PROCEEDINGS OF

The Second AMEEF INNOVATION CONFERENCE

"On the Threshold: Research into Practice"

Fremantle, Western Australia
4 – 5 August, 1999

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PART I – SUMMARY

INTRODUCTION

The Australian Minerals & Energy Environment Foundation (AMEEF) is an independent, non-political, non-profit body established in 1991 to promote the implementation of the principles of sustainable development in Australia's mineral, energy and related industries. The mission of AMEEF is to encourage and support continual improvement and excellence in environmental management in Australia's minerals, energy and related industries and to communicate the environmental achievements of these industries to the community.

AMEEF aims to achieve this objective through a number of activities: coordinating a national Environmental Excellence Awards scheme, publishing the quarterly magazine GROUNDWORK with a circulation of around 5000, sales and distribution of over 80 publication titles, production of an Occasional Paper series, and providing a wealth of online information.

In 1999 AMEEF also initiated the 'Innovation Conference' series, aimed at promoting the latest developments in environmental research and technology in the minerals, energy and related industries. The First AMEEF Innovation Conference *"On the Threshold: Research into Practice"* was held on 31 March – 1 April at the Sofitel Hotel, Melbourne and was a resounding success.

The Second AMEEF Innovation Conference *"On the Threshold: Research into Practice"* was held on 4 - 5 August 1999 at The Esplanade Hotel, Fremantle and was sponsored by the Australian Nuclear Science and Technology Organisation (ANSTO). Over one and a half days, innovative and cutting edge environmental management research relevant to the Australian minerals industry was presented to an audience which included representatives from industry, government, consultancies, education, research and conservation.

Sixteen papers, varying in degrees of technical content, made up the day and half long program, in seven separate sessions covering: Rehabilitation, Waste, Sand, Processing, Closure and Tools. Presenters were drawn from organisations such as Curtin University of Technology, ANSTO, University of Western Australia, D.A. Lord & Associates, ACMER, University of Queensland and various divisions of CSIRO.

The Second AMEEF Innovation Conference

"On the Threshold: Research into Practice"

4 – 5 August, Fremantle WA
Esplanade Hotel

PROGRAM

DAY ONE

8.30am Registration

8.55am Official Opening — *Conference Chair*

9.00am **Rehabilitation 1**

Enhancing the re-establishment of spinifex on mined land
Assoc. Professor John Fox, Director Mulga Research Centre, Curtin University of Technology
• is spinifex cultivable? • testing of seed quality • role of top soil • what should be done?

Spectral sensing of the effects of iron ore dust on mangroves
Cindy Ong[1], Peter Hick[1], Mark Piggott[2], Mike Caccetta[1] and Jenny Wilson[1]
1. CSIRO Minesite Rehabilitation Research Program, Division of Exploration and Mining 2. BHP Iron Ore
• effect of iron ore dust on mangroves • hyperspectral, proximal and remote reflectance spectrometry techniques • prediction of dust loadings • potential for the use of airborne spectrometers

Rehabilitation of Exploration Disturbances - The Planned Approach Adopted at an Eastern Goldfields (WA) Underground Nickel Mine
Assoc. Professor Joan Osborne, Mine Rehabilitation Group, School of Environmental Biology, Curtin University of Technology
• drill line disturbance and contaminated sump holes • direct seeding • remediation treatments • end land use • bond recovery

10.30am Morning Tea

11.00am **Waste**

Improvements in Technology for the Immobilisation of Arsenic released from Mining Operations
Ms Maree Emett, Dr Ging Khoe & Dr Myint Zaw, Environment Division, ANSTO
• growing problem of arsenic • impact of tighter regulations • improved technology for removing and immobilising arsenic wastes • alternatives to chemical oxidants

Your mineral processing wastes may be someone else's solution
Dr Bob Gilkes, Head, Soil Science and Plant Nutrition Group, Faculty of Agriculture, University of Western Australia
• wastes as profitable products • plant nutrient elements in wastes • wastes from titanium processing, bauxite refining and gold and minerals sands mining • from processing plants to farmers' paddocks

Remote In Situ Monitoring of Gaseous and Dissolved Oxygen in Sulphidic Minewaste Repositories
Brad M Patterson, Research Scientist, Centre for Groundwater Studies, CSIRO Land and Water
• innovative oxygen monitoring to assess acid mine drainage potential • oxygen ingress to a sulphidic tailings facility • assessment of a cover remediation strategy • long-term assessment of leakage and oxidation potential

12.30pm Lunch

2.00pm **Sand**

Use of water balance modelling in designing reconstructed soil profiles after mineral sand mining
Assoc. Professor Keith Smettem[1], Eliza Cummins[1], Peter French[2], Ian Watson[2]
1. Soil Science and Plant Nutrition Group, Faculty of Agriculture, University of Western Australia
2. Westralian Sands Pty Ltd
• water balance modelling • material characterisation • pasture water use • best practice application

Environmental Management of Shellsand Dredging: Owen Anchorage, Western Australia
Des Lord, D.A. Lord & Associates Pty Ltd
• effects of dredging • distribution of sea grasses • mechanical transplantation of seagrasses

Charophytes (Stoneworts) as Tools for the Rehabilitation of Sand Mine Wetlands, Capel WA - A Case History
Assoc. Professor Jacob John, School of Environmental Biology, Curtin University
• rehabilitation of sand mine voids into productive wetlands • enhancement of water quality by metal removing algae the charophytes • increasing abundance of invertebrates and fish by charophytes • factors regulating growth and propagation of charophytes

3.30pm	Afternoon Tea	
4.00pm	**Processing**	**Biotechnology in Mineral Processing** *Dr Martin Houchin, Program Manager Base and Precious Metal Hydrometallurgy, CSIRO Minerals* • latest research in biotechnology • bioleaching as an environmentally better mineral processing alternativ • biodegradation for managing toxic effluent including cyanide
	Closure	**A science-based approach to decommissioning procedures and criteria for the minerals industry** *Mr Alex Armstrong, ACMER Research Program Manager* Overview of the latest research outcomes in • waste rock dump design • final void water quality predictior • sulphidic waste management • tailings disposal facility closure • ecosystem reconstruction
5.00pm	Closing	*Conference Chair*
7.30pm	Pre-Dinner Drinks	Island Suite, Esplanade Hotel
8.00pm	Conference Dinner	Island Suite, Esplanade Hotel
		DAY TWO
8.55am	Opening Day Two	*Conference Chair*
9.00am	**Tools**	**Computational Tools for Predictive Aqueous Geochemistry** *Dr Paul Brown & Dr Richard Lowson, Environment Division, ANSTO* • accessible models of aqueous geochemistry and contaminant plumes • overseas and Australian developments • modelling slow processes over a mine's life time • techniques for parameter estimation
		Indicators of reclamation success - recovery patterns of soil biological activity compared to remote sensing of vegetation *Mr Yoshi Sawada & Dr David Jasper, Centre for Land Rehabilitation, University of Western Australia* • soil microbial biomass as a measure of soil recovery • remote sensing of revegetation using DMSV • both tools indirectly measure site fertility and thus revegetation progress
		Advanced Systems for Managing the Risks of Dust from Mining *Dr Youzhi Wei and Mr Wayne Robertson, Environmental Engineering Research Group, CSIRO Division of Exploration and Mining* • effective control of environmental risks from dust • better support for decision making • new dust management system • computer modelling tools
10.30am	Morning Tea	
11.00am	**Rehabilitation 2**	**Strategies for Successful Rehabilitation of Waste Dumps and Tailings at Kidston Gold Mine** *Dr David Mulligan, Director, Centre for Mined Land Rehabilitation, University of Queensland* • capping of waste rock • erosion from dump slopes • direct revegetation of tailings • monitoring of success
		The Role of Remote Sensing for Measuring Mining Impact on the Australian Arid Environment and the Link to Ecological Function *Peter Hick, CSIRO Exploration and Mining* • hyper-spectral remote sensing to quantify environmental characteristics • Landscape Function Analysis • remotely sensed data and ecological performance • case studies from the Pilbara, NT and Queensland
		HyMap Data Analysis for Acid Mine Drainage (AMD) Assessment at Brukunga Pyrite Mine, SA *Dr Goetz Reinhaeckel, CSIRO Exploration and Mining*
12.20pm	**Future Directions**	**AMEEF - Innovation Conference 2000 Workshop session** *Delegates are invited to work with AMEEF to develop a framework for future AMEEF Innovation conferences*
12.30pm	End of Conference	*Lunch*

PART II – PRESENTATION NOTES

A. REHABILITATION I
B. WASTE
C. SAND
D. PROCESSING
E. ACID
F. TOOLS
G. REHABILITATION II

A. REHABILITATION I

A. REHABILITATION I

Enhancing the Re-establishment of Spinifex on Mined Land

Presented by Associate Professor John Fox,
Director, Mulga Research Centre,
Curtin University of Technology

Can Spinifex Establishment on Mined Land be Improved?

by
J. E. D. Fox, R. C. Goldman and J. A. McKinney
School of Environmental Biology,
Curtin University of Technology

Abstract

Australian minesites in arid areas face problems in securing adequate seed of good quality. Seed gathered from natural communities forms the basis of supply for rehabilitation. Commercial supplies may vary in the ability to produce seedlings and may only be available from distant sources. This is particularly important in the case of spinifex (*Triodia* spp.) vegetation. Spinifex formations cover some 22% of Australia. Activities associated with mining constitute the most important form of land use. Management of topsoil is of paramount importance in seeking regeneration of spinifex land disturbed by mining.

For seed that is often not readily available a solution exists in developing methods of partial cultivation. If extant areas can be treated they may provide local sources of adequate seed. Preliminary conclusions in respect of spinifex are that mature plants can take up more nitrogen when available, the number of panicles is influenced by fertiliser and seed quality may be improved with supplementary nutrition. Mean panicle weight per hummock is significantly greater with additional nitrogen. Seed yield differs between years due to rainfall and supplementary irrigation should improve seed quality in times of inadequate rainfall. Overall, added nitrogen gives a positive response but this is improved in combination with phosphorus. Further research is necessary to refine seed quality measures, to obtain patterns of yield over runs of seasons and to contrast field performance of "improved" seed against natural supplies.

In securing spinifex renewal, topsoiling is the preferred method. Topsoils contain large, persistent seed banks with a number of relatively short-lived species in addition to spinifex. When topsoil is stripped and directly placed onto contoured dumps, germination from within the soil seed bank is stimulated by rainfall. It is important to prepare sites before summer rainfall, to spread fresh topsoil and rip surfaces before sowing. Judicious topsoil placement and ripping prior to rainfall is more likely to promote spinifex regeneration than is seeding into sites that have no topsoil. Supplementary seeding is recommended if topsoil has been stored.

Long-term trials have been established to allow examination of the development of *Triodia* stands beyond the initial establishment stage. This is an important ongoing priority, as past examples had not been adequately documented. Of particular concern is possible competition between fast-growing pioneer species that establish at dump preparation, to the possible detriment of initially slow-growing *Triodia* species.

INTRODUCTION

Some 22% of Australia, mainly in the arid parts, has natural vegetation dominated by spinifex formations of *Triodia*. Species in this genus number 64 (Lazarides 1997) and are characterised by the hummock shape, unique to Australia, giving rise to the term "Hummock Grassland". Activities associated with mining constitute the most important form of land use in regions where hummock grasslands predominate. Mining companies have an interest in understanding the regeneration processes of *Triodia* species.

Concern has been expressed with the level of spinifex regeneration obtained on disturbed land. Techniques of regeneration after disturbance have not been widely understood and where spinifex seed has been used, establishment success has often been poor. Seed supplies have been difficult to obtain and when available, anecdotal evidence suggested that seed has often been of poor quality.

Triodia species differ from other grasses in that individual plants (hummocks) can be very large. Large individuals may also be of considerable age. During active growth, usually in moist northern summer conditions, a large spinifex hummock can be quite awesome. It positively bristles with active, new stolons. These arch outwards and downwards seeking anchorage away from the extant plant. Inflorescence stalks (panicles) can arise at all active nodes. Several species are known to sprout after fire. These may result in clonal growth due to breaking up of individual hummocks. Seeds are small and seedlings are not known to grow particularly fast.

Most *Triodia* species are believed to occur on soils of low fertility where other species cannot grow. It follows that spinifex grasses can probably tolerate low fertility and may even be disadvantaged on soils of higher fertility. Most species occur on well-drained sandy soils or rocky hills. Seed collection is typically opportunistic and criteria for selection of sound material are not widely understood. Previous studies on the reproductive success of other grasses have examined responses to nutrient addition and irrigation. Since *Triodia* occur in areas of limited soil nutrition and water availability, manipulation of these factors may enhance seed quantity and quality.

In this paper we report experimental work designed to test whether improved supplies of *Triodia* seed can be obtained from partial domestication by fertilising and irrigating natural stands. We also summarise the results of monitoring natural regeneration using returned topsoil. Our hypothesis was that spinifex establishment on mined land can be improved with careful attention to detail and without incurring great costs.

ROLE OF TOP SOIL

Several areas of recent rehabilitation where procedures differed were selected (Boisvert 1997). These were sampled and observed for several growing seasons after treatment. The objective was to determine what effect different factors exert on regeneration success.

The rate of return of *Triodia* (and associated species) differed with treatment in relation to climatic conditions and whether topsoil was spread prior to rainfall. Topsoils contain large, persistent seed banks with a number of relatively short-lived species in addition to spinifex. Mycorrhiza presence in spinifex roots suggests that topsoil may also assist with early establishment of healthy plants through contributing mycorrhiza inoculum.

When topsoil is stripped and directly placed onto contoured dumps, germination from within the soil seed bank is stimulated by rainfall. Highest spinifex numbers follow total site preparation prior to summer rainfall. Timeliness in preparing areas to be regenerated is of great importance. It is recommended that all earthworks, especially topsoil preparation, be completed prior to the onset of summer rainfall.

When adequate topsoil is not available, supplementary seed should be sown. The species of *Triodia* to be used should come from the vicinity of the minesite. Seed should be stored under cool, dry conditions after partial cleaning of outer integuments. Partial cleaning prior to sowing gives good results but total cleaning appears detrimental to subsequent field germination.

Rehabilitation sites that achieve inadequate density in the first few years following treatment may be extremely difficult to improve later on. Reasons include low germination or poor establishment, inferior quality seed and often limited seed supply. These would all be overcome with the use of topsoil and on sites where topsoil is used spinifex consistently has significantly higher density compared to sites where spinifex seed is broadcast with no topsoil.

Factors affecting spinifex re-establishment are site specific. Management can control early site preparation, water harvesting, use of topsoil, local seed and surface stability. Environmental factors less amenable to control include availability of soil nutrients and lack of rainfall after sowing.

Sites to be regenerated should first be sculptured and stabilised with appropriate contouring. All other tasks including spreading of fresh topsoil and ripping of spread surfaces should be completed before summer rainfall. Judicious topsoil placement and ripping prior to rainfall is more likely to promote Spinifex regeneration than is seeding into sites that have no topsoil. Supplementary seeding is recommended if topsoil has been stored. Lack of rainfall after rehabilitation works may severely reduce the available seed pool. Purchased seed should be of local species and of high viability. Initial post-sowing or post-topsoil placement should aim at >10 spinifex seedlings per square metre. Regeneration sites should be monitored over time. Further research is necessary to unravel site-specific differences, particularly regarding nutrient tolerances among the main *Triodia* species.

SEED AUGMENTATION

Experimental Design

The objective of this study was to examine the effect of nutrient addition (nitrogen and phosphorus) and irrigation on seed production in *Triodia pungens*. It was assumed that panicles from hummocks receiving highest fertilisation and irrigation levels would be heavier, *i.e.* contain more floral structures, more seed and be more numerous (McKinney 1997).

TABLE 1. Mean soil attributes (± SE) of site in December 1995.

Soil Attribute	Position re- hummock				Significance
	Under (n = 9)		Between (n = 8)		
	Mean	SE	Mean	SE	p=
Nitrate (mg Kg)	1.22	0.22	1.38	0.26	0.662
Ammonium (mg Kg)	3.00	0.29	4.38	0.63	0.056
Available P (mg Kg)	7.89	1.02	8.38	1.40	0.780
Available K (mg Kg)	241	24	239	26	0.956
Conductivity EC $_{1:5}$ H_2O (dS/m)	0.039	0.006	0.043	0.008	0.753
pH 0.01M $CaCl_2$ $_{1:5}$	5.9	0.3	6.2	0.3	0.477
Nitrogen (%)	0.029	0.008	0.029	0.006	0.989
Ca (meq . 100g) †	4.39	1.57	6.787	3.52	0.570
Mg (meq . 100g) †	2.02	0.13	2.30	0.14	0.199
Na (meq . 100g) †	0.17	0.03	0.45	0.36	0.480
K (meq . 100g) †	0.43	0.06	0.57	0.18	0.525
Al (mg/kg) †	0.16	0.06	1.00	0.00	0.374
Total P (mg/kg) †	355	34	327	44	0.636

† n = 3

The study site is ~ 15 km south of Pannawonica (21°39'S, 116°19'E), in a *Triodia* grassland on pastoral land leased by Robe River Iron Associates. Mean rainfall is 390 mm. In December 1995 a 12 ha site was marked out and soil samples analysed.

Soil analysis confirmed the anticipated low fertility of the site with nitrogen at ~0.03% and the mean value of available phosphorus at ~8 ppm (Table 1). These levels were used to define treatment application rates. Three levels of N and P fertiliser were used - the natural level (control), 2 x the natural level and 3 x the natural level. These three levels were applied in nine treatments (Table 2).

A nested design was set out with sets of 4 hummocks selected and numbered at 9 different positions along 9 transects. There were 3 transects in each of 3 irrigation blocks. Thus for each transect 36 plants were assessed (324 plants in total). Fertiliser treatments were randomised among the sets of 4 hummocks. The total number of treatments was 27 - 3 irrigation levels and 9 fertiliser levels. Four hummocks received the same treatment within each transect and this was replicated 3 times within each irrigation block.

Fertiliser was scattered evenly within a 1m x 1m square in and around each of the four hummocks within the set.

TABLE 2. Fertiliser amounts and combinations for each treatment.

No.	Treatment	Sets	Plants
1	nil (control),	9	36
2	2x natural N;	9	36
3	3x natural N;	9	36
4	2x natural P;	9	36
5	3x natural P;	9	36
6	2x natural N + 2x natural P	9	36
7	2x natural N + 3x natural P	9	36
8	3x natural N + 2x natural P	9	36
9	3x natural N + 3x natural P	9	36
	Total numbers	81	324

Irrigation levels for blocks were - nil (control), 25 mm and 75 mm. These simulated summer rainfall events with low and high rainfall amounts. Irrigation was applied 24 hours after fertilisation. Water used for irrigation came from surplus ground water pumped out of the adjacent mine as part of a dewatering process (mining is done below the water table). Chemical analysis confirmed this water has 2.6 mg L of total N, 0.1 mg L of total P and all metals below detection limits. The water was applied *via* a reticulation system that delivered 7 mm of water per hour to the transects.

Hummock dimensions were measured and panicles counted for all hummocks. *Triodia* hummocks in the trial had mean maximum diameter of 123 cm when first assessed in December 1995 (Figure 1). Fertiliser and irrigation treatments were applied in December of 1995-1998. Any inflorescence stalks present were removed at first measurement to ensure any inflorescences collected later had emerged over the growing season. Hummocks were reassessed after flowering in 1996 and at least annually to December 1998.

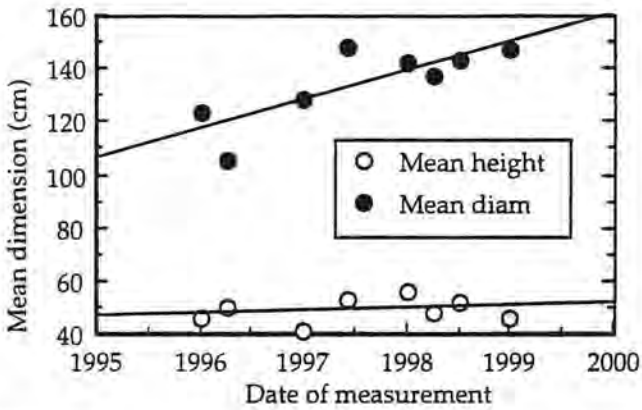

FIGURE 1. Mean diameter and height of all measured hummocks December 1995-1998.

Vegetative growth over the period suggests that plants had attained a general level of structural height at commencement, but that peripheral growth continued over the trial period (Figure 1). By the end of 1998 many hummocks had developed characteristic hollow centres.

Reproductive Growth

Many more inflorescences were produced over the 1996/97 summer compared to the previous year, associated with higher rain fall December 1996 to May 1997. At May 1997 the mean number of panicles per square metre was 131 ± 70, with a minimum of 12 and a maximum of 473. Significant interactions occurred between applied N and P for the number of panicles per square metre ($p < 0.001$). The highest level of N had significantly more panicles per square metre than no added N and twice the natural N. At no added N the highest level of P gave most panicles, at 158 per square metre. This is significantly more than with lower levels of P for the same level of N ($p < 0.001$). For the higher levels of N, there were no significant differences in the number of panicles for any level of P. There were significant interactions between irrigation level and both N and P.

At May 1997 mean panicle weight per hummock was increased in fertilised hummocks. High irrigation levels significantly decreased mean panicle weight when combined with no added N and twice the natural level of N. The overall mean number of florets per panicle was 156 ± 81. Despite a trend of increase in the number of florets for both higher fertiliser and irrigation, differences between treatment means were not significant.

A mean of 35 ± 22 % of examined florets were full *i.e.* contained a caryopsis. The percentage of full florets ranged from 0 (occurring in all treatment levels) to 72%. Values of zero were obtained from florets that were either immature or had already shed the majority of seed. The number of branchlets per panicle is relatively constant. The mean number is 14 ± 2.8, with a minimum of 8 and a maximum of 21. The number of spikelets per panicle is also not significantly different between levels of fertiliser or irrigation. They range from 28 to 97 per panicle with a mean of 62 ± 15.

There was a significant fertiliser effect on the number of full florets per panicle ($p < 0.01$). More full florets were found on panicles from fertilised hummocks than from the control. The mean number of full florets is 44 ± 33, with a minimum of 0 and a maximum of 124 per panicle.

Vegetative Growth

Mean hummock dimensions have changed with time. Most change is associated with initial size rather than with treatment effects *per se*. These are not shown here.

The foliar percentage of N and P was higher after fertilisation than before application. Three months after initial fertilisation all sets, except hummocks with only P added, had higher N levels than control. Contrasts between plants with only N or only P and control were highly significant. Foliar N exceeded 1% in two sets. There were no differences due to irrigation treatments. In the second year, there were significant differences in tissue N at 5 months after fertilisation including more nitrate in irrigated than in control hummocks. In the third year, all treatments had more N than the control.

Seed Quality

The end result of the success of partial cultivation would be production of high quality seed. Seed collected in March 1999 from the trial was tested in April 1999. It is believed that freshly collected seed has a proportion of seed that does not readily germinate. This after-ripening condition is an adaptation that permits seed to remain dormant from the period of seed fall (summer) through the cooler, drier periods that may be relatively unfavourable for germination.

Seed was prepared for germination by:

1) Pre-treatment of half of each batch by storage in an oven set at 60°C for 2 wk; the other half kept at ambient room temperature ~ 20°C;
2) Selection of apparently fertile florets (filled) by hand;
3) Removal of palea and lemma;
4) Shaking for 1-2 min in sodium hypochlorite solution(2%); and,
5) Incubation at ~ 38-40°C.

The results suggest that seed quality in 1999, expressed in terms of weight or germination percentage, was not affected by the level of irrigation (Table 3). As in 1997, the 1999 summer rainfall was comparatively high and may have over-ridden any effect of irrigation. Fertilisation also did not affect seed weight. Seeds stored at 60°C lost some 15% weight. This contained water loss may have contributed to higher germination as conditioned seeds germinated fourfold more than those not treated. Seed taken from hummocks that had the highest level of N fertiliser also showed enhanced germination over those that had less or no N supplement (Figure 2).

TABLE 3. Mean seed weights and germination percentage from partial cultivation. Seed collected March 1999. Tested April 1999. Seed taken from a range of hummocks.

Field Treatment: Irrigation

Category	High	Low	Nil	Significance
Seed weight (g)	0.001268	0.001154	0.001290	NS
Germination % (28 day)	26.5	25.4	28.1	NS

: N Fertilisation

Category	Nil	2 N	3 N	Significance
Seed weight (g)	0.001174	0.001321	0.001196	NS
Germination % (28 day)	21.0 **b**	23.1 **b**	36.1 **a**	p=0.005

: P Fertilisation

Category	Nil	2 P	3 P	Significance
Seed weight (g)	0.001219	0.001223	0.001265	NS
Germination % (28 day)	22.0	29.1	28.9	NS

Lab Treatment: Pre-treatment

Category	Conditioned 2 wk 60°C	20°C	Significance
Seed weight (g)	0.00113 **b**	0.00132 **a**	p=0.003
Germination % (28 day)	36.0 **a**	9.1 **b**	p=0.0001

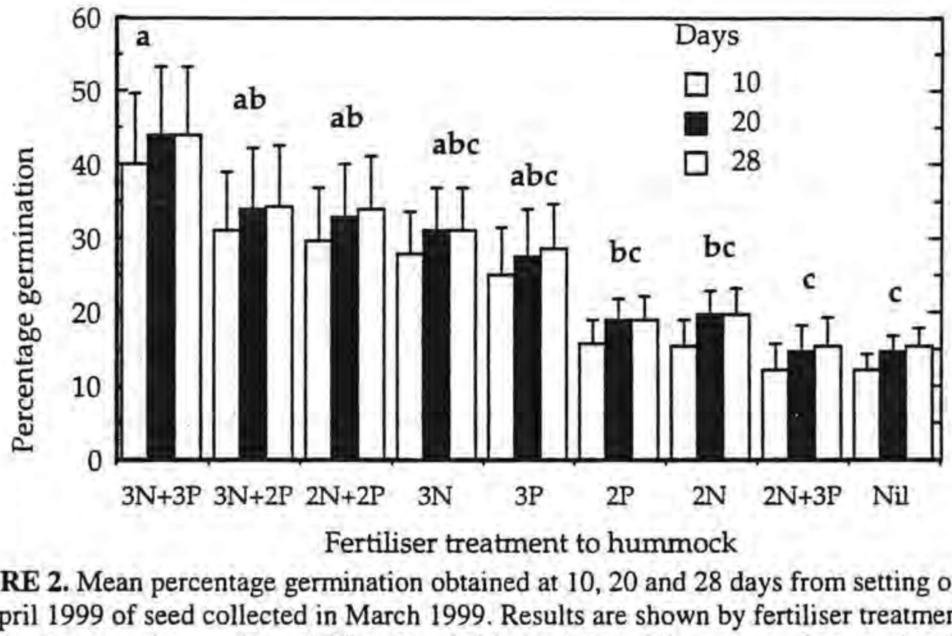

FIGURE 2. Mean percentage germination obtained at 10, 20 and 28 days from setting out in late April 1999 of seed collected in March 1999. Results are shown by fertiliser treatments applied to hummocks over Dec 1995 to Dec 1998. Seed from 3 hummocks from each of 9 treatments was used.

DISCUSSION

Careful attention to site preparation is important in securing regeneration of *Triodia* on disturbed sites. Long-term trials have been established to allow examination of the development of *Triodia* stands beyond the initial establishment stage. This is an important ongoing priority, as past examples of good establishment (as well as several poor examples) had not been adequately documented. Of particular concern is the development of competition between fast-growing pioneer species that establish at dump preparation, to the possible detriment of initially slow-growing *Triodia* species (Boisvert 1997).

Seed from natural communities is the basis of supply for most minesite rehabilitation. Commercial supplies may vary in the ability to produce seedlings. Some poor results are probably associated with insufficient attention to sowing procedures. However, laboratory germination results suggest that sowing of more seed should produce adequate numbers of seedlings. Poor quantity seed may follow low rainfall. Initiation of flowering, seed set and seed development are critical stages in development of a good crop of seed. Summer rainfall of 50 mm in one event may be a minimum to trigger substantial flowering. Results presented suggest that seed quality may be improved with supplementary nutrition. The implication is that this approach may have wide application to a number of other native species where seed supply is problematical.

Partial cultivation is a satisfactory approach to securing quantities of *Triodia* seed of good quality. Supplementary nutrition and irrigation either alone or in combination do increase the number of panicles produced per hummock, the mean weight of panicles and the size of hummocks in *Triodia*. Added N gives a positive response to hummock attributes but this response is improved by combining N with P. Additions of P alone do not influence reproductive or vegetative growth as much as N alone. Seed quality, as measured by germination success in the laboratory, is improved when hummocks are fertilised at higher levels of N and P. It is necessary to follow this up in the field by comparing seedling establishment and early growth of progeny taken from partial cultivation with wholly "wild" seed.

The number of panicles per square metre of hummock was significantly influenced by the application of N and P combined. This differs from other results (Rice *et al.* 1994) where added nutrients did not increase the number of panicles on hummock grasses. We find both the number of panicles per hummock and mean hummock diameter can be increased by adding fertiliser but this must be combined with adequate moisture for best results. If larger hummocks are required, presuming they will provide more inflorescences, then only irrigation needs to be applied to get an increase in growth. This approach to partial cultivation may be most important in increasing seed production because a) larger hummocks may produce a more panicles and b) more panicles per square metre will mean an increase in the total amount of seed.

Mean panicle weight increases with added N but not irrigation. The mean panicle weight may not be as important in determining reproductive growth as originally thought, as differences are not evident in the number of floral structures or the percentage of full florets per panicle. The proportion of 35% of filled florets is a markedly higher level of fecundity than the 10% reported in Westoby *et al.* (1988). A better indication of the effect of water availability on panicle development will come from data that include two or more growing seasons of differing rainfall amounts.

ACKNOWLEDGMENTS

David Button, Paul Collie, David Fletcher and Ken Walker (Environmental Staff of Robe River Iron Associates) are thanked for their support and encouragement. Michael Boisvert, Darren Coulson, Belinda Jeanes, Vanessa Malcolm, Rachel Meissner and Melita Rees assisted with field work. Philip Davidson of The University of Queensland undertook seed viability tests. Final year Environmental Biology (1999) students at Curtin University participated in germination trials.

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A. REHABILITATION I

Spectral Sensing on the Effects of Iron Ore Dust on Mangroves

Presented by Ms Cindy Ong,
CSIRO Minesite Rehabilitation Research Program,
Division of Exploration and Mining

Spectral Sensing of Iron Ore Dust on Mangroves, Port Hedland

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SUMMARY

This paper reports the results of a study designed to quantify the amount and effect of iron ore dust on mangroves in the Port Hedland area using hyperspectral, proximal and remote reflectance spectrometry techniques.

INTRODUCTION

Port Hedland (Figure 1) handles the largest tonnages of bulk materials in Australia (70Mtpa). The harbour has a series of mangrove-lined tidal creeks that play a key role in protecting the iron ore handling facility from erosion and sedimentation and they provide nursery grounds for marine species. BHP Iron Ore (BHPIO) has a fundamental need to understand the role and contribution of mangroves. The environmental programs at BHPIO, Port Hedland include monitoring and research on mangrove distribution, decline and recruitment, and the impacts of dust that may be generated from the handling of iron ore. In collaboration with BHP, CSIRO is conducting studies to establish an operational, non-destructive method that can efficiently assist the management of dust problems at the handling facility by providing quantitative information about dust loadings. Specific objectives include:

1) Can iron ore dust on mangroves be identified?
2) Can the dust loadings be quantified and monitored?
3) Can the source and nature of the dust be determined? and
4) What is the impact of iron ore dust on mangrove physiology?

Figure 1: Aerial photo showing the Port Hedland harbour and handling facility. Mangroves along the banks of the creeks appear as dark green.

FIELD STUDY

Paling, et al. (1996) found that most of the iron ore dust are on the surfaces of the leaves and not in the stomatal cells and that *Avecinnia Marina* are most affected by iron ore dust through entrapment by the abaxial hairs. This and the fact that both vegetation and iron oxides have diagnostic spectral signatures in the visible to short wave infrared region indicated that a remote technique measuring surface materials may be able to measure dust on the mangroves. A field trial was designed to measure a range of leaves (Figure 3) with an IRIS field spectrometer in the visible to short wave infrared spectral regions (400-2500 nm). Figure 2 shows spectra acquired with the for clean leaves in green and dusted leaves in red (see also Figure 3). The left graph shows the topside of leaves and the right graph shows the underside of leaves. Note that. approximately 35-40% of leaves imaged from a remote platform, for example, an aircraft, are of the underside. It is clear from these data that there are distinct spectral differences between clean and dusted leaves on both the top and underside of the leaves. In particular, increased iron oxide is associated with pronounced broad absorption centred at 860 nm as well as changes in the visible colour (500 - 650 nm). The 860 nm centre indicate the iron oxide dust is hematite-rich (Cudahy and Ramanaidou, 1997).

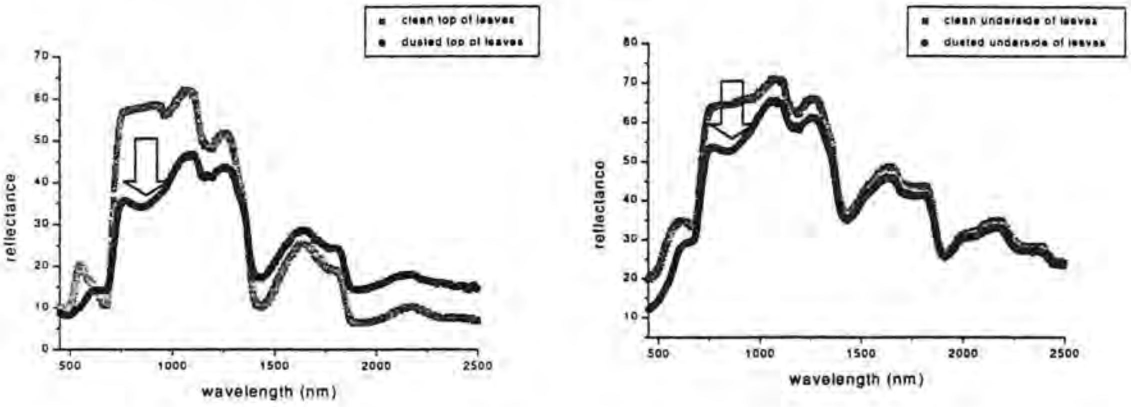

Figure 2: Spectra of clean (green) and dusted (red) *Avecennia Marina* leaves measured with the IRIS field portable spectrometer. The arrow shows the iron oxide absorption region.

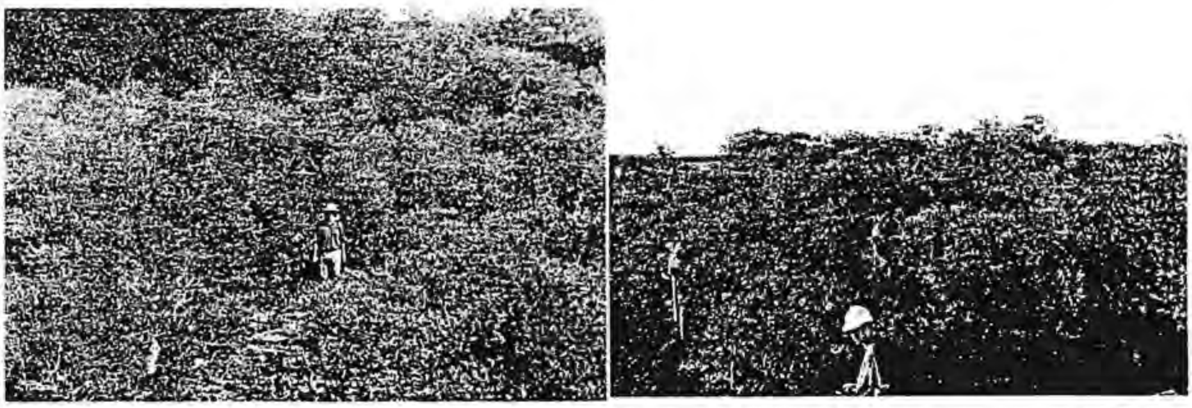

Figure 3:. Clean sample collection site (left) showing experimental spectral dust collection stands in the background and dusted sample collection site (right) with traditional dust depositional gauges in the background.

These encouraging preliminary results provided a useful indication as to how the airborne hyperspectral data could be used to map iron ore dust loadings.

AIRBORNE STUDY

Airborne Hyperspectral (HyMap) data over the Port Hedland harbour were acquired concurrently with field spectral measurements in November 1998 and again in March 1999. (HyMap is an Australian-designed and manufactured system (Integrated Spectronics, http://www.intspec.com) and as a new operational technology. significant amount of research is currently being undertaken to maximise the information content from these data). The aim of this study was to evaluate the potential of these datasets for mapping the source, pathways and deposition of dust on the mangroves. HyMap is a 128 spectral band airborne imaging spectrometer that scans successive lines of a swath (typically 3-5 km wide) in the flight direction for continuous spectral coverage between 400-2500 nanometres (Vis-NIR-SWIR). The spatial resolution is nominally 3.5-10m and the Port Hedland data was collected at 5 m resolution. Corrections must be applied to account for the atmosphere, instrument settings and brightness variations across the imagery.

The HyMap data can be considered as a "data-cube", being made up of *x* lines along flight direction, *y* pixels wide in swath and *z* bands deep. Therefore at spatial position (*x,y*) a spectrum of that pixel, *z*, can be extracted. All materials reflect solar energy in a characteristic manner that relates to their physical and chemical composition. After correction for the effect of atmosphere and angular incidence of illumination the composition of each pixel can be determined.

Various methods are currently being tested to enable accurate, reproducible mapping and monitoring of dust levels using these hyperspectral data, including unmixing (Boardman, 1993) and partial least squares (Haaland and Thomas, 1988). However, simple indices were first considered given that the iron ore dust has strong spectral effects on the green mangrove leaves (Figure 2). Following is an example where three indices were chosen (Figure 4).

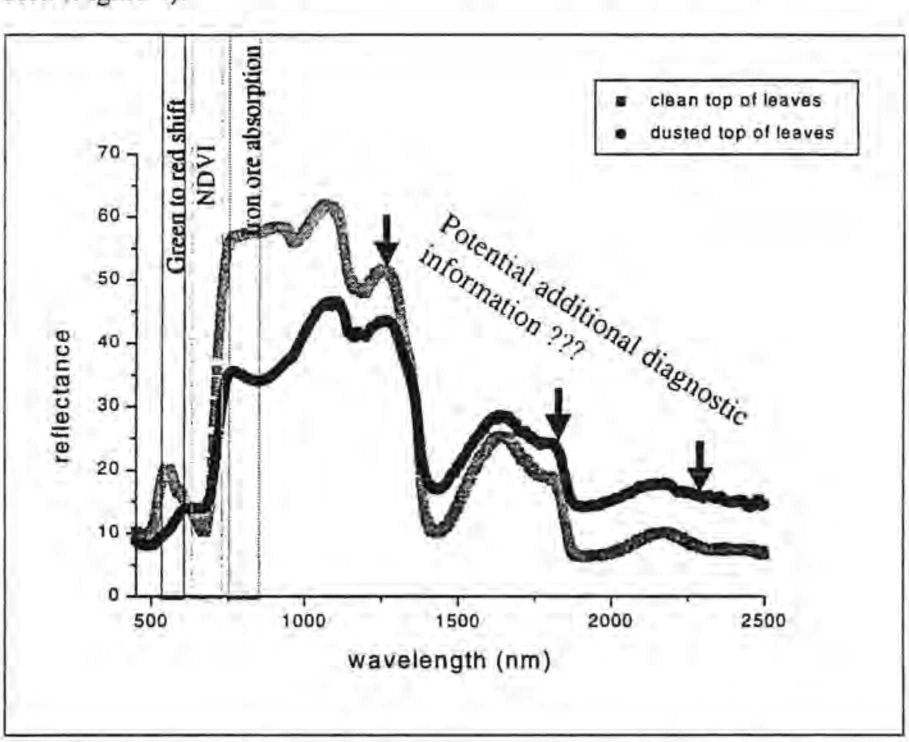

Figure 4: Ground spectra of clean and dusted leaves with the positions of the red, green and blue image colour guns used to create Figure 5.

Figure 5 shows part of the HyMap image, obtained on the 13 November 1998 with an enhancement based on the indices chosen on Figure 4. Therefore, green areas are of clean healthy mangroves, yellow areas show high mangrove vigour with high dust loading, pink areas show less vigorous mangrove, typically seen on the fringes, with high dust loadings and blue areas are mangroves of less vigour surrounding the fringes. This image provides useful spatial information on the distribution of iron ore dust but also the status of the mangroves as even the most dust affected mangroves still show a large chlorophyll absorption and strong infrared plateau indicating healthy vegetation. This image correlates well with ground observation stations where field spectra have been recorded.

Figure 5: Areas affected by iron ore dust are shown on these two unregistered flight lines of HyMap over the Port Hedland harbour as yellow to magenta tones. Dust free mangroves show as green.

COMPARISON OF FIELD AND AIRBORNE DATA

Figure 6 shows a comparison of spectra derived from airborne (HyMap), in red and the ground data from the field (IRIS) in black. The airborne spectra compare well to the ground spectra for both the clean and dusted sites, indicating that there is strong potential for the use of airborne spectrometers to detect iron ore dust on mangroves.

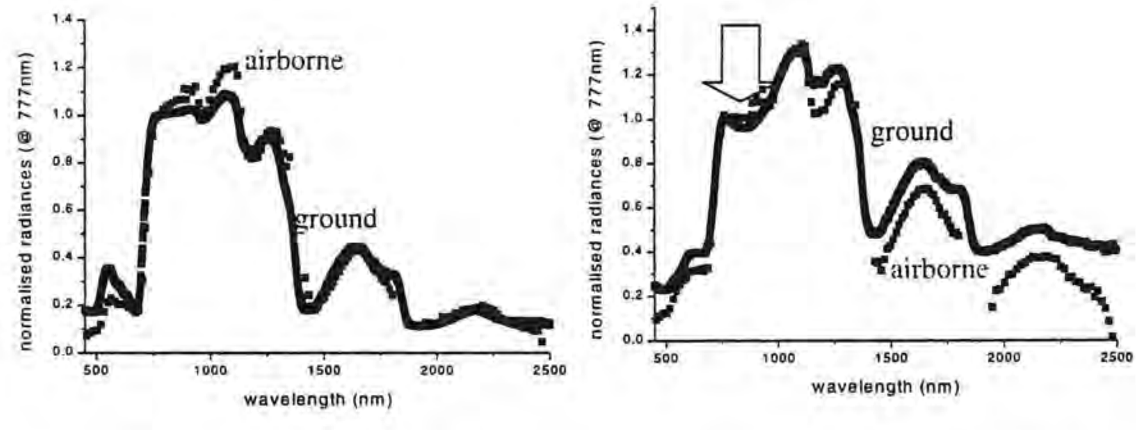

Figure 6: Spectra derived from airborne (red) and ground (black) hyperspectral spectrometers for clean (left) and dusted (right) mangroves. The arrow shows the iron oxide absorption region.

CONCLUSION

The results of the project to date have shown that it is possible to spatially map the iron oxide dust distribution on the mangroves from both ground and airborne hyperspectral measurements. Work is currently in progress to develop methods to determine quantitatively the level of dust loadings on the mangroves.

Simultaneous research using laboratory measurements is under way to develop methods for obtaining quantitative measurements of iron ore dust levels. This includes quantitative measurement of the chemistry and mineralogy using X-ray diffraction and X-ray fluorescence, scanning electron microscopy, which will be combined with the spectral data using statistical techniques such as Partial Least Squares (Haaland and Thomas, 1988). Research is also in progress to define spectral characteristics that may be associated with mangrove physiology.

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A. REHABILITATION I

Rehabilitation of Exploration Disturbances – The Planned Approach Adopted at an Eastern Goldfields (WA) Underground Nickel Mine

Presented by Associate Professor Joan Osborne,
Mine Rehabilitation Group, School of Environmental Biology,
Curtin University of Technology

REHABILITATION OF EXPLORATION DISTURBANCES: THE PLANNED APPROACH ADOPTED AT AN EASTERN GOLDFIELDS (WA) UNDERGROUND NICKEL MINE

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Abstract

The presentation addressed remediation of areas disturbed by exploration activities; drill line disturbance and drill sump holes. Cost benefit analysis of an early approach to restoration is given. Drill line rehabilitation was at A$1,400 per ha, individual sump holes were A$190. The drill lines had displayed a degree of vehicle compaction and related disturbance. The sump holes were contaminated by salts and hydrocarbons.

Application of seed over scarified drill lines led to the presence of a variety of plant taxa. Control and scarified drill line treatments (neither seeded) were characterised by the establishment of one or two species only after one and a half years. This is contrasted with higher species richness (16) and a greater range of life forms over the seeded treatment, coupled with significantly greater plant density and cover. The three sump hole treatments where deep ripping occurred are now covered by a variety of chenopods, with many acacias and eucalypts also prevalent. Application of good quality seed at 15 kg ha^{-1} with fertiliser, in late autumn, on newly prepared surfaces, has seen successful plant establishment over disturbed highly saline sumps, which contained hydrocarbon derivatives. This written paper also addresses ecological trends after three and a half years using a quantitative approach to reporting.

INTRODUCTION

Background

Outokumpu Base Metals Oy (OBM) and Mining Project Investors Pty Ltd (MPI) held, until October 1998, Mining and Exploration leases on rangeland used for grazing sheep 53 km north east of Kalgoorlie, Western Australia. An underground nickel mine was developed with project management by Black Swan Nickel Pty Ltd (BSN), a wholly owned subsidiary of MPI. In October 1998 Outokumpu gained full ownership of the nickel deposit and associated leases.

Open eucalypt woodland covers most of the project area with acacias, cassias and eremophilas the dominant and characteristic woody perennial species on soils acidic in reaction. A succulent chenopod understorey is present where soils are more alkaline. Winter ephemerals from the Amaranthaceae and the Asteraceae are represented. The woodlands are in good condition. Many of the plant species tend to have widespread distributions, particularly the mulga zone acacias.

The main rehabilitation objective is to restore the disturbed areas to biologically sustainable ecosystems, requiring minimum long-term management. These are to be compatible with the pastoral land-use of the general area. Revegetation species will represent a range local to the area and match the rehabilitation substrate.

The region experiences hot, dry summers and cool winters. In the temperate zones of Australia an arid classification is given to areas with an average annual rainfall less than 250 mm (Beard 1990). Kalgoorlie (air-port) records an average annual rainfall of 265 mm. Rainfall between April and September averages 144 mm and accounts for approximately 55 percent of the yearly total (Bureau of Meteorology: 1939-1998 data). Winter rains are more reliable (40 raindays) (Pringle *et al.*, 1994). Long term rainfall (mm) and temperature (°C) readings, with rainfall recordings for the 1997-1998 study period are given in Appendix 1.

Exploration

The presentation addressed remediation of areas disturbed by exploration activities. Exploration rehabilitation trials specifically address two different types of exploration disturbance; drill line disturbance and sump holes (RAB, RC and diamond drilling).

There had been clearing of some passages of vegetation for the development of the geophysical and geological exploration grids. Although use has been made of existing access tracks and clearing of upperstorey species (*i.e.* trees and large shrubs) has been minimised, understorey vegetation has been damaged by drill rig activity. There has also been ground compaction from light and heavy vehicular traffic.

A second disturbance has occurred in the latter stage of exploration, during appraisal of the ore body. Intensive drilling associated with final resource evaluation ultimately leads to ground disturbance over a selected area. Drilling water collected in adjacent sump holes is extremely saline, and contains drilling fluids and hydrocarbon by-products. Sampling indicated contaminated soil within the sump holes is extremely saline (Table 1).

TABLE 1: Salinity and pH: Sump hole materials (n = 2) for each sample description, noting maximum tolerance of pasture crops is 4 dS m^{-1} (ECe).

Site	Description	$EC_{1:5}$ dS m^{-1}	ECe dS m^{-1}	ppm approx.	pH
1	control: not contaminated	0.82	6.57	4,205	6.22
2	saline and hydrocarbons	7.88	63.04	40,346	7.60
3	hydrocarbon materials	11.58	92.68	59,315	7.88
4	saline materials from drilling	32.97	263.73	168,787	7.60

The rehabilitation trials considered cost effective approaches for compacted and (or) contaminated exploration sites. Data from the initial three assessments are being used to ascertain how the surrounding disturbed area should best be treated in future years. For example there are over 100 sump holes within a 10 ha exploration area. Successful techniques can be applied to other exploration projects located in an arid climatic regime, where there are either benign or like contaminating materials.

METHODS

Drill Line Trial

The drill lines displayed some degree of vehicle compaction and related disturbance. The Drill Line Trial sought to determine whether scarification (surface ripping) and seeding of these disturbed areas increased revegetation success. Three treatments were incorporated into the following experimental design:

Treatment 1	**control (no scarification, no direct seeding)**
Treatment 2	**+ scarification – seeding**
Treatment 3	**+ scarification + seeding**

There were ten replicates of each experimental treatment; replicates measuring 20 m by 4 m. Ripping using a multi-tine grader was to 0.3 m depth. Manual seeding was at 6 kg ha^{-1} in early May 1996 (Table 2). No fertiliser was applied.

Sump Hole Trial

The Sump Hole Trial sought to determine whether surface deep ripping, broadcasting of seed, and applying fertiliser increases revegetation establishment over highly saline disturbed areas containing hydrocarbon derivatives. Soil amelioration over time is also being considered.

The trial was established over sump holes for which associated mineral exploration drilling practices had ceased. Four treatments (10 replicates) were incorporated into the following experimental design:

Treatment 1	**control (untreated)**	
Treatment 2	**deep ripping – seeding**	**+ fertiliser**
Treatment 3	**deep ripping + seeding**	**– fertiliser**
Treatment 4	**deep ripping + seeding**	**+ fertiliser**

Sump holes were filled by topsoil replacement and levelled using a front end loader. The surface was ripped by a multi-tine grader to 0.3 m depth. Two replicates each 10 m by 5 m cover a single sump hole. The seeding mixture was predominantly local chenopod species, but also included some of the more salt tolerant acacias and eucalypts (Table 2). Seed was applied by hand (early May 1996) at a rate of 15 kg ha^{-1} over Treatments 3 and 4. A fertiliser with a high elemental composition of nitrogen and phosphorus ("Agras No. 1": 17.5% nitrogen, 7.6% phosphorus and 17.0% sulphur) was applied at 100 kg ha^{-1} to Treatment 2 and Treatment 4 replicates.

Quantitative assessment of both trials was initially in early December 1996 (revegetation age seven months) and continued in early December 1997 (revegetation age 19 months) and early October 1998 (29 months). Plant growth parameters considered revegetation success, and provided comparison between experimental treatments (using appropriate data transformations ANOVA and Fisher's test, $\alpha = 0.05$). There was detailed analysis of soil condition, allowing for documentation of changes over time.

TABLE 2: Seeding mixture with application rates (kg/ha) for Drill Line and Sump Hole (– not applied) Trials at Black Swan Nickel.

FAMILY Species	Drill Line kg ha^{-1}	Sump Hole kg ha^{-1}	FAMILY Species	Drill Line kg ha^{-1}	Sump Hole kg ha^{-1}
AMARANTHACEAE			MIMOSACEAE		
Ptilotus obovatus	0.18	–	*Acacia acuminata*	0.39	1.20
CAESALPINIACEAE			*Acacia aneura*	0.33	–
Senna artemisioides	0.18	–	*Acacia hemiteles*	0.21	0.55
Senna nemophila	0.36	–	*Acacia colletioides*	0.39	–
CHENOPODIACEAE			MYOPORACEAE		
Atriplex bunburyana	0.12	0.35	*Eremophila glabra*	0.15	–
Atriplex codonocarpa	0.21	1.15	*Eremophila maculata*	0.33	–
Atriplex nummularia	0.27	1.10	MYRTACEAE		
Atriplex semibaccata	0.15	0.75	*Eucalyptus lesouefii*	0.21	–
Atriplex vesicaria	0.27	1.30	*Eucalyptus salicola*	0.03	0.25
Enchylaena tomentosa	0.21	1.25	*Eucalyptus salmonophloia*	0.06	–
Maireana brevifolia	0.15	0.75	*Eucalyptus salubris*	0.06	0.55
Maireana georgei	0.36	1.25	*Eucalyptus straticalyx*	0.06	–
Maireana pentatropis	0.21	1.10	PITTOSPORACEAE		
Maireana sedifolia	0.21	1.10	*Pittosporum phylliraeoides*	0.18	–
Maireana tomentosa	0.21	1.10	SAPINDACEAE		
Maireana triptera	0.27	1.25	*Dodonaea lobulata*	0.12	–
			Dodonaea viscosa	0.12	–
			Total	6.00	15.00

RESULTS AND DISCUSSION

Drill Line Trial

Data available over three growing seasons (to 29 months) are summarised in Figure 1 with interesting and conclusive trends evident. Seeding, in this case at 6 kg ha^{-1}, of the disused exploration lines led to significantly more plants and greater revegetation cover.

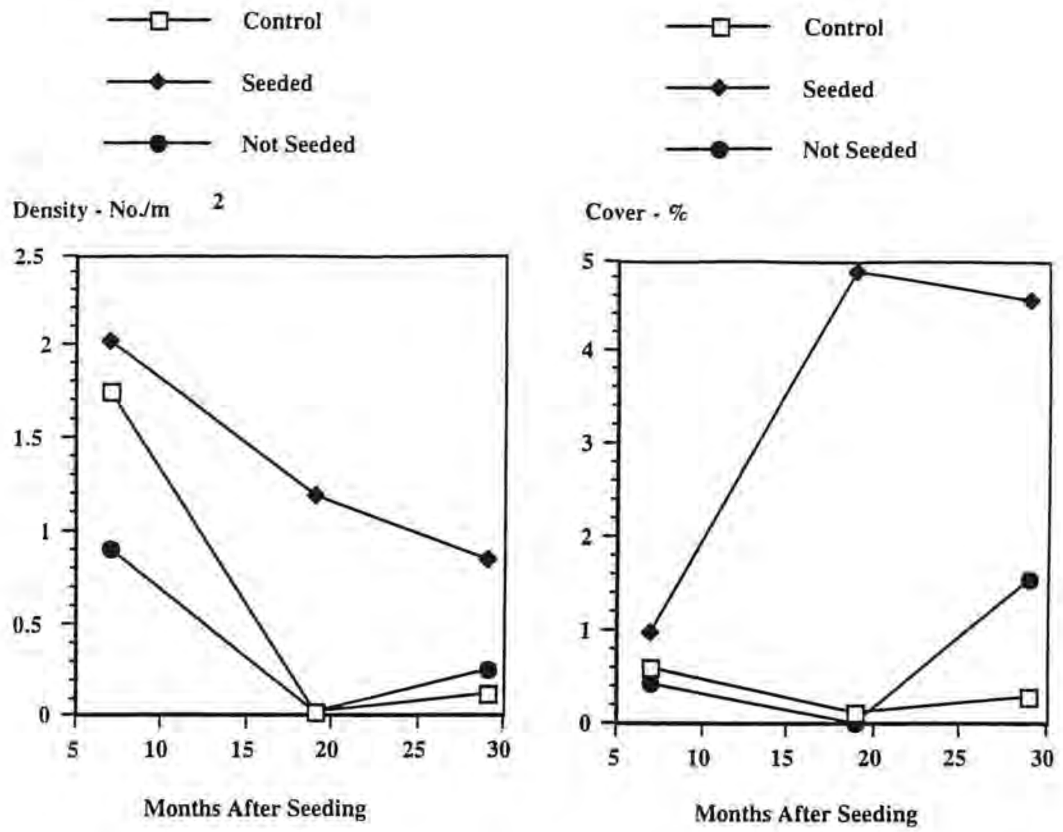

FIGURE 1: Drill Line Trial, with three growing seasons, density (plants m^{-2}) and revegetation cover as a percent, over time (Dec '96 and '97, Oct '98).

Detailed data collected from the Drill Line Trial in December 1996 and 1997 are presented in Table 3. Although application of seed over scarified drill lines had not significantly increased revegetation density or cover after the first growing season, almost twice the number of plant taxa was recorded within the seeded treatment. Differences within the revegetation were evident in the following year, as perennial plants became well established on the treatment where there was both scarification and seeding (Table 3, with additional data available on request from the author).

After seven months the control and scarified treatments (neither seeded) were characterised by the dominant establishment of grasses, which comprised 80 percent and 67 percent of the total revegetation density in each treatment respectively. Historical exploration in the area confirms grasses continue to dominate disturbed areas up to twenty years after clearing activities have ceased. A greater range of life forms was present in the seeded treatment. Annual grasses had volunteered, however in lower numbers (18 percent of total density). Eleven chenopod species provided 59 percent of the total revegetation density, with *Maireana georgei* the dominant species (2,400 plants per ha). The four *Acacia* spp. (800 plants per ha) and four *Eucalyptus* spp. (2,600 plants per ha) initially recorded will provide a middle and upper storey in the revegetation over the longer term. For example, *Eucalyptus salubris* is an erect branched tree reaching 15 m in height and endemic to Western Australia. The common name "gimlet" refers to the trunks being spirally fluted like a gimlet or corkscrew. There are often several trunks covered with a smooth, shining, red-brown or copper coloured bark which is shed in ribbons. An average of 264 viable seed is produced from 1 g of seed, and on areas revegetated by direct sowing seed production occurs after 6-8 seasons.

After nineteen months, on the control (no treatment) drill line just two species were captured. *Ptilotus obovatus* an opportunistic coloniser following rains, and *Senna nemophila*. They averaged 200 plants per ha. The scarified but not seeded drill line recorded one species only, at 300 seedlings per ha. However, on the scarified and then seeded drill line areas contrasting trends are now clearly exhibited. The species richness of 16 includes 14 seed mixture species (data available on request from the author). Revegetation number averages 11,830 per ha. It is noted eucalypts are averaging 4,600 individuals per ha and acacias 600 per ha. The most prevalent chenopods are *Atriplex bunburyana, A. nummularia, A. vesicaria* and *Maireana georgei* with densities in the order of 1,100-1,300 per ha.

In December 1996 soil pH and salinity were similar in all treatments, *i.e.* pH range 6.34-6.39 and salinity range 0.49-1.04 dS/m ECe . Twelve months later the pH range was 7.28-7.40, the salinity range 0.24-0.48 dS/m ECe.

TABLE 3: Drill Line Trial: Mean densities (individuals per m^2) and cover (%) using 20 by 1 m transects. Revegetation ages 7 months (Dec '96) and 19 months (Dec '97) (ANOVA and Fisher's Test within years, like means given by similar letters).

	December 1996 transects: control n = 10, others n = 8			December 1997 transects: control n = 10, others n = 6		
Treatment	**Density per m^2**	**Species Richness**	**Cover %**	**Density per m^2**	**Species Richness**	**Cover %**
control (no treatment)	1.740 a	16	0.602 a	0.015 b	2	0.116 b
+ scarification – seeding	0.900 a	17	0.435 a	0.025 b	1	0.005 b
+ scarification + seeding	2.013 a	28	0.974 a	1.183 a	16	4.870 a

Sump Hole Trial

Sump Hole Trial data are presented in Tables 4. From both assessments significantly higher revegetation density and cover were recorded in the two seeded treatments. Higher average values were recorded for the fertilised treatment, however differences between the two were not statistically significant. Chenopod species have been dominant. In the absence of fertiliser, seeding led to plant cover over 25 percent of the area compared with 35 percent coverage with the fertiliser application, at revegetation age 19 months. Fertiliser addition has increased the productivity of the majority of chenopod species.

The soil salinity was related to vegetation cover (ECe = 54.5 – 64.5 cover; df=1,6; P=0.024 - see Appendix 2) (transformed data - $\sin^{-1}$ square root of the proportion). Increased revegetation cover was associated with lower surface salinity, *i.e.* surface salinity had decreased by 75 percent on the deep ripped, seeded and fertilised treatment, over a 12 month period, compared with a 21 percent decrease on the control (no treatment) surfaces.

TABLE 4: **Sump Hole Trial: Mean densities (individuals per m^2) and cover (%) using 20 by 1 m transects, salinity (dS/m) and pH. Revegetation age 7 months (ANOVA and Fisher's Test within years, like means given by similar letters).**

Treatment	Density per m^2 n = 10 transects	Cover % n = 10 transects	Species Richness	ECe (dS m-1) n = 30	pH n = 30
control (no treatment)	0.810 b	1.015 b	23	41.52 a	6.36 b
deep ripping – seeding + fertiliser	1.456 b	3.603 b	29	52.37 a	7.17 a
deep ripping + seeding – fertiliser	5.870 a	8.518 a	29	52.24 a	7.43 a
deep ripping+ seeding + fertiliser	7.195 a	13.250 a	33	29.97 a	7.53 a

TABLE 5. **Sump Hole Trial: Mean densities (individuals per m^2) and cover (%) using 20 by 1 m transects, salinity (dS/m) and pH. Revegetation age 19 months (ANOVA and Fisher's Test within years, like means given by similar letters).**

Treatment	Density per m^2 n = 10 transects	Cover % n = 10 transects	Species Richness	ECe (dS m^{-1}) n = 10	pH n = 10
control (no treatment)	0.890 c	2.626 c	18	32.72 a	6.75 b
deep ripping – seeding + fertiliser	3.135 b	13.580 b	25	23.49 ab	7.43 a
deep ripping + seeding – fertiliser	4.080 ab	26.220 a	19	24.18 ab	7.52 a
deep ripping+ seeding + fertiliser	4.870 a	35.050 a	23	7.24 b	7.63 a

In December 1997, on the un-treated sump holes there were fewer plants and less revegetation cover than on the treated areas (see Table 5; $F_{density} = 21.87$, df=3,36, $P < 0.001$; $F_{transformed\ cover} = 38.67$, df=3,36, $P < 0.001$). In the deep ripped, fertilised, not seeded, treatment; 25 plant taxa were represented 19 months after surface preparation. Vegetation covered 13.5 percent of the plots with *Atriplex semibaccata* covering over 5 percent of the total area sampled. Although this treatment was not seeded, deep ripping has increased the potential for seed lodgement from wind blown seed. At least 18 of the species present have volunteered from neighbouring sown revegetation plots.

Good revegetation can be achieved on the inhospitable sump hole surfaces when seed and fertiliser application on prepared ground (Table 5 and Fig. 3), is coupled with an appropriate sowing time. Applying good quality seed at 15 kg ha^{-1} with fertiliser led to a chenopod ground cover (*e.g. Atriplex codonocarpa* and *A. semibaccata*) and development of an understorey layer (*e.g. Atriplex nummularia, Maireana georgei, Acacia acuminata*). *Atriplex semibaccata*, a prolific seed producer, has been a ready coloniser of the sump areas, tolerating relatively high levels of soil salinity and providing dense mat cover. *Acacia acuminata* and *Acacia hemiteles* are species giving structure to the rehabilitation stand. Eucalypts averaging 3,100 plants per ha (0.31 per m^2) will provide the upperstorey layer. Ecosystem development trends over a longer period will be elucidated with regular documentation. There is now comparison with natural chenopod shrublands of the lease areas.

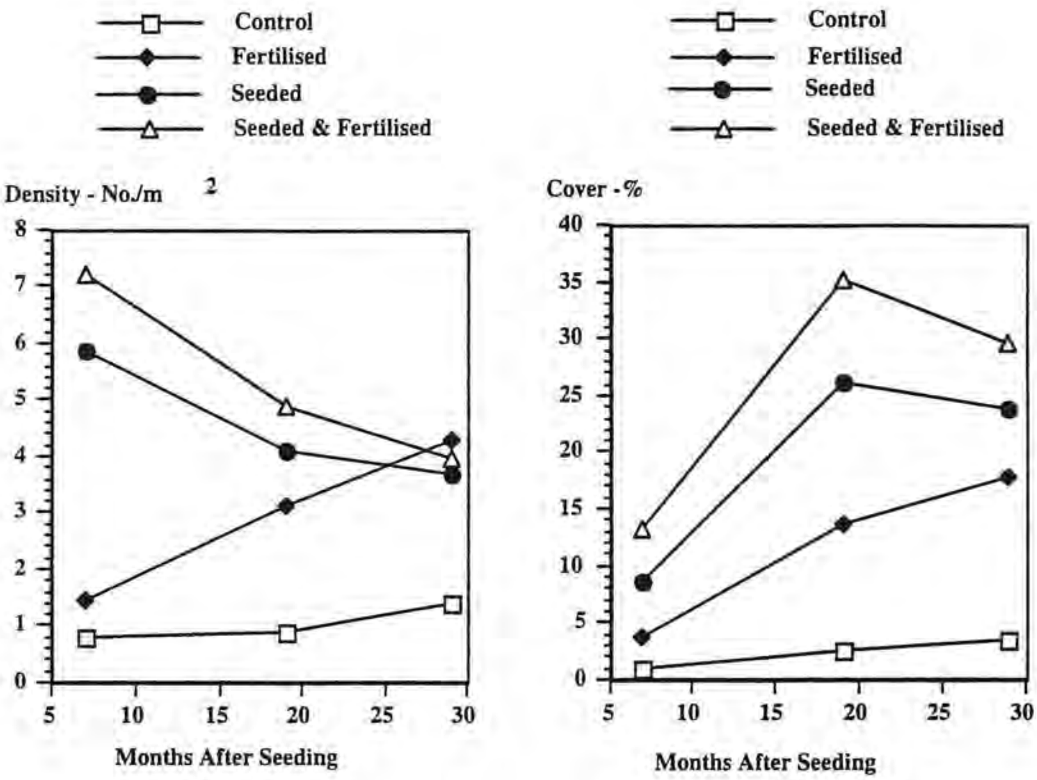

FIGURE 2: **Sump Hole Trial, with three growing seasons, density (plants m^{-2}) and revegetation cover as a percent, over time (Dec '96 and '97, Oct '98).**

CONCLUSIONS

Application of seed over scarified drill lines led to the presence of a variety of plant taxa, with drill lines having displayed a considerable degree of vehicle compaction and related disturbance. Control and scarified drill line treatments (neither seeded) were characterised by the establishment of one or two species only after one and a half years. This is contrasted with higher species richness (16) and a greater range of life forms over the seeded treatment, coupled with significantly greater plant density and cover. Drill line rehabilitation at A$1,400 per ha, was extremely cost effective. Mine machinery on-site was readily scheduled with no mobilisation cost incurred.

The three sump hole treatments where there was deep ripping are now covered by a variety of chenopods, with many acacias and eucalypts also prevalent. Application of good quality seed at 15 kg ha^{-1} with fertiliser, in late autumn, on newly prepared surfaces, has seen successful plant establishment over disturbed highly saline sumps, which contained hydrocarbon derivatives. Individual sump hole rehabilitation of soil placement, ripping and seeding was A$190.

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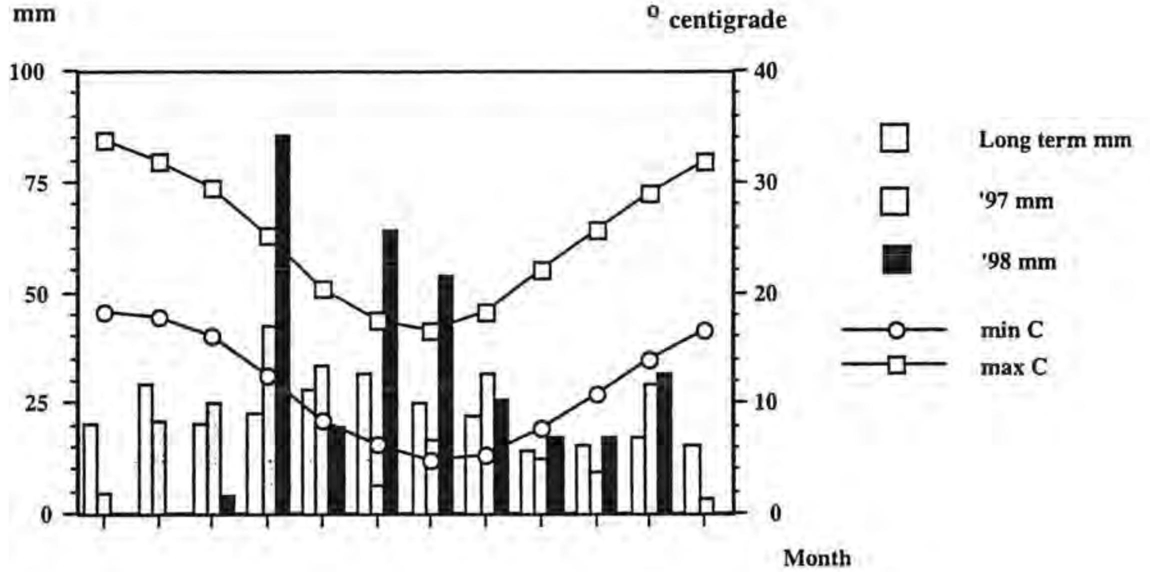
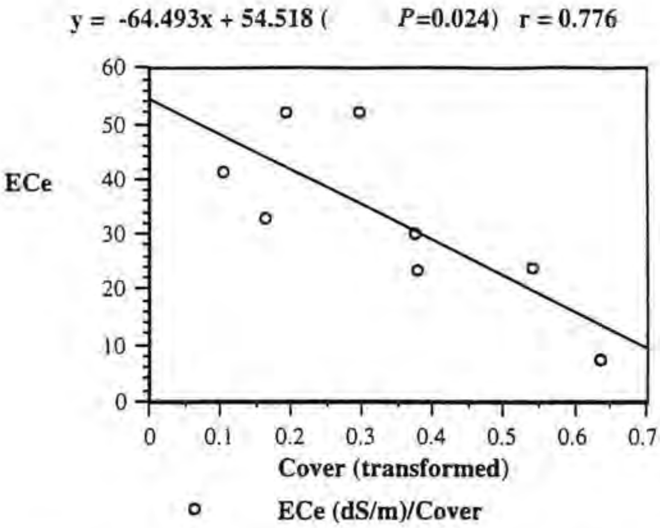
APPENDICES



APPENDIX 1: Kalgoorlie long term ('39-'98) and 1997 (mm) rainfall, and long term ('39-'98) maxima and minima temperatures (°C) from the Bureau of Meteorology Western Australia (collected Kalgoorlie airport); with 1998 (mm) rainfall figures from the Black Swan site.



APPENDIX 2: **Relationship between salinity (ECe in dS m^{-1}) and revegetation cover on the rehabilitated sump holes - increased cover led to lower salinity at the surface 10 cm.**

B. WASTE

C. WASTE

Improvements in Technology for the Immobilisation of Arsenic Released from Mining Operations

Presented by Ms Maree Emett, Environment Division, ANSTO

REMOVAL AND IMMOBILISATION OF ARSENIC FROM THE MINING INDUSTRY

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ABSTRACT

Arsenic is an unwanted by-product of the mining and metallurgical processing of precious and base metals. Australia will continue to be one of the world's largest producers of arsenic wastes because of the increase in the mining of sulphide ores particularly those containing arsenopyrite. In the last several years, environmental authorities have taken a more stringent attitude to arsenic because of concerns for cancer risk, for example the lowering in the limit for arsenic in drinking water, discharged effluents and tightening in the leachability testing for solid wastes. Many of the aqueous waste streams contain trivalent arsenic, which need to be oxidised in order to achieve effective removal and to generate water treatment residues, which are environmentally more stable.

In this paper we show that dissolved iron(III) in the presence of UV light, for example from sunlight or from low-pressure mercury lamps, can be used instead of a chemical oxidant. The subsequent precipitation of iron(III)-hydroxide removes and immobilises the oxidised arsenic. Leachability testing of the treatment residues is discussed.

Recently, an UV assisted sulfite-oxygen process has been developed to oxidise arsenic(III) for more effective applications in neutral or alkaline conditions. Waste sulfur dioxide gas from smelters may be used instead of sodium sulfite for non-drinking water applications.

INTRODUCTION

Growing Environmental Problem.

Australia will continue to be one of the world's largest producers of arsenic wastes because of the increase in the mining of sulphide ores particularly those containing arsenopyrite. Arsenic-bearing wastes may take many forms, eg. acid mine waters, tailings, process effluents and flue dust. Flue dust from the roasting and smelting of arsenic-bearing ores is one of the most concentrated sources of arsenic trioxide. A great deal of flue dust from past mineral-processing operation is still kept in temporary storage space pending safe disposal options. In Australia, as elsewhere in the world, partially treated or untreated arsenic-bearing wastes are often stored in locations pending satisfactory disposal options.

Furthermore, in recent time environmental authorities have taken a more stringent attitude to arsenic in the environment because of increasing concerns for cancer risk (Chen, 1988). For example the World Health Organisation guideline for arsenic in drinking water was revised from 0.050 to 0.010 mg/L in 1993 and the Australian drinking water limits were subsequently lowered from 0.050 to 0.007 mg/L in 1996 (WHO, 1993 and NHMRC, 1996).

Alternatives to Chemical Oxidants.

With these new regulations, the need to remove arsenic from wastewaters such as acid mine waters, tailings, process liquors and effluents and ground water becomes important. Many of the waste streams contain arsenic(III), which requires a pre-oxidation step for effective removal using common methods such as iron-coprecipitation, ion exchange and precipitation as calcium arsenate. Since the oxidation rate of dissolved arsenic(III) by oxygen is extremely slow, oxidants such as chlorine, ozone or permanganate needs to be used. However, it was discovered that, in the presence of visible or near-UV light and dissolved iron compounds which act as a photo-absorber, the oxidation rate of dissolved arsenic(III) by air (dissolved oxygen) can be increased by more than four orders of magnitude without using chemical oxidant (Khoe *et al.*, 1997a).

Removal and Stabilisation of Arsenic Wastes.
The oxidised arsenic can then be removed by an iron co-precipitation process because of the excellent adsorptive capacity of the iron hydroxide precipitate (thus using the added iron as an oxidant as well as a coagulant). The oxidation of arsenic(III) to (V) provides the additional benefit of generating water treatment residues, which are environmentally more stable. The resulting treatment residues, with or without cement solidification were carried out United States Environmental Protection Agency leach test (USEPA. 1990) for landfill disposal as well as the Australian Nuclear Science and Technology Organisation (ANSTO)-developed long-term leach test using aerated water (Zaw *et al*, 1998).

The light-enhanced oxidation and immobilisation process was used to treat acid mine water from an abandoned gold-lead-silver mine during a demonstration project in Montana. The demonstration project was carried out under the Mine Waste Technology Program, which was funded by the U.S. Environmental Protection Agency. The resulting treatment residues, with or without cement solidification, were also carried out the U.S. EPA leach test for landfill disposal (USEPA, 1990) as well as the ANSTO-developed long-term leach test using aerated water.

The results of past testwork carried out in ANSTO laboratories show that the stability of iron-arsenic residues from water and wastewater treatment plants is enhanced when cations (eg. calcium, magnesium or heavy metals) are co-precipitated or/and when iron to arsenic mole ratios in the residues are increased. Under this condition, the stability of the residues increases from pH range of 4 - 7 to 4 - 9 (normal pH ranges in the environment) (Khoe *et al*, 1994, 1997b).

Furthermore, it was shown that drying (at 25 to 135°C) does not adversely affect the stability of the arsenic-bearing ferrihydrite residues. In fact, it improves the arsenic-loading characteristics of the stabilised waste form. In addition, pre-drying the precipitates facilitates the cement-solidification process: it enables the solidification of arsenic into cement monoliths with minimum water and cement content. The chemisorption of arsenate species severely retards the transformation of the amorphous material into crystalline phases and enhances the stability of the iron-arsenic residues. Disposed arsenic bearing iron compounds are stable provided the repository environment can be kept from becoming anoxic (Zaw *et al*, 1998).

TREATMENT OF ACID MINE WATER

The light-enhanced process was demonstrated for the U.S. Environmental Protection Agency in Montana in late 1996. ANSTO is collaborating with MSE Inc. of Butte, Montana to carry out the demonstration in August-September 1996 (MSE, 1997). Test streams with low (acid mine water draining from Susie Mine, parts per million) and high initial arsenic concentrations (smelter flue dust with grams per litre) were treated.

The demonstration project was conducted under the Mine Waste Technology Program, which is funded by the U.S. EPA. Many of these waters contain dissolved arsenic in the trivalent and pentavalent state. Iron is usually present in significant concentrations in acid mine waters. Depending on the oxidation-reduction potentials of the waters, a high proportion of the iron can be present as iron(II), for example the mole ratio of iron(II)/arsenic(III) present in five acid mine waters surveyed in Montana in 1994-96 varied from 12 to 506 (MSE, 1997). In conventional treatment plants, the presence of a large excess of iron(II) in the feed water would result in an extra requirement for chemical oxidant because all the dissolved iron(II) would need to be oxidised first in order to ensure the completion of arsenic oxidation.

In this project, dissolved iron(III) in the presence of UV light was used to initiate and sustain the oxidation of arsenic(III) in acid water (with an Fe(II)/As(III) mole ratio of 41) draining from Susie Mine, an abandoned mine in Rimini in Montana, USA. Two types of photo-reactors were used for the demonstration in Montana: light weight plastic troughs (Figure 1) for the sunlight-based process and an UV lamp reactor which is commercially available in the United States (Figure 2). Air sparging of the solution in the solar troughs was used. Both sunlight and artificial light from UV lamps (240 nm light) can be used to initiate and sustain the photochemical process in the presence of dissolved iron and at least 97% of the arsenic was oxidised to arsenic(V).

The photolysis reactions of iron(III) in water involve the transfer of one electron from the complexed ligand, such as organic, hydroxide or chloride species, to the iron(III)-centred orbital forming Fe(II) and a free radical (Hatchard and Parker, 1956; Zafiriou *et al.*, 1984). The generated hydroxyl radicals oxidise arsenic(III).

$$Fe^{3+}(OH)^{-} \xrightarrow{h\nu} Fe^{2+} + {}^{\bullet}OH$$

As depicted in Figure 3, the arsenic oxidation process in the Susie Mine water was complete in about four hours in the presence of decreasing sunlight during an autumn afternoon in Rimini (41°N). The 10 mg/L arsenic(III) initially present was oxidised in the presence of a large excess (180 mg/L) of iron(II). Iron(III) was added at 190 mg/L and acid (hydrochloric acid) was added because of the unusually high pH of the Susie Mine water (a pH value of 4.8 as compared to the typical pH range in acid mine waters of between 1.5 and 3 (Kelly, 1988); no extra iron(III) addition would have been necessary for acid mine waters containing sufficient dissolved iron(III).

Figure 1. Solar troughs used during the demonstration project in Montana.

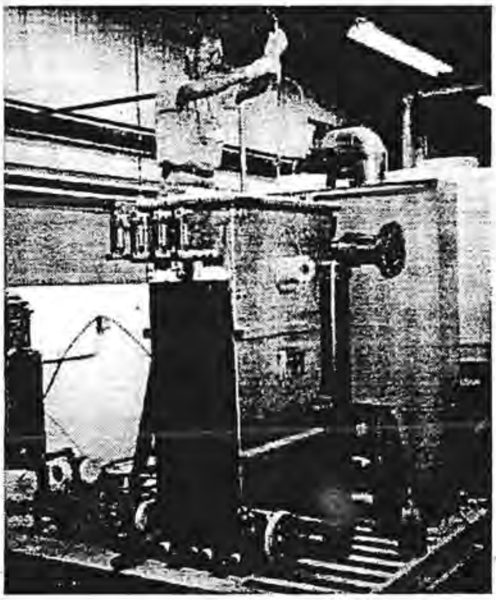

Figure 2. Commercially produced UV lamp reactor of 570 L capacity with 24 low-pressure mercury lamps each of 65 W capacity.

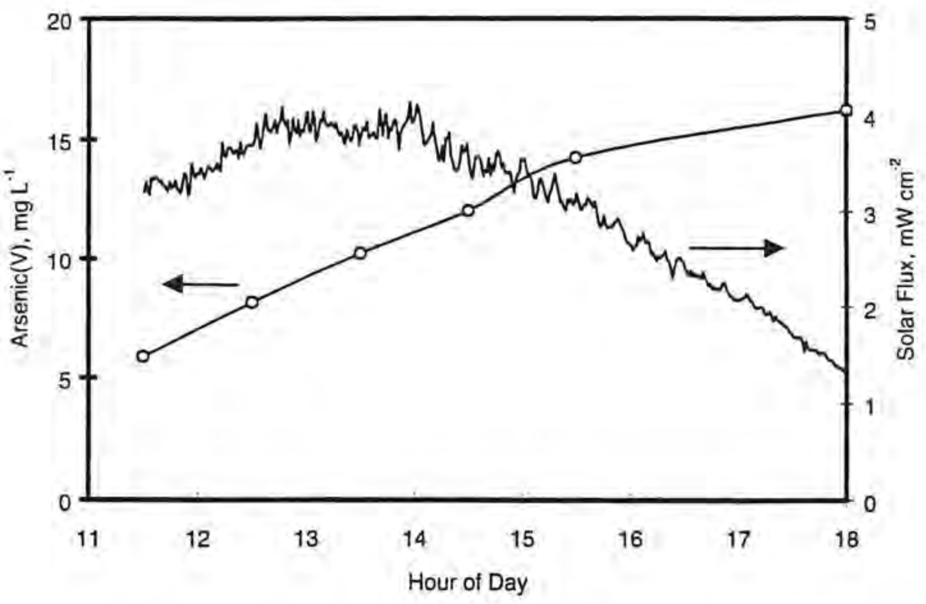

Figure 3. The oxidation of arsenic(III) in acid mine drainage water from an abandoned gold mine in Montana in the presence of sunlight.

Solidification of the Iron Sludge

The oxidised arsenic in the Susie Mine water was removed from solution by iron co-precipitation at pH 7 using lime and aerating the solution to oxidise and precipitate dissolved ferrous to ferric hydroxide. The sludge obtained from the processing of Susie mine water contains excess iron (Fe/As mole ratio of at least 22/1). Then the sludge was dried at room temperature. For the preparation of the cement-solidified samples, the dried filter cakes were weighed and then mixed with ordinary Portland cement, lime and a measured quantity of water. Then the solids were closed in a plastic bag during the 28 days of curing. U.S. EPA Toxicity Characteristic Leaching Procedure (TCLP) and ANSTO aeration tests were performed on the precipitates with and without cement solidification.

Leachability Test of Arsenic-bearing Solids

Figure 4 shows the basic equipment used to perform the leach test using aerated water. This test was developed to investigate the long-term stability of the solids, which had passed TCLP test. Demineralised water (2 litres) was added to get the required leachate to solid ratio. Air or synthetic air (CO_2 free) was continuously bubbled (0.5 L/2 L of sample solution/min) throughout the experiment. All the filtrates (0.05 μm) were acidified and analysed for metals using ICP-MS, ICP-AES and AAS-HG.

All the treatment residues (with and without cement solidification) met the requirements of the U.S. EPA standard leach test for landfill disposal (USEPA, 1990). In addition to the standard TCLP test, leach testing of the solids using aerated water for three months was also performed. All the treatment residues also met the requirements of the U.S. EPA standard leach test as well as the aerated water test. This test (developed at ANSTO) is used to verify whether arsenic is present in the residues as iron-arsenate material. Calcium arsenate compounds, which are subject to attack by dissolved atmospheric carbon dioxide (Robins and Tozawa, 1982), may form during the lime neutralisation operation usually practised in conjunction with the iron co-precipitation process. (Zaw *et al.*, 1998).

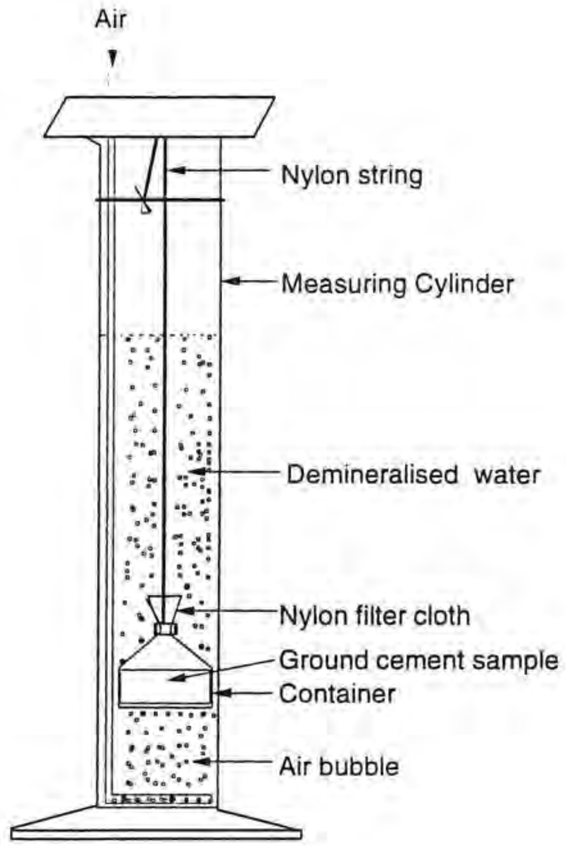

Figure 4. Schematic diagram of aerated water test rig.

OXIDATION USING SULFITE AND OXYGEN

The iron-based photo-oxidation process is not as fast in neutral pH conditions compared as in acidic solution when the added iron can be present as dissolved iron(III). Consequently we have developed an advanced oxidation process using dissolved sulfur(IV) as the photo-absorber. It has been known for more than seventy years that when a mixture of sulfur dioxide and oxygen is bubbled in a solution, the mixture behaves like an oxidant eg. the oxidation of dissolved ferrous in acid solution (Leaver and Thurston, 1923; Ralston, 1927). The novelty introduced in the ANSTO-CRC process (Khoe *et al.*, 1999) is the use of UV light to accelerate the oxidation reaction, which in some cases hardly proceeds without illumination eg. the oxidation of arsenic in the presence of dissolved carbonate which is common in groundwater.

The acceleration in the rate of oxidation of arsenic in the presence of UV light and dissolved sulfur(IV) is depicted in Figure 5. It shows the increase in As(V) concentration and the concomitant decrease in sulfite concentration when 1.7 litre of solution containing 0.47 mg/L of As(III) and 10 mg/L of sulfite was illuminated with UV light from a 15 W low-pressure mercury lamp (non-ozone producing lamp). The corresponding change in As(V) concentration in the absence of UV light is also shown. Air was bubbled at a rate of 2.5 L/min and the solution was adjusted to pH 9 using sodium carbonate.

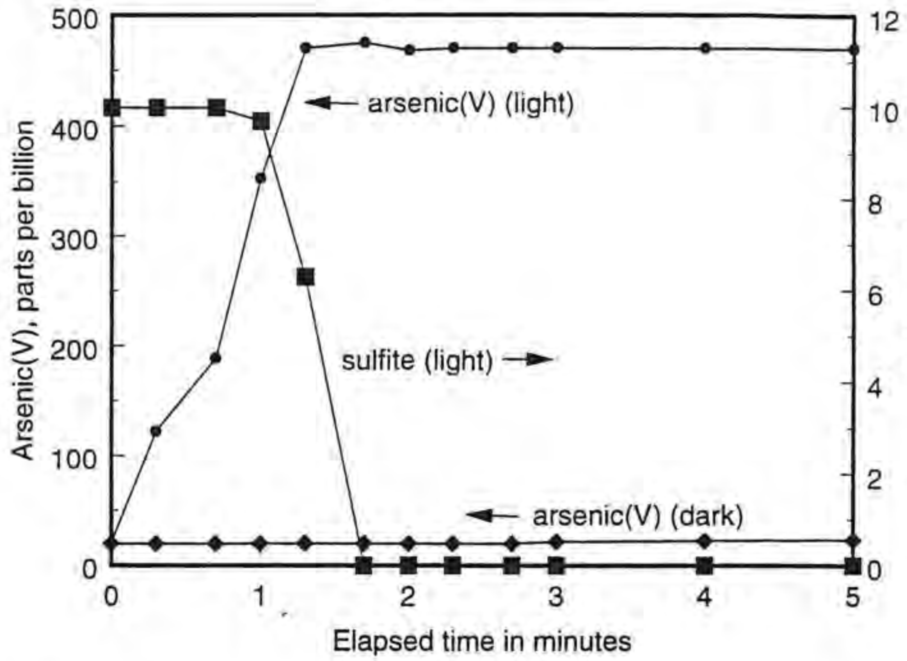

Figure 5. As(V) and S(IV) concentration as a function of elapsed time in the presence and absence of UV light.

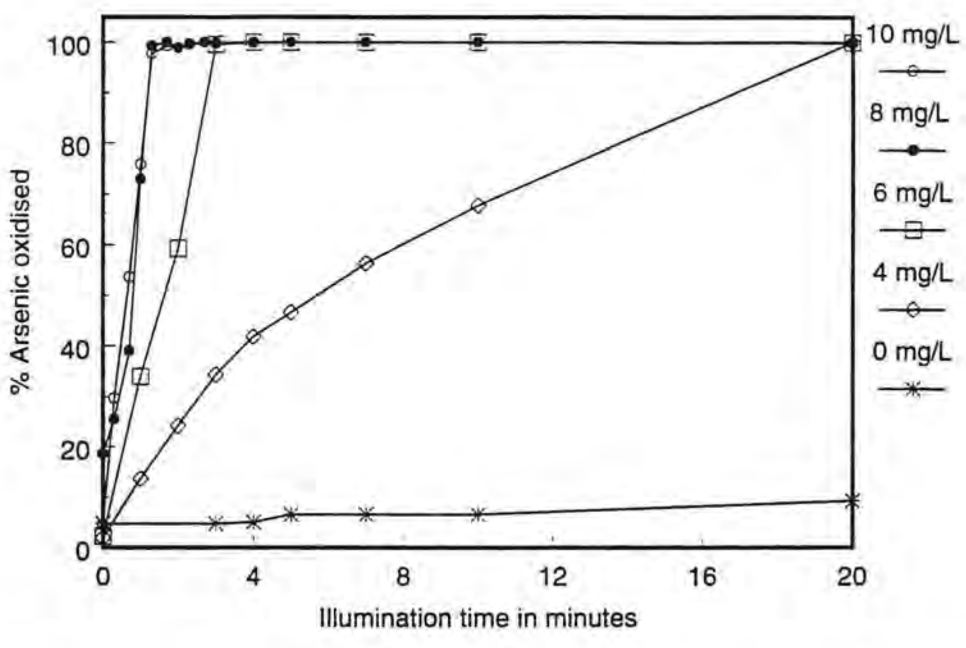

Figure 6. Arsenic oxidation rate as a function of the sulfite addition.

The rate of oxidation as a function of the initial sulfite concentration is shown in Figure 6. The added sulfite was completely oxidised to sulfate (no taste of sulfite after treatment and barium sulfate was precipitated with the addition of barium chloride). A slight increase in sulfate concentration in the water (<10 mg/L) will result for the oxidation of arsenic(III) typically present in groundwater (<1 mg/L). In non-drinking water applications, waste sulfur dioxide eg. from smelters, may be used instead of sodium sulfite.

CONCLUSION

The iron-based photochemical process was successfully used to oxidise and remove arsenic from waters and wastewaters. This photo-oxidation process was used to oxidise and remove arsenic in the presence of iron from mine water draining from an abandoned hard rock gold, silver and lead mine in Montana. The water treatment residues with and without cement solidification passed the standard U.S. EPA leach test for landfill disposal. In addition, the solids were shown to be stable when subjected to leach testing using aerated water for three months.

A new advanced oxidation process using sulfite as the photo-absorber has been developed. Compared to the iron-based photo-oxidation process, a much faster rate of arsenic oxidation can be achieved especially in neutral and alkaline pH conditions. Other dissolved contaminants such as manganese(II) can also be rapidly oxidised.

The stability of iron-arsenic residues from water and wastewater treatment plants is enhanced when iron to arsenic mole ratios in the residues are increased and when cations (eg. calcium, magnesium or heavy metals) are co-precipitated. The chemisorption of arsenate species severely retards the transformation of the amorphous material into crystalline phases and enhances the stability of the iron-arsenic residues. Disposed arsenic bearing iron compounds are stable provided the repository environment can be kept from becoming anoxic.

ACKNOWLEDGEMENT

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B. WASTE

Your Wastes May Be Someone Else's Solution

Presented by Dr Bob Gilkes,
Head, Soil Science and Plant Nutrition Group,
Faculty of Agriculture, University of Western Australia

Your Wastes May Be Someone Else's Solution!

Professor Bob Gilkes
Centre for Land Rehabilitation
The University of Western Australia

In this presentation I question whether the abundant waste products produced by mining and mineral processing can be used to improve our soil and water resources. This is a question of vital importance as Western Australia is mantled by highly weathered soils with many and diverse adverse properties. Consequently our farmers are seeking novel and economic solutions to their soil problems. In my view there are many opportunities for mineral wastes to improve land and I give several examples in the following pages.

Table 1: Some WA mining and processing wastes

Some present and potential WA wastes	*Rough estimates*
Alumina refinery residue - red mud	> 100 Mt
Clay slimes - gold and mineral sands	>1000 Mt
Neutralised acid effluent - synthetic rutile	>10 Mt
Fly ash - coal power stations	> 100 Mt
Coal washings and fines	> 10 Mt
Phosphogypsum - phosphoric acid production	> 1 Mt
Hydrometallurgy residues - jarosite etc.	> 1 Mt
Spent oil cracking catalyst	> 0.1 Mt
Cement kiln dust	> 1 Mt?
Paper mill bark ash (mineral material)	> 1 Mt
Quarry washings - fines of basalt, diorite, etc.	> 1 Mt
Water from mineral processing	> 10 Mt p.a.

There is no thorough inventory of the wastes being produced by mining and manufacture in Western Australia or for Australia as a whole. Similarly little is known of wastes from past mining and manufacturing processes that have been dumped in our land, rivers and oceans. There is clearly a need to rectify this omission as many wastes have the capacity to contaminate land and water together with the food and fibre produced from contaminated environments. However not all wastes are hazardous and many can be use din beneficial ways to improve our environment and economy. Twelve examples of wastes from Western Australian mining and industry are listed in Table 1.

Many other wastes exist in WA. Globally and locally they represent a vast, underutilised resource.

Table 2: Major land and water management problems in WA

Land management problems in south western WA in need of sustainable solutions	*Rough % of area*
Salinity inadequate water use by plants	30%
Waterlogging as above and subsoil structure decline	40%
Top soil structure decline = sodicity excess of Na ions	30%
Top soil structure decline = other causes especially lack of organic matter	30%
Water repellence of sandy soils = lack of clay	30%
Soil acidity = lack of alkali ions and acid retention sites in soils	30%
Infertility = lack of nutrient ions or their fixation	90%
Nutrient leaching = lack of clay and organic matter	10%
Toxicity = contaminants and a lack of adsorbing surfaces or excess acidity	5%
Wind erosion of sandy soils = lack of clay to provide cohesion	30%
Lack of high quality land = competition from urban and industry users	10%
Lack of high quality irrigation water = competition from urban and industry users and salinisation of rivers	10%

To best understand the potential beneficial uses of these wastes we must first identify the environmental problems that confront the WA community. There is no shortage of these as in 100 years of agricultural development of the State we have damaged most land, water and biological resources. It is unfortunate that we did not learn from the mistakes made by other land developers since the dawn of the era of agriculture in the Middle East 7000 years ago. We have made all the same mistakes so that much farming land in WA is now threatened by salinity and many other types of land and water degradation. I have listed 12 of the most pressing problems in Table 2 and made informed guesses of the percentages of the agricultural area that are affected.

This list is not exhaustive and the same problems occur world-wide and are expanding. This paper will now focus on the use of wastes to combat land management problems. I will illustrate this use of wastes via four examples or case studies. The diverse non-agricultural uses of wastes will not be discussed (e.g. phosphogypsum in plaster, red mud pigments) but an equally large number of opportunities exists.

Case study A: Use of bauxite processing wastes (red mud) to improve sandy soils on the Swan Coastal Plain

There are four bauxite refineries in SW Australia that produce wastes consisting of two streams; quartz sand and very fine grained (~30nm) iron oxide crystals together with various forms of alkalinity (red mud). The Swan Coastal Plain is adjacent to the bauxite refineries and has a high proportion of acid sands and sandy duplex soils that are used for grazing. These soils allow P fertilizer to leach and pollute streams, estuaries and the ocean and the soils also do not retain water for plant use

Sandy soils can be improved by mixing about 10% red mud through the topsoil, the mud can be first mixed with gypsum (phosphogypsum) to reduce pH to ~ 8.4 from its initial very high value of pH ~ 10 that is harmful to plants.

The iron oxides and alkalinity retain P and other ions against leaching. The alkalinity of red mud corrects excess soil acidity. Red mud may provide Fe, Mn and other nutrients to plants. There have been several successful field trials with red mud that have demonstrated its remarkable capacity to prevent leaching of P and thereby increase soil fertility and plant growth. Typical results of such experiments where the addition of only 200 t/ha of red mud reduced leaching of fertilizer P by about 95%.

There are some potential problems facing the widespread use of red mud on sandy soils:

(i) P is retained so strongly plants can not release it.
(ii) red mud is messy and needs careful management.
(iii) red mud is slightly radioactive.
(iv) red mud contains trivial amounts of toxic elements (Cd, Pb) etc.
(v) red mud can not be removed from soil (irreversible).

Case study B: Use of clay slimes from gold, mineral sands and other mining to prevent water repellency in sandy soils

There are many sources of clay slimes from the mining industry including slimes from beneficiation of mineral sands and processing of lateritic gold deposits. Slimes commonly consist of clay minerals (kaolinite, halloysite, smectite, illite) with minor amounts of Fe and Al oxides. Their pH varies from moderately acid to alkaline depending on source and process and they are sometimes salty.

Sandy soils throughout the agricultural and urban areas of WA become coated with hydrophobic organic waxes during summer so that rainfall does not infiltrate. This causes water erosion, poor crop yields, inefficient use of herbicides and fertilizers and excessive recharge of saline groundwaters. There are very large areas of sandy soils in Western Australia that are actually or potentially hydrophobic and which could be improved by addition of clay slimes from adjacent mining activities.

Mixing about 2% clay (slime) through the top 10cm of soil almost completely overcomes water repellency. Farmers in South Australia and Western Australia are 'claying' over 50,000 ha a year using clays from local sources. The added clay provides many benefits as follows.

(i) clay particles coat wax on sand grains.
(ii) clay particles absorb wax.
(iii) clay helps water infiltrate.
(iv) clay provides plant nutrients.
(v) clay prevents fertilizer nutrients from leaching.
(iv) clay retains water in the soil for plants.

Greatly increased yields of crops have been observed for sandy soils of the Albany region that have been treated with clays. As for all soil treatments we must be aware of possible adverse effects of claying. For example clayey sands may 'hardset' preventing seedling emergence. Nutrients absorbed by clay may not be available to plants so that fertilizer efficiency could be reduced. Salty clays such as slimes from gold mines may damage plants through osmotic and Na toxicity effects. However the amount of salt added as even a highly saline slime at ~100 t/ha of slime is about 2 t NaCl/ha which is very much less than the salt load of most WA farmland (about 1000 t NaCl/ha in subsoil). Indeed addition of slimes to topsoil increases water use by plants thereby reducing the rise of water tables and associated salinisation of farmland.

Case study C: Use of phosphogypsum to improve the structure of sodic soils

Phosphoric acid plants associated with fertilizer and chemical factories have produced phosphogypsum waste that represents a valuable resource. Phosphoric acid is produced by reaction of sulfuric acid with mineral apatite to give phosphoric acid and gypsum ($CaSO_4.2H_2O$) waste (phosphogypsum) which is presently landfilled. Throughout the world there are large tonnages of phosphogypsum awaiting beneficial end uses. Clay-rich topsoils in the wheatbelt of WA often have abundant Na adsorbed onto surface exchange sites of the clay minerals (i.e. they are sodic). Such soils are common in valley side and floor situations throughout the <650 mm rainfall zone of south western Australia. These sodic soils spontaneously dissagregate and disperse when wet and structure is destroyed by cultivation. Consequences include erosion, flooding and crop losses. Sodicity can be rectified by the application of 2-10 tonnes/ha of gypsum to the soil surface.

As gypsum dissolves in soil water Ca replaces some of the adsorbed Na on clay particles and increases the ionic strength (concentration) of soil solution. These two processes stabilise soil structure. The residual P and S in phosphogypsum are available to plants providing an added benefit. Substantial increases in plant yield have been reported for sodic soils treated with gypsum. Phosphogypsum may contain minor amounts of toxic Cd and F so that the permissible loads and ultimate fate of these elements should be researched. Phosphogypsum is difficult to spread using conventional agricultural machinery unless it is first granulated but this should be easily achieved using simple binders.

Case study D: Use of quarry washings as fertilizers (remineralizers)

Aggregate and other quarry products are washed to remove dust which is generally land filled at the quarry site. The dust consists of fine particles of granite, diorite, basalt, dolerite or shale which contain large amounts of some plant nutrient elements (Ca, Mg, K, Fe, Mn, etc.). Most WA soils are extremely infertile and require additions of these plant nutrient elements in the form of chemical fertilizers. Biodynamic farmers are not allowed to use unnatural (chemical) fertilizers so that there is an opportunity to use rock dusts as fertilizers. Indeed many farmers in Europe and America have started to use rock dusts to improve the yield and quality of agricultural products. Such farmers were once regarded as a 'lunatic fringe' but as the public's desire for green and clean food and fibre is now very evident in western countries so the prices for biodynamic products increases above that of products of conventional agriculture.

Applications of about 50t/ha of quarry washings dust to nutrient deficient soils may provide adequate plant nutrients to sustain economic plant yields. Many quarries are conveniently located close to areas of infertile soil. Dust minerals dissolve in acid soil solution releasing nutrients to plants. Data shows that only a small proportion (3%) of the total K in the rocks dissolved during the brief plant growth period can be applied. Dissolution of dust has a liming effect on acid soils and reduces water repellence of sandy soils thereby providing benefits in excess of those due to nutrition. Rock dust being a natural material does not usually contain elevated concentrations of heavy metals such as Cd which is present in some chemical fertilizers and is accepted as being 'biodynamic'. Dissolution of dust may be too slow to match plant demands for nutrients but we have shown that high energy milling of dust increases its solubility. Rates of application are much greater than for chemical fertilizers (<1t/ha) but the residual value of the dust will persist for many years. Quarry dust can be contaminated with undesirable hydrocarbons so that careful control of the product is required.

Overview

I commenced this article by showing tables identifying 12 wastes and 12 land management problems. Naturally not all 12 wastes can be used to solve all 12 problems. To provide a full explanation of all the complex interactions that occur in soils and agricultural systems is beyond the scope of this paper but I will describe one example, that of the many benefits derived from claying of sandy soils. Addition of clay (slime) to sandy soil increases water use by plants which apart from increasing yield reduces waterlogging and consequently the rise of saline water tables and development of stream salinity. Nutrients are not leached below root depth in clayed soils so that soil fertility is improved and acidity due to ion leaching decreased. The added clay together with increased soil organic matter resulting from greater plant growth can reduce toxicities, and improve soil structure thereby reducing erosion. All of the above processes improve the quality, productivity and value of the land.

Conclusions

There are certainly many opportunities for miners, industry and farmers to mutually benefit from appropriate uses of wastes. I am often asked why this does not commonly happen and the answers are probably:

- The need for a moderate amount of further research to confirm benefits and identify hazards;
- A lack of awareness by farmers of the mineral waste resources available in WA and associated ignorance by miners and industry of the utility and value of their wastes;
- A cumbersome statutory and legal framework for innovative practices so that providers and potential users of wastes are uncertain of their liability where wastes are applied to land, so both providers and users do nothing; and
- The absence of a 'one stop' funding source for such 'cross-cultural' research and development initiatives, governments should take a lead as the community is the ultimate beneficiary. Mineral industry and forming industry funding bodies both expect the other to fund this type of research and market development.

If you are interested in pursuing any of the initiatives identified in this presentation contact me or Dr David Jasper at the Centre for Land Rehabilitation.

Acknowledgement

I am grateful to Irene McKissock and Nick Middleton for assisting in the preparation of diagrams for this paper.

B. WASTE

Remote *In Situ* Monitoring of Gaseous and Dissolved Oxygen in Sulphidic Minewaste Repositories

Presented by Mr Brad Patterson, Research Scientist,
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Remote *In Situ* Monitoring of Gaseous and Dissolved Oxygen in Sulphidic Minewaste Repositories

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Introduction

The oxidation of sulphide minerals in minewaste/minewater and generation of low-pH leachates is a major environmental problem worldwide. Oxygen transport to the sulphide material is often the rate-limiting mechanism for oxidation to occur (Davis and Ritchie, 1986). Techniques for minimising acid production often involve limitation of oxygen (air) supply to the wastes, through low-permeability covers, or maintenance of water-saturated conditions (Nicholson et al., 1989). There is a need to monitor oxygen, if possible *in situ*, remotely and in real-time, to ensure that oxygen delivery to the waste materials is minimised, and to estimate rates of oxygen utilisation.

In situ probes have been developed by CSIRO, which can measure oxygen remotely and continuously, in dry and variably saturated porous media such as waste piles, tailings facilities or groundwater (Patterson et al., 1995; Davis et al., 1997). The probes are typically buried in the subsurface and connected to a data logger at the ground surface. The logger stores sensor output for later recovery, or possibly for dispatch via telemetry to a laboratory/office.

This paper presents data from a trial conducted to monitor oxygen concentrations at multi-depths within a sulphide-rich tailings repository to monitor the effectiveness of an 'impermeable' liner as a barrier to oxygen ingress.

Installation of Oxygen Probes

Multi-depth oxygen probes were installed at three locations (centre, mid and edge locations) within a sulphide-rich tailings repository. Probes were installed at a number of depths, both above and below a synthetic liner (see Figure 1). The probes were monitored hourly over a period of 6 months, and the data were stored on-site using a multi-channel loger.

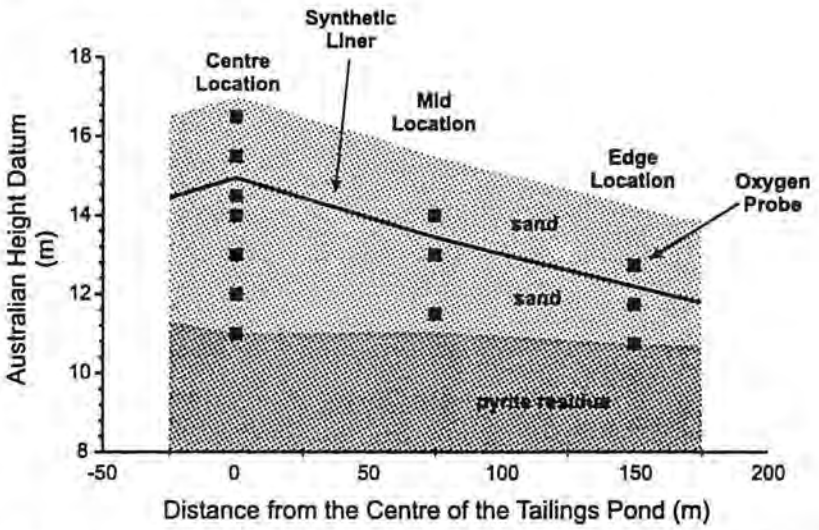

Figure 1. Schematic showing depth locations of oxygen probes relative to the synthetic liner and the pyrite residue.

Results and Discussions

The oxygen concentrations measured above and below the synthetic liner provide indications of the rates of oxygen ingress from the atmosphere compared to oxygen usage at these depths. At all locations, oxygen concentrations in the clean sand (no pyrite residue) above the synthetic liner were close to atmospheric concentrations (21%).

Below the synthetic liner, at the centre of the tailings repository (centre monitoring location), oxygen concentrations decreased, although there were considerable fluctuations in concentrations over time, particularly at 0.5 m below the synthetic liner. The rapid increases and frequency of fluctuation in oxygen concentrations at 0.5 m below the synthetic liner suggests the ingress of oxygen was probably a result of poor sealing of the synthetic liner coupled with barometric pumping of air below the cover. During periods of relatively high atmospheric pressure, gas below the liner will compress if gaps are present in the liner and air will move down through the gaps, resulting in increased oxygen concentrations below the liner. During periods of low atmospheric pressure the gas will decompress and move out through any gaps. Also, oxygen entering through the gaps during high pressure periods will be rapidly consumed by the pyrite residue below the liner. This would reduce oxygen concentrations to below the detection limit of the oxygen probes (<0.5 %). Further sealing of the bentonite (used to seal the synthetic liner after the probes were installed) using 25L of water stopped fluctuations in oxygen concentrations below the liner. Oxygen concentrations then decreased uniformly to less than 0.5%, suggesting the leak in the liner had been sealed. No increases in oxygen concentrations below the liner at this location has been observed since. Oxygen data from the centre location are shown in Figure 2A.

At the mid location, oxygen concentrations below the liner decreased rapidly after the oxygen probes were installed. Oxygen concentrations remained low (< 0.5%) indicating negligible ingress of oxygen below the liner occurred at this location (see Figure 2B).

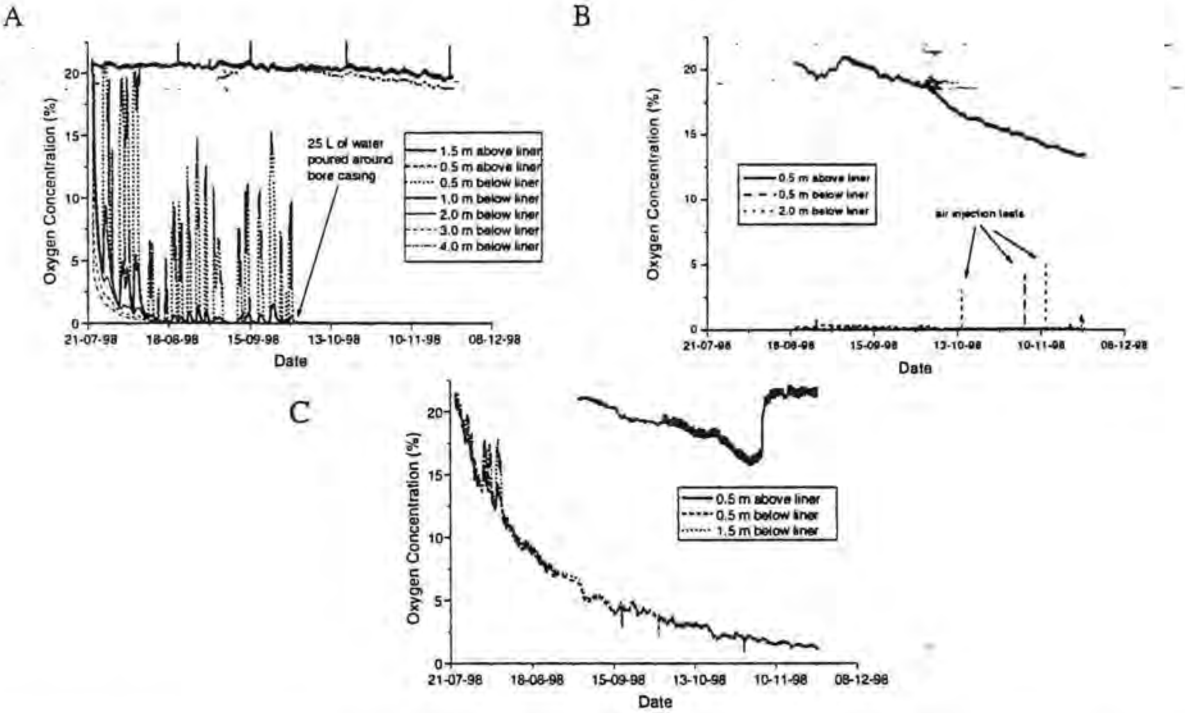

Figure 2. Oxygen concentrations determined from probes at the centre location (A), the mid location (B) and the edge location (C). The synthetic liner was located at 2.0 m below ground surface.

At the edge location, oxygen concentrations below the cover decreased from 21% to approximately 2% over a period of 4 months (Figure 2C). This rate of oxygen concentration decrease is significantly lower than rates observed at the centre and mid locations. The low rate of oxygen decrease indicates either a low rate of oxygen consumption from pyrite oxidation, vertical or horizontal ingress of oxygen below the liner, or a combination of both. Since oxygen concentrations at 0.5 and 1.5 m below the liner were very similar, i.e. vertical gradients were negligible, lateral oxygen ingress to this location may be occurring. Further investigation at this location is being undertaken to better understand this low rate of oxygen decrease.

The oxygen probes were also tested in remediation trials of hydrocarbon contaminated soils and groundwater (Patterson et al., 1999). The probe data were used for assessment of oxygen utilisation rates, and estimation of biodegradation rates for petroleum contaminants.

Conclusions

The *in situ* oxygen probes provided detailed vertical oxygen data during a 4-month field trial, enabling a better understanding oxygen transport processes in sulfide materials. The new technology provides significant improvement in monitoring capability at remote sites, and cost-effective methodologies for monitoring cover integrity and also process effectiveness (e.g. in heap leaching) at minesites. The monitoring technique is non-invasive once installed, and can provide unattended, remote monitoring results for several months at a time. Probe lifetimes on average are likely to be several years.

Acknowledgment

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C. SAND

C. SAND

Environmental Management of Shellsand Dredging: Owen Anchorage, Western Australia

Presented by Mr Des Lord,
D. A. Lord & Associates Pty Ltd

ENVIRONMENTAL MANAGEMENT OF SHELLSAND DREDGING: OWEN ANCHORAGE, WESTERN AUSTRALIA

Desmond A. Lord
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SUMMARY

Marine carbonate sediments (shellsand) off the coast of Perth, Western Australia are presently being dredged for use in the manufacture of lime and cement. The increase in water depth modifies the wave climate in the adjacent area. In addition, seagrasses occur in some of the areas proposed for dredging.

A comprehensive Environmental Management Programme (EMP) has shown that dredging is not adversely affecting shipping and navigation, and that the adjacent shoreline continues to accrete. Further, seagrasses of the area have shown a significant natural increase in density and cover. A major successful development has been transplantation of seagrass in the area.

INTRODUCTION

Success and Parmelia Banks are two unconsolidated and relatively uniform marine sedimentary deposits off the coast of Western Australia. They consist predominantly of calcium carbonate and are currently being dredged under a State Agreement Act, for use in lime and cement production.

Dredging took place initially on Parmelia Bank (1971–1981), then moved to Success Bank in 1981 for reasons of resource quality. The dredging that took place between 1971 and early 1994 formed part of the proposed second shipping channel through Owen Anchorage *(Figure 1)*.

In 1994, dredging of shellsand was proposed on Success Bank in a 67 ha area largely free of seagrasses, located between the Fremantle Port Authority (FPA) shipping channel and second channel, (short-term dredging area). The bulk of the remaining area between the two shipping channels is termed the proposed medium-term area *(Figure 1)*.

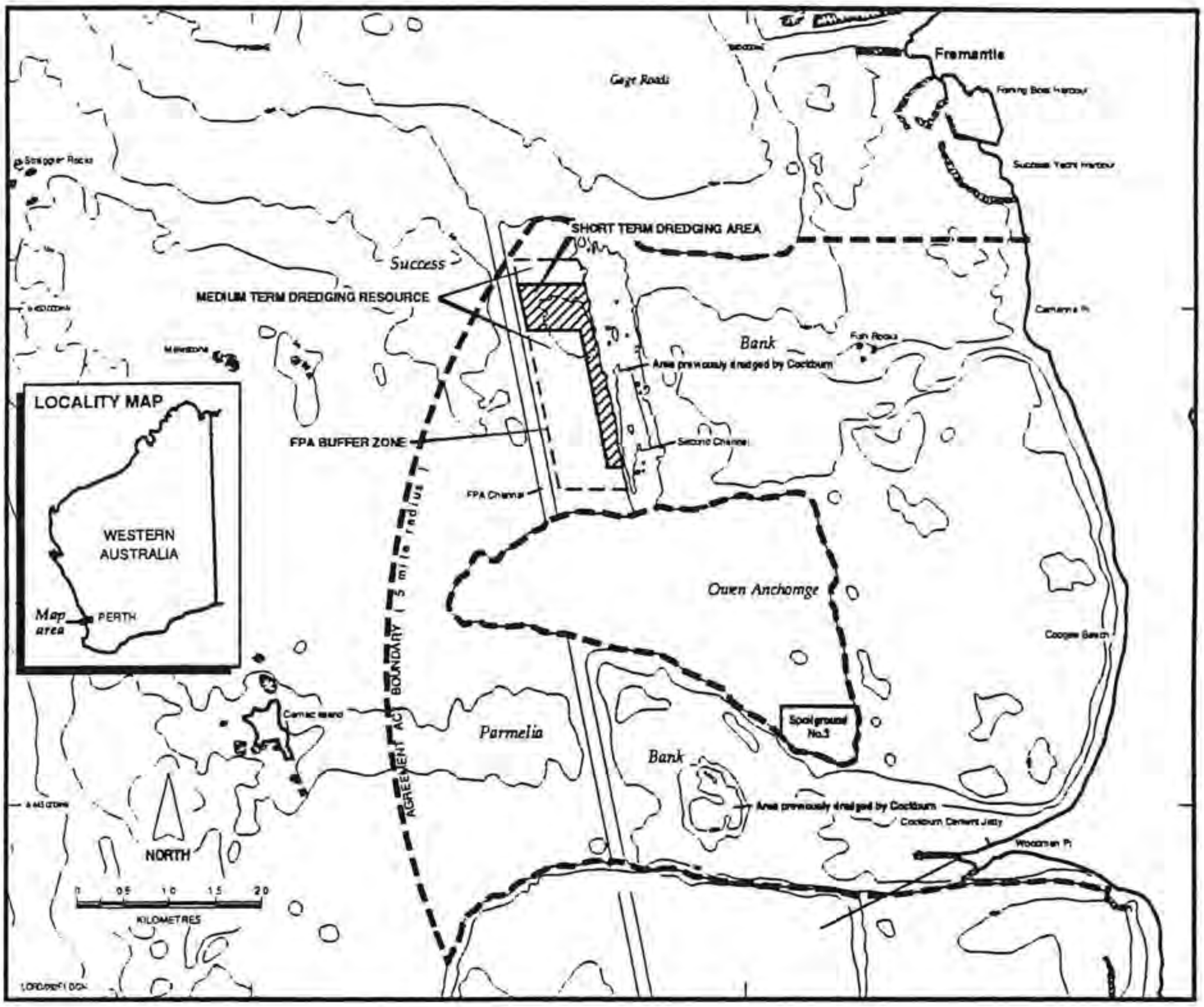

Figure 1
Areas dredged for shellsand and proposed for dredging of shellsand, Owen Anchorage

This proposal generated considerable response and in 1995, a major programme of scientific research and technical investigations termed the Shellsand Dredging Environmental Management Programme (EMP) was commenced, that addressed the following matters:

- Determine the change in ecological function due to the removal of seagrass by dredging.
- Develop methods for seagrass rehabilitation.
- Examine the effects of dredging on wave climate, sediment transport, and shoreline stability.
- Develop methods for the beneficiation of lower grade shellsand.
- Evaluate alternative resources for lime and cement production.

The principal purpose of the EMP was to develop the base of information that would allow for better environmental management of dredging operations, and to facilitate an objective evaluation of future dredging proposals.

BACKGROUND

Origin and Formation of the Banks

The features known as Success and Parmelia Banks formed over the last 6,000–7,000 years, subsequent to the rapid sea level rise of approximately 27 m that occurred about 10,000 years ago (1). The bank material is derived largely from sediment transported toward to shore from the adjacent shelf. Detailed measurements of the production of calcium carbonate from animals living in the sediments or on seagrasses growing on the banks indicates that this in situ production accounts for less than 15% of the banks volumes (2).

Effects of Dredging on Wave Climate, Navigation and Shipping, and Sediment Transport and Shoreline Stability

The general purpose spectral wave prediction model 2GWave was applied to the area, with calibration and verification undertaken using measurements of offshore wave characteristics and concurrent directional wave measurements made in the vicinity of the dredging operation (3).

Model results showed that the complete dredging of the areas designated short- and medium-term would produce some minor changes in wave height in the vicinity of the dredging operation, and under storm conditions, changes in mean wave direction of up to 13° could occur in the deeper areas of Owen Anchorage, and some localised areas on the banks. Minor, or no changes were predicted at the shoreline.

Repetitive surveys of the shoreline of Owen Anchorage (1974–1998) indicates that this shoreline is accreting at an average rate of 60,000 m^3/yr. There is no evidence that the construction of the shipping channels, which occurred in the early 1950s, has influenced this shoreline accretion. The most significant influences on shoreline sediment redistribution are structures along the shore.

Changes in Seagrass Cover on Success and Parmelia Banks

The detailed mapping of changes in seagrass cover in Owen Anchorage has been undertaken using aerial photography from 1965, 1972, 1982 and 1995. Seagrass cover is dynamic, with marked gains and losses occurring *(Table 1)*.

Table 1
Seagrass areas, Owen Anchorage, 1965, 1972, 1982 and 1995 (ha)

REGION	TOTAL AREA (ha)	SEAGRASS COVER							
		1965		1972		1982		1995	
		ha	%	ha	%	ha	%	ha	%
Success Bank East	1115.3	229.4	20.6	340.9	30.6	456.5	40.9	482.7	43.3
Success Bank Central	382.3	53.4	14.0	121.9	31.9	138.8	36.3	94.6	24.7
Success Bank West	893.6	224.5	25.1	297.7	33.3	382.8	42.8	458.6	51.3
SUCCESS BANK: TOTAL	2391.2	507.3	21.2	760.5	31.8	978.1	40.9	1035.9	43.3
Parmelia Bank East	708.3	487.0	68.8	491.5	69.4	289.2	40.8	324.1	45.8
Parmelia Bank West	875.2	248.1	28.3	285.2	32.6	343.6	39.3	375.1	42.9
PARMELIA BANK: TOTAL	1583.4	735.0	46.4	776.7	49.1	632.9	40.0	699.2	44.2

Since 1965, in some regions seagrass cover/density has decreased (centre of Parmelia Bank, centre of Success Bank West, and south of Fremantle), while in other parts seagrass cover/density had increased markedly (Success Bank East, north of western side of Success Bank).

The interpretation of aerial photography, coupled with field measurements has shown that the scales at which these gains and losses of seagrass cover occur are quite different (4). Seagrass gains throughout Success Bank and on the western side of Parmelia Bank are seen in patches that have scales of tens to hundreds of square metres, reflecting the processes of seedling colonisation and rhizome extension. The majority of seagrass growth between 1972 and 1995 on Success and Parmelia Banks has predominantly been in assemblages *of Amphibolis griffithii, Posidonia coriacea* and mixed assemblages of *Amphibolis griffithii and Posidonia coriacea* (3). Seagrass losses have occurred at fewer locations, and are attributed to dredging of the FPA shipping channel, shellsand dredging, eutrophication and sand sheet movement. These losses generally cover areas that have scales of hundreds to thousands of square metres.

The Ecological Significance of Seagrass in Owen Anchorage

Seagrasses have a number of attributes that contribute to their ecological function, including: The provision of primary (plant) and secondary (animals, including fish) production; the trapping and binding of sediment and particulate matter; supporting the organisms that contribute to the production of calcium carbonate for sediments; the provision of a three-dimensional habitat; and the assimilation and cycling of nutrients.

Success Bank has a complex mosaic of seagrasses and shallow bare sand habitats, and five main habitat types are considered to dominate. These include: *Amphibolis griffithii* meadows (>70% cover), *Posidonia coriacea* meadows (>20% cover), *Heterozostera tasmanica* meadows, unvegetated sediment in shallow water, and unvegetated sediment in deep water. The distribution (cover and density) of these seagrasses varies from dense meadows (more typical of *Amphibolis*) to isolated clumps and patches of plants (more typical of *Posidonia coriacea*).

Each of these habitats has significantly different assemblages of biota (epiphytic algae, invertebrates and fish) and primary and secondary production rates. Biodiversity on Success Bank is greatest in *Amphibolis* habitat, (although fish diversity is higher in *Posidonia sinuosa* meadows on Parmelia Bank). Patchy meadows dominated by *Posidonia coriacea* have the lowest diversity of biota of the various types of seagrass meadows on Success Bank. Biodiversity of invertebrates and fish in shallow unvegetated habitats is significantly lower than in seagrass meadows, and biodiversity in deep unvegetated habitats is intermediate. Similar trends are found for primary and secondary production.

The overall assessment of ecological function is being undertaken using measurements of those attributes that contribute to ecological function such as seagrass production and fish biomass. Changes in ecological function that would be caused by dredging are calculated using an ecological matrix that incorporates these attributes.

Most importantly, these studies have shown that the seagrasses of Owen Anchorage do not directly support a significant recreational and commercial fishery.

Seagrass Transplantation

Mechanical transplantation techniques for seagrass have been developed based on the use of an underwater mechanical harvester, ECOSUB I, which extracts large sods of seagrass of approximately 50 x 50 cm in size, to a depth of 40 cm with most of their root and canopy structure intact. Sods are transported underwater, and are planted into excavated holes of the same dimensions as those from which they were removed.

Since December 1997, ECOSUB I has been transplanting an average of 100–120 sods per month, more than double the average of 45 sods transplanted per month over the previous ten months.

In total over 1,000 sods had been planted by June 1999 *(Figure 2)*. Survival of sods was approximately 80% after five months from transplanting, a survival level that remained constant through the first 15 months from transplanting. Many transplanted sods have now survived a full winter, and are still displaying high shoot densities and spreading *(Figure 3)*.

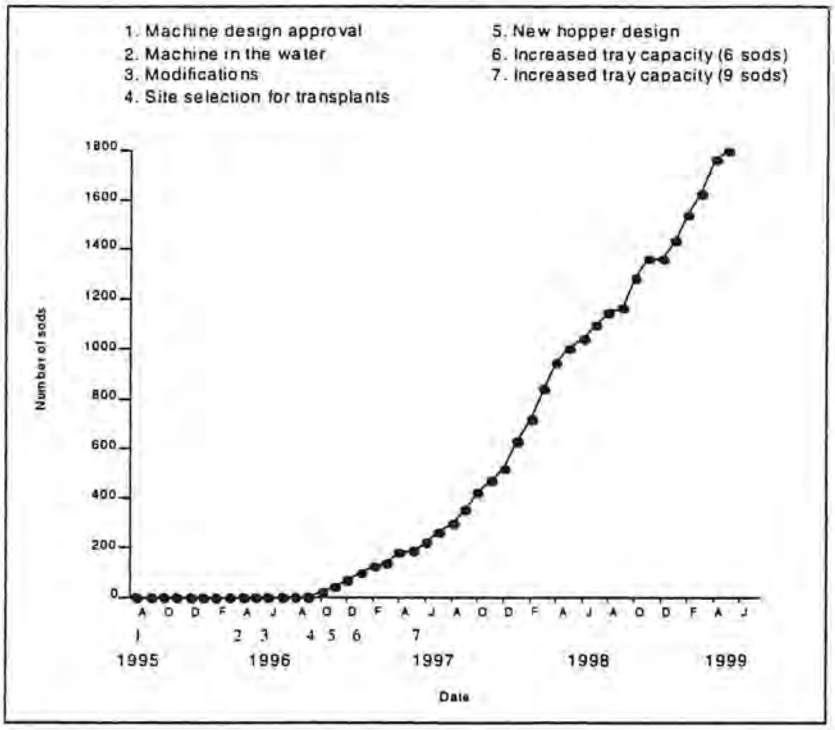

Figure 2
Cumulative number of sods planted mechanically, through June 1998

A second phase transplantation system, ECOSUB II, is now being constructed with the goal of transplanting ten times faster.

The implementation of an operational mechanical transplantation technique is one of the major achievements of this EMP, and has considerable potential for applications in other locations and situations.

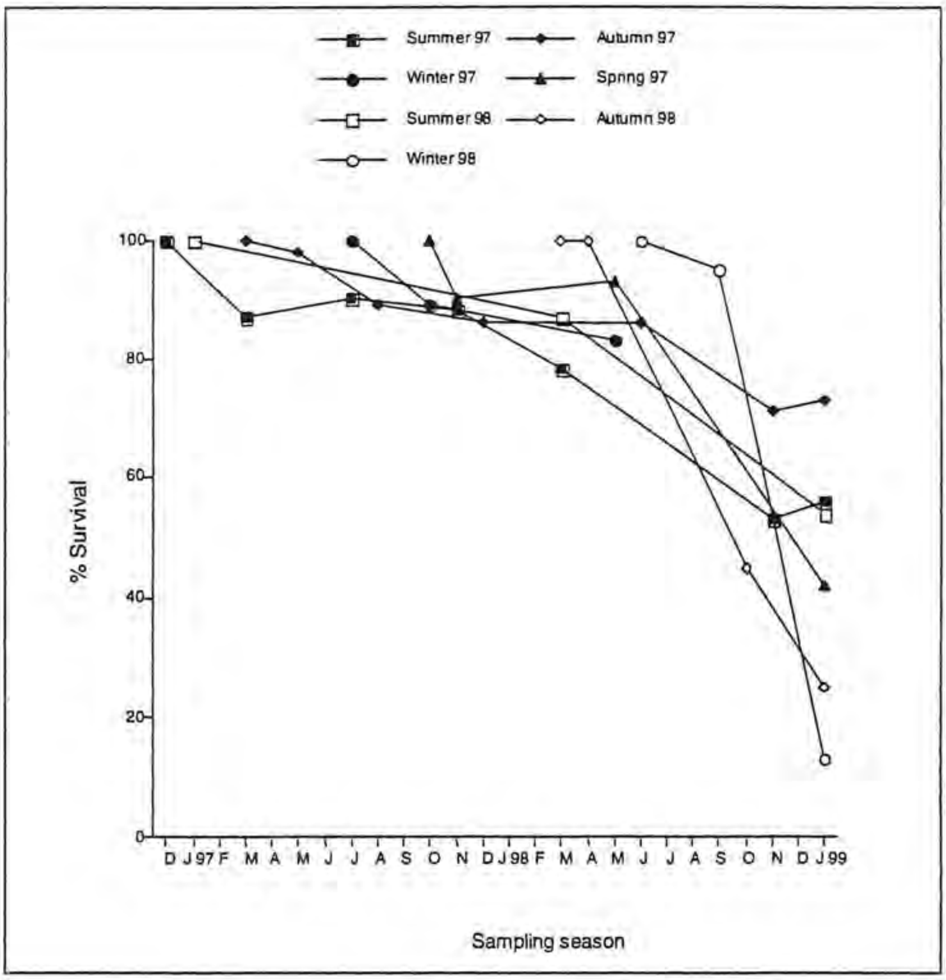

Figure 3

Percent survival of sods transplanted by February 1997 after 5 (T1), 10 (T2) and 15 (T3) months (T1 and T2, n = 76, T3, n = 52)

ACCESS TO RESOURCES: FUTURE

The EMP has developed a comprehensive base of information to allow decisions to be made for future access of marine carbonate resources in the area. Presently there is considerable interest in expanding the shipping channel into Cockburn Sound through Success and Parmelia Banks with the carbonate sands being removed used as a resource. The environmental effects of this expansion will be able to be soundly assessed, and will include the evaluation of greater exchange of deep water out of Cockburn Sound with the proposed larger shipping channels.

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C. SAND

Charophytes (Stonewarts) as Tools for the Rehabilitation of Sand Mine Wetlands, Capel WA – A Case History

Presented by Associate Professor Jacob John,
School of Environmental Biology,
Curtin University of Technology

Charophytes (Stonewarts) as Tools for the Rehabilitation of Sand Mine Wetlands, Capel WA – A Case History

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School of Environmental Biology,
Curtin University of Technology

Introduction

Charophytes are a group of algae, which look so different from other algae. They are an ancient group of algae whose ancestors are closely related to the ancestors of land plants. They resemble higher plants in possessing a main axis, leaf-like branchlets and rootlike rhizoids. They are universally present in freshwater lakes, dams, shallow streams and rivers and colonise artificial wetlands with reasonable water quality. As natural wetlands are declining in number, one group of wetlands is on the increase: the mine voids.

Open cut mine voids, particularly sand mine voids often intercept water table and become artificial wetlands. These wetlands if properly rehabilitated, can be an important freshwater resource for the enrichment of biodiversity, reversing the current trend of degradation and extinction of natural wetlands. However, there are several factors limiting the development of mine voids into functional wetlands.

Prominent among these limiting factors are:

1. Acidity (eg. pH 2-6).
2. Salinity (eg. 3-37 ppt).
3. Low levels of nutrients, specifically phosphorus (eg. 0-15μg/l).
4. High levels of ammonia (eg. up to 50,000 μg/l).
5. Low organic carbon.
6. High concentration of iron, magnesium, manganese, zinc, copper, sulphate, chloride.
7. Lack of macrophytes and other primary producers.
8. Poor biodiversity, lack of complex food chain.
9. Steep shoreline, substrates, hard or too soft, poor morphometry not conductive to the development of periphyton.
10. Lac of emergent and peripheral vegetation.

This paper summarises the research work carried out by myself and my research students over the past eight years on the potential use of Charophytes as ideal tools for wetlands remediation dealing with some of the problems mentioned above, focusing on RGC Wetlands Centre, Capel, Western Australia.

RGC Wetlands Centre, Capel

Western Australia is the leading producer of titaniferous minerals like, ilmenite and rutile. Sand minerals have been mined in Capel, 200 km south of Perth (33°S, 116°E) in Western Australia since 1956. After mining, the mine pits were converted into artificial wetlands between 1975 and 1979. These wetlands occupy an area of 50 hectares, now known as RGC Wetlands Centre (Rennison Goldfield Consolidated Mineral Sands Ltd) and comprises a chain of 15 lakes mostly interconnected (Fig 1).

The Wetlands Centre was established in 1985 with the objective of developing a self-sustaining ecosystem for conservation of waterbirds. In 1984 and 1985 (Brocks 1991, Doyle and David 196) initial studies showed that the system was not productive enough to attract birds as the pH was mostly 2-4, ammonium levels were high and available phosphorus was too low, and the concentration of iron, manganese, magnesium and sulphate were very high favouring binding of phosphate. Subsequently, the effluent water entering the chain of lakes from the mineral processing plant was buffered to high pH above eight. The lakes were landscaped, islands and peninsulas were created and the steep shoreline was modified to create shallow margin and emergent and peripheral vegetation was established by the Wetlands Centre under the management of representatives from Royal Australian Ornithologist Union (RAOU), RGC Mineral Sands Ltd and the various tertiary institutions in WA. The remediation measures considerably improved the water quality of the Wetlands Centre.

The average annual rainfall of the area is 830 mm and the climate is Mediterranean characterized by dry summers and wet winters with a temperature range of 20-36°C in the summer and 8-15°C in the winter. The lakes range in depth from 1 m to more than 6 m. The water level drops down drastically in severe summer periods. Within six months of improving the water quality of the effluent water, signs of improvement in productivity in all the lakes were obvious (John 1993). The number of water birds visiting and nesting at the wetlands steadily increased. However, the general productivity remained low compared to the nearby natural wetlands.

Attributes of Ideal Macrophytes

Insufficient submerged macrophytes was generally perceived as an impediment to the development of the system. Attributes of ideal macrophytes in a developing self-sustaining ecosystem can be summarised as follows:

(i) Macrophytes must increase primary productivity and fulfill a functional role:
(ii) Macrophytes should enhance the diversity and abundance of invertebrates, fish and birds by providing habitat, food and shelter;
(iii) A healthy stand of submerged macrophytes should enhance water quality by decreasing turbidity and increasing water clarity;
(iv) They could be used as biomonitors as their decline would reflect poor water quality; and
(v) The macrophytes should be able to adapt its life cycle to fluctuating levels in wetlands where filling and drying cycles are of annual occurrence.

Nitella hyalina – An Ideal Macrophyte

In 1991, while studying the ecology of a semi-naturak lake (Lake Leschenaultia) 40 km east of Perth, we discovered that the lake was dominated by meadows of *Nitella hyalina* – a mucilage producing Charophyte (Fig. 2a&b). The water in this lake was noted for its clarity and high quality. An analysis of the Charophyte revealed that it was a hyperaccumulator of P, Ca, Mg, Cu, Mn and Fe (Table 1).

By the same year (1991) we found that two of the mine voids at Capel were colonized by *Nitella hyaline* and had the lowest electrical conductivity and highest water clarity in the system. It was confirmed that the mucilage ensheathment of the growing meristem of the Charophytes was involved in accumulating high concentrations of metals and phosphorus (Table 2).

Charophyte tissue, sediment and water from Plover Lake (one of the likes in the RGC Wetlands Centre colonized by Charophytes) were analysed for Ca, Fe, Mg, Mn and P (Fig. 3). The Charophyte tissue itself showed very high concentrations of Mn, Ca and Fe (Table 3). The same study by Ward, my Honours student in 1995, also revealed that the ponds occupied by *Nitella hyalina* had consistently higher abundance of invertebrates than the lakes without the Charophyte (Fig. 4). This lake was also the first to be colonized by native fish species. During summer months, the Charophytes became an important source of direct food by waterfowl. There were also two other species of Charophytes occurring with *Nitella hyalina: Chara globularis* and *Chara fibrosa*, forming a lush green fully submerged Charophyte meadow in the clear water of Plover Lake.

In 1996, we discovered two more lakes at the RGC Wetlands Centre were colonized by *Nitella hyalina.* Further study of these lakes showed that these lakes had reduced electrical conductivity and higher pH compared to the previous records (Table 4).

In 1998, we analysed the concentration of Al, Fe, Ca and Mn in the sediment mucilage and *Nitella hyalina* tissue and standing water in Plover Lake, which has been colonized by the Charophytes since 1990 and Pobblebank Lake inhabited by *Nitella hyalina* probably in 1995 or 1996 (Figs. 5 & 6). Once again the role of

Nitella hyalina as a hyperaccumulator of metals, particularly the part played by the mucilage in sequestering the minerals became evident.

Attempts have been made to introduce Charophytes to other lakes with varying success (Burkett 1998). High concentrations of sporebank at the end of summer and autumn was left in the sediment at the lakes dominated by Charophytes for starting a new population. Transfer of sediment samples to other lakes has shown that the spores do germinate in the new environment. Germlings have been established successfully in two other lakes (Burkett 1998). Further work is required to establish appropriate propagation techniques for Charophytes, so that the rest of the lakes at the Centre can be rehabilitated. We are also searching for suitable Charophyte species throughout Western Australia as rehabilitation tools. *Chara australis* appears to be an appropriate candidate.

Acknowledgements

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Table 1. Chemical analysis of *Nitella hyaline* and standing water from Lake Leschenaultia 1991

	Dry Wt (%)	Total N (%)	Total P (%)	Ca (%)	Mg (%)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)
Nitella (Plant tissue)	11.9	2.0	0.06	1.6	0.8	1.0	35	1,600	2,500
Nitella (Plant tissue and mucilage)	9.0	2.0	0.11	1.0	0.5	6.0	60	1,950	6,000

Standing water of Lake Leschenaultia 1991

pH	HCO_3 (ppm)	Conductivity (μs cm^{-1})	Phosphate (μg l^{-1})	Nitrate (μg l^{-1})	Na (ppm)	Ca (ppm)	Mg (ppm)	Fe (ppm)
6.2 – 7 Low pH in winter (lower pH at the bottom)	30	700 – 118	< 0.1 – 5	10 – 40	190	10 – 11	35 – 38	Not in detectable levels

Table 2. Chemical analysis of *Nitella hyalina* and standing water from Plover Lake RGC Wetlands Centre 1992

				Total N	**Total P**	**Ca**	**Mg**	**Cu (ppm)**	**Zn (ppm)**	**Mn (ppm)**	**Fe**
Nitella (Plant tissue)				1.71%	0.045%	4.5%	0.7%	8	40	1700	0.037%
Nitella (Plant tissue and mucilage)				1.08%	0.065%	3.5%	0.5%	10	50	2900	0.69%
	Conductivity	**HCO_3 PPM**	**pH**	**Nitrate (ppm)**	**Phosphate (ppm)**	**Ca (ppm)**	**Mg (ppm)**	**Cu (ppm)**	**Zn (ppm)**	**Mn (ppm)**	**Fe (ppm)**
Standing water	350 – 780 µs cm-1	90	8 – 9.3	< 0.2	0.01	20 – 30	12	< 0.01	< 0.01	0.07 – 0.87	0.05 – 0.45

Sediment: Ca – 60 ppm, Mg – 650 ppm, Cu – 0.7 ppm, Zn – 28 ppm, Mn – 70 ppm, Fe – 1.0%
Dissolved oxygen fluctuates from 40% - 140% saturation
Order of dominance of cations in water: Ca > Mg > Mn > Fe > Cu

Table 3. Element analysis of Charophytes from Plover Lake, 1 May 1995 (a lake at Capel Wetlands Centre colonised by *Nitella hyalina*).

Element	Site 1	Site 2
Total Phosphorus (%)	0.06	0.05
Total Sulfur (%)	0.28	0.22
Potassium (%)	0.4	0.91
Sodium (%)	0.18	0.11
Calcium (%)	*5.6	*8.3
Magnesium (%)	0.82	0.3
Copper (ppm)	3	4
Zinc (ppm)	8	80
Manganese (ppm)	*4000	*5000
Iron (ppm)	*9400	*4300

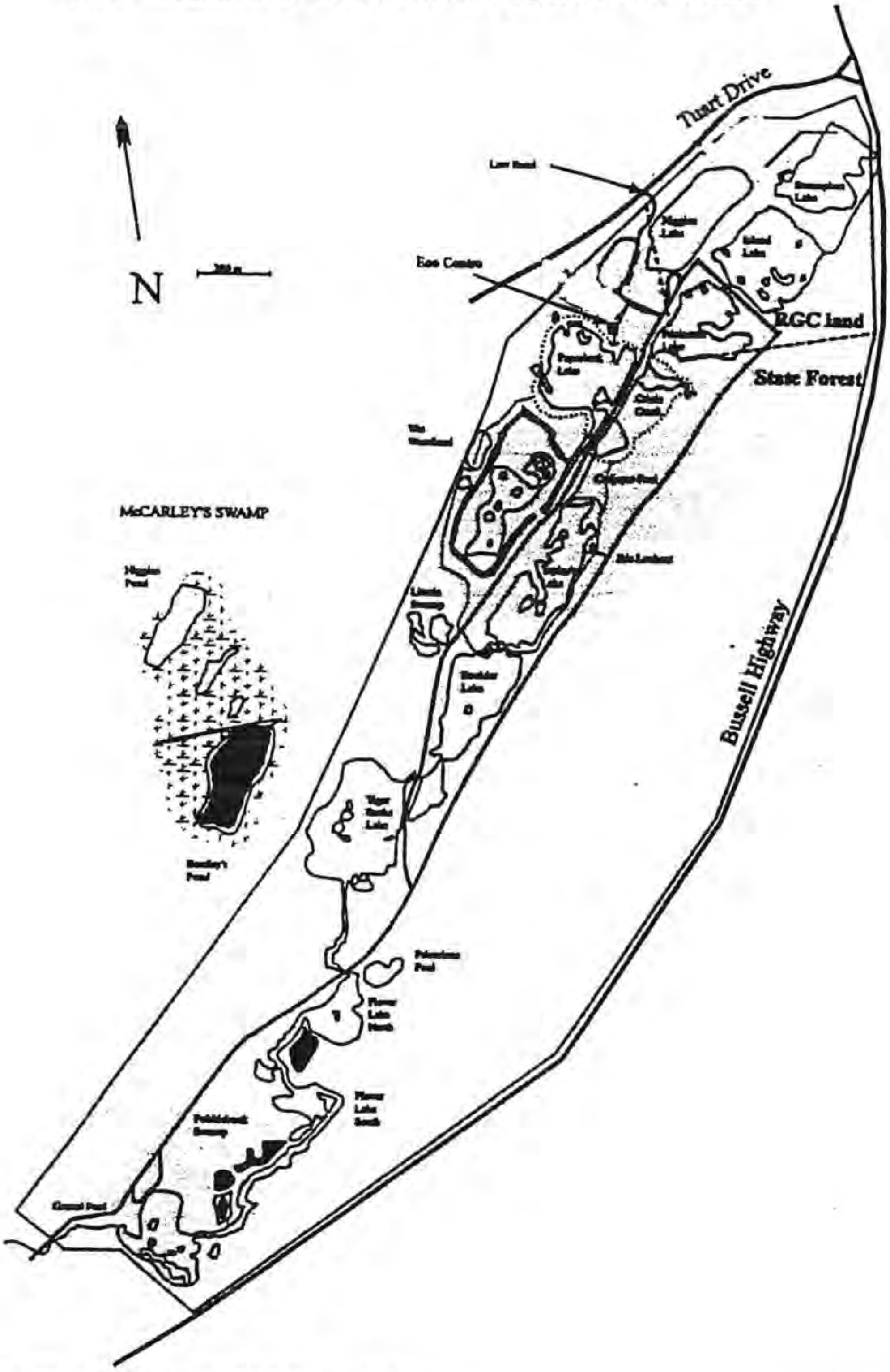
*high concentration

Table 4. Water quality RGC Wetlands

	Year	pH	Conductivity µS/cm
Plover Lake	*1992 *1997	8 – 9 8 – 9.5	700 – 800 189 - 490
Pobble Bank 1	1992 *1997	6 – 6.7 8.5 – 9	4570 – 5050 685 - 1005
Pobble Bank 2	1992 *1997	8.5 8.3 – 8.9	1500 130 – 362
Taylor Lake⁺	1997	6.8	2580
Cadjeput⁺	1997	7.5	2500

* Colonised by Charophytes ⁺ No Charophytes

RGC WETLANDS CENTRE, CAPEL WESTERN AUSTRALIA



■ Chain of lakes at the RGC Wetlands Centre

Fig. 1. Colonised by Charophytes.

Fig. 2(a). *Nitella hyalina* under culture at the School of Environmental Biology, Curtin University. The mucilage on growing meristem appears sequester ions and particles in water increasing the clarity of water.

Fig. 2(b). Mucilage surrounding the growing tip of *Nitella hyalina*. The mucilage has a microbial community of diatoms and desmids.

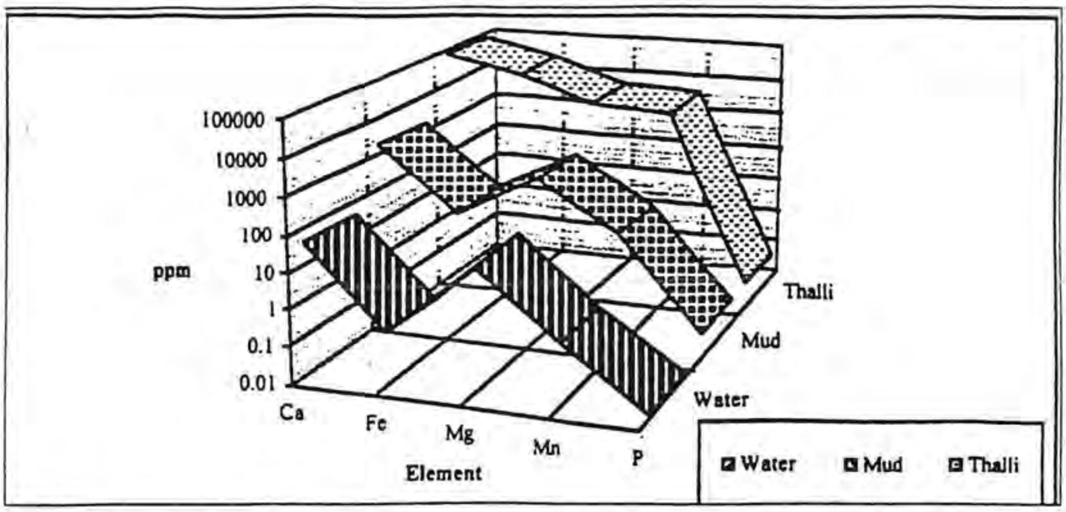


Fig. 3. Comparative levels of different elements in water, sediment and *Nitella hyalina* in Plover Lake (Ward 1995)

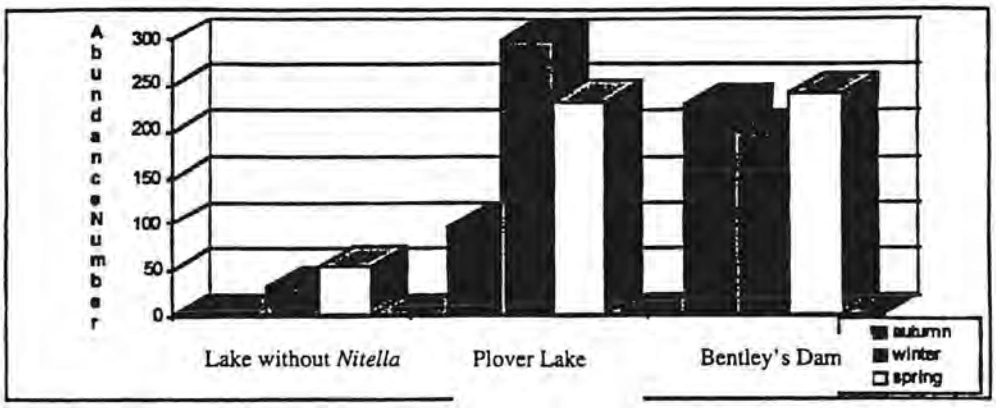


Fig. 4 (a). Difference in total abundance of invertebrates between a lake without *Nitella* and Plover Lake and Bentley's Dam (both have *Nitella*).

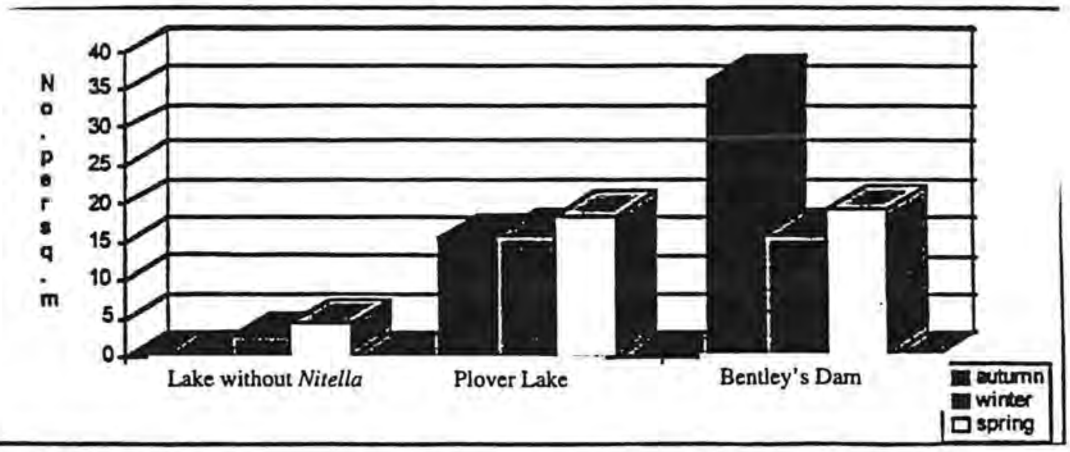
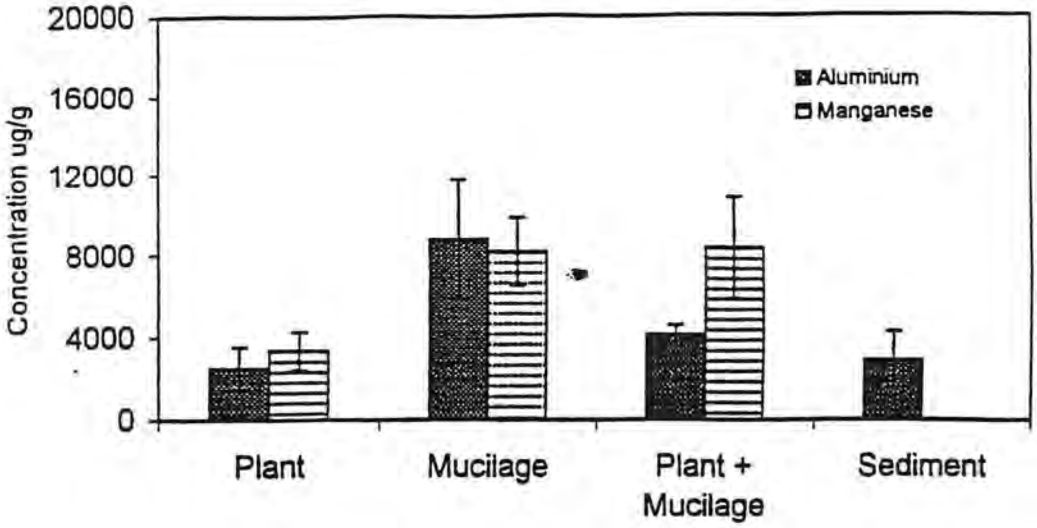


Fig. 4 (b). Difference in number of invertebrates per m^2 between a lake without *Nitella* and Plover Lake and Bentley's Dam (both have *Nitella*).



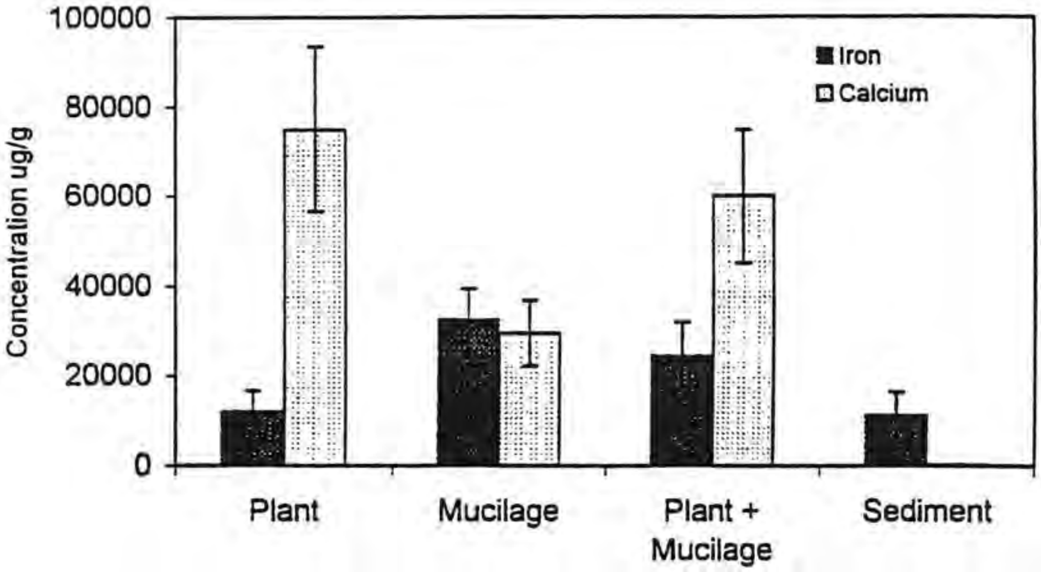


Fig. 5(a) & 5(b). Concentration of Metals in *Nitella hyalina* (Plover Lake)

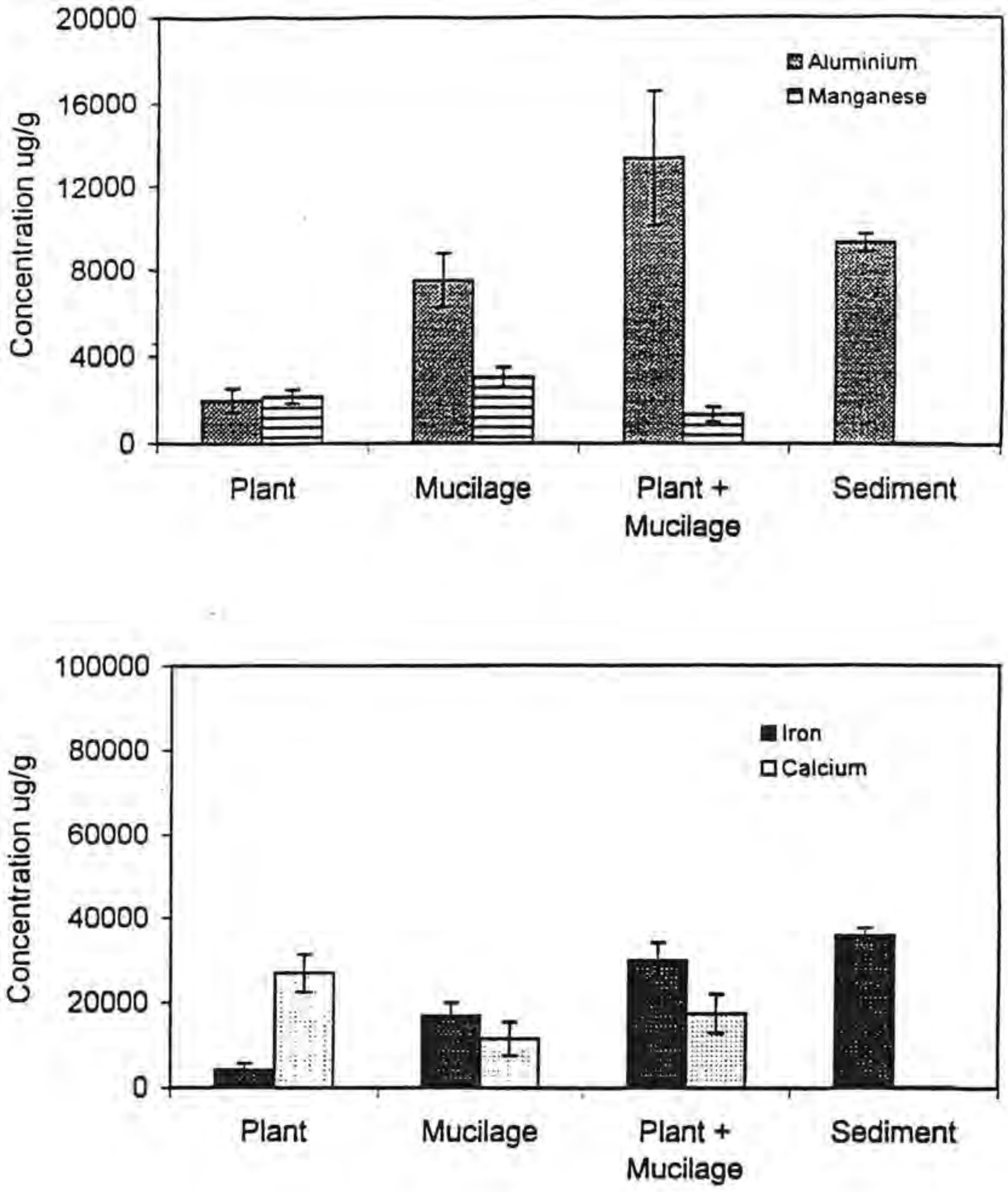


Fig. 6(a) & 6(b). Concentration of Metals in *Nitella hyalina* (Pobblebonk Lake 2)

D. PROCESSING

D. PROCESSING

Biotechnology in Mineral Processing

Presented by Dr Martin Houchin,
Program Manager Base and Precious Metal Hydrometallurgy,
CSIRO Minerals

Biotechnology in Mineral Processing

By B C Cashmore, B J Clark, M R Houchin, L P Quan, M B Stott, H R Watling (*AJ Parker CRC for Hydrometallurgy, CSIRO Minerals, Waterford, WA*), P D Franzmann, L R Zappia (*CSIRO Land and Water, Floreat Park, WA*)

Abstract

Biotechnology offers a number of environmentally-attractive alternatives in mineral processing, especially in the areas of mineral leaching and effluent treatment.

This paper presents some recent results from bio-leaching and bio-degradation studies on gold processing performed at the CSIRO. The refractory gold mineral, calaverite ($AuTe_2$) was bio-leached to remove the Te, releasing the Au for subsequent leaching. Bio-degradation of thiosulphate, present in gold processing effluent, was demonstrated, allowing recycle of effluent to a bio-oxidation plant.

Introduction

The major drivers for technological innovation in mineral processing include:

- Reduction in processing costs, for both current and future operations.
- New or improved processes for complex ores.
- Environmental considerations ("license to operate" issues), particularly with respect to controlling toxic effluents (gases and liquids) and landcare / rehabilitation.

Bacterial mineral processing can address many of the challenges facing the mining industry. Biomineral processing can be particularly useful for processing complex refractory ores, where production of toxic effluents (liquids and gases) is of concern.

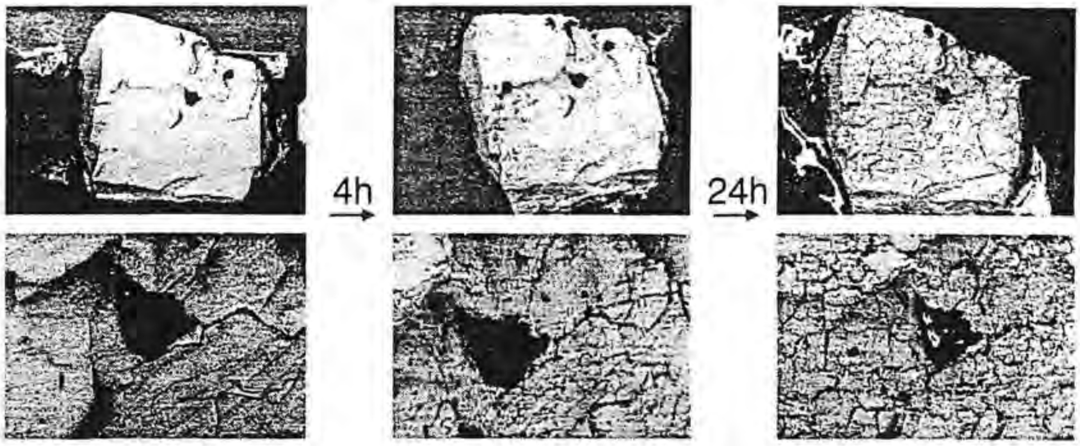
Most refractory sulphide ores are pyrolised (roasted or smelted) to decompose the sulphide matrix, thus allowing the metal to be recovered. In the process, large amounts of toxic SO_2 can be produced. Bacteria can also be used to decompose sulphides. In the bio-oxidation process, bacteria metabolise sulphide to sulphate, utilising the exothermic reaction as a source of energy. No SO_2 is produced.

Bacteria can also be used to degrade toxic effluents produced during mineral processing. For example, cyanide is used to leach gold and often reports to tailings dams where it is regarded as an environmental hazard. Chemicals (eg sulphur dioxide or chlorine) can be used to degrade the cyanide, but bacterial degradation offers a low cost alternative.

Bioleaching a refractory gold telluride ore – Calaverite ($AuTe_2$)

Calaverite is a refractory gold mineral that is usually associated with sulphidic gold ores. To recover gold from refractory sulphidic gold ores, the sulphide matrix harbouring the gold must first be disrupted. Traditionally, roasting has been used to oxidise (disrupt) the sulphide matrix, however roasting produces sulphur dioxide, which is of environmental concern. Biological oxidation of the sulphidic ore using naturally-occurring bacteria, is an environmentally-acceptable alternative to roasting.

To investigate bacterial leaching of calaverite ($AuTe_2$), grains of the mineral were mounted on teflon stubbs and suspended in an inoculated medium (mixed culture of mesophilic bacteria). After prescribed periods of time, the mounts were removed from the inoculum and examined under a scanning electron microscope (SEM) equipped with energy dispersive spectroscopic facilities (EDS), for elemental analysis. Fig 1 shows that initially the Au:Te atomic ratio in the specimen was ~1:2 as expected for calaverite. As biooxidation proceeded, the Te was removed, releasing the Au for subsequent leaching.



Element	Atomic %	Element	Atomic %	Element	Atomic %
Te	62.47	Te	1.67	Te	-1.26
Au	26.94	Au	57.08	Au	78.30

Fig 1 SEM images and EDS analyses of a calaverite grain after 4h and 24h bio-oxidation.

Biodegradation of thiocyanate in gold processing effluent

Following bio-oxidation, gold from refractory ores is dissolved and recovered via cyanide leaching and adsorption onto carbon (the CIP process). A by-product of the cyanide leach is thiocyanate. The presence of thiocyanate in the leach effluent prevents its recycle to a bio-oxidation plant because thiocyanate is toxic to the bacteria used for bio-oxidation. More generally, thiocyanate is stable (to natural degradation in the environment) and therefore represents a disposal problem.

The ability to recycle water can be of considerable economic importance, for example:

a) In WA's goldfields, where fresh water is a scarce, valuable commodity.

b) In high rainfall areas (eg northern Australia) where disposal of contaminated water is an environmental issue.

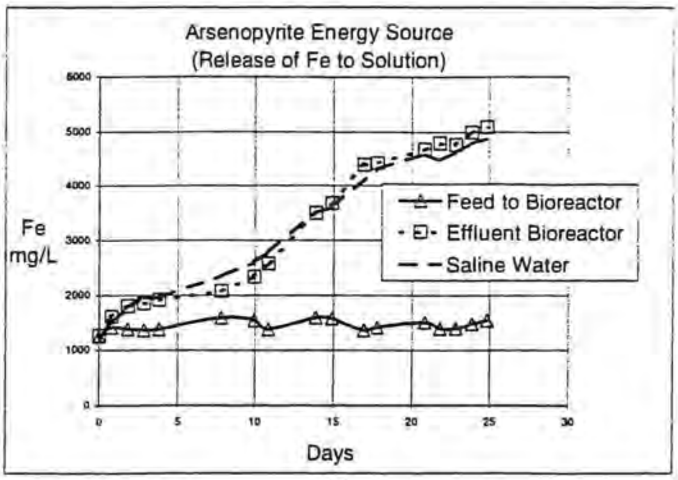
In this study, bacteria were selectively cultivated from water samples collected from Australian gold mines, by feeding them on an appropriate diet. Two new chemolithotrophic bacterial strains active to thiocyanate degradation were isolated and characterised by 16S rDNA sequencing. One strain belonged to the genus Halomonas and the other to the genus Thiobacillus. A laboratory-scale biodegradation reactor was constructed in which the thiocyanate-degrading bacteria were attached to an inert, high-surface-area substrate. The reactor was a fixed-film, rotating biological contactor (RBC). Fixed-film RBC's allow high solution flowrates through the reactor without "washing out" the bacteria. Effluent containing 2000 ppm SCN^- was degraded to <1 ppm SCN^-, with the only nutrient addition required being low level phosphate.

Mass / chemical balances confirmed that degradation proceeded according to the reaction:

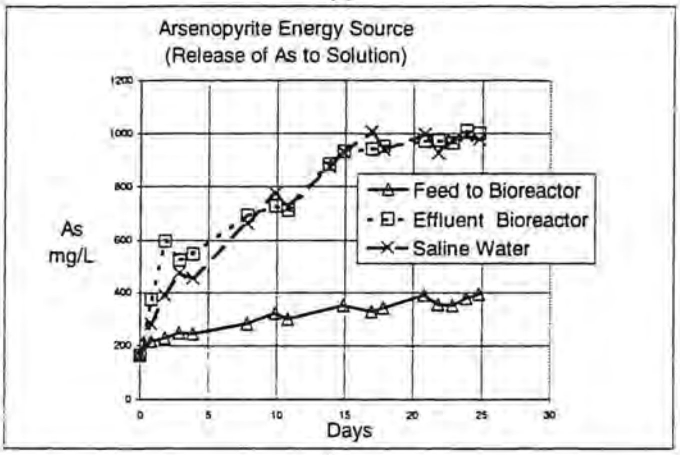
$$SCN^- + 2H_2O + 2O_2 \rightarrow NH_4^+ + SO_4^{2-} + CO_2$$

ie environmentally compatible by-products were produced.

To test whether the effluent from the biodegradation reactor was suitable for recycle, a saline solution with 250 ppm added thiocyanate, was fed to a laboratory-scale bio-oxidation reactor, both before and after passing through the thiocyanate bio-degradation reactor. The same saline solution, without added thiocyanate, was also fed to the bio-oxidation reactor. The bio-oxidation reactor contained a slurry of arsenopyrite ($FeAsS_2$). Bio-oxidation was monitored by following the amount of Fe and As released into solution. The results are shown in Figure 2.



(a)



(b)

Figure 2: Release of (a) Fe and (b) As from arsenopyrite bio-oxidation, (i) with thiocyanate bio-degradation of the feed solution (Effluent Bioreactor) and (ii) without thiocyanate bio-degradation of the feed solution (Feed to Bioreactor), compared with thiocyanate-free control (Saline water).

When the bio-degradation reactor was by-passed, no biological activity was observed in the bio-oxidation reactor, ie the thiocyanate inactivated the bio-oxidising bacteria. When the thiocyanate solution was passed through the bio-degradation reactor before being fed to the bio-oxidation reactor, bio-oxidation proceeded at the same rate as for the saline solution with no added thiocyanate.

The same methodology as that developed in this study can be used to degrade cyanide in gold tailings dams or more generally for removal of organics, or C, N, P, S-based inorganics from mineral processing feed or effluent streams.

Conclusion

Bacteria can be effectively used in mineral processing applications for bio-oxidation (as an alternative to roasting) and for bio-degradation of toxic effluents. Both applications produce environmental benefits.

E. ACID

E. ACID

A Science-based Approach to Decommissioning Procedures and Criteria for the Minerals Industry

Presented by Mr Alex Armstrong,
ACMER Research Program Manager

A SCIENCE - BASED APPROACH TO DECOMMISSIONING: PROCEDURES AND CRITERIA FOR THE MINERALS INDUSTRY

Alex Armstrong[1] and Clive Bell[2]

[1]Research Program Manager and [2]Executive Director
Australian Centre for Mining Environmental Research

Minerals Council of Australia Mine Closure Policy (1999)

Objective:
To leave sites in a condition which is safe, stable and limits further environmental impacts so that mining tenements can be relinquished for alternative land use.

To achieve objective, MCA will encourage minerals industry to:
- Recognise that effective stakeholder involvement is essential for successful planning and implementation of mine closure;
- Contribute to focused and relevant research into strategic issues of significance to mine closure;
- Promote the integration of mine closure into planning and management of all phases of mine operations;
- Make adequate provision for the costs of mine closure; and
- Work with government and other stakeholders to address issues relating to abandoned mine sites.

Research Program

Areas of Focus:
- Landform Stability - Key processes controlling the long-term behaviour and stability of constructed landforms;
- Water Systems - Key processes controlling downstream surface and groundwater quality;
- Waste Treatment and Disposal - Key processes controlling long-term treatment and disposal of waste products; and
- Ecosystem Reconstruction - Key processes controlling the long-term sustainability of constructed ecosystems.

Operational Research Programs:
- Waste Rock Dump Stability.
- Final Void Water Quality.
- Acid Mine Drainage.
- Tailings Disposal and Remediation.
- Ecosystem Reconstruction Processes and Strategies.

Tailings Disposal and Remediation

Aim:
To develop cost-effective, environmentally acceptable design, management and closure strategies for tailings disposal facilities by researching the critical processes governing the geotechnical, chemical, hydrological and edaphic behaviour of tailings deposits.

Projects:
- Definition of the Research Needs for the Management and Rehabilitation of Tailings Disposal Facilities.
- Tailings Closure Project.
  - Capping design.
  - Geochemistry of tailings and ground water.

- o Models of ecological risk assessment

Tailings Closure Research Program

Key Issues:

- The degree of cover and encapsulation required to develop and sustain a vegetative cover to ensure acceptable post-mining use for tailings areas;
- Seepage from TSFs and its effects on groundwater and surface water: and
- The time frame over which covers and barriers must maintain their integrity.

Components of Stage 1:

- Design of tailings covers.
- Geochemistry of tailings and groundwater matrices.
- Models of ecological risk assessment.

Design of Tailings Covers:

- Use of water balance models to predict optimum depths of rooting zones for various capping materials; and
- Prediction of erodibility of vegetated and non-vegetated caps.

Geochemistry of Tailings and Groundwater:

- Basic geochemical research leading to development of multi-component contamination transport models; and
- Development of predictive techniques for the quantification of the geochemistry of long-term tailings containment.

Ecological Risk Assessment:

- Development of basic parameters for ERA;
- Development of generic tools for the assessment of the impact of seepage and escape of solids from TSFs into the surrounding environment; and
- Development of a model of ERA for use by operators in the design of tailings rehabilitation procedures and by legislators in approving the rehabilitation procedures for long-term stability.

Final Void Water Quality

Projects:

- Review of Management and Impact of Mining Voids.
- Review of Final Void Water Quality in Australia - State of the Art and Development of a Generic Model.
- Final Void Water Quality Prediction at Benchmark Sites.

Prediction and Management of Water Quality in Final Voids

General Objective:
Develop better techniques than those which currently exist to characterise, predict and manage water quality in final voids.

Specific Objectives

- Development of generic numerical models for the prediction and management of final void water quality;
- Identification of the key parameters required from site and/or lab measurements for the calibration of the numeric models;
- Using the validation models, assessment of the long-term water quality of "flagship" voids and the implications for closure and remediation; and
- Assessment of the feasibility of treatment of final void waters for practical improvement of water quality.

Long-term Outcomes:

- Consolidation of capability to investigate closure and management options for final voids;
- Demonstration of the capability of industry to develop and implement capability in the area of *FVWQ* management, thereby influencing the course of regulatory policy development; and
- Development of chemical and/or biological treatment methodologies for prevention or alleviation of deleterious water quality in final voids.

Ecosystem Reconstruction Processes and Strategies

Aim:
To create a stable, near-natural ecosystem that requires no management inputs additional to those in operation prior to mining

Projects:

- Spinifex Re-establishment.
- Native Understorey Species Regeneration at NSW Coal Mines.
- Dormancy Mechanisms of Native Plant Species.

Indicators of Ecosystem Rehabilitation Success (Stage 2)

Objectives:

- Verify the Landscape Functional Analysis (LFA) indicators on representative mine sites using conventional field and laboratory measurements of landscape integrity, nutrient cycling, soil stability and soil infiltration.
- Report the results of testing the hypothesis that reliable indicators for assessing ecosystem rehabilitation success on mine sites can be identified using the rapid, field-based techniques of Ecosystem Functional Analysis (EFA).
- Communicate the EFA techniques and the results of the Stage 2 study to mine-site personnel, regulators and community groups through workshops and an interactive EFA manual on CD-ROM for the mining industry.

Outcomes and Benefits:

- Scientific validation of a technique which has the potential to provide a cost-effective index of the success of ecosystem reconstruction;
- If validated, the technique should gain acceptance by industry, government and the community and assist in the process of assessment of rehabilitation success; and
- The technique can provide mine-site personnel with a cost-effective tool which can be used in-house to assess the performance of various rehabilitation strategies.

Acid Mine Drainage

Aim:
To develop cost-effective techniques to prevent and remediate acid mine drainage

Projects:

- Acid mine Drainage in Australia - Its Extent and Potential Future Liability.
- Management of Sulfidic Mine Wastes (Stage 1).
    - assessing correlation between laboratory- and field-measured sulfidic oxidation rates and their usefulness in prediction and monitoring of management options.
    - producing a manual of recommended techniques for measurement of sulfidic oxidation-related processes.
    - informing industry of best practice measures for managing sulfidic wastes.
    - identifying future research needs.

ACMER Technology Transfer Initiatives

Native Seed Biology:

- Establishment of national database for use by mining industry and community groups such as Landcare and Greening Australia.
- Conduct of regional workshops on native seed collection, storage and treatment in conjunction with Florabank, Australian Network for Plant Conservation, Landcare, Greening Australia and the mining industry.

Environmental Management for Small to Medium Mining and Quarrying Operations:

- Short courses and workshops on environmental management conducted in regional centers.
- Supported by Federal Government.

1999 Short Course (SC) and Workshop (W) Program

- Rehabilitation Issues for the Queensland Coal Industry (W).
- Use of Exploration Data to Minimise Environmental Risk (SC).
- Cyanide Management (SC).
- Decommissioning of Mines (W).
- Mining Environmental Management (SC).
- Fourth Australian Acid Mine Drainage Workshop (W).

Conclusions

- Industry and government require scientifically based compliance and completion criteria.
- Industry requires information to enable it to meet criteria for operation and decommissioning in cost-effective manner.
- Considerable advances in environmental management technology for the minerals industry have been made in the past decade.
- Deficiencies in appropriate technology remain, however, for dealing with some issues that have high liability.
    - decommissioning of tailings disposal facilities.
    - long-term stability of waste rock dumps.
    - management of acid mine drainage.
- Cost effective solutions to these problems can be achieved through research.
- The Australian Centre for Mining Environmental Research (ACMER) has a major role to play in addressing these research needs and transferring the resultant technology to industry.

F. TOOLS

F. TOOLS

Computational Tools for Predictive Aqueous Geochemistry

Presented by Dr Paul Brown, Environment Division, ANSTO

Computational Tools for Predictive Aqueous Geochemistry

Paul L Brown and Richard T Lowson
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PMB1 Menai, NSW 2234
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The strongest argument of the detractors of mining is that the fields are devastated by mining operations . . . Further, when ores are washed, the water which has been used poisons the brooks and streams, and either destroys the fish or drives them away . . . Thus, it is said, it is clear to all that there is greater detriment from mining than the values of the metals which the mining produces.

Agricola, De Re Metallica, published 1556 [Highland, 1983]

ABSTRACT

In the past computer programs as support tools for modelling aqueous geochemistry and contaminant plumes, have been restricted to the 'experts' due to the complexity or specialist nature of the algorithms, the machine requirements and the un-forgiving and un-welcoming format input requirements of the code. The advent of the high powered PC, pre-processors for inputting data and post processors for out-putting results, have made these models and codes more generally available. The authors will discuss some recently developed computer codes as tools as tools for assisting in designing covers to control Acid Rock Drainage from waste rock heaps, SWIM^{HEAPCOV}, describing the geochemistry and transport of a chemical active contaminant plume in ground water, MODPHRQ, and GMT3D, and Ecological Risk Assessment, AQUARISK.

Introduction

Agricola's observation of public perception is as valid today as it was in the 15th century, the only difference being that the sheer size of mining operations has magnified the concern. The mining industry is now recognising that the industry's short comings of today will become the industry's liability of tomorrow, and industry's license to operate in 20-50 years time could jeopardised by industry's actions of today (Satchwell 1999).

The driver of long term environmental management is closure and the time frame has been extended from ecological self sustainability after seven years to environmental security after 1000 years.

This is beyond the practical demonstration in the laboratory or field, and environmental managers have to resort to thought experiments, what if scenarios and conceptual models of the future. They use computer codes as computational tools to assist them in reaching a conclusion. The codes themselves are not the models simulating the future, although very often the structure, input and equations of the code define the boundaries and limitations of the model. This paper describes some tools developed within the ANSTO laboratories to undertake these tasks.

A few rules should be recognised when developing a model and computer code to represent reality. These are:

- A model is a mathematical statement (system of equations) of concepts and assumptions used to describe some aspect of reality.
- A code is a computational tool for solving a model.
- A model can be calibrated.
- A model can never be validated.
- A model may be invalidated.
- A model will never be reality.

Bearing this in mind computer codes as tools are going to be described for:

- Assisting in designing covers to control Acid Rock Drainage from waste rock heaps, $SWIM^{HEAPCOV}$
- Describing the geochemistry and transport of a chemical active contaminant plume in ground water, MODPHRQ, and GMT3D
- Ecological Risk Assessment, AQUARISK

Acid Rock Drainage - $SWIM^{HEAPCOV}$

Acid Rock Drainage is a significant environmental hazard both in the Australian and world context. It is a result of the exposure of the common iron sulphide pyrite, also referred to as Fools Gold due to its golden appearance, to the atmosphere. Pyrite is unstable under these conditions and oxidises to sulphuric acid and dissolved iron compounds as:

Pyrite + Atmospheric Oxygen + Water → Sulphuric Acid + Dissolved Iron

In a waste heap the acid solutions trickle down through the heap dissolving below mill grade trace chemicals out of the rock. The acidic solutions either enter the ground water table below the heap, or appear as environmental hazardous, acidic springs around the base of the heap.

It is not possible to stop the oxidation reaction in a waste heap. However, it can be controlled by limiting the amount of oxygen entering the heap. This is achieved by covering the heap with local clays and soils. The $SWIM^{HEAPCOV}$ is a tool for calculating the effectiveness of a cover in reducing the Acid Rock Drainage for a given set of parameters such as air and water permeability, thickness, concentration of pyrite etc. The code is based on the extensive Acid Rock Drainage studies carried out by ANSTO over the past 20 years coupled with the robust SWIM code developed by CSIRO.

Contaminant transport in ground waters, MODPHRQ and GMT3D

Contaminant transport modellers tend to group the nature of the contaminant into:

- Insoluble inactive contaminants such as oils and Dense Non-Aqueous Phase Liquids (DNAPLs);
- Water soluble, inactive contaminants such as salts and brines; and
- Water soluble, reactive contaminants such as dissolved metals, acids and alkalies.

The different properties of the three groups are then taken into consideration in constructing a model to describe the process. ANSTO has been working on the *'Water soluble, reactive contaminants'* problem. This requires a description of the hydrology, the mass transport and the chemistry of the system. These are all significant tasks and in the past have been handled separately. ANSTO has coupled these three tasks in a computer code for Geochemistry and Mass Transport in 3 Dimensions, GMT3D, Guerin and Zheng (1999). This is made up of three components; the USEPA code MODFLOW for modelling the hydrology; the USEPA code MT3D for modelling the mass transport, and was designed to couple directly with MODFLOW; and the ANSTO code MODPHRQ for modelling the chemistry and has been designed to couple with MT3D. MODFLOW and MODPHRQ are modular codes so that the user selects those modules applicable to the job in hand in the same way that one selects the modules of a domestic sound system to play music from a radio, tape deck, phonograph or CD player. MODPHRQ is derived from the robust set of PHREEQE codes developed by the U.S. Geological Survey, with PHREEQE being the defining code [Parkhurst *et al.*, 1980] and used for modelling the equilibrium chemistry.

During the testing stage of GMT3D it was shown that the transport portion of the code consumed only 2.2% of the total simulation time, while the rest of the time was spent solving the geochemistry. Memory size and processor capability is still the major limitation in the use of the coupled coded and it is still only possible to run simple models even on main-frame machines.

Ecological Risk Assessment, AQUARISK

A continuing problem for both the mine operator and mine regulator is handling conflicting opinions for a perceived environmental impact. Ecological Risk Assessment provides a quantitative tool for resolving this issue. Such a tool recognises that chemical concentrations in a river vary about a mean value. The variation may be due to the vagaries of the weather, plant operation and other effects. A monitoring program will identify the variation and allow it to be described by a frequency distribution curve. Similarly, the impact of a pollutant on aquatic species will also vary from species to species. The risk of impairment can be obtained by comparing the distribution of water quality values with the distribution of measured values of the impact of a pollutant on aquatic species.

ANSTO has created a computer code to undertake this task, AQUARISK, and inbedded it into a step by step user-friendly interface for the non-specialist. The program will accept water quality monitoring data, or in the absence of such data then values generated by a predictive model from equivalent sites. The water quality data are compared with dose response data extracted by the program from the ANZECC ecotoxicity dose-response data base. The output from the comparison provides an estimate of the probability of exceeding the hazardous concentration for 5% of the species, HC_5. This value can then be compared against the value set for the selected pollutant in the Water Quality Guidelines. The program and tool competently applies a basic screening of water quality measurements to identify contaminants of potential concern, and allows quantitative ecological risk assessment. The program will be refined further to include components for chemical speciation, habitat and ecosystem effects, data amalgamation and filtering.

References:

Guerin, M. and Zheng, C., 1999. GMT3D - Coupling MT3D and MODPHRQ for Modelling Multicomponent Reactive Transport in Three Dimensions. (In press).

Parkhurst, D.L., Thorstenson, D.C. and Plummer, L.N., 1980. PHREEQE - A computer program for geochemical calculations. U.S. Geological Survey, Water Resources Investigations Report 80-96. NTIS Accession No. PB 81 167801.

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F. TOOLS

Indicators of Reclamation Success - Recovery Patterns of Soil Biological Activity Compared to Remote Sensing of Vegetation

Presented by Dr David Jasper,
Centre for Mined Land Rehabilitation,
University of Western Australia

Indicators of Reclamation Success - Recovery Patterns of Soil Biological Activity Compared to Remote Sensing of Vegetation

David Jasper & Yoshi Sawada
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The University of Western Australia
Nedlands WA 6907

Developing indicators to assess progress of mine rehabilitation is subject to several constraints. Firstly, achieving rehabilitation objectives needs to be measurable. However, achieving a 'complete' ecosystem is not possible in the time frames associated with mine rehabilitation, given the periods required for successional changes in vegetation. Therefore, key components of sustainable ecosystems need to be identified, and their recovery patterns defined.

Ecosystem rehabilitation indicators should have some key characteristics as follows:
- Accommodate all land uses;
- Describe generic factors (eg. physical stability, vegetation characteristics or soil processes);
- Focus on factors which add resilience to the ecosystem (nutrients, microbial activity, invertebrates, plant species diversity etc);
- Able to be repeatedly measured to indicate direction of change ; and
- Absolute value needs to be comparable with:
  - pre-mining environment (without specific expectations of replicating it), and
  - post-mining/pre-rehab (with on-going need to demonstrate appropriate development).

Some possible indicators of satisfactory progress in rehabilitation include measures of soil physical fertility (soil stability / erodibility; infiltration and hydraulic conductivity; water run-off quality), chemical fertility (e.g. available and mineralisable N and P) and biological fertility (soil organic carbon; symbiotic micro-organisms; microbial C and respiration; litterfall and rate of breakdown; invertebrates (eg. collembola, ants); pathogens). Also important are vegetation parameters (numbers, cover, and richness of appropriate plant species), together with plant reproductive capacity / resilience (i.e. capacity to survive, regrow or re-establish after fire, drought etc; includes soil seed banks) and vertebrate fauna.

In this paper, I would like to focus on selected biological processes in soil. Soil biological processes are of interest because they are essential in nutrient supply and uptake. Key processes include:
- mineralisation of organic matter (soil animals, soil microbial biomass).
- enhanced uptake of immobile nutrients (mycorrhizal fungi).
- supply of nitrogen through N2-fixation (rhizobia, Frankia).

Soil microbial biomass is the living microbial fraction (bacteria, fungi, protozoa, micro-fauna etc) of soil organic matter (1 to 4%). It is responsible for decomposition and mineralisation of organic matter, contributes to soil structure development and is a source and sink of plant nutrients. The soil microbial biomass has potential as an indicator because it is always present at some level and very responsive to management changes (more so than total soil C, or soil nutrient content). Low or decreasing soil microbial biomass implies low or declining plant productivity.

Mycorrhizal fungi assist in nutrient uptake for most plants, and therefore will contribute to the sustainability of revegetation. These fungi can be severely reduced by soil disturbance and stockpiling during mining. The particular occurrence of mycorrhizal fungi can depend on plant species present, and this restricts their potential as a generic indicator.

Soil animals are responsible for the breakdown of plant residues, enabling subsequent mineralisation. Through their activities they enhance soil structure. Soil animals do have potential as generic indicators. **N_2-fixing symbionts** have limited potential as indicators because they may have a specific host range and in our experience appear to be able to survive well in soils.

Several studies within the Centre for Land Rehabilitation at The University of WA (e.g. Sawada, 1996) and elsewhere (e.g. Greenslade and Majer, 1993) have focused on soil biological parameters in the bauxite-mining industry in south-western Australia. The uniform nature of the soils and landscapes, and of rehabilitation strategies, make it possible for comparisons over various ages of rehabilitation to be made.

In brief, total soil C in surface soils is substantially lower in respread topsoils and increases very slowly, even under highly productive re-vegetation. By contrast, soil microbial biomass increases rapidly and substantially from around 2 years through to 8 years. Its rate and magnitude of response parallel that of the vegetation, and therefore appear to make it suitable as an indicator.

VA mycorrhizal fungi follow a similar recovery pattern in topsoil, to that of microbial biomass. However they are more difficult to measure and given their constraints described above, are less suitable as an indicator. Although equivalent time sequences are not available for soil animals, Greenslade and Majer (1993) found that the total number, of species and individuals of decomposing collembola related very strongly to increasing plant and litter cover.

It appears that the recovery patterns of all the microbial parameters appear to parallel that of the revegetation, and thus they indirectly indicate progress in mine revegetation. This is to be expected, given that vegetation provides the resources for microbial processes in soil. Direct measures of vegetation parameters may then be a more logical approach, but are extremely difficult to obtain. Recent research has shown that remote sensing of vegetation, for example of photosynthetic vigour, gives a similar values to direct measures (Jasper *et al.*, 1998).

In summary, overall plant productivity is an integration of total site fertility, and appears to be associated with recovery of key microbial populations in soil. Broad-scale approaches, such as these remote sensing, to measure vegetation parameters allow, large areas of revegetation to be assessed , earlier generation of data, and a standard for normal rehabilitation to be defined. In addition, less-productive areas may be able to be identified, and the causative factors investigated.

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REHABILITATION II

G. REHABILITATION II

Ecosystem Development on Anthroposols at Kidston Gold Mine, North Queensland, Australia

Presented by Mr David Bowen,
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Ecosystem Development on Anthroposols at Kidston Gold Mine, North Queensland, Australia

By D.Bowen and D.R. Mulligan
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Background

Kidston Gold Mine(18°53S, 144°09E) is located approximately 260km SW of Cairns in far north Queensland. The area has a mean annual rainfall of 719mm predominantly falling between November and April. The mine is a large, open pit, operation. Ore is processed on site using the cyanide leach and carbon in pulp adsorption process. At the end of mine life the total area of new landforms created will be 613ha of which waste rock dumps will comprise 49% (303 ha) and a Tailings Dam 51% (310 ha).

This paper focussed on the four logical steps in the research sequence necessary for the ultimate establishment of native species on mined soils.

- Establishment of vegetation baseline data.
- Characterization of anthroposols.
- Native species establishment trials.
- Monitoring the success of establishment trials.

Establishment of vegetation baseline data

The assessment of reference ecosystems provided a vegetation blueprint of a range of native species communities and a suite of species likely to be of potential in native species establishment at Kidston mine. Three reference sites were chosen within close proximity to the lease to generate a vegetation set of typical surrounding woodland. Using classical survey methods the following data was derived: species composition and abundance, foliage projective cover (ground and canopy), tree, shrub and native grass density, community structure and floristics, species diversity indices and soil parameters (nutrient status, pH and electrical conductivity).

The three sites under survey have a history of cattle grazing. Two sites were characterized by gently sloping topography interspersed with several knolls. The soils supporting the Savannah woodland at these two sites were classified as dermosols and kurosols (red and yellow podzolic). Dominant tree species comprised the taxa *Eucalyptus*, *Corymbia*, and *Terminalia*. The third site was characterized by an escarpment with steep (20-28°) scree slopes on the western and eastern faces. The soil was basaltic in origin and the vegetation of the western scree slopes was characterized by relict rainforest tree species including *Mallotus*, *Pouteria* and *Planchonia*. as well as open woodland dominated by eucalypts. Native grasses including *Dichanthium*, *Bothriochloa*, *Heteropogon*, *Panicum*, *Schizachyrium*, *Aristida* and *Eragrostis* species comprised the ground layer in differing proportions at each site.

Characterization of anthroposols

Anthroposols were characterized in order to assess their suitability as germination and growth media for native species. The following parameters were determined: soil structure, porosity macro /micro nutrient content, pH, electrical conductivity, cation exchange capacity, phytotoxic metals content.
Wastes rock dumps at Kidston mine are composed of mostly barren and some mineralized waste with an oxide capping (0.5m). A loose layer of oxide (2-3m) caps this material. The oxide is weathered rock (essentially a C horizon of the original podzolic soil) with a clay content of 10 -15% and an alkaline pH (8-9). Nutrient content is low, particularly with respect to phosphorus (3mg/kg) and potassium (0.11 cmol(+)/kg). Elevated levels of Cu (0.3mg/kg), Mn(3mg/kg) and Fe (6mg/kg) are found in oxide.
Tailings are the by-product of mineral processing and are comprised of coarse and fine fractions. The coarse fractions, which were deposited close to spigot outlet points, contained acid generating sulfide minerals. The fine fractions contained high amounts of calcium hydroxide, which induced alkaline conditions. The pH of the tailings is thus variable and ranges from 3 to 9. This medium is also extremely saline (1.8 - 6.7 dS/m,

1:5). Nutrient levels are low, particularly phosphorus (3-8 mg /kg) with high levels of Cu (2-13mg/kg), Zn (10-87mg/kg), Mn (9-105mg/kg) and Fe (16-167mg/kg) found in tailings.
Both substrates are devoid of organic matter and are initially sterile.

Native species establishment trials

A number of species establishment trials have been undertaken by the Centre for Mined Land rehabilitation over the last five years at Kidston mine. Four of these will be addressed in this paper (Table 1).

Table 1. Species establishment trials at Kidston mine

Anthroposol	
Tailings	Oxide
11 ha tubestock trial - large scale (1994)[a]	Broadcast seeding trial - large scale (1996)[a]
Broadcast seeding trial - small scale (1998)[a]	
Broadcast seeding trial - large scale (1999)	

[a] trial with irrigation

Tailings : large scale tubestock trial

Methods

A trial of drip irrigated tubestock was initiated in 1994 at the southern end of the dam on a deposit of 6 to 9 years old tailings. Over 1800 individual seedlings were planted over an 11ha area. These comprised 21 species mainly from the myrtaceous genera *Corymbia*, *Eucalyptus*, *Callistemon* and *Melaleuca* as well as taxa from *Allocasuarina*, *Casuarina* and *Acacia*. Trees were planted on a 5 × 10m grid. Tree height and survival rates were recorded on 6 occasions between April 1994 and May 1997. Root excavations and analyses were carried out in 1997 to determine rooting distribution and presence of microsymbionts (mycorrhiza and *Rhizobium*).

Results

By 1997 survival rates of most species of *Eucalyptus*, *Melaleuca* and *Allocasuarina* were greater than 75% while that for Acacias was less than 75%. Heights of eucalypts (notably *E.camaldulensis*) reached 6m, *Allocasuarina cunninghamiana* 5m, while *Acacia* and *Melaleuca* species reached 4m. First filial generation seedlings of *Acacia holosericea*, *A. leptoloba* and *Melaleuca leucadendra* had arisen on the bare tailings while seedlings of *Eucalyptus crebra* had recruited from adjoining woodland. Exotic (rhodes grass and *Urochloa* and *Cynodon* species) and native (*Themeda quadrivalis* and *Panicum* sp.) grasses had established between tubestock rows.

Roots of Acacia species were well nodulated with nitrogen fixing *Rhizobium* bacteria. Roots of *E.camaldulensis*, *Allocasuarina cunninghamiana* and *A. holosericea* were infected with an ectomycorrhizal fungus with honey colored hyphae and rhizomorphs. The causative fungus was quite possibly the Gasteromycete *Pisolithus*, sporocarps of which were often prominent on acidic tailings in direct hyphal association with roots.

Tailings : small scale broadcast seeding trial

Methods

A small scale seeding trial was set up in February 1998 on a deposit of one year old tailings. The aim was to assess the suitability of tailings for the germination of native species seed provided with an optimum soil moisture regime. A total of 20 native woody and grass species were tested for their emergence and growth in tailings. Species were chosen from *Corymbia*, *Eucalyptus*, *Melaleuca* and *Acacia* and available native grasses, *Astrebla* and *Heteropogon*. Seeding substrates were bare tailings and a thin layer (10-20cm) of oxide over tailings. Crop King fertilizer (high N P K) was applied at 2 rates (200 and 400kg/ha). Seeding rates were 1 and 10kg/ha for woody and grass species respectively. There were 4 replicates for each treatment in a randomized block design. The trial was drip irrigated for 6 months.

Results

At 6 months all species had emerged on tailings. On the tailings only treatment, fertilizer effects on height occurred with 5 species of *Eucalyptus*. Eucalypt species ranged from 20 to 40cm in height with individuals of *Eucalyptus camaldulensis* and *E.drepanophylla* attaining the greatest biomass. Individuals of all myrtaceous species, however, exhibited nutrient deficiency symptoms consistent with phosphorus.
By comparison germination of Acacia species on tailings was poor and individuals were chlorotic, stunted (< 10cm) and the roots were unnodulated. Nitrogen deficiency symptoms were also noted on the grasses. Trial plots were invaded by rhodes grass which established along driplines.

On the oxide treatment, the numbers of seedlings were, over all species, lower than those on tailings although most species had germinated (19 of 20) by 6 months. Fertilizer effects on height were found with *E.drepanophylla* and *E.camaldulensis* only. Heights of eucalypts ranged from 10cm to 30cm but individuals appeared healthier than those on the tailings treatments.

Emergence of acacia species on oxide was low but individuals were markedly healthier and exhibited greater height variation (10cm to 50cm) than on tailings. Individuals of *Acacia victoriae* were well nodulated and reached 50cm. Similarly, sown grass species emergence was very low but individuals were vigorous and healthy. Plots were overrun with red natal grass (not sown) which exerted inhibitory effects on native seed emergence on the oxide.

Tailings : larger scale broadcast seeding trial

Methods

A seeding trial was instituted in the wet season of 1999 on a deposit of one year old tailings. The aim was twofold; firstly, to determine if native seed could survive and germinate in tailings under natural rainfall conditions and secondly to assess the feasibility of larger scale broadcast seeding of tailings. Species were selected from the emergence data of the earlier trial and the list expanded to include three native grasses (*Dichanthium*, *Themeda* and *Bothriochloa*). In total 5 tree and 5 native grass species were trailed. Three plant group treatments comprised eucalypts, grasses and a eucalypt/grasses combination. Two fertilizer rates (Crop King) were imposed (200 and 400kg/ha). Treatments were replicated 5 times in a randomized block design with experimental plots of 10 × 5m. There were 4 blocks each of 30 plots. Seeding rates were identical to those of the earlier trial. The trial site was lightly harrowed prior to, and after, seeding. The first monitoring is scheduled for spring 1999.

Preliminary observational results at 6months indicated the emergence of eucalypt and native grass species along harrow lines.

Oxide : large scale broadcast seeding trial

Methods

A seeding trial was undertaken on the South Dump in June 1996. The purpose was to determine if oxide would support the germination and growth of native species. A range of eucalypt (6species), Acacia (6species) and native grass(5species) species were selected from the list of reference ecosystem species. Four plant group treatments and 4 fertilizer rates (0,50,100 and 200kg/ha) of Crop King were devised. Treatments were replicated 4 times in a randomized block design. Experimental plots were 10 ×10m with a 5m buffer between blocks. Seeding rates were 1 and 10kg/ha for woody and grass species respectively. The trial site was levelled prior to seeding to reduce the effect of extraneous factors. Plots were hand-seeded and spray irrigated for 4 months until the advent of the wet season of 1996/1997.

Results

At 2 years, 3 species of eucalypt and 4 Acacia species have become established. Sown native grass species have also established. Overall, eucalypt densities were higher (2000 -10000 stems/ha) than acacias (<3500 stems/ha). The most common eucalypt and acacia were *E.crebra* and *A.holosericea* respectively. Other species which became established were *E.camaldulensis*, *Corymbia citriodora*, *A.gonoclada* and *A.julifera*. Eucalypt species ranged in height from 1 to 2.5m while *Acacia* species varied from 1.5 to 3m. Sown native grass species such as *Bothriochloa decipiens* and *Dichanthium sericeum* reached 20000 plants /hectare.

Recruitment of exotic species (rhodes grass and buffel grass) had occurred into plots, with rhodes grass density comparable to that of the more common sown grass species.
In plots of eucalypts alone, there was a significant fertilizer effect on density of *E.crebra* (Fig.1). Density, but not height, was affected by competition in *E.crebra* (Fig.1). There were no significant fertilizer effects on density or height of *A. holosericea* , but competition reduced density in plots without fertilizer (Fig.2).

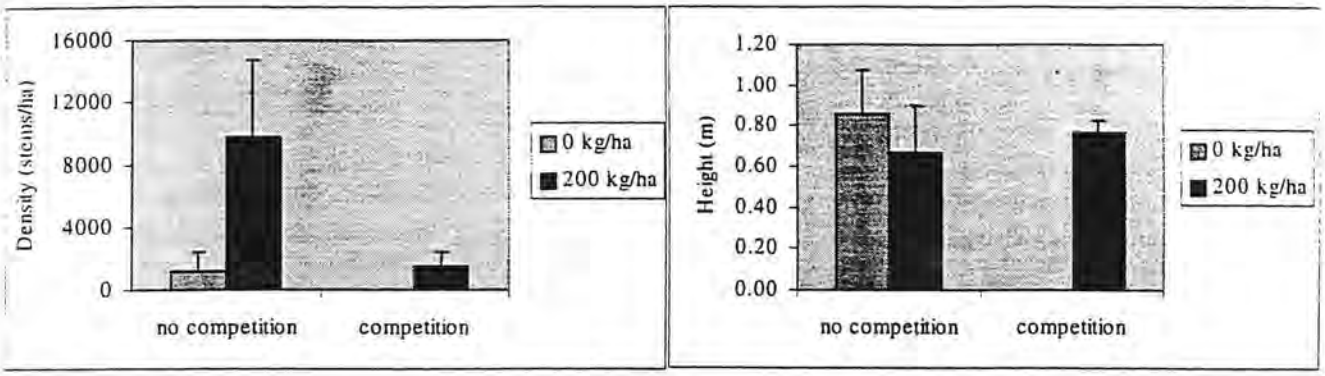

Figure 1. Density (stems/ha) and height (m) of the dominant eucalypt (*Eucalyptus crebra)* at 2 years on oxide.

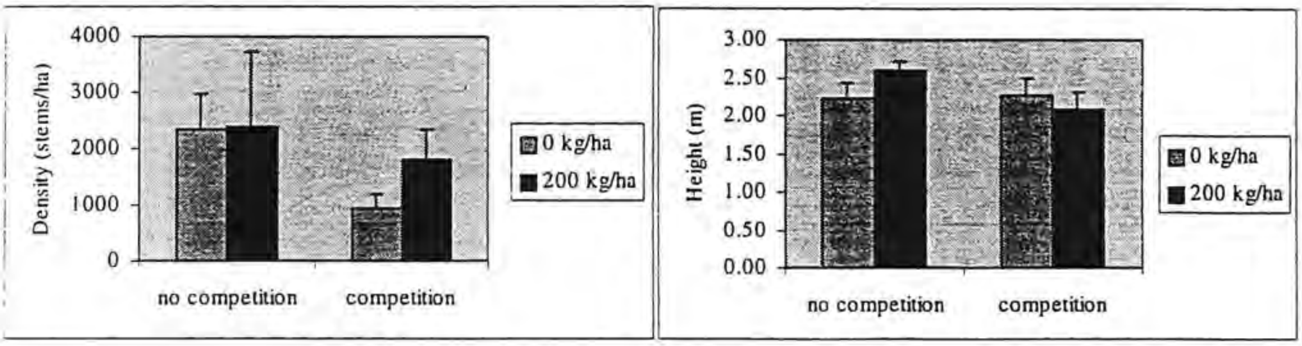

Figure 2. Density (stems/ha) and height (m) of the dominant Acacia (*Acacia holosericea*) at 2 years on oxide.

Conclusions

These trials have demonstrated that both tailings and oxide will support the emergence and growth of native species. Further monitoring is necessary, however, to determine the long term sustainability of the ecosystem being established on oxide. High eucalypt densities, in combination with the establishment and seeding of acacia and native grass species, constitute a verifiable indicator of early ecosystem establishment on this medium.

On tailings the recruitment of woodland tree species into the 11ha tubestock environs suggests that the substrate in this area has been favourably modified by the growth of native species. The production of seed in some tubestock acacias indicates that the tailings will support the growth to fruiting phase of native tree species. F1 generation seedlings of *Acacia* and *Melaleuca* represent the first stage in ecosystem establishment on tailings.

Broadcast seeding trials showed that emergence occurred for all native species which suggests that local species will germinate and grow on tailings. Preliminary results on larger scale broadcast seeding without irrigation are encouraging and indicate that successful seeding of tailings with native species within the optimum rainfall period is attainable. These results also point to a low capital cost for rehabilitation of tailings with no associated requirement for topsoil or oxide capping.

It was likely that high grass seed loads in the thin oxide layer significantly reduced the emergence of native seed on this medium. However, the presence of effective nodules on individuals of *A.victoriae* and the health and vigour of native grass species suggested that prior, shallow stockpiling of the oxide material with attendant colonization by perennial grass species initiated the buildup of propagule levels of symbiotic organisms in oxide. This in turn would have primed the oxide with beneficial soil bacteria and fungi including *Rhizobium* for *Acacia* species and mycorrhiza for grass species. This has direct implications for the storage and treatment of oxide prior to seeding.

Future research

Future research will center on three topics namely, plant nutrition, microsymbionts and plant water relations. Nutritional issues to be addressed include nutrient cycling, leaching and fixation of nutrients in tailings and oxide respectively. Microsymbiont work will focus on nitrogen fixing bacteria (*Rhizobium*) for leguminous species and on mycorrhiza for all native tree species. Methods for microsymbiont inoculation and seedling application (peat *Rhizobium* inoculum for Acacia species, basidiospore inoculum of ectomychorrhizae for Myrtaceae, Casuarinaceae and Mimosaceae) will be tested on species in oxide and tailings. Water relations research is currently centered on tailings dam hydrology and oxide capping depth.

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G. REHABILITATION II

The Role of Remote Sensing for Measuring Mining Impact on the Australian Arid Environment and the Link for Ecological Function

Presented by Mr Peter Hick, CSIRO Exploration and Mining

The Role of Remote Sensing for Measuring Mining Impact on the Australian Arid Environment and the Link to Ecological Function

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Summary

This paper briefly reviews the criteria and methods for measuring ecological performance and indicators of the ecological rehabilitation of post-mining landscapes, and is a subset of a more definitive study by the same authors. It is based on the site-specific approaches as promoted by three separate ecologists. Most of their work seeks to use readily observed or field-measurable indicators of ecological status to predict rehabilitation direction and success. Based on these criteria, an estimate of the contribution that appropriate remotely sensed data can objectively contribute toward determining these indicators is made. Particular emphasis is placed on the role of hyperspectral sensing (or airborne-spectrometry)

Introduction

At least three ecological researchers are doing significant work on developing procedures for the assessment of landscapes and their ecological status, Milnes et al. (1992). Their work is relevant to rehabilitation of minesites but is based on many years of ecological measurement and observations of arid and semi-arid natural ecosystems. We have chosen the approaches of David Tongway, David Mulligan and Alister Spain to test the value and limitations to the use of remotely sensed data to provide some of the key parameters that these researchers have deemed as important for assessment of post-mined ecosystems.

There is a general assumption that is common to all three. That is: "that criteria based on a narrow set of vegetation indices or single parameters have generally been found to be inadequate, Reddell et al. (1992; 1993) and a combination of attributes at both the landscape level and specific ecosystem properties are necessary.

Landform stability is a major pre-condition for satisfactory rehabilitation and has two components: an adequate engineering design that includes the concept of landform evolution over time and surface stability. Ecosystem development in the post-mining environment involves the establishment of a suitable vegetative cover that will help achieve stability but will have the additional desirable attributes of self-maintenance, resistance to stress but resilience when external stresses, such as drought and fire, are inevitably applied. Further, it is considered desirable that such ecosystems possess an ecological integrity consistent with the surrounding landscape.

Remotely-sensed data have played a significant role in the mining industry in Australia both for exploration and for assessing the spatial environmental impact of mining. Panchromatic aerial photography was acquired over in Kalgoorlie in the early 1930's. At this time photogrammetry, or the use of the photo acquisition geometry to determine land shape, was developed and, while this is a very important aspect it is not covered in the scope of this study. In the 1950's colour and infrared photography added a spectral dimension. A significant new insight into the spatial and spectral variability was presented with the opportunities offered by multispectral satellites in the 1970's especially for assessing mining impacts. Now in the 1990's airborne and spaceborne hyperspectral systems are providing the detailed insight required for resource discrimination.

Detailed spectral analysis of plants and minerals has long been identified as diagnostic capabilities, (Elvidge, 1990; Kruse et al., 1990; Bellairs et al., 1996). Typical hyperspectral instruments may have 100 to 200 contiguous spectral bands with 12 bit quantisation and still retain a high spatial resolution. The challenge of using hyperspectral, or over-sampled data, is to make use of the important diagnostic information about specific surface materials within in data.

Ecological assessment; the Tongway approach

Despite this approach being attributed to David Tongway it is drawn from his work with other close colleagues, Paul Reddell, John Ludwig and Norman Hindley of CSIRO Wildlife and Ecology (CWE). It is based on their Land Function Analysis work, (Tongway and Reddell, 1996; Ludwig et al. 1997; and, Tongway and Hindley 1995). Their perspective is derived from a classical "whole of system" approach captured to any scale. The work that is of particular interest is the approach that they took to assessing the status of the rehabilitation on treated tailings at KCGM at Kalgoorlie. This site is based on inhospitable tailings in an arid central goldfields environment.

Land Function Analysis (LFA) has two parts:
(1) a conceptual framework describing the sequence of processes involved in the functioning of an ecosystem or landscape; and,
(2) a methodology that provides information or indicators of the current status of the ecosystem. The methodology has an elegant interpretational framework that, although generic, is also site specific.

Basically, LFA tracks the fate of vital resources, such as water and nutrients in space and time in an ecosystem or landscape. Both biotic and abiotic regulators of resources are recognised and their respective and combined effects assessed. LFA assesses the status of a landscape as a continuum from "highly functional" or highly retentive of vital resources to "dysfunctional" or "leaky". This is an ecological assessment, not related to any specific land use but is specifically linked to surrogates. Many of them can be quantified remotely. However, at a later stage, a connection can be made with land use, via a "value judgements" discriminator, which acknowledges the specific needs of a given land use and user. A landscape can then be described in terms of "condition", rather than function. It is possible for a landscape to be somewhat "dysfunctional" yet in good "condition" for a specified use. Because the approach develops a predictive understanding, it provides a framework from which to look at biodiversity, sustainability and rehabilitation issues.

The next phase of ecosystem development has analogues in the Tongway approach (Tongway, 1994) where he determines the "patchiness" of the system. Fertile patches can be relatively small but represent a high proportion of the biological activity between relatively barren "inter-patch" that tend to "feed" the micro-topographically preferred fertile patches that are able to grow to accumulate resources. The recognition and measurement of patchiness is possible using high-resolution remote sensing, especially when the geo-mechanical design of the rehabilitated surface encourages this process.

The study at KCGM's Fimiston site is an assessment to evaluate a field trial using surface sheeting of waste rock dumps with oxidized waste in relation to the long-term capability of the artificial soil medium to support appropriate, sustainable vegetation and the long term resistance to erosion

Tongway found at Fimiston that there was:

- a lack of species of perennial trees and shrubs (other than chenopods);
- a high proportion of annual species;
- a lack of 'patchiness;
- a lack of structural (multi-layered) development; as well as,
- on-going erosion of the highly dispersive and saline oxide waste.

Conclusion from Tongway's work

It is reasonable to conclude that appropriate remote sensing could have contributed significantly to these findings. The species distribution and the system patchiness could be readily mapped and with hyperspectral data it would be possible to map the surface chemistry and infer it's implications for erosion. Tongway and his research group are now integrating remotely sensed data with ground observations with significant success. This work will be published in the near future, (Tongway, pers. comm.)

Ecological assessment; the Mulligan approach

Ecological Success Criteria at Weipa by David Mulligan of the University of Queensland (UQ) used a duplicated plot approach with random selection and measurement and concentrated on the important soil properties with less attention being paid to the plants.

At the Weipa Bauxite mine in tropical savanna woodland in far North Queensland summer rainfall is high and reliable and the soils are "two layered replaced-stripped topsoils" over a ripped kaolinitic clay with minimal relief (Reddell and Hopkins, 1994). Weipa rehabilitates up to 500ha/yr, with good mechanical practices and has a good age range for study. Weipa has been the site of extensive ecological research. The work was based on the LongTom trial. This study was dominated by soil and nutrient management in relation to growth and nutrient supply and related to mycorrhizal aspects, Malajzuk et al. (1994). It was determined that there was a need for periodic re-measures of soil and plant factors and they provided some target levels for these indicators. These have been included as a generalised summary below.

The important Soil Factors

Compaction. Measured with a penetrometer with complication of soil moisture and depth structure of the replaced and ripped profile. (Target <300N/cm^2)
Organic matter. Soil organic matter, need to determine residual material transported when stripping and that developed in situ. (Target >1.5% 0-5 cm)
Microbial Biomass Biogeochemical nutrient cycling and soil structure development and includes all living microbial components. (Target >400mg/kg 0-5 cm)
Plant-available P P is invariably very low in the soils at Weipa and the Fe-, Al+ fixes most of the available P (Target >4mg/kg 0-5 cm)
Root symbioses Microbial associations and mycorrhizal N-fixers and the importance of their activity is considered important at Weipa. (Target is presence of nodules on >50% of roots – with some species description)
Invertebrate activity. Ants are abundant and diverse, with diversity being as important as abundance. Presence of Termite mounds also important. (Target >25 ant species, evidence of termites)

The Important Plant Factors

Species richness/diversity indices This includes numbers of species, evenness and relative abundance. Stability and perturbations are difficult to assess. (Target >20 native species across 8 genera)
Acacia and Eucalypt densities and height. Early domination of acacias with development of eucalypts in the preferred structure of the overstorey. (Target Max 40% declining to 15% acacia stems, Eucs to increase to minimum of 10% at or above canopy)
Foliar P and N. nutritional status linked to photosynthetic activity and competitive species (Target >0.08% P, and 0.18% N for leaf, some species variation)
Grass and litter cover. Contribution to stability (erosion), nutrient cycling and habitat considered beneficial, competition for nutrients and space detrimental. (Target >30% grass cover 20% litter)
Weed presence. Weed invasions symptomatic of incomplete use of site resources/competition etc. inappropriate rehabilitation strategy. (Target Max 2 species or 10% of total)
Seedling recruitment. Ecosystem must be capable of, and/or demonstrate that it is reproducing itself from both internal and external sources.

Conclusion from Mulligan's work

For the soil factors it reasonable to conclude that remotely sensed data are not likely to be able to quantitatively determine any of those soil-related indicators. However, there are implicit information requirements that could definitely be determined that are relevant to Weipa. Variability in soil colour and mineralogy as determined by spectral analysis of the redistributed stripped surfaces would, for example, indicate profile heterogeneity that could control future rehabilitation success.

Conversely, the plant factors could all be quantitatively determined with the appropriate remote sensing and ancillary data. Even using the 4-spectral band airborne video at Weipa, it was possible to separate many key species, plant vigour and to separate weed infestation (Hick and Ong, 1995). The experience at other sites indicates that hyperspectral data at the appropriate spatial resolution could determine these plant factors.

Ecological assessment; the Spain approach

<u>Soil and Biological Criteria augmented with satellite measures.</u>
The work of Alister Spain CSIRO Land and Water (CLW), Soil and Biological Criteria, at Pannawonica is an ideal example of resource-scarce rehabilitation assessment, Spain 1999. The mining process at Robe River in the Pilbara of WA is done by removing a series of benched layers of pisolitic ore from discrete mesas. Topsoil is scarce and the resulting landforms do not really have direct analogues in nature. The desired endpoint is a spinifex grassland with a few mixed eucalypts and acacias.

The aim of post-mining rehabilitation at the Robe mesas is the stabilisation of waste material in appropriate landforms with the establishment of suitable ecosystems on their surfaces. It is expected that the ecosystems developed will enhance surface stability but will also impart other favourable attributes to the post-mining environment.

This variability within the developing mine soils are a mixture, reputedly, of the upper 'useful' part of the available topsoils applied as a layer over the waste materials and mechanically-created niches designed to concentrate scarce resources. Over the brief period of development, considerable changes take place. These involve the very early stages of soil formation: a series of physical, chemical and, above all, biological changes. Soil development on raw parent materials is a slow process and soil development in even the most benign mine wastes makes minimal progress. An "A" horizon may take more than 100 years to develop and full development for soils takes at least 1000 years for vertisols and inceptisols extending to 10^5 to 10^6 years for oxisols (Spain, 1997).

Where the soil can be preserved from the stripping process, and is of good quality and represents the horizon to be developed, considerable advantages result from its application to post-mining landforms at Robe. Unfortunately such soil resources are scarce. Therefore, the work developed by Spain at Robe concentrated on soil-forming processes as an indication of a site's potential to reach the desired end point. Site observations were a mixture of traditional Eularian transect-based measurement coupled with a Lagrangian site "parcel" ecological status reporting system. The latter approach was developed as a concession to the inevitability of objective measurement of remote surrogates. A separate study by these authors had used coarse 30 metre resolution calibrated satellite data to observe the progress of the rehabilitation at Robe since the late 1980's (Hick et al.1999)

The **measurement of surface soil properties** and profile morphology included:
- Soil chemical properties.
- Soil biological and faunal properties.
- Time, this aspect and its effects on profile development is a fundamental factor.

The **measurement of the vegetation** development also accounted for:
- Seed store, application and "seed-rain".
- Species mix direction/trend.
- "Baselines" determined by analogues.
- Transects (long-term).
- Parcels based on spectral/spatial imaging.

The **historic satellite measures** and future remote observations were based on what had been achieved to date and what could be reasonably expected from routinely-available systems from here onwards. These include:
- Routine acquisition at pre-determined season/time.
- Standardisation by invariant calibration.
- Validation against transects/parcels.
- Opportunistic hyperspectral acquisition for vegetation and mineralogical characterization.
- Statistical analysis and prediction modeling.

Conclusion from Spain's work

The level of detail observed by Spain included the recognition of changes taking place at Robe that included:

- reorganisation of the soil particles (fluviation and oxidation);
- development of a lag layer or a concentration of fines as a consequence of erosion;
- the creation of internal void spaces and injection of organic materials into the upper profile through litter fall, root turnover and the activities of termites and ants;
- developing microbiota species that influence soil development and N-fixing.

Without simultaneous detailed ground validation none of these highly vital processes could be expected to be reliably detected using remotely sensed data.

However, the systematic progress of the vegetation and the associated litter can and has been reliably tracked at Robe. The direction toward control sites (analogues) selected from unmined and relatively undisturbed sites is being modelled and this can continue. The expectation of the time it may take to reach endpoint criteria may be much greater than is currently recognised by some from both industry and the regulators. This fact therefore reinforces the need to have models that not only indicate the current status but also should plot the position on a time scale of the expectation of satisfactory completion criteria.

Progress with Remote Sensing systems

Recent significant advances in the application of spatial data for mine impact assessment and determination of quantitative indicators has more recently concentrated hyper-spectral remote sensing. However, much of the development work was based on future satellite simulations, as most existing satellite systems were perceived to be too coarse both spatially and spectrally for mine rehabilitation-type studies. One such system that was used extensively during the mid-nineties was an airborne video that could simulate some of Landsat, Spot and the proposed environmental satellites Ikonis and Earth Watch.

The Digital Multi Spectral Video (DMSV) Lyon et al. (1994), is an Australian-made, four-camera video-based airborne system that frame-grabs images (typically 1x1.5 km) in four narrow spectral bands centred at 450, 550, 650 and 770 nanometres (Vis-NIR). The individual frames have a range of essential processing, (Ong et. al., 1994) before they can be mosaicked to create a seamless image. These processes involve geometric and radiometric corrections to remove the effects image shading caused by the wide field of view lenses. Spatial resolution is usually 1-3 m. These data also require calibration with invariant targets when used for monitoring as was the case at Weipa and other sites.

Of much more relevance to the objectives of ecological indicator determination is the HyMap$^{(TM)}$ which is a 128 spectral band airborne imaging spectrometer that scans successive lines of a swath (typically 3-5 km wide) in the flight direction for continuous spectral coverage between 400-2500 nanometres (Vis-NIR-SWIR). Spatial resolution is 3-10 m and parallel flight lines can be mosaicked. Atmospheric and shading correction, as well as field calibration, is also required although the system does have some internal calibration capabilities. HyMap is also Australian-designed and manufactured and as a new technology significant amount of research is currently being undertaken within CSIRO to maximise the information content from these data.

The HyMap data can be considered as a "data-cube", being made up of *x* lines along flight direction, *y* pixels wide in swath and *z* bands deep. Therefore at spatial position *(x,y)* a spectrum of that pixel, *z*, can be extracted (Figure 1).

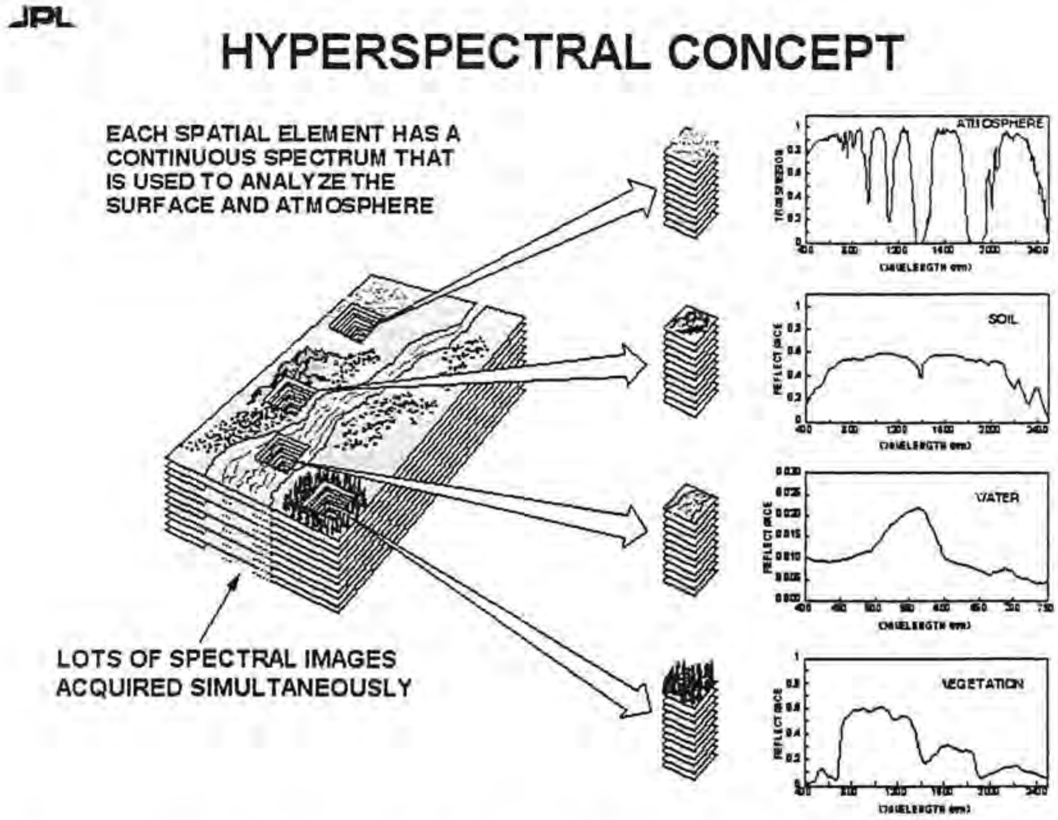

Figure 1: A graphic illustration of the Hyperspectral system concept (courtesy JPL) showing the data cube with examples of spectra of specific materials or surfaces on a regional scale.

All materials reflect solar energy in a characteristic manner that relates to their physical and chemical composition. After correction for the effect of atmosphere and angular incidence of illumination the discrete properties, or combined properties of each pixel, can be quantitatively determined from "hyperspectral" data (Figure 2).

Hyperspectral sensors therefore have the ability to measure ecological indicators that have characteristic physical or chemical components such as:

- Chlorophyll (vigour and type).
- Cellulose (litter and senescence).
- Clay mineralogy (clayness/sandiness).
- Iron content and soil colour (hematite:goethite).
- Organic matter (soil disturbance and char).
- Soil chemistry (sulfitic/dispersive).

Coupled with the spectral capability there are ecological indicators that can be interpreted using the spatial characteristics when coupled to photogrammetric and geographic information systems. These include:

- Plant cover (structure).
- Surface texture (smoothness/roughness).
- Patchiness ("niche-ness").
- Extent and severity of fire.
- Drainage patterns.
- Natural and contrived landforms.

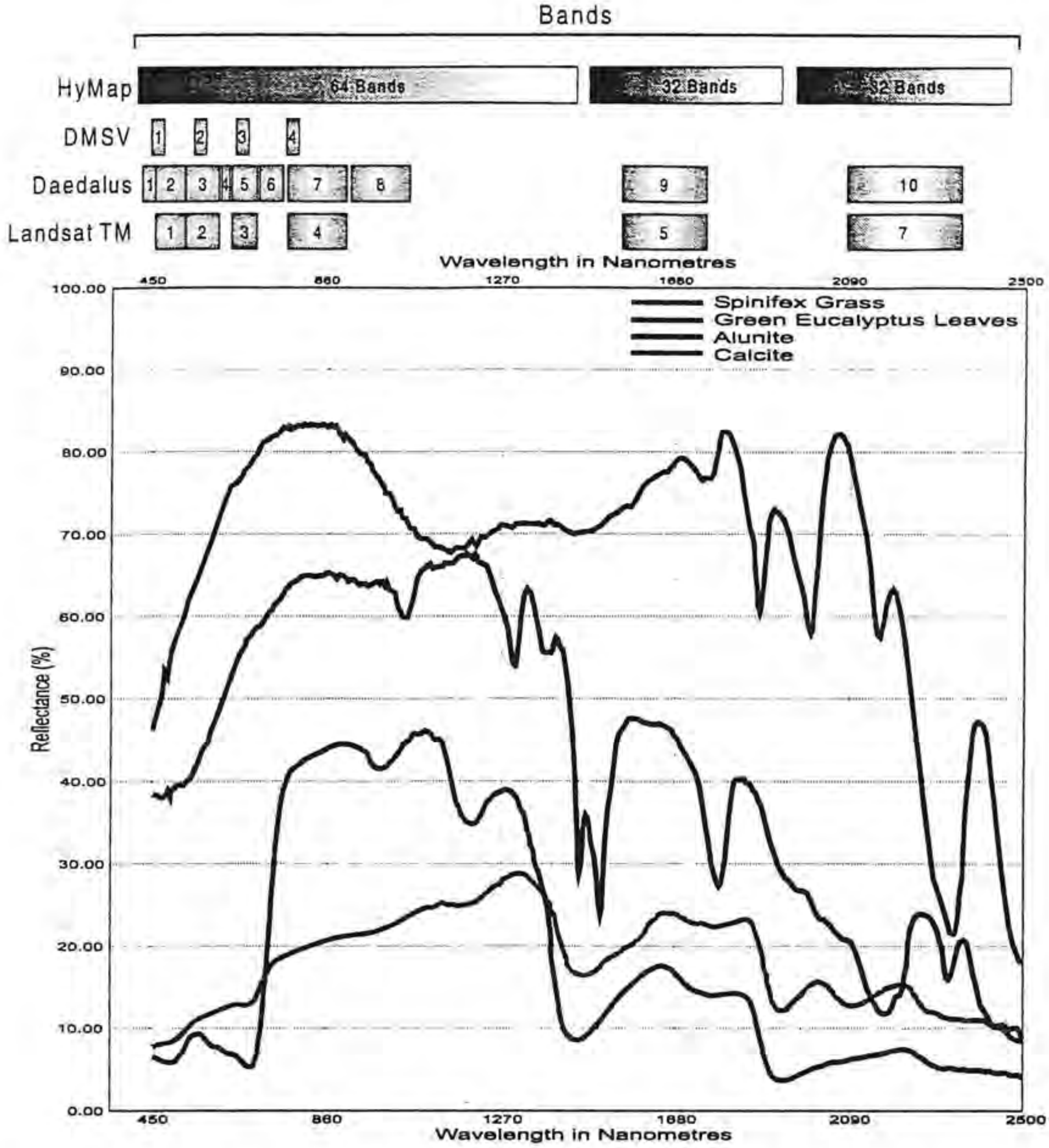

Figure 2: Spectra of specific materials having discrete characteristics enabling their mapping from Hyperspectral image data. At the top are the spectral regions covered by the 128 Bands of the Integrated Spectronics Ltd. Hymap; SpecTerra's 4 band DMSV; the 10 bands of Daedalus ATM and Landsat TM's 6 bands covering the vis, reflected and shortwave infrared.

Conclusions

This brief review shows that there is general consensus in the sort of measurements that need to be made to record the status and progress of reconstructed landform following mining. As expected each site has its specific requirements but the overall impression is that, with the appropriate mix of remotely-sensed data and specific ground measurements, many meaningful observations can be made. However, this must be shown to be both cost-effective and reliable before the approach is routinely accepted throughout the mining industry.

Remotely sensed data can provide useful information on the status of rehabilitated ecosystems if it is acquired with adequate ground validation and calibration. It must also be processed to exacting radiometric standards if it is to be taken to the next stage of comparison over time for monitoring purposes. The quantum leap is the quantitative extraction of species and abundances of target indicators that will enable exact biological measurements to be calculated. This is being shown to be a realistic expectation with the use of airborne hyperspectral data at several sites in Australia.

This development has been matched with advances in airborne geophysics, especially radiometrics and electro-magnetics, and the development of computer capacity to manipulate large spatial data sets to create Geographic Information Systems. Within Australia, industry and government are developing multi-instrument technology that includes reflected and thermal hyperspectral, radiometrics and electromagnetics on one airborne platform. Despite these advances being originally focussed on mineral exploration the greater opportunities and benefits may lie in the exacting requirements of the mining environment industry.

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G. REHABLITATION II

HyMap Data Analysis for Acid Mine Drainage (AMD) Assessment at Brukunga Pyrite Mine, S.A.

Presented by Dr Goetz Reinhaeckel,
CSIRO, Division of Exploration and Mining

HyMap Data Analysis for Acid Mine Drainage (AMD) Assessment at Brukunga Pyrite Mine, S.A.

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CSIRO, Division Exploration & Mining, Floreat Laboratories, WA, Australia

1. Introduction

Acid mine drainage (AMD) from sulfidic mine waste and the contamination of water and soils is considered as one of the major environmental impacts of the mining industry. Therefore, methods are needed to assess and monitor ongoing geochemical processes at the minesites.

In this study, hyperspectral airborne data from the Brukunga pyrite mine in South Australia were analyzed with respect to AMD-related mineral occurrences. The objective of the study was to identify areas affected by AMD processes using remotely sensed data. Although acid and contaminating metals themselves are unable to be detected from hyperspectral data, it is possible to identify and spatially map secondary minerals associated with specific geochemical environments.

Recently, Swayze et al. (1998) have shown the potential of AVIRIS imaging spectrometer data for locating acid-generating minerals in Colorado. High correlations between specific mineral abundances and pH values/metal mobility were observed. The great use of spectral information from the visible to the thermal infrared (0.45-13 µm) to derive quantitative mineral maps has been demonstrated in a study, conducted in the Central German Lignite District. DAIS 7915 airborne scanner data allowed here a compositional analysis of lignite overburden dumps (Reinhaeckel & Krueger, 1998; Reinhaeckel & Mueller, 1998).

2. Study area

The Brukunga pyrite mine in South Australia is located approximately 50 km east-south-east of Adelaide. It was established in the early 1950's to provide a local source of sulfur for the manufacture of superphosphate. The production ceased in 1972, after sulfur was being obtained at relatively low cost from overseas. The Brukunga ore body is mainly formed by pyritic metasediments which are enclosed within metamorphised rocks.

3. Methodology

3.1 Chemical/mineralogical interactions and their spectral significance

The oxidation of ironsulfides is a complex, biologically catalyzed process, strongly influenced by the specific environment (e.g. pH, SO_4, CO_3). With a decrease of the pH, dissolved heavy metals are transported as aqueous phases into nearby streams. Secondary minerals such as kaolinite, alunite, goethite, hematite and jarosite may be formed by oxidation processes.

A schematic diagram indicating the formation of pyrite and its transformation to jarosite, schwertmannite and goethite is shown in Fig.1. These reactions depend on the SO_4 concentrations and the pH of the environment. Weathering products of the pyritic schists are kaolinite ($Al_4Si_4O_{10}(OH)_8$) and halloysite, a hydrated form of kaolinite.

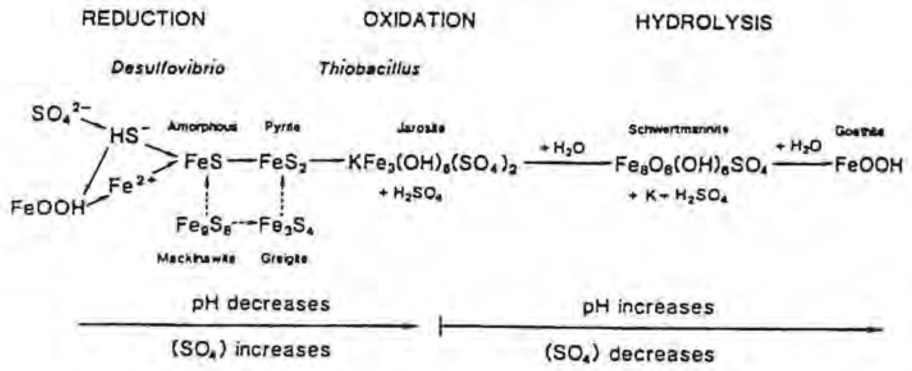

Fig.1: Schematic diagram of pyrite formation and transformation (modified after Schwertmann & Fitzpatrick, 1992)

The secondary minerals mentioned above, are Fe-rich and/or hydroxyl-bearing. This allows their identification on the basis of characteristic spectral features (Goetz, 1989). Visible near-infrared (VNIR, 0.4 to 1.3 µm) and shortwave infrared (SWIR, 1.3 to 2.5 µm) reflectance spectrometry is a widely used method for the discrimination and identification of geologic materials by their spectral features (Goetz, 1989).

3.2 Data processing

Two HyMap airborne scanner datasets were recorded in April 1998 and April 1999. HyMap (Hyperspectral Mapper) is a commercial airborne imaging spectrometer built and operated by Integrated Spectronics Pty. Ltd., Australia. The systems scans the earth's surface in 128 contiguous spectral bands between 0.45-2.5 µm. The spatial resolution of the datasets were 5 m (1998) and 3 m (1999), respectively. To allow a quantitative analysis, the data had to undergo various pre- and postprocessing steps. This included a dark current correction, the calibration of the data and an atmospheric correction to account for atmospheric scattering and absorption processes.

For data analysis spectral unmixing was performed. The mixture-tuned matched filtering (MTMF, RSI, 1998) approach was chosen. The processing of the two datasets (1998 and 1999) was performed separately. Because of the scene dependency of the unmixing technique, a direct comparison of the two datasets is limited. Four spectral endmembers were chosen can be related to AMD-processes: kaolinite, jarosite, gypsum and goethite.

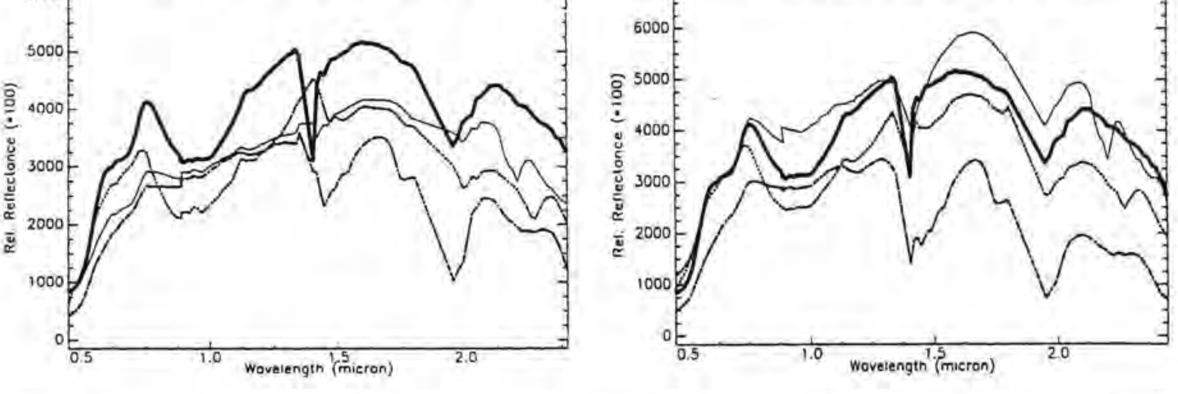

Fig.2: Spectral endmembers, extracted from the HyMap data (solid/thin= kaolinite, solid/thick= goethite, dotted= jarosite, dash-dotted= gypsum)

For a multitemporal, quantitative analysis of the mine environment, the comparability of remotely derived information with field and laboratory measurements plays an important role. To account for this, the HyMap endmember spectra were compared to spectral library data from the USGS (United States Geological Survey). In Fig. 3, the results for gypsum and jarosite are shown. To allow a better comparability, the spectra were continuum normalized (Reinhaeckel & Krueger, 1998). The plots show a very close fit of the hyperspectral airborne data (dotted) and the spectral library laboratory spectra. Minor variations can be found in the watervapour wavelength regions but the overall spectral shape correlates well. Even small absorption bands can be matched, e.g. the 1.75 µm feature for gypsum and the 2.4 µm band for jarosite.

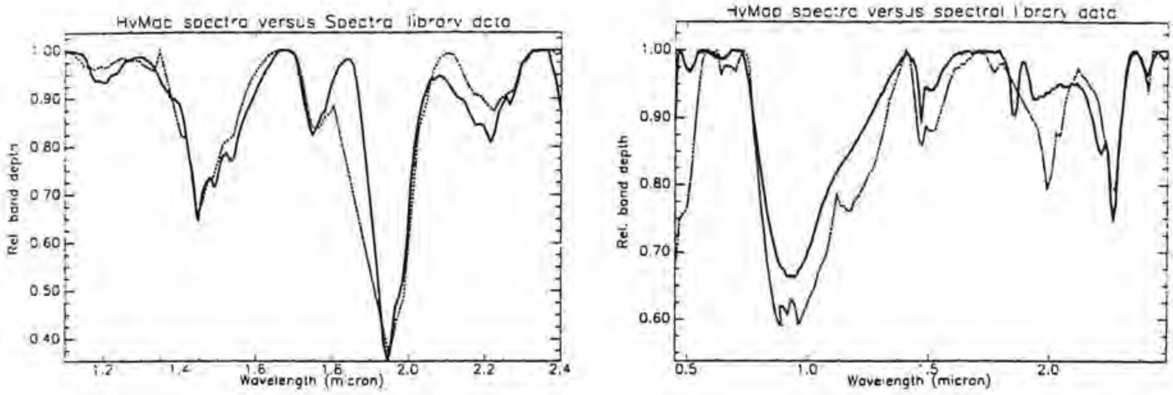

Fig.3: Comparison of HyMap endmember spectra (dotted) and USGS spectra library data (solid). All spectra were continuum normalised. left= gypsum, right= jarosite

4. Results

Mineral maps for the years 1998 and 1999 were created by unmixing the HyMap data. In Fig.4, kaolinite, gyspum, jarosite and goethite were spatially mapped. Most parts of the rock dump are covered by significant jarosite abundances. The occurrence of gypsum is mainly concentrated on the Upper Holding Pond and a southern area of the waste rock dump. The material was transported from the holding ponds where gypsum is the major precipitate.

Kaolinite can be identified within the northern area of the dump and along some roads and fields in the upper part of the images. The variations between 1998 and 1999 are remarkable especially in terms of jarosite, goethite and gypsum distributions. A decrease of jarosite-covered regions can be observed, whereas goethite seems to be more dominant in the some southern area in 1999.

In Fig.5, the distribution of jarosite and goethite is highlighted. The abundances were derived by unmixing the VIS-SWIR spectral information. Goethite is displayed in yellow colors. For jarosite, two classes are shown. The classes represent low to middle mineral abundances (displayed in blue) and high to very high mineral abundances (red), respectively. Therefore, the red pixels are supposed to be composed of relatively pure jarosite.

The jarosite/goethite maps reveal a wider distribution of jarosite in 1998 than in 1999, especially in the southern part of the dump. Very high mineral abundances (red colours), indicating the existence of relatively pure jarosite, can be identified easily in the 1998 imagery but not in the 1999 data. The appearance of goethite remains fairly constant from 1998 to 1999, some increase in the south may be seen. Interestingly, the spectral analysis doesn't show any occurrence of jarosite and goethite apart from the waste rock dumps and tailings dam, e.g. along the river etc.

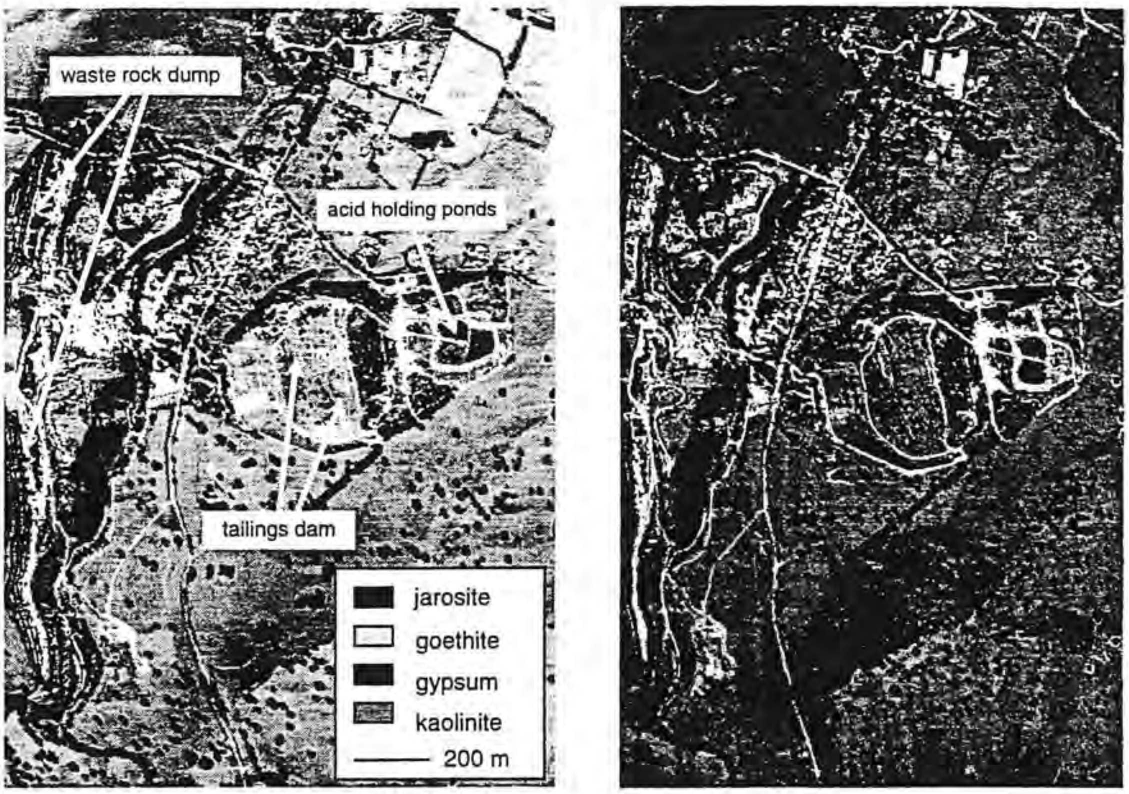

Fig.4: Mineral abundance maps showing the distribution of jarosite, goethite, gypsum and kaolinite at Brukunga (left= 1998, right= 1999)

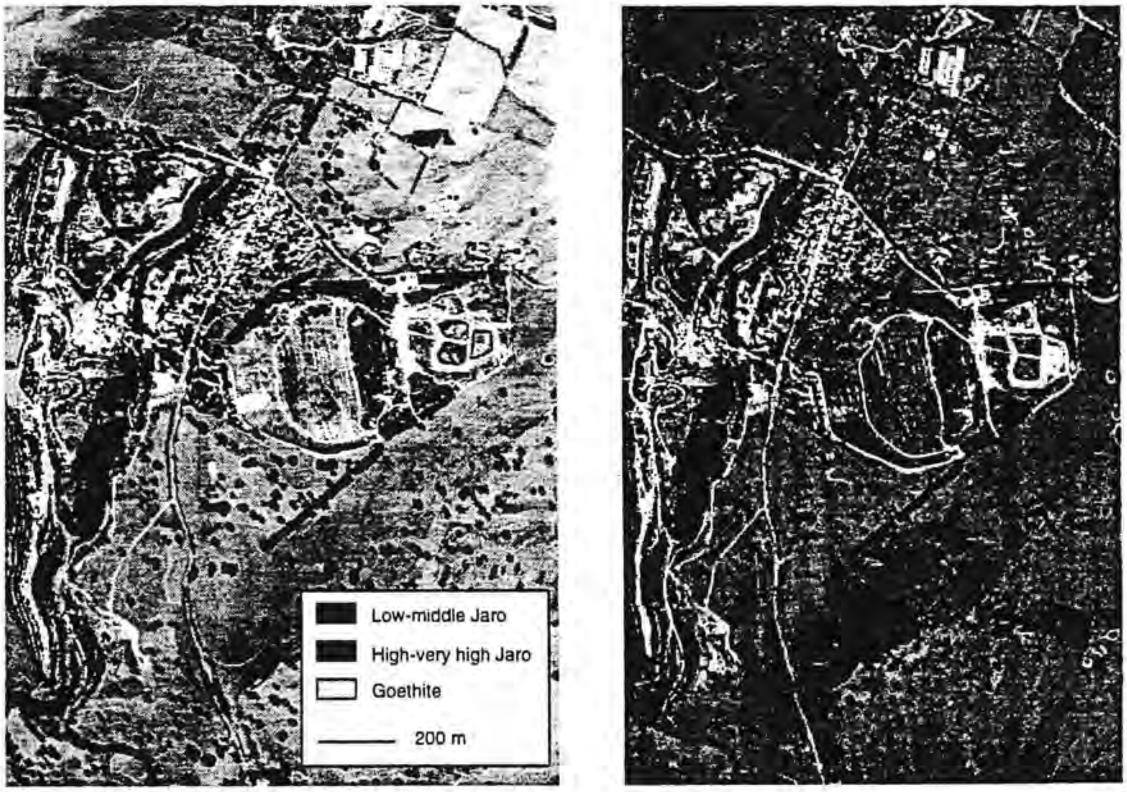

Fig.5: Mineral abundance maps showing the distribution of jarosite and goethite at Brukunga (left= 1998, right= 1999)

5. Conclusion

Spectral maps of secondary minerals related to AMD-processes at the Brukunga pyrite mine in South Australia were generated using spectral unmixing approaches. The maps were derived from remotely sensed hyperspectral HyMap data acquired in 1998 and 1999. The results show that jarosite, goethite, gypsum and kaolinite occur mainly within the minesite. No significant distribution of goethite and jarosite was identified outside the mining area. A comparison of the 1998 and 1999 data indicates some mineralogical changes at the waste rock dumps associated with jarosite abundances, and variations of gypsum and kaolinite, mainly at the acid holding ponds.

As shown recently, specific geochemical environments favour the formation of secondary minerals. Boudreau (1990), Bingham et al. (1996) and Schwertmann & Fitzpatrick (1992) describe the interactions between acidic SO_4 systems and the minerals' dissolution and precipitation. They have demonstrated that e.g. jarosite is mainly formed at relatively low pH values (below pH 3) whereas schwertmannite and goethite occur between pH 3-5 and above 5. On the other hand, there is a close relation between pH and the metal mobility. With a decrease of the pH, metals like zinc, copper, iron, manganese etc. become more soluble (Fairbridge & Finkl, 1979).

Minerals maps generated from HyMap airborne scanner data therefore could provided a fast and reliable method of screening AMD-related processes and acid-generating sources at the abandoned Brukunga pyrite mine. Mineralogical parameters, which are likely to be correlated to acidity and metal mobility, were derived remotely. This information should be regarded in context with other quantitative mineralogical mapping techniques (Reinhaeckel & Krueger, 1998). The combination of these techniques has great potential to assess the dimension of AMD and to monitor recultivation activities at small scale.

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PART III – APPENDICES

APPENDIX ONE

Conference Delegate List

The Second AMEEF Innovation Conference

"On the Threshold: Research into Practice"

4^{th} – 5^{th} August 1999
Esplanade Hotel,
Fremantle WA

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Name	Name
Jane **Aberdeen** Executive Officer, Environment Affairs The Chamber of Minerals and Energy WA	Mary **Fletcher** Environmental Coordinator Normandy Limited
Alex **Armstrong** Consulting Research Manager Australian Centre for Mining Environmental Research	John E. D. **Fox** Associate Professor Curtain University
David **Bowen** Research Officer Centre for Mined Land Rehabilitation	Peter **French** Rehabilitation Research Officer Iluka Resources Limited
Dennis **Brooks** Director AMEEF	Kate **George** Environmental Science Graduate Murdoch University
Paul **Brown** Principal Research Scientist ANSTO	Robert J. **Gilkes** Professor The University of Western Australia
Rob **Brown** Senior Environmental Officer Cable Sands WA P/L	Laurence **Guilfoyle** Environmental Chemist IT Environmental
Norm **Caporn** Executive Officer Department of Conservation and Land Management	Vanessa **Guthrie** Environmental Manager – Corporate Affairs WMC Limited
Nick **Caswell** Environmental Technician Iluka Resources Limited	Darren **Herpich** Senior Environmental Officer Iluka Resources Limited
Felicity **Clarke** Environmental Scientist TJ Waters EMC	Peter **Hick** Principal Research Scientist Minesite Rehabilitation Research Program, CSIRO
Phillip **Davidson** Group Environmental Coordinator Straits Resources Limited	Ian **Hopton** Environmental Adviser Primary Industry & Resources SA
Peter **Davies** Land Manager Lynas Gold NL	Martin **Houchin** Program Manager Base & Precious Metal Hydrometallurgy, CSIRO Minera
Maree **Emett** Chemist ANSTO	David **Jasper** Director Centre for Land Rehabilitation, UWA
Kenneth G **Evans** Senior Research Scientist ERISS – Environment Australia	Jacob **John** Associate Professor Curtain University
Don **Ferguson** Rehabilitation Coordinator Iluka Resources Limited	Rochelle **Jones** Environmental Officer Iluka Resources Limited

The Second AMEEF Innovation Conference

"On the Threshold: Research into Practice"

4[th] – 5[th] August 1999
Esplanade Hotel,
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Name

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Harley **Lacy**
Director
Outback Ecology

Grant **Lamb**
Acting Regional Operations Officer – Mining
Department of Conservation and Land Management

Karen **Lee**
Soil Scientist
Outback Ecology

Brett **Loney**
Environment and Community Relations Manager
Aurora Gold Ltd

Des **Lord**
Director
D. A. Lord & Associates P/L

Rachel **Lovegrove**
Environmental Officer
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