed, ecologically functioning biotopes is understood, then this knowledge can be used to develop an index of rehabilitation progress/success, to indicate progress towards the development of a functional ecosystem on either the biotope or landscape scales.

Small lizards can be excellent indicators of rehabilitation progress because they are relatively easy to sample and identify, display a good community structure based on dietary requirements (e.g., herbivorous, omnivorous, invertivorous, carnivorous), foraging strategy (e.g., sit-and-wait versus widely-foraging predators), activity period (e.g., nocturnal and diurnal), body size (small to large) and variety of habitat requirements (e.g., arboreal, terrestrial and fossorial). Most small lizards have a defined activity area, only move in response to competitive pressures, and have a life span long enough to recolonise rehabilitated areas and establish new communities. Most mining areas in arid and semi-arid regions in Western Australia have an abundance of lizards: normally about 40 species (Pianka, 1989). For example, a research site near Bungalbin Hill studied for the past 12 years has 47 reptile species (P. Withers, pers comm.), and a study site in the Great Victoria Desert studied for the past 27 years has 47 species of lizards (E. Pianka, pers. comm.).

The primary purpose of this study is to develop a rehabilitation index based on knowledge of small lizards' community structure that will enable mine site environmental officers and government regulators to monitor progress toward the development of a functional ecosystem in rehabilitated mine sites. This index could then be used as one of the primary tools in assessing when a mine can be released from their rehabilitation obligations.

DATA SOURCE

Pit-traps were placed in undisturbed biotopes to determine lizard species richness and abundance. Similar sampling was conducted on five rehabilitated waste dumps of various ages. This enabled comparisons to be made between lizard species richness and abundance in the undisturbed biotopes, the transition area (area between the undisturbed area and top of the rehabilitated waste dumps) and rehabilitated areas on top of the waste dumps at various stages of development.

A total of 888 pit-traps were used for sampling ($\approx$ 50 000 pit-trap nights to date). Undisturbed areas have 48 pit-traps in 8 arrays of 6 pit-traps, and the transitions or slope of the waste dump and the top of the waste dumps have 36 pit-traps each; 6 arrays of 6 traps. All the sites were surveyed 5 times a year in January, April, June, September and December for 2 years.

REHABILITATION INDEX

Since Karr (1981) first wrote about his *Index of Biotic Integrity* (IBI) many research projects have used his methods of assessing ecosystem health, particularly in fish communities (Karr, *et al.*, 1986). Biotic integrity is defined as the ability to support and maintain "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr & Dudley, 1981). In general, biotic integrity is possessed by ecosystems in which composition, structure, and function have not been adversely affected by human activities. In the context of Bradshaw's (1984) diagram (Figure 1) it is represented by the filled in circle in the top right hand corner.

The *Rehabilitation Index* that I am developing is based largely upon the IBI that was designed by Karr *et al.*, (1986) to measure the health of riverine ecosystems, most of which were being degraded by pollution and land management practises. My rehabilitation index measures the reverse; i.e., progress toward the establishment of a self-sustaining functional ecosystem in a rehabilitated area. Karr *et al.*, (1986, p.1) explains that the "strength of the IBI is its ability to integrate information from individual, population, community, zoogeographic, and ecosystem levels into a single ecologically based index". If these aspects can be captured, then this makes any rehabilitation index a powerful tool for monitoring rehabilitation success.

Karr *et al.*, (1986) used 12 parameters in the IBI, which fall into three main categories: species composition, trophic composition and fish abundance and condition. Data were obtained for each of these parameters at a given site and evaluated in light of what might be expected at an unimpacted or relatively unimpacted location in a similar geographical region (Karr *et al.*, 1986). A numerical rating was then allocated based on whether its evaluation deviates "strongly from", "somewhat from", or "approximates expectations". The sum of the 12 ratings then determines the overall site score (Karr *et al.*, 1986).

My index is in the initial stages of development and is likely to be extensively modified as it is more thoroughly examined and analysed. What follows is a preliminary outline of the general structure of the index and how it might operate.

Thus far I have used five parameters to develop the Rehabilitation Index; species richness, abundance, trophic composition, preferred habitat and predatory composition. Use of this assessment system assumes that my monitoring strategy samples the entire reptile community in a biotope. I have extensively sampled eleven undisturbed habitats, five of which are adjacent to the five rehabilitated waste dumps I have also sampled.

The values obtained for each parameter in a rehabilitated area are compared to the value expected at a site located in a similar geographical area where human influences have been minimal in this case the adjacent undisturbed area. Specifically, I have compared the pit-trappable reptile assemblage structure in the rehabilitated area with the adjacent undisturbed area and other undisturbed areas in the vicinity. A rating system has been assigned to each parameter and the scores used to judge the extent to which the rehabilitated area approximates that of the adjacent undisturbed habitat. The sum of these scores from each of the five parameters is then used to provide an overall index score for the waste dump (see Table 1).

Formulation of most parameters still to be fully worked out and the numbers used here are to show how the index is calculated.

The data presented for 'waste dump' calculations is from the sampling on the top of waste dumps. Data are also available for the waste dump slopes and in future these data will be combined with that for the top, to provide an overall index for the waste dump. I will use two waste dumps (Gimlet South and Rose) to demonstrate how the index will work.

Gimlet South waste dump was rehabilitated in 1993 with some extra earthworks being conducted during 1997. The waste dump is primarily constructed of blue rock with a thick layer of clay topsoil. Rose waste dump was rehabilitated in the 1994 and has a good coverage of soil and vegetation. Both waste dumps are about 50 km north-west of Kalgoorlie (Gimlet South UTM 313518, 6635628 and Rose UTM 333205, 6619667).

Parameter 1 – Species richness

This parameter has two subsets: the total number of species for the area and the number of species within the skinks, geckoes, dragons, goannas, legless lizards, blind and elapid snakes groups expressed as a proportion of the total number of species present. The expectation is that species richness will be higher in undisturbed areas than rehabilitated waste dumps, and as the rehabilitated area progresses towards the self-sustaining functional ecosystem the number of species will increase. The proportion of species in each group in the rehabilitated area will progressively shift as the site progresses towards mimicking the undisturbed functional ecosystem.

The total number of species is scored out of a possible score of 50 (Table 2). The undisturbed area always gets the highest score and the waste dump score is calculated based on the proportion of species found, compared to the number of species in the undisturbed site (Table 2). This way, the waste

Table 1: Index scores, integrity classes and the attributes of those classes.

Total index score (sum of ratings)	Attributes
141-180	Comparable to the best situation without human impact; regionally expected species for habitat type; species present with a full array of age (size) classes; balanced trophic structure; self-sustaining functional ecosystem.
121-140	Species richness approaching expected levels; not all late succession species present, some species present with less optimal abundances or size distribution; trophic structure incomplete.
85-120	Species richness below expectation, some groups not well represented, some specialists not present.
51-85	Lack of specialists; fewer species, skewed trophic structure and relative abundances.
31-50	Few vertebrates present; only early colonisers present, lack of community structure.
0-30	Early succession species only. No community structure. Only opportunistic early colonisers are present.

dump score is always relative to the undisturbed area. The extent to which the proportion of species in each of the groups (skinks, geckoes, dragons, goannas, legless lizards, blind snakes and elapids) matches that in the undisturbed area is scored out of 40. The index scores are assigned based on how well the proportion of the various reptile groups in the rehabilitated area matches that in the undisturbed site. If the proportion of reptiles in each of the groups mimics that of the undisturbed site the score is a 5; if the rehabilitated site deviates strongly from the expected proportion in the undisturbed area then it can score as low as 1. An overall score for species richness is obtained by summing the two scores; species richness and proportional representation of species. A similar method is used to score each of the five parameters.

Parameter 2 – Abundance and diversity

There are three subsets to the abundance and diversity parameter; absolute abundance or density, relative abundance or evenness and diversity. The density score is determined by the number of reptiles caught per 100 pit trap days. Density is an important measure of the capacity for the ecosystem to support individuals. It would normally increase as the environment approaches a climax community. Both Rose and Gimlet South waste dumps have fewer specimens than at the undisturbed site (Table 3).

Relative abundance can be measured in two ways - evenness (Tramer, 1969) or a measure of the slope of the graphical presentation of the relative abundance data (see figure 2 and 3). The pattern of relative abundance and evenness for Rose waste dump is similar to the undisturbed site (Table 3). This demonstrates that this waste dump is starting to develop a community structure similar to the undisturbed area. Gimlet South waste dump has one dominant species rather than an even spread of species; this is not representative of the undisturbed area (Figure 2 and 3). This dominant species probably occupies niches of other species in the undisturbed community structure. There are also about half the number of species found on the waste dump compared to the undisturbed area. Rose therefore scores more highly in the relative abundance parameter than Gimlet South. Simpson's (1949) diversity index scores are similar for both the undisturbed areas ($\cong 0.90$). Rose waste dump has a more comparable Simpson's diversity index than Gimlet South respective to their undisturbed areas; resulting in a higher score. On preliminary analysis, for abundance and diversity, Rose waste dump scored a 24, and Gimlet South waste dump would score 16 compared a possible 40 in the undisturbed area (Table 3).

Parameter 3 –Trophic composition

The trophic composition parameter examines how the reptile assemblage is segregated into dietary niches. Species are assigned to a trophic group based on their adult feeding patterns. The subsets in this parameter include the proportion of dietary specialists, and proportion of omnivores, carnivores (vertebrate only), and invertivores within the community. An omnivorous species is defined as one that consumes significant quantities of both plant and animal material. A 'significant quantity' is defined as greater than 25% animal and 25% plant material. An invertivore is defined as a species whose diet consists of at least 85% invertebrates and a carnivore is a species whose diet consists of at least 85% vertebrate prey. A species is defined as being a 'dietary specialist' if greater than 85% of its diet comes solely from one food source (i.e., ants or termites). Data for diets were obtained from the published literature and from discussions with field biologists/ecologists.

Table 4 shows that both of the undisturbed areas have similar trophic compositions with about 84-90% of the reptiles being invertivores, 6-8% are omnivores and the remainder vertebrate carnivores. In both of the waste dumps there are no carnivores and more omnivores, suggesting that carnivores might be later colonising species. The proportional representation of species in each of the trophic groups compared with that in the undisturbed area is scored on a scale of 1 to 15 (Table 4).

There are no dietary specialists for Rose waste dump compared to 20% in the undisturbed site (Table 4). Dietary specialists are scored on a scale of 1 to 10 (Table 4). The summary of scores for Rose and Gimlet South waste dumps are out of a possible maximum of 25.

Parameter 4 – Preferred habitat

The preferred habitat parameter is a measure of the proportion of arboreal, terrestrial and fossorial species in the rehabilitated area compared with the undisturbed area. Data on the ecology and biology of the species was obtained from published literature, discussions with biologist/ecologists and from personal experience in the field. Arboreal species are those that primarily forage and inhabit trees or under bark. Fossorial species are those that primarily forage and inhabit loose soil, leaves and organic matter and terrestrial species are those that primarily forage and live in open areas, generally digging their own holes, living in other species holes or sheltering under bushes and shrubs. This parameter is scored on a scale of 1-15. Rehabilitated areas with reptile assemblages that closely mimic that in the undisturbed area get a higher score.

The proportion of species living in preferred habitats is very similar for Gimlet South and Rose undisturbed sites with terrestrial species dominating the habitat composition (Table 5). Gimlet South waste dump proportions are very similar to the undisturbed sites, whereas, Rose has a higher proportion of terrestrial species and no fossorial species in the rehabilitated sites (Table 5). On a preliminary analysis, Rose waste dump scored an 8, and Gimlet South waste dump scored 12 compared with a maximum of 15 in the undisturbed area (Table 5).

Table 2: **Summary of parameter scores for species richness at Gimlet South and Rose undisturbed areas and waste dumps**

	Sites	Gimlet South				Rose			
	Maximum score	Undisturbed		Waste dump		Undisturbed		Waste dump	
		(#) / %	Score	(#) / %	Score	(#) / %	Score	(#) / %	Score
Total number of species (#)	50	30		11	18	25	50	11	22
% skinks		30		18		28		9	
% geckos		20		55		36		36	
% dragons		13		18		12		36	
% goannas		7		0		4		9	
% legless lizards		7		0		0		0	
% blind snakes		7		9		8		0	
% elapids		17		0		12		9	
Proportional number of species	35				15				20
Parameter 1 score	85		**85**		**33**		**85**		**42**

Table 3: **Summary of parameter scores for abundance and diversity at Gimlet South and Rose undisturbed areas and waste dumps**

	Sites	Gimlet South				Rose			
	Maximum score	Undisturbed		Waste dump		Undisturbed		Waste dump	
			Score		Score		Score		Score
Number of captures/100 trap nights (density of captures)	20	8.59	20	2.78	6	9.20	20	3.43	8
Simpson's diversity	10	0.91		0.68	4	0.90		0.82	7
Evenness (J)	10	0.82		0.68	6	0.81		0.80	9
Parameter 2 score	40		**40**		**16**		**40**		**24**

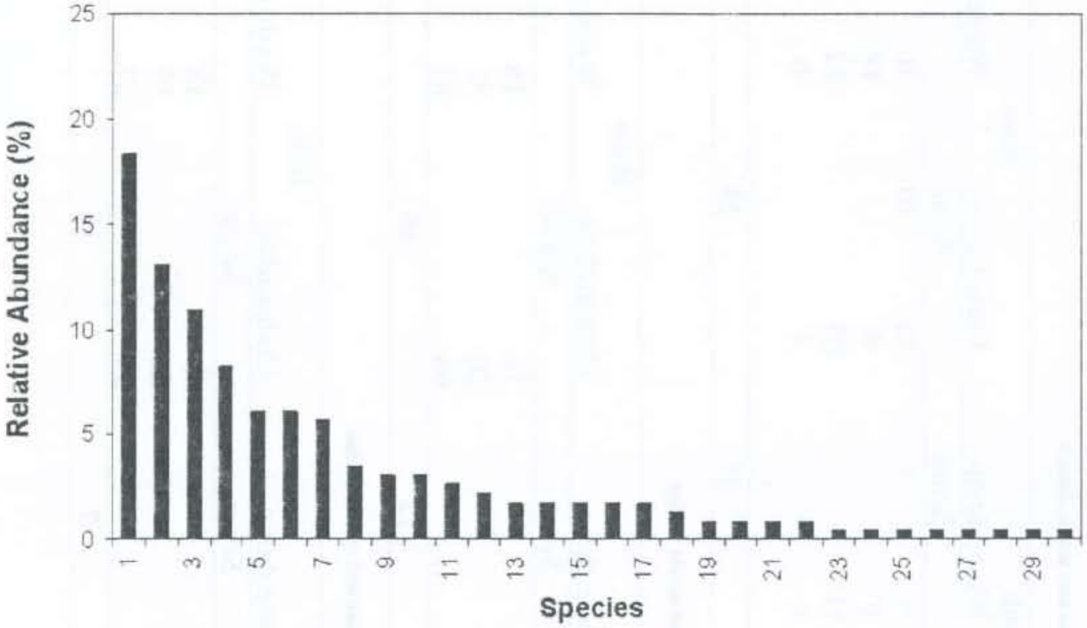


Figure 2: Relative abundance of reptiles at Gimlet South undisturbed

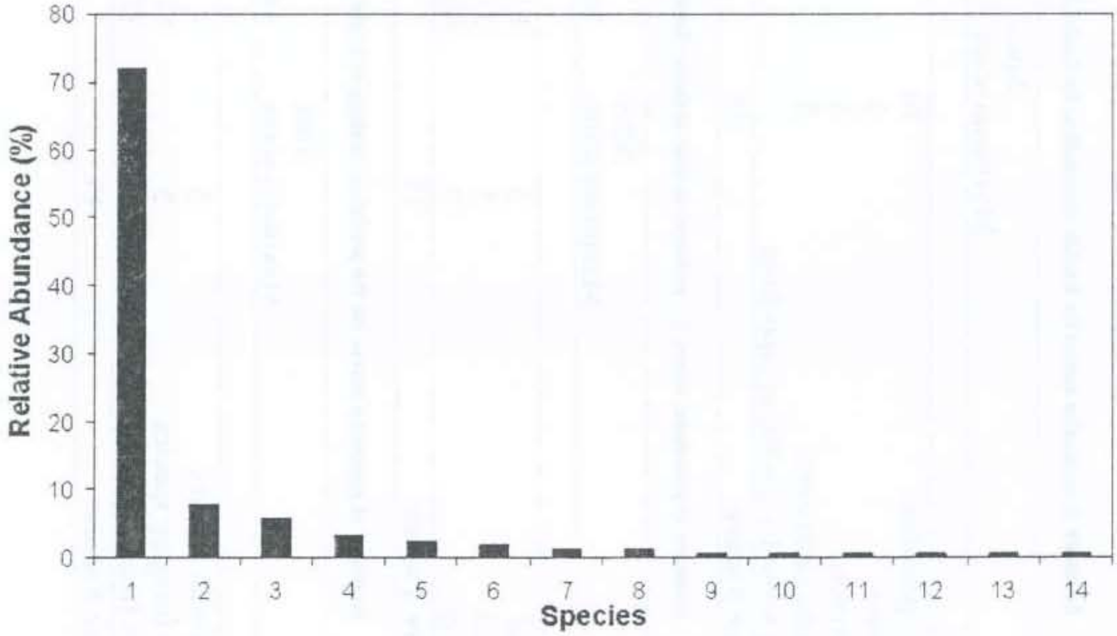


Figure 3: Relative abundance of reptiles at Gimlet South waste dump

Table 4: Summary of parameter scores for trophic composition for Gimlet South and Rose undisturbed areas and waste dumps

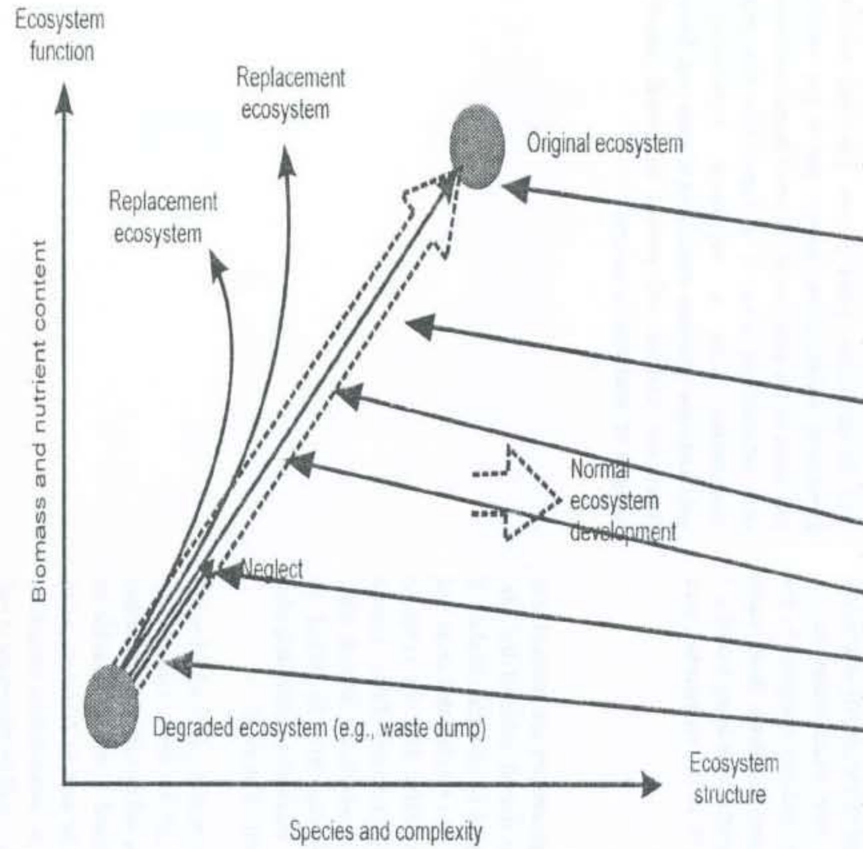
	Sites	Gimlet South				Rose			
	Maximum score	Undisturbed		Waste dump		Undisturbed		Waste dump	
			Score		Score		Score		Score
% dietary specialists	10	23	10	9	3	20	10	0	1
% omnivores	5	7		9		8		18	
% invertivores	5	90		91		84		82	
% vertebrate carnivores	5	3		0		8		0	
Summary score for trophic composition					13				8
Parameter 3 score	25		**25**		**16**		**25**		**9**

Table 5: Summary of parameter scores for preferred habitat at Gimlet South and Rose undisturbed areas and waste dumps

	Sites	Gimlet South				Rose			
	Maximum score	Undisturbed		Waste dump		Undisturbed		Waste dump	
			Score		Score		Score		Score
% arboreal	5	17		18		16		18	
% fossorial	5	23		18		20		0	
% terrestrial	5	60		64		64		82	
Parameter 4 score	15		**15**		**12**		**15**		**8**

Table 6: Summary of parameter scores for the predatory strategy at Gimlet South and Rose undisturbed areas and waste dumps

	Sites	Gimlet South				Rose			
	Maximum score	Undisturbed		Waste dump		Undisturbed		Waste dump	
			Score		Score		Score		Score
% sit-and-wait species	5	7		27		8		18	
% widely foraging species	5	57		18		68		55	
% actively foraging species	5	37		55		24		27	
Parameter 5 score	15		**15**		**7**		**15**		**10**



Total Index score (sum of ratings)	Attributes
141-180	Comparable to the best situation without human impact; regionally expected species for habitat; species present with a full array of age (size) classes; balanced trophic structure; self-sustaining functional ecosystem.
121-140	Species richness approaching expected levels; not all late succession species present, some species present with less optimal abundances or size distribution; trophic structure incomplete.
85-120	Species richness below expectation, some groups not well represented, some specialists not present
51-85	Lack of specialists; fewer species, skewed trophic structure and relative abundances
31-50	Few vertebrates present; early colonisers, lack of community structure
0-30	Early succession species only. No community structure. Only opportunistic early colonisers present

Figure 4: Linkage between Bradshaw's (1984) process of ecosystem development and the rehabilitation index scores

Table 7: Summary of overall index scores for Gimlet South and Rose undisturbed areas and waste dumps

Sites	Undisturbed sites	Gimlet South Waste dump	Rose waste dump
	Maximum score	Score	Score
Species richness	85	33	42
Abundance	40	16	24
Trophic composition	25	16	9
Preferred habitat	15	12	8
Predatory strategy	15	7	10
Overall Score	180	84	93

Parameter 5 – Predatory composition

The predatory composition parameter is a measure of the proportion of sit-and-wait species, widely foraging species, and actively foraging species. Actively foraging species are those that forage over a broad area, relatively quickly looking for a dispersed food source. Widely foraging species are those that forage over a wide area but feed from a concentrated food source (i.e. termite mound or ant nest). Sit-and-wait predators are ambush predators and may move from one location to another in search of sites from which they can rapidly move to catch their prey.

The proportion of sit-and-wait species in both the undisturbed sites is low compared to the actively and widely foraging species (Table 6) and both waste dumps have a higher proportion of sit-and-wait predators compared to the undisturbed sites. On a preliminary analysis, Rose waste dump scored a 10, and Gimlet South waste dump scored a 7 compared with a maximum of 15 in the undisturbed area (Table 6).

Overall Index

The scores for each of the five parameters are summed into a table (Table 7) to provide an overall index of the site. Scores can range from 0-180. Based on an understanding of the succession of reptile species into rehabilitated areas and a preliminary analyses of the available data, the range of scores (0-180) can be divided into six classes (Table 1) and a general description of the reptile assemblage at each class can be developed. This table can then be linked to Bradshaw's (1984) process of succession from degraded ecosystems to a climatic community (Figure 4).

There are other possible parameters that can be added to the index such as lizard size and activity times. Like all the parameters described above these will be subjected to further investigation. When fully developed it may be feasible to indicate an index score that can be used to determine when the mine can be released from its rehabilitation obligation. As this index only deals with the small herpetofauna it will probably need to be considered in conjunction with a measure or index of stability [(e.g. Landscape Function Analysis (Tongway, 2001)] and vegetation structure. It is also possible the index can be developed to incorporate small mammals and birds and maybe some groups of invertebrates. I have data on the small mammals for all my research sites and this aspect of the index will be further developed.

For this index to have a wider application than the sites from which it has been developed it should be tested in a range of other habitats, e.g. sandy coastal heath, inland red sand dunes covered with spinifex, woodlands and forest in the south west of WA.

This Rehabilitation Index is not the total solution to monitoring rehabilitation success, but it can provide an indication of the progress of the small faunal recolonisation onto rehabilitated areas. It is hoped that this index in combination with a vegetation monitoring and soil/landscape structure monitoring scheme (e.g. Ecosystem Functional Analysis) will provide an overall quantifiable measure of rehabilitation success.

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TERRESTRIAL FAUNA SURVEYS: WHY, WHEN AND HOW MUCH?

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ABSTRACT

Surveys of small vertebrate terrestrial fauna provide regulators and mine site environmental staff with a valuable source of data to plan, monitor and obtain closure on rehabilitated mine sites as well as preparing an EIA. Presuming the objective of a rehabilitation program is to create a functional ecosystem, then it is important that a comprehensive survey of the terrestrial fauna is undertaken in the rehabilitated area, and the undisturbed area that the rehabilitated area is designed to mimic. The survey effort required to capture a nominated proportion of the species on a site can be determined from the species accumulation curve. Twenty litre buckets are superior to PVC pipes as pit-traps, but pipes catch species unlikely to be caught in buckets and therefore should be used in conjunction with buckets. Pit-traps with drift fences are better than Elliott traps, but should be supplemented by Elliott and funnel traps for a complete survey of an area. Pit-traps should be placed 5 –7 m apart, arranged in a straight line, with shelter in the bottom of buckets. Ideally, surveys should be undertaken during spring, summer and autumn and in more than one year if the data are to provide an understanding of biodiversity and ecosystem function.

INTRODUCTION

As land managers our aim should be to leave the site without anyone knowing we have been there. This can be difficult in some mining environments as the scale and impact of the disturbance is such that mining companies would argue that it would make the mine economically non-viable, particularly as overseas competitors are not required to meet similar environment standards. However, as stewards for the environment it behoves us to work towards this objective. In circumstances where it is neither reasonable nor feasible to achieve such an objective, then being 'environmentally neutral' may be the next best option. For example, it may not be feasible to fill a mining void, however, to offset the blight that this void has on the landscape and the environment, the mining company might negotiate with the regulators to improve another part of the degraded environment under their stewardship by de-stocking an overstocked rangeland and letting the natural fauna and flora return, eradicating feral pests, or supporting environmental research.

If we accept the objective of *leaving the site without anyone knowing we have been there*, then our rehabilitation programs should be designed to recreate the self-sustaining functional ecosystem that existed before the disturbance. It is appreciated that this will be difficult for some sites and will have to settle for recreating 'similar' functional ecosystems.

Bradshaw (1984) provides a very useful model that represents the development of ecosystem function and structure as a 2-dimensional graph (Figure 1). In a rehabilitation context, natural ecosystem development, or succession, involves moving from a disturbed and degraded environment through a series of stages to a more complex state at the top right of the graph (Figure 1). Rehabilitation involves planning a process that assists the environment to move toward this final state. Incomplete or inappropriate rehabilitation will result in an ecosystem that differs from that which originally existed. If our objective is to leave the site without anyone knowing we have been there, then the objective of our rehabilitation programs will be clear. The recreation of functional ecosystems will require that we stabilise the substrate, ensure appropriate topsoils are in place and revegetate the site as near as possible to the vegetation community structure that existed before the disturbance. We then let nature take its course and hope that the invertebrates and vertebrates from the surrounding areas will move in and colonise the area.

If we consider the broad scale successional process, an appropriate floral community structure will only develop on suitable soils. Invertebrates will only colonise an area if suitable habitat (shelter and food source) is available. Small vertebrates are either herbivorous and thus require the appropriate vegetation, invertivorous and are dependent on the availability of invertebrates which depend on the vegetation, which depend on the soils, or are carnivorous, feeding on small vertebrates. It is therefore obvious that small terrestrial vertebrates (e.g., reptiles, frogs and mammals) are generally the last to move into an area, and seldom are these introduced by human intervention. Small terrestrial vertebrates can therefore provide a useful indicator of the extent to which an ecosystem is moving toward the recreation of the original system, or a replacement system, as they are the last stage in the rehabilitation process. If we understand the structure and dynamics of the small terrestrial vertebrate community in the original ecosystem then we can use this knowledge to develop a rehabilitation index, which can tell us how far we are along the path to recreating the original ecosystem (see Thompson, S. 2002, Rehabilitation index based on reptile community structure for mine site monitoring, this volume).

Why do we need to survey the terrestrial fauna? Well the answer is obvious; we need to understand the structure and dynamics of the small terrestrial fauna in an undisturbed ecosystem if we intend to recreate it. If we intend to use fauna as a measure of rehabilitation success (e.g., rehabilitation index) then we need to collect the input data.

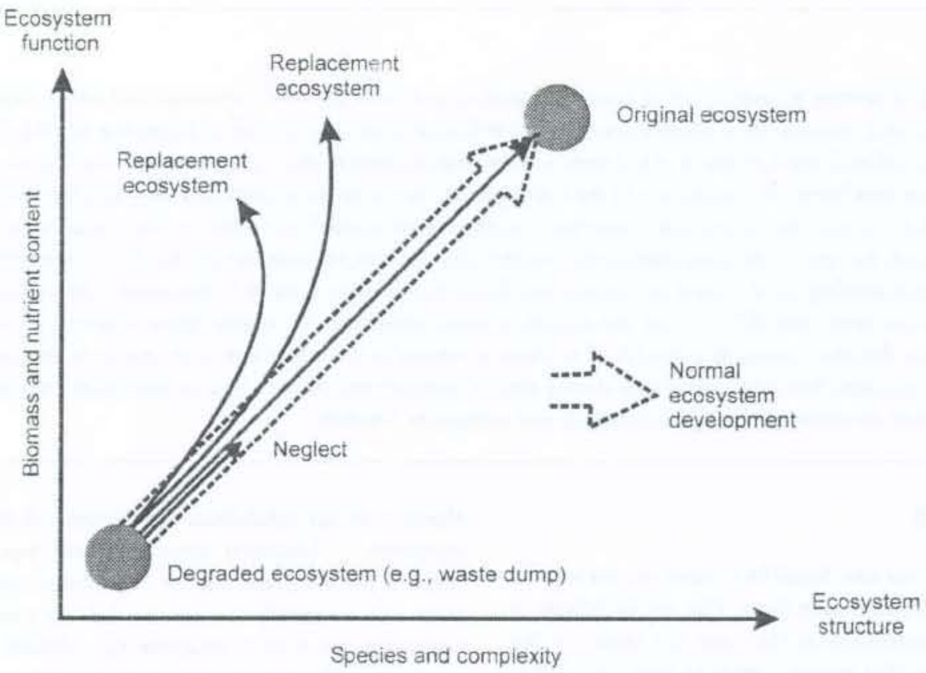

Figure 1: The process of ecosystem development (Bradshaw, 1984)

There are also legislative reasons for undertaking small terrestrial vertebrate fauna surveys at mining sites. The Commonwealth Environment Protection and Biodiversity Conservation Act 1999, section 18, indicates a person must not take an action that will impact on threatened, critically endangered, endangered and vulnerable species. Similarly, a person must not take an action that will significantly impact on a listed threatened or endangered ecological community. Clearly, before disturbing an area, appropriate fauna surveys need to be undertaken to ensure compliance with this Act. More recently the Environmental Protection Authority (EPA, 2002) has issued Position Statement No. 3, *Terrestrial Biological Surveys as an Element of Biodiversity Protection.* In this publication the EPA has grouped the Interim Biogeographic Regions (IBRA) in Western Australia (WA) to define the level of biological survey expected for the preparation of an environmental impact assessment (EIA). Depending on the scale and nature of the impact, proponents of a disturbance are required to either undertake; a) a desktop study and reconnaissance survey, or b) a desktop study, reconnaissance survey, and a comprehensive flora and fauna survey. No detail is provided of what the EPA expects in regard to a 'comprehensive' fauna survey. However, the EPA does indicate it expects proponents to ensure the terrestrial biological surveys provide sufficient information to address biodiversity conservation and ecological function. Biodiversity value is to be considered at the genetic, species and ecosystem level, and ecological function, at the ecosystem level. Clearly, to assess issues related to biodiversity and ecological function a near complete list of fauna species for the site is required. The importance of 'rare' species in the context of ecosystem function will determine whether a complete list of vertebrate species should be required.

Current level of terrestrial fauna surveys in Western Australia mining industry

We surveyed 88 mines in WA seeking information on the extent to which mines had developed completion criteria and to ascertain the current status of flora and fauna monitoring in the mining industry in this state. Thirty six companies responded to the questionnaire, of these 23 systematically monitored flora and only three monitored fauna. Although, we failed to capture information for all of the mines in WA, for those we did, few are systematically surveying the fauna.

Current level of fauna surveying for the preparation of EIA

Fraser (2001) assessed the extent of fauna surveys and data analysis undertaken by consultants during the preparation of 15 of the most recent EIA in the Coolgardie IBRA. Of these, only three searched the Department of Conservation and Land Management (CALM) and Western Australian Museum (WAM) databases, but most reviewed the published literature. Only three of the 15 consultants undertook field surveys in both spring and autumn, most undertook a single survey in either spring or autumn, and only one consultant surveyed the site during summer.

Fauna surveys for a biotope were sampled at one location only by all consultants; the mean number of pit-traps, Elliott traps and cage-traps used was 8, 11 and 1 respectively. The mean trapping effort within a season was 138 pit-trap nights, and for all seasons was 164 pit-trap nights for a biotope (Fraser, 2001). For fauna surveys covering a landscape scale impact, the mean number of pit-traps, Elliott-traps and cage-traps used was 76, 92 and 8 respectively, and the mean number of pit-trap nights for a single season was 1 211, and for all seasons it was 1 507 (Fraser, 2001). Only 12 of the 15 consultants had a component of their field survey designed to search for rare/endangered or priority-listed fauna. Fraser (2001) concluded there was insufficient field survey effort to provide anything other than a cursory understanding of faunal diversity and little effort was made to detect the presence of species requiring special protection under existing legislation.

Based on the findings of Fraser (2001) it is apparent that insufficient field survey effort was undertaken by most of the consultants to enable mine site environmental officers to plan and monitor rehabilitation programs in the Goldfields region if we are to use Bradshaw's (1984) approach.

SURVEY PROTOCOLS AND ISSUES

Well, what should be the protocols for surveying small terrestrial fauna? For the remainder of this paper we review the literature to see what advice others offer and we summarise some of our data from an extensive pit-trapping program that we have undertaken in the Ora Banda region over the last two years to provide guidance for terrestrial fauna survey protocols.

We consider the following questions:

- How much survey effort is required?
- What sort of trapping protocol should be used?
- What strategies can be used to search rare and range restricted species?

How much?

We can answer the 'how much' question by reviewing species accumulation curves. Species accumulation curves simply graph the rate at which new species are identified for the amount of trapping effort.

A species accumulation curve typically rises steeply as the common species are caught during the initial trapping effort and then the slope of the curve flattens as considerably more effort is required to capture the rare or difficult to trap species (Figure 2). Trapping effort can be measured as either the number of pit-trap days (or Elliott-trap days) or the number of specimens caught.

The relative abundance of species at most sites takes on a characteristic concave to the origin curve if species abundance is arranged in an array from highest to lowest (Figure 3). The graph of relative abundance can be related to the species accumulation curve, as the more abundant species are normally caught first and a much greater trapping effort is required to catch the less abundant species. For example, the species accumulation curve in Figure 2 commences to plateau between 42-44 species, which corresponds with the species being represented less than 0.15% in the population (Figure 3).

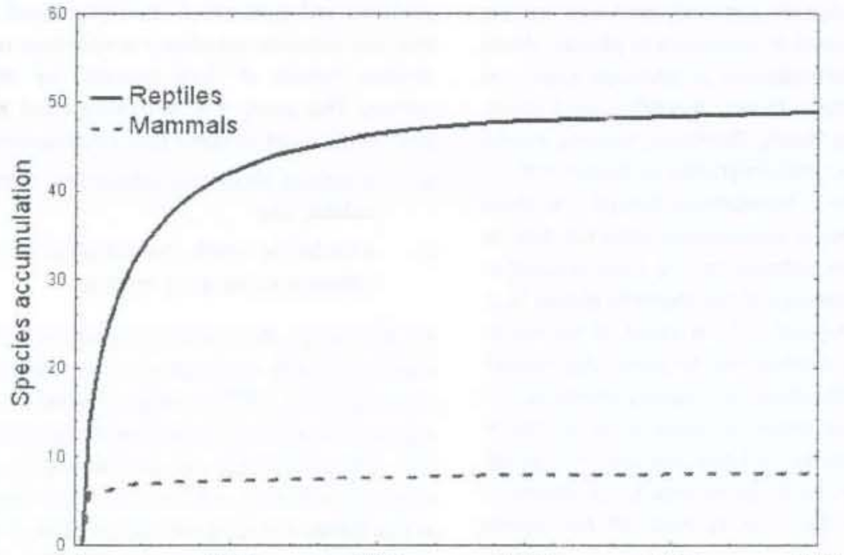

Figure 2: Species accumulation curves for reptiles and mammals for Ora Banda study sites

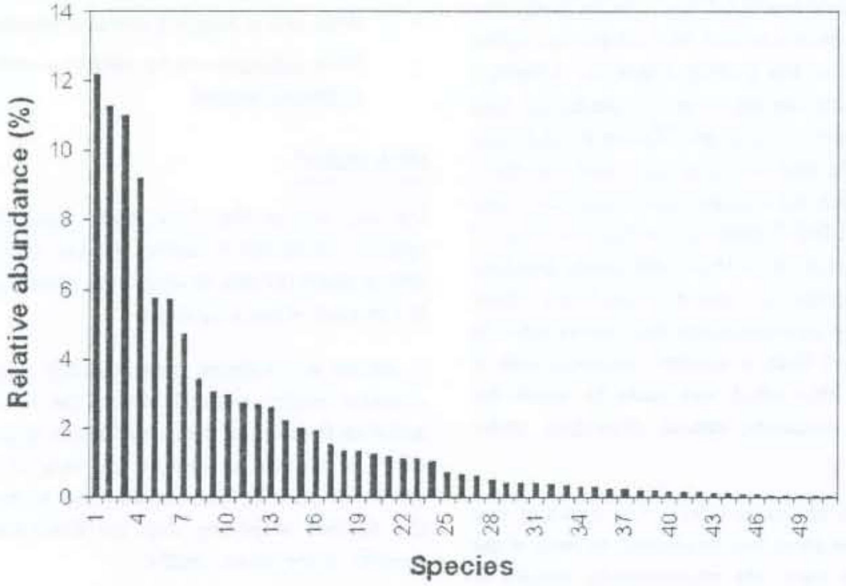

Figure 3: Relative abundance of reptile species at Ora Banda

The shape of species accumulation curves is influenced by species richness, diversity and evenness (Thompson and Withers, unpub. manuscript). Therefore, species accumulation curves are likely to differ among sites (Thompson, Withers, Pianka and Thompson, unpub. manuscript).

How then can species accumulation curves be used as a tool for predicting species richness and what is the survey effort required to assess diversity at a particular site? Determining the survey effort is a two-stage process. The first stage involves a survey to capture sufficient specimens for the species accumulation curve to commence to plateau. Based on our data for five heterogenous or landscape scale sites (two in the Great Victoria Desert, Bungalbin sand plains, Barrow Island and Ora Banda; Thompson, Withers, Pianka and Thompson, unpub. manuscript) this is about 1 000 - 1 500 specimens, and for a homogenous biotope it is about 400 specimens. The species accumulation curve can then be used to estimate species richness and the effort required to catch a nominated percentage of the trappable species (e.g., 75%, 95%, etc). To determine the full extent of the survey required, two measures of effort must be used; a) the number of specimens caught will indicate the trapping effort required to catch a nominated percentage of species at the site, and b) pit-trap days will indicate the field time and costs of trapping. For a given number of species to be caught, the number of specimens or pit-trap days can be read off the species accumulation curve.

Two cautionary notes are in order here. Species accumulation curves are not always smooth and the earlier plateauing of a species accumulation curve may provide an under-estimate of species richness. For example, Thompson, *et al.* (Thompson, Withers, Pianka and Thompson, unpub. manuscript) show the species accumulation curve for a Bungalbin sand plains site does not plateau even after 40 000 pit-trap days (Figure 4). For a heterogenous site in the Great Victoria Desert, after 11 000 pit-trap days species richness was estimated to be 43, but as trapping continued and more rare species were captured, after 25 000 pit-trap days species richness was estimated to be 55 species.

Fraser (2001) established a panel of experts consisting of six academic and government researchers, and six consultants that had extensive experience in terrestrial fauna surveys to develop criteria of 'best practice' for terrestrial fauna surveys. This panel of experts were asked to nominate the pit-trapping effort required to adequately survey:

a) a biotope, which was defined as a homogenous habitat, and

b) a landscape, which was defined as a heterogenous habitat containing ten biotopes.

For the biotope, these experts considered 137 trap-nights per season and 409 trap-nights for all seasons, and for the landscape scale, 1 371 trap-nights per season and 3 630 trap-nights for all seasons was sufficient to adequately survey the area. When these data are plotted to species accumulation curves for a biotope and landscape scale sites in the vicinity of Ora Banda it is apparent that the level of surveying effort recommended is inadequate to catch 95% of the species in the area (Figures 5 and 6).

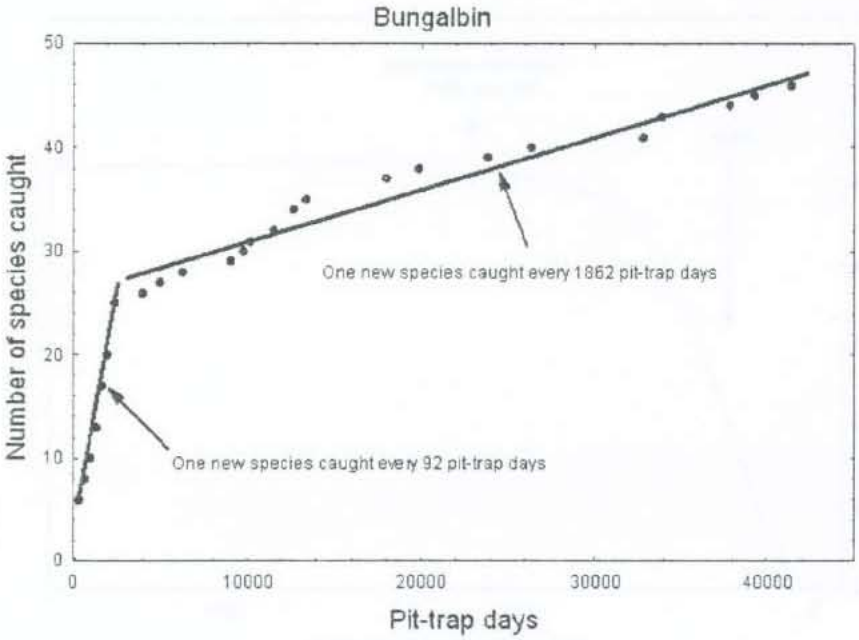

Figure 4: *Species accumulation curve for a Bungalbin sand plains site (Thompson, Withers, Pianka and Thompson, unpub. manuscript)*

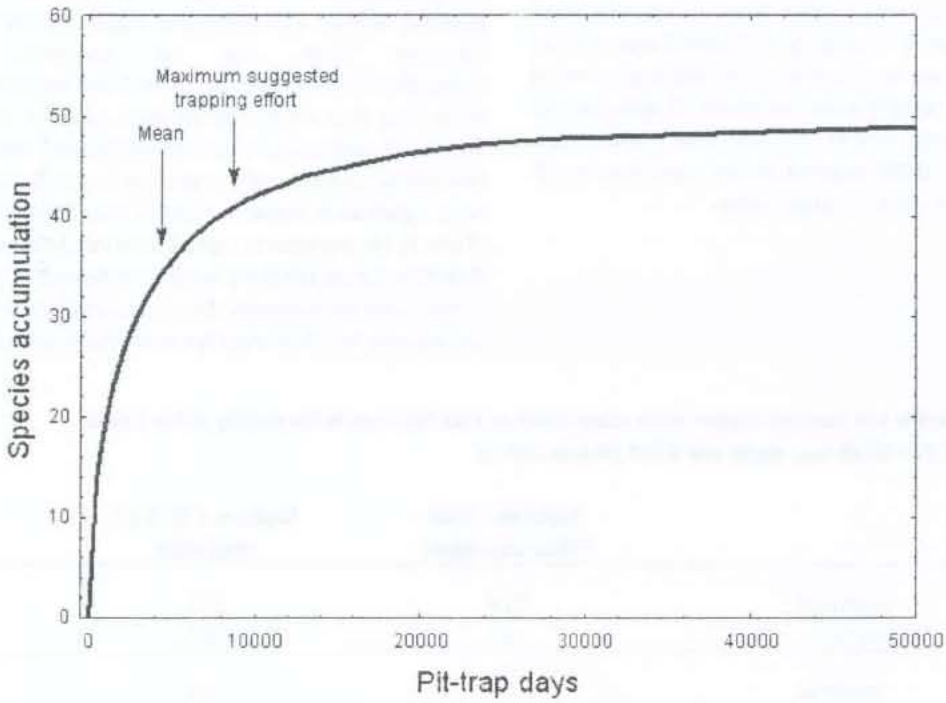

Figure 5: *Species accumulation curve for Ora Banda at landscape scale showing the trapping effort suggested by experts*

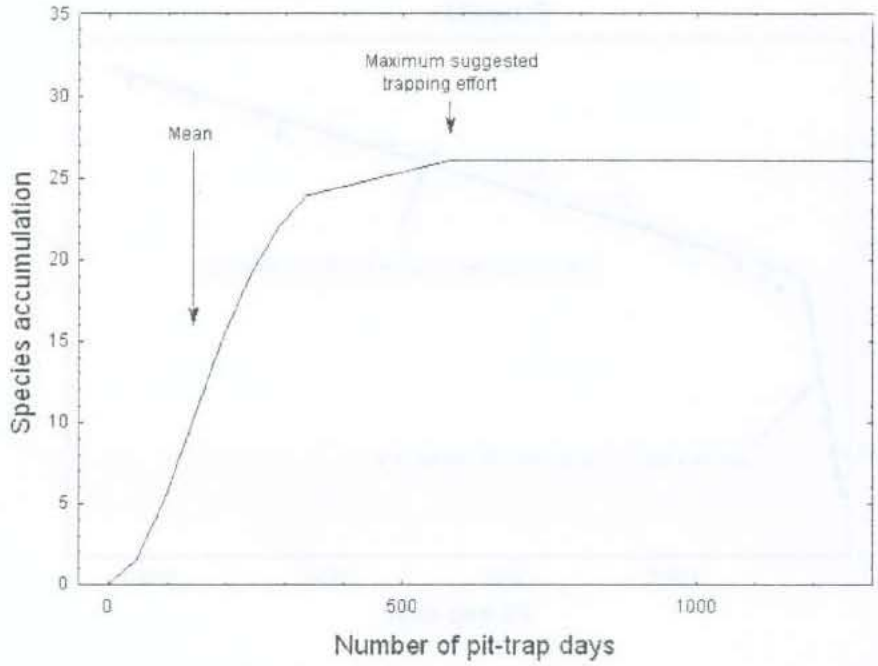

Figure 6: Species accumulation curve for site at biotope level scale showing the trapping effort suggested by experts

Trap design and layout

Cage vs pit-traps

Cockburn *et al.* (1978) report pit-traps with drift fences to be more effective than baited Elliott traps for catching small reptiles and mammals. Greenberg *et al.* (1994) report pit-fall traps captured fewer species than single and double ended funnel traps, but yielded more individuals of many species and higher average species richness than funnel traps. Cockburn *et al.* (1978) reported funnel traps were much more successful in catching large snakes.

In October, 2001 we placed 90 Elliott traps 100 m apart along a disused track on the Bungalbin sandplains, an area where we had previously caught 47 species of reptiles and 8 mammal species. 180 Elliott-trap nights yielded only one *Ctenotus* skink and no mammals. During September/October, 2001 we set 90 Elliott traps for a period of six days then moved and set them again for another six days in 11 undisturbed and five rehabilitated areas around Ora Banda. Overall capture rates for mammals and reptiles were significantly higher for pit-fall traps than Elliott traps (Table 1). More species of reptiles were caught in pit-fall traps than Elliott traps and there was little difference in the species capture rate for mammals. These data indicate pit-fall traps are superior to Elliott traps for terrestrial fauna surveys.

Table 1: Reptile and mammal capture rates using Elliott and pit-fall traps in the vicinity of Ora Banda (1 260 Elliott-trap nights and 6 230 pit-trap nights)

		Captures / 1000 Elliott trap nights	Captures / 1000 pit-trap night
No specimens	mammals	23.0	36.9
	reptiles	2.3	52.8
No Species	mammals	1.6	1.2
	reptiles	2.4	5.3

Buckets vs pipes as pit-fall traps

Both 20 L PVC buckets and 150 mm x 600 mm PVC storm water piping are used for pit-fall traps. Which is better? Friend *et al.* (1989) and Morton *et al.* (1988) report buckets caught more animals than pipes. A closer examination of the data by Friend et al. (1989) indicates that large lizards and geckos showed highly significant biases for large pits; frogs, small lizards, snakes and legless lizards less so, while small mammals were caught equally often in both pit types.

We have 888 pit-fall traps installed on waste dumps and undisturbed areas in the vicinity of Ora Banda. A line of pit-fall traps consists of 3 buckets and 3 pipes that alternate and are joined by 30 m of fly-wire drift fence. Based on approximately 50 000 pit-trap days of data, buckets caught more reptiles than pipes, whereas pipes caught more mammals than buckets. Some large lizards (e.g., *Varanus gouldii*, *Ctenophorus cristatus*), snakes (e.g., *Pseudonaja modesta*) and the larger mammals (e.g., *Notomys mitchelli*) are more likely to jump out of buckets than pipes. We conclude from this that if only one type of trap is to be used, buckets would be preferred, however, there is a case for using buckets and pipes because of the additional mammals and larger reptiles that are caught. Based on the data of Cockburn *et al.* (1978) there is a case for using funnel traps, perhaps placed along pit-fall trap drift fences.

Drift fences

Drift fences are generally made of fly-wire (300 - 350 mm high). They stand vertical and run between pit-fall traps, and are used to guide animals into the pit-fall traps. As they are expensive to purchase and install; are they worth the effort?

Bury and Corn (1987), Morton *et al.* (1988) and Friend *et al.* (1989) report pit-fall traps joined by drift fences were more effective than those without in capturing small vertebrate fauna. The ideal distance between pit-fall traps seems to be between 5 and 7 m. Morton *et al.* (1988) report the optimal design to maximise captures was to arrange the pit-traps and drift fences in the form of a cross, however, a more recent investigation by Hobbs *et al.* (1994) suggest the most effective design was a straight line of pit-traps and drift fences with buckets 7 m apart.

Friend *et al.* (1989) report small mammals, geckos and small lizards showed significant bias towards permanently erected fences, while frogs, snakes and legless lizards showed the opposite response. Some reptiles are attracted to fresh diggings (e.g., *Varanus eremius*) and data from one trapping period to the next is unlikely to be comparable because of 'digging in' effects.

Table 2: Seasonal difference in the number of specimens and species caught in a pit-trapping program in the Tanami Desert (Morton *et al.* 1988)

	Season / Design	Big pits	Cross arm	Fence	No fence
No specimens	Oct. / Nov.	226	173	121	83
	March / April	91	85	70	49
No species	Oct. / Nov.	21	23	17	7
	March / April	14	12	9	7

Table 3: Seasonal differences in the number of reptile specimens caught in a pit-trapping survey around Ora Banda

	Sept. 2000	Dec. 2000	Jan. 2001	April 2001
Total No geckos	276	322	386	127
Total No skinks	149	155	197	60
Total No dragons	38	16	44	19
Total No goannas	0	12	14	3
Total No legless lizards	6	8	5	2
Total No snakes	29	28	29	2
Total No reptiles	498	541	675	213

Data from 10 undisturbed and 4 rehabilitation sites for September, December, January and April 2000/01; 5 376 pit-trap days for each season.

Covers on pit-traps

During summer, the interior of pit-traps often heat to above the critical thermal maximum of most mammals and reptiles. To avoid heat-stress of captured animals different types of covers have been tried. Hobbs and James (1999) placed external covers over the pit-traps to reduce thermal radiation and heat-stress. Insulation foil covers reduced the core temperature in pit-traps, but these above-ground foil covered traps caught 39-43% fewer small vertebrates.

We have used both white styrene 'meat' trays and egg cartons placed in the bottom of PVC buckets to provide shelter for captured animals. As the animals cannot detect this material in the bottom of the pits until they are in the pit-trap, their presence is unlikely to affect capture rates. Our experience is that few species die from heat stress in 600 mm deep, 150 mm diameter pipes.

Seasonal differences

Morton *et al.* (1988) report significant differences in the total number of specimens and the number of species caught in a pit-trapping survey in the Tanami Desert between October/November and March /April (Table 2).

Our data for Ora Banda also demonstrates significant seasonal differences in the number of reptiles and mammals that were caught across 10 undisturbed and four rehabilitated habitats (Tables 3, 4 and 5).

In addition to seasonal differences there are also temporal differences. We surveyed the same 10 undisturbed and four rehabilitation sites in September 2000 and 2001. The daily maximum temperature was generally higher in September 2000 than in September 2001, the consequence was a significantly higher number of reptiles and mammals were caught in September 2000 (Table 6).

These data provide clear evidence that a terrestrial fauna survey in a single season in one year is inadequate to provide an understanding of species richness, diversity or abundance at an individual site or at a landscape scale. Data are not available to enable us to understand year-to-year natural variations in the population structure over a successive number of years, however, it is apparent that there are considerable changes from year-to-year.

Table 4: Seasonal differences in the number of dragon lizards caught in a pit-trapping program around Ora Banda

	Sept. 2000	Dec. 2000	Jan. 2001	April 2001
Ctenophorus cristatus	0	0	5	0
Ctenophorus reticulatus	10	2	17	7
Ctenophorus scutulatus	*3*	*0*	*3*	*0*
Moloch horridus	5	1	2	0
Pogona minor	15	9	17	12
Tympanocryptis cephala	5	4	0	0

Data from 10 undisturbed and four rehabilitation sites for September, December, January and April 2000/01; 5 376 pit-trap days for each season.

Table 5: Seasonal differences in the number of mammals caught in a pit-trapping program around Ora Banda

	Sept. 2000	Dec. 2000	Jan. 2001	April 2001
Cercartetus concinnus	32	30	22	3
Mus musculus	112	118	55	144
Ningaui spp.	4	0	1	7
Notomys mitchelli	0	1	0	0
Pseudomys bolami	0	46	19	21
Pseudomys hermannsburgensis	14	22	5	2
Sminthopsis crassicaudata	35	116	48	66
Sminthopsis dolichura	11	45	12	22
Total	208	378	162	265

Data from 10 undisturbed and 4 rehabilitation sites for September, December, January and April 2000/01; 5 376 pit-trap days for each season.

How useful are desk studies?

The EPA advocates (*Terrestrial Biological Surveys as an Element of Biodiversity Protection. Position Statement No. 3., 2002*) that where a project is likely to affect biodiversity then one of two levels of investigation be undertaken. For projects in some IBRA with either low or moderate potential impacts (Level 1) a desktop study and reconnaissance survey is required, for impacts assessed to be higher in scale or nature then a desktop study, reconnaissance survey and a comprehensive flora and fauna survey are required. No guidance is provided on what might be expected of the desktop study, but it is presumed that a search of the literature be undertaken to identify fauna species likely to occur in the area, with particular attention to rare, range restricted or endangered species. It might also be expected that consultants or proponents would consult both the CALM and the WAM databases, however, we know from Fraser's (2001) study this does not always occur.

How useful are searches of CALM and WAM databases, and literature reviews in identifying species likely to be found in a particular area? The Ora Banda area of the Goldfields was one of the WAM/CALM regional survey areas. Our Ora Banda study sites fall within the Kurnalpi - Kalgoorlie study area and are closest to the Black Flag Homestead study area (McKenzie *et al.* 1992). Specimens caught during the CALM/WAM survey were vouchered with the WAM and species lists along with a description of the vegetation can be found in McKenzie *et al.* (1992).

McKenzie *et al.* (1992) also searched the WAM database and species not captured but likely to be in the area were listed in their report. It might therefore be concluded that the fauna for the Ora Banda region is well documented and a desktop study and literature review would identify all possible species likely to be pit-trapped at our Ora Banda study sites.

Table 7 lists species of reptiles we have caught after approximately 50 000 pit-trap days from July 2000 to April 2002 that were not recorded in the field survey of CALM/WAM (McKenzie *et al.* 1992) for the Black Flag Homestead area. We also indicated those reptile species the WAM/CALM staff thought should be in the area based on WAM records (Table 7). A similar analysis was undertaken for the mammals in the area with a surprising result. We recorded one reptile, and two or possibly three species of mammals not likely to be identified being in the area based on a desktop study comparable with that likely to be undertaken by a diligent consultant. It is therefore evident that our relatively scant knowledge of the distribution of some species is such that erroneous conclusions might be drawn about biodiversity and ecological systems, even in areas where our knowledge of the fauna is considered reasonable.

Table 6: Temporal differences in the number of specimens of reptiles and mammals caught in a pit-trapping program around Ora Banda

	Sept. 2000	Sept. 2001
Total No geckos	276	172
Total No skinks	149	45
Total No dragons	38	22
Total No goannas	0	3
Total No legless lizards	6	1
Total No snakes	29	19
Total No reptiles	498	262
Total No frogs	11	0
Cercartetus concinnus	32	37
Mus musculus	112	50
Ningaui spp.	4	18
Pseudomys bolami	0	8
Pseudomys hermannsburgensis	14	6
Sminthopsis crassicaudata	35	41
Sminthopsis dolichura	11	20
Total No mammals	208	180

From 10 undisturbed and four rehabilitation sites during September 2000 and 2001; 5 376 pit-trap days for each season.

Table 7: **Species caught in during 55 000 pit-trap days not recorded in earlier surveys or thought to be in the area (McKenzie *et al.* 1992).**

Identified in the Ora Banda survey but not recorded by the WAM/CALM survey	Suggested as likely to be in the area by the WAM/CALM study from other sources	Not anticipated in the area
Reptiles		
D. assimilis		
E. richardsonii	X	
E. striata		X
P. minor	X	
T. cephala	X	
V. tristis	X	
D. butleri		
D. fraseri		
P. lepidopodus	X	
D. fasciata	X	
P. australis	X	
R. australis	X	
R. bituberculatus	X	
R. hamatus	X	
S. bertholdi		
S. semifasciata		
Mammals		
Ningaui ridei	X	
Ningaui yvonneae	X	
Notomys mitchelli	X	
Pseudomys hermannsburgensis	X	
Pseudantechinus woolleyae		X
Antechinomys langier		??
Pseudomys albocincereus		X

Strategies for detecting rare, range restricted or endangered species

Within the Coolgardie IBRA there are two reptile species with a priority status: Woma Pythons (*Aspidites ramsayi*) and Carpet Pythons (*Morelia spilota imbricata*) are both listed in Schedule 4, of the Wildlife Conservation Amendment Regulations 2001. We have a confirmed sighting (photograph) of *M. s. imbricata* within 1 km of the Ora Banda town site in 2000, and WAM records suggest that there are likely to be other specimens of this python in the IBRA.

WAM records also indicate that the Woma python was relatively abundant in the wheatbelt up until the 1970s (Maryan, 2002). Recent WAM records show Womas to the east of Kalgoorlie, and there is a 1966 WAM record of a Woma being caught south of Menzies.

Maryan (2002) reports a recent sighting of a Woma at Bandya homestead north of Kalgoorlie. The preferred habitat of Womas appears to be myrtaceous heath on sand plain (Smith, 1981), of which there is considerable in the IBRAs covering the Goldfields. In the right habitat it is therefore probable there are few remaining specimens of this Schedule 4 species.

If we consider rare or range restricted mammals in the IBRAs around the Goldfields, and consult Strahan's distribution in *The Mammals of Australia*, it is evident there could be a number of rare, endangered or range restricted species in the region. Pit-traps, Elliott traps and the other search strategies commonly used by consultants are unlikely to turn up either of the Schedule 4 pythons and most of the listed mammals if they were in the area.

Table 8: Possible search strategies to identify priority-listed and range restricted taxa.

Example taxa	Strategy	Reference
Pythons	Road searches, tracks	
Woolley's Pseudantechinus	Hair traps	Lobert, Lunmsden, Brunner & Triggs 2001
Marsupial moles	Examination of carnivore scats	Paltridge, 1998
Large snakes	Funnel traps	Greenberg *et al.* 1994
Arboreal varanids and mammals	Tree nooses, snares	Reed 2000
Mallee fowl nests, burrows of Mulgaras, Bettongs and Bilbies	Aerial photograph searches	
Mammals	GIS searches based on habitat	Catling & Coops 1999
Mammals and birds	Airborne, videography	Catling & Coops 1999

It is evident that to identify many of the rare and priority-listed species alternative search strategies should be adopted. To date little has been documented on how we might approach this issue. We currently have a PhD student investigating suitable cost-effective terrestrial fauna search strategies that might be used for the purposes of preparing an EIA, complying with the Environment Protection and Biodiversity Conservation ACT 1999 and the thrust of the EPA guidelines. Detection of priority-listed species will be an aspect of this study. There is a range of search options that could be useful and will be explored, and these are shown in Table 8.

SUMMARY

There is evidence to suggest that a poorly planned and executed terrestrial fauna surveys or ones that apply inadequate effort are a waste of time and resources. Inadequate terrestrial fauna surveys are unlikely to provide useful data on the presence of species in a particular site, and are unlikely to be useful in planning or monitoring rehabilitation sites. Therefore, the adage 'do it right or don't waste your time and money' seems most appropriate when considering terrestrial fauna surveys. Desktop studies cannot be relied upon to provide comprehensive species lists for sites, particularly in areas that have been poorly surveyed.

The question of how much survey effort is required to identify a nominated proportion of the species at a site can be estimated in a two stage process; a preliminary survey to establish a species accumulation curve to the point the plateau commences to consolidate, and using this curve to predict the number of species for a site. The survey effort can be determined from a species accumulation curve based on the number of specimens caught, and the time and cost for the survey from a species accumulation curve based on pit-trapping (or Elliott trapping) effort.

Existing data suggest that pit-traps are better than cage traps but, to capture the entire range of trappable species, pit-traps should be supplemented by cage and funnel traps. Drift fences enhance captures. The optimal distance that pit-traps should be apart along drift fences is between 5 - 7 m, and a line of pit-traps is as good as the alternative configurations. Shade, in the form of egg cartons or styrene trays placed in the bottom of PVC buckets provides shelter for captured animals and reduces heat stress. Pit-traps should be dug in and left until the 'digging in' effects have disappeared to ensure trapping data are comparable between different survey periods.

Ideally, areas should be trapped/searched in late spring, summer and early autumn to obtain an understanding of small terrestrial vertebrate diversity and abundance at a site. Single surveys in January are likely to provide the highest species and specimen counts, closely followed by December, and to a lesser extent late spring and early autumn. Year-to-year variation in species abundance and overall diversity, suggests that surveys need to be undertaken over a number of years if a complete understanding of the dynamics of the ecosystem are to be understood. The presence of many of the rare and priority-listed species is unlikely to be identified using the search strategies commonly applied for the purposes of preparing an EIA. More innovate approaches are required.

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INCREASING CONSIDERATION OF SUSTAINABILITY BY THE WA GOVERNMENT AND ITS IMPLICATIONS FOR THE MINING INDUSTRY

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ABSTRACT

The issue of sustainability and sustainable development is now one of the most hotly debated issue that faces the minerals industry. It has the potential to affect every aspect of the industry and it's operations and it's rights to carry out exploitation of natural resources. *This paper looks at the growing need for the West Australian mining sector to address sustainability and sustainable development requirements in light of increasing scrutiny and consideration by the community as well as regulatory authorities. In the last few decades there has been considerable improvement in environmental performance by the mining sector, which has included community involvement. However, scepticism remains as to whether the mining sector has truly embraced the concept of sustainability and sustainable development and their willingness to deliver on their words and commitments. This discussion paper endeavours to provide some background information on sustainability and what direction industry, community and government may pursue in dealing with this issue. In conclusion, the paper explores the need for industry to take a proactive approach in jointly developing with community and government the manner and extent to which this occurs.*

INTRODUCTION

In the last decade the sustainability agenda has become a prominent topic within community, government, private organisations and individuals, each exploring it's concept and application. Various members within the mining industry, particularly the larger mining houses, are closely involved with this movement, seeking out new ideas and practises that challenge traditional thought patterns and modes of operation. Sustainability in it's widest sense encompasses every aspect of our existence; focussing on the simultaneous balance and optimisation of economic, social and environmental goals. It is becoming a mainstream philosophy of governments and businesses worldwide, with many groups expressing a heightened interest and commitment to sustainability practises.

This heightened interest continues with the growth of awareness and commitment to improved sustainability and sustainable development across different levels within the wide spectrum of government, private organisations and community. There are a number of initiatives and examples of where this growing awareness and commitment is taking place. These range from the imminent World Summit on Sustainable Development (WSSD), to be held in Johannesburg, South Africa later this year to industry specific examples such as the Mining, Mineral and Sustainable Development Initiative (MMSD). The creation of the Western Australia Premier's Sustainability Policy Unit and the development of a State Sustainability Strategy are clear indications of this State's increasing level of consideration and commitment to introducing sustainability and sustainable development to how we conduct business in Western Australia (WA).

Sustainability was identified at the 1987 United Nation's World Commission on Environment and Development. From which the Brundtland report identified sustainable development as:

"Development which meets the needs of the present without compromising the ability of future generations to meet their own needs."

In Australia, a national Ecologically Sustainable Development (ESD) strategy was developed in 1992, which is used to guide decision-making and policy development within the three tiers of Federal, State and Local Government.

The concept of 'triple bottom line' (TBL) engenders the move to recognise the equal status of the environment, economic activity, and social considerations. Utilising these definitions, various international governments and groups have embraced and actioned the concepts of sustainability. In recent years corporate governance has joined the TBL to provide a more complete balance to sustainability.

The term and concept of sustainability and sustainable development are often used as if agreement exists concerning their meaning and application between the different disciplines or professionals such as planners, developers, economists, regulators and environmentalists. This is definitely not the case and causes much confusion between the different disciplines and groups using the concept. When using the term each group appears to assign a different value or meaning depending on their expectation values, priorities and perspectives. The source of confusion surrounding the concepts appears to stem from a lack of agreement regarding exactly what is to be sustained, for whom, for how long and by what means (Hounsome & Ashton, 2001).

Sustainable development is often perceived in terms of several kinds of capital, namely: (Hancock and Roarty, 2001 and Hounsome & Ashton, 2001)

- natural capital, defined as all natural resources, both environmental and those of traditional economic value;
- produced capital made by humans, defined as produced goods and the built environment;
- human capital, defined as health, well-being, intellectual and capability of individuals; and
- social capital, defined as social relations and the institutions within and between societies, their norms and functionality.

Sustainability is then considered to fall between two classes summarised as (Hounsome & Ashton, 2001 and Hancock and Roarty, 2001):

Weak sustainability, which preserves the overall amount of capital but not necessarily equal amounts of each kind because it allows for substitution or conversion of one type of capital for another. For example mineral resource capital to produce capital goods. This is clearly untenable where a capital stock would run down to the point of depletion and no return (i.e. exhaustion with no recovery or substitution with alternatives).

Strong sustainability, which requires that all the above types of capital stocks are preserved and that one cannot be substituted for another. Thus, natural capital such as mineral resources must not be diminished in order to increase or maintain produced, human or social capital. This too is untenable, as it would ban extraction of non-renewable resources denying the opportunity to manage beneficial conversion of this capital.

The WA mining industry doesn't endorse either of these two extremes but neither has it achieved a balanced between the two. Although the industry pursues relatively good management practices and legislative compliance it is yet to embrace the concept of a balanced and unbiased equity between the values attributed to the environmental, economic and social elements of sustainability (Hancock & Roarty, 2001).

CURRENT STATUS

Mining in WA has played and will continue to play a significant pivotal role in Australia's economic development. It has also in recent years shown improvements in its environmental performance and consideration of community issues and involvement. However, the industry continues to be subject to negative public perception and scepticism, which stems from the adverse environmental and social impacts associated with its various activities (Hancock & Roarty, 2001 and Hounsome & Ashton, 2001). In the past, the mining industries have taken an insular and often arrogant approach to these issues leading to a lack of transparency and failure to report incidents and events honestly. Current players are being judged by this legacy of past poor environmental performance, abandoned operations and sites that continue to remain on care and maintenance for extended periods with no clear outcome or commitment from the owners or operators.

Industry stewards and champions have emerged from time to time providing leadership and establishing new benchmarks, but this has tended to be *ad hoc* in nature. In more recent times a significant improvement has become apparent in the wider mining sector's performance. The improved performance has included waste minimisation and recycling initiatives, progressive rehabilitation, greater stakeholder engagement and community consideration, improved environmental monitoring and corporate reporting. Many of which are measurable and widely recognised.

The more forward looking members in the mining industry are seeking to embrace the sustainability agenda and would like to see this reported commitment to sustainability and sustainable development added to this list of improved performance. However, a number of serious issues arise regarding the industry's understanding and acceptance of the concepts of sustainability and sustainable development when their commitment to and assessment of sustainability is investigated (Hattingh, 2000). This is exacerbated by the limited ability to measure performance and quantify an organisation's commitment and contribution to sustainability when it is so poorly understood in the broader community.

The term sustainability is used widely in the community and is applied to many different situation and applications. There appears to be a common misconception in the wider (Australian) community that sustainability is an issue of environmental protection. Although this is partially the case, sustainability is a much broader issue and greater understanding and knowledge needs to be established. This misconception may stem from the inclusion, unlike other nations, of the term 'ecological' in the Australian sustainable development definition.

Discussion and consideration of sustainable development within the mining industry has predominantly focused around the environmental (ecological) aspect, followed by community involvement (social), with less consideration going to economics, the natural resource and governance. Although the Australian mining industry has introduced some ground breaking initiatives of which the code for environmental management would be the most significant, in particular the voluntary public annual reporting of environmental performance. This voluntary corporate reporting and compulsory financial reporting has predominantly revolved around discussion of environmental, economic and community issues rather than how the companies operations contribute to sustainability and sustainable development. All too often the terms sustainability and sustainable development are included and 'discussed' under the heading of environment and not a concept applied to the whole of company operation. Instead of an organisation relating the activities of their firm and operations under an overarching strategy of sustainability they deal with the specific elements in isolation and neglect to tie them into an integrated and balanced whole (i.e. sustainability).

It is apparent in the industry's performance and attitude that the social, economics and environment elements of an organisation and its operation are often considered and managed separately. This is usually driven by economic factors and indicate the greater level of importance attributed to this element in preference and at the detriment of the other elements. This comes as no surprise and is founded in the requirement of company management to ensure the survival of the company and need for ongoing enhancement of its assets and value. These judgements are not made with sustainability in mind or consideration of any of the sustainable development philosophies.

Applications for development approvals, annual and corporate reports often include the terms sustainability and sustainable development. Similarly, company policies and vision statements also use these terms but when one digs below the surface of the rhetoric contained within these documents there is limited substance or intent (Hattingh, 2000). Scepticism of industry environmental and social performance and motives is not restricted to the community and the regulators; it often originates within the industries own workforce. This scepticism stems from the workforce being directed or expected to perform contrary to company commitments and policies or out of staff loyalty to protect a company's interests. These range from blatant misrepresentation to 'window-dressing'. Whatever the degree of deception it generates scepticism and distrust that carries over to the wider community.

Community perceptions, commonly reflected by government policy and legislation, have periodically supported, encouraged and restrained the mining sector. Hancock and Roarty (2001) state that over the past 30 years Australia has experienced a dramatic change in community perception of the mineral industry from strong support to one of negative environmental and social perceptions. They go onto say that the mining sector is seen as a generally capable performer in environmental and business management but still viewed as big business, uncaring of people and only responding positively to secure its 'licence to operate'.

Since the 1970s there has been a move away from a predominantly prescriptive regime of regulation to one of self-management where companies agree to performance outcomes and enter into contracts with performance bonds to protect the community's interests. Fiscal reporting has long been a regulatory requirement and this now includes reporting on environmental matters that could have a material effect on fiscal performance (Hancock & Roarty, 2001). General corporate environmental performance reporting and most recently, sustainability reporting, has emerged as a voluntary initiative and considerable effort and resources are consumed by this initiative. However, as indicated by Maitland (2002) there is a risk that the stakeholders at whom the reports are aimed will not read them; as once the information has been released many are no longer interested because they don't believe the information contained within.

There is a common held belief that the term sustainable development and mining are contradictory. While this is clearly not the case it is just as clear that one of WA's primary challenges is to recognise that our economic and social prospectively cannot indefinitely rely solely on the utilisation of our abundant natural resources (Hancock & Roarty, 2001). Although mining has and will continue to play a significant pivotal role in Australia's economy and culture there appears to be growing concern that Australia is subject to the Dutch Disease, where its economy is mineral dependent. If Australia's mining sector is to be sustainability and avoid economic demise, compared with other developed countries, it must achieve greater diversification, downstream manufacturing and improved efficiencies. In doing so it must pursue good management of environmental, social and economic elements not in isolation but as part of a fully integrated and inclusive management system. The role of these elements must be considered in an equitable manner, where one doesn't take preference over another and the net long-term benefit is pursued.

Mining companies and the industry as a whole have and continue to establish new benchmarks of environmental and community performance. For those that establish new benchmarks they are often recognised and may receive awards for their efforts. There is a risk however that those setting these new benchmarks of improved performance are the stewards and champions of the industry and while in fact operating in a more sustainable manner may not be recognised for this. This returns to the problem that without a means by which sustainability can be measured there remains the difficulty of determining how their performance can be evaluated. It is also possible that there are some industry players who are unlikely to ever receive recognition for setting new benchmarks of performance but which might be much closer to achieving sustainability than these other more highly decorated players.

It is likely that with the development of a State Sustainability Strategy there will be a requirement to report on sustainability and sustainable development. This will be seen as an integral part of project approvals and performance review. Increased pressure on industry will stem from the need to supply more accurate and informative data on their intent and performance. How this can be achieved, giving a reasonable representation of what has in fact taken place, is not clear and will require a considerable amount of careful thought and development. The need for reporting may extend to the government, including the decision making authorities (DMAs), industry players and require the reporting on progress made towards achieving sustainability and or established targets/milestones. The challenge for the mining industry will be to do this in a manner that is open, honest and will be accepted by a somewhat cynical community.

FUTURE DIRECTION

Whether they formally recognise it, the regulatory authorities, both State and Federal, have been pursuing sustainable development and including sustainability principles in their assessment and evaluation of development proposals. Many of the current requirements for approval, although undertaken in isolation, contribute to meeting the basic requirements of sustainable development. Industry has been experiencing increasing requests for further information, greater substantiation and the need to consider the interaction of these principles. Specific requests for discussion on the sustainability of projects and or key aspects of projects are being made. There has already been some debate about major projects having to substantiate their sustainability before approval should be granted. There is certainly a real need for operators to carry out their commitments with conviction, demonstrating by performance that they mean what they say.

Currently, the assessment of a project may be undertaken by a number of agencies before it can be approved. Each agency will be operating under it's own specific legislation and each will have specific issues to deal with. These have traditionally dealt with each issue in isolation and have not been carried out in any holistic sense. To date formal assessment by the EPA comes closest to meeting this requirement. However, their mandate currently excludes economic factors. It is conceivable that each DMA will have to undertake an increasing role in assessment of whether a proposal is sustainable in a broader sense. Again there is no established method or system for evaluating whether a project is sustainable or not or to what degree it contributes to sustainability.

Although there have been no changes in WA State legislation to date there are increasing signs of greater consideration of the need for sustainability. "Beginning in 2002, the Environmental Protection Authority will oversee the development of the next 'state of the environment report' for WA. The report will analyse and outline environmental trends and indicators of sustainability in natural resources sectors and the regions of WA." (WA Govt, 2001)

Similarly, the proposed State Sustainability Strategy will identify headline sustainability indicators for WA and will also examine the effectiveness of information and decision support systems for sustainability in this State. It has been proposed that part of the role of the Strategy is to establish:

- Short, medium and long term goals for sustainability across regions and sectors;
- Targets and indicators that can be used to assess progress of implementation;
- Policy and management tools to improve decision making for sustainability; and
- Actions to promote and encourage sustainability, including new initiatives, policy and legislation changes and institutional reform.

It is quite clear that dealing with future developments will require some form of assessment of their contribution to sustainability. The challenge will be for industry and the regulators to develop practical measure and processes to implement these requirements without stifling development by making it all too difficult.

The real value of the Strategy will be derived from practical change. This is anticipated to require new decision making processes, which go beyond the economic motivators that have historically driven development. The Strategy needs to support a decision making framework that allows individuals to prioritise recommendations for development in accordance with social, economic and environmental factors. This framework should attempt to work off existing decision making processes and structures to encourage an efficient and seamless change. Ultimately the Strategy or any changes should function as a risk/projects management aid for industry that facilitates sustainability in practice.

Any move by the government to include greater emphasis on sustainability should be encouraged to have clearly defined objectives and offer tangible benefits. It is imperative that this is not perceived as just another layer of bureaucracy and a further encumbrance on industry.

The debate on what sustainability means is unlikely to be fully resolved in the short-term due to the differences in stakeholder opinion. However, the debate has now moved on from one of definition to one of what and how to measure performance and progress (Hancock & Roarty, 2001). Any move by the government or industry to provide guidance and support of a means through which sustainability performance can be assessed or measurement must be credible and unbiased but it must take place.

Any benchmarking or evaluation tool needs to be universally recognised and accepted and based on measurable elements and indicators. Care should be taken that external bias from disaffected parties does not have an unfair influence.

The tool should enable a level of sustainability to be established and assist in a decision making role to target areas for improvement that can then be prioritised and weighted in order of importance or preference.

The high degree of rhetoric and lip-services to the endorsement and practice of sustainability is impacting on the credibility of the industry and contributing to the scepticism and its negative perception. In many cases the word sustainability is used frivolously to coach and engender an application, report, policy or strategy to win acceptance and improve perception. Sustainability jargon is often used with little understanding or ability to substantiate its use, which reduces the credibility of the industry and the move for greater sustainability performance and reform. Greater education and understanding of these terms are necessary and careful consideration given in their use. The mining industry needs to treat the issue seriously if they want to maintain and improve their credibility.

Depending on the scale and nature of their operation mining companies can report to a large range of regulatory agencies, involving much repetition, and their desire to seek a more efficient system and a 'one-stop-shop' for licensing and reporting is understandable. The potential for change and review in part may provide an opportunity by which the mining industry can play a role through which they can provide guidance and support of changes to their benefit.

CONCLUSION

The lack of understanding and awareness of the terms and meaning of 'sustainability' and 'sustainable development' has meant that they have been seen as a threat to economic development. However, many of the world's largest corporations and business associations are now embracing the ideas and opportunities that operating in a sustainable manner offers as it is being proven that eco-efficiency (reducing resource requirements while increasing productivity) can be achieved by a factor of four to ten (WA Govt, 2001). Businesses that can demonstrate such sustainability have a chance of creating new economic opportunities locally and globally, while making a contribution to sustainability at the global scale.

There is increasing scrutiny and consideration by government, other industry groups and the community of sustainability and sustainable practices in this State. This is likely to continue and contribute to increased pressure on the mining industry for greater substantiation of their sustainable performance. Although the mining industry has shown that it can be better than most other industries in leading the way in improved environmental and social performance it also has a negative perception to overcome.

Historically the industry has embraced the elements of sustainability separately and not integrated them on an unbiased and equal footing as required to achieve real sustainability.

If the industry ignores this issue it may be left behind as the rest of the world embraces sustainable production. As a result approvals and operational requirements could become encumbered in further bureaucracy generated by the State in its attempt to seek a more sustainable approach to development and continue to be perceived negatively. The industry needs to prevent this and take a proactive approach in guiding how the government supports and plans to encourage this process. This can be achieved through a number of methods, all of which include engaging in close liaison, cooperation and debate with key authorities or by leading the move to embrace sustainability.

It is likely that sustainability and sustainable development factors and principles will become a larger part of the regulatory authorities mandate when evaluating project applications and industry performance (i.e. annual reports). To what degree this occurs remains to be seen but will require generous debate to reach an amicable solution that supports sustainability and sustainable development such that the mining sector *meets the needs of the present without compromising the ability of future generations to meet their own needs.*

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SUSTAINABLE WATER DEVELOPMENT IN THE GOLDFIELDS

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OVE ARUP & PARTNERS

ABSTRACT

Since the industrial revolution of the 1800s the world has enjoyed unprecedented economic growth, with most countries now experiencing a higher personal standard of living, health and longevity than ever before in history. However, progress has come at a high cost and since the 1960s there has been a growing awareness of global environmental and social costs that have accompanied this progress. The world population is currently growing at a staggering rate that has increased over tenfold in the past 200 years. World population is currently around 6.5 billion and will exceed 7.2 billion by 2025. Western Australia's growth rate is even higher than the world trend and our population is expected to increase by 50% by 2025. Increases in population are accompanied by increasing rates of urbanisation, deforestation, land and water degradation, greenhouse gas emissions and natural resource depletion. All of these factors in turn contribute to global warming, the now well-known El Niño effect, declining fish stocks and high rates of species extinction.

Water is essential for sustaining life, yet by 2025 at least 40% of the world's population will have serious difficulties obtaining fresh water for life, agriculture and industry (Hiscock, 2002). The sustainability of fresh water resources is also emerging as a key concern in Western Australia, where two thirds of water consumption is used for mining and agriculture and the current demand is predicted to double by 2025 (WRC, 2000b). In the goldfields region more than 98% of groundwater consumption is used in mining, with water being drawn primarily from marginally renewable palaeochannel resources. The highest allocation priority is given to protecting environmental flows, but most of the remaining palaeochannel resources have now been allocated and are being steadily depleted. Competition for the remaining, often less favourable, palaeochannel resources is fierce and there are pressures to challenge allocations already reserved environmental flows.

Sustainable water development in the goldfields is about:

- *understanding the true value of the limited resources that we have;*
- *working smarter to make these resources go further; and*
- *supporting the development of alternative external water supply strategies.*

This paper examines the significance of water in the development of the Western Australian goldfields and discusses how sustainable development principles should be applied for current and future growth.

Sustainable Water Development in Australia

Sustainable development was first addressed seriously in Australia in 1984 in the National Conservation Strategy for Australia. It is aimed at meeting today's needs without compromising the needs of future generations. It is tied to the concept of stewardship, which recognises that "we did not inherit the earth from our parents, we borrow it from our children".

At the 1992 Rio de Janeiro Earth Summit, representatives from 182 countries, including Australia, agreed on the principles that all countries need to adopt to manage the future development of global resources on a sustainable basis.

Agenda 21 lists 27 principles for the achievement of sustainability, of which four core principles were identified (Comm. EPA, 1995):

- take a precautionary approach when assessing new developments;
- protect or enhance the productivity of the environment for future generations;
- conserve biodiversity and essential ecosystems; and
- price the cost of living according to the burdens of social disruption.

In the same year the Australian Commonwealth, State and Territory governments agreed on a National Strategy for Ecologically Sustainable Development (NSESD), which is described in the Intergovernmental Agreement on the Environment, making these principles Law.

In 1996 more than 36 of Australia's largest mining companies became signatories to the Mining Industry Environmental Code of Practice, committing the mining industry to adopt them (Minerals Council Australia, 1996).

The challenge of sustainable water development is how to extract the most economic value out of finite and marginally renewable water resources without jeopardising the diversity and functionality of wetlands and water dependant ecosystems. In addition, how to prevent unacceptable degradation of the aquifer quality by impacts such as saltwater intrusion, land subsidence or other undesirable physical and social impacts. The principles of sustainable water development in Western Australia have been debated in Government for many years, but chronic water shortages in Perth, the goldfields and surrounding areas in recent years have raised the urgency.

Groundwater resources are most easily described in terms of "stored" and "renewable" resources. The stored resource is the quantum of fossil water held in an aquifer, whereas renewable water is the rate at which the aquifer would be refilled by seasonal rainfall and river recharge (Johnson *et al.* 1999). However, neither of these terms is a useful measure of sustainable resources because:

- not all water held in an aquifer can be accessed by pumping; and
- it is not realistic to assume that all runoff or rainfall infiltration can be captured, infiltrated or used.

The term "commandable storage" was developed to describe how much stored groundwater could be economically and practically pumped from an aquifer in a given timeframe, but even this concept is not an entirely useful measure because very rarely will it be acceptable to mine the entire groundwater resource.

In 2000, a technical working group involving Commonwealth and WA State Government environmental and water regulators, Invest Australia and mining industry representatives developed a definition of 'sustainable yield'(Anaconda, 2001):

> *"the amount of water that can be extracted from a system over a given timeframe without causing unacceptable levels of stress and protects dependent economic, social, and environmental values".*

By definition, sustainable water development must respect significant environmental and social values as a priority in conjunction with the economic benefits from development of the water resource.

Only after demonstrating that adequate resources have been reserved for environmental flows can the sustainable yield of the aquifer be calculated (Rohan, 2001). There is a common perception that sustainable yield means only using water at the renewable rate and that mining of fossil groundwater is unsustainable. This definition is too restrictive because in arid regions renewal rates can be almost negligible and most palaeochannel water is too saline to be of value for anything other than mineral processing. Had development of groundwater in the palaeochannels been restricted to the renewal rate, much of the economic and social benefits derived from the goldfields would never have been realised. Recognising that the level of salinity affects the environmental and social value of the water resource, the Western Australian State government accords different levels of protection to fresh, brackish or saline quality groundwater resources. In effect fresh water resources have the highest level of protection, while brackish to hypersaline resources are generally suitable for mining.

Planning timeframe is also an important factor. Intuitively, if water demand is perpetual, then it would be unsustainable to extract more water than the hydrogeological system could renew on a regular basis. The situation is quite different if the water is only required for a defined period of time, because fossil water that is temporarily withdrawn from groundwater storage over the project life will be replenished after pumping ceases. In the latter case the defined planning timeframe includes both the extraction and recovery periods.

In arid environments, where fossil water resources are vast yet replenishment is negligible, the timeframe for full recovery would be many times longer than the actual abstraction period. In other words, within a lifetime fossil groundwater is an essentially non-renewable resource. Non-renewability creates an issue with equitable "governance" of the natural resource, sometimes referred to as the fourth element in the "quadruple bottom line". Governance means obtaining highest value from our limited resources by ensuring that they are not wasted, but rather allocated to the highest existing or future "beneficial use", whether that be environmental, social or economic.

Prior to 1999, water rights in Western Australia were allocated by the State Government free of charge. Nowhere was the value of intangible environmental and social benefits or costs of degradation reflected in the price paid for the water. In 1999, Western Australia embraced a number of water reforms including "tradeable water rights", an efficient means of using market forces to determine the price of water and encourage companies to consider water conservation, reuse and recycling (WRC, 2000a). Since 2001, groundwater resources in Western Australia are no longer allocated on a "first come first served" basis. Proponents of new water resource developments must now demonstrate that theirs would be the highest beneficial use of the resource both now and in the future.

Historic water development in the goldfields

The goldfields region is a flat semi-arid breakaway terrain with internal drainage to vast salt lakes, known as salinas, which may be intermittently filled largely after cyclonic rains in February and March. For the most part the region receives an unreliable average rainfall of 150 to 200 millimetres a year and natural sources of fresh water are rare.

When European settlers first arrived in the region, limited supplies of fresh water could be obtained from scattered gnamma holes, rock pools and shallow wells. However, water became so scarce during the summer months that individual travel had to be tightly regulated and policed, so that water holes along the main routes had a chance to recharge between successive carriage parties. There were numerous occasions on which gold production in most centres had to be halted for months on end for lack of process water (Evans, 2001).

The desperately short supplies of fresh water in the summer months led to high mortality rates from water-related diseases such as typhoid and dysentery. Although little was known of the subsurface geology, many suspected the existence of a large underground water reservoir similar to the Great Artesian Basin, but numerous attempts to drill deep wells, including one drilled 1000 metres through granite during1893, failed to find the elusive buried "sea of water".

Between 1896 and 1898, a number of concrete lined and covered storm water harvesting tanks, typically of about 12 ML capacity, were constructed in the main mining centres. These relied on the infrequent and unpredictable rains. In addition, a number of small but inefficient steam condensers were built to distil saline water obtained from wells, mine shafts or trenches on the salt lakes. At the largest of these, the "Mammoth" at Coolgardie, daily water production of less than 1.5 kl entailed a daily timber consumption of several tonnes (Whittington, 1988).

In 1898 John Forrest commissioned construction of the ambitious Goldfields Water Supply Pipeline, which was designed and supervised by the State Engineer-in-Chief, C.Y.O'Connor. The pipeline opened in Coolgardie and Kalgoorlie in 1903, delivering what seemed a vast and reliable supply (23 Ml/day) of fresh water to the Kalgoorlie, Coolgardie and Dundas goldfield regions. The seemingly limitless water supply allowed higher productivity from underground mining and hydrometallurgical technology for extracting gold, using cyanide leach to replace traditional water restricted methods such as alluvial mining, dolly pots, dry panning and sluicing.

During the wars years from 1914 to 1945, investment stalled partly through labour shortages and partly as a result of the Great Depression. Although prosperity steadily returned to the goldfields after 1945, it was not until the discovery of nickel sulphides near Laverton in 1969 by Poseidon that large groundwater supplies were developed. The first bulk treatment of sulfide ores using xanthate flotation methods required over an order of magnitude more water than the average gold operation of the day, using of the order of 5 Ml/day of low chloride water. The high water demand and remoteness of the new nickel find could not be serviced from the Goldfields pipeline, so Poseidon commissioned the largest groundwater exploration program ever conducted in the state. At first Poseidon's water consultants turned to the sand covered sedimentary Officer Basin, 80 kilometres east of Laverton, but they dropped this target when their ground resistivity and drilling program identified a closer fresh water resource in buried rivers near Valais Well, just 20 kilometres east of the deposit. This became the first major development of a palaeochannel borefield in the Goldfields.

In the 1980s, open pit mining techniques used by the iron and coal industries were adopted in gold and nickel mining. The softer ores could be mined and milled at much higher throughput rates, thereby increasing the productivity of the goldfields. Mill expansions were accompanied by further increases in water exploration activity, with palaeochannel systems being the most obvious targets.

In late 1990s, the Murrin Murrin, Cawse and Bulong nickel laterite projects were introduced, promising to tap the abundant and previously untouched vast Ni/Co laterite reserves using pressure acid leach technology.

In 1985 and 2000, the Waters and Rivers Commission audited statewide water availability and use. The findings of those two audits show that gross annual water use across the state has more than doubled from 835 Gl/yr to 1791 Gl/yr in little over 15 years (WRC, 2000b). The report estimates the total sustainable groundwater yield of the goldfields region to be 1740 Gl/yr based on the renewable rate, but most of this yield is contained in fractured rock aquifers that are difficult to develop for large scale commercial applications. Allowing for environmental allocations, the sustainable yield of more productive palaeochannel resources have now been almost fully allocated.

Reconciling Sustainable Water Development with Palaeochannels

Looking forwards, while the water contained in palaeochannels may be up to 10 times saltier than seawater, these water-laden sediments are still the most productive and commercially attractive groundwater resources for large scale development in the goldfields.

New projects, particularly the large nickel laterite projects, require more water than ever. There are plans for several major nickel mill expansions and new nickel projects over the next 5 to 10 years, each requiring a further 25 to 60

Ml/day. These projects alone would raise the State's annual water demand by a further 100 Gl/yr. With the sustainable yield of the palaeochannels already rapidly approaching full allocation, competition for the remaining resources is fierce and the costs for new palaeochannel supplies will increase exponentially as industry is forced to develop resources currently considered undesirable because of either high salinity or distance from mining activity. Significant investment is being made in treatment technology to handle increasingly saline resources, but there is also increasing pressure from industry to tap water allocations previously reserved to protect environmental and social values.

The Commonwealth Government has identified the cumulative impacts associated with palaeochannel development as one of its priorities (Hancock *et al*, 2001). Where a resource is mined it should therefore include a mechanism to ensure that water resources are allocated to the highest beneficial use in terms of sustainability (i.e. environmental, social and economic benefits). This requires the developer to:

- protect the functionality and diversity of wetlands and water sensitive ecosystems;
- use renewable resources in preference to non-renewable resources;
- use resources efficiently and ensure that they are not wasted;
- explore opportunities to use or recycle water in the process;
- provide safeguards against unacceptable impacts to the resource, environment and community;
- monitor their impacts on the resource, environment and community; and
- remedy any unacceptable impacts on the resource, environment and community.

In response the State Government has developed Groundwater Management Plans to ensure that water resources are allocated equitably and managed to minimise interference between competing stakeholders and the environment. The challenge for national and local regulators is deciding how much water development can be sustained without risking irreversible damage to ecological and social values for future generations. The challenge for water developers is to substantiate their requirement and provide enough surety and safeguards to allay these concerns. This is not easy given the complex and often poorly understood coupling between different palaeochannel aquifers, surface water environment and ecological habitats.

For instance, while the deeper palaeochannel aquifers hold water of little value other than mineral processing, they are usually hydraulically coupled to better quality shallow water resources that may support a rich mosaic of water-dependent vegetation communities, often with regional or national significance. Massive calcrete deposits suitable for mineral processing tend to be best developed in the central drainage areas where the water table is shallowest and water most abundant. However, water-filled cavities within and beneath calcrete deposits often provide the habitat for poorly understood subterranean fauna. Springs and soaks along the margins and central drainage areas usually have historical and spiritual significance to both Aboriginal and European communities (Anaconda, 2001).

Resource developers are increasingly looking towards water use efficiency, reduction of wastage and the development of more sustainable local water sources through artificially recharging the more important aquifers and developing storm water harvesting to supplement groundwater resources.

The future of the goldfields' water

In the goldfields, escalating demand and intensifying environmental restrictions are already restricting new project approvals. This is likely to continue with increasing levels of scrutiny and greater consideration of sustainability issues by regulatory authorities. Unless an alternative external water source is developed, future economic development will be curtailed as the commercially viable groundwater resources become fully allocated.

Providing and maintaining large scale infrastructure for importing external water sources would require considerable financial capital for hundreds of kilometres of pipelines power machinery, plant and labour. There is debate over who should pay and operate the scheme, although it is apparent that the costs are too great for any single private utility company to justify without at least some State and/or Commonwealth subsidy as part of a multi-user strategy. A private utility company would likely be more efficient and better able to service the needs of the growing mining industry demands, but Swanson (2002) argues that water is such a strategic resource that it is dangerous to allow it to fall into private hands and be subject to fluctuations in the market place. The Economist (2000) believes that any pricing strategy, whether applied as an environmental levy on unsustainable supplies and/or high unit prices on a new external supplies, is justified if it helps discourage squandering of valuable resources through inefficient water management.

Notwithstanding uncertainty over the ultimate form of funding, the State government has been considering several external supply options:

- Ord River Dam - surface water piped from the Kimberly;
- Geraldton Desalination - desalinated seawater piped from Geraldton;
- Officer Basin - low salinity groundwater piped from the Officer Basin to Kalgoorlie via Laverton and Leonora; and
- Esperance Desalination - desalinated seawater piped from Esperance to Kalgoorlie.

The latter two options have received considerable attention over the past two years.

Officer Basin Groundwater Supply

The Officer Basin was first mooted as a potential regional water supply in 1969, during water exploration program for the Mount Windarra Nickel Mine. A number of potential drilling targets were identified around Lake Rason from resistivity geophysical surveys, but subsequent drilling by the AGSO (formerly the BMR) in 1973 encountered a shallow granitic basement. There are numerous water supply bores throughout the Basin but without exception these tap the relatively low yielding surficial fluvial glacial aquifers, which are generally at depth of less than 120 metres. Through the years a number of scattered oil exploration holes have suggested more favourable aquifer properties in the Lennis Sandstone and Wanna Formation.

Anaconda drilled a number of 300 to 450 metre water bores in several areas around the Basin and in April 2000, and announced that they had found what appeared to be a large fresh water resource in the Lennis Sandstone. Exploration activities rapidly focused in on a 3000 square kilometre portion of the Gun Barrel Basin between Warburton and Laverton. By December 2000 considerable air transient electro-magnetics (TEM), ground geophysics, drilling and testing had been conducted in the target zone and showed a large uniform sand aquifer, which was 200 to 400 metres thick, containing abundant sub-potable water (less than 2000 mg/l TDS).

The question with the Officer Basin proposal is not whether there is a suitable quality and quantity of water in the Basin (there is), but rather whether this is the most economically, environmentally and socially attractive development option.

Esperance Desalination Project

The reverse osmosis process is based on the principle that when salt water is pumped under pressure across a fine membrane, some fresh water will pass through the membrane leaving behind a brine waste product.

The Esperance desalination option would involve construction of a large scale reverse osmosis plant, 2 metre diameter seawater intake pipeline and brine disposal facilities capable of handling upwards of 200 Ml/day. The fresh water will then be piped 400 km north to Kalgoorlie.

Concluding Remarks

Water allocations to protect the functionality and diversity of the environment are now accorded the highest priority in WA. Water resources that are surplus to environmental requirements are available for allocation to industry. As the sustainable water resources available in the goldfields rapidly approach full allocation, industry is forced to either develop resources currently considered undesirable due to high salinity or distance from mining activity, or to tap allocations previously reserved to protect environmental and social values. Efficient on-site water management will become increasingly important as the costs to convey water from greater distances or treat and manage saline water increase. Companies will need to understand and demonstrate their credentials in terms of sustainability and sustainable development as pressure on water resources becomes increasingly acute.

Ultimately, an external water source must be developed for the goldfields to ensure the continued prosperity of the region. The funding issue for such a scheme must be resolved to spread the burden between the beneficiaries: the mining industry, the State and private utilities.

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IN-PIT TAILINGS: COMPUTER MODEL PREDICTIONS OF SECURITY OF CONTAINMENT & IMPLICATIONS FOR REHABILITATION, RANGER URANIUM MINE

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ABSTRACT

The Ranger Uranium Mine is located approximately 230 km east of Darwin, Northern Territory. Since August 1996, neutralised tailings have been deposited into Pit #1 which is the void from which orebody 1 has been mined. Orebody 3 is currently being mined from a separate pit. Prior to mine closure, ERA is required to return all tailings to the mined out pits. Studies of tailings properties and behaviour have been in progress for some time and the data have been used to plan and implement optimum tailings deposition techniques, as well as evaluate the long-term behaviour of the tailings and residual pore-water following mine closure.

Consolidation modelling was undertaken by looking at the likely long-term rates of settlement within Pit #1. This is important because of the relationships between consolidation and settlement and permeability of the tailings and the impact of these properties on secure containment. The results of modelling so far predict the surface of the tailings deposits in the pit after settlement with reasonable accuracy. The results also indicate that the current method of central deposition, rather than peripheral deposition, is likely to significantly reduce tailings settlement[1] *.*

Groundwater modelling has been used to simulate options for post-closure capping of tailings and pit backfilling, and to see if there might be any long-term impacts on water quality. Interim results indicate that if the pit is filled to above the base of the more permeable weathered zone, potential impacts to downstream water quality can be managed by modifying the properties of the tailings or constructing seepage barriers.

INTRODUCTION

The security of containment of tailings in Ranger's Pit #1 has been modelled using a number of approaches including large strain one-dimensional tailings consolidation modelling and three-dimensional saturated/unsaturated solute transport modelling. Consolidation modelling was undertaken to evaluate post-closure settlement of the Pit #1 final landform. The studies were carried out in conjunction with investigations of tailings properties to confirm whether depositional and drainage strategies were appropriate to maximise consolidation (Li *et al.*, 2001).

The principal objectives of recharge and solute transport modelling were to identify sealing and capping requirements and to examine the potential for post-closure changes in groundwater quality downstream of the pit. For example, recharge could sustain heads within the pit and hence the driving force to move solutes away from the pit. Consequently, a range of modified tailings and seepage limiting barrier configurations were tested to assess pit backfilling options.

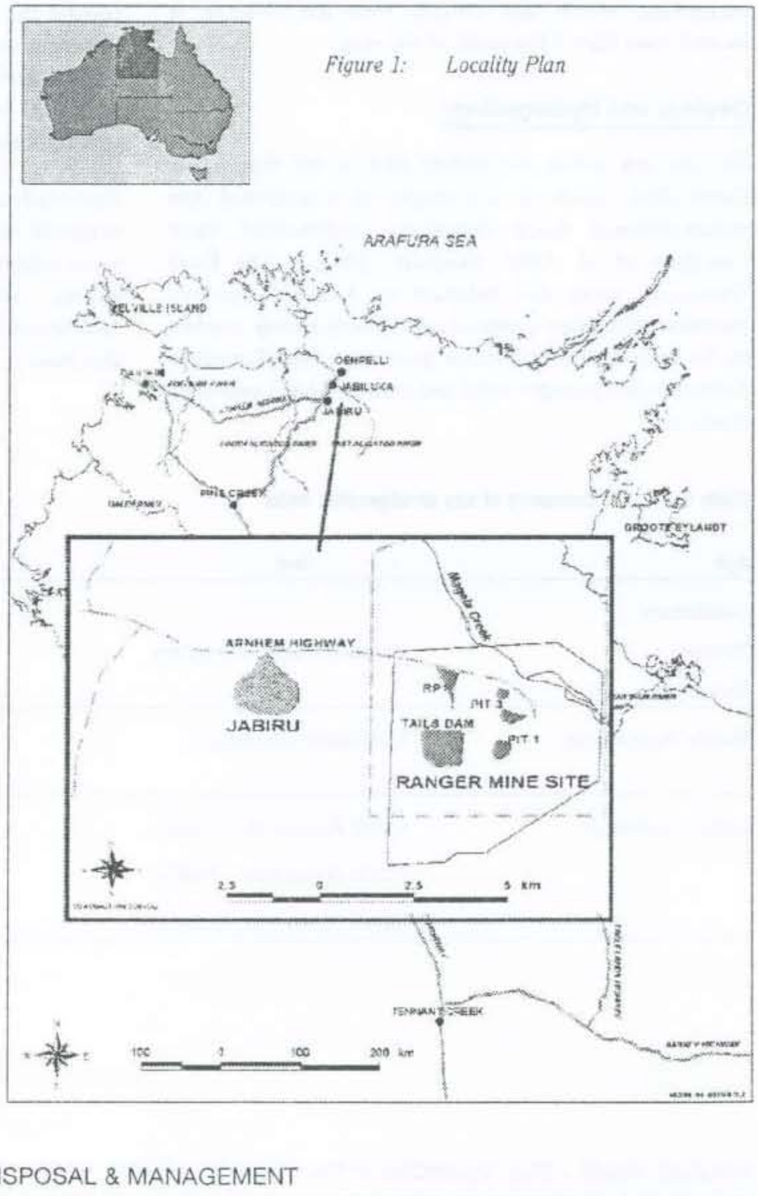


Figure 1: Locality Plan

[1] Early predictions from modelling suggested that peripheral tailings deposition generated low density slimes in the centre of the pit, and that these could take more than 100 years to reach 95% of final consolidation and settlement could be more than 20 metres.

BACKGROUND

Field Site

The location of Ranger Mine in the Northern Territory is shown in Figure 1. The Ranger Project Area is surrounded by, but separate from, World Heritage Kakadu National Park.

Climate

The climate is monsoonal with a wet season during the months of October to April and a dry season from May to September. The average annual rainfall recorded at the Jabiru Airstrip is about 1,500 mm (1971-2000). Average monthly rainfall in the peak wet season months of January and February is 377 and 327 mm/month, respectively.

Topography

The landscape is typically undulating and comprises slopes of between 1 to 4%, with hill crests around 20 m above the bed levels of the flanking Magela Creek. The Arnhem Land escarpment, which rises abruptly from the lowlands, is located more than 2 km south of the mine.

Geology and Hydrogeology

The site lies within the eastern part of the Pine Creek Geosyncline, which is a remnant of a deformed and metamorphosed Early Proterozoic sedimentary basin (Needham et al, 1980; Needham, 1982). The Early Proterozoic rocks are underlain by Archaean granitoid basement (Nanambu Complex) and unconformably overlain by flat lying Middle Proterozoic quartzites of the Kombolgie Formation and younger rocks and unconsolidated sediments (Table 1).

Hydrogeological conditions around Pit #1 include relatively tight schists and basement gneisses, and a permeable zone comprising fractured schists located in the south-east corner of the pit. The latter is the principal area of hydraulic connection between the pit and downstream groundwater and surface water systems. A plan showing the pit layout and bore locations is shown in Figure 2.

Tailings deposition and tailings properties

Pit #1 is 170 m deep and 750 m wide at ground surface level. Prior to June 2000, the tailings slurry was deposited from spigots located on the pit perimeter and cascaded down the walls (peripheral deposition). While tailings were initially deposited sub-aerially, a large excess of process water due to a succession of high rainfall wet seasons dictated that deposition was essentially sub-aqueous. Thus, coarser tailings deposits occur around the pit walls and the finer fractions (slimes) settled in the central areas of the pit.

In June 2000, deposition of tailings in the central parts of the pit commenced from a floating pipeline in order to begin to counter the impact of the low-density slimes deposits. The surface of the tailings through time, up until March 2000, is illustrated in Figure 3. Surveys were carried out by surface soundings from a boat. The contours show that the tailings surface is not flat.

Cemented and un-cemented paste tailings have been examined by Kalf & Dudgeon (1999) and Jones *et al.* (2001) as an option for minimising solute migration from Jabiluka tailings. Data from these studies have been utilised in subsequent solute transport modelling conducted as part of this study.

Table 1: Summary of key stratigraphic units

Age	Unit	Lithology
Quaternary		Alluvium, silt, sand
Tertiary	Bathurst Island Formation	Laterite
Cretaceous		Sandstone, conglomerate, siltstone
Middle Proterozoic	Kombolgie Formation	Sandstone, conglomerate, shale, quartzite, volcanics
Early Proterozoic	Cahill Formation "Upper"	Semi-pelitic/psammitic schist, amphibolite
	Cahill Formation "Middle"	Pelitic/semi pelitic schist, minor carbonate
	Cahill Formation "Lower"	Massive carbonates-dolomite

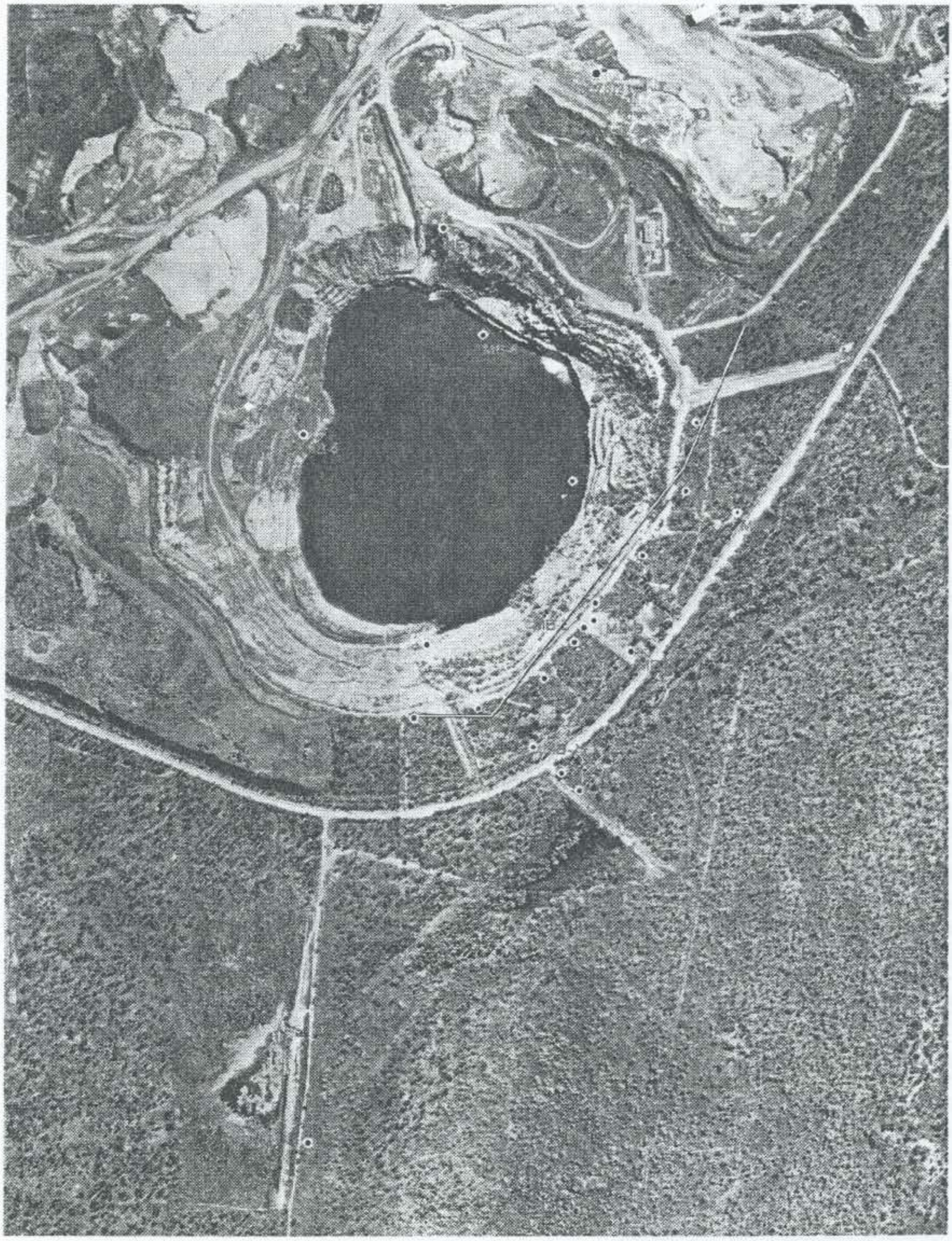


Figure 2 Pit #1 Layout

PIT 1 GEOPHYSICAL SURVEY AND BORE LOCATION

SCALE 1:8000
50 0 50 100 Metres

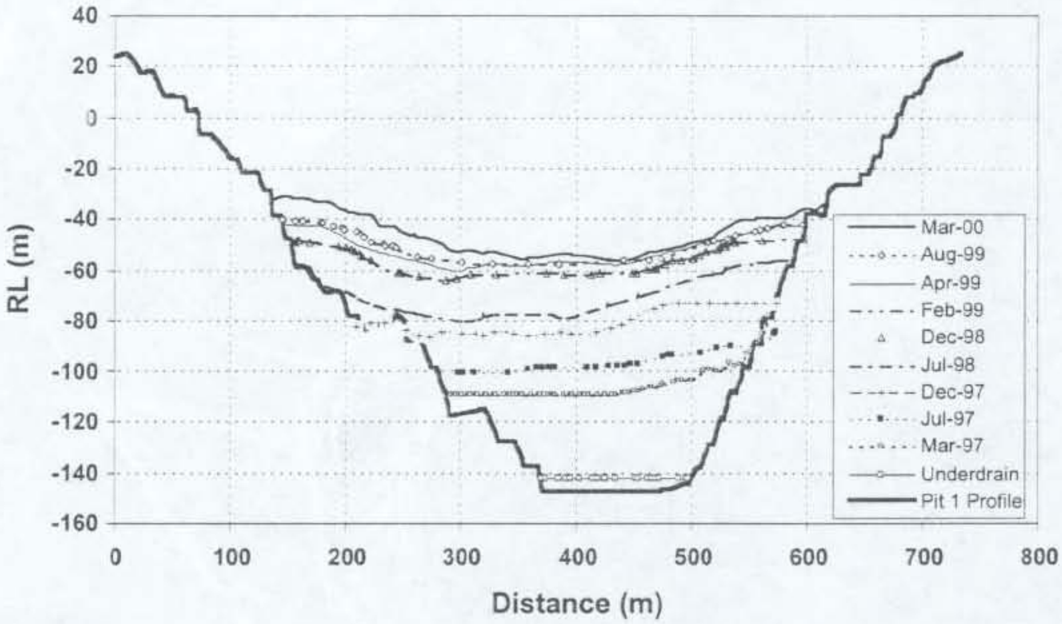
Approx. Location of Geophysical Survey
Bores

N

EWL Sciences

Map Prepared By EWL Sciences
PO Box 39443
Winnellie NT 0821
8 June 2000
Using Arcview 3.2
00282-01-00006-DJ

Figure 3: Pit #3 tailings distribution



The average dry density of the tailings deposits was calculated using tailings slurry input tonnages to the pit and the volume of tailings from surveys of the tailings surface at given times. The average tailings surface was determined by interpolating the relationship between RL levels and Pit #1 volume using the measured tailings volume. The average tailings density has reached or exceeded a target of 1.2 t/m^3 since deposition commenced, although densities were generally lower in the early years due to relatively small pit volumes.

Prior to tailings deposition, an under-drain was constructed to expedite consolidation and settlement. Other techniques (not described in any detail here) were trialled to enhance drainage within the tailings.

MODELLING CONSOLIDATION AND SETTLEMENT

Introduction

The modelling required simplification of *in-situ* conditions within the tailings deposits, which are highly complex. Tailings properties are heterogeneous and anisotropic and boundary conditions are difficult to define due to the nature of the depositional processes including particle transport, flocculation, sedimentation and consolidation.

Methodology

The consolidation program used for numerical modelling was TAILS (TAGAsoft, 1999). The program calculates rates of consolidation of tailings and dredge spoils under self-weight and/or under surcharge loadings. The program performs these calculations in a one-dimensional plane and allows large deformation and arbitrary variations in the rate of deposition. The program has been widely tested and validated (e.g. Townsend & McVay, 1990). The material properties required are:

a) specific gravity of the tailings (2.75, based on laboratory data for Ranger tailings (Richards *et al.*, 1989; Li & Cramb, 1999);

b) sedimentation void ratio measured from column settling tests and defines the point at which individual particles come in contact with each other and consolidation begins. Direct measurement of sampled tailings in Pit #1 show that the tailings densities near the surface were between 0.65 and 0.97 t/m^3 (Cramb, 1997; Li and Cramb, 1999). An arithmetical average of 0.80 t/m^3 was obtained. Hence, the sedimentation density is taken as 0.8 t/m^3, and the sedimentation void ratio is 2.44; and

c) compressibility and hydraulic conductivity, which controls overall consolidation behaviour.

The compressibility determines the degree of consolidation, and the permeability controls the rate of consolidation. The compressibility and hydraulic conductivity parameters are described by the power laws:

$$e = a(\sigma'_v)^b$$
$$k = ce^d$$

where

e = void ratio

σ'_v = vertical effective stress, kPa

k = hydraulic conductivity, m/s, and

a, b, c and d = empirical material constants.

A number of laboratory tests have been carried out to determine the compressibility and hydraulic conductivity of Ranger tailings (Table 2).

It can be seen from Table 2 and Figure 4 that consolidation parameters vary significantly, most likely due to sample properties such as density, particle size distribution, stress history and chemistry of the pore water.

Table 2: Assumed consolidation parameters

Material	a	b	c (m/s)	d	Method
ROM tailings (Knight Piesold, 1992)	1.61	-0.105	4.95E-8	1.52	Slurry consolidation test
ROM tailings (Knight Piesold, 1992)	1.53	-0.109	1.06E-8	4.75	Oedometer test
ROM tailings (Knight Piesold, 1992)	1.66	-0.123	1.52E-8	6.15	Combined slurry and oedometer tests
Dam tailings (Richards et al, 1989)	1.27	-0.068	5.0E-10	21.17	
Pit #1 central tailings (Li & Cramb, 1999)	1.42	-0.053			Oedometer test
ROM tailings (2000)	1.18	-0.071	6.75E-8	5.73	Oedometer test

Note: obtained by curve-fitting laboratory testing results

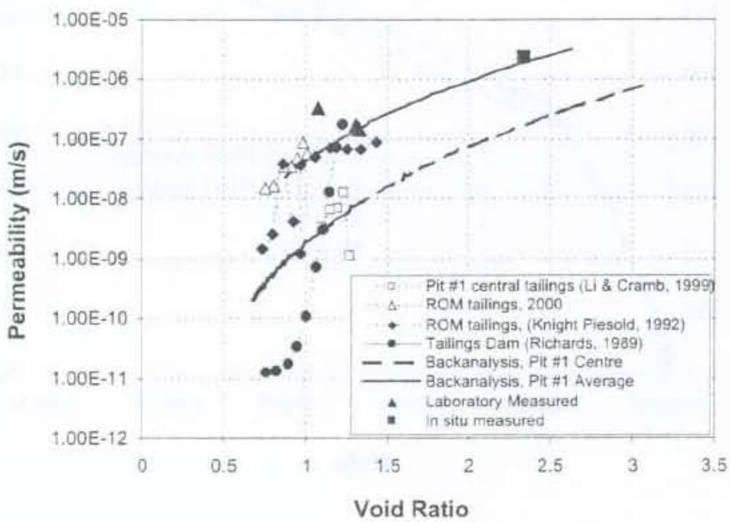


Figure 4: Hydraulic Conductivity and Void Ratio Relationships

Results

The modelling indicates that the surface of the tailings deposits will reach RL0 (approximately sea-level) by mid-2009 (Figure 5). The predicted average tailings dry density is 1.4 t/m^3. In modelling average tailings behaviour, the tailings surface is assumed to be flat. However, due to the nature of the slimes deposits in the centre of the pit, the tailings surface here was approximately six and half metres lower than the average level of tailings. Central tailings deposition was implemented to generate coarse tailings deposits and thus surcharge in the central parts of the pit and so counteract the poor settling and consolidation properties of the slimes (fines).

Reverse-osmosis (RO) treatment of process water above the tailings mass is expected to commence in 2003 and will lead to sub-aerial deposition which should significantly increase the tailings density and rates of consolidation and settlement.

Had central deposition not been implemented, one-dimensional consolidation analysis shows that the post-deposition settlement of slimes could be more than 20 metres in the central parts of Pit #1, taking more than 100 years to reach 95% consolidation under self-weight. However, one-dimensional analysis is limited in capability because only vertical water flow is considered and, in reality, horizontal hydraulic conductivities are likely to be larger than vertical hydraulic conductivities (probably by an order of magnitude).

Interpretations

The consolidation modeling results show the benefits of central tailings deposition. In the event that peripheral tailings deposition continued, tailings (slimes) in the central area of the pit would undergo slow consolidation and settlement would be significant. This would make it difficult to access to the tailings and to construct capping layers and would require particular engineering of sealing layers over the tailings and final landform shaping.

RECHARGE AND SOLUTE TRANSPORT MODELLING

Introduction

Groundwater modelling was undertaken in a two-stage process of 'recharge' and 'solute transport'. Recharge modelling was undertaken to look at possible requirements for capping the tailings deposits in order to limit infiltration and thus minimise groundwater levels within the tailings and hence solute movement away from the pit. Solute transport modelling was undertaken to assess a number of in-pit tailings deposition scenarios and potential impacts to downstream groundwater quality.

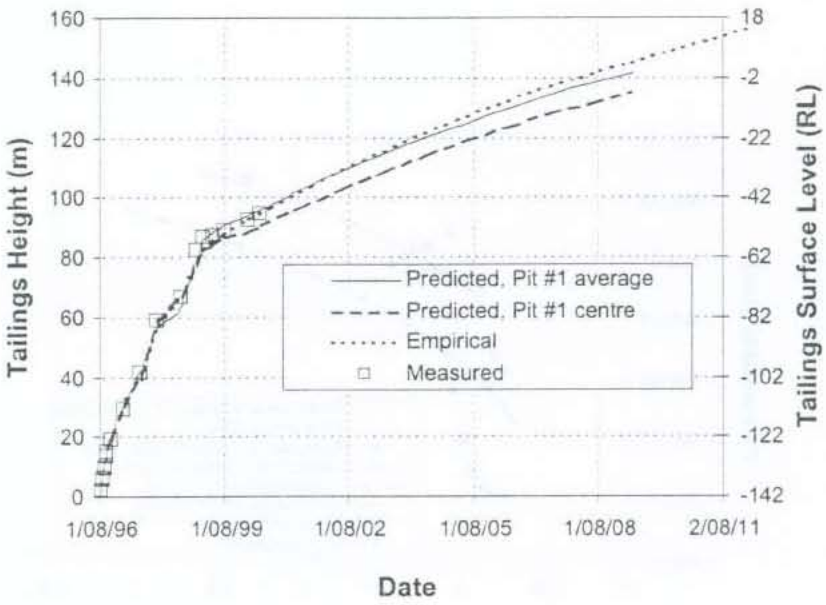


Figure 5: Measured and predicted surface level of Pit #1 tailings

Assessments were also made of various scenarios including cement addition to tailings-paste to reduce the source concentrations of key solutes and porewater volumes, and the placement of downstream barriers to limit the hydraulic connectivity of the pit with downstream water systems.

Methodology

Recharge Modelling

Materials placed over the tailings can significantly influence the infiltration rates and in turn influence potentiometric levels within the tailings and movement of contaminants away from the pit. It is proposed to place a capping layer immediately over the tailings deposits to enable truck movement on the tailings to fill the pit void with waste rock to the original land-surface. Recharge modelling was undertaken using potential final landform topographic data from GIS coverages, which define the pit outlines at the land surface. A relatively simple mesh-design, comprising 1,916 elements and 1,350 nodes, was developed to represent the pit area. The model is a 3-dimensional saturated/unsaturated groundwater representation and comprises four layers.

Values for saturated hydraulic conductivity and effective porosity (within waste rock) are based on hydrogeological data collected from the Ranger site. Some assumptions have been made to reflect long-term sealing from infilling of pores due to weathering. Similarly, unsaturated hydraulic properties for waste rock were derived using data for saturated hydraulic parameters and assumptions that air-entry pressures and residual saturation are likely to be negligible.

Given the relative paucity of available data, a relatively simple linear parametric model was applied as follows:

$$s = s_r + \left(\frac{\Psi_c - \Psi}{\Psi_c - \Psi_a} \right) (s_s - s_r)$$

$K_{unsaturated} = K_{saturated} \times s$

where

$K_{unsaturated}$ = unsaturated hydraulic conductivity (m/s)

s = saturation

Ψ = pore pressure (m)

s_s = maximum saturation (i.e. unity)

s_r = residual saturation = 0.0025

Ψ_c = fringe pressure = 4.1 m

Ψ_a = *air − entry* pressure (assumed to be zero)

Ψ_{min} = - 100.0 m

Constant-head boundary conditions (i.e. groundwater levels set at a constant value of RL19 or ground-surface) were incorporated along the south-east border of the model to permit drainage from the waste rock layer.

Net surface fluxes to the model were estimated by calculating the difference between daily rainfall, potential evaporation (Class 'A' Pan evaporation x Pan coefficient) and surface detention of incident rainfall. Actual data from 1 September, 1979 to

31 August, 2000 were used. Rainfall and evaporation data were collected from the Ranger site and Jabiru Airstrip monitoring stations, respectively. Long-term Pan coefficients were taken from Chiew & Wang (1999). A surface detention[2] value of 5 mm was adopted.

Two scenarios were modelled as follows:

Scenario No.1: Compacted clay-rich (laterite) layer (seal) constructed between the tailings and overlying waste rock layers

Scenario No.2: No compacted clay-rich layer

Solute Transport Modelling

The approach utilised the conceptual hydrogeological model developed by Salama & Foley (1997) and Salama *et al.* (1998). Simulations were undertaken using adaptations of the numerical model (three-dimensional, solute transport model developed in FEFLOW) and Pit #1 GIS-coverages developed by Kin *et al.* (1999) and information collected from an earlier assessment of final tailings repository options for the Ranger mine (Salama *et al.*, 1998). The Pit #1 groundwater model grid contains 20 slices (19 layers) and in excess of 320,000 elements. The model grid reflects pit and local hydrogeological boundaries, with smaller elements used in areas where groundwater or solute fluxes are likely to be high.

The model comprises 19 layers and approximately 320,000 elements. The model assumes that a permeable zone in contact with the pit is located south-east of Pit #1 and extends a distance of 250 m around the pit edge (from about MB-H to MB-K) and from surface to about RL -20. Elsewhere within the model domain, the pit walls are assumed to be essentially impermeable, based on historical data, which indicate negligible seepage from other parts of the pit. A number of scenarios were tested, with the pit backfilled with waste rock and tailings, or simply tailings in various forms, including neutralised, paste and cemented-paste. The hydraulic properties assumed for the waste rock are the same as those used for the recharge modelling. It was also assumed that the waste rock used in the pit backfilling was not itself a source of contaminants. This assumption has yet to be tested.

[2] reflects water that is stored within surface ponds of the waste rock and is subsequently evaporated

Assumed values for tailings material properties are contained in Table 3. The assumed values are considered to be conservative and are based on data derived from the above testing, tailings data presented by Knight-Piesold (1992) and leach test work described by Jones *et al.* (2001).

Solute transport was simulated using SO_4 as a tracer. Given its relatively conservative characteristics (i.e. unlikely to chemically react or adsorb), predictions of the fate of a potential contaminant plume from Pit #1 are considered to be "worst-case" for the given assumptions. Initial SO_4 concentrations within the tailings mass were assumed to be equal to the values obtained from laboratory testing, with upper-end values assumed (Table 3).

Initial groundwater levels (heads) within the pit were assumed to be equal to the 'steady-state' (equilibrium) groundwater levels previously calculated by Kin *et al.* (1999). Within the tailings, groundwater levels were assumed to be the same in all layers, i.e. vertical hydraulic gradients within the tailings were assumed to be negligible. In the short-term, when consolidation-settlement has only been partially achieved, the permeabilities are likely to be much higher than that assumed over the long-term.

Constant-head boundary conditions were assigned at Corridor Creek (located between OB14 and OB30), since most groundwater probably discharges into it. In reality, groundwater flow may also discharge in downstream areas.

A total of seven model simulations were run as indicated in Table 4. For each scenario, the model was modified by altering the values assigned to tailings properties or by changing pit backfilling configurations. Each scenario was run to 10,000 years, or for a fewer number of years where progressive results indicated unacceptable changes to water quality in groundwater systems located immediately downstream of the pit.

Two 'tests' were applied to establish whether each scenario resulted in detrimental impact to downstream water quality. In test No.1, predicted heads (groundwater levels) in Corridor Creek were compared to pre-mining heads to establish the likelihood of surface breakout of deeper groundwater. This is considered to be an important issue in terms of ensuring no significant change in the post-decommissioning flow regime in Corridor Creek, and also minimising risk of delivery of salts to the surface water environment. In test No.2, predicted concentrations of SO_4 at Corridor Creek were compared to first flush SO_4

Table 3: Assumed tailings material properties

No.	Solids (%)	Cement (%)	Hydraulic Conductivity (m/sec)	Porosity	Approx. SO_4 in the porewater* (mg/L)	Comments
1	70	0	1.5×10^{-8}	0.50	18,000	thickened tailings, neutralised tailings
2	70	4	1.2×10^{-8}	0.41	2,000	thickened tailings, cement added
3	70	8	4.6×10^{-9}	0.37	500	thickened tailings, cement added
4	approx. 50%	0	1.5×10^{-8}	0.50	18,000	neutralised tailings

* *solute source term*

Table 4: Summary of Modelling Scenarios

Simulation No.	Modelling Scenario
1	neutralised tailings to RL +8
2	neutralised tailings to RL -16
3	neutralised tailings to RL -16, paste tailings +8% cement to RL +12
4	neutralised tailings to RL -16, paste tailings +4% cement to RL +12
5	neutralised tailings to RL +12 in NW, paste tailings +8% cement to RL +12 in SE
6	neutralised tailings to RL +30 in NW, paste tailings +8% cement to RL +12 in SE
7	neutralised tailings to RL -16, paste tailings +4% cement to RL +14
8	"Impermeable" seepage barrier located immediately downstream of SE pit wall

concentrations measured from existing downstream monitoring bores OB14 and OB30 in November/December 2000. Concentrations of SO_4 were found to vary significantly from 24 mg/L (OB30; 16 November, 2000) to 182 mg/L (OB14; 28 November, 2000). This range of SO_4 concentrations is considered to be the background threshold criterion for the purpose of this investigation.

Results

Recharge Modelling

Predicted water balances for each of the model scenarios are shown in Table 5. In both scenarios, predicted groundwater levels in the waste rock show seasonal fluctuations of around 4-6 m. However, in the underlying tailings groundwater levels remain relatively constant, at about RL 23. Initial infiltration fluxes to the underlying tailings are observed to be relatively high as groundwater levels in each of the layers approach equilibrium after around 2 years.

The average annual infiltration flux to the underlying tailings is around 1 mm/year. Predicted fluxes and groundwater levels for Scenario No.2 are shown in Figure 6.

The water balance shows that without the placement of a seal between the waste rock and the tailings (Scenario No.2), higher surface infiltration rates and groundwater storage occurs. The water balance also demonstrates the importance, in both scenarios, of the hydraulic conductivity of the tailings mass and the toe-drain situated in the SE corner, in controlling seepage rates to the underlying tailings. The drain intercepts between 22 and 33% of surface infiltration and significantly minimises seepage to the underlying tailings.

The results of the recharge modelling indicate that for the given assumptions, recharge rates to the underlying tailings are likely to be low regardless of whether or not a low-permeability seal or cap is placed on the upper surface of the tailings.

Table 5: Recharge Model Water Balance

Process	Scenario No.1 – with compacted laterite seal	Scenario No.2 – without compacted laterite seal
Surface Infiltration	+8,330	+14,705
Change in Groundwater Storage	-3,800	-9,645
Drain (SE corner) Discharge	-2,810	-3,285
Surface Discharge	-1,720	-1,775
Net Balance (sum of the above)	0	**0**

Note: all values shown are cumulative totals (1979-2000) in m3

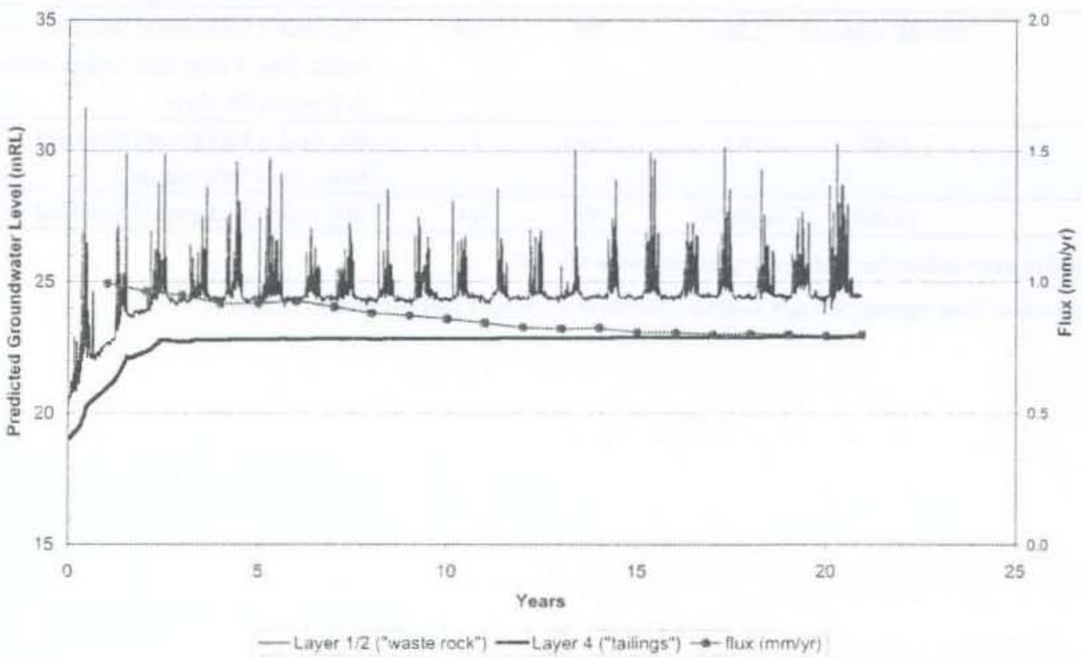


Figure 6: Recharge Model - Predicted Fluxes and Heads (Scenario No.2)

The low recharge rates are due to both the relatively low permeability of the tailings deposits and the presence of a drain at the base of the slope (south-east corner of the pit). This drain will be considered in the context of post-closure site water management strategies.

Solute Transport Modelling

The results of the solute transport modelling are summarised in Table 6. Specifically, the modelling results show that by reducing hydraulic conductivities and solute source concentrations within the tailings, long-term impacts to groundwater quality can be minimised.

Alternatively, placement of a downstream permeability barrier in the south-east corner of the pit may achieve similar outcomes.

The results of Scenario No.6 suggest that placement of tailings above pre-mining groundwater levels in the pit area could result in dry season groundwater flows in Corridor Creek.

Table 6: Summary of Solute Transport Modelling Results

Simulation No.	Approx. SO_4 Conc.* (mg/L)	Predicted Peak SO_4 Conc.** (mg/L)	Approx. Dilution Factor	Approx. Time for SO_4 Peak** (years)	Comments
1	18,000	3,307	83%	276	SO_4 peak > background threshold criteria; heads show little change
2	18,000	>14,800	<26%	>100	SO_4 peak > background threshold criteria; heads show little change
3	2,000	0.2	>99%	10,000	SO_4 peak < background threshold criteria; heads show little change
4	500	3.6	99%	325	SO_4 peak < background threshold criteria; heads show little change
5	500 (SE segment)	122	77%	32	SO_4 peak < background threshold criteria; heads show little change
6	500 (SE segment)	1,580	NA	>0.6	SO_4 peak > background threshold criteria; heads show a large rise, with perennial flow in Corridor Ck likely
7	2,000	0.1	>99%	0.1	SO_4 peak < background threshold criteria; heads show little change
8	18,000	Negligible	NA	NA	SO_4 peak < background threshold criteria

* *assumed to exist within the Tailings Repository above RL -16*

** *within solute front passing through shallow aquifers at Corridor Creek (at Nodes 31/32/33/34)*

CONCLUSIONS

Consolidation and groundwater modelling have been undertaken to assess the extent to which tailings and tailings porewaters may be securely contained within Ranger's Pit #1. The consolidation modelling shows that recently commissioned central deposition of tailings is likely to counteract the possibility of tailings slimes in the central area of the pit resulting from peripheral deposition undergoing slow consolidation and substantial settlement.

Recharge modelling suggests that an infiltration-limiting barrier located at ground surface or the interface between the waste rock and tailings is unlikely to significantly reduce recharge to the tailings mass and hence the "driving force" of plumes away from the pit. On the other hand, solute transport modelling indicates the importance of reducing hydraulic conductivities and/or solute source concentrations within the tailings to minimise impacts on downstream groundwater quality. Alternatively, a downstream seepage-limiting barrier will provide similar protection.

The modelling approaches, when used together, have provided an invaluable tool for the assessment of pit backfilling and capping options in the context of examining potential environmental impacts in relation to final pit rehabilitation.

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PALEOCHANNEL PITS AS INPIT TAILINGS DISPOSAL FACILITIES - THE MT PLEASANT STORY

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ABSTRACT

Inpit tailings disposal has been employed at a number of mine sites around Australia. It has a number of advantages over conventional above ground tailings storage practices with respect to construction and operating costs, environmental impact and closure requirements. To date most of the inpit tailings disposal facilities have been developed in "rock" pits (including saprolite/saprock pits).

At Mt Pleasant, several abandoned paleochannel pits have been used for inpit tailings disposal. Initial, trial disposal, was to the Black Lady Sands Pit. Following the success of this trial operation, the disposal system (known as the Inpit 1 TSF) was expanded to include the Manly South and Lady Bountiful Extended Pits. Inpit 1 TSF reached full capacity in mid 2001, and a second system (Inpit 2 TSF) was commissioned. At Mt Pleasant, the advantages of inpit tailings storage included:

- *Much lower cost and much less environmental impact than the alternative (a new above ground ring-dyke structure).*
- *Infilling of pits which have generally unstable walls, thus providing for a more stable long-term landform.*
- *Naturally controlled underdrainage drainage system provided by the paleochannel sediments, which allows confident prediction of seepage pathways and targeting of monitor and recovery bores.*

Inpit 2 TSF was recently shut down when the Mt Pleasant Plant was decommissioned. However, the successful operation of the inpit systems at Mt Pleasant highlights the benefits (cost and environmental) of using paleochannel pits for tailings disposal.

1. INTRODUCTION

Centaur Mining and Exploration Limited discovered the Lady Bountiful Extended (LBE) gold mine in 1988. Centaur operated this mine between 1989-1995. In 1995 Centaur purchased the adjacent Mount Pleasant Gold Operations from Mining Corporation of Australia. Until late 1999, tailings disposal at the Mt Pleasant Gold Operations had largely been to conventional above ground "ring dyke" structures TSF1 to TSF4 and TSF6. The only exception was in 1993, when some tailings were also deposited into a mined out pit (Black Lady Sands Pit) north of TSF6

Options for tailings deposition beyond the life of TSF6 included a new above ground structure (TSF7) and a modified/improved inpit system using a series of mined out shallow pits along a regional paleodrainage system. Following review of the cost and environmental implications of each option, it was decided to proceed with the inpit option. The first stage in the process of changing from an all above ground tailings storage system to an all inpit system, involved the interim Inpit TSF1 system (a combined inpit and above ground system). This system was used in conjunction with TSF6 during part of 2000 and continued until late 2001, when the new all below ground Inpit TSF2 system was commissioned.

The Inpit TSF2 system, designed to operate for at least two years, only operated until early 2002 because of the Mt Pleasant plant being decommissioned. The mine was acquired by Goldfields (now Aurion Gold Limited) in late 2001, and all Mt Pleasant ore is now processed at the nearby Paddington Plant.

However, despite its very brief operating history the performance of Inpit TSF2 and Inpit TSF1 demonstrates the advantages of inpit tailings deposition into paleochannel pits.

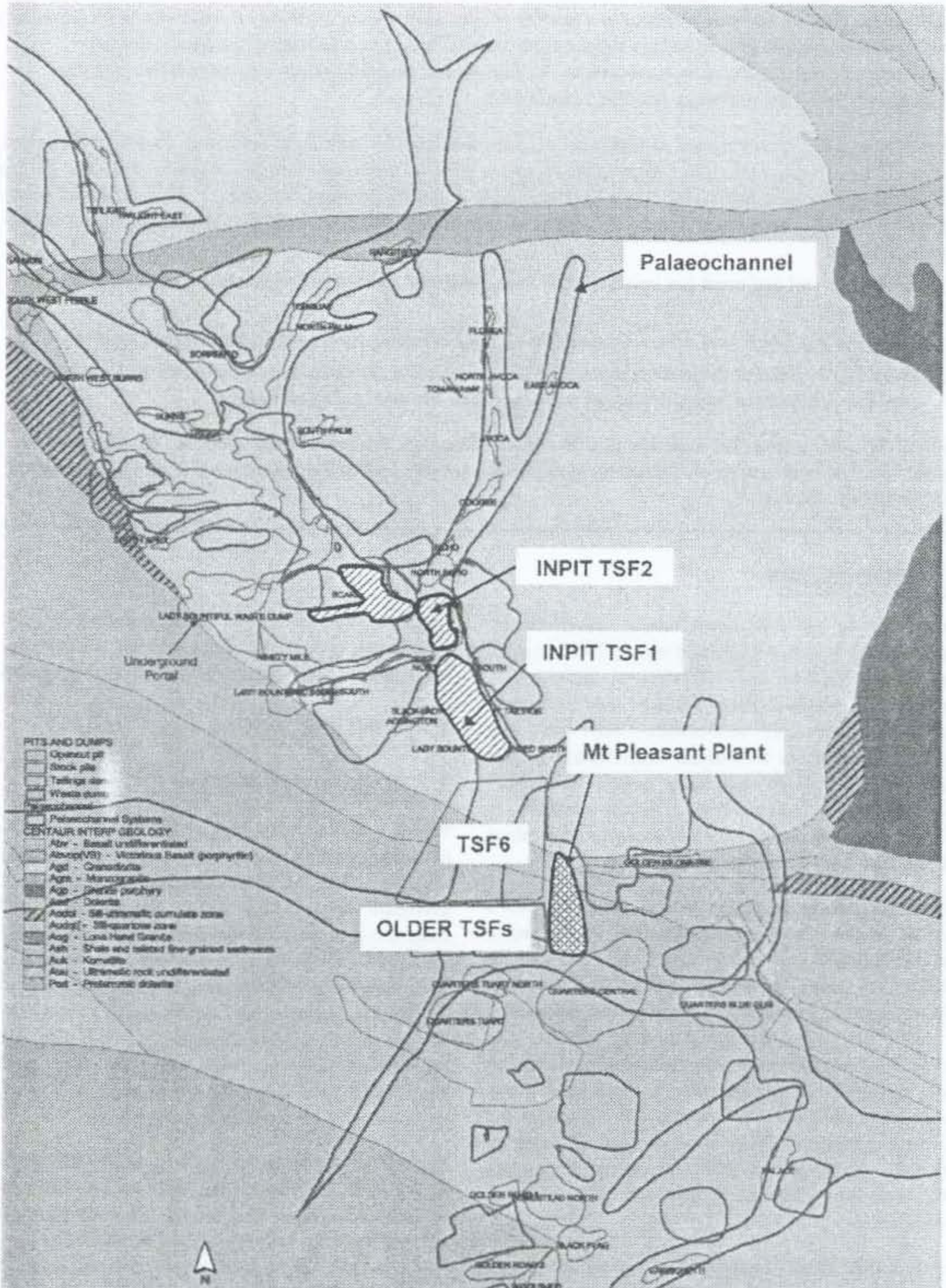
2. PHYSICAL SETTING

2.1 Regional Hydrogeology

Figure 1 shows the location of the Mt Pleasant minesite (including pits from current and historical mining activities, the plant and all the TSFs) plotted over a map of the major geological units in the area. The basement geology comprises a series of steeply dipping Archaean basalts and ultramafics (that make up part of one of the main regional greenstone belts) with younger Archaean granite intrusives. The basement complex has been incised by ancient drainage systems that have been subsequently infilled with Tertiary paleochannel sediments (basal sands and overlying clays). These major geological units are overlain by a veneer of insitu weathered material and alluvial cover.

Regional groundwater flows are from topographic high areas in the northwest towards the extensive salt lake systems (Black Flag and White Flag Lakes) to the southeast. The bulk permeability of the basement rocks is significantly lower than the permeability of the paleochannel sands and the alluvium in the present day drainage systems, and there is some convergence of groundwater flow lines towards these drainage systems.

Figure 1: Location Plan



Groundwater quality in the area is generally saline to hypersaline (with the higher salinities associated with the paleochannels and the downgradient areas. There are likely to be some pockets of low salinity water in some areas near the headwaters of catchments, but no low salinity groundwater has been reported in any of the mine areas.

2.2 Hydrogeology of Inpit TSF Areas

The Inpit TSF 1 pits (Lady Bountiful Extended, Black Lady Sands and Manly South) and Inpit TSF 2 pits (Manly and Scarborough) are located in the lower reaches of the northern tributary arm of the regional paleochannel system. The typical subsurface sequence comprises the following:

- Lateritic clays and gravels to around 5m depth.
- Mottled clays with abundant haematite/limonite pods to around 20 to25m depth.
- Kaolin clays with minor sandy beds towards the base to around 25 to30m depth.
- Paleochannel sands with basal gravels to around 30 to35m depth.
- Saprolites (decomposed granite) over granite.

Gold was mined from the basal gravelly sections of the paleochannel sequence and from the upper 1 to 3m of the saprolites during the late 1980's and early 1990's. The local water table was around 15 to 20m deep, although significant groundwater inflows to the pits did not occur until the pits intersected the top of the paleochannel sands. The Black Lady Sands (BLS) and Lady Bountiful Extended (LBE) Pits were dewatered by a combination of perimeter bores and sumps. The Manly and Scarborough Pits were dewatered by sump pumping.

Following completion of mining, groundwater levels only partially recovered. This is common in the Goldfields (and elsewhere in arid zones) where evaporation losses from pit walls and open water surfaces in final pit voids commonly exceed groundwater inflows, and the pits become groundwater sinks.

Prior to development of the Inpit TSFs, pit void water levels were observed to be at/near the base of each of the pits, except where they were influenced by seepage from TSF6 and/or the initial BLS TSF (refer Section 3).

2.3 Condition of Pits

The pits were all excavated into unconsolidated alluvial and eluvial sediments and overall pit wall angles were relatively flat at around 50o to 60o. Even with relatively gentle angles of repose, there were numerous small scale slope failures, predominantly circle failures within intact clays, but with some sliding failures over surfaces within the mottled clay horizon.

Geotechnical assessment of the condition of the pits indicated the potential for eventual large scale pit wall failures.

3. PERFORMANCE OF EARLIER TSFS

3.1 Above Ground TSFs

The first stage of the ore processing plant was commissioned in February 1988 to handle 0.5Mtpa of hard underground mined ore. Plant capacity was upgraded in late 1988 to handle 1Mtpa of softer open pit mined oxide ore. Initial tailings deposition was to TSF1, 2 and 3, a series of small rectangular above ground "ring-dyke" structures adjacent to the plant. TSF 4, an extension to TSF3 was commissioned in 1990.

Plant capacity was increased to around 2Mtpa and TSF6 a large rectangular structure was constructed on the north side of the existing TSFs in 1992. TSF 6 operated continuously from 1992 to 1999, although in 1993 some disposal to the BLS inpit TSF also took place. Intermittent tailings deposition to TSF6 continued through early to mid 2000 (shared with disposal to Inpit 1 TSF) before TSF6 was shut down.

Seepage from the tailings resulted in elevated levels of indicator water quality parameters (including WAD cyanide) and rising ground water table in many of the bores around the perimeter of the TSFs. Seepage from the TSFs was also detected in trial paleochannel dewatering bores for the Quarters Pit in 1998. This indicated some preferred seepage along the paleochannel (Note: Tailings seepage is still being detected in seepage from the paleochannel sediments into the Quarters Pit.

By 1998, groundwater mounding had brought the water table and elevated cyanide levels close to the natural ground surface. Additional monitor bores and some recovery bores (equipped with air-well pumping systems) were commissioned in 1998 and continue to operate (the need to continue operation of these bores will be reviewed in late 2002). Recovered bore water was pumped back to TSF6. Operation of the recovery bores successfully kept the water table below ground surface and, apart from seepage along the paleochannel towards Quarters Pit, restricted the lateral spread of seepage away from the TSFs.

In all, over twenty bores (monitor bores and recovery bores) were required to provide adequate coverage of seepage from all sides of the above ground TSFs.

3.2 BLS Inpit TSF

The BLS Pit, located upstream of TSF6 was used for tailings deposition, in conjunction with TSF6, in 1993. Water level and water quality data from monitor bores around the BLS Pit indicated preferred seepage into the paleochannel sediments. However, water table mounding around TSF6 seepage resulted in a hydraulic barrier to down channel migration of seepage from the BLS Pit, seepage remained in a "halo" around the pit and the water table mounded close to the surface. This water table mounding also resulted in shallower depths to water in the pit lakes in the pits immediately to the north and south of the BLS Pit (ie Manly South and LBE Pits).

The operation of perimeter recovery bores, commencing in 1998, drew the water table down to well below surface and restricted the potential, lateral migration of seepage through basement rock aquifers.

4. DEVELOPMENT AND OPERATION OF INPIT TSF1 AND INPIT TSF 2

4.1 Inpit TSF1

In 2000, an expanded BLS tailings deposition system (Inpit TSF1) was commissioned. This system was designed as an interim facility system designed to handle tailings deposition as the capacity of TSF6 became exhausted. It was planned that Inpit TSF1 would operate until the new Inpit 2 TSF was approved (by regulators) and constructed. Inpit 1 TSF included the Manly South and LBE Pits located immediately to the north and south of the BLS Pit. However, to provide sufficient tailings storage capacity, a low ring dyke was constructed around the pits to allow some aboveground tailings storage also.

During initial operation of the expanded Inpit TSF1 system, water table mounding and the lateral migration of seepage was restricted by the operation of a small network of recovery bores, most located in paleochannel sediments and all pumping back to the TSF. Up to five recovery bores were required to control and recover seepage. However, once the level of tailings progressed above natural ground surface, some seepage at the toe of the ring dyke was observed. Seepage was restricted to the southern margin of Inpit TSF 1, close to the northern margin of TSF6, where the interference effects of seepage from both facilities resulted in the highest water table mounding. Seepage recovery trenches were installed in this area to capture shallow sub-surface flows. These trenches flow to a common sump for recovery.

Primary deposition of tailings into Inpit TSF1 system was completed with the commissioning of Inpit TSF2 in September 2001.

Operation and monitoring of the recovery bores is continuing, with a review of their operational future due in late 2002.

4.2 Inpit TSF2

Inpit TSF 2 was to be the first of a series of purpose constructed below ground TSFs in paleochannel pits, that would see out the projected life of mine life. As such, it was subjected to a much higher level of investigation and scrutiny by the mine and by the regulators.

4.2.1 Investigation and Approvals

The Notice of Intent (NOI) for the initial design of Inpit TSF2 was submitted in September 2000. The initial design include tailings deposition in the eastern apart of the Ninety Mile East (NME) Pit, located to the west of Manly Pit. The Department of Minerals and Energy (DME) expressed some concern at the time regarding the potential impacts of tailings disposal on a proposed re-opening of the nearby Lady Bountiful underground mine. The concerns were related to groundwater seepage from the tailings and the possibility of the failure of the upstream wall of the NME Pit and a subsequent surface "rush" of tailings.

More detailed assessment of existing local groundwater conditions and predictive groundwater modelling indicated that seepage from the Inpit TSF2 system would be highly unlikely to reach anywhere near any new mining activities. In fact the assessment indicated that any upstream migration of seepage would be restricted to the immediate area of the TSF and not extend beyond the bounds of the NME Pit. Figure 2 (taken from the Hydrogeological Report prepared at the time) shows the interpreted pre-mining groundwater conditions and predicted groundwater flow paths during and post tailings deposition to the Inpit TSF2 system. Following review of the results of the hydrogeological investigation by DME, Water and Rivers Commission (WRC) and the Department of Environmental Protection (DEP) in November 2000, potential groundwater seepage ceased to be an issue.

At the same time, more detailed geotechnical assessment indicated that the potential for the western wall of the TSF in NME (largely a natural pillar left by selective mining) to collapse was extremely low. The assessment also indicated that there was sufficient storage volume in the western part of the NME Pit to accommodate all the tailings from NME section of the Inpit TSF2 system. The results of the assessment were technically accepted by DME, however, objections to the TSF system lodged by the tenement-holder of the LBE underground operation, were causing delays to the overall approvals process.

It was decided in early 2001, to remove the NME Pit from the Inpit TSF2 system. A revised NOI was submitted and accepted in March 2001.

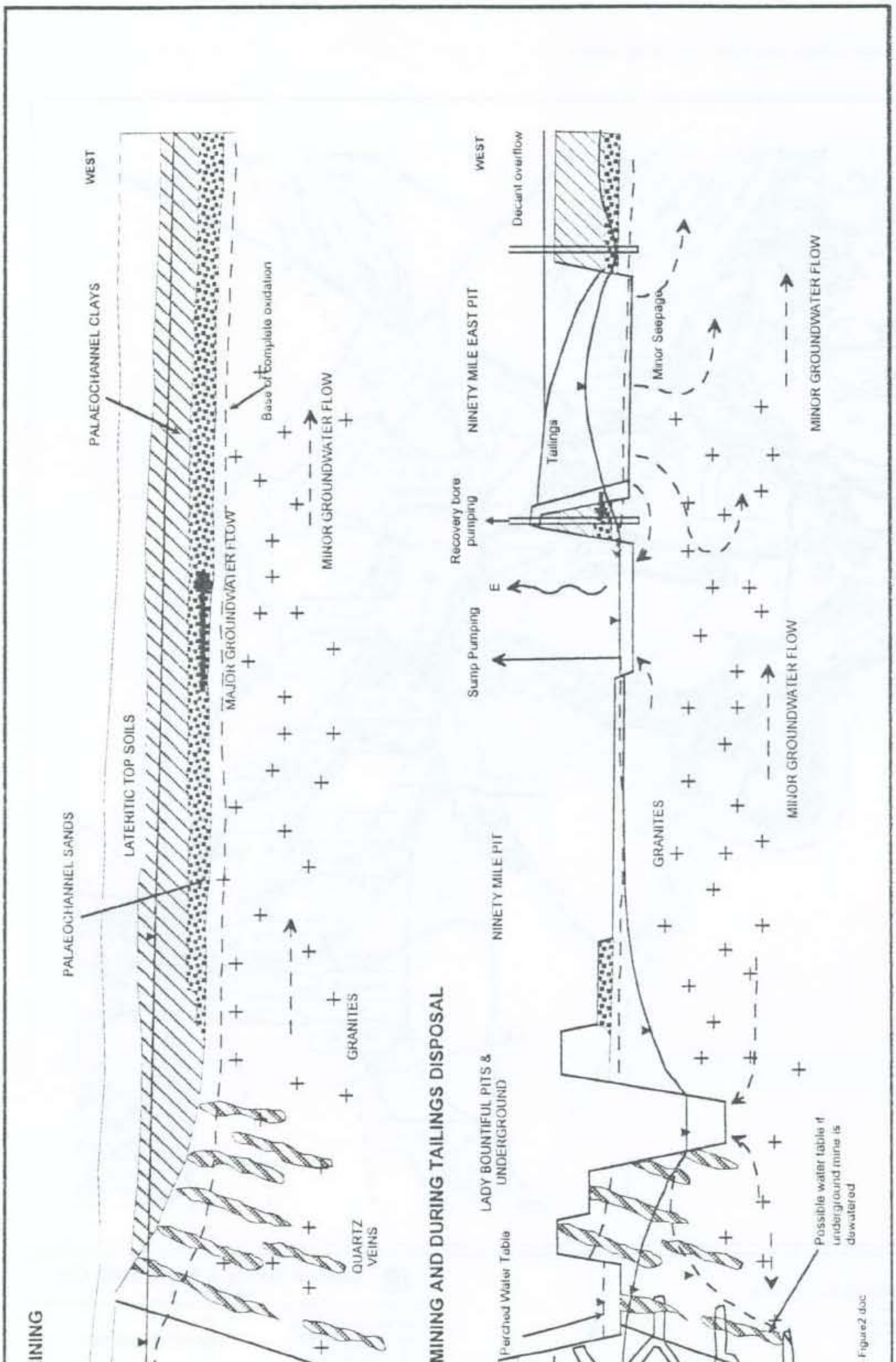
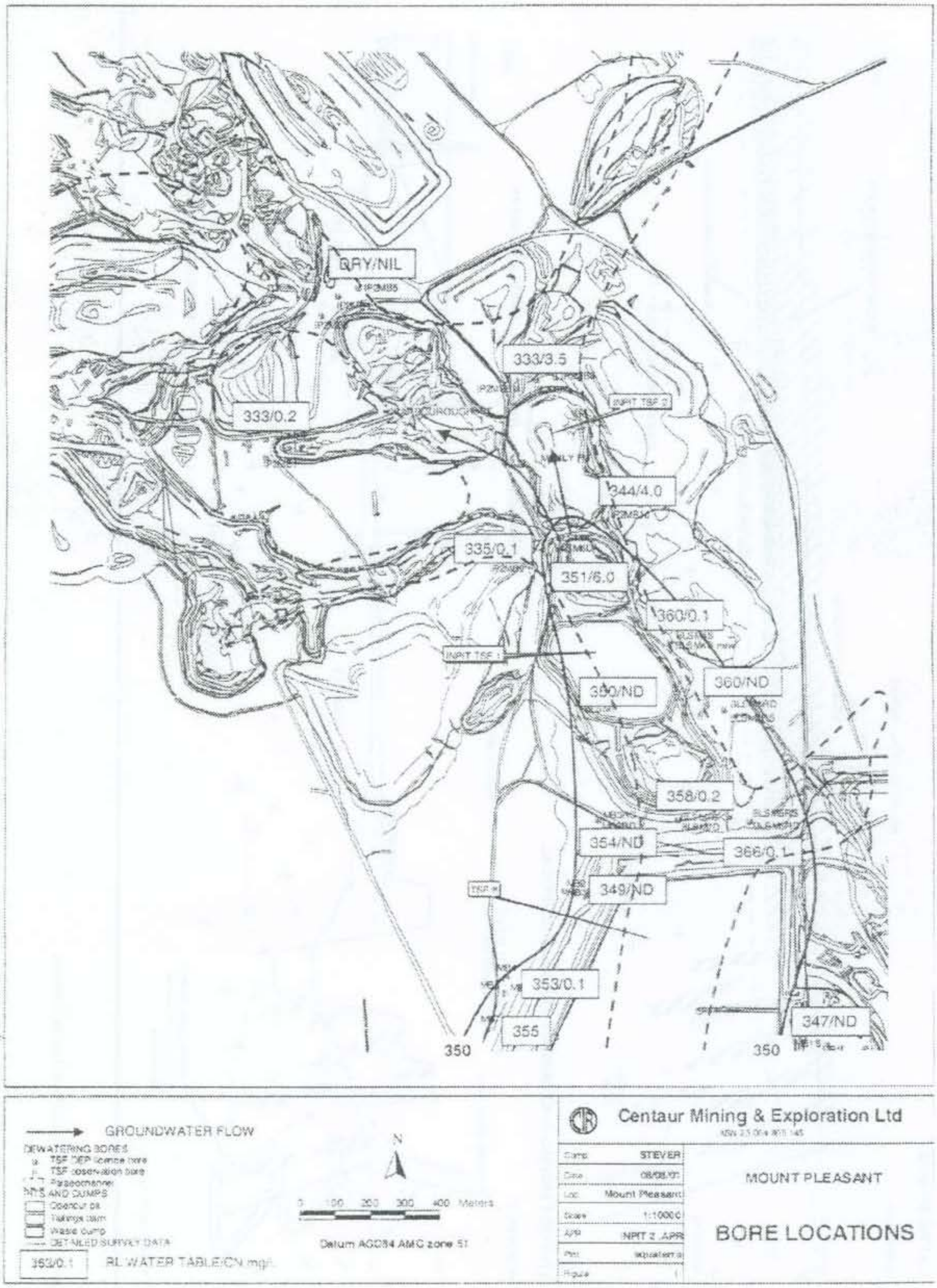


Figure 2: Schematic Hydrogeological Sections

Figure 3: Tailings Storage Area Bore Monitoring Results



4.2.2 Construction

Construction of the Inpit TSF2 system was completed in August 2001. Construction only required minor earthworks and civil construction works at the pits themselves. Most of the work (and cost) involved the installation and bunding of the tailings disposal and decant return pipelines to/from the plant.

Key features of the construction of the Inpit TSF2 system include:

- Roller compacted clayey mine waste linings to the upstream walls of Scarborough Pit.
- Installation of monitor/recovery in locations largely defined by the presence of, and course of the paleochannels.
- All the bores were equipped with Air-Well recovery pumping systems.

The presence of the paleochannels, which act as preferred flow pathways, meant that the number and distribution of bores could be restricted to key areas. It would have been possible to cover the potential exit flow paths with as little as four new bores, although ten new bores were installed to provide the additional security of overlapping coverage and backup. Eight bores were installed at the upstream ends of Inpit TSF2, three bores each at the upstream paleochannel ends of Scarborough and Manly Pits, and two bores installed into weathered basement at the western extremity of an arm of Scarborough Pit. Two bores were installed on the downstream paleochannel end of Manly Pit, one bore between Manly and NME Pits and the other at the southeastern end of Manly Pit.

The costs of earthworks and installation of bores and pumps was around $300,000. By comparison the estimated cost of earthworks and monitoring/recovery systems for the alternative TSF option at Mt Pleasant (above ground ring dyke structure) was estimated to be around $2.5 million.

4.2.3 Operation

Inpit TSF2 was commissioned in September 2001 with spigotted tailings deposition commencing from the downstream end of Manly Pit. Prior to commissioning, several rounds of baseline monitoring of the new monitor/recovery bores were carried out. The results showed the presence of some TSF seepage from the Inpit TSF1 system extending to the upstream end of Manly Pit and the western arm of Scarborough Pit. Bores at the upstream end of Scarborough Pit were dry. Figure 3 shows an interpreted plot of water table contours and WAD cyanide concentrations in groundwater prior to the commencement of tailings deposition into Inpit TSF2.

Following commencement of tailings disposal, water level rises and increases in some water quality parameters in the bores at the upstream and downstream ends of Manly Pit indicated the arrival of seepage from the decant pool (of open water that developed upstream of the tailings "beach") via the paleochannel sediments.

Some minor water level fluctuations were also apparent in the bores at the end of the western arm of Scarborough Pit. However, there were no corresponding rises in the water quality parameters and it is interpreted that the water level fluctuations more reflect variations in recovery pumping rates than the appearance of additional seepage.

The bores at the upstream paleochannel end of Scarborough Pit remained dry.

The Inpit TSF2 system was shut down when the plant was shut down in January 2002, when the Mt Pleasant Operations were acquired by Goldfields Limited (now Aurion Gold Limited) and the processing of Mt Pleasant ores was transferred to the Paddington Plant. The recovery bores remain in operation (this will be reviewed in late 2002).

5. CONCLUSIONS

5.1 The Mt Pleasant Story

Despite its very brief operating history the performance of the Inpit TSF2 system, together with the performance of the Inpit TSF1 system before the tailing deposition went above ground, demonstrates the advantages of inpit tailings deposition into paleochannel pits. These are:

5.1.1 Capital Cost

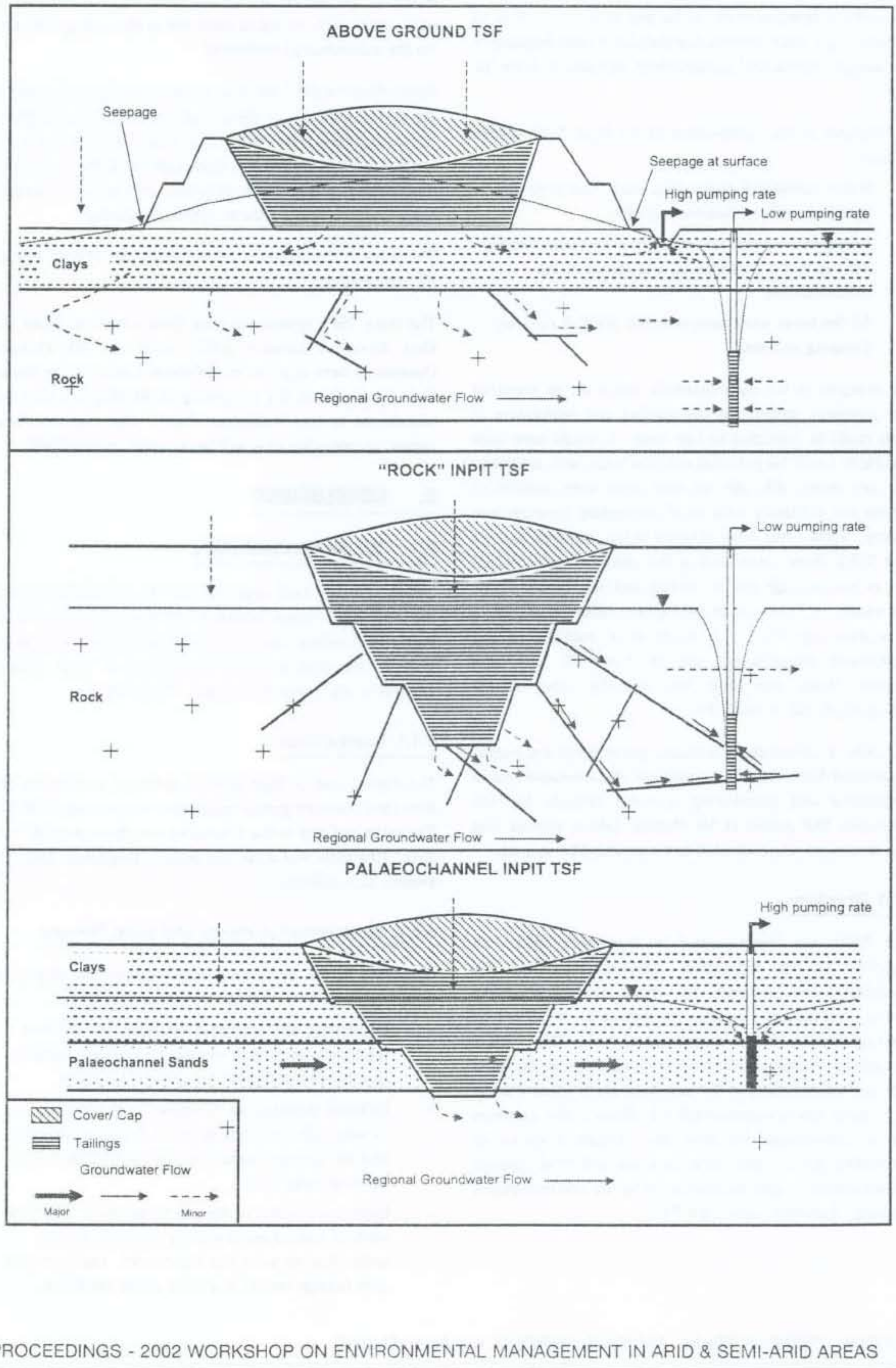
The capital cost of Inpit TSF2 in terms of earthworks and bore (and recovery pump) installation was around $300,000. The estimated cost of the alternative (an above ground, "ring dyke" structure) was some one order of magnitude higher at around $2.5 million.

5.1.2 Environmental Impact and Mine Closure

Compared to the alternative (above ground structure) the Inpit TSF2 system provided several key advantages:

- No residual above ground structure that requires significant shaping to provide longer-term stability and incorporation into the general landform.
- Reduced potential for "flooding" of the surface due to water table mounding, as the decant pond level and any phreatic surface within the tailings will be below ground level.
- Improved stability of the pits themselves. The final voids of paleochannel pits are generally far less stable than those of pits into "rock". Infilling these with tailings results in a more stable landform.

Figure 4: Schematic Comparison of TSF Options



5.1.3 Environmental Control

The major advantage that tailings disposal to a paleochannel inpit system provides is that it has a naturally occurring local/regional underdrainage system that is geologically stable. This allows for confident short-term and long-term prediction of seepage pathways and location of seepage recovery systems.

At Mt Pleasant, the paleochannel downstream of the Inpit (and above ground) TSFs is completely cut by the Quarters Pit. This then restricts downstream migration of any seepage. At present, residual seepage from the paleochannel sediments into Quarters Pit either evaporates from the pit face or is removed by sump pumping. In the longer-term, the pit will become a groundwater sink and any seepage will be largely evaporated from the surface of the pit lake that will eventually form.

5.2 Paleochannel Inpit TSFs in General

The advantages of inpit TSFs in general over above ground structures has been the subject of previous GLRG presentations (eg Lane, 2000) and are also highlighted by the Mt Pleasant experience. Inpit TSFs provide for low cost, environmentally stable long term repositories for mine tailings. Where the pits intersect paleochannels sequences, there is additional environmental benefit in being able to more reliably predict and/or recover any seepage from the tailings mass while also providing an environmentally sound closure strategy for [potentially unstable final voids.

These advantages are summarised in the schematic sections through alternative TSFs in Figure 4.

5.3 The Future

AurionGold is planning for the development of several new Inpit TSFs at Paddington (Panglo Pit) and Kanowna Belle (QED Pits). The Panglo Pit intersects both paleochannel sediments and rock at depth, while the QED Pits are primarily paleochannel pits.

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IMPACT OF SEEPAGE AND RUNOFF ON CLOSURE OF TAILINGS STORAGE FACILITIES IN THE KALGOORLIE REGION

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INTRODUCTION

The paper covers a number of issues that control the impact of seepage and runoff on closure of Tailings Storage Facilities (TSFs) in the Kalgoorlie mining region. These include the moisture state of the tailings, their shear strength controlling their ability to support a cover, the presence or absence of a cover, and the potential for erosion of the containment walls.

The climate of the Kalgoorlie region is arid, with a mean annual rainfall of 270 mm, a mean annual pan evaporation of 2,630 mm, and temperatures that range between a mean maximum daily temperature of 33.6˚C in January and a mean minimum daily temperature of 4.8˚C in July. Mean relative humidity varies between 58% at 9 am and 35% at 3 pm. The climate is highly variable, with the highest recorded monthly rainfall (308 mm in February, associated with cyclonic activity) exceeding the mean annual rainfall, and zero rainfall having been recorded in most months. The highest recorded daily rainfall was 178 mm, in the month of February. The last five years have recorded well above average rainfalls, of about 350 mm.

Tailings moisture state

Figure 1 shows schematic pore water pressure profiles with depth within a body of tailings. The straight line plot above the watertable represents a *hydrostatic* or *no-flow* condition (Murray Fredlund, May 2000), where the pore water suction above the watertable balances the positive pore water pressure below the watertable. For a particular body of tailings under constant climatic conditions, the pore water pressure profile will approach (hydrostatic) equilibrium, but will become "*wet*" or "*dry*" of hydrostatic if unbalanced by net infiltration or net evaporation, respectively. Net infiltration will produce downward flow and a rise in the watertable, while net evaporation will produce upward flow and a lowering of the watertable. As climatic conditions revert to the long-term average, the flow induced will cause the system to return to (hydrostatic) equilibrium.

By defining the *moisture state* of a body of tailings at a given point in time, including the location of the watertable, it can be determined whether net infiltration or net evaporation is occurring, and hence the need for engineering controls. The moisture state of the tailings may be established by measuring the profile of matrix suction above the watertable. Alternatively, the moisture content may be measured and the suction inferred from a Soil Water Characteristic Curve for the particular tailings, under drying or re-wetting conditions, as the case may be.

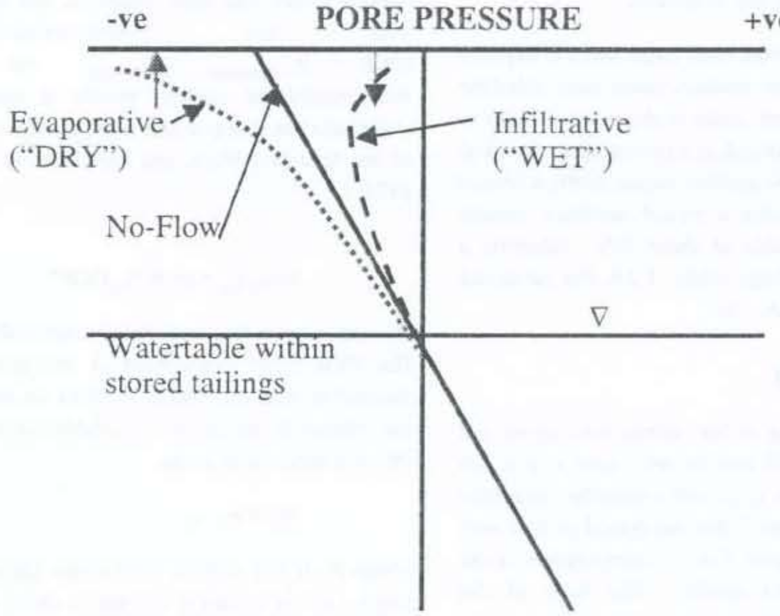


Figure 1: Hydrostatic (no-flow) condition

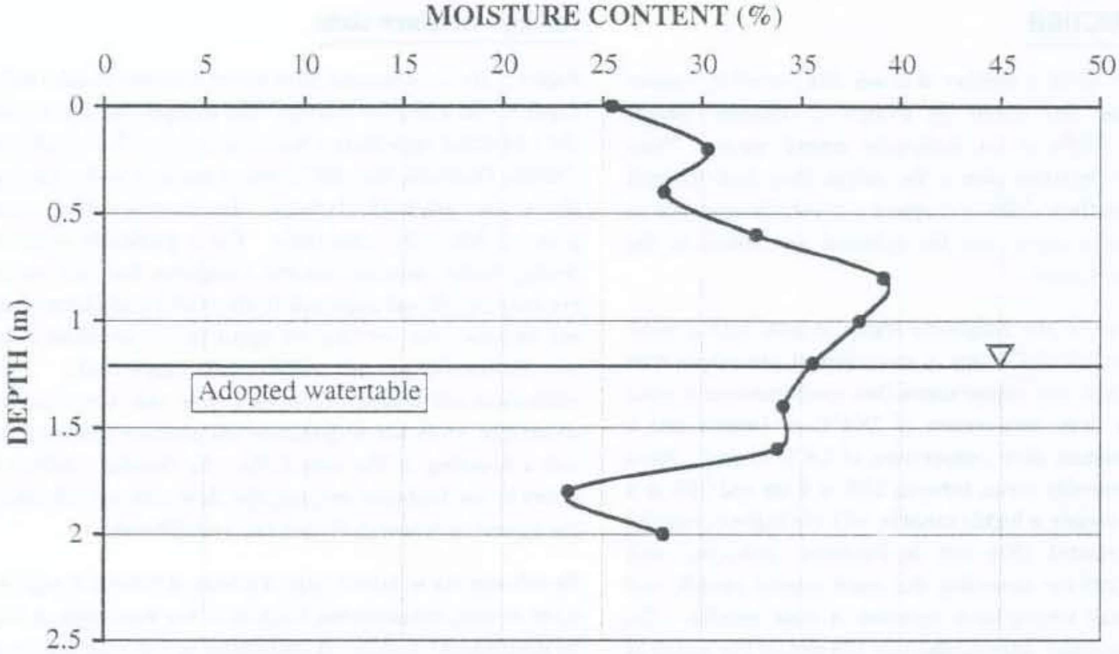


Figure 2: Typical tailings moisture content profile with depth

In the arid Kalgoorlie region, the watertable mound within the tailings will drop after operation of the facility has ceased. It may then be possible to retain all incident rainfall on the top surface of the TSF, whether or not it is covered, to take advantage of surface evaporation, with no ongoing seepage. This would obviate the need for expensive and potentially erodable drop down structures to handle runoff. If a vegetative cover can be established over the tailings, transpiration by vegetation will extract moisture from the tailings and further depress the watertable.

Tailings samples collected from hand auger holes in deposits of different age and different moisture states were tested for gravimetric moisture content (ratio of the mass of water to the mass of dry solids, expressed as a percentage). A typical plot of gravimetric moisture content versus depth is shown on Figure 2, which indicates a typical moisture content below the adopted watertable of about 30%. Adopting a specific gravity for the tailings solids of 2.8, the calculated wet density is about 20.0 kN / m^3.

Tailings shear strength

Vane shear strength testing of the tailings was carried out using a 130 mm long by 65 mm diameter vane at 200 mm depth intervals. Both the peak and remoulded strengths were determined, with Figure 3 showing typical profiles with depth. Also shown on Figure 3 is an interpretation of the peak vane shear strength profile. The basis of the interpretation is the ratio of the shear strength τ to the vertical effective stress $\sigma v'$, given by (Wroth, 1974)

$$\tau/\sigma_v' = \text{a constant} \quad (1)$$

The constant of proportionality in Equation (1) depends on the degree of overconsolidation or stress history of the tailings profile. For normally consolidated (nc) tailings, which have never been subjected to a higher effective stress than that currently applied, the constant is typically about 0.25. An example of a normally consolidated tailings profile is one which has always been below water. For overconsolidated (oc) tailings, which have a current vertical effective stress of less than the maximum to which the tailings profile has been subjected, the constant increases with the overconsolidation ratio ($OCR = \sigma_{v\ maximum}' / \sigma_{v\ current}'$). An example of an overconsolidated tailings profile is one in which the watertable has dropped and subsequently risen on rewetting of the tailings surface, and Equation (1) becomes (Wroth, 1974)

$$(\tau/\sigma_v')_{oc} = (\tau/\sigma_v')_{nc}.OCR^m \quad (2)$$

The exponent m has been found empirically to be about 0.8. The OCR is at a maximum at the ground surface and diminishes with increasing depth to be unity at and below the historical maximum watertable depth. The vertical effective stress is given by

$$\sigma_v' = \sigma_v - u \quad (3)$$

where σ_v is the vertical total stress (given at a particular depth z by the weight of everything above that depth) and u is the pore water pressure. Under saturated conditions (that is, below the watertable), Equation (3) becomes

$$\sigma_v' = \gamma'.z = (\gamma_t - \gamma_w).z \quad (4)$$

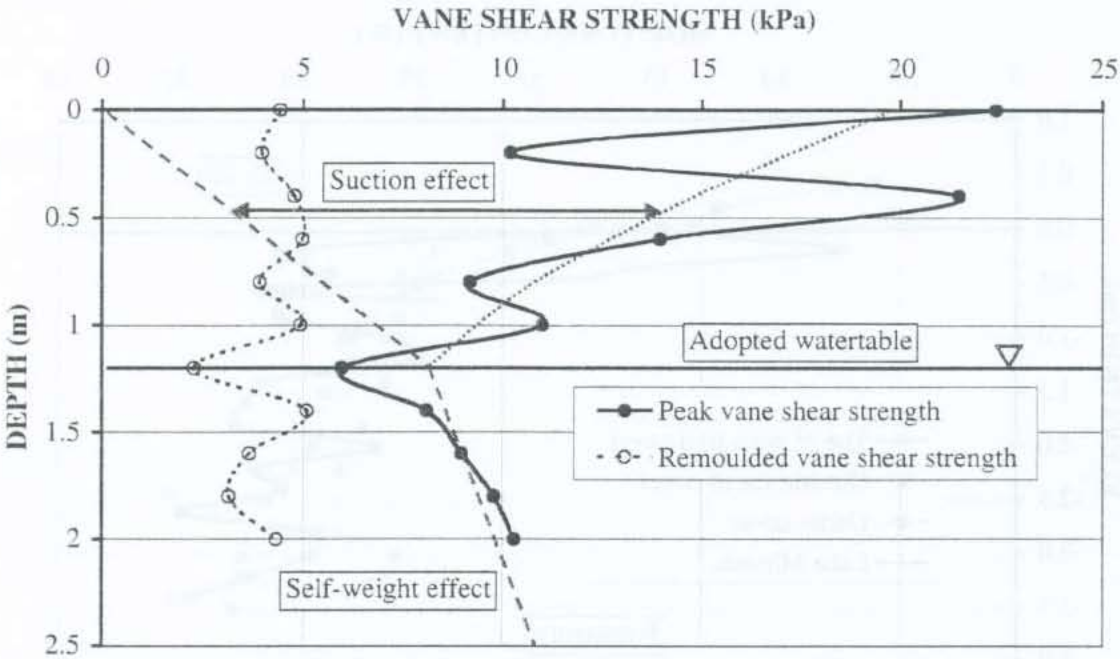


Figure 3: Typical tailings vane shear strength profiles with depth

where γ' is the effective unit weight of the tailings, γ_t is the total unit weight of the tailings (calculated to be 20.0 kN/m^3) and γ_w is the unit weight of water (= 9.81 kN/m^3). Under unsaturated (or partially saturated) conditions (that is, above the watertable), Equation (3) becomes

$$\sigma_v' = \gamma_t.z - (-u) \quad (5)$$

where -u is the negative pore water pressure or matrix suction of the unsaturated tailings profile, that is, the sum of the self-weight induced vertical effective stress and the suction-induced vertical effective stress. The matrix suction increases from zero at the watertable to increasingly large values towards the unsaturated tailings surface.

It is difficult to determine the OCR with precision. For the peak strength profile shown on Figure 3, a good fit is obtained using an average value for $(\tau/\sigma_v')_{oc}$ of 0.33 above the adopted watertable. This implies an average value for OCR above the watertable of 1.42, increasing from unity at the watertable and below, to a value of about 3 at the tailings surface.

Characterising covers on tailings storage facilities

Tailings can contain a significant volume of entrained water on closure, with the potential for recharge through ongoing rainfall infiltration, and the potential for an upward hydraulic gradient due to evaporation and any transpiration. In the arid climate of the Kalgoorlie mining region, evaporation is expected to dominate. The process water used is often hypersaline, resulting in the expectation that the saline tailings will be covered to facilitate revegetation and to limit rainfall infiltration and / or enhance evaporation.

The success of a conventional cover system is dependent on the extent to which the cover limits the upward evaporation-driven migration of salts from the tailings into the cover. The results of field testing of trial covers on saline tailings to establish the extent of upward migration of salt from the saline tailings into the cover are compared with the results of similar testing on a nearby natural salt pan analogue on Lake Miranda.

The high salt content of the tailings has a number of effects. The formation of a salt crust on the surface of the tailings on evaporative desiccation tends to close off further desiccation, while at the same time limiting dusting. The salt crust also makes revegetation problematic.

Where tailings contain highly saline pore water, a continuous cover will require a capillary break to prevent saline water rising to the vegetation root zone within the cover. An alternative is to construct discrete cover mounds to act as island sanctuaries for vegetation, and to spread rainfall runoff over a large area to facilitate evaporation rather than infiltration. In between the mounds the tailings are left bare. The mounds are limited in areal extent to limit the extent to which the highly saline tailings water will be drawn up into the cover. Infiltrating rainfall will form a fresh water source above the saltine pore water to supply any vegetation on the mound. At the test mine site, various trial covers were constructed over dis-used highly saline tailings in about 9 months before the investigations described. Tailings disposal had ceased about 5 years prior to the cover trials being constructed. The cover trials comprised one main cover measuring about 60 m by 60 m in plan, and a number of smaller covers of the order of 10 m in diameter.

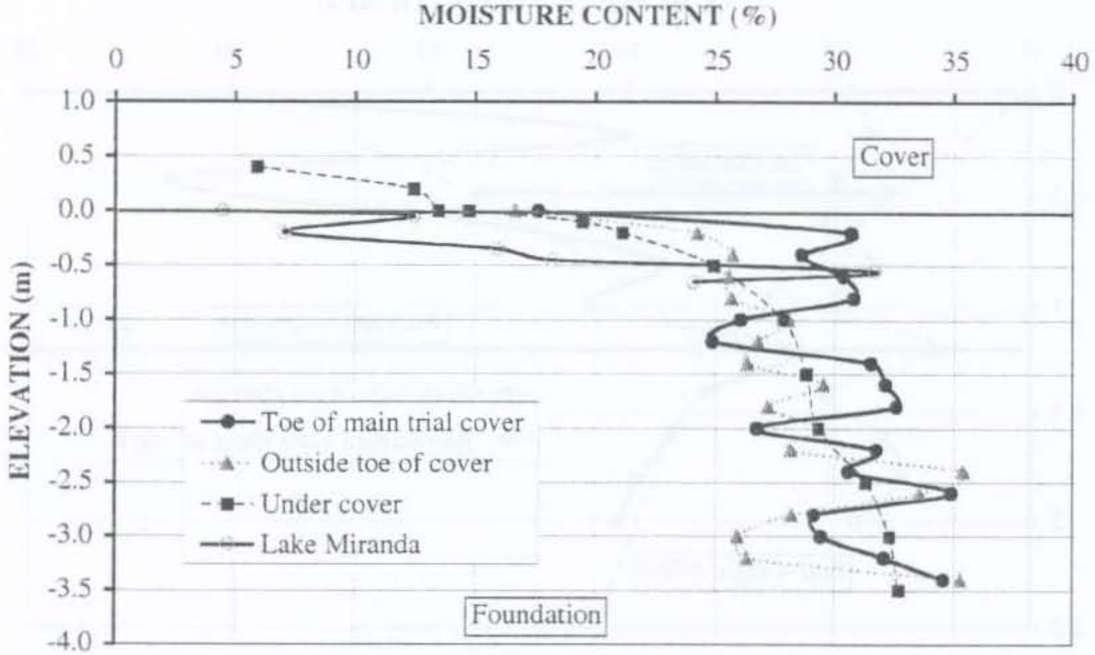


Figure 4: Summary plots of gravimetric moisture content with elevation for main cover trial and Lake Miranda salt pan

The cover thickness varied from 0.4 to 0.8 m, typically comprising a coarse-grained layer of brown, weathered quarry rock, overlain by red quarried "topsoil" of relatively poor quality. The lower coarse-grained layer was intended to serve as a capillary break to limit the upward migration of moisture and the salts it would carry from the tailings. At the time of the investigation, which followed lower than average winter rainfall, only very limited revegetation of the cover surface was evident.

The cover trial testing involved hand augering through the tailings, and into the underlying foundation at 3.2 to 3.8 m below the tailings surface, to obtain closely-spaced samples, and the sampling of the cover materials from the sides of test pits. The moisture content of the recovered samples was determined, and selected samples were subjected to total suction (using a portable psychrometer), and paste pH, Electrical Conductivity (EC) and salinity (Total Dissolved Solids, TDS) testing. The pH, EC and TDS determinations were carried out on a paste formed by adding distilled water to the moist sample in a nominal water (distilled water plus pore water) to dry solids mass ratio of about 5 to 1.

The distilled water had a neutral pH and negligible salinity. As a result, the pH of the samples was not affected by the addition of distilled water. The EC and salinity of the samples were determined on a solids dry mass basis. The amount of distilled water added was sufficient to ensure that all soluble salts on the tailings particles were dissolved, yielding the Total Dissolved Solids. The EC values in µS / cm were almost exactly twice the numerical TDS values in ppm. Similar sampling and testing was carried out on the surface salt crust and underlying soils at the natural salt pan.

Moisture content

Summary plots of the measured gravimetric moisture content with elevation are presented in Figure 4, which shows the profile obtained at the toe of the main trial cover, average profiles outside the toe and beneath the cover, and the profile obtained beneath the natural salt pan. The surfaces of the tailings and of the natural salt pan are located at zero elevation.

Figure 4 reveals a striking similarity between the plots, with a general trend of increasing moisture content with depth, both in the cover and in the underlying tailings, as well as in the natural salt pan sediments. The cover materials and the surface crust of the salt pan, at 5 to 10% moisture content, are much drier than the underlying materials (in the range from 25 to 35% moisture content). The moisture content profile at the toe of the trial has distinctly higher values towards the surface. This results from rainfall runoff from the surrounding tailings surface and the cover both reporting to the toe of the cover.

No watertable was encountered, either within the tailings or underlying foundation, nor within the salt pan sediments. The density of the tailings was not measured, but earlier data suggests that the dry density would be about 1.5 t / m^3, indicating that the degree of saturation of the tailings ranged between about 0.6 just beneath the surface and about 1.0 at the foundation level.

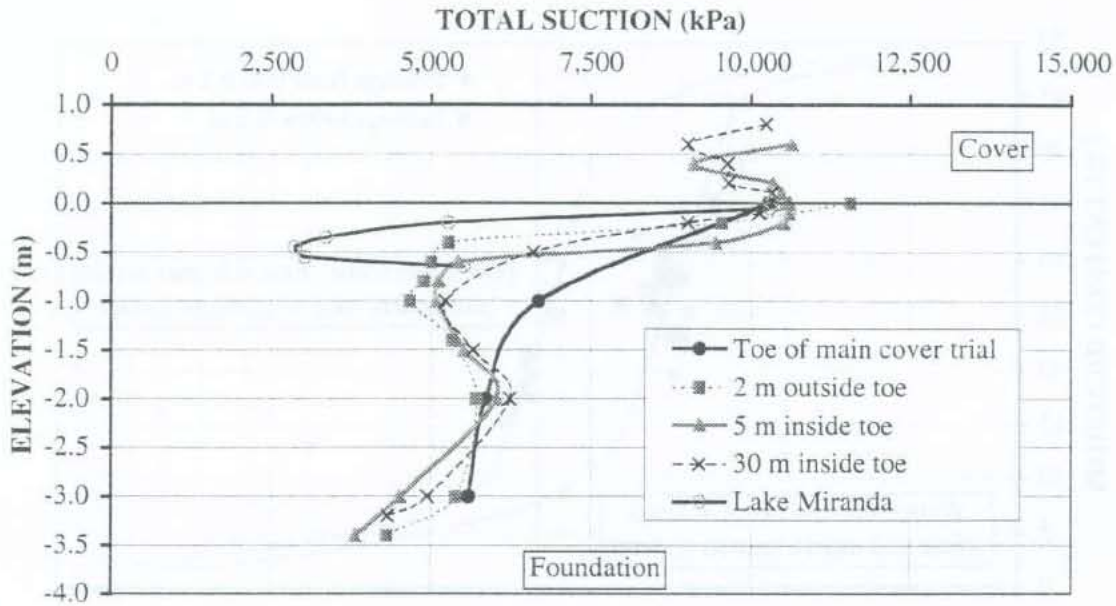


Figure 5: Plots of total suction with elevation for main cover trial and Lake Miranda salt pan

Total suction

Plots of the measured total suctions with elevation are presented in Figure 5, which shows the profile obtained at the toe of the main trial cover, profiles obtained at locations outside and beneath the cover, and the profile obtained beneath the natural salt pan. As with the moisture content profiles, there is a striking similarity between the plots, with relatively high suctions (of the order of 10,000 kPa) being recorded in the cover and near-surface tailings, and in the salt crust overlying the natural salt pan. To put this high total suction in context, it is equivalent to the loading imposed by about 500 m height of fill.

The high total suctions in the cover materials are largely explained by their low moisture content, giving rise to high matrix suctions. On the other hand, the high total suctions in the near-surface tailings and in the natural salt crust are due to salinity-driven high solute suctions and desiccation-driven matrix suctions in combination. Further laboratory testing will be carried out to separate the solute and matrix suction effects.

The total suction-moisture content data for the near-surface tailings (0 to 0.2 m below the surface) are separated from the corresponding data for the tailings below 0.2 m depth on Figure 6.

The near-surface tailings, being drier and more saline due to desiccation effects, have higher solute and matrix suctions, and hence higher total suctions, and plot along a straight log-linear line. The deeper tailings, being wetter and less saline due to the declining effects of desiccation with depth, have lower solute and matrix suctions, and hence lower total suctions. These data plot roughly along a straight log-linear line, although they are scattered due to the changing conditions with depth. Also plotted on Figure 6 are the diagrammatic extrapolations of the full SWCCs for the near-surface and deeper tailings. The actual SWCCs will be determined in the laboratory.

pH

Plots of the measured paste pH with elevation are presented in Figure 7, which shows the profile obtained at the toe of the main trial cover, profiles obtained at locations outside and beneath the cover, and the profile obtained beneath the natural salt pan.

The surface cover materials and the natural salt crust both have an acidic pH of about 4.5, indicating the natural pH state of surface soils in the region. The tailings are alkaline due to the presence of process chemicals, with a pH in the range from 9 to 10. The lower part of the cover and the interface between the foundation and the tailings are also alkaline, with a pH of about 9. Surprisingly, the deeper natural salt pan sediments are also alkaline, with a pH of about 8.

The pH of the tailings reduces towards the foundation and towards the surface, regardless of the presence of a cover. In the lower part of the cover, the pH has risen towards 9, as has the foundation at the interface with the tailings. The fact that the natural salt sediments at depth also have a relatively high pH suggests that this rise in pH below the surface may be a natural phenomenon, rather than being solely due to leaching or evaporation of the alkaline tailings.

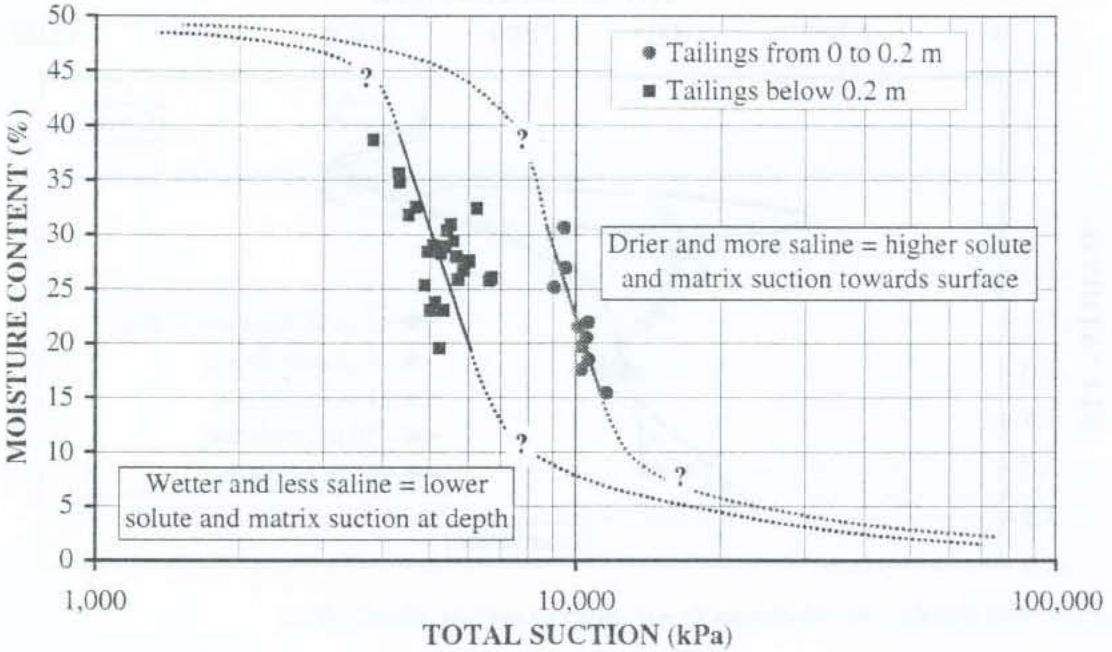


Figure 6: Plots of moisture content versus total suction for main cover trial, including diagrammatic extrapolations of the full Soil Water Characteristic Curves (SWCCs)

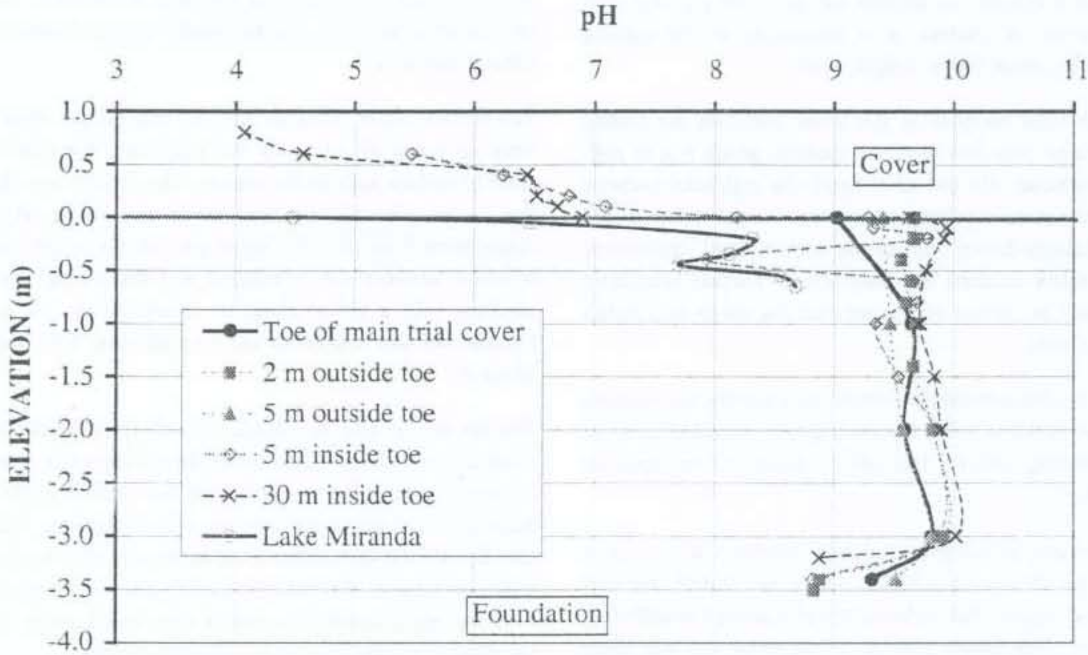


Figure 7: Plots of pH with elevation for main cover trial and Lake Miranda salt pan

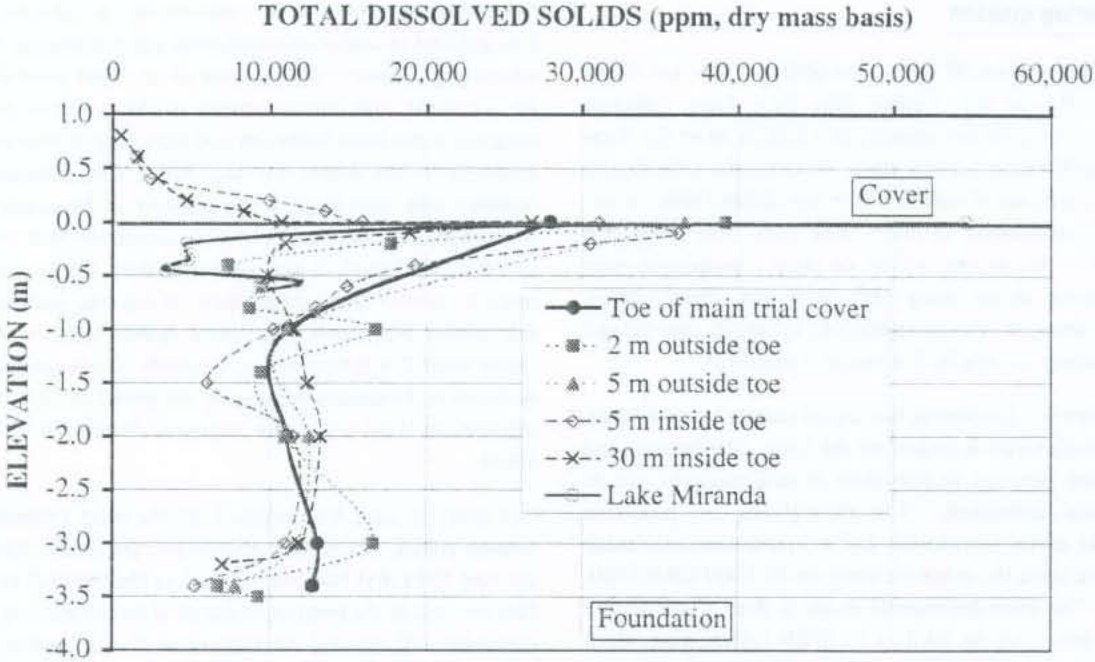


Figure 8 : Plots of total dissolved solids with elevation for main cover trial and Lake Miranda salt pan

Total dissolved solids

Plots of the measured total dissolved solids (TDS), expressed on a dry mass of solids basis, with elevation are presented in Figure 8. This shows the profile obtained at the toe of the main trial cover, profiles obtained at locations outside and beneath the cover, and the profile obtained beneath the natural salt pan.

The maximum TDS of about 55,000 ppm (almost twice the salinity of sea water) was recorded in the natural salt crust, and values approaching this were obtained at the surface of the uncovered tailings.

The effect of the tailings cover was to reduce the salinity of the desiccated surface tailings somewhat. At depth, the tailings had a salinity of about 10,000 ppm, with the underside of the cover and the top of the foundation recording similar values. Between about 0.2 m and 0.5 m depth, the natural salt pan sediments recorded a TDS of about 5000 ppm, sufficiently low to readily support salt-tolerant vegetation found in the region. The salinity recorded in the cover surface soils was low.

This suggests that salts from the tailings have migrated into the foundation somewhat with the seepage that most likely would have occurred during the operation of the tailings storage. Salts from the tailings have also likely migrated into the underside of the cover due to desiccation effects. The leaching of salts into the foundation is likely to have ceased with the cessation of tailings deposition. However, the upward migration of tailings salts into the cover may continue with ongoing or seasonal desiccation. This will be assessed during subsequent field investigations.

Implications for rehabilitation of saline tailings

The natural salt pan of Lake Miranda is capable of supporting an indigenous salt bush *Samphire Halosarcia*, despite the hardness, low moisture content, high suction, low pH and high salinity of the surface salt crust. The germination of this species requires the surface salt crust to be broken. Its sends a tap root down to about 0.1 m below the surface, drawing relatively good quality water from the zone between 0.1 m and 0.5 m depth. The similarity between the tailings and the natural salt pan suggest that this species may well survive in tailings, with the addition of nutrients.

The establishment of a cover comprising a lower capillary break layer overlain by a growth medium layer may well be capable of supporting drought-tolerant indigenous species that are also reasonably salt tolerant.

A combination of salt bush establishment in bare tailings and vegetated discrete cover mounds may well provide a sustainable eco-system on dis-used tailings in the arid Kalgoorlie mining region. The tailings would likely require the addition of fertiliser to overcome the likely lack of nutrients in the tailings. The constructed mounds could act as island sanctuaries for vegetation, and spread rainfall runoff over a large area to facilitate evaporation rather than infiltration. Further research is required to demonstrate that the revegetation of bare saline tailings and cover mounds on saline tailings is both achievable and sustainable in an arid climate.

Monitoring erosion

Monitoring erosion off steep, unvegetated TSF outer slopes is difficult and few reliable data have been gathered. Difficulties include the isolation of a section down the slope from which measurements are to be taken, the collection of the high volumes of sediment from unvegetated mine slopes, and the remoteness of many mine sites. An alternative method of monitoring erosion on steep, unvegetated mine and natural slopes using high resolution, digital stereo-photogrammetry, and its application to largely unvegetated mine tailings storage facility slopes is described.

A baseline for positioning the digital camera is established, and a single target is located on the slope. The baseline and target are surveyed so that their relative positions can be accurately determined. The photographs are processed using the survey information, and a three-dimensional image produced using the computer program 3D MAPPER (CSIRO, 2000). The three-dimensional image is then imported to a topographic program such as SURFER (1999), from which the volume of erosion gullies can be determined. Subsequent photographs taken of the same slope, from the same baseline, enable the erosion over time to be monitored. Close-up photographs of the surface texture of the slope may be processed using the proprietary computer program Split-Desktop giving an estimate of the particle size distribution of the surface particles, but results are not reported here.

The first-pass application of the stereo-photogrammetric method to the measurement of gully erosion loss from steep, unvegetated TSF slopes is compared with that from an adjacent steep natural slope, known as the "Breakaways".

Stereo-photogrammetry is essentially a process of triangulation of angles measured from a pair of images. With reference to Figure 9, the position of an object point P can be calculated from measurements of the positions of the image(s) of the point in the left and right images (that is, the positions of the points PL and PR). This information, together with knowledge of the position of the camera for each image, the orientation of the camera for each image, and the focal length of the camera, enables the position in space of point P to be determined. If the true positions of the camera are known, the actual spatial position of the object point P is determined. Conversely, if only the relative positions of the camera are known, the spatial position of the object point P relative to the camera is determined (CSIRO, 2000).

The study to date has focussed on the most pronounced erosion gullies, which were observed in the outer slopes of dis-used TSFs that had been capped to shed rainfall runoff. This resulted in the ponding of runoff at low points along the perimeter wall, causing overtopping of the wall and erosion gullying of the outer face. The baselines were generally established beyond the toes of the outer slopes, but some were also established at the crest to study sediment build up beyond the toe of the wall, and mid-slope to better capture the gullies.

The image positions were surveyed for x, y and z - co-ordinates to an accuracy of 0.5 cm in the survey datum adopted by the mine, with every effort being made to preserve the staked baselines to allow future repeat studies and experiments. Digital photogrammetry can achieve 1 to 2 cm precision at a measurement range of 50 m (CSIRO, 2001).

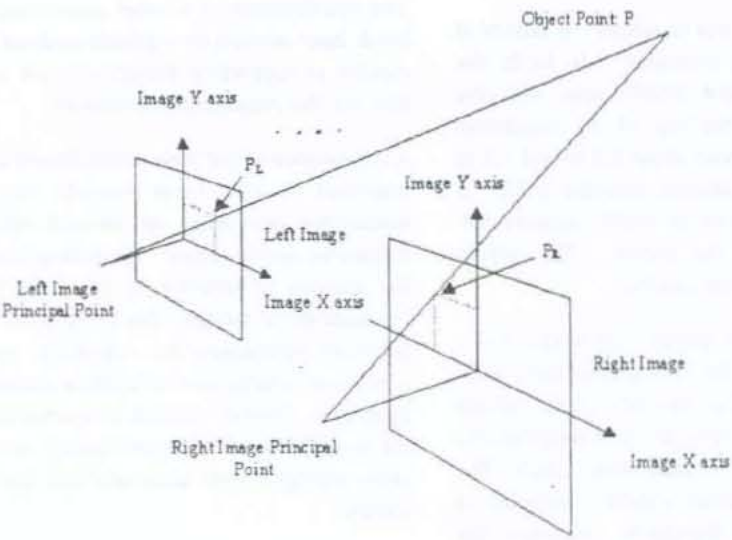


Figure 9: Geometry for the determination of the position of a point in object space (CSIRO, 2000)

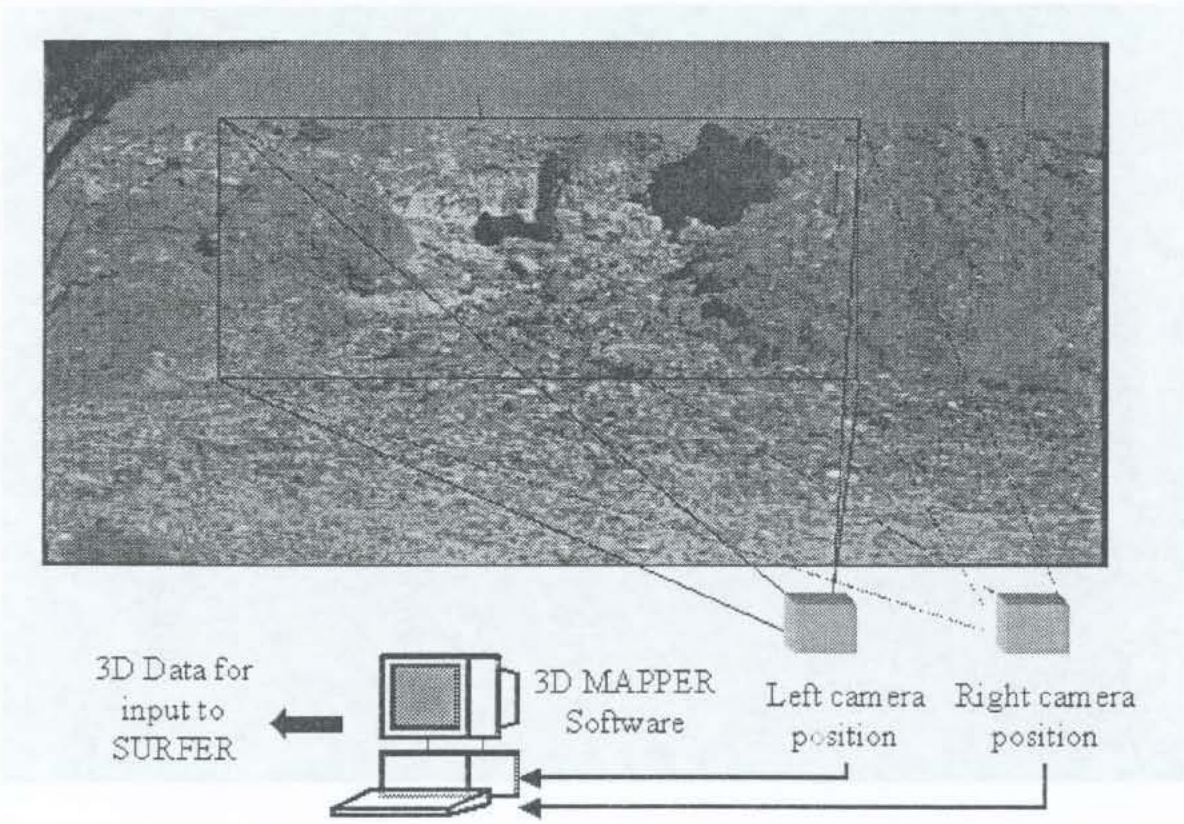


Figure 10: Erosion measurement and monitoring using stereo-photogrammetry

The stereo-photographs of the erosion gullies were processed using CSIRO's proprietary computer program 3D MAPPER to produce three-dimensional images, from which x, y, z - co-ordinates were derived. The co-ordinates were then imported into the commercial contouring and three-dimensional surface mapping computer program SURFER (1999) to enable estimates to be made of the total amount of erosion that the gullies had experienced. A simplistic chart representing this methodology is presented on Figure 10.

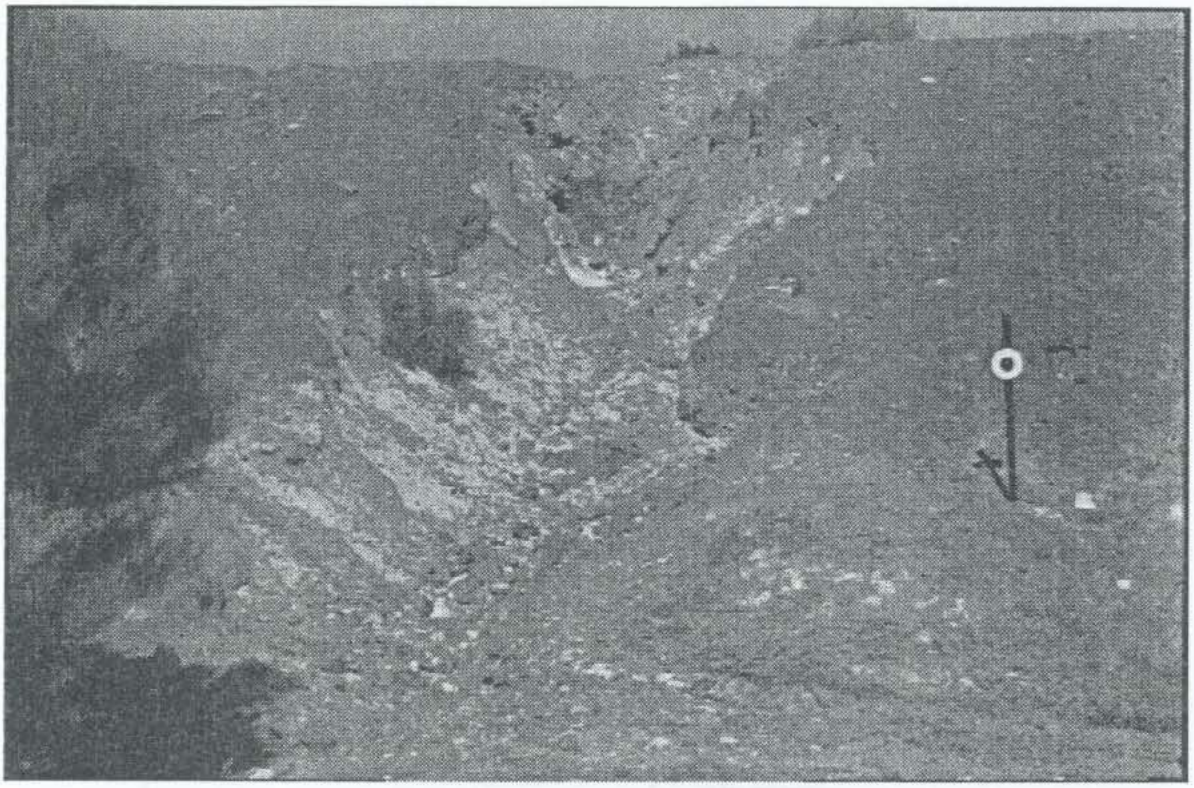
The gully erosion volumes calculated from the processing of these first pass images are necessarily approximate only, since the as-constructed slope profile and age of the slopes were not known precisely. Subsequent images taken from the same baselines will allow accurate estimates to be made of the erosion loss due to known rainfall volumes and intensities.

The initial processing results from 3D Mapper indicated that the digital stereo-photogrammetry technique and software are capable of accurately determining the three-dimensional profile of an eroding slope. Figures 11 to 14 each present corrected images (that is, the original digital images with distortion removed), and the SURFER wireframe plot produced from the 3D Mapper data points, for TSF A (mid-north face), TSF B (south and east faces), and the "Breakaways", respectively.

The estimated total erosion losses for all gullies investigated are presented in Table 1. Figures 11 to 14 and the results in Table 1 show that the erosion mechanisms are similar for the unvegetated TSF and natural slopes. However, the duration of erosion loss to date is obviously much greater for the natural slope, and the catchments feeding the slope, the height of the slope, and the erodability of the face materials vary. Data on these parameters are being collected.

Table 1: Results from stereo-photogrammetric investigation of gully erosion loss

LOCATION	ESTIMATED TOTAL EROSION LOSS (m^3)
TSF A (mid-north face)	21.6
TSF B (south face)	391
TSF B (east face)	139
"Breakaways" natural analogue	1315



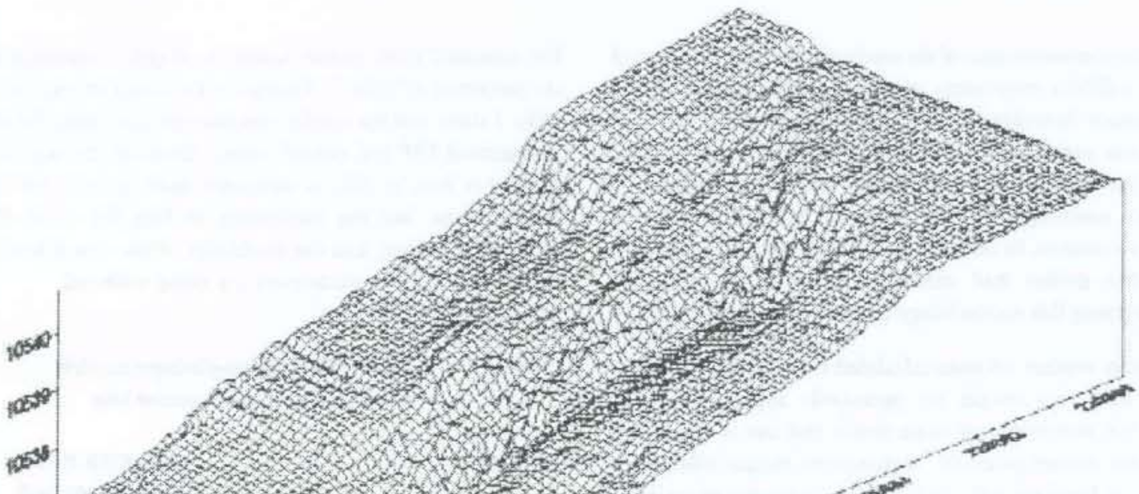


Figure 11: TSF A (mid-north face) corrected left-hand image and SURFER wireframe plot

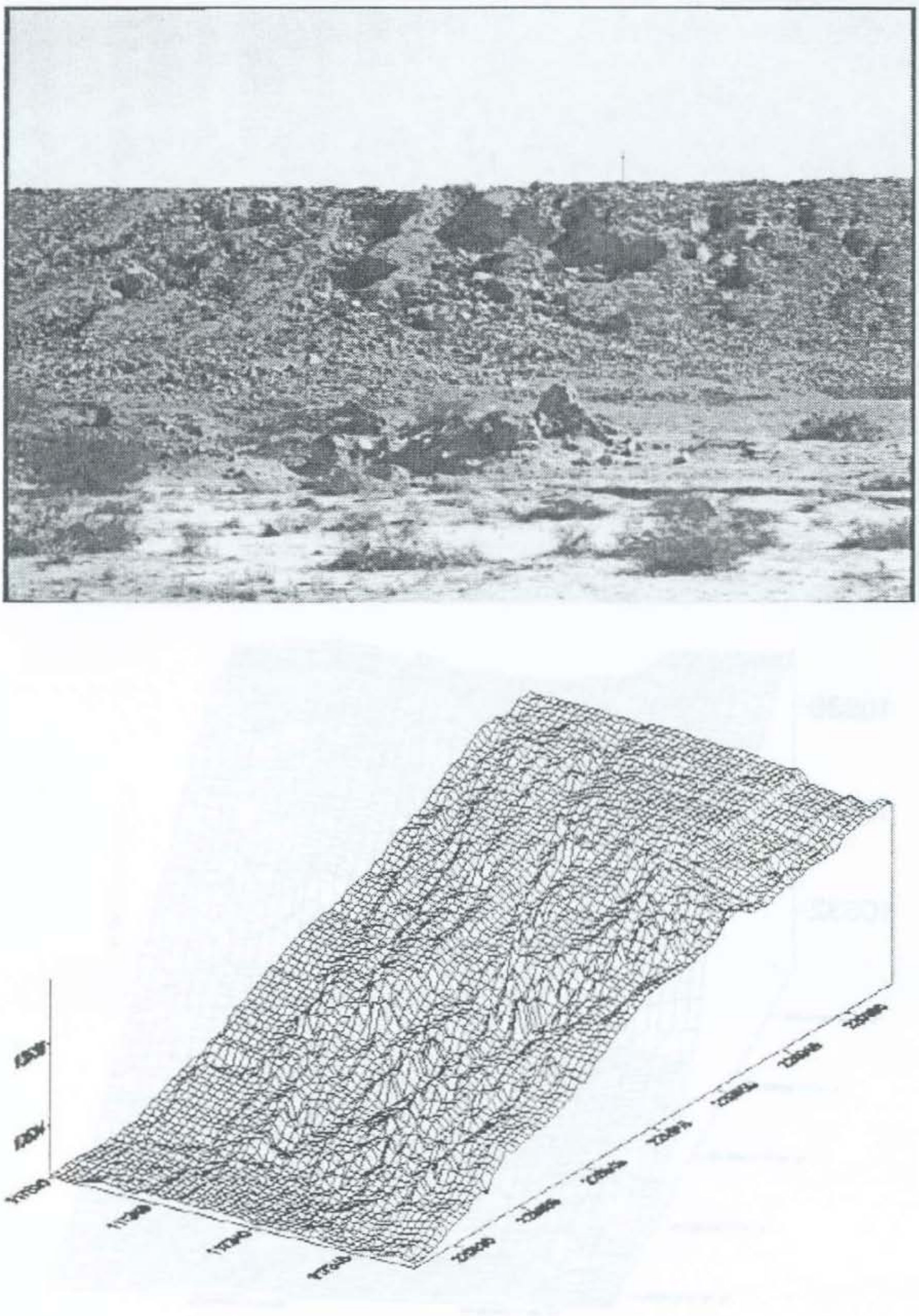


Figure 12: TSF B (south face) corrected right-hand image and SURFER wireframe plot

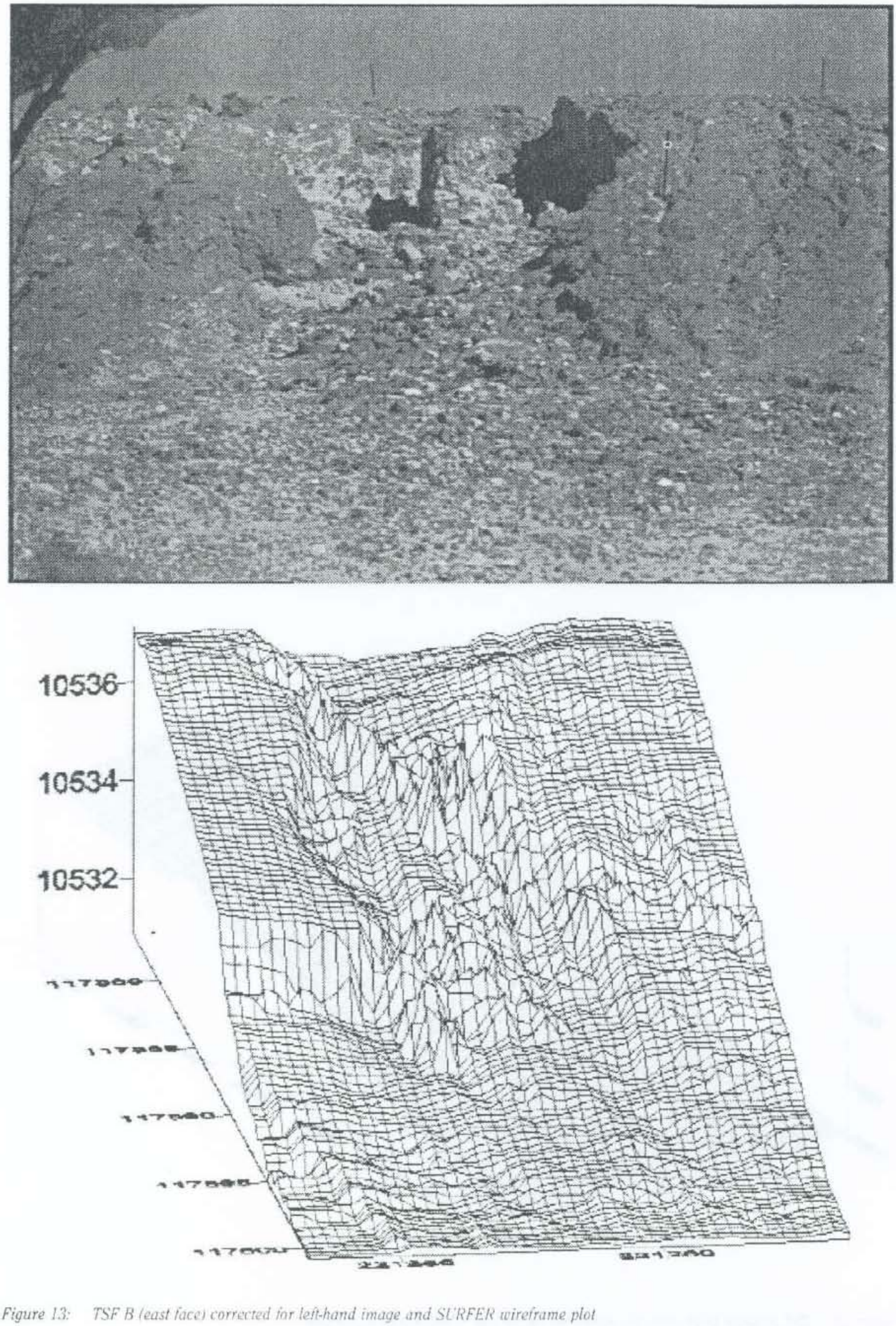
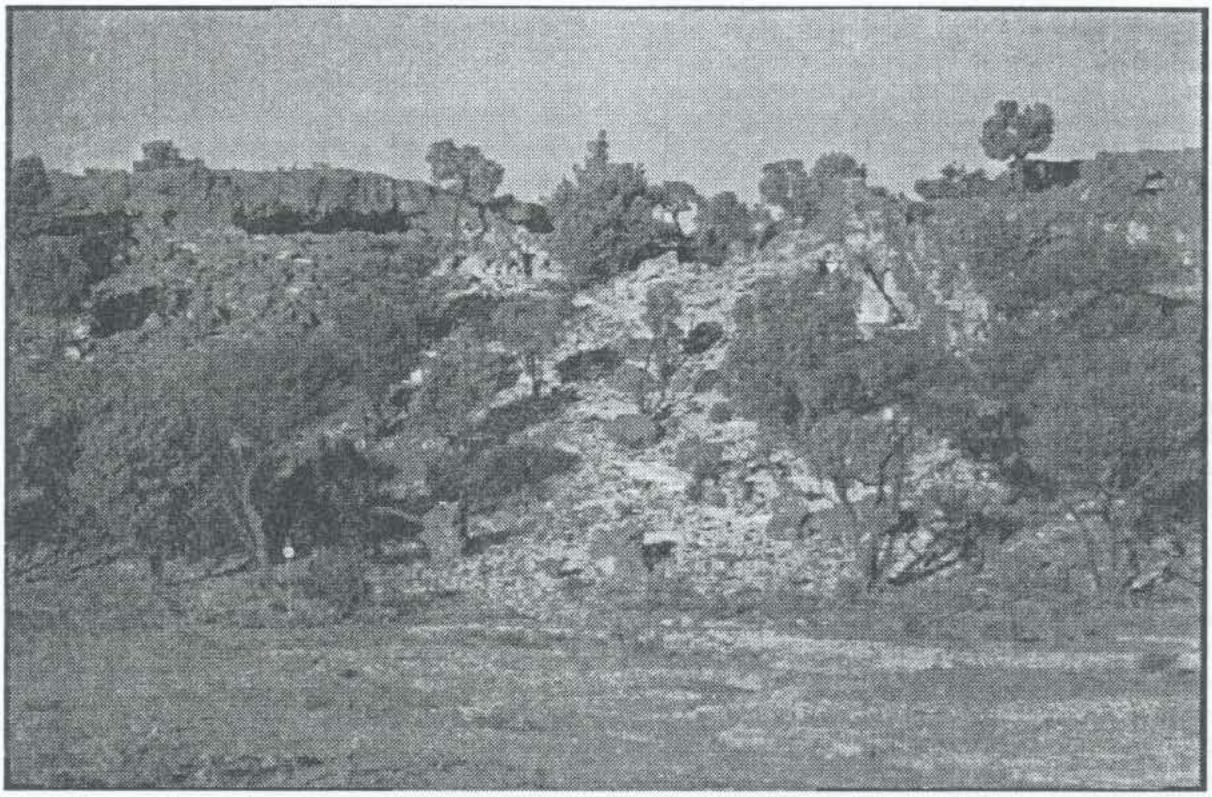


Figure 13: TSF B (east face) corrected for left-hand image and SURFER wireframe plot



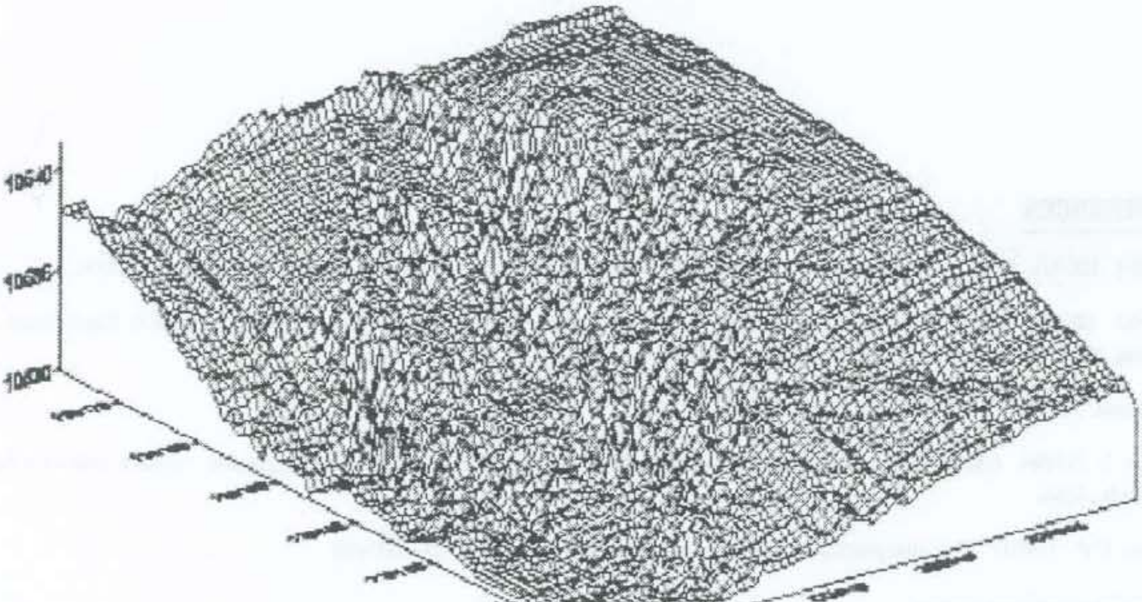


Figure 14: "Breakaways" natural analogue corrected right-hand image and SURFER wireframe plot

Future monitoring of both slope types will provide an indication of whether or not the rates of erosion loss are similar for the natural and TSF slopes, and whether they are constant or variable. Erosion rates will obviously vary with the different physical and chemical parameters and age of the different surface materials, and with slope geometry and the extent of the catchment feeding the slopes.

Future erosion loss measurements will follow significant rainfall events, and various remedial works will be monitored to test their success in controlling erosion rates and volumes. The same baselines will be used and the later stereo-photographs compared with the first to establish the precise amount and location of gully erosion occurring at each site, as a function of the amount and intensity of rainfall, and the elapsed time.

The paper describes a method of monitoring erosion on steep, unvegetated mine tailings facility and natural slopes using high-resolution digital stereo-photogrammetry. Automated digital photogrammetry can deliver 3D data within minutes of acquiring the images and is therefore well suited to such tasks as the large scale mapping of erodable TSF slopes. The digital stereo-photogrammetric techniques applied to the study of rainfall runoff-induced erosion of TSFs are not dependent on the poorly suited agriculturally based methods, and lend themselves to the accurate estimation of large volume erosion loss from steep slopes, that would otherwise be very difficult to monitor. They are also applicable to the study of the erosion of waste rock dump slopes and the degradation over time of dis-used open pit slopes.

CONCLUSIONS

To fully describe the moisture state of tailings as it may impact the environment, the direction of moisture flow must be determined. This can be achieved by measuring matrix suctions in the tailings above the watertable.

The results of field and laboratory investigations highlight the similarity between saline tailings and natural salt pan systems. This provides some reassurance that saline tailings in an arid climate may be rehabilitated to an acceptable state, somewhat akin to an elevated salt pan.

A promising method for remotely monitoring the erosion loss from steep, unvegetated TSF outer slopes, involving high resolution, digital stereo-photography, has been described. The mimicking of TSFs by natural, physical and chemical analogues is crucial to their successful rehabilitation, particularly under arid climatic conditions.

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PROCEEDINGS - DAY 2

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THURSDAY 30TH MAY 2002

9:00am	Depart WMC Conference Centre
9:40am	Kundana Operations
	- Raleigh Pit
	- Moonbeam rock/veg mulch trials
	- Strzelecki backfill operations
	- TSF #3
11:00am	Mt Pleasant Operations
	- Inpit TSF #1/2
	- Lady Bountiful Area
12:00am	Broad Arrow Tavern - Lunch
	- Sponsored by Rainstorm
1:30pm	Paddington Operations
	- Wendy Gully
	- Lone Oak/Deep Leads
3:00pm	Kanowna Belle Operations
	- Dolocrete/AsO_3 discussion
	- SO_2 management
4:30pm	Kalgoorlie

2002 Workshop on Environmental Management in Arid and Semi-Arid Areas

PROCEEDINGS - DAY 3

SESSION 1 - WATER MANAGEMENT & MONITORING
SESSION 2 - APPROACHES TO REHABILITATION
SESSION 3 - COMPLETION CRITERIA & CLOSURE

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WATER DISPOSAL TO SALT LAKES: DISCHARGE OPTIONS AND CONSEQUENCES

Melanie Ward
OUTBACK ECOLOGY SERVICES

ABSTRACT

Since the gold rushes of the 1800's, gold mining has undergone progressive development in Western Australia. Most gold operations are concentrated in the semi-arid and arid areas of the state, and have developed from single man shafts to significant-sized operations. Salt lakes have become increasingly important to mining operations in recent years, with a number of operations located adjacent to or within these natural water bodies. Salt lakes may provide a source of ore, a facility for mine dewatering, or both.

Increasing pressure from regulatory, stakeholder and environmental groups in the past few years has led to a heightened awareness of salt lake ecosystems, primarily through intensive baseline and one-off studies funded by mining companies. A diverse range of lake flora and fauna has been identified, including many new, endemic species. These studies have underlined the environmental significance of salt lakes, to the point that 'fees' may be imposed for dewatering in the future.

This paper discusses alternative options for disposal of dewatering discharge: from direct, uncontrolled deposition to salt lakes, to full containment on land. A case study into the assessment of discharge options is also presented. The case study discusses discharge options that were investigated during the approvals process for the Wallaby Project, owned by Placer Granny Smith, and final outcomes.

1.0 INTRODUCTION

A number of mining operations in semi-arid Western Australia reside near salt lakes. Mining pits are located either in the lake proper, or adjacent to the lake. In both situations, the pit operation can only occur if the dewatering requirements are met. High groundwater tables near these pits necessitate dewatering at a rate of up to 80 litres per second. To date, disposal of this water has primarily been directed to old mining pits, or directly to salt lake playas.

Salt lakes have become increasingly important in the past ten years, leading to heightened regulatory conditions on their use, which parallel intensive research into their ecosystems. Recent research indicates that while fresher process water deposition may have a positive effect on a salt lake ecosystem, there is some degree of negative impact when saline or hypersaline groundwater is disposed. Indeed, most operations in the eastern Goldfields report saline to hypersaline groundwater quality. The environmental impacts of discharging hypersaline water to a salt lake must therefore be considered.

1.1 Summary of main environmental impacts of dewatering

In order to understand the need for alternative disposal options for hypersaline dewatering discharge, one must understand the various impacts that dewatering discharge may have on the environment. Overseas and local studies alike have identified a number of potential environmental impacts from mine dewatering, though investigations have been largely hydrological (and therefore not considering biotic components of the ecosystem).

The main impacts are seen as:

- Physical disturbance including alteration of drainage paths
- Creation of temporary new environments that are not maintained in the long term
- Lowering of the water table ("storage depletion"), and the subsequent effect on flora and fauna (terrestrial and subsurface)
- Long term salinity changes
- Adverse effects on regional water quality, attributed to a high concentration of contaminants, differences in water volume, high solids loads, or substantial differences between discharge and receiving water quality.

(Koontz, pers. comm.; Water Quality Protection Guidelines, 2000; DRD, 2002, Great Basin Mine Watch, 2002).

When determining the most appropriate method for disposing of dewatering discharge, the minimisation of some or all of these environmental impacts is a primary concern. There are a number of guidelines and license conditions that regulate dewatering discharge and set upper limits on discharge contaminants.

1.2 Guidelines and licenses

In recent years, the dewatering discharge license report (DDLR) guidelines (DEP) have become more focussed and detailed, requiring that mining companies undertake regular monitoring of their discharges, with results to be reported annually. Dewatering discharge licenses are issued with the proviso that if the discharge is found to be harmful to the environment during a given monitoring period, the proponent must pay a fee. It is difficult to define 'harmful' discharge, especially considering site-specific differences in the receiving environment (which is invariably an episodic salt lake, though there are exceptions). Only regular monitoring of both the dewatering discharge and the receiving environment can determine whether there has been a harmful impact to the environment.

The Water Quality Protection Guidelines for Mining and Mineral Processing – Mine Dewatering (WRC, DME and DEP, 2000) state the conditions considered indicative of impact. These are shown in **Table 1.** The fee for discharges that are deemed 'harmful' is calculated according to the nature of the contaminant and the volume of water discharged, as outlined in **Table 2** (Environmental Protection Amendment Regulations 1996).

To date, no company has shown its discharge to be 'harmful,' therefore no fines have been allocated. Even so, fines have been threatened in a number of situations, particularly when companies have submitted incomplete reports or inadequate monitoring data.

The cost of 'harmful' discharge can be significant. For a company discharging an average of 30 litres/second, at a TDS of 100 000ppm for the period of one year, the cost would be in the order of $50 000.00. This payment ('fine') would be additional to the prescribed premises category fee.

An increased awareness of salt lakes ecosystems has led to a push to regulate dewatering discharge (both quantity and quality), and the types of fines mentioned above may be enforced at any time.

In the future, a dewatering 'fee' may also be introduced, charged on a cost-per-unit basis. The cost would be balanced against the benefits of environmental protection using a Cost Evaluation Matrix.

To the best of the author's knowledge, new guidelines are being developed by ANZECC for the protection of salt lake ecosystems, which may further tighten restrictions on their use. Considering these developments, the investigation of alternative disposal options is viable.

Table 1: Receiving Water Quality Criteria (from Water Quality Protection Guidelines for Mining and Mineral Processing – Mine Dewatering (WRC, DME and DEP, 2000))

Indicator	Criterion
pH	Discharge water should not cause the seasonal background pH of the receiving waterbody to vary by more than ±0.5 units
Total Dissolved Solids	(TDS)Discharge water should not cause the seasonal background TDS of the receiving waterbody to vary by more than 10%
Dissolved Oxygen (DO)	Discharge water DO concentration should not cause the seasonal background DO concentration of the receiving waterbody to decrease by more than 10%
Suspended solids/ turbidity	Discharge water should not cause the suspended solids/turbidity seasonal background concentration of the receiving waterbody to increase by more than 10%
Floatable matter	Discharge water should not be the cause of visual floating oil, foam, grease, scum, litter or other objectionable matter being present in the receiving waterbody
Settleable matter	Discharge water should not cause the deposition of settleable matter that may adversely affect the visual, recreational and ecological values of the receiving waterbody
Odours and colours	Discharge water should not produce discernible variation in odour or colour in the receiving waterbody
Temperature	Discharge water should not cause the receiving water temperature to vary by more than 2°C from its seasonal background temperature
Toxicants	The level of toxicants discharged (e.g. cyanide, heavy metals) should not cause the seasonal background concentration of toxicants in the receiving waterbody to increase by more than 10%
Radionuclides	Radionuclides in the discharge water should not cause the receiving waterbody's seasonal background radionuclide concentration to increase by more than 10%
Nutrients	Discharge water should not add nutrient substances or other growth stimulants (e.g. phosphorous, nitrogen) in quantities sufficient to cause excessive or nuisance algal growth in the receiving waterbody

Table 2: Discharges onto land or into waters (from EPA Amendment Regulations, 1986)

No	Kind of Waste		Fee Units (c)
1	Liquid waste that can potentially deprive receiving water of oxygen (for each kilogram discharged per day) -		
	(a) biochemical oxygen demand (in the absence of chemical oxygen demand limit)		0.5
	(b) chemical oxygen demand (in the absence of total organic carbon limit)		1
	(c) total organic carbon		0.5
2	Biostimulants (for each kilogram discharged per day) -		
	(a) phosphorous	(i) Swan Coastal Plain	10
		(ii) elsewhere	2
	(b) total nitrogen	(i) Swan Coastal Plain	10
		(ii) elsewhere	2
3	Liquid waste that physically alters the characteristics of naturally occurring waters -		
	(a) Total suspended solids (for each kilogram discharged per day)		0.5
	(b) Surfactants (for each kilogram discharged per day)		10
	(c) Colour alteration (for each platinum cobalt unit of colour above the ambient		0.05
	colour of the waters in each megalitre discharged per day)		0.05
	(d) Temperature alteration (for each 1∞C above the ambient temperature of the waters in each megalitre discharged per day) -		
		(i) in the sea south of the Tropic of Capricorn	0.05
		(ii) in other waters	0.25
4	Waste that can potentially accumulate in the environment or living tissue (for each kilogram discharged per day) -		
	(a) aluminium, arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, vanadium and zinc		100
	(b) pesticides		100
	(c) fish tainting wastes		100
5	E. *coli* bacteria as indicator species (in each megalitre discharged per day) -		
	(a) 1 000 to 5 000 organisms per 100mL		5
	(b) 5 000 to 20 000 organisms per 100mL		10
	(c) more than 20 000 organisms per 100mL		5
6	Other waste (per kilogram discharged per day) -		
	(a) oil and grease		0.05
	(b) total dissolved solids		0.05
	(c) fluoride		1
	(d) iron		1
	(e) total residual chlorine		10
	(f) other		1

2.0 DISCUSSION

2.1 Dewatering discharge options

There are several options for dealing with dewatering discharge, apart from direct disposal to salt lakes. The Water Quality Protection Guidelines for Mining and Mineral Processing - Mine Dewatering (WRC, DME and DEP, 2000) suggest the following as suitable options for mine water disposal:

- Recycling (Dust control, process water, cooling and washdown) consistent with zero-discharge - use depends on water quality
- Local groundwater recharge (depends on area available, levels of solids, impact on receiving water quality and impact on local hydrology)
- Agreement to provide waste water to a neighbouring site for recycling
- Direct discharge to nearby wetlands, rivers, drains or drainage lines (provided environmental values and beneficial uses are not compromised, receiving water criteria can be met, and discharge is consistent with the provisions of an applicable Environmental Protection Policy)
- Irrigation (provided water quality meets criteria, evaporation rates have been considered, and the quantity of water involved and effects on the proposed discharge area have been considered)
- Storage within a secure impoundment for disposal by evaporation (i.e. evaporation pond)

In undertaking any of these options, comprehensive impact assessment is required in order to maintain protection of the receiving waters, and monitoring programs must be undertaken (monitoring of discharge water quality and quantity, dewatering system integrity, monitoring facilities and flora and fauna). Additional options may also be considered, such as dewatering to disused pits, water treatment (desalinisation) or salt harvesting.

2.2 Environmental Consequences of different dewatering discharge options

Each method of water disposal has its own limitations, which are typically site specific.

Discharge to disused pits is probably the low-impact of all options, as the areas are generally cleared of vegetation (likely to be the only biota that could be impacted).

Water recycling may also be a good option, though hypersalinity of the discharge water may lead to impacts on flora. An example is the documented death of trees and shrubs near haul roads, where hypersaline water has been used for dust suppression. Use in irrigation may also have the same types of impacts, if water is of poor quality.

Aquifer re-injection has the benefit of replenishing subsurface water, though suspended particles in the water may cause clogging, and there may be issues if fresh aquifers are contaminated with poorer quality water, or if stygofauna are present in the aquifer (Koontz, pers. comm.).

Evaporation dams require the clearing of a large area of land in order to provide sufficient storage space, and are costly to rehabilitate. Embankment stability and permeability may also be a problem, making surrounding vegetation and fauna susceptible to contamination through leaks or leaching (Koontz, pers. comm.).

Direct discharge to salt lakes or other aquatic systems undoubtedly has the highest potential environmental impact, given that they are functional ecological units whose dominant species (both aquatic and terrestrial) depend on reasonable quality surface water for survival.

There is some assumption that freshwater input (rainfall) allows 'flushing' of water bodies, negating the impact of dewatering discharge. In ephemeral or episodic salt lakes in arid areas, the potential for flushing is quite low, particularly in the case of smaller lakes, implying low assimilative capacity. Ongoing studies into salt lake ecology are broadening the knowledge of their ecosystems and potential impacts upon them due to hypersaline dewatering discharge. The main likely impact is elevated salinity, though it is not known whether this is a long- or short-term effect. Studies currently being conducted by OES are focussing on monitoring 'recovery' of biota in old dewatering discharge areas, with the aim of answering such questions.

The one main environmental consequence common to most dewatering discharge options is elevated salinity, in cases where dewatering discharge is hypersaline. In addition, the environmental value of a salt lake has a bearing on the significance of impact by dewatering discharge.

2.3 Choosing the right option

There are numerous factors that must be considered when choosing a suitable option. The viability of different dewatering discharge options for any given site depends on a number of factors, mainly;

- The environmental cost of the option, and impact uncertainty
- The monetary cost of the option, both up front and long term
- The option most practical given the nature of the working environment
  - Any logistical difficulties?
  - Is the method viable in a particular situation?
- Safety issues
- Staff resources
  - Experienced staff or specialist contractors required to manage the option?
  - Number of staff required?
- Time required to establish infrastructure for the method
- Any side benefits from undertaking a particular option
- Stakeholder acceptance

These factors may be site specific therefore the suitability of different disposal options varies between sites. This implies that thorough investigation of all options is required. A company should construct a matrix of cost, time, resources and environmental risks/benefits associated with each option. The final decision on which option is the most viable may be primarily made by mining company executives, but would ideally consider the opinions of;

- Local stakeholders (where applicable);
- Qualified scientists (who can provide supplementary information regarding environmental issues and the validity of each option considered);
- Government organisations (who legislate the mining conditions); and
- Specialist contractors (if applicable, who may be able to provide supplementary information and advice relating for particular options such as desalination)

2.4 Case study: Placer Granny Smith

The Wallaby Project is located on the north eastern shore of Lake Carey, near Laverton, W.A. There are currently a number of companies mining near or on the lake, which spans approximately 70 000 ha. Lake Carey is part of a paleodrainage system that runs south from Wiluna, toward the Great Australian Bight.

The disposal of hypersaline groundwater from the dewatering program at Wallaby is a major component of the Wallaby Project and a key environmental issue. Drilling confirmed the presence of large volumes of groundwater in and around the Wallaby Pit. This groundwater system also includes the water contained in a palaeochannel intercepted by the pit at depth. Initial site investigations found the groundwater to be hypersaline, with Total Dissolved Solids (TDS) concentrations of the order of 250 000 mg/L. These conditions are typical of the lake. A range of saline water disposal and management options was considered in detail as part of the scoping process undertaken for the Wallaby Project.

A preliminary review of disposal options for the dewatering program was prepared in 1999 (Blandford, 1999b, cited in Placer Granny Smith, 2000). This discussion paper defined the saline water disposal options and outlined the issues associated with each option. The options considered were:

(1) Disposal to the north-west salinaland

(2) Joint disposal to the north-west salinaland and Jupiter Pit

(3) Full containment on Lake Carey

(4) Full containment on the land

(5) Partial-temporal containment on Lake Carey

(7) Deep well injection

(8) In-pit disposal

(9) Containment and harvesting

(10) Direct discharge to Lake Carey

(11) Direct discharge to depressions on the surface of Lake Carey

(12) Direct discharge to Lake Carey with passive recharge

(13) Desalination.

Several of these options involved some degree of direct discharge to Lake Carey. The options involved clearing of vegetation and storage on land, and were dependant on local evaporation rates. Three options were related to replacing subsurface water, and depended primarily on available storage space (i.e. pit volumes or aquifer capacity) and evaporation rates. One option considered amendment of water quality for recycling or discharge.

After these options were put forward, an evaluation was undertaken on the above options and a further three options were added to the list (Dames & Moore, 1999). Additional options included shallow well injection, construction of a grout curtain, and construction of a slurry cut-off wall across the palaeochannel.

The results of the evaluation were then reviewed considering the following criteria:

(1) Practicality

(2) Safety

(3) Robustness

(4) Environment

(5) Cost

(6) Construction

(7) Internal Stakeholder Acceptance

(8) External Stakeholder Acceptance

(9) Impact Uncertainty

A detailed consideration of these parameters and their impacts on each disposal option was undertaken.

Options were ranked and the review indicated that the best option with regard to minimising the environmental aspects of discharge, whilst maintaining project viability, was a combination of options (8) (In-pit disposal) and (10) (direct discharge to Lake Carey). The final option was to discharge the greater proportion of the hypersaline water into disused pits with the remaining portion of the water discharge uncontained onto Lake Carey.

Based on the available data, this approach was considered to have the least environmental impact on Lake Carey. The use of mine voids was considered viable as there are a number of decommissioned voids in proximity to the proposed Wallaby Project. The storage potential of existing pits was calculated, taking into consideration any natural recharge (s) that may occur.

It was proposed that Windich pit would be used for water harvesting to supplement the low salinity water in the Mt Weld borefield, and that a monitoring plan to be undertaken to assess the impact of direct disposal to the Lake Carey playa.

Baseline studies were undertaken to assess the impact of direct hypersaline water discharge to the Lake prior to dewatering, and results indicated that least disturbance may be achieved by direct discharge rather than construction of a bunded storage facility on the lake surface. Construction of a lake bunded facility would create a significant level of disturbance on the Lake playa and also create a major mine closure and rehabilitation issue. Details of this evaluation and the outcomes of the ranking process are contained in the Dames and Moore (1999) report (cited in Placer Granny Smith, 2000).

Direct discharge has been occurring from the Wallaby project area since 2001, utilising an erosion-minimising groyne structure lined with gravel.

Placer Granny Smith is undertaking bi-annual monitoring of lake biota and the local environment as a means of assessing whether impact is occurring, and is contributing to a number of ongoing studies into the effect of dewatering discharge on Lake Carey.

3.0 CONCLUSION

Numerous salt lakes scattered throughout WA are vehicles for dewatering discharge from mining operations. Intensive study into these ecosystems in recent times has led to the tightening of regulations on their use. In the future, direct discharge to salt lakes may incur a per-volume cost, related to the perceived value of the wetland, its assimilative capacity, and the uniqueness of flora and fauna in the ecosystem.

In light of these events, the investigation of alternative discharge options is warranted. Site-specific issues dictate that there is no single best option that is most suitable for the disposal of hypersaline dewatering discharge.

The investigation of dewatering discharge options by mining companies should involve stakeholders, scientists and government representatives, with a primary aim being to determine the most cost effective option with the lowest environmental impact.

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STORMWATER HARVESTING IN OPEN PIT FINAL VOIDS AS A MEANS OF SUPPLEMENTING AND MAINTAINING THE QUALITY OF LOCAL WATER RESOURCES IN THE NORTHERN GOLDFIELDS OF WESTERN AUSTRALIA

J.P. Gerrard
HILL 50 LIMITED

ABSTRACT

There are over one thousand open pit mines in Western Australia where mining has extended below the water table. As a result of the significant deficit between rainfall and evaporation the salinity of water that fills these pits is expected to gradually increase. In areas of the state where high groundwater quality and open pit mining coincide there is the potential for degradation of groundwater quality.

In late 1999 Mt Magnet Gold NL (MMG) initiated stormwater harvesting in three mined out open pits which provided significant cost savings in the production of water for processing. This initial success has now led to a further application and the granting of approval for harvesting of stormwater in MMG's Milky Way pit. The local groundwater quality is good and one of MMG's fresh water production bores is located immediately adjacent to the pit. The reason for the initiation of stormwater harvesting at this site is to offset the rainfall-evaporation deficit, which would otherwise result in a gradual deterioration of pit water quality and resultant impact on the adjacent water supply.

The paper outlines a simple pit water balance model which has evolved from monitoring of water levels in and around these as well as other mined out open pits and illustrates how, when correctly planned and implemented, surface water harvesting represents a valuable water management strategy for mines in WA's arid interior. The potential to locally increase high quality water resources, raises numerous additional opportunities, which could lead to new land uses after final mine closure.

1 INTRODUCTION

The Mt Magnet Gold operation (MMG) is located 560km north of Perth in Western Australia. Gold was discovered in Mount Magnet in 1888, mining in the area commenced in 1891. Mining has continued to the present day and has been conducted by many different companies and individuals. Since mining commenced over 3000 shafts of varying depths were dug and over the last 20 years around 30 open pits have been mined.

MMG now holds mining tenure over most of the area and currently mines gold bearing ore from five open pits as well as the Hill 50 and Morning Star underground workings. In 1999 the processing plant was upgraded in order to increase the annual rate of processing of ore by 1,000,000 tonnes per annum. Approximately 1kL of water is required for each tonne of ore processed so additional bores were constructed and equipped to meet the increased demand. Stormwater diversion drains were also constructed to divert stormwater into three disused open pits in order to supplement the process water requirement.

Salination of the pit lakes that result from open pit mining have long been recognised as having the potential to degrade local groundwater resources over time. One of MMG's fresh water bores is located next to the Milky Way open pit. Harvesting of stormwater into this pit has been initiated in an effort to offset the effect of evaporation at this site and thus help to maintain the quality of water in the pit preventing a degradation in the quality of the fresh water supply.

This paper examines some of these results and shows how these have been used to develop a sim-ple, but effective water mine balance model.

2 CLIMATE

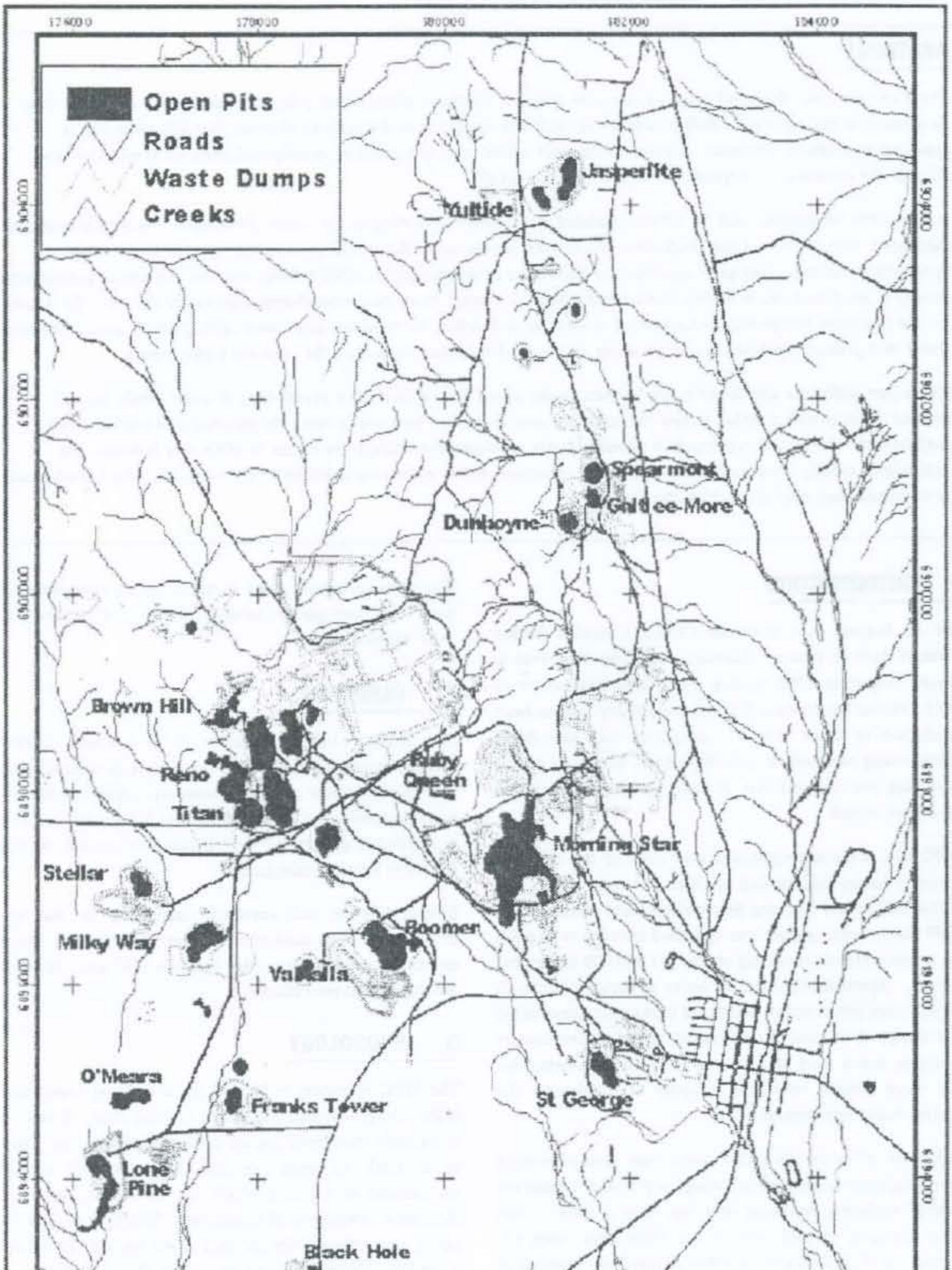
Mt Magnet has a climate that borders between Mediterranean and desert and has an average annual rainfall of 228mm. Annual rainfall is however highly variable with historic extremes of 75mm (1911) and 645mm (1915). There is significant geographic rainfall variation as well are large distances between rain gauges.

Evaporation is not currently measured in the area. Evaporation rates used in this paper are based on average monthly evaporation recorded between 1967 and 1974 at the Mount Magnet post office.

3 HYDROLOGY

The MMG operation is located on a regional to-pographic high, where two large catchment systems meet. Creek flow is typically short lived (hours to days) and generally limited to a couple of times per year. There is little available information in the area which can be used to accurately determine rainfall runoff parameters. When creek flow does occur, water flows from the area of the mining operation to a salt lake system to the south west of Mount Magnet.

Figure 1: Mt Magnet Gold Location Plan



4 HYDROGEOLOGY

The Mt Magnet greenstone belt contains a multiply deformed sequence of ultramafic, mafic and felsic rocks, with interbedded volcanogenic sediments, predominantly banded iron formations. The greenstone belt is flanked and intruded by granitic stocks and batholiths, and deformed gnessic granitoids.

The depth of weathering ranges from near surface (banded iron & granite) to a depth of up to 50m (mafic, ultramafic & felsic rock). Saprilitic clays are formed by the weathering of mafic, ultramafic and felsic rocks. These clays have a low permeability and cover much of the area.

Useful local groundwater resources are limited to fractured rock aquifers. These are found where the more brittle rock types have been subjected to significant deformation, often coinciding with gold mineralisation and thus locations for open pits.

The hydraulic gradient through the area is low at approximately 1:200. Direct rainfall recharge ap-pears to be most effective along BIF ridges and some of the better developed drainage systems. The salinity of groundwater in these areas is generally low (< 800mg/L TDS). The quality deteriorates with residence time and distance away from these recharge areas.

The development of acid mine drainage issues are unlikely as concentrations of sulphides found in the rocks are low in comparisom to carbonate. Concentrations of sulphate and trace elements in ground water are generally low, salinity and regionally elevated boron and nitrate concentrations are factors that most commonly limit groundwater use.

5 SURFACE WATER HARVESTING

Surface water harvesting was initiated in late 1999 with three creeks being diverted into three open pits where mining had been completed. Significant rainfall events in February 2000 resulted in a harvest of over 25% of the operation's annual process water requirement. Water is recovered through the use of both bores that are hydraulically connected to the respective pits as well as in-pit pumps.

More recently the construction of a stormwater diversion drain into the Milky Way pit, next to which the operations highest yielding fresh water production bore is located. The objective of diverting stormwater into this pit is to offset the effect of evaporation which could lead to a gradual deterioration in pit water quality and in turn affect the quality of water drawn from the bore.

6 MONITORING

Water levels in open pits are generally surveyed on a quarterly basis however additional measurements are recorded after significant storms. Water samples from production bores next to open pits and water levels in monitoring bores near selected open pits are also measured regularly.

Flora monitoring stations up and down stream of stormwater diversions have been established to monitor potential effects of the diversions on down stream vegetation. To date there has been no observable effect.

Several of the pit lakes that have formed are supporting yabbies, marron, insects and bird life. Formal monitoring of the biodiversity of the pit lake environments that have been formed is yet to be undertaken.

7 PIT WATER BALANCE MODEL

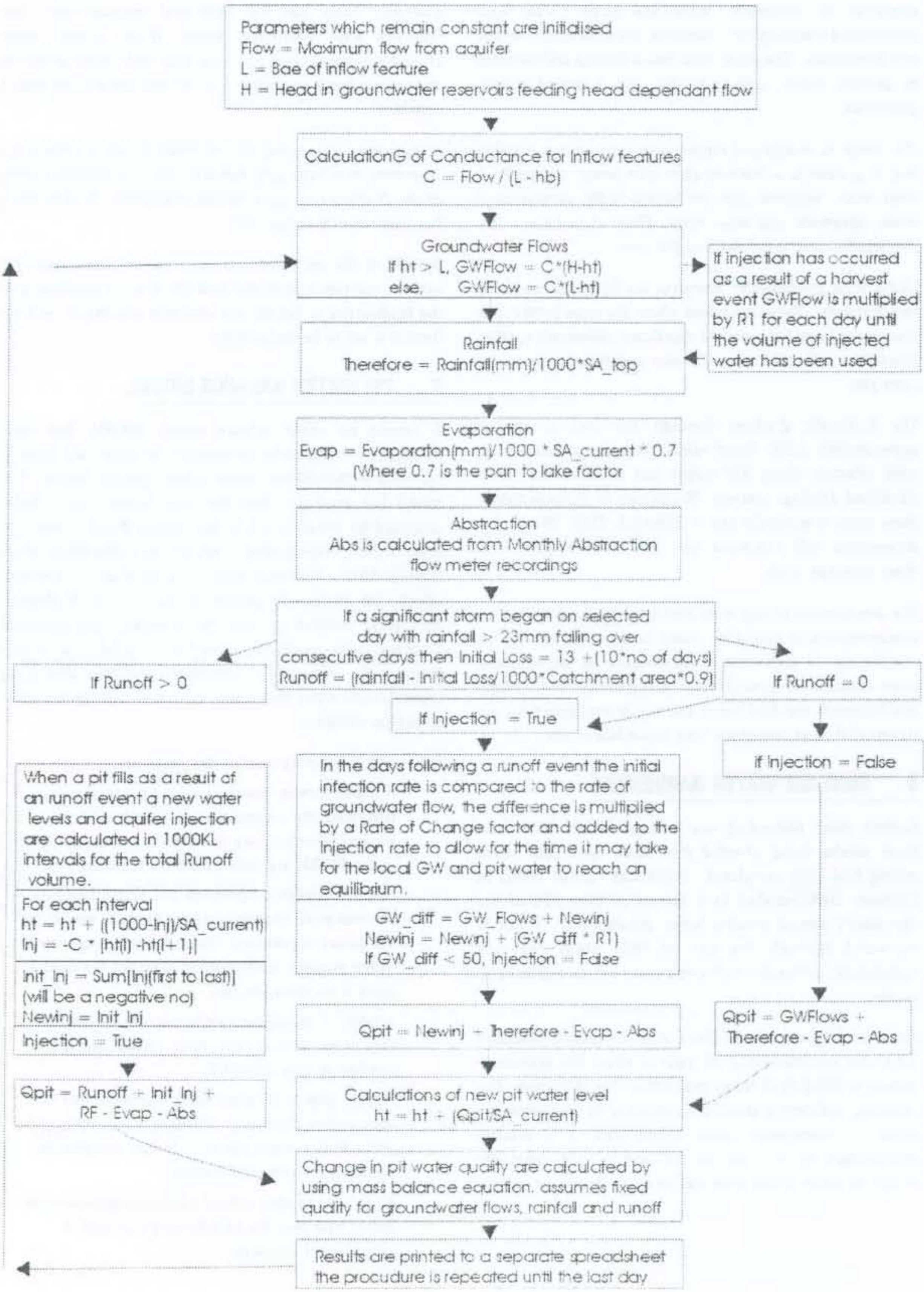
A simple pit water balance model (PWBM) has been developed in order to better estimate the losses and gains to pit voids as they fill with water following mine closure. The model has developed from the Mine Water Filling Model proposed by David Banks in the Ground Water Journal for relatively dry underground mines in low permeability strata (Banks, 2000). After accounting for rainfall and evaporation effects, the model was applied to open pits at Mt Magnet, with good correlation's between measured and predicted recovery. The model has been further developed to also include the effects of stormwater harvests and local ground/mine water abstraction as well as average pit water chemistry variation.

Important parameters used in the model are:

- A digital terrain model for each pit was used to determine the volume of each 1 meter vertical interval. Surface area and volume parameters used in the PWBM are drawn from the resulting table.
- Monthly rainfall, evaporation and abstraction rates are converted to daily averages for each month for the model calculations. Recorded values are used where possible, while historic averages are used if there is no recorded data.
- A table of significant storms was set up with the date of the start of each storm, rainfall and the number of days of rainfall.
- R1 is a calibrated factor which has been used to approximate the rate at which pit water levels and groundwater levels will move toward equilibrium following a stormwater harvest.
- R2 is used to approximate additional ground-water inflow back into the pit following a pe-riod of groundwater recharge.

Figure 2: Outline of Pit Water Balance Model

The PWBM and calculations used in this pit water balance model are outlined in Figure 2, below.



8 RESULTS

The results of the PWMB output has been compared with measured water levels at several pits.

8.1 Lone Pine

The Lone Pine pit was mined between 1994 and 1996. Dewatering of the Lone Pine pit ceased in early 1996 and since this time groundwater flow has been gradually filling the pit. Pre mining pumping tests indicated that a maximum flow of 350kL/day with head dependency to a level of 380mRL would be expected during mining. Using these parameters the modeled change in pit water levels as the pit filled, closely matched measured water levels (Figure 3).

8.2 Milky Way

Located next to the Milky Way pit is production bore W18. Mining commenced in mid 1999 and was completed in August 2000. The maximum flow into the pit was approximately 500kL/day including water drawn from W18. Using PWBM a good correlation was obtained for modeled and measured water levels pit (Figure 4).

Production water levels have not been consistently measured in W18. However, abstraction is recorded monthly. An average of approximately 250kL/day is continually drawn from this bore and accounts for half of the operation's fresh water re-quirement.

There are also four monitoring bores located around the pit perimeter. Stormwater harvesting has recently been initiated at the Milky Way site however there have been no recent significant rainfall events.

8.3 Spearmont

The Catchment area above the Spearmont pit is approximately 3.6km² and all runoff from this area is diverted into the pit (Figure 5). Rainfall runoff parameters for the area are still very much an estimate. However, these estimates should improve with continued monitoring and future harvests.

Water is abstracted from the pit via a bore located next to the pit which intersects historic underground workings beneath the pit.

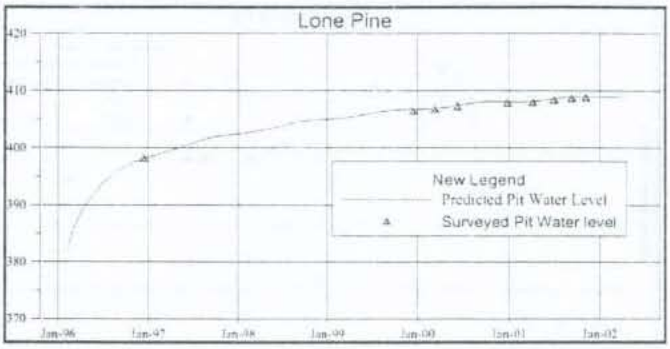


Figure 3: Recovery of the Lone Pine pit fol-lowing the suspension of dewatering.

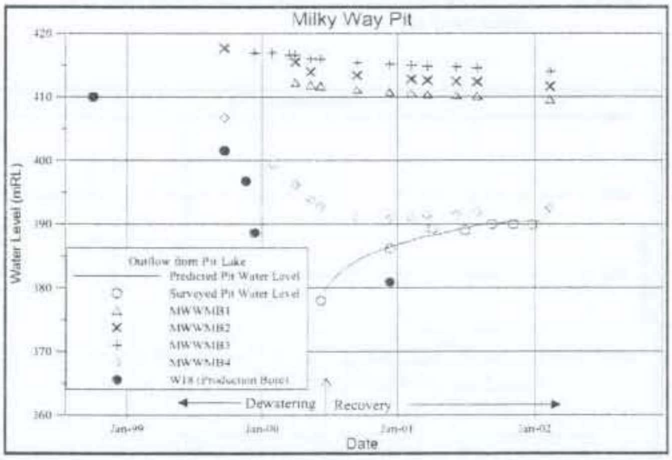


Figure 4: Recovery of water levels in and around the Milky Way.

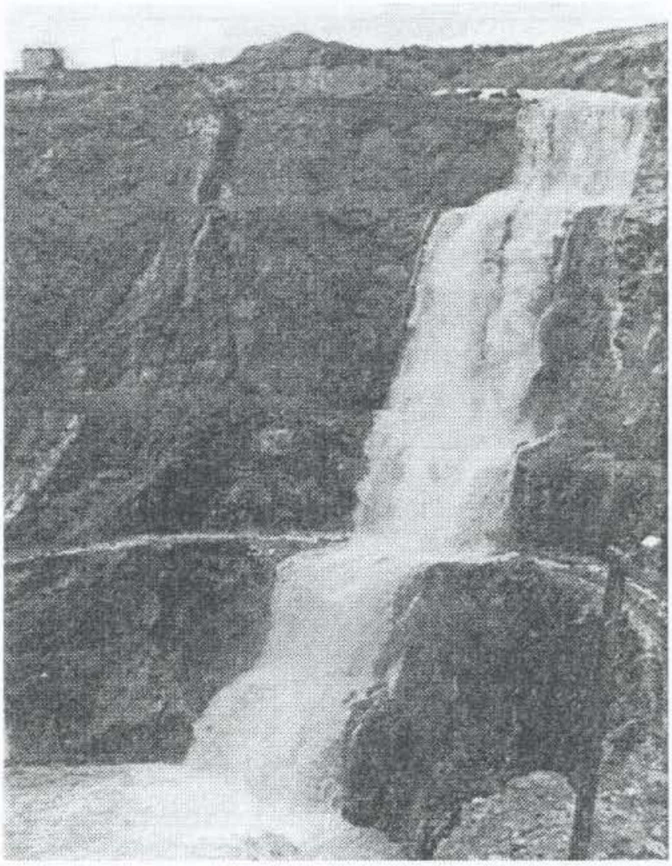


Figure 5: Harvesting Stormwater into the Spearmont Open Pit, February 2000.

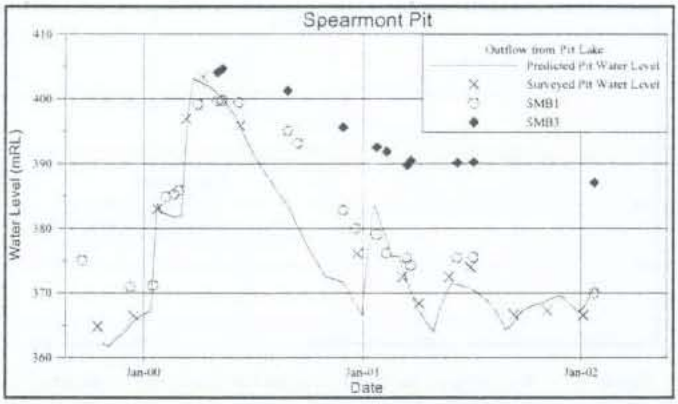


Figure 6: Measured and Modeled water levels in and near the Spearmont pit.

In applying the PWBM to Spearmont the factors determining both head dependent flow and rainfall runoff properties were varied in order to gain a reasonable correlation between predicted and measured water levels obtained (Figures 5). After calibration of the PWMB for Spearmont, predicted and measured chloride concentrations for 1999 to early 2002 also showed a reasonable correlation (Figures 6 and 7). When the pit is near empty the sensitivity to varying initial parameters is high and obtaining a good correlation between predicted and measured water levels is difficult.

Monitoring of the nearby bores SMB1 and SMB3 has also shown that stormwater harvests have had a significant influence on nearby groundwater levels.

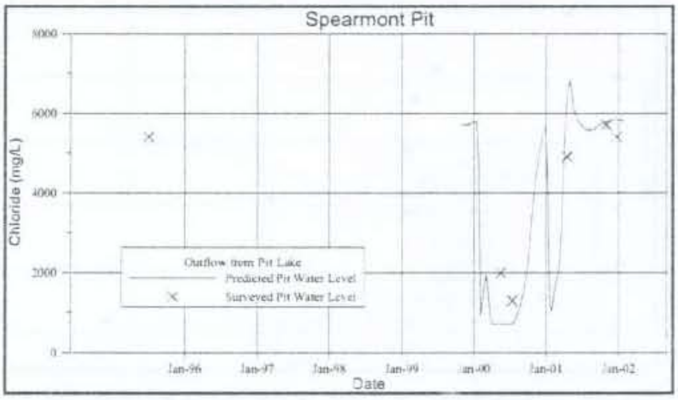


Figure 7: Measured and Modeled Chloride concentrations in samples taken from the Spearmont production bore.

9 PREDICTIONS

For demonstration purposes the Spearmont pit has been used as this has the most monitoring data associated with it.

The model has been run over 22years for three different scenarios:

- no future abstraction and no stormwater harvesting (Figure 8),
- no future abstraction and stormwater harvesting (Figure 9),
- continued abstraction and stormwater harvesting.

In order to estimate the future significant storms the model was run for four 22 year segments taken from rainfall records for the last 100 years. Results were then averaged for the predicted water levels, chloride concentrations and water balance calculations presented in this paper.

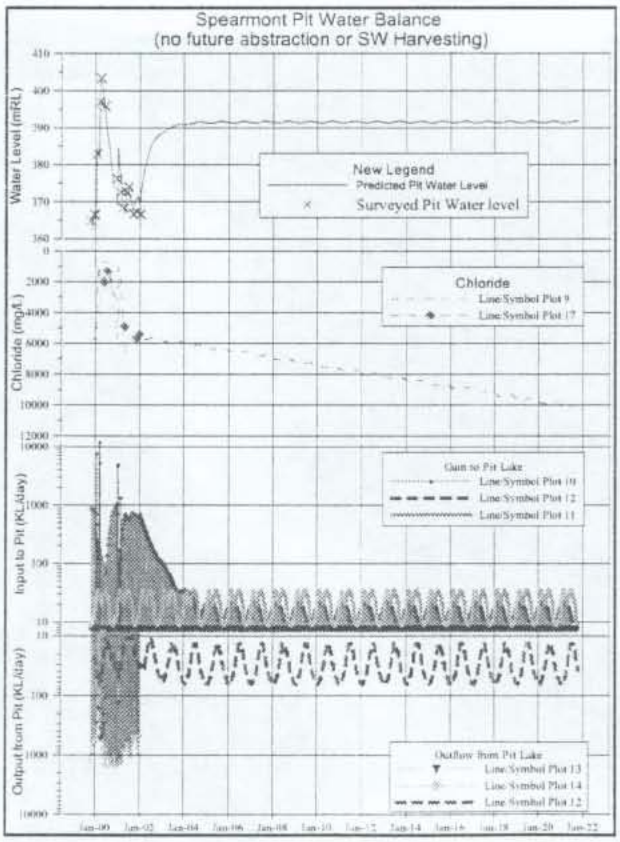


Figure 8: Predicted water balance if stormwater harvesting and abstraction at Spearmont were suspended.

9.1 Scenario 1- No Stormwater harvesting and no future abstraction.

If stormwater harvesting into the pit and abstraction from the bore next to the pit ceased the pit water level would rise to a level where groundwater inflow and the deficit between rainfall and evaporation would reach an equilibrium. It is expected that the average chloride concentration in the pit would then increase at a rate of approximately 500mg/L per year (Figure 8). This would continue until the density of the pit water reaches a level where density driven flow from the pit into local aquifers would begin.

9.2 Scenario 2 - Stormwater harvesting without continued abstraction.

If abstraction from the pit ceased and stormwater harvesting continues the pit will become a window through which recharge from rainfall runoff can directly enter the groundwater system. The pit will become a groundwater source with water flowing from the pit into local aquifers. The expected annual average harvests are much greater than the average annual rainfall evaporation deficit so the average chloride concentration in the pit water will gradually decrease, which will in turn lead to a gradual improvement in groundwater quality (Figure 9).

Although stratification of both pit and groundwater does occur and mixing is expected, this has yet to be incorporated into this model.

9.3 Scenario 3 - Stormwater harvesting with continued abstraction

The model was also run for the case where stormwater harvesting continues and abstraction is also continued at several abstraction rates. Predic-tions indicate that water quality will be maintained with high rates of abstraction. A gradual improvement in quality could be expected if annual abstraction rates were maintained at less than the annual harvest volume minus the evaporation loss.

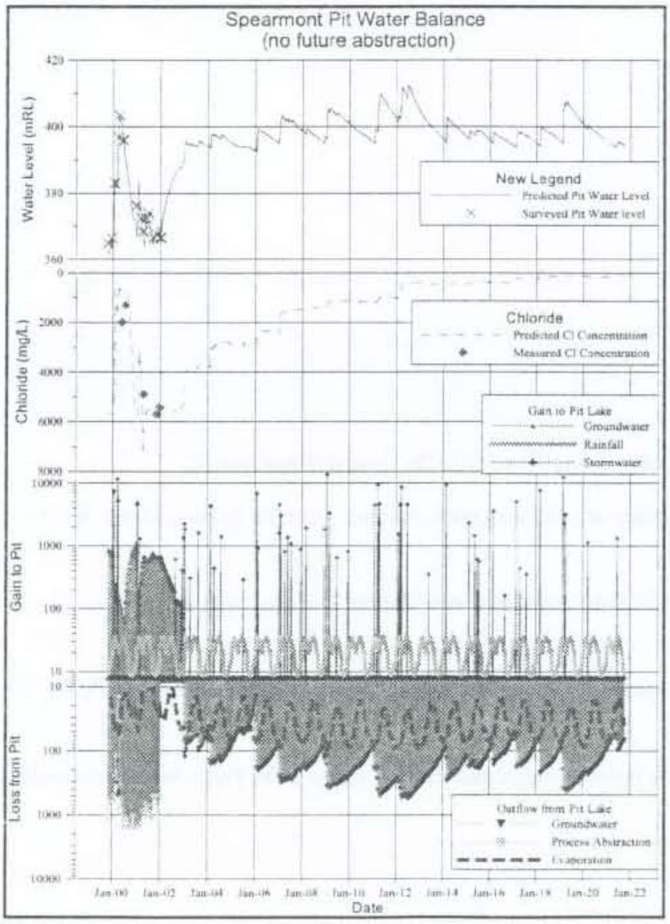


Figure 9: Predicted water balance if stormwater harvesting continues and abstraction at Spearmont is suspended.

10 CONCLUSION

The pit water balance model described in this paper has proved a useful tool in better quantifying the losses and gains to the volume of water in an open pit after the completion of mining. It is also easily applied with reasonable success to pits where available hydrogeological and hydrological data is limited.

Predictions are not expected to be particularly accurate. However, it is hoped that with continued monitoring, at an increased number of sites, pa-rameters such as rainfall-runoff can be improved. The determination of the volumes and rate of injec-tion into the aquifers hydraulically connected to the pit, as well as recovery of this water is still quite rough and continued monitoring is required to validate this approach.

Maintaining the quality of water in suitable open pit final voids through stormwater harvesting is feasible. Stormwater harvesting has provided benefits to the mining operation by supplementing groundwater resources and could be used to initiate other projects.

Several of the open pits currently support yabbies and marron. It is expected that commercially aquaculture initiatives could be undertaken at some of these sites if water quality is maintained.

Where the groundwater is of a high quality this could be maintained to reticulate inland horticultural projects such as sandalwood plantations.

There are over a thousand open pits in Western Australia where there is potential for saline pit lakes to develop (Wright 2000). Many of these pits are located on pastoral stations and near towns that grew to support the mining industry. Eventually the mines will close and in order for these towns to survive new industries need to be developed.

Looking toward the future there are several sites where the quality of groundwater flowing into open pits is high and up stream catchment areas are large enough to provide useful harvests. It is hoped that these pits can be used to provide increased and useful water resources and that these will help to maintain groundwater resources and aid the long term economic sustainability of the region.

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THE VALUE OF A COMPREHENSIVE MINE WATER MANAGEMENT STRATEGY

Alan Wright
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ABSTRACT

Most mines have at some stage developed a minesite water management plan (MWMP) and it is now common practice for regulators to require a MWMP when assessing major new mine developments. Unfortunately however, as with so many other management plans, the MWMP is often destined to collect dust in the minesite filingroom/library. At most mines water management remains a relatively low-key responsibility shared by a number of staff scattered across several departments/sections. Water related problems are dealt with in an ad hoc way by consultants for specific departments/sections with minimal interaction with other sections – a typical case of "what happens beyond the boundary fence is someone else's problem".

This paper attempts to show that water management is all about developing an integrated understanding of how water is managed throughout the entire mining operation, identifying opportunities and developing a strategic water management approach. The MWMP is just one component of a dynamic process that evolves as mining proceeds. Implementation of an effective mine water management strategy not only makes a tangible difference to the operations bottom line, but takes into account the fact that it is the perceptions of the community at large that allows the activities of a mining company to take place. It helps remove the artificial fences that have been created between the environmental coordinator, the plant superintendent, mining engineer and the community at large.

INTRODUCTION

All mining operations are faced with water management issues. Water, and the management thereof, is often critical to the profitable development and operation of a successful mine. This is particularly true in the Goldfields where challenges can range from insufficient resource availability for processing needs to encountering excessive groundwater during mining. The types of challenges to be faced also change as a mine proceeds through its development. Post closure water issues are often quite different from operational issues.

The development and implementation of a PWMP is now standard practice in the mining industry. The complexity of the MWMP depends largely on the nature and size of the mining operation, characteristics of the hydrological cycle at the minesite and the ecological and environmental sensitivity of the surrounding area. The plan is however just one component of a dynamic process that evolves as mining proceeds. This is especially true today as the mining industry grapples with a host of new issues and management concepts. In the environmental arena there are concepts such as sustainable development, intergenerational equity, and the corporate need to demonstrate a sense of frankness, transparency, accountability and responsibility. On the other hand market forces continue to necessitate the drive to reduce production costs.

Water management is not just about meeting environmental management obligations and reducing water consumption per unit of output. Rather it is about obtaining an integrated understanding of how water is managed throughout the entire mining operation, identifying opportunities and developing a strategic water management approach. It cuts across mine departments/disciplines and provides the mechanism for dealing with non-systematic issues delivering whole of mine life benefits. It not only makes a tangible difference to the operation's bottom line, but also takes into account the fact that it is the perceptions of the community in these environmentally aware times that allow the activities of a mining company to take place.

THE APPROACH TO WATER MANAGEMENT

The principle

It is important that the mine water management strategy be based on the following principles:

- A *"whole of mine" approach.* By adopting a catchment based approach it ensures that the strategy takes account of catchment issues as well as mine lease area issues. It should also cover all three phases of mining, namely, development, operational and decommissioning. The most cost-effective solutions come from integrated investigations rather than isolated ad hoc studies.
- A *risk management approach.* A formal risk management approach allows mines to identify and define appropriate measures and responses to deal with operational risks that generate potentially adverse water management consequences. It provides a useful technique for determining priorities. Loss of credibility in the eyes of the community (and regulators) is a risk that should not be underestimated.

- *Industry best practice.* Water management best practice is about achieving more than compliance with legislation. It is about cost-effectively and proactively developing and implementing systems to meet both mining requirements and prevent or minimise environmental impacts. It is important that, although companies need fairly uniform standards/targets/procedures across the group, these also need to be site specific to be relevant.
- *A proactive approach* that feeds into mine planning. There are significant cost savings in integrating minesite water management with mine development and mine closure planning. This optimises coordination of minesite infrastructure development and rehabilitation with water management measures.
- *Regular performance review.* The MWMP is a living document that requires regular reviewing and up-dating. Annual reviews of the performance of key components of a minesite water management system are needed, and should compare actual performance to performance indicators.

The approach

A systematic approach is adopted in developing a water management strategy (Figure 1). The product is a water management system that is integrated across the entire mining operations, details of which are fully documented in a MWMP. The MWMP being a dynamic document that is regularly up-dated. The level of attention given to each aspect will depend on the individual mine scenario. Examples of areas covered are detailed below.

The operating environment

Establishing the regional hydrological setting, mining regime and stakeholder concerns/perceptions:

- Overview of mining operations and company strategies
- Overview of regional water resource potential
- Identification of surrounding/neighbouring water users
- Identification of major community and stakeholder concerns

Water use

Establishing water requirements, usage and supply availability:

- Identification of water supply needs and existing use
- Overview of existing water supply system
- Identification of alternative sources of water supply
- Establishment of water use efficiency
- Determination of impact on environment

Wastewater disposal

Establishing all water discharge to the environment and its impact:

- Overview of dewatering and waste water discharges
- Identification of water loss/seepage/leakages
- Identification of water reuse strategies (existing and potential)
- Determination of impact on environment

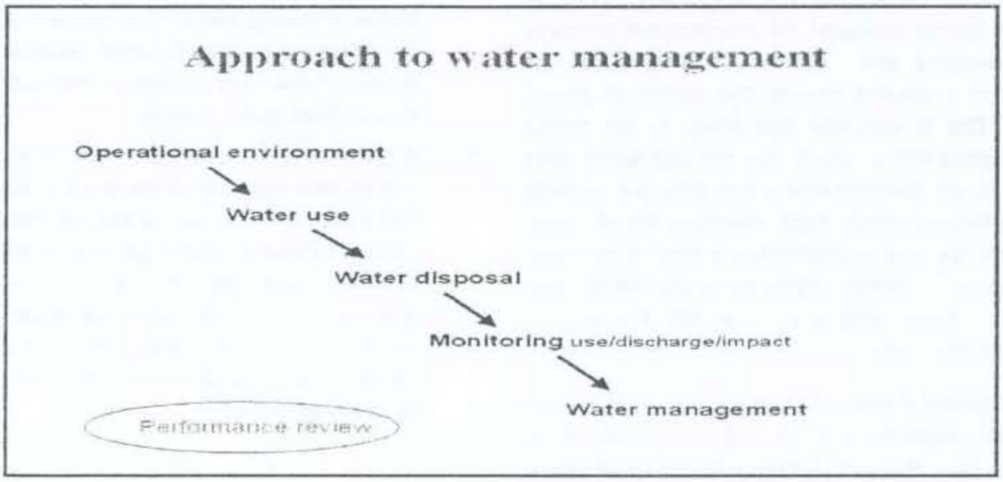

Figure 1: The approach taken when developing a water management system

Monitoring

Monitoring water use, disposal and the resultant impacts on the environment:

- Network design
- Determination of parameter choice and measurement frequency
- Data management (storage and integrity)
- Data evaluation and reporting

Water management

Establishing best practice procedures and processes:

- Effectiveness of distribution and utilisation of information
- Development of an integrated water management information system
- Environmental and financial impact appraisal
- Formulation of responsibilities and accountability
- Evaluation of the quality management system with regard to water management
- Target generation
- Identification of mine water closure issues and possible management strategies

Performance review

Evaluate existing performance and identify areas requiring improvement and those offering promotional opportunities:

- Audit of regulatory compliance
- Audit of Company procedures and standards
- Review performance against Corporate and operational targets
- Review performance against water consumption eco-efficiency targets

THE MINESITE WATER MANAGEMENT PLAN

The MWMP is the documentation that describes the mine water management system. The development and implementation of a comprehensive and coordinated minesite water management plan is a fundamental prerequisite for mine water management best practice (Environment Australia, 1999). The MWMP identifies all water management issues associated with developing, operating and decommissioning a mine. It enhances the coordinated development and implementation of an integrated system of cost-effective, environmentally responsible and ecologically sustainable management measures as mining proceeds. The plan is a public statement by a mining company about how it proposes to manage potentially adverse impacts of mining operations on the local and regional water resources.

The implementation of an effective MWMP generates commercial, environmental, social and operational benefits.

The size and complexity of the MWMP depends largely on the nature and size of the mining operation, characteristics of the mine site hydrology, and the cultural and environmental sensitivity of the surrounding area. Table 1 summarises those aspects that should be included in a MWMP.

Table 1: Issues covered in a typical Mine Water Management Plan

The operating environment
• Project description
• Physical environment
The hydrological setting
• Surface water hydrology
• Groundwater hydrology
Water supply
• Present and future water demand
• Potential/possible water supply sources
• Description of existing supply system
• Potential impacts of water supply system on the environment
Water usage and disposal
• Water use (water circuit diagram & water balance)
• Waste water discharges
• Water reuse strategies / conjunctive use options
• Water losses/leaks/seepage
• Potential impacts on the environment
Compliance needs
• Statutory requirements, obligations and commitments
• Corporate standards and procedures
• Key environmental issues
• Community expectations
Management strategies
• Water management goals and objectives
• Surface water management strategies
• Groundwater management strategies
• Mine closure water management strategies
• Water use efficiency targets
• Information management and reporting systems
Monitoring program
• Monitoring objectives and strategies
• Network design - surface and groundwater
• Monitoring program - parameters /frequency /procedures
• Data storage and integrity (water quality criteria)
• Data management (evaluation & reporting)
• Quality assurance system
Performance review
• Staff responsibilities and accountability
• Reporting regime
• Water management KPI's
• Review/auditing regime
• Performance review system

The MWMP serves as the primary source of information on water management at a mine site. It provides a general overview of the mine site hydrology, what management measures are in place and who is responsible for implementing these. It is home to the operational manuals and as such is an all-encompassing water management "bible". It is also a requirement of the Environmental Management System and HSEC standards. It is therefore a document that should be in frequent use and easily accessible to all mine staff via the Intranet. As with all systems, the mine water management system, constantly changes to reflect operational changes, which means that the MWMP needs constant up dating and a periodic review and upgrade.

Many current MWMPs are rather static, one-dimensional documents and it's not surprising when, once mining approval is granted or the EMS audit is complete, these are relegated to the archives. With a little more effort the document could be made far more comprehensive and useful, ensuring that staff actually have a use for it.

DISCUSSION

Some key areas requiring additional attention are:

The water balance. It is amazing how few mines have adequate "whole of minesite" water balances. Individual departments such as the process plant/mill generally have very detailed water circuit diagrams and some idea of the volumes of water entering their domain, but these seldom extend beyond their boundary fence. Significant process efficiency gains and eco-efficiency targets can only be established if all the individual components are seen as a whole. This can only be accomplished through a joint effort by the hydrogeologist, services engineer and plant/mill superintendent.

The first step is developing a water circuit diagram (Figure 2) after which volumes and qualities may be added. The level of sophistication will vary from mine to mine and should in all cases evolve over time.

This is a fundamental water management tool that both mine management and regulators (Government water resource managers) should want to see. The water balance provides a "snap shot" of water use across the mining operation enabling management to identify opportunities for process improvement, water reuse/recycling, loss control, rationalisation of water supply/disposal, and potential areas of environmental impact.

The monitoring program. Water monitoring programs should not be driven by what the regulators want, but rather what is necessary for "best practice" water resource management. The water management strategy and monitoring program must be developed by the mine staff and not by some bureaucrat or technocrat sitting in Perth or Canberra. Mines currently expend considerable money and resources in water monitoring. It is therefore essential that this be done in the most cost effective and efficient manner. A poorly designed network and sampling/measurement program will inevitably lead to a costly exercise of useless data collection. A common mistake made by industry is believing that commitments and monitoring requirements made in environmental approval documents and licence conditions are set in stone. Far from it! These are the best guidelines /criteria at the time of writing and should be constantly reviewed and modified if, and where, necessary. It is up to industry to go back to the regulators to motivate for improvements where the original criteria are no longer appropriate.

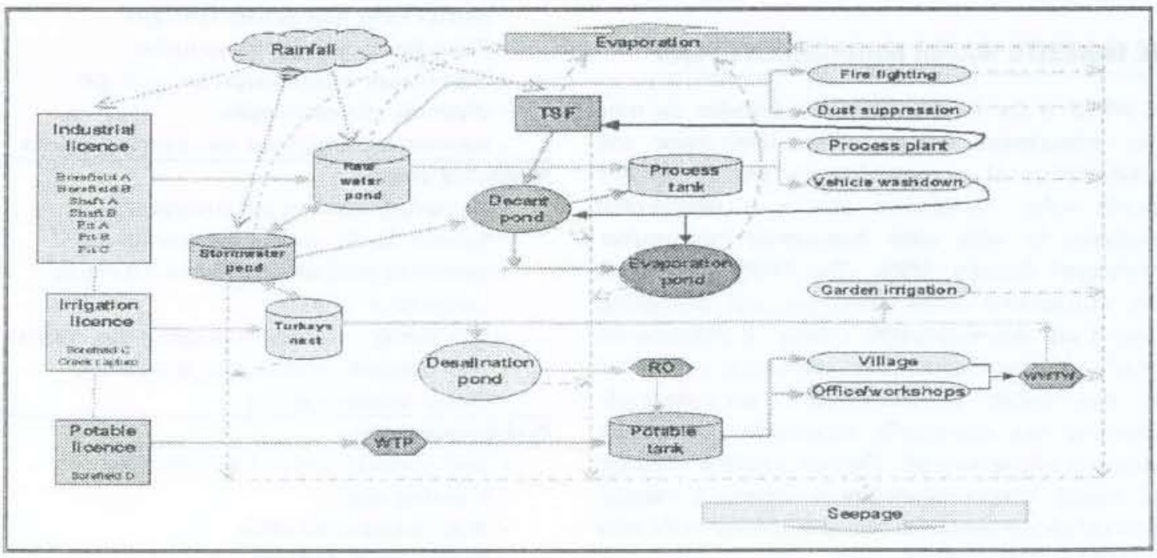

Figure 2: A conceptual minesite water circuit diagram

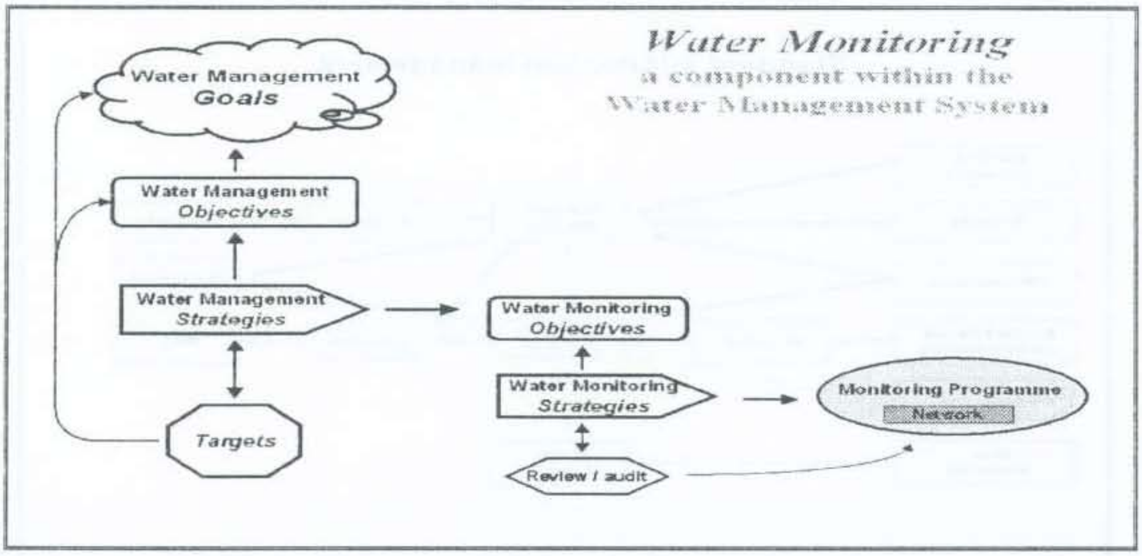

Figure 3: Water monitoring is merely a single strategy within the overall Water Management System

Any attempt to evaluate, improve or "optimise" a water monitoring network should begin with the question, "Why do we want to monitor?" We concentrate almost exclusively on determining how to monitor or how to collect data and very rarely do we examine why we monitor or how we utilise data and resulting information. The water monitoring program is but a tool used as a strategy to meet water monitoring objectives. These in turn are a subset of water management strategies within the broader water management system (Figure 3).

Once the environmental values for a water body have been defined, the level of environmental protection (and water quality) necessary to maintain each value must be determined. It may be broadly defined through the establishment of management goals that describe more precisely and in greater detail what is to be protected. As with environmental values, the management goals should be defined according to community needs and desires and therefore will involve consultation with relevant stakeholder groups. They should be structured so that they can become the key objectives to be achieved through management plans and therefore should relate to particular parts of the environment that can be measured. In particular, management objectives should reflect the specific problems and/or threats to the established values, the desired levels of protection for aquatic ecosystems, and the key attributes of the resource that must be protected. From the management objectives it should be obvious which are the key water quality indicators, and therefore which guidelines should be selected for establishing water quality objectives. The specific water quality objectives more tightly define the desired level of water quality, and are compared with the existing water quality to assess performance. However management objectives not only have to reflect the legal objectives, but the economic constraints.

Environmental regulation and management in Australia are currently undergoing major change, adopting a more holistic and integrated pollution-prevention approach to environment protection (ANZECC, 2000). This change must be reflected in the water management strategy. The current changes involve a shift from control to prevention, from end-of-pipe regulation to cleaner production, from a focus on prescriptive regulation to a focus on outcomes and on cooperation rather than direction. This new approach is being increasingly adopted in formulating water resource management policies and strategies. It requires the commitment of industry and government and the involvement of the community to establish cooperative best management and overall responsibilities for maintaining and improving water resources. Cooperative best management focuses on attaining goals of environmental quality rather than on compliance *per se*.

Cooperative best management involves monitoring and impact assessment. Although risk assessment concepts are familiar to many water resource managers, analogous concepts of the potential for errors in statistical inferences based on monitoring data are often poorly understood, or neglected. Consistent with the principle of cooperative best management, this approach should result in benefits to all stakeholders. All parties should be aware of the targets for monitoring, the statistical criteria by which statistical decisions will be made, what will trigger management action, the level of safeguard built into the decision making process, and the risks of expense or environmental impact arising from errors in the assessment and monitoring process.

The need to tailor water monitoring criteria/guidelines to local conditions and acceptance that exceedance of the criteria indicates that there is potential for an impact to occur (or to have occurred), but does not provide any certainty that an impact will occur (or has occurred). Trigger

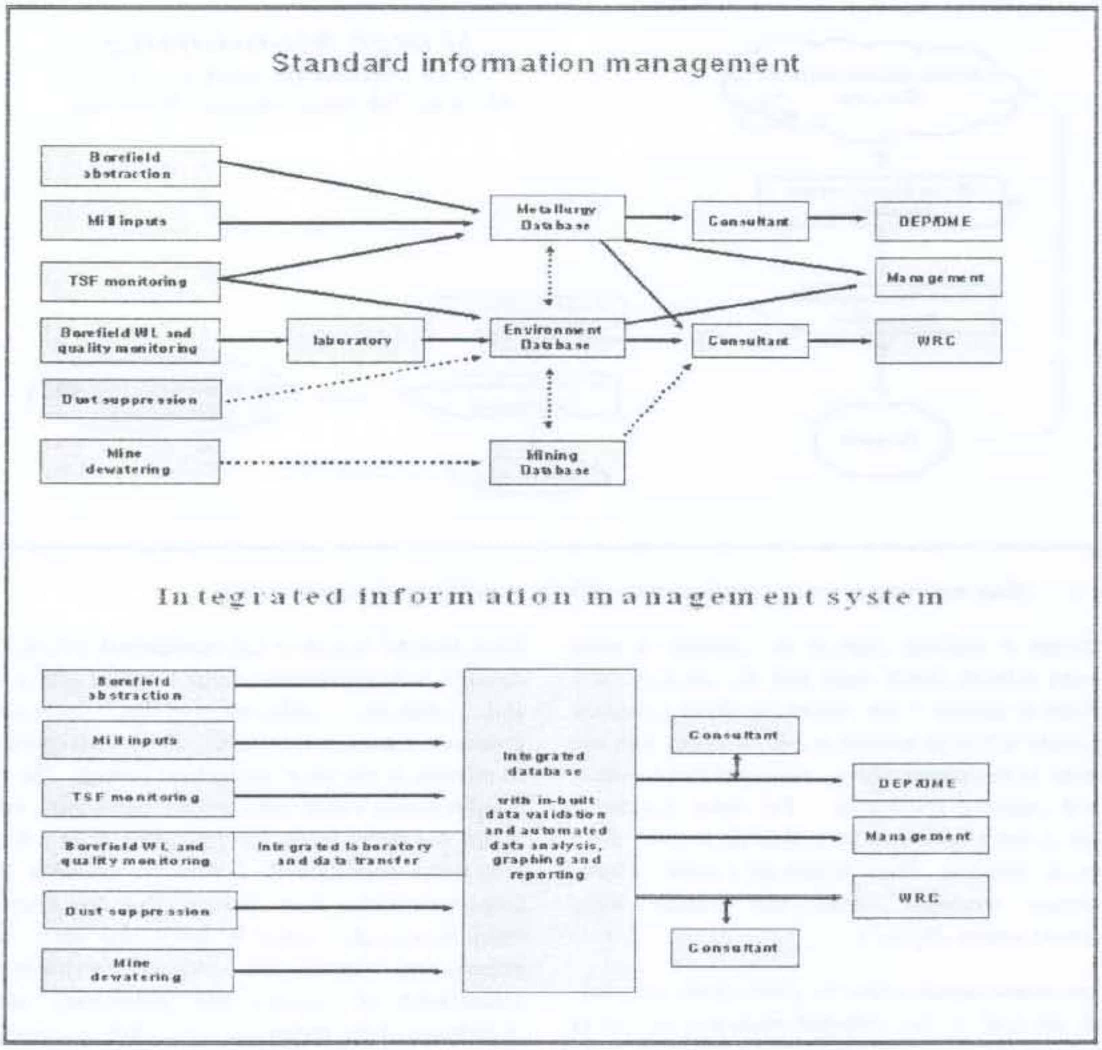

Figure 4: The conceptual information management system

values are concentrations that, if exceeded, would indicate a *potential* environmental problem, and so 'trigger' a management response, e.g. further investigation and subsequent refinement of the guidelines according to local conditions.

Information management and reporting. Effectively monitoring and reporting on water not only demonstrates the mine is meeting its environmental obligations, but provides the mine with an effective management tool for dealing with non-systematic issues. Figure 4 illustrates the concept of a fully integrated information management system.

Stakeholder expectations of the mining industry have increased enormously and environmental performance reporting is now expected to include not only the successes, but also the failures. The community expects companies to demonstrate a sense of frankness, transparency, accountability and responsibility. Liasing effectively and continuously with regulatory agencies and stakeholders is now an important component of mine management and critical in meeting environmental obligations. This has become increasingly important as the regulatory agencies place more reliance on self-regulations. Both mine management and the regulators have to recognise that performance should be judged on "issue identification and management response" rather than strict compliance (often to minimum standards) and ability to avoid/hide issues. Annual water management reports assist management gauge how well a mine is managing a natural resource and costs, and not compliance of legal commitments/regulations. Regulator compliance is best gauged through audits.

Compliance monitoring and reporting is however not only important for influencing stakeholders in order to maintain an environmental licence to operate, but also to improve mining systems/processes to help reduce production costs. Considerable money and resources are invested in monitoring water data across the many mine departments and if not well managed/coordinated results in the development of a multitude of individual management systems (Figure 4).

The integration of these systems across the mine is critical to achieve efficiencies and whole of mine cost savings. The effectiveness of these systems and processes can, however, not be quantified unless annual data reports are prepared and data used for decision making and monitoring programs reviewed regularly and where necessary modified. Only when this is done will it be possible to realise considerable savings.

CONCLUSION

The importance of water management needs to be recognised both at the mine and the company's corporate offices. A fully integrated mine water management system can not only provide operational savings, but deliver whole of mine benefits. Water management is an important component of the environmental management system and there is little doubt that those businesses which fail to act responsibly on environmental issues today, will not get a licence to operate in the future. Community acceptance of a company's environmental management ability has become as important, as financial management when assessing new mining developments.

The minesite water management plan is at the heart of mine water management. The minesite water management plan serves as the central information source on all water issues, water management strategies and deliverance thereof. The monitoring, data management, and reporting systems providing the mechanism for achieving management decisions and stakeholder acceptance. The reporting of data per se is pointless, what is required in reports is identification of issues (and potential issues), possible management strategies and performance of existing management strategies.

The mining industry clearly needs to move beyond regulatory compliance and accept the challenge of striving to achieve "best practice". Water management needs to be taken seriously. Regulators in turn have to embrace the concepts of risk management, self-regulation and cooperative best management.

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"PROGRESSIVE REHABILITATION": LOCKING THE IDEA INTO A SYSTEM TO DELIVER RESULTS.

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1.0 INTRODUCTION

The mining and extractive industries have historically rehabilitated mines in a highly variable manner, often unplanned. Planned decommissioning work was rarely undertaken in the past for numerous reasons, including insufficient regulatory controls and only minor awareness within the industry of the costs and benefits relating to well planned or progressive decommissioning. We define well planned mine decommissioning as - the "Progressive Rehabilitation Process".

Environmental problems from poorly planned decommissioning have become quite apparent at many sites around Australia and throughout the world. Impacts associated with these operations are mainly due to acid rock drainage (ARD), however, many other abandoned and active mine sites also present serious environmental and safety issues such as dust, erosion, sedimentation in waterways, unstable landforms, and visual impacts. A stark example of this in West Australia is the long abandoned Wittenoom asbestos mine where unstabilised tailings continue to pose a threat to public health. The Australian mining industry was also influenced by revelations in the USA and Canadian mining industry of the massive liabilities associated with decommissioning abandoned mines and the creation of the "Superfund programm" (CERCLA, 1980)

Advancements in rehabilitation aimed at progressively closing areas disturbed by mining were most notable in Australia within the bauxite/alumina and mineral sands industries in the 1970's and early 80's. The iron ore and coal industries also began to develop rehabilitation programmes for large areas disturbed through many years of operations. Realisation of decommissioning as an integral part of mine planning and operations management became more prominent through the 90's and is common practice in most current operations. However, there are still many legacies of past practices that will need to be dealt with in coming years.

Mining is a temporary land use and while new orebodies and mineral resources are constantly being discovered through exploration, the reserves contained in any particular deposit on which a project is based are finite. Factors contributing to cessation of mining activities include; depletion of mineable reserves, technical constraints, changes in market conditions, financial viability of the company or even adverse environmental or political conditions.

Unfortunately, sudden unplanned or temporary closures remain common in the mining industry and are most often unforeseen. People providing funds and working within in the mining industry are often very positive and "eternally optimistic". As a consequence, - they tend to not accept that the resource they are mining is finite. However, a mine is exhausting a fixed stock of mineral that cannot be maintained indefinitely (Von Below, 1993). The denial of this fact, in much of the industry, results in a fading out of mines and the staff who run them "Mines never close - they just fade away". This tendency has, in the past, resulted in many mine closures being poorly managed, with considerable environmental consequences and legacies worldwide.

2.0 CLOSURE ISSUES

During the last decade the authors have had to grapple with the issue of mine closure at a series of operations. The lead author was in particular preparing a number of medium size gold mines for the inevitable exhaustion of resources in the mid 1990's. The knowledge gleaned from these experiences came together to generate the Progressive Rehabilitation System (PRS).

On initiation of the Placer Dome "Sustainability Policy" in 1999, Granny Smith Mine commenced a review of all existing systems and how they related to the new policy. This motivated the Sustainability Group at Granny Smith to look at a major project involving a baseline review of the decommissioning issues currently facing the company, and a systematic approach for accountability, implementation and sign off for all closure issues. Subsequently, the first Progressive Rehabilitation System (PRS) was pioneered at the Granny Smith Mine, followed by their Joint Venture partner Delta NL who adopted the system and added the Stakeholder components for its Kalgoorlie operations in 2001. The "PRS" system was formally demonstrated to the DME and many Stakeholders in 1999-2000, and has started to gain acceptance with the managers, owners, operators and regulators of these mining operations.

Until recently, the objectives and principals for mine closure and rehabilitation have been vague. The publication of a Strategic Framework for Mine Closure (ANZMEC/MCA 2000) has now provided a broad position and a series of objectives for the industry to work within. In general, mine decommissioning and closure is the process of shutting down a mining operation with the broad objective of leaving the area in a safe and stable condition, that is consistent with the surrounding physical and social environment and does not need ongoing maintenance. The mine area may also be suitable for alternative post-mining land uses depending on site-specific circumstances. It is at this point that the "Ideals and Goals" of Sustainability become necessary to mention.

Sustainability is an important factor in mine closure considerations and directly links to the ideas of achieving mine closures that are socially acceptable to the community, with few, if any, negative legacies. There is now a wide range of different understandings of the word "sustainability". Broadly, and in relation to mine closure, we define the term as "closure so that the ongoing sustainable use of the land is not overly compromised by the effects of the mining operation". Involving the local stakeholders in deciding on the most appropriate decommissioning option, supports the long-term economic and social sustainability of local communities, and assists in the protection of the environment associated with the mine.

Another important facet of quality mine decommissioning is the achievement of the Triple Bottom Line of Environment, Social and Economic Concerns. The Progressive Rehabilitation System is designed to captures this outcome, and importantly, the issue of Corporate Governance. We believe this can be partially enacted by the initiation and ongoing support of the Progressive Rehabilitation System.

Costs associated with closure can contribute significantly to overall project costs and hence the bottom-line. In some extreme cases unforeseen costs associated with decommissioning can far exceed any financial gains achieved over the life of a project. In most cases it is considered economically efficient to rehabilitate disturbed areas progressively throughout the operational life of a mine. However, despite this general understanding, it is quite common for projects to arrive at the end of their mineable resources with a large and expensive backlog of closure works.

The Strategic Framework (ANZMEC 2000) provides some principles for financial provisions in mine decommissioning as follows:

- A **cost estimate** for closure should be developed from the closure plan;
- Closure costs should be **reviewed regularly** to reflect changing circumstances;
- The **financial provision** for closure should reflect the real cost;
- **Accepted accounting standards** should be the basis for the financial provision; and
- **Adequate securities** should protect the community from closure liabilities.

The intent of these principals should be an objective to be met in any form of PRS, and was one of the focal issues for the designers of the system described in this paper.

In an attempt to prevent degradation of local environmental systems broad objectives for mine decommissioning are often set in the context of a generic outcome. Decommissioning ultimately determines what is left behind as a benefit, or legacy, for future generations. If decommissioning and closure is not undertaken in a planned and effective manner, chances are that the site will continue to be hazardous and a source of pollution for many years to come. The overall objective of mine closure is to prevent or minimize adverse long-term environmental (physical, social and economic) impacts, and to create a self-sustaining ecosystem based on an agreed set of land use objectives.

3.0 The Evolution of Mine Closure Planning through to a Systems Concept

In this section we will essentially draw an understanding of the process from the *Strategic Framework for Mine Closure*, that was jointly developed by the Australian and New Zealand Minerals and Energy Council (ANZMEC) and Minerals Council of Australia (MCA) in 2000, to promote a nationally consistent approach to mine closure management across Australia. The objectives and principals outlined in the Strategic Framework are consistent with a systems approach as they emphasize the importance of continuous planning, implementation and review, throughout the life of a mining operation.

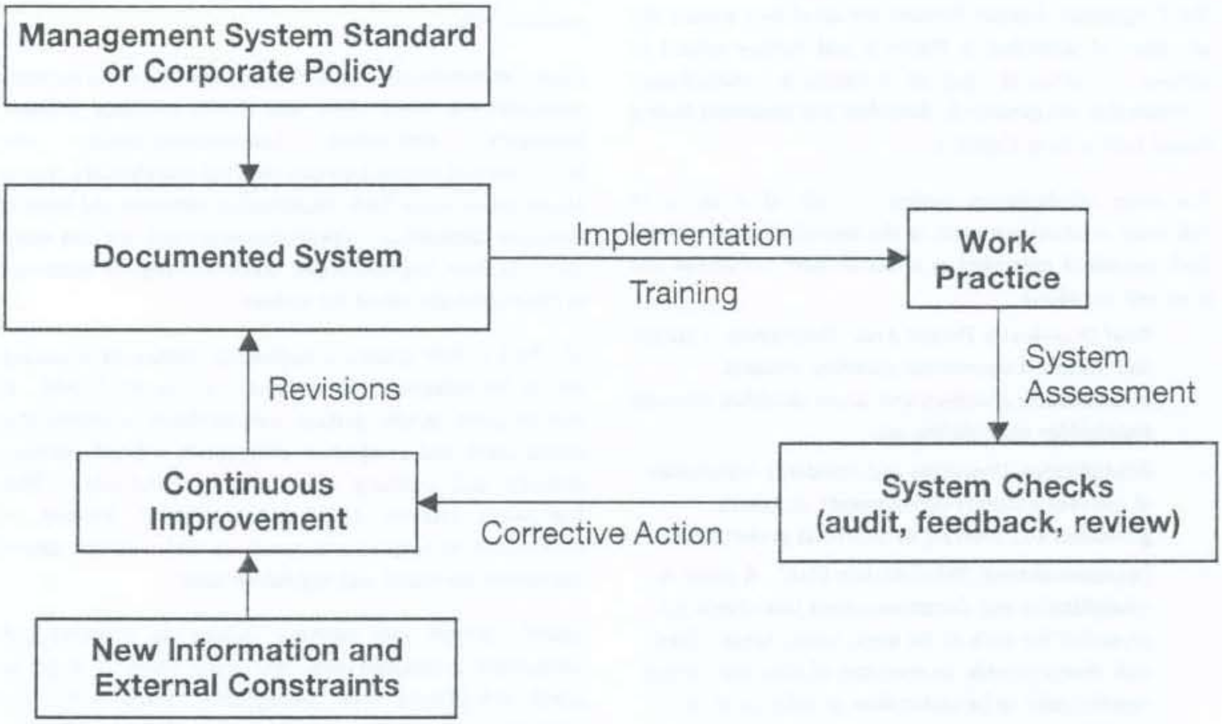
Many mine closure plans currently being developed are largely "regulator driven" through conditions attached to project approvals. Such conditions often require closure plans to be submitted at some stage of the operation, either prior to commencement of mining or at some other interval corresponding to the projected closure date. As a consequence, closure planning and implementation is considered to be an add-on, rather than an integral part of day-to-day operations.

Developing a mine closure plan is not a "one-off" exercise that only occurs prior to project approval or at the time when closure is imminent. Different approaches to closure planning are appropriate to various stages of a project.

Mine closure concepts need to be taken into account in initial project design and feasibility studies, as these may have a significant impact on the bottom-line or even the viability of the project. At this early stage, the mine closure plan may only be a list of broad objectives, basic design criteria and indicative unit costs to guide the engineers and project planners.

A Conceptual Closure Plan can then be developed in conjunction with the environmental impact assessment undertaken for project approval. Information gained through the environmental studies, mine planning and detailed engineering design will help to build on the initial closure concepts to produce the conceptual closure plan. However, it should not be expected that a detailed mine closure plan incorporating definitive completion criteria could be produced at this stage. This can only be done through operational experience, as site specific conditions are better understood, and therefore the concept of the ever evolving closure planning system.

Figure 1: Management System Flow Diagram



During the construction phase, the Conceptual Closure Plan should evolve into the first Closure Plan, and post-mining land use objectives should be refined at this time. This does not preclude land use objectives being varied during the mine life to reflect changes in both knowledge and technology (ANZMEC/MCA 2000). It is well known, but often not acknowledged, that every mining project deviates from the original plan during the course of operations due to a number of factors. It is therefore appropriate that the mine closure plan is regularly reviewed and updated throughout the productive phase of the operations to respond to these changes. More detailed completion criteria can also be developed during operations through experience gained from progressive rehabilitation and research.

Towards the end of the project, the mine closure plan needs to focus on matters such as infrastructure removal and completing the rehabilitation of active areas. The final closure plan must also include a programme for post-closure monitoring to demonstrate that completion criteria have been met.

Systems are becoming widely used in industry for many different purposes. Systems approaches have been developed and applied for quality assurance in design, development, production, installation and servicing (AS/NZS ISO 9001), occupational health and safety (AS/NZS 4801) and environmental management (AS/NZS ISO 14000 series).

The systems approach is most effective when applied to an activity that changes over time as it facilitates regular review and continuous improvement. The Progressive Rehabilitation System described within this paper is designed to reach that ideal. A simple management system flow diagram is presented in Figure 1.

It is therefore logical to apply a systems approach to mine closure. Linking the PRS with the Environmental Management System so that progressive rehabilitation and other closure related activities become part of day-to-day operations can do this. However, as with any other system, it is only effective if it is actively used and maintained. The following key points must be applied to gain the maximum benefit from the system:

- the maintenance of the system is a priority for senior operations management and adequate financial and human resources are allocated to ensure implementation;
- supervisory personnel are involved in the initial development and ongoing review of the system;
- responsibilities for various tasks within the system are clearly allocated;
- tasks are scheduled as part of routine mine planning;
- progress against the tasks is regularly reported;
- the system is periodically audited and updated accordingly.

4.0 SYSTEMATIC WORK – PROGRESSIVE REHABILITATION AND CLOSURE SYSTEMS

The Progressive Closure Systems are developed around the processes as described in Figure I, and further refined to achieve a continual loop of progressive rehabilitation activities that are generically described and generated from a formal system as in Figure 2.

The mine rehabilitation system consists of a series of individual modules for each of the identified project areas. Each module is presented as a "stand-alone" document and is set out as follows:

- Brief Overview of Project Area - Description of recent and historical operational activities, location, infrastructure inventory and issues identified through stakeholder consultation etc.
- Rehabilitation Objectives and Standards - Summary of relevant statutory commitments, standards, guidelines etc, applying to individual project areas.
- Decommissioning/Rehabilitation Plan - A series of rehabilitation and decommissioning task sheets are presented for each of the mine project areas. These task sheets provide an inventory of sites and identify specific tasks to be undertaken in order to meet rehabilitation criteria.
- An enhanced task format has been adopted for infrastructure areas such as the mill, crushing, borefields and other support facilities as these are generally more complex to close.
- Closure Cost Estimate - Cost tables for individual project units based on known rehabilitation and earthwork costs
- Statutory Commitments and Conditions - Series of tables summarizing relevant statutory conditions and commitments covering each respective project area.

5.0 IMPLEMENTATION – COMMUNICATION IS ESSENTIAL

Critical to suitable and harmonious implementation of the PRS is support and ownership from senior management. Corporate staff, the general manager and operations managers must be made aware of the benefits of the PRS and supporting plans. Operations managers can then ensure that their own work plans are aligned to the objectives of the PRS and can integrate their own work schedules to the plan. The modular composition of the system enables simple allocation of particular responsibilities.

For example, rehabilitation trials and seepage management works at the Kanowna Belle tailings storage facility (TSF), were recently completed as part of the contract for the tailings lift, whilst machinery was readily available. Significant cost benefits were realised as processing plant personnel were aware of PRS - TSF closure requirements and so PRS requirements were integrated into operational requirements.

Clear communication of the PRS to operations and external personnel via board visits and within meetings between managers, production superintentendents, site environmental committees and external stakeholders ensure all are aware of the PRS. Stakeholder concerns and input is therefore captured and operations personnel are also made aware of their responsibilities, understanding the outcomes of their tasks and using the system.

The PRS is built around a methodical framework including policy, commitments and objectives, all clearly defined. It also includes specific project area modules, a stakeholder consultation and integration component, a bond recovery strategy and auditing and updating capability. This framework enables easy and consistent transfer of information to corporate accountants and auditors, senior operations personnel and regulators alike.

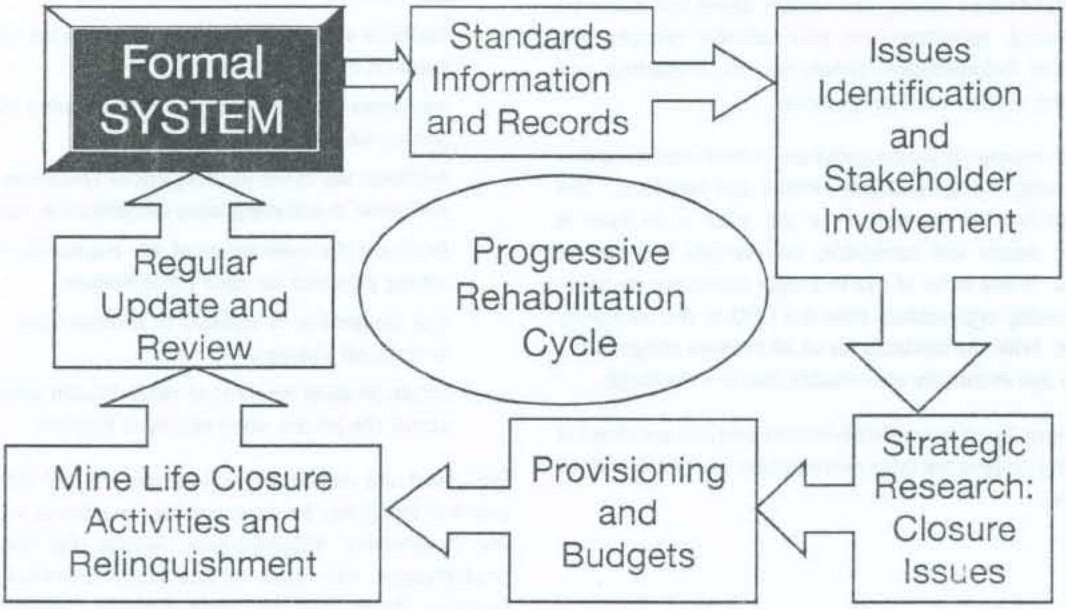
Specific project area modules include an overview and subsequent breakdown into sub- areas where a series of aerial and ground level photographs clearly define the location of the task needing completion. Closure objectives and standards derived from DMPR tenement conditions, NOI documents, CER's and policy documents are compiled and very detailed inventories and task sheets are also completed. Resources and costs required to complete these tasks are derived and included so operations personnel can easily formulate budgets. This feature enables easy integration into day to day management.

The Strategic Framework (ANZMEC/MCA 2000) identifies stakeholder involvement as an essential part of the mine closure process. The PRS follows a series of stakeholder principles:

- Identification of stakeholders is an important part of the planning process.
- Continuous consultation with stakeholders should occur throughout the life of the mine.
- Effective consultation is an inclusive process that encompasses all parties.
- A targeted communication strategy should reflect the needs of the stakeholder groups.
- Adequate resources should be allocated to ensure the effectiveness of the process.

Both Granny Smith and Kanowna Belle have commenced a process of stakeholder iterations and found that it is always challenging to create a successful interface with external stakeholders. Stakeholders often have informed relevant and influential views on aspects of the mining operation but may not always have the technical expertise to become more

Figure 2: Progressive Rehabilitation Cycle



deeply involved in closure planning. Consequently the PRS supports the development of a stakeholder component within the system. An area within the documentation is specifically allocated for stakeholder commitments to be recorded. As an example, Granny Smith Mine has conducted regular stakeholder gatherings for the past three years. During these meetings, the many stakeholder issues relating to closure are captured as a matter of course, and inserted into the system where they will remain to be answered or actioned.

6.0 AUDITING AND REPORTING - A BIANNUAL PROCESSES

With the systems implementation, ongoing auditing is the key to the sustained success of the PRS. Biannual auditing is suggested, and will allow the updating of the system at low cost. The greater the length of time between audits, the greater the effort required to update the system.

The auditing process allows for the:

- Sign off of completed tasks,
- Addition of new tasks,
- Updating new components
- Adjustment of costs and provisions.

The auditing process is usually organized by the Environmental department, however, it cannot be stressed enough, that the system must be integrated into the mine plan in order for a practical task completion schedule to be arranged. Site engineers, managers and mine planners must be involved in the auditing process of the PRS in order for the system to be ultimately successful.

The PRS puts the company in a position to understand its potential costs early in the mine life. Financial provisioning can commence at the beginning of a project but may be highly inaccurate, as it is difficult to predict the course of mine development. The PRS helps a company to focus on the areas of decommissioning where there is the greatest uncertainty in the outcomes. This enables priorities to be set for further work and research studies to be undertaken to better define appropriate rehabilitation and decommissioning of areas not easily rehabilitated.

The biannual review of the PRS ensures that cost estimates must be regularly reviewed to account for project changes including, new developments, progressive rehabilitation, new approaches to decommissioning, changing social expectations and inflation. The review process provides the company with an accurate and current cost estimate of its rehabilitation and closure liabilities.

7.0 CONCLUSION

The PRS has been found to be as effective for closure planning of individual small operations as for large operations, as the initial modules were developed to close small satellite type mines. The Granny Smith and Kanowna Belle mining operations are now actively bringing the Progressive Rehabilitation System into the budgeting, and scheduling of their work programmes.

The PRS represents a new paradigm in best practice and is still evolving, being constantly refined and improved. The challenge for the developers of the PRS is to keep it practical, simple and applicable, with targets that can be achieved. It has to be of use to people across the spectrum of the mining organization from the CEO to the machinery operator. With the tendency for us all to make things overly complex and eventually unworkable, this is a challenge.

In summary, Progressive Rehabilitation Systems are aimed at facilitating progressive mine rehabilitation over the life of the operation.

The application of a systems approach to mine rehabilitation planning and implementation provides the following benefits:

- reduces liabilities associated with mine closure;
- forms a basis for the progressive recovery of securities;
- identifies areas of high risk as priorities for ongoing research and/or remediation;
- maximizes rehabilitation undertaken during the productive phase of mining operations;
- facilitates the direct involvement of operations personnel in achieving mine rehabilitation outcomes;
- facilitates the involvement of key stakeholders in setting priorities for mine rehabilitation;
- it is designed to be updated to accommodate operational changes;
- results in small amounts of rehabilitation outstanding across the project when mining is finished.

Developed and refined in the field over the last three years and now being run by major mining operations, we believe the Progressive Rehabilitation System represents the crystallization into reality of the ideals promoted in The Strategic Framework for Mine Closure (ANZMEC/MCA 2000).

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"MINESITE REHABILITATION – A NEW GENERATION OR 'MINESITE REGENERATION REGENERATION'?"

Adrian Williams[1], Louis Evans[2], Emmanuel Chanda[3] and Ed Barrett-Lennard[1]

ABSTRACT

There is interest amongst Aboriginal groups and others in the development of alternative land-based industries in the Goldfields and other regions. However the strict controls over land clearing in Western Australia act as a disincentive to such development. Mine sites and particularly waste rock dumps are examples of land where clearing has been permitted. Prior to mine closure such areas have to be rehabilitated – usually by the establishment of native local plant species of limited economic value. The only economic value might be seed production to perpetuate the current practices.

This concept paper considers the notion that certain waste rock dumps have the potential to grow novel horticultural and tree crops of native flora. Such crops could include Sandalwood, crops for essential oil production, 'bush tucker' or crops for the production of Aboriginal traditional medicines. Introduced tree crops such as olives may provide other opportunities.

The benefits from such re-use of minesites could include increased local economic diversity, increased long term employment in horticulture and downstream processing, and support for Aboriginal groups and others in the region. A further benefit might be a relaxation of the criteria for completion of minesite decommissioning since the sites will be under continuing active management.

We outline the likely steps and administrative changes that would be required to allow such end uses for minesites to become reality.

INTRODUCTION

This is a concept paper. Its purpose is to alert residents and land users in the mining areas of inland Australia to a project to develop the re-use of decommissioned mine sites for horticultural purposes. The project outcomes promise benefits to all stakeholders, and contributions to the triple bottom line of economic, social and environmental improvement.

Consultations indicate that Aboriginal elders are concerned over the potential loss of age-old Aboriginal knowledge of plants and plant uses. At the same time Aboriginal communities are seeking to become more self reliant and economically independent (Wongi Regional Council, 1993). There have been calls over the last decade from a number of quarters, including State Government, for greater diversification of industry and economy in the heartlands of Australia (Pastoral Wool Industry Task Force, 1993). Aboriginal communities could lead this push towards economic diversification should they wish.

Starting from the premise that the process of industry diversification should begin by considering what is already present, the development of enterprises based on the products from native plants seems most worthy of consideration. This could have the added benefit of providing incentive to maintain traditional Aboriginal knowledge for future generations.

Enterprises that use native flora can be developed on 'wild harvest'. This has three drawbacks for a commercial business. Wild harvest is (1) time consuming, (2) subject to seasonal fluctuations and, therefore, (3) unable to provide continuity of supply. A production system closer to farming is suggested where supplementary irrigation may be available (from pit reservoirs) to maintain production in drier years. However, land-clearing legislation limits the land available for the cultivation of native species (Government of Western Australia, 1992).

There may be an alternative source of land that does not include additional land clearing - by re-using land cleared by the mining industry. Miners are permitted to clear land, but under strict conditions imposed by the Department of Minerals and Petroleum Resources. These conditions include leaving decommissioned minesites in a safe and stable condition, and the payment of bonds to ensure that land rehabilitation work is undertaken to a satisfactory standard. Currently native species of limited economic value are used in the rehabilitation of minesites. This project proposes collaboration between Aboriginal communities, mining companies, schools and TAFE, government and University research teams to develop the use of minesites as the locations for future plant-based enterprises.

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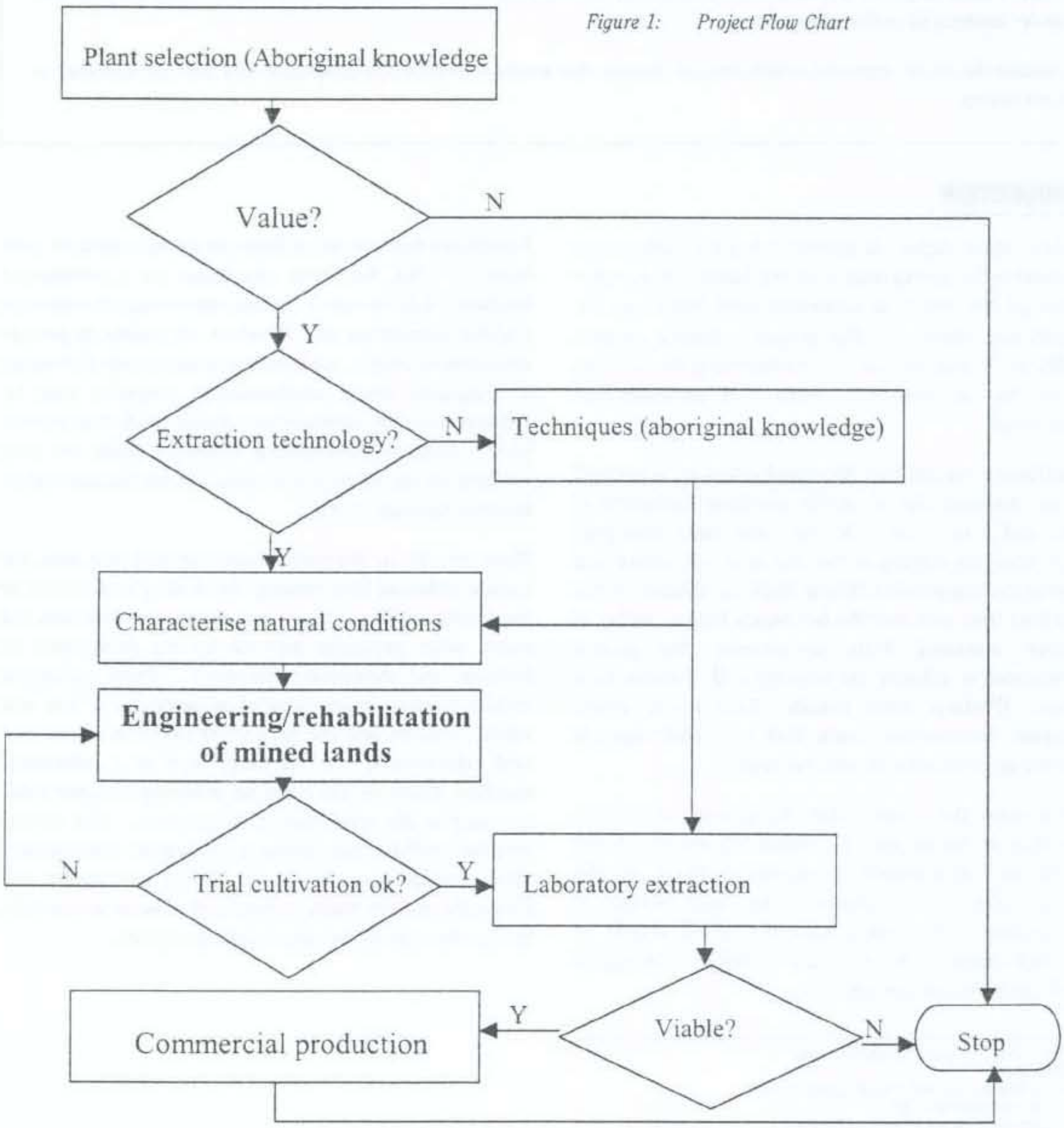
The benefits of the proposal would flow to all the collaborators:

- Aboriginal communities would find the encouragement to maintain their traditional knowledge of plants and plant uses, and use that knowledge as the basis to start economic enterprises.
- Others in the general community would benefit from associated economic opportunities, the multiplier effect in the local economy or from the products that become more widely available as a result of the project.
- Mining companies would gain kudos in the local community. Decommissioned minesites would continue to be actively managed under this proposal, and the rehabilitation of waste rock dumps would be undertaken in collaboration with the subsequent land user. It is anticipated that there would be changes to mining completion criteria and the bond system, along with necessary changes to enabling legislation.
- Researchers would gain new knowledge and validate their role in society by facilitating this exciting and worthwhile project.
- Dump design for new mining projects will take into account dump rehabilitation strategies for future land use.

Figure 1: Project Flow Chart



The project has been given the name 'Plants for People'.

PROJECT DESCRIPTION

A project to maintain traditional Aboriginal knowledge of plants and plant uses and to develop the framework and capability to start enterprises based on growing native plants on decommissioned minesites is bound to be multi-disciplinary. The project would contain the following five sub-projects:

1. Gathering, documenting and valuing Aboriginal knowledge of native plants of medicinal, nutritional, other commercial or cultural value from selected study sites. The development of management plans for conservation of these plants and traditional Aboriginal knowledge of their use (aboriginal heritage and educational initiatives)
2. Developing appropriate technologies for cultivation of plants on mine dumps or other locations (employment creation, science and technology).
3. Laboratory evaluation of the nutritional and medicinal value of selected native plant extracts and compounds and of the production and evaluation of essential oil products derived from cultivated plants (science and technology)
4. Business planning and business development with emphasis on tourism, plant production and essential oils.
5. Legislative changes required to permit re-use of de-commissioned minesites and legislative aspects of safeguarding Aboriginal knowledge of traditional medicines

A Flow Chart of the project is given at Figure 1.

1. Gathering, documenting and valuing Aboriginal knowledge of native plants

This part of the research and development project will be conducted at selected Aboriginal community sites and collaborating minesites in Western Australia. The project will be a cooperative enterprise involving Aboriginal people knowledgeable about native plants and the landscape, mining and pastoral companies, groups of school children and TAFE students, government and university researchers.

Education and training will be an integral part of the program through secondary school and TAFE programs, community training activities and undergraduate and postgraduate research projects. School programs focussed on plant identification and documentation will be an important activity within the project. Plant names will be recorded in the local language as well as English. TAFE students in the Goldfields and Pilbara will commence documenting in which soils and position in the landscape the chosen plants grow well.

TAFE students of horticulture will commence trials on seed germination and storage. They will also commence the study of plant nutrition and water requirements for economic growth.

This sub-project would record the available knowledge regarding the use of native plants. The project proponents recognise and respect the fact that certain traditional knowledge regarding the medicinal use of plants is secret and carefully guarded, and must remain so. An important part of this project is the safeguarding of traditional knowledge while sharing what is available to share.

Mining companies and other sponsors and Aboriginal community elders will be closely involved with the scoping and implementation of this sub-project at its individual and various sites.

2. Developing appropriate technologies for cultivation of plants on mine dumps

Suitable plant species will be identified in Sub-project 1, and passed on to this Sub-project as the plant species that will be the main focus of the trials.

Sub-project 2 will have a number of inter-related sectors:

a.) Engineering design for optimum plant establishment and growth

Existing rock dumps will be surveyed for the success of current plant rehabilitation compared to the soil and environmental characteristics of the sites. Site characterisation will include:

- Plant species present
- Plant measurements in random quadrats or transects
- Date of dump construction, date of topsoiling, and date(s) of rehabilitation
- Topsoil storage prior to use, topsoil depth on the dump
- Cultivation, ripping following topsoiling
- Topsoil material (physical and chemical analysis) and degree of biological activity (index to be developed)
- Characterisation of rock material in the root zone
- Dump slope, size and location of berms and water management
- Height and aspect of inspection sites on dumps

This information will be incorporated with engineering design principles and considerations for accessibility and safety to 'model' an ideal dump design for horticultural uses (McCarter, 1990). In collaboration with a participating mining company and the Department of Minerals and Petroleum Resources this dump will be built as a research site.

Ideally plant growth on this dump should be capable of meaningful comparison with plant growth on adjacent, contemporaneous dumps of normal design and comparable materials.

Other sites will be surveyed and partially modified to provide comparative sites for plant establishment and growth.

b.) *Water management for minimum erosion and optimum plant growth*

The sub-project will undertake hydrological modelling of the catchment in which mines are located in order to assess the risk of flooding during mining and water harvesting potential subsequent to mining. Assistance in planning safe water management and disposal and maintenance of off-site downstream vegetation during mining will be an offshoot of this part of the investigation.

At an individual dump scale hydrological modelling will be incorporated into the engineering design to produce a dump that absorbs the majority of the rainfall that falls upon it. Designs will incorporate safe disposal of excess water from rare rainfall events.

The aim will be to maximise the amount of water available in the root zone without causing a groundwater mound and rising salinity.

c.) *Plant characteristics and horticultural requirements of the chosen plant species*

The sub-project will study the plant physiology of the chosen species and identify soil, nutritional and water requirements through trials in the field and shade house. These studies will identify germination and growth requirements. Field and shade house studies will assess plant survival and re-growth following different methods of harvesting plant parts (for the species where this is appropriate).

The study of plant water requirements for optimum growth will be linked to meteorological and hydrological information to identify likely frequency and quantity of irrigation that will be needed to maintain productive plant growth.

d.) *Identification of training needs in the area of site design and plant management for horticultural purposes*

The sub-project will develop a statement of training needs both for mining company personnel and for those who will re-use and manage the decommissioned minesites. Training packages will be prepared as an output of the project.

Subjects would include:

- Minesite rehabilitation techniques
- Horticultural practices - particularly applied to native plant species of economic importance
- Irrigation technology and practice
- Research and survey methodology
- Plant monitoring techniques
- Seed technology
- Meeting procedures
- Report preparation

3. Laboratory evaluation of the nutritional and medicinal value of selected native plant extracts and compounds and of the production and evaluation of essential oil products

A number of Research Centres from universities across Australia will each analyse the use of one or more native plant species. Again, this will depend on the traditional knowledge of native plants that Aboriginal people are prepared to share. The analyses will include extraction, preparation and storage of 'bush tucker', traditional medicines and essential oils. The extraction of essential oils, the use of native plants for non-traditional medicines (such as the relief of diabetes) and the use of introduced plants (such as the Brahmi plant in Queensland) are not subject to Aboriginal traditional taboos or impediments. Work on such plants can start as soon as the project is financially supported and government permits and licences have been issued.

4. Business planning and business development

In this section economic, management and marketing specialists will work with Aboriginal groups or individuals to develop business skills. Together they will develop business plans for tourism, horticulture, minesite rehabilitation and essential oil production. The businesses will be based on native plants and in some cases introduced plants. The sub-project will also research business systems best adapted for use in conducting these enterprises and will provide assistance in the development of business enterprises.

5. Legislative changes required to permit changes in land use and safeguarding of traditional knowledge

The re-use of decommissioned minesites will involve on-going and active land management. This will require a re-thinking of the completion criteria and legislation concerning mining as an industry and a land use. It will also require new thinking regarding safe and sustainable practices for the following land use enterprise, the new form of land tenure and the process for change in tenure between mining and subsequent land users. Members of the research team intend to work with industry, community and government stakeholders to draft recommendations regarding these administrative issues.

The required completion criteria and the system of bonds is likely to change in the light of ongoing, active site management, as is the issue of continuing levels of liability. Such legal issues will be addressed in this sub-project.

Legal aspects of the intellectual property rights associated with traditional Aboriginal knowledge of plant uses will be reviewed with the intention to strengthen those rights and to identify who holds them.

ADHERENCE TO ETHICAL PRINCIPLES AND GUIDELINES

We believe that it is important to emphasise that the project will be conducted in accordance with the Guidelines for Ethical Research in Aboriginal Studies developed by the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS). Study sites for Aboriginal Heritage and Business Development initiatives will be selected following consultation and negotiation with the Aboriginal community and community leaders. Core team members of each of the five sub-project teams will be nominated and chosen by community members. The community projects will be conducted in stages, with communities at selected study sites playing an active role in identification of study aims and methods and providing approval for advancement to the next stage.

Significant input with respect to Aboriginal knowledge systems and processes will be fundamental to successful project outcomes. Study sites will be selected at geographically distant sites so as to encompass a diversity of inputs and outcomes. Insofar as Aboriginal people are prepared to divulge traditional plant information, particular attention will be paid to intellectual and cultural property rights. This is to ensure that maximum benefits arising from the study (eg. patents on medicines, bush food ingredients) will, as far as possible within the Australian legal system, flow to Aboriginal community participants. At the commencement of the research at a selected community site a formal agreement will be negotiated for the conduct of the research and distribution of benefits to ensure compliance with the AIATSIS guidelines.

OUTCOMES

The range of outcomes from the project will become clearer once the project has been running for about one year. At this stage the anticipated outcomes include:

1. New policies for mining completion and the re-use of decommissioned minesites
2. Clearer goals for completion of minesite decommissioning and closure due to new procedures for mining completion that benefit the mining industry
3. Increased economic self reliance amongst Aboriginal people due to the development of alternative, profitable land-based enterprises in mining areas of inland Australia and the development of business skills and plans to run such enterprises
4. Improved health. In particular due to:
   - Development of plant product materials for the use in treatment of diseases in the community - particularly in Aboriginal communities
   - Development of novel topical applications for treatment of skin conditions that occur in high prevalence in Aboriginal communities
5. Increased biodiversity on decommissioned minesites and community controlled natural resource management and conservation of native plants of importance in local ecosystems
6. On-going management of mined areas after the completion of mining operations
7. Increased tourism destinations based on demonstrations of native plant culture and use
8. The development of an essential oil industry based on native plants
9. The development of business system models for Aboriginal business enterprises
10. Improved courses at school and tertiary levels (including TAFE) based on the knowledge derived from the project. This will be developed through the production of websites, displays, pamphlets and other forms of publication documenting botanical descriptions along with the environmental, economic and cultural values of selected native plants, and new technology for mine closure.

SUPPORT FOR THE PROJECT PROPOSAL

The project has been accepted as part of the bidding documentation for the proposed Cooperative Research Centre for Desert Knowledge (CRC DK). The proposal for the CRC originated in the Northern Territory. This project and its host WA institutions will become a node of the CRC if the Federal Government accepts the proposal. When an earlier version of this project was presented to the Chamber of Minerals and Energy (Eastern Region Council) there was in principle support for the concept. At that stage the project was insufficiently developed for companies to fully commit to the proposal. The project has received the support of the Department of Minerals and Petroleum Resources Environmental Division. The Minerals and Energy Research Institute of Western Australia (MERIWA), the Australian Mining Industry Research Association (AMIRA) and the CME Environmental Committee have all expressed interest in the project. More recently branches of the State Government have indicated a willingness to consider financial support for the project through the creation of a virtual Centre of Excellence in 'Plants for People'.

The Western Australian Department of Training has invited Curtin University in conjunction with Karratha TAFE College to submit a proposal to the Science and Technology Innovation Fund. The submission will be for a TAFE level research and development project involving early parts of the overall 'Plants for People' project.

The University schools and centres that have expressed an interest to be involved in the project include:

- The Aquatic Science Research Unit, Muresk Institute of Agriculture, Curtin University
- Centre for the Management of Arid Environments, Curtin University
- Western Australian School of Mines
- Mulga Research Centre, Curtin University
- Physiology Department, University of Western Australia
- Department of Biomedical Science, Charles Sturt University, NSW
- School of Pharmaceutical, Molecular and Biomedical Sciences, University of South Australia
- Department of Biological Sciences, Macquarie University, NSW
- Curtin Indigenous Research Centre (CIRC), Curtin University, WA
- Centre for Indigenous Natural & Cultural Resource Management (CINCRM), Northern Territory University
- Western Australian Chemistry Centre
- Massey University, NZ
- University of Winsconsin, USA

Representatives of the following mining companies have expressed an interest in the project:

- Sons of Gwalia Limited
- AurionGold
- Kalgoorlie Consolidated Gold Mines
- Wesfarmers Premier Coal Limited
- Griffin Coal Mining Company Limited

Others are yet to be approached.

PROPOSAL

The next stage in the process of project development will be a one-day workshop in Perth for invited interested parties during the second week of June. The participants will be presented with an update on the project and related issues, and will be asked to develop the proposal to the next level of discrete action statements and milestones. Stakeholders are being canvassed and invited to attend.

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ECOSYSTEM FUNCTION ANALYSIS MONITORING OF THE DECOMMISSIONED BOTTLE CREEK MINESITE (1998 – 2001)

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INTRODUCTION

An opportunity to assess the effectiveness of EFA as a rehabilitation monitoring method at the Bottle Creek minesite was undertaken in November 2001. In conjunction with seven officers from the Department of Minerals and Petroleum Resources, a two-day field trip was utilised as a training tool for the officers by Outback Ecology Services (OES) staff and for data collection. This fully relinquished site had previously been monitored by two other environmental consulting companies undertaking EFA, allowing for a data set spanning three consecutive years.

Ecosystems are defined as "communities of organisms interacting with one another and with the chemical and physical factors making up their environment" (Miller, 1990 - pg A40). The condition of an ecosystem is reflected in the level of functionality displayed. Ecosystem restoration, as undertaken in minesite rehabilitation, can be monitored through Ecosystem Function Analysis (EFA). This field monitoring tool developed by members of CSIRO, is used to assess the functional status of natural and rehabilitated ecosystems. Three modules are incorporated in the EFA method. These include 1) Landscape Function Analysis (LFA), 2) Vegetation Dynamics and 3) Habitat complexity.

LFA involves two procedures, which includes characterising the landscape into strata or landscape zones and conducting soil surface condition assessments for each of the identified landscape zones. The process is usually carried out down a slope following the line of resource flow (Tongway *et al.*, 1997; Sarre, 1998). In the first component of LFA, the slope is characterised into run-off and run-on zones, where the sections of the slope that shed and accumulate resources are identified. The second step involves a soil surface assessment of the landscape zones using a set of indicators. Scores are allocated to each of the soil surface features, according to the criteria outlined in Tongway and Hindley (1995). This data is used collectively to provide indices for the stability, infiltration and nutrient cycling in the landscape. These processes are important to landscape function because when the soil, water and nutrients within the system are being conserved and recycled, it is considered to be highly functional (Burnside *et al.*, 1995).

A vegetation monitoring programme is conducted in conjunction with LFA to provide information about the condition of the vegetation. The condition and extent of the vegetation in a landscape is integral to ecosystem function, particularly in arid and semi-arid environments, as plants help to conserve moisture, and leaf litter produced contributes to mulching effects on the soil surface (Burnside, *et al.*, 1995). The Point Centre Quarter (PCQ) method, a plotless vegetation monitoring technique, is used. This technique is described in detail by Mueller-Dumbois and Ellenberg (1974).

The habitat complexity assessment has been adapted from a method used for habitats in a forest structure for Eucalypt dominated forests and is based on research conducted by Newsome & Catling (1979) and Catling and Coops (1999).

The habitat complexity technique assesses the capability of the landscape and plant community to provide niches for vertebrate fauna. The method comprises five indicators that are important features to vertebrate fauna in arid and semi-arid environments. These indicators include the stratification of the plant community, the presence of logs, rocks and debris for faunal habitation, the level of ant activity evident and the availability of water.

The EFA data for the rehabilitated sites is considered in relation to the data recorded at analogue sites. Plotting the results over time will reveal whether the rehabilitation is improving with time and approaching the values of the analogue or whether the values are plateauing at a value below the critical threshold for sustainability. The critical threshold is determined as the range of values that indicate that the ecosystem is functioning at a sustainable level, where further inputs of nutrients, seed, water or management are not required for the system to be self-sustaining (Tongway, 1999).

SITE HISTORY

The Bottle Creek Gold Project is located on two Mining Leases, M29/150 and M29/151, and is 95km North West of Menzies.

The mine commenced operation in June 1988 and ceased operation in November 1989. The initial 1987 Notice of Intent (NOI) (Dames & Moore, 1987) was prepared for the Electrolytic Zinc Company of Australasia Ltd a subsidiary of North Broken Hill Holding Ltd. Three open cut pits were established during the operational stage of the project. These were the V.B., Boags and Emu (partially mined) pits, with associated waste dumps constructed adjacent to the pits.

A plant site, ROM pad, two tailings storage facilities and a 36 km process water pipeline (which extends to the south of the mining leases) were also constructed.

A mine camp was established along with an airstrip and associated borrow pits, and a geological exploration camp also existed.

On 1st May 1990 the State Mining Engineer, from the Department of Mineral and Petroleum Resources (the Department), approved a proposal submitted by Norgold Limited (holder of M29/150 and M29/151) titled "Proposal for Rehabilitation of V.B. and Boags Waste Dumps Bottle Creek Mine" (Dames & Moore, 1989) which allowed for waste dump batters to remain at the angle of repose (approximately 36 degrees) with topsoil spread over the upper surface of each batter, berm and the top surface of the waste dump.

The criteria for acceptance of this design by the Department was that the waste dump landforms would be safe stable structures.

In October 1992, the Minister for Mines imposed further conditions on the two mining leases. One of these conditions required the final outslopes of the waste dumps to have a maximum slope of 20 degrees from the horizontal. Another condition required Unconditional Performance Bonds to be lodged with the Minister for due compliance with environmental conditions imposed on the tenements.

The mine was initially rehabilitated in 1994. However in February 1995, 300mm of rainfall from cyclone Bobby resulted in significant erosion gullying on the Boags and V.B. waste dumps. The Department requested the owners, Norgold Limited, undertake appropriate rehabilitation works to repair the damage caused by the cyclone.

On 6 September 1996, Norgold Limited requested that the Department release the Bonds held against both Bottle Creek tenements. An Environmental Inspector from the Department, undertook a site inspection of the tenements in the company of a Norgold Environmental Officer on 24 September 1996. This inspection resulted in a report, from the Department, detailing a number of issues that required attention prior to either Bond being retired. These issues included such things as remediation of erosion gullies, reseeding poorly vegetated areas, battering-down of slope angles (on some of the remaining structures), application of topsoil to several areas, backfilling of drillholes etc. The list was extensive and there were numerous items that were unsatisfactory.

Two more joint sites inspections were undertaken on 30 October 1996 and 23 June 1997. Norgold Limited was requested to submit a rehabilitation plan to detail how, when and to what standard it would undertake the remediation works required by the Department.

In November 1997, Norgold Limited submitted a document titled "Bottle Creek Gold Mine Rehabilitation Project" (Knight Piesold, 1997). This document was a scope of works that detailed the proposed civil project works that were planned for the minesite.

The document addressed the following aspects.

- Removal of all mine and process plant equipment, pipework, fencing, concrete, steel, exploration sample bags, debris and rubbish from the entire project work area.
- Reshape, redevelop and rehabilitate all defined areas, as detailed in the contract clauses and shown on the drawings.

  (This included reducing the slopes of the waste dumps to less than 15 degrees, the tailings dam walls to 17 degrees and the Emu pit walls to less than 15 degrees from the horizontal).
- Reseeding of topsoiled areas with a mixture of native plant species.
- Securely plug all drill holes, exploration holes and bore holes and flag areas for deep ripping.
- Construct stormwater diversion works and creek diversion (Bottle Creek).
- Construct abandonment bunds along design alignment and repair existing bund wall.
- Excavate and place topsoil in specified areas, as defined on the drawings.
- Contour rip batters, deep rip roads, access corridors and other specified areas.
- A wire-mesh fence was erected around the perimeter of the rehabilitated structures to exclude stock and other feral animals.

These activities were completed in May 1998 by Consulting Engineers, Knight Piesold.

There were several aspects of the mine infrastructure that were not included in the rehabilitation project, and these were items that the local pastoralists had requested be retained for their use. These items are outlined below.

- Bottle Creek Airstrip
- Exploration (Geologist) Camp access road
- Site access road from Mt Ida Road
- Airstrip access road.
- Former exploration camp site
- Former borefield access road (4m width)

Pastoral lessee's from Perrinvale, Riverina and Walling Rock stations accepted all responsibility and obligations associated with the use, maintenance and rehabilitation of the above-mentioned infrastructure.

As a consequence, the Department exempted Norgold Limited from all responsibilities associated with these items.

In February 1998, the pastoralist raised some concerns about deterioration of rehabilitation work undertaken along a fence line and this issue was resolved by Norgold Limited to the satisfaction of the pastoralist on 18 June 1998.

The Department undertook another site inspection in May 1998 and detailed further rehabilitation works which needed to be completed. In June 1998, part of the perimeter fence was cut down, allowing feral goats to enter the rehabilitated areas.

In November 1998, Norgold Limited's consultants ERA Environmental Services, submitted a compliance review (of mining lease conditions attached to the Bottle Creek project) as well as a monitoring program report (which included information on LFA results).

A close-out inspection was undertaken on 14 December 2000, by five Environmental officers from the Department of Mineral and Petroleum Resources, an officer from the Department of Agriculture WA and Rio Tinto's (Norgold Limited) Manager of Human Resources and Corporate Relations.

The close-out inspection identified two issues that had not been resolved to the satisfaction of the Department. One was the possibility of acid rock drainage emanating seepage from some of the remaining structures and the other issue was that of the presence of feral goats within the fenced area.

Rio Tinto (who bought out Norgold Limited) investigated these concerns, and subsequently addressed them to the satisfaction of the Department. The Department's Environmental Inspector responsible for handling the Bottle Creek Mine, recommended that the Bonds be returned to Norgold Limited and that all tenement conditions relating to the project be deleted from the schedule of conditions attached to each tenement.

On 28 November 2001, the Minister for State Development (formerly the Minister for Mines) deleted all tenement conditions associated with the Bottle Creek Project and returned the Bonds. Thereby confirming that Norgold Limited had rehabilitated the site to the satisfaction of the State Mining Engineer.

Rehabilitation Programme

The Bottle Creek minesite was originally rehabilitated in 1994 which included the capping of the tailings storage facility with 0.5m of waste rock. The failure of the rehabilitation across the site was attributed to the steep batter angles (approx 30 degrees) and the limited use of topsoil and seeding. In 1998, Norgold Limited undertook a major rehabilitation programme which involved the reshaping of waste landforms and the reduction of slope angles to approximately 15 degrees or less (17 degrees for the tailings dam walls). Topsoil was applied to an average depth of 100mm on the VB and Boags landforms and 50 to 150mm on other areas. Surfaces were deep ripped along the contour and seeded with a mix of 23 native species at a rate of 7.82kg ha^{-1}. In total, 184 hectares were seeded. Fertiliser was aerially sprayed at a rate of 300kg ha^{-1}.

In May 1999 a further seeding of seven additional species (predominantly Acacia species) was conducted at a rate of 2.42kg ha^{-1}. Of the two cells of the tailings dam, plant establishment was successful on Cell 2 but failed on Cell 1 after the original 1994 rehabilitation. In 1998, 0.7m of waste material and 200mm of topsoil was placed on Cell 1 before contour ripping and seeding. All major rehabilitation areas were fenced.

Monitoring Using EFA

In April 1998 an EFA monitoring programme was established at the Bottle Creek minesite by an environmental consultancy. Ten survey sites, comprising two 20m transects, were established on the constructed landforms with one analogue site placed in undisturbed mulga woodland on the Ida Range (approx. 2.6km from the minesite). Three waste landforms (VB, Boags and Emu), Cell 1 of the TSF, the ROM pad and Emu pit were assessed. LFA and vegetation surveys were conducted in April and August 1998 and February and October 1999. In January 2000, a second consulting company undertook the EFA monitoring of the site, conducting both LFA and vegetation surveys.

In November 2001, Outback Ecology Services was commissioned to involve Departmental Officers in a workshop to reassess the Bottle Creek rehabilitation using EFA. The purpose of this exercise/workshop was to assess the effectiveness of EFA as a rehabilitation monitoring tool, document the progression of the rehabilitation and to provide instruction in the field methodology of EFA to the seven attending Departmental officers. Assistance in the interpretation of EFA results was also provided to allow for the understanding and critique of future EFA monitoring within the mining industry.

The ten sample sites were revisited however the two 20m transects were replaced by a single transect placed between the original transects and traversing the entire slope of the batter. An erosion assessment was also added which involved the placement of two 50m transects perpendicular to the LFA transect, one on the upper slope and one on the lower slope. Erosion features were measured and an average proportion of the bank eroded was calculated. Habitat complexity was not assessed as the previous EFA monitoring had not included this component. The original analogue site located in dense Mulga woodland was not revisited as the vegetation community was not considered a realistic comparison to the rehabilitation. Two new analogue sites were established on hillslopes within the vicinity of the mine. The first was established in an open Acacia woodland with an understorey of *Ptilotus obovatus* and the second in an open Casuarina woodland with a *Maireana sedifolia* understorey. It should be noted that analogue sites are used only as a representative guide of values attained by ecosystems in the area surrounding the mine area.

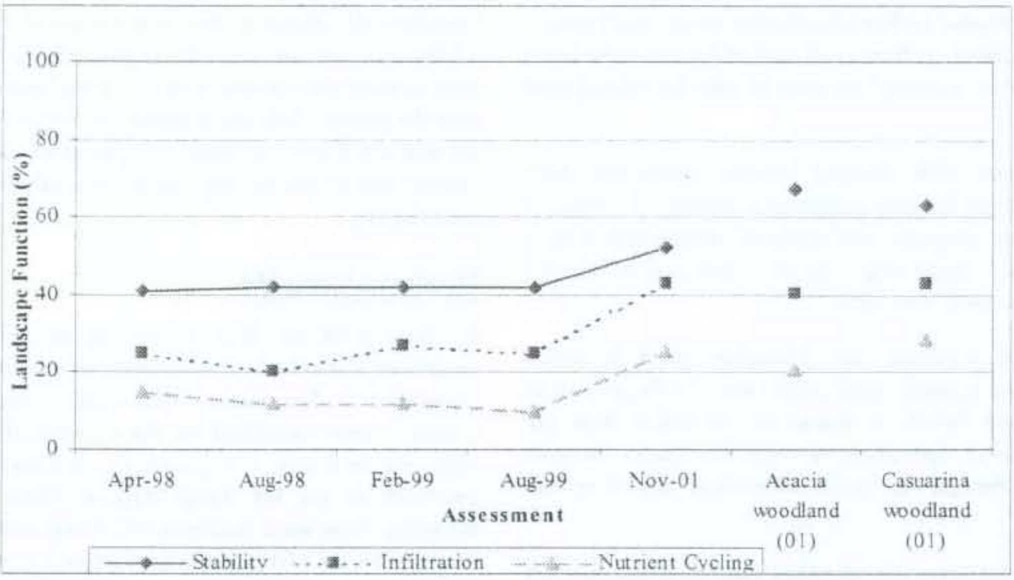

Figure 1: Landscape condition for rehabilitation on the eastern face of the Boags waste landform, in comparison to the analogue sites.

Results

The LFA data obtained from the November 2001 monitoring was added to the historic data set and graphed. It became apparent that the LFA monitoring undertaken in January 2000 had returned values that indicated a discrepancy in the field methodology of the soil assessment. This data was removed from the data set. It was also noted that vegetation assessments conducted previously had included a number of annual plant species. As only perennial species were included in the November 2001 assessment, fluctuations within the data set were evident. All sites showed improvement in regard to ecosystem function as the stability, infiltration and nutrient cycling indices had increased steadily since the initial assessment in April 1998. Figure 1 presents the LFA data for the rehabilitation on the eastern face of the Boags waste landform.

The vegetation on the eastern face of the Boags waste landform had established well, reflected in the increase in the stability, infiltration and nutrient cycling indices between the initial assessment and the November 2001 monitoring. The level of litter retention across the slope was high, both in troughs and on vegetated banks, contributing to infiltration and nutrient cycling values that were comparable to the analogue sites. The stability value remained lower than that

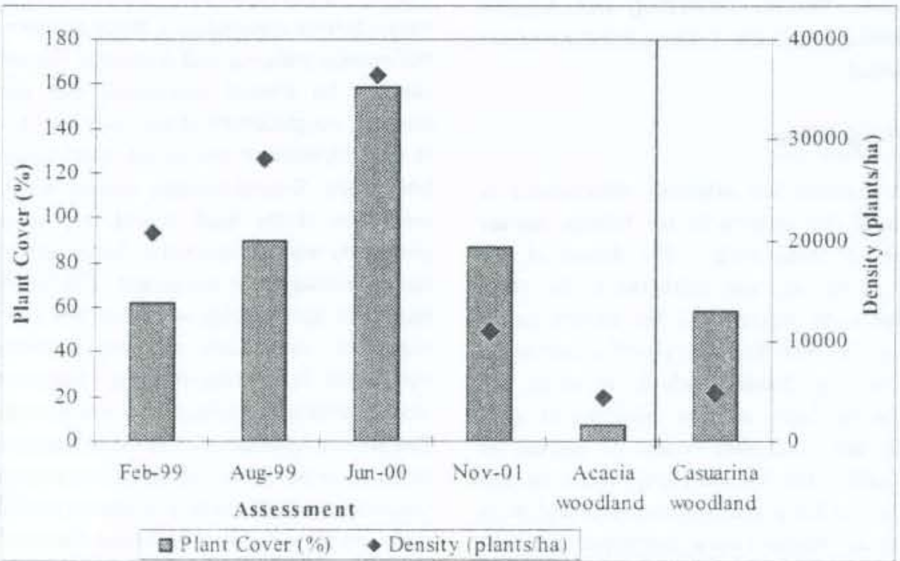

Figure 2: Plant cover and density for the rehabilitation on the eastern face of the Boags waste landform, in comparison to the analogue sites.

of the control sites. The level of protection from rainsplash erosion was high at both analogues due to the high level of rock coverage of the soil surface. Although this coverage is absent from the rehabilitation, it is expected that further development of the vegetation community will serve to increase the stability value.

The combination of LFA, vegetation and erosion assessments assisted in determining areas of rehabilitation at the Bottle Creek site that were developing well while highlighting areas that performed less strongly. Many of the rehabilitation sites recorded infiltration values comparable to or exceeding those of the analogues. These values reflect a good plant density, water trapping zones and adequate leaf litter in the transects. Similarly, the nutrient cycling values for many of the rehabilitation sites were comparable to those of the analogues. This relates to a higher density of perennial plants and a subsequent high level of leaf litter. The vegetation results for the eastern face of the Boags waste landform are presented in Figure 2.

The results presented in Figure 2 were indicative of the majority of rehabilitation sites in that the current level of plant cover and density were comparable to, or in excess of, that of the analogue sites. The earlier vegetation assessments included a number of annual species, hence the higher vegetation parameters. Rehabilitation of the Bottle Creek minesite was dominated by species of Maireana and Atriplex. It was promising to note the presence of Acacia species on the TSF, Boags landform and the ROM pad, indicating the possible future formation of a scattered overstorey, as is evident at the analogue sites. At the November 2001 assessment, weeds were absent from the Bottle Creek rehabilitation.

All the rehabilitation sites monitored at Bottle Creek can be considered to be progressing well. With regard to EFA highlighting less successful rehabilitation, the least stable slope of all the sites was that of the ROM pad. It should be noted however, that this rehabilitation returned strong infiltration and nutrient cycling values as the level of plant density and cover exceeded that of the analogues. A lower stability value in comparison to other sites was the result of the presence of a higher level of erosion (approximately 5% of the bank eroded). In turn, this may be attributable to the steeper slopes when compared with the other waste landforms. However, this level of erosion may still be considered low. The erosion assessments conducted on the Bottle Creek rehabilitation showed little or no erosion, due in part to the successful establishment of perennial vegetation. The reduction of the batters to approximately 15 degrees (at the majority of sites) and deep ripping along the contour appears to have created landforms capable of withstanding significant rainfall events (eg 108.8mm in 72 hours, March 1999) without incurring major erosion.

CONCLUSIONS

The addition of the EFA data obtained from the November 2001 monitoring to the historic data base, indicated that the rehabilitation of the Bottle Creek minesite is progressing well. All sites showed improved ecosystem development with increases in the stability, infiltration and nutrient cycling indices evident. The rehabilitation generally recorded infiltration and nutrient cycling values comparable to those of the analogue sites due to the successful establishment of the perennial plant community. Stability values were lower than the control sites but it is expected that future development of the plant community will result in an increase in this index.

The comparison of data obtained during the November 2001 monitoring, with that from earlier assessments, highlighted that to maintain an industry standard:

- Users of EFA must be competent in the field methodology of the system; and
- The EFA field methodology must be applied consistently.

Variation from the standard EFA method, whether from a lack of competence or consistency in application of the methodology can potentially produce significant data variations which can detract from the value of the technique.

To verify the value of the EFA monitoring technique, the Department intends to continue monitoring the Bottle Creek site using the EFA methodology.

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DEVELOPING COMPLETION CRITERIA FOR REHABILITATION ON ALLUVIAL MINED AREAS IN DRY TROPICAL SAVANNAS

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ABSTRACT

*Success on mine rehabilitation areas can be assessed on the basis of completion criteria. Argyle Diamond Mine (ADM) processes alluvial deposits along Limestone and Smoke Creeks in the Kimberley region and has mined over 1000 hectares of land that is in the process of being revegetated. ADM requires completion criteria to be formulated for mined terrace areas at their alluvial minesite. Few studies worldwide have addressed the issue of practical completion criteria for mined lands in dry tropical savannas, which are characterised by highly variable and strongly season rainfall, frequent fires and a mosaic of herbaceous and woody plant communities. This paper examines the plant ecological aspects of the alluvial mine rehabilitation process at ADM, and rehabilitation progress in relation to objectives. The characteristics of the tropical savanna system are compared with those of the southwest of Western Australia where rehabilitation of mine sites has a longer research record than in the far north. In both systems, understanding the biology of species and the impact of fire is critically important. However, there are also important differences related to the environment and the species and communities that occur in the respective locations. The vegetation on the terraces beside the creeks (*Plains *vegetation) was suitable as a reference community on which to base completion criteria for assessing the success of the alluvial mining rehabilitation areas. It appears unrealistic in the short-term, to expect rehabilitated communities to be closely similar to what existed before mining. However, reinstated plant communities should contain dominant local species that are functionally similar to those that were present before mining. During the development of completion criteria for the dry tropics it is necessary to take into account the patchy structure of the natural vegetation and the highly variable climatic conditions.*

INTRODUCTION

Dealing with the changes in landscapes and landforms resulting from mining and the large amount of waste produced in the mining and ore refining processes has undergone considerable change over the last 50 years (ANZMEC and MCA, 2000). In some parts of Australia rehabilitation practices are well advanced after many years of research and development. Strong commitment to research has produced a quite detailed knowledge of the way natural plant communities operate and how plants regenerate after disturbances (eg. Bell, 1999; Herpich *et al.*, 1994; Ward *et al.*, 1997). However, it is becoming apparent that there are no universal solutions to mine site rehabilitation. What is needed is knowledge of the function of ecological systems and the biology of the species in the area where the mine occurs (Lesica and Allendorf, 1999). Appropriate knowledge is needed to ensure a successful result with an optimal input of resources.

While considerable advances in rehabilitation techniques have been made, it is not always clear that the vegetation on rehabilitated mine sites will be self-sustaining. Community concern for the sustainability of rehabilitated landscapes and governmental requirements that companies, rather than the general community, are responsible for rehabilitation means that systems need to be in place to ensure success and accountability. Devising completion criteria is one approach that is intended to guarantee accountability for the proposals put forward by mining companies for their rehabilitation (ANZMEC and MCA, 2000).

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In southern Western Australia significant research into completion criteria has been undertaken on mineral sands mines in the Kwongan heathlands and bauxite mines in the jarrah forest. Minerals sands mining at Eneabba removes topsoil followed by extraction of minerals using either dry surface methods or wet dredging. Rehabilitation involves pumping of clay and sand tailings back to mined-out pits (Herpich et al., 1994). Bauxite mining differs as a complete soil horizon is removed in the mining process (Ward et al., 1988).

For Iluka's (formerly RGC's) Eneabba operation, completion criteria for vegetation take the form of targets for plant species/m^2, plant density/m^2 and percentage plant cover which is applied to all rehabilitated areas uniformly (Petersen and Brooks, 1996). Plant establishment is not predictable and establishment rates are linked to water availability and seed biology (Herpich *et al.*, 1994).

Completion criteria for vegetation at Alcoa's bauxite operations are applied uniformly at all locations but criteria change over time, reflecting the aspect of ecosystem function which is important at that stage of development. Rehabilitated areas are assessed at 9 and 15 months after rehabilitation, if criteria are not met at these times rehabilitation works may need to be repeated (Elliott *et al.*, 1994; Ward *et al.*, 1996). For bauxite mining in the jarrah forest, these approaches have been refined over thirty years of research and have shown that rehabilitation prescriptions produce predictable and relatively uniform outcomes on a year to year basis.

In this study we contrast the tropical savanna of northern Australia with those of the better known southwest in order to develop ideas about criteria for revegetation which could be used to judge the progress of rehabilitation work on alluvial mine areas at the Argyle Diamond Mine (ADM) in the east Kimberley region. We ask:

1. What are the main differences and similarities between the tropical savanna and southwest ecosystems that are relevant to land rehabilitation?
2. What is the intended state for the post mining landscape?
3. What are the appropriate analogues that could be used as a guide for planning rehabilitation activities?
4. What are appropriate preliminary completion criteria for assessing the revegetation success in the alluvial mine areas?

BACKGROUND

At ADM extensive areas of terrace deposits along Smoke and Limestone Creeks have been mined for alluvial diamonds. These areas have been the subject of rehabilitation treatments over a number of years and are the focus of this study. ADM is located in the East Kimberley region of Western Australia, 110 km south of Kununurra at the headwaters of Smoke and Limestone Creeks. The region has a dry tropical climate that is characterised by a hot dry-season and highly variable wet season rainfall (Argyle Diamond Mine, 2000).

Diamondiferous alluvial gravels occupy recent and historic drainage lines within the Argyle lease area. The alluvial diamond deposits are classified into 4 classes, which reflect the age of the alluvial terraces and their geomorphic setting. They indicate the level of the land surface when alluvial sediments were deposited along the river valleys.

The D terrace represents current stream beds while A terrace gravels (that occur at higher elevations in the land scape) were deposited around 20 million years ago and are expressed as isolated low lying duricrust capped hills. B and C terraces represent intermediate age deposits (Argyle Diamond Mine, 1999b). The C terrace is the most extensively mined alluvial terrace at ADM (Botje, 2001).

Alluvial gravels are mined in shallow trenches using an excavator. A mobile screening unit separates the diamondiferous gravels (particles > 2 mm) from the reject material that is returned to the mined trench (Argyle Diamond Mine, 1999b).

Topsoil and/or overburden along with stockpiled vegetation is respread on the surface of levelled trenches. Construction of drainage lines, absorption banks and shallow ripping along contours complete the landforming operations. A seed-mix containing local plant species is broadcast by hand and seedlings are transplanted in some areas. Patches of vegetation that are usually of about 0.03-0.05 ha are left undisturbed within the mining area. These tree retention clumps usually centre around large boab trees (*Adansonia gregorii*) and are intended to aid the rehabilitation process once mining is completed (Argyle Diamond Mine, 2000).

The rehabilitated alluvial terraces at ADM are to be integrated with the management of surrounding unmined vegetation to support cattle production and traditional aboriginal use (Samaraweera *et al.*, 2000). To comply with this use, the vegetation is required to be safe, stable, self-sustaining; and maintenance free. (Argyle Diamond Mine, 2000; Mattiske Consulting Pty Ltd, 1998, 2000; Samaraweera *et al.*, 2000). In the case of future traditional uses of rehabilitated land, the establishment of plants of cultural significance is an additional major goal (Argyle Diamond Mine, 2000 ;Samaraweera *et al.*, 2000).

In the absence of specifically derived completion criteria, ADM has applied the approach developed by Muir (1996, cited in Argyle Diamond Mine, 2001). This system is derived from field data and based on the estimation of two parameters; total cover index (TCI) and rainfall variability index (RVI), and relates fauna re-colonisation to floral richness (Samaraweera and Muir, 2001). However, the system has not yet been validated in the dry tropical environment.

This project examines vegetation monitoring data collected annually by ADM to explore the development of completion criteria. The study areas were mined C terraces from the 1996, 1997 and 1998 years of rehabilitation. The plots from these areas are prefixed R, S and T respectively. These areas were chosen as they occupy similar positions in the landscape and received the same rehabilitation treatment but were subject to differing rainfall distributions in their first year following seeding. Detailed methods and results are reported elsewhere (Mattiske Consulting Pty Ltd, 2000; Sherriff, 2001).

Community composition was sampled using 50 m² quadrats located in undisturbed vegetation and rehabilitated areas along Limestone and Smoke Creeks. Quadrats were ordinated using multivariate analysis based upon the Bray-Curtis similarity in the PRIMER package. The scaling was done on percentage cover for perennial species because the inclusion of annual species may have distorted the output due to seasonal fluctuations.

Total annual rainfall and its distribution were highly variable in the period from July 1996 to June 2001 in which the three rehabilitation areas were established (Figure 1).

The wet season rainfall for the establishment year for the R and T rehabilitation areas was above the long-term average of 568 mm (Argyle Diamond Mine, 1999a) totalling 999 mm and 894 mm, respectively.

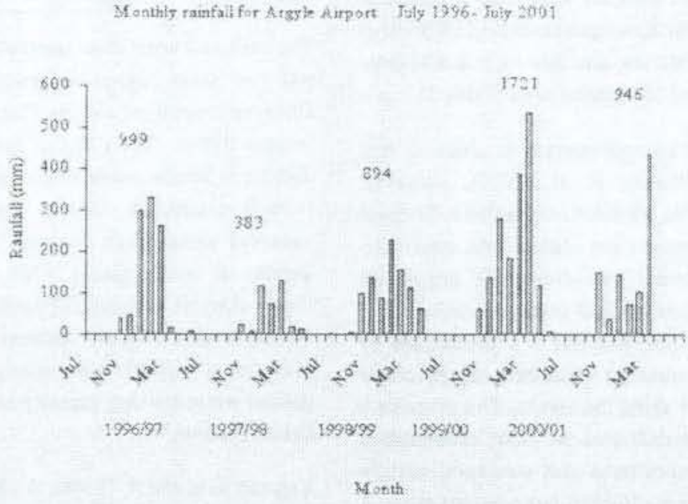

Figure 1: Monthly rainfall (mm) received at Argyle Airport since 1996. Total wet-season rainfall (months) is included as numerals above each year.

The R area received the bulk of this rain in a three-month period and the T area received substantial rainfall throughout the wet season. The S rehabilitation area received below average rainfall in its first year (383 mm). Since establishment of these areas above average rainfall has occurred: 1721 mm in 1999/2000 and 946 mm in 2000/01.

DEVELOPING COMPLETION CRITERIA

Differences and similarities in ecosystems that are relevant to environmental restoration

The dry tropical savanna has extremely seasonal, unreliable summer rainfall (Walker and Gillison, 1982; Williams et al., 1996). The strong seasonal rainfall results in a limitation of plant-available soil water and suspension of plant growth during the dry season (Walker and Gillison, 1982). Perennial plants cannot persist in these landscapes unless they are able to find ways to access groundwater or stored water during the dry season (Harrington, 1991; Scholes and Archer, 1997). Establishment of a species during a wet season following rehabilitation is no guarantee that the species will remain alive in the longer term. If a wet season has very low rainfall, survival over the subsequent dry season may be very poor. In the south rain is also highly seasonal but occurs in winter and is relatively reliable while the summer is generally dry. At Eneabba early germination of plants is desirable so that root development can reach a stage where plants can persist through the dry summer on the sandy soils (Petersen and Brooks, 1996).

In the jarrah forest rainfall is higher than at Eneabba, plant growth is slow during the cool winters (Gentilli, 1989) but is also slow or absent in the summer. However, seedling survival is more reliable than at Eneabba.

Fire is a conspicuous part of both southern (Bell *et al.*, 1989) and northern systems (Walker and Noy-Meir, 1982; Williams *et al.*, 1999). In the jarrah forest (Bell, 1999) and Kwongan heathlands (Dixon *et al.*, 1995) fire promotes seed germination of many plant species (Bell, 1999) and has been used to enhance plant establishment on mined lands (Ward *et al.*, 1997). Relatively slow build up of fuel in the heathlands and jarrah forest ensures a fire return frequency of several years, which is in contrast to the possibility of 1 - 2 year fire cycles in the tropical savanna. In the dry savanna, fire limits woody plant recruitment by killing seedlings in the period before individuals have developed sufficiently to withstand grass fires (Scholes and Archer, 1997; Williams et al., 1999). Established sprouter tree and shrub species may be maintained as suppressed individuals due to repeated removal of sprouts by short return fire intervals (Bond and van Wilgen 1996). The balance between the rapidly growing annual component of the plant community and the more slowly growing perennials is strongly influenced by fire frequency. Including criteria specifying the number of fire tolerant woody plants per hectare may assist in judging resilience to fire. Developing a classification of plants as fire tolerant or not, based upon size or age would be helpful in assessing the prospects for plant survival. This subject would benefit from further research.

Table 1: Comparison of nutrient status of tropical savanna and jarrah forest soil.

Location	Nitrogen (mg/kg)	Phosphorus (mg/kg)	Source
Tropical savanna (Melville Island)	84-283	<5	(Wilson and Bowman, 1994)
Jarrah forest (Boddington)	10-20	10	(Raphael, 1994)

Soils are low in nutrients in both the Australian dry tropical savanna (Cole, 1982) and the Kwongan heathland (Wisheu et al., 2000). Jarrah forest soils are also low in N but slightly higher in P when compared to savanna soils (Table 1).

Bauxite and mineral sand mining operate in areas of very high species diversity (Wisheu et al., 2000). However, structurally the communities are relatively uniform. In these areas rehabilitation prescriptions are applied with minor site-to-site variation in an attempt to recreate the pre-mining systems. By contrast, the dry tropical savanna around ADM has relatively low species diversity but is characterised by herbaceous and woody dominated vegetation on the plains with densely wooded forest along the creeks. This presents a range of challenges to rehabilitation as plant communities with different species compositions and structural pattern may need to be established in different but adjacent areas. A summary of factors relevant to environmental rehabilitation in the dry tropics and the Mediterranean southwest is listed below (Table 2).

Appropriate analogues for rehabilitation at ADM

The unmined vegetation sampled in this study was classified into two main vegetation groupings, the heavily wooded *Riverine* vegetation and the *Plains* vegetation complex (after Weston 1980). The contrast between the groups was most distinct at Smoke creek where very high woody plant density (<3500 plants/ha, mostly *Terminalia canescens*) was observed along creek channels adjacent to areas with low density of woody plants (<700 plants/ha). The Limestone Creek channel was not as heavily wooded but the forest did spread further from the channel than at Smoke Creek. This may be correlated with substrate differences related to greater water holding capacity of the soil near the Limestone Creek channel.

Vegetation in the R (1996), S (1997) and T (1998) C terrace rehabilitation was more similar to the *Plains* complex than to the *Riverine* vegetation. The *Plains* vegetation occupied the C terrace away from creek channels. And most of the mining is also situated in this part of the landscape.

Table 2: Comparison of climatic and biotic factors and vegetation characteristics relevant to rehabilitation between dry tropical savannas of north west Australia and the Mediterranean south west.

	Dry tropical savanna	Mediterranean south west
Environmental factors		
Soil nutrient status	Low	Low
Rainfall	Strongly seasonal, highly unreliable.	Strongly seasonal, relatively reliable winter rainfall and occasional summer storms
Annual temperature variation	Low	High
Fire	Destroys new seedlings and suppresses established resprouts	Required for germination of many seeds and revitalises some resprouters Destroys new seedlings and suppresses established resprouts
Rehabilitation substrate	Entire soil profile rearranged, similar to original but depleted in fine soil fraction	Bauxite -upper soil horizons removed. Mineral sands - entire soil profile rearranged, replaced material physically similar to original
Reconstructed landform	Similar to original	Bauxite- landscape relief and drainage increased. Mineral sands - similar to original
Biotic factors		
Plant species richness	Low	High
Plant growth period	Limited period following summer rain and stops in the winter dry period	Plant growth from late winter into early summer
Plant establishment	Germination requirements for many species are poorly understood. Growth to fire resistant stage is critical to recruitment	Fire may be required for germination. Growth to fire resistant stage is critical to recruitment
Life forms	Dominant annual and perennial components	Dominant perennial component
Vegetation structure	Patchy, characterised by competing herb and woody plant dominated vegetation	Patchy if attention given to providing variation for fauna and plant communities

Hence the Plains vegetation group is an appropriate model for rehabilitation of mined C terraces and may also be applicable to B terraces.

The *Riverine* vegetation would provide a suitable natural reference state with which to construct completion criteria for mined D terrace areas, which occupy recent creek channels and banks. Preliminary visual observations of the vegetation on rehabilitated D terraces indicate that some *Terminalia* and *Eucalyptus* species and boabs are occurring at a relatively high frequency.

Completion criteria derived for C terraces may not be appropriate to A terrace. The deeply weathered A terrace material readily breaks down into weathered constituents leaving a mined profile that is higher in fine material than are the B, C and D terraces, in which the rocks remain intact during the mining process (Botje, 2001). The findings of this study should not be applied to A terrace lands without further examination and are more applicable to the younger terraces.

Like C terrace rehabilitation, rehabilitated B and D terraces are unlikely to mirror unmined analogue areas in the short-term. In setting rehabilitation objectives and completion criteria for these areas it is not appropriate to expect all the species in the unmined areas to return. However, it is reasonable to expect plant communities be reinstated whose dominant species are functionally similar to those on unmined areas.

Preliminary completion criteria for the biological systems in the mine area

Hobbs and Norton (1996) proposed that criteria for success of rehabilitation can be developed which show the natural range in variability for parameters which have been determined as important to ecosystem function. In their method mean values from rehabilitated areas are compared to the natural range in variation of a suitable reference system.

The following completion criteria were developed using this approach, the parameters used recognise that identical species composition to unmined areas is not presently a realistic goal and uses lifeform groupings as a basis for developing a suitable vegetation structure. The *Plains* vegetation group is used as the natural reference state from which the ranges in these parameters were determined.

For herbaceous taxa total percentage cover is used as the measure of abundance as herbaceous plants establish themselves quickly in rehabilitation and cover allows useful comparisons to be made. Density (plants/ha) is used for woody plants as density estimates allow more meaningful comparisons to be made between younger rehabilitation and more mature ecosystems.

As the reference system contains a wide range of cover for the herbaceous lifeform species, the total range may not provide a useful target for rehabilitation. First and third quartiles are proposed in preference to the total range in natural variation. Preliminary criteria for herbaceous plant lifeform cover are summarised in Table 3.

The very large range in natural variation of woody plant density reflects the patchiness in distribution of these species in the *Plains* vegetation group. First and third quartile ranges are very narrow for woody plant density and would not be appropriate in constructing completion criteria. For woody species, the range of density that represents a 90% confidence interval of the mean, calculated from the *Plains* vegetation group for each plant lifeform is proposed.

For the deciduous tree lifeform (primarily *Adansonia gregorii*) the lower confidence interval is 0 plants/ha. Clearly this is not a suitable target for a completion criterion. Given that this study showed that *Adansonia gregorii* established at values in excess of the *Plains* vegetation mean value, a lower limit to deciduous tree density of 20 plants per hectare is tentatively suggested. Given that *Adansonia gregorii* seedlings are fire sensitive this criterion should be further refined to 20 fire tolerant plants per hectare (Table 3). The size at which *Adansonia gregorii* becomes fire tolerant needs to be further investigated so that a time frame can be assigned.

For herbaceous and woody plant abundance measures, lower limits are more important than the upper limits prescribed in Table 3.

Table 3: Examples of the tentative completion criteria for alluvial diamond mining areas on C terrace landforms.

	Lower range	**Upper range**
	Herbaceous vegetation	
Herbs	9 % cover	77 % cover
Annual grass	20 % cover	72 % cover
Perennial Grass	4 % cover	50 % cover
	Woody vegetation	
N-fixing Shrub	682 plants/ha	1902 plants/ha
Shrub	381 plants/ha	1526 plants/ha
Tree	153 plants/ha	832 plants/ha
Deciduous tree	20 plants/ha	46 plants/ha

The results showed that most of the rehabilitation from 1996-1998 had achieved a total cover similar to control values, indicating that if one or two of the lifeforms are just achieving the minimum level, the other lifeforms should compensate by occurring at abundances in excess of their lower limits.

Completion criteria are particularly difficult to define for a landscape such as occurs in the northwest of Australia, which is highly heterogeneous, and is situated in a very unpredictable and variable climate. A broad leeway needs to be accepted to encompass the variation due to natural stochasticity in climate and other aspects of the environment. Further monitoring on rehabilitated land will help to clarify the dimensions of vegetation change and help refine notions of what is achievable and acceptable.

CONCLUSIONS

Completion criteria and rehabilitation goals need to be based on an understanding of plant establishment within the landscape in which the mine occurs, so that they are flexible enough to account for temporal and spatial variation that is characteristic of the area, and yet ensure that the long-term resilience and function of the system is maintained.

In setting completion criteria it is not appropriate to expect all the species in the unmined areas to return (Environmental Protection Agency, 1995b). Factors affecting the establishment of some species still need to be investigated. However it is reasonable that plant communities be reinstated whose dominant species are functionally similar to those in the unmined areas, allowing rehabilitated lands to be incorporated into the management of the surrounding lands. Completion criteria also need to account for nutrient dynamics and faunal recolonisation to ensure successful rehabilitation (Environmental Protection Agency, 1995b). These topics are subject to ongoing research and monitoring at ADM.

Some of the approaches used in the Mediterranean south west may be applicable but with modifications to allow for the variation in climate and natural vegetation patchiness. Germination of desirable structural and functional species is regarded as critical for long term vegetation establishment within rehabilitated bauxite mines in the jarrah forest and has led to the development of criteria which are applied to rehabilitated lands after 9 months (Environmental Protection Agency, 1995a).

Timing of the vegetation assessment of rehabilitated lands in dry tropical savannas has historically been undertaken on an annual basis at the end of the wet season to accomplish the assessment of both annual and perennial growth as well as success of regeneration of plant species. The regularity of additional monitoring times is constantly under review as it is recognised that species can continue to emerge three or more years following topsoil application and their survival is critically dependent upon available soil water. Given the variability of the annual rainfall (total amount, length of the wet season and the nature of the rainfall events), and the complex nature of particle size distribution of the newly created soil profile, yearly assessment during the initial phase (first three years) and subsequent regular (once in every three to five years) assessments are suggested.

In addition to high variation in annual plant establishment, there are the highly unpredictable grass fires. Knowledge of the age or size at which individual woody species become tolerant to 'typical' early dry season grass fires needs to be incorporated into completion criteria in order to provide a basis for estimating the resilience to fire of particular components of the vegetation on mined alluvial lands.

Unlike approaches for completion criteria in the southwest where criteria are often expressed as minimum targets, a range of acceptable values is proposed for dry tropical savannas. All rehabilitated lands studied achieved vegetative cover values similar to those of analogue sites. By assigning a range of acceptable woody plant densities and herbaceous plant cover, the spatial heterogeneity of the vegetation can be incorporated into the completion criteria. If for instance woody plant density is close to its minimum acceptable value, the deficit in plant cover should be compensated by herbaceous plants and *vice versa*.

This approach to completion criteria for dry tropical savannas may also be of some use in other arid environments. In these areas, seeds can remain viable in the soil for many seasons, plant establishment is critically dependent upon an unpredictable rainfall regime, and the vegetation is structurally heterogeneous.

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ECOSYSTEM FUNCTION ANALYSIS: SOME RECENT PROGRESS

David Tongway & Norman Hindley
CSIRO SUSTAINABLE ECOSYSTEMS

INTRODUCTION

Ecosystem Function Analysis (EFA) is a monitoring procedure that uses quickly deployed field indicators to assess the state of biophysical functioning of landscape systems used for a variety of purposes. It examines the status of a range of landscape processes. A number of "indices", reflecting overall landscape organisation and soil surface processes are generated by the procedure. Existing monitoring procedures tend to focus on composition (eg species present) and/or structure (grassland, woodland, etc), which do not have an intrinsically dynamic interpretation. Together, this trilogy of procedures has the capacity to fully inform rehabilitation issues.

In an initial study brokered by ACMER (Tongway *et al* 1997), EFA was shown to have potential in assessing the progress of rehabilitation on mines and also in being able to contribute to mine closure criteria, by providing a record of the "ecosystem trajectory" over time and the achievement of ecologically significant targets. Figure 1 shows a set of possible scenarios of rehabilitation suggested in Stage 1.

At that time the Industry asked that a second stage be undertaken to demonstrate that the landscape indices derived from EFA were genuinely related to the measured variables they purported to represent. A two-year project, again brokered by ACMER, has been under way for a little over 12 months and this paper is a progress report, using data from the project to provide further proofs of concept and of verification. Nine mines in Australia and Indonesia are represented in the study and cover the climatic range from 200 mm to 4000 mm precipitation.

MINESITE EXAMPLE

We have selected the Nabalco Gove Bauxite mine to demonstrate the use of EFA in tracking ecological progress over time and in verifying the EFA indices. This mine has used very similar rehabilitation techniques continuously for over 27 years and supervision of the work has been by the same person over that period, thus providing an adequately long pseudo-chronosequence without abrupt changes. This enables us to illustrate the concept of "ecosystem trajectory" in practice.

Methods

We used sites representing nine ages of rehabilitation: zero, 1, 2, 3, 4, 8, 13, 20 and 26 years, selected at random from the set of sites available on the mine. We also selected a site outside the mine to use as an analogue to compare progress on the mine. None of the sites on the mine had ever been burnt during the period of rehabilitation, but the analogue site had burnt at about annual intervals though was 18 months after the previous fire at the time we assessed it. The sites were several hectares in size.

We assessed each site with a single transect between 30 and 60 m long, depending on landscape pattern and available space, located in the body of the rehabilitation. On each transect we recorded "landscape organisation" data: the sizes and location of runoff and runon zones identified by the criteria of Tongway and Hindley (1995 and 2001).

Within each zone type, we recorded the values of each of eleven soil surface indicators according to the same set of rules. Typically, with practice, this takes about 60-80 seconds per zone.

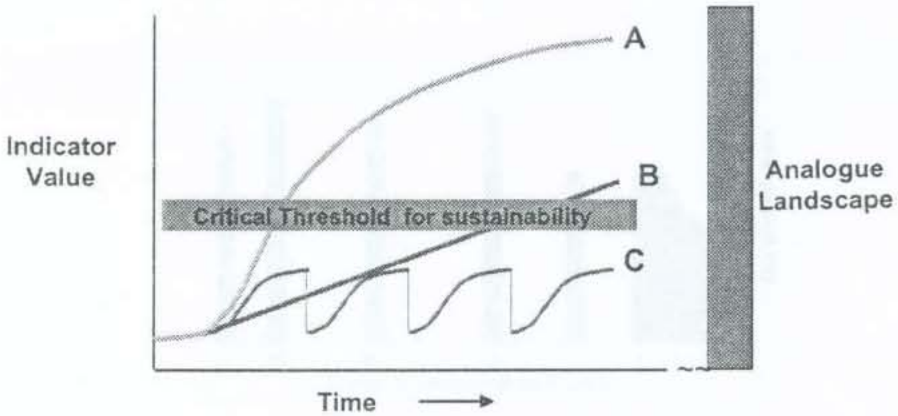

Figure 1: Possible ecosystem function trajectories over time. System A shows a satisfactory response over time, passing rapidly through a critical functional threshold and continuing to improve, eventually plateauing at high functional values. It is likely to be self-sustaining. Curve B represents a system that develops slowly and hence subject to stochastic stress and disturbance events and possible failure. Curve C represents a system where the biota frequently succumbs to external threats (eg fire) and fails to develop into a self-sustainable system. Not shown for clarity is another system whose trajectory arcs over without ever crossing the critical threshold, due to continuing erosion.

In addition, we measured the infiltration rate of water in saturated flow mode, using a disc permeameter on three replicates of each zone type, and the soil respiration in duplicate at each of the sites used for infiltration. Respiration is a measure of soil biological activity. We also sampled the soil at 0-1, 1-3, 3-5 and 5-10 cm close to the other sites and returned the samples to the Lab. for chemical analysis.

Results

1. *Landscape Organization*

The data in Table 1 shows that the proportion of each transect designated as runon zones steadily increased with time, implying that the sites were becoming increasingly competent in capturing and retaining resources.

2. *EFA Indices*

Figures 2 to 4 show the value of each of the EFA indicators representing a "whole of site" assessment. All show low to moderate initial values, increasing over time. The stability index (Fig. 2) shows a steep increase, with a plateau value of about 80 (%) achieved by 13 years. The infiltration index (Fig. 3) lags the stability index by several years in reaching a plateau and the nutrient cycling index has not reached an asymptote in 26 years (Fig. 4). Nutrient cycling is largely dependent on litter fall and decomposition, and the main supplier of litter, *Eucalyptus tetradonta* continues to grow and produce more litter over an extended time. Data not presented here shows that runoff zones initially have lower EFA index values than runon zones, but that over time, this difference, as well as the runoff zone proportion diminish.

Table 1: Runoff and Runon zone types and proportions for all Gove study sites.

Rehabilitation Period	Proportion of runon zone (%) and *number per 10m*	Proportion of runoff Zone (%) and *size range*
zero	16.5 *(3.2)*	83.5 *(0.5 - 2.7)*
1 year rehab	27.7 *(1.9)*	72.3 *(0.4 - 10.2)*
2 years rehab	66.7 *(3.8)*	33.3 *(0.4 - 3.2)*
3 years rehab	74.0 *(0.3)*	26.0 *(6.9 - 8.1)*
4 years rehab	67.9 *(1)*	32.1 *(1.0 - 7.2)*
8 years rehab	42.2 *(3)*	57.8 *(0.5 - 5.0)*
13 years rehab	74.7 *(2.2)*	25.3 *(0.3 - 5.2)*
20 years rehab	93.3 *(4)*	6.7 *(0.5 - 1.7)*
26 years rehab	100 *(1)*	0
Analogue	100 *(1)*	0

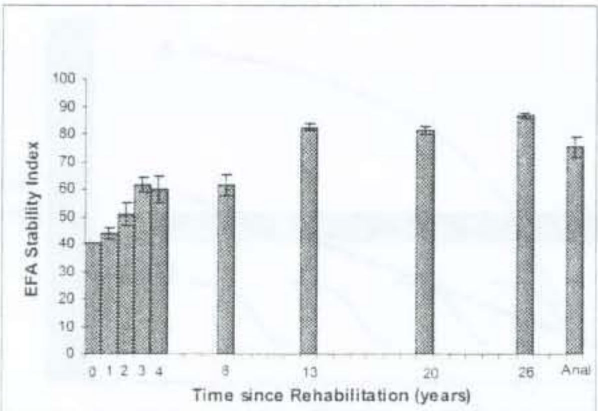

Figure 2: Comparison of the whole-of-site Stability Indices across all sites. A sigmoidal or "S" shaped curve can be seen to emerge from the data. The 8 year-old rehabilitation is an "outlier" to this general rule, possibly because of its higher proportion of runoff zones on this site compared to other sites (see Table 1). Note that the analogue site is noticeably lower than the older rehabilitation

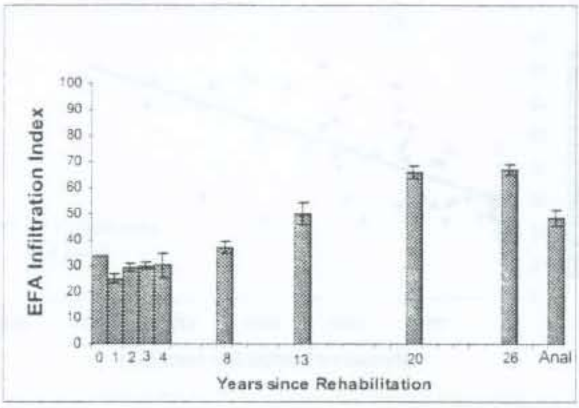

Figure 3: *Comparison of whole-of-site Infiltration Indices across all sites. As for Stability, a sigmoidal response can be discerned. Again, the analogue site lags the older rehabilitation sites.*

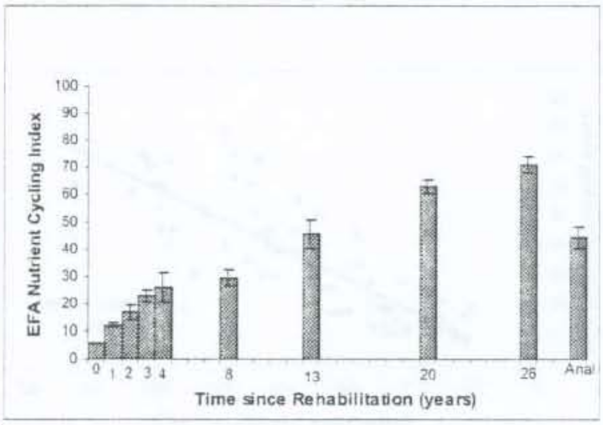

Figure 4: *Comparison of the whole-of-site Nutrient Cycling indices across all sites. Again, the sigmoidal response over time can be discerned. The analogue site has less accumulated litter due to a recent fire, thus reducing the index value.*

3. Verification of EFA Indices

Figures 5 and 6 show regression relationships between measured infiltration and the infiltration index and soil respiration and the nutrient cycling index respectively. Measured infiltration was frequently very high indeed, due at least in part to abundant pisolitic gravel in the profile. Nevertheless, a good relationship was found (Fig. 5). Soil respiration data supported the nutrient cycling index very well (Fig. 6).

4. Laboratory Verification

Figure 7 depicts the relationship between nutrient cycling index values and accumulated organic nitrogen in the 0-1 cm layer. Similar relationships exist for all the other soil depths sampled, confirming firstly that the nutrient cycling index has been verified as soundly based and that the progress of rehabilitation has been very satisfactory. Organic carbon gave similar relationships.

Other laboratory analyses are still coming.

Not specifically shown here is the N content of the analogue soil, but it mirrored the nutrient cycling index in that it was similar to 10-year-old rehabilitation. We take this to represent the effect of the persistent loss of litter in fires before it could be decomposed and incorporated into the soil. In addition, the response of plant root viability in near-surface soil layers was affected. Roots in the rehabilitation sites were often located on the soil-litter interface, with fine roots entangled in litter, whereas the roots in the analogue site were several centimetres below the soil surface, thus evading the effect of fire. **This highlights the caution needed when selecting and using analogue sites as representing both "sensible" ecological models and EFA target values.** Fire is such a frequent and wide spread occurrence in the northern savannas; it is unlikely that fully satisfactory analogue will ever be found for these regions.

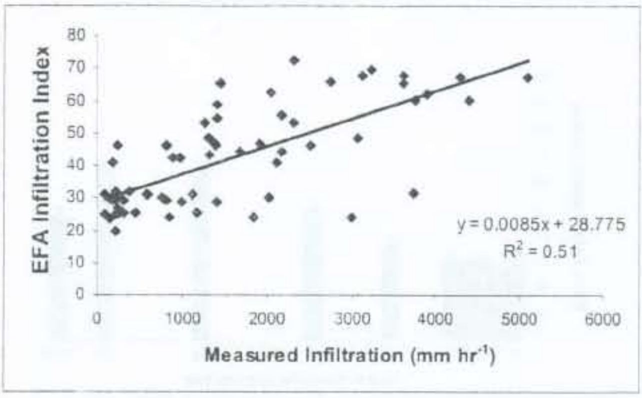

Figure 5: *The relationship between the EFA Infiltration Index and measured infiltration. Data from all studied rehabilitation sites and the analogue site are included in this plot. Note that measured infiltration rates are very high at all locations and do not represent an infiltration problem in rehabilitation.*

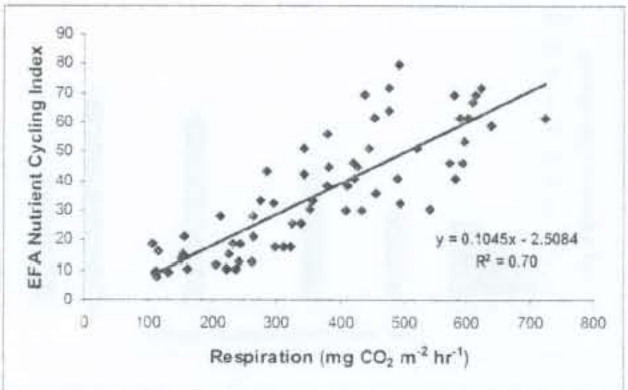

Figure 6: *The relationship between the EFA Nutrient Cycling index and soil respiration, using data from all studied rehabilitation sites and the analogue. The good relationship verifies that the EFA nutrient cycling index can be used as a surrogate for costly and time-consuming measurements in monitoring rehabilitation progress.*

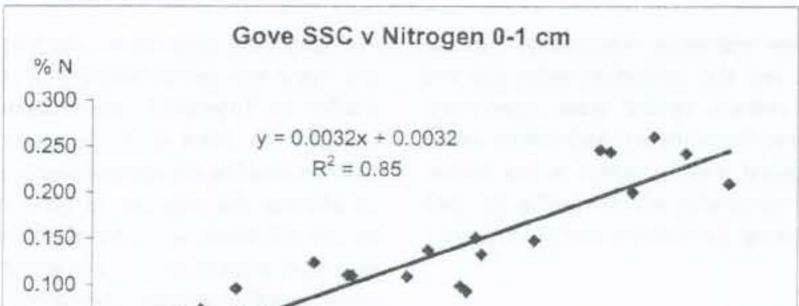

Figure 7: *The relationship between the nutrient cycling index and the concentration of organic nitrogen. Taken with Fig. 6, the accumulation of N with age of rehabilitation is demonstrated.*

INTERPRETATIONAL FRAMEWORK

The data from the Gove site provide confirmation that S-shaped curves, representing a satisfactory rehabilitation trajectory, are likely to be useful tools in predicting ultimate success (or lack of it) in minesite rehabilitation assessment. Figure 8 depicts the salient features of this curve type.

The sigmoidal relationship has the form

$$y = y_0 + a / 1 + e^{-(x-x_0)/b}$$

- **y** represents an indicator of ecosystem function (eg soil stability, infiltration, nutrient cycling, species composition, soil faunal abundance),
- **(y_0+a)** represents the value of the upper asymptote (rehabilitation is as good as it can be with the prevailing soil type and climate; The biogeochemical potential of the site)
- **y_0** represents the value of the lower asymptote, (the functional starting point of rehabilitation)
- **x_0** is the location of the inflection point of the curve on the x-axis and represents the time taken for the ecosystem to begin to "plateau out"
- **b** is the gradient at the inflection point and represents the rate of increase of the assessed index over time. Low values of b represent quickly responding ecosystems, whereas high values denote slow response.

These curve parameters thus represent important components of ecosystem function: how functional it can be when fully rehabilitated and how unstable it becomes when stressed.

The location of the points of maximum curvature (arrows) could be used as additional threshold values. The upper point could be used to differentiate between self-sustaining landscapes close to the 'ultimate goal', and the lower threshold those landscapes that are so dysfunctional as to require intervention.

INTERIM CONCLUSIONS

These and data from the other Sponsors mines have provided good support for using the EFA indices as surrogates for measured biophysical variables across a wide range of mines in Australia. "Ecosystem function" has become a mainstream ecological concept and likely to strengthen. The analytical procedure to determine target values for completion criteria has the potential to remove subjectivity from the assessment of completion, but more examples need to be studied to make this process a routine analytical tool to examine EFA data with and assist in judging whether completion criteria have been satisfied.

Products from this project will be targeted revised EFA methodologies for each of the major mine types represented: Coal, Mineral Sand, Bauxite and Hard Rock. These will be available on CD, and incorporate the material presently in the Training Course manual.

The outcome of this project would be improved by more active participation of Miners and Regulators with Research Providers in an adaptive learning environment.

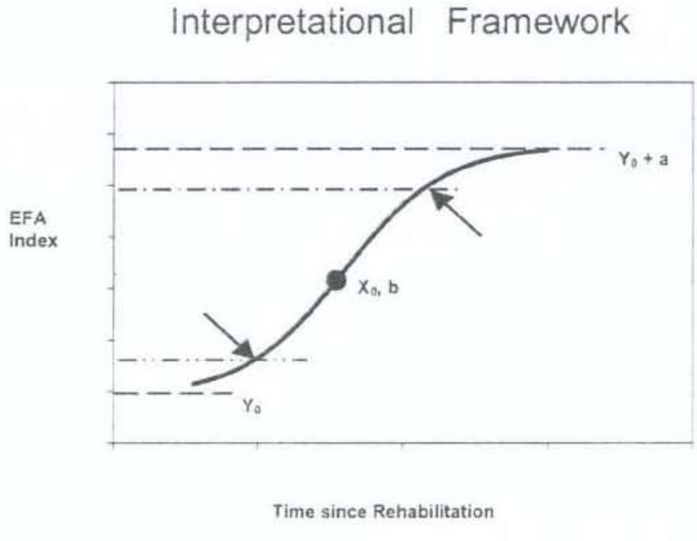

Figure 8: A sigmoid-shaped response curve.

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A GRAND ENTRANCE, A SMOOTH EXIT (LEGAL ASPECTS OF MINE CLOSURE)

Brad Wylynko & Louise Millard
MALLESONS STEPHEN JAQUES

INTRODUCTION

While the opening of a new mine is a highly publicized event, mine closure tends to be a muted affair. Mine closure results in job losses, a revenue downturn, and of course, the potential for longer term environmental impacts. However, as the issue of mine closure gains greater public profile, particularly in the Goldfields, the process of mine closure and rehabilitation is coming under increasing public and government scrutiny.

It is also coming to the attention of company directors who want to ensure no "trailing liabilities".

The Western Australian government's objective for mine closure is a site that is "safe, stable, non-polluting and sustainable." [1] This objective is realized through site specific completion criteria developed in consultation with the company and the community. Upon attaining the criteria a company may relinquish its interest and retire the required performance bonds. The company can then walk away from the mine - at least in theory.

In practice, as the Australian New Zealand Mining Environment Council Mining Framework points out - relinquishment is one thing: walking away from legal liability is another. Governments are very reluctant to assume the environmental risks of a former mine site. Neighbours are quick to point fingers should a closed mine cause environmental problems. These "trailing liabilities" will only increase if proposed contaminated sites legislation is passed by parliament this autumn. Even after relinquishment, a mining company may still be on the hook for environmental damage caused by the mine. The trick for "a smooth exit" is in understanding and anticipating that liability.

THE LAW

Mine closure in Western Australia is governed primarily by the Mining Act 1978 and the *Environmental Protection Act 1986*. [2]

Mining Act 1978

The Mining Act provides that the Minister may grant a mining lease on such terms and conditions as the Minister considers reasonable. In addition, the Minister may, at any time, impose on the lessee reasonable conditions for preventing or reducing, or making good, injury to the natural surface of the land.

The Department of Mining and Petroleum Resource's (**DMPR**) standard mining lease conditions include:

> *"No development or productive mining or construction activity being commenced until the tenement holder has submitted a plan of the proposed operations and measures to safeguard the environment to the State Mining Engineer for assessment and until his written approval has been obtained."* [3]

This plan (or Notice of Intent) outlines the project's environmental impacts, determines a level of significance for each impact and details management and amelioration measures. Rehabilitation and final land use options are also covered. The "NOI" becomes the basis for the site's environmental management system. [4]

Upon approval by the State Mining Engineer, the commitments in the NOI also become conditions of the mining lease.

In addition to approval of the NOI commitments, a mining lease may also contain any of the following conditions:

(a) all topsoil must be removed ahead of mining operations from sites such as pit areas, ore stockpile areas, pipelines, haul roads and new access roads and stockpiled for respreading;

(b) at the completion of operations, all buildings and structures must be removed from the site or demolished and buried to the satisfaction of the State Mining Engineer;

(c) at the completion of operations or progressively where possible, all access roads and other disturbed areas must be covered with topsoil, deep ripped and revegetated with local native grasses, shrubs and trees to the satisfaction of the State Mining Engineer;

(d) the lessee must provide an unconditional bank guarantee or bond;

(e) the lessee must submit to the State Mining Engineer an Annual Environmental report outlining the operations and rehabilitation work undertaken in the previous year and the proposed rehabilitation program for the following year; and

(f) the lessee must at his expense rehabilitate all areas affected by mining or operations associated with mining conducted during the term of the lease. Rehabilitation being to the satisfaction of the State Mining Engineer.

Environmental Protection Act 1986

In addition to the above lease conditions, a mining operation is also subject to the *Environmental Protection Act 1986* (**EP Act**).

Under the EP Act, a mining proposal that appears likely, if implemented, to have a significant impact on the environment must be referred to the Environmental Protection Authority (**EPA**) for review. The EPA will require the mining company to prepare an Environmental Review Document describing the proposal, the expected environmental impacts and a management programme. Following public review, the EPA prepares a report to the Minister for the Environment and Heritage. The Minster can then grant authority to the DMPR to permit implementation of the mining proposal, subject to environmental conditions (which usually become part of the NOI). Such conditions often include a requirement for a rehabilitation plan.

In addition, the Department of Environment (**DEP**) may require an EP Act works approval and licence for processing plants and tailings disposal facilities. These approvals follow the Minister's decision to approve the proposal, and do not become incorporated into the NOI. [5]

It is worth noting that Part V of the EP Act places a general duty of care on all persons to prevent pollution. Where a person (including an occupier) intentionally or with criminal negligence causes pollution or allows pollution to be caused, that person commits an offence which may lead to a corporate penalty of up to $1,000,000, and an individual penalty of up to $500,000 or imprisonment up to 5 years.

In addition, the DEP may issue a pollution abatement notice to either an owner or occupier of polluted land. The notices are registered on title and require the person to take any action the DEP deems necessary to "prevent, control or abate" a discharge of waste. Intentional failure to follow a notice may result in a corporate penalty to a maximum of $500,000.

COMPLETION CRITERIA

In its 1998 document, *Guidelines to help you get environmental approval for mining projects in Western Australia* the DMPR states that its rehabilitation goal is to return a mine site to its "natural condition". The Department recognizes that it is,

> *"... necessary to develop conditions and criteria that can be used to assess if and when the environmental management and rehabilitation program has been successfully completed."*

These "completion criteria":

> *"... should be objective and preferably quantitative and consistent with the reporting requirements given in the DME document 'Guidelines for the Preparation of an Annual Environmental Report' (April 1996)."*

The 1996 Guidelines require the following information:

(g) a summary of activities;

(h) management of rehabilitation activities such as topsoil clearing, access, erosion control and monitoring including interpretation of monitoring results;

(i) seed mix and fertiliser used, source of seed and rates applied;

(j) monitoring flora and fauna, air quality, surface water and groundwater;

(k) waste management; and

(l) education and training. [6]

At a conference held in Perth on 17 August 2001, representatives of the DMPR and the DEP further developed these criteria. [7] They drew upon the Australian and New Zealand Minerals and Energy Council and the Minerals Council of Australia's *Strategic Framework for Mine Closure (2000)*.

The ANZMEC Framework is not a detailed set of guidelines and standards for mine closure, rather it is designed to "... provide a broadly consistent framework for mine closure across the various Australian jurisdictions". The objective is to "encourage the development of comprehensive closure plans that return all mine sites to viable, and wherever practicable, self- sustaining ecosystems, and that these plans are adequately financed, implemented and monitored within all jurisdictions". It sets out six objectives:

(a) to enable all stakeholders to have their interests considered during the mine closure process;

(b) to ensure the process of closure occurs in an orderly, cost effective and timely manner;

(c) to ensure the cost of closure is adequately represented in company accounts and that the community is not left with liability;

(d) to ensure there is clear accountability, and adequate resources, for the implementation of the closure plan;

(e) to establish a set of indicators which will demonstrate the successful completion of the closure process; and importantly,

(f) to reach a point where the operator has met the agreed criteria to the satisfaction of the Responsible Authority.

The Framework proposes that mine closure and rehabilitation should lead to a site that does not endanger public health and safety, that alleviates or eliminates environmental damage, and that allows "... a productive use of the land similar to its original use or an acceptable alternative". The Framework also recommends that the legislative requirements for closure should be accepted as the minimum standard required - best practice should exceed such standards whenever possible.

The Framework recognizes that "while it is one thing to expect to be released from mine closure obligations, it is quite another to expect to be discharged from further liabilities under broad environmental and civil laws." Nevertheless, the Framework seeks relinquishment of the site on the basis of meeting specific environmental criteria such that "the management and maintenance of the site would rest with subsequent owners or the State."

The term "completion criteria" is defined in the ANZMEC Framework as "an agreed standard or level of performance which demonstrates the successful closure of a site." Completion criteria are specific to the mine site being closed, and "reflect the unique set of environmental, social and economic circumstances of the site". They should be "developed in consultation with stakeholders". Finally, the criteria should be "flexible enough to adapt to changing circumstances without compromising the agreed end objective."

The DMPR notes that the "stringency of closure will vary according to the environmental sensitivity of the site and its surrounds, and the activities undertaken during the operation." [8] Completion criteria should reflect the unique set of environmental, social and economic circumstances of the site and must be developed with community input.

The DMPR policy involves identifying a responsible authority who may make the final decision on accepting closure of the mine. In general, this authority will be the DMPR. [9]

LEGAL EFFECT OF THE COMPLETION CRITERIA

Once developed, the criteria are given legal effect through three mechanisms: the mining lease, the Mining Act, and the performance bonds.

The Mining Lease

Commentators view a mining lease as "probably [capable of being] characterised as a lease at common law".[10] The judiciary has found difficulty with determining the nature of a mining lease, variously describing it as "in substance a sale of minerals"; [11] "not in reality leases at all in the sense as one speak of an agricultural lease;"[12] and "in the nature of a *profit à prendre*, an irrevocable licence coupled with an interest." [13]

At common law, a lease of land confers on a lessee for a definite term the legal right of exclusive possession. [14] In *ICI Alkali (Aust) Pty Ltd v Federal Commissioner of Taxation* McInerney J held that a miscellaneous salt lease granted under the *Mining Act 1930-1962* (SA) was a lease for the purposes of the *Income Tax Assessment Act*, as the mining lease granted the "lessee" the legal right to exclusive possession of the land. [15] This conclusion was upheld by the High Court. [16]

However, whether the "result and reasoning in this case apply under the mining legislation in other states depends on the construction of the relevant legislation." [17]

Cardner has suggested that a mining lease in Western Australia granted under the Mining Act gives rise to exclusive possession due to a number of factors, among them the definite term, the obligation to pay rent, the exclusive right to conduct mining operations on the whole of the leased land, restrictions on use and occupation of the land and restrictions on parting with possession. [18] The "correlative conclusion" to a finding of exclusive possession is that a mining lease under the Act may be characterised at common law as a lease. [19]

If a mining lease can be characterised as a lease under common law, the failure to comply with the terms of a mining lease may constitute a breach of contract. The Minster may take action against the mining company for such a breach as a debt due to the Crown. Clearly, environmental conditions expressly stated in the lease, (such as the conditions in the NOI) are terms of the lease. The question however is whether the completion criteria are conditions of the mining lease, and whether a mining company can be sued for not fulfilling the completion criteria.

Once the NOI is approved by the State Mining Engineer with input from the DEP and the Minister for Environment, it is incorporated into the mining lease. However, as completion criteria are developed well after the granting of the lease and the preparation of the NOI, how can they become binding conditions of the lease?

The answer may lie in s.84 of the Mining Act. Section 84 gives the Minister of Mines the power to impose subsequent conditions on the mining lease to prevent or reduce or make good, injury to the land. This section, in effect, allows the Minister to change the lease without the consent of the mining company.

Furthermore, s.84(4)(b) provides that any conditions imposed by the Minister will have effect as a condition to which the lease is subject regardless of whether the conditions have been endorsed on the lease. Thus, the completion criteria can become part of the lease on the unilateral direction of the Minister. Breach of the completion criteria becomes a breach of the lease.

The Mining Act

The Mining Act provides two mechanisms to deal with a failure to comply with the Act. Section 97 of the Act provides the Minister may forfeit a mining lease for a breach of a condition to which the lease is subject. Additionally, section 82(g) provides that the lessee shall be liable to have the lease forfeited if he is in breach of any of the conditions of the lease, or if he fails to comply with any requirement under section 84(1) in relation to the lease. Of course, this power is of little assistance if the operation is coming to the end of its mine life; or indeed, if the mining lease has come to the end of its term.

However, the Act also provides an alternative to forfeiture of a lease for breach of its conditions. In *Austwhim Resources* (8 Feb 1996, Perth Warden's Court) a prospecting licence had expired before a plaint for forfeiture was determined, and thus a fine was imposed pursuant to section 96(3). Sections 82(2) and 97(5) allow for similar fines of up to $5000 to be imposed on holders of mining leases as an alternative to forfeiture.

Unconditional Performance Bonds

The primary method for enforcing obligations in the Mining Lease remain the unconditional performance bonds.

The DMPR requires an unconditional performance bond be lodged before any mining lease is granted. The bond becomes part of the standard conditions of the lease and provides a security for compliance with conditions imposed in relation to the lease. The bond is a contract between the Minister for Mines and a third party of financial standing acceptable to the Minister, providing for the third party to unconditionally pay the agreed sum to the Minister on request following the failure of the tenement holder to meet the previously agreed environmental commitments. The amount of the bond is assessed on the first two years of disturbance and then reviewed on an annual basis.

The Bond covers all land required to be rehabilitated which will normally include waste dumps, tailings disposal facilities, stockpile areas, backfilled pits, hardstand areas, plant sits, haul roads, airstrips, accommodation areas and the safety zone around any abandoned pit. Should the completion criteria not be met, the bond will not be retired and may even be realised.

Clearly, a failure to meet the closure criteria may have several consequences. It is very important to ensure that the criteria are specific, achievable and measurable. Development of the criteria should not be taken lightly for until the criteria are met, the company is "on the hook". The next question, of course, is whether there remains legal liability even if the criteria are met.

OTHER SOURCES OF LIABILITY

The common law

If despite meeting the closure criteria material from the mine site subsequently damages neighbouring properties the former occupier may be liable in the nuisance or negligence.

Nuisance

Nuisance recognises the right of neighbouring landowners to enjoy their property without unreasonable interference. If through the migration of contamination damage occurs to a neighbour's land, for example the contamination of a water bore, an action in nuisance may lie.

Individual cases are decided on the basis of reasonableness. Whether an activity is reasonable will depend on the nature of the locality in question, the frequency and extent of the nuisance and its potential for harm. However, it is never reasonable to cause damage to another's property, and so emissions which actually cause harm are likely to be treated much more strictly in nuisance than those which do not. [20]

In the case of *Qantas Airways v Mascot Galvanising (Holdings)* (unreported Supreme Court NSW 17 December 1998) groundwater within land owned by Qantas was contaminated with zinc acid and heavy metals from Mascot's processing plant. Qantas alleged nuisance. The Court considered whether Mascot, in causing or allowing the contamination of groundwater which flowed onto Qantas' property had indirectly caused physical injury to the land and substantially interfered with Qantas' right to use and enjoy the land. The Court found that Mascot was guilty of nuisance and ordered it to pay remediation costs of $88,030.30.

Negligence

Negligence may also be found if a neighbouring land owner can show that the occupier had a duty of care to prevent damage to the neighbour's property by way of contamination, and that the owner or occupier did not act as a reasonable person would have to prevent the damage.

All persons, including corporations, owe a duty of care in carrying out their activities to avoid injury to persons who might reasonably be foreseen as likely to be injured by the corporation's conduct.[21] In determining the existence of a duty, the particular injury need not be foreseen.

Additionally, there must be a relationship of proximity between the corporation and an injured plaintiff. [22] Although, in the more settled areas of the law of negligence involving ordinary physical injury or damage caused by the direct impact of a positive act, reasonable foreseeability of loss or damage is commonly an adequate indication in itself that the requirement of proximity is satisfied. [23]

Of course, proof of damage is required. The plaintiff must establish, on the balance of probabilities that the defendant caused the damage complained of and that the damage suffered was not too remote.

Future Legislation

Contaminated Sites Bill 2000

The State government has released a draft Contaminated Sites Bill for public discussion. If passed, this new legislation will apply to land included in mining leases and will be an important factor in mine closure to the extent that the land is contaminated.

"Contaminated" is defined as meaning that a substance is present in, on or under land or in the underground water, at a concentration that presents, or has the potential to present, a risk of harm to human health or any environmental value.

An occupier of contaminated land, or a person who has caused contamination, must report the contaminated site to the Chief Executive Officer. Failure of a body corporate to do so may result in a fine of $150,000 with a daily penalty of $50,000.

The Bill sets out the following hierarchy of responsibility:

(m) the owner of the land is responsible to the extent that remediation is required because of a change in the use of the land;

(n) if the use of the land has not changed, the person who "caused" or "contributed to" the contamination is responsible;

(o) if the person responsible for remediation is an insolvent body corporate, then each director of the insolvent body corporate or each related body corporate to the insolvent body corporate may be responsible;

(p) if a director can not be held responsible, the owner of the land is responsible; and

(q) if no-one else is responsible, the State will take responsibility.

The government may by notice order remediation. Failure to obey the notice may result in a corporate penalty of up to $500,000 with a daily penalty of $100,000. Furthermore, the government can clean-up and recover the costs from the person responsible. This becomes a debt due to the Crown.

This new regime may have far-reaching consequences for the mining industry. In their article [24] on similar legislation in New South Wales, Peter Briggs and Stephanie Panayi suggest the following actions to help mining companies minimise their potential exposure to liability:

(a) consider whether the costs of any remediation of contamination can be recovered from previous owners of the land;

(b) consider obtaining a benchmark audit before leasing, acquiring or disposing of any land to determine the extent of any contamination;

(c) companies who might be responsible for contamination in the past should develop an action plan to manage the risk. This might include collating and preparing documentary evidence about past good environmental practices;

(d) ensure the corporate memory is preserved. Consider taking statements from past managers and employees;

(e) put in place an information management system including periodic site audits to ensure the timely warning of possible contamination;

(f) review existing site contamination reports to decide whether any matter must be reported; and

(g) consider whether a claim can be made under insurance policies in relation to orders to investigate or remediate contaminated land.

SUGGESTIONS FOR A SMOOTH EXIT

The current and proposed legal regime for mine closure raises a number of questions about the true viability of "walking away" from a former mine site.

Given the legal effect of not meeting the closure criteria, (ie breach of the lease, the Act, or the continuation or realization of the bond) a great deal of thought needs to go into the terms of those criteria. They must be specific, measurable and above all, achievable. This is no small task given today's (and tomorrow's) community expectations.

In addition, merely meeting the criteria and relinquishing the lease does not mean that all legal liability is extinguished. As a result of unanticipated environmental effects, or changes to community standards, a mining company may yet find itself liable for costs following relinquishment.

What can it do to anticipate such costs?

First, as the ANZMEC Framework suggests, rehabilitate to best practice, even if not required by the completion criteria. This will assist to ensure no future environmental problems.

Second, continue to monitor the site even after closure to ensure that any problems that do arise are brought to the attention of the company early.

Third, as Briggs and Panayi suggest, conduct a benchmark audit and ensure corporate memory. Ensure that records are maintained.

Fourth, consider whether to take out insurance or to set aside funds as a contingency in the event that problems do arise.

And finally, attempt to get an indemnity from the owner of the site, whether this is the State or another mining company; and any future occupier of the site. Even a partial indemnity may at least reduce future costs.

In essence, a smooth exit results from planning for the long term. In many ways, mine closure is simply another stage of mine operations.

NOTES

[1] See Kim Anderson "Criteria for Mine Closure - A Department of Mineral & Petroleum Resources view" published in the proceedings of a conference entitled, "Current Issues for Mine Closure" held on 17 August 2001, Perth, organized by the Centre for Land Rehabilitation, University of Western Australia at p 1.

[2] Other pieces of legislation play a role, such as the *Conservation and Land Management Act 1984 and the Rights in Water and Irrigation Act 1914*. However for the most part the requirements of these pieces of legislation are accommodated within the Mining and Environmental Protection Act processes.

[3] Department of Minerals and Energy, "Guidelines to help you get environmental approval for mining projects in Western Australia", March 1998, p 1.

[4] Ibid, see pp 21 - 30 for detailed guidelines for an NOI.

[5] Gold extraction operations (the carbon in leach process, the carbon in pulp process or a process using sodium cyanide) are exempt from the licensing provisions of the EP Act. They are instead subject to the *Environmental Protection (Gold Extraction Operations) Exemption Order 1993* made pursuant to s. 6 of the EP Act.

[6] Department of Minerals and Energy, Guidelines for the Preparation of an Annual Environmental Report, April 1996, p 5.

[7] Proceedings of a conference entitled, "Current Issues for Mine Closure" held on 17 August 2001, Perth, organized by the Centre for Land Rehabilitation, University of Western Australia.

[8] Anderson, p 12.

[9] The DMPR and the EPA have entered into a Memorandum of Understanding outlining procedures to ensure that the appropriate conditions for the prevention of environmentally significant impacts are formulated and applied to mining leases.

[10] Hunt, 2001 *Mining Law in Western Australia*, The Federation Press: Leichhardt, NSW, p 118.

[11] *Railway Commissioners of New South Wales v The Perpetual Trustee Co* (1905) 3 CLR 27 at 39 per Griffith CJ.

[12] *Ex parte Henry, Re Commissioner of Stamp Duties* [1963] NSWR 1079 at 1083 per Herron ACJ.

[13] *Mills & Anor v Stokman & Anor* (1966) 116 CLR 61 at 77 per Kitto J.

[14] *Radaich v Smith* (1959) 101 CLR 209.

[15] (1976) ALR 324.

[16] *ICI Alkali Australia Pty Ltd v The Commissioner of Taxation* (1979) 53 ALJR 220.

[17] Forbes and Lang, *Australian Mining and Petroleum Laws* (2nd ed), Butterworths, Sydney, 1987, para 995.

[18] Gardner, "Exclusive Possession and the Legal Character of a Mining Lease under the *Mining* Act 1978 (WA)" (1989) 8 AMPLA *Bulletin* 115.

[19] Ibid, p 120.

[20] Halsey v Esso Petroleum [1961] 2 All ER 145).

[21] Donoghue v Stevenson [1932] AC 562.

[22] Jaensch v Coffey (1984) 155 CLR 549 at 584-5.

[23] Sutherland Shire Council v Heyman (1985) 157 CLR 424 at 495.

[24] "The Contaminated land Management Act 1997 (NSW) Impacts and Recommendations for the Mining and Resources Industry" (1999) 18 AMPLJ 63