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An Assessment of the Direct Revegetation Strategy on the Tailings Storage Facility at Kidston Gold Mine, North Queensland, Australia

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1 INTRODUCTION

A closure objective of Kidston Gold Mines Limited was to return a self-sustaining savannah woodland vegetation of native trees and introduced and native ground cover species to areas disturbed by its Kidston mining operation. One of the major areas of disturbance was the 310 ha tailings storage facility (TSF) into which approximately 68 Mt of tailings were deposited between 1985 and 1996. Early revegetation trials conducted in the early-mid 1990s demonstrated the capacity of the tailings to support vegetation growth without the requirement for a capping layer of soil or other cover material. The tailings storage facility was decommissioned at the end of 1997 and as the accessible area on the surface of the facility became progressively available (from March 1998 through to December 2001), planting and seeding of over 50 native tree and shrub species and 8 introduced and native pasture species was undertaken. With the support of drip irrigation over the first few months and initial fertilisation, the alkaline tailings have proven to successfully support the establishment and growth of a range of native tree and shrub species. Greatest success with upper-and mid-storey species has been where competition from introduced grasses has been minimised.

Since 2001, up to four areas of different aged rehabilitation across the surface of the TSF have been monitored on an annual or biennial basis by The University of Queensland's Centre for Mined Land Rehabilitation (CMLR). The overall aim of the Kidston monitoring program has been to assess the progressive development, functioning and composition of the rehabilitation areas prior to relinquishment by the company. This paper presents some background on rehabilitation works and research trials undertaken on the tailings and reports on the most recent findings from the vegetation monitoring that has been conducted on the four TSF sites (TD40, TDNA, TDNB and CTD) in the period 2001 to 2005. The 2005 findings are presented in relation to two unmined analogue communities and preliminary rehabilitation targets. Monitoring against these interim targets has proven to be a valuable process for tracking the structural and functional development of these vegetation communities. In addition, an ongoing assessment of the tailings attributes contributes to our understanding of soil development processes and hence the longer–term sustainability of the reconstructed ecosystem as the company aims towards lease relinquishment.

2 BACKGROUND

2.1 Site Description

Kidston gold mine (latitude 18°53’S, longitude 144°09’E) is located 260 km south-west of Cairns in north Queensland, Australia. The general climate is characterised by pronounced wet and dry seasons. On average over 80% of annual rainfall (719 mm) falls between November and April, comprising high intensity storms and monsoonal events. Mean daily temperatures vary between 12°C and 37°C with average minimum and maximum temperatures of 18.3°C and 32.8°C, respectively.

The mine lies within the Copperfield River catchment and the surrounding area is part of the Einasleigh-Copperfield plain. The area is characterised by a topography of low hilly to broadly undulating form, punctuated by several knolls. The soils are of the catenary sequence and comprise red and yellow podzolics (Gutteridge *et al*., 1982). The parent rock is composed of micaceous metamorphics with a profile (0–5 cm) of reddish brown fine sandy loam with quartz grading at depth (5–10 cm) to fine sandy clay loam with higher proportions of quartz.

The vegetation communities of the region range from low open woodland to open woodland (Neldner, 1993), largely uncleared but altered substantially since European settlement by the presence of domestic stock and an altered fire regime (Grundy and Bryde, 1989). The dominant tree genus is invariably *Eucalyptus* with *Corymbia* a common co-dominant. *Eucalyptus microneura* is the most common tree species at the western end of the uplands with *E. crebra* a co-dominant species (Perry and Lazarides, 1964) on undulating irregular low relief. The sparse shrub layer is dominated by *Carissa ovata* and less commonly by *Dodonaea* spp. Other less common eucalypt species may be present, including *Corymbia erythrophloia*, *C. dallachiana* and *Eucalyptus shirleyi* in semi-arid habitats on shallow rocky soils. Native grasses comprise perennial drought tolerant tussock grasses (*Heteropogon contortus*, *Themeda triandra*, *Bothriochloa* spp., *Dichanthium sericeum* and several *Aristida* spp.). Forbs are less common than grasses and include legumes (*Indigofera*, *Cajanus* and *Tephrosia* species) and non-legumes (*Gomphrena* and *Evolvulus* species).

The analogue sites referred to in this paper are: "Airstrip", which consists of *Eucalyptus microneura* and *E. crebra* low open woodland adjacent to the mine; and "Copperfield" which is a low open woodland dominated by *E. shirleyi* and *Lophostemon grandiflorus*, 20 km south of the mine on the road to Copperfield Dam.

2.2 Previous and Concurrent Tailings Trials

In 1992, an area of approximately 11 ha at the southern end of the TSF (Figure 1), where tailings were deposited between 1985 and 1988, was partitioned from the then active facility by the erection of a berm wall. In 1994, this area was planted with almost 1800 tubestock of 21 native tree and shrub species and after six years, the *Melaleuca, Casuarina* and *Callistemon* species were shown to be the most successful genera, with *Acacia* and *Eucalyptus/Corymbia* also performing well (Roseby *et al*., 1998). Due to the periodic inundation of large areas of the trial site, those species that were adapted to flood plains or riparian zones, such as *Casuarina cunninghamiana, Melaleuca leucadendra* and *Eucalyptus camaldulensis*, displayed the greatest success in more waterlogged areas. Recruitment as second generation emergents from seed of the planted species was also beginning to occur for a number of species such as *Casuarina glauca*, *Acacia holosericea* and *Melaleuca leucadendra*.

Although the early studies had demonstrated that the use of tubestock was likely to be a successful means of initially establishing middle and upperstorey components of the vegetation community on the main TSF upon decommissioning, it was recognised that there was still a need to ensure that there could be successful establishment of the key species from seed. In March 1998, broadcast seeding trials of native species on tailings were instigated and proven to be successful, indicating that it was possible to establish woody species, particularly local *Corymbia* species, from seed.

Numerous other research trials and monitoring campaigns have been conducted over the years to build confidence in the robustness of the strategy to directly revegetate the tailings. These include establishment and growth trials with a range of local native grass species, studies on the water use of different tree species (Sanidad *et al*., 2000), understanding the erosion and infiltration characteristics across the breadth of the tailings surface where physical attributes can vary, and challenging the vegetated landscape with a potential end land use which could involve the presence of cattle. This latter study was required not only to assess the impacts of hoofed animals on surface condition and ground cover, but also from the perspective of the potential for uptake of heavy metals into the cattle through either the vegetation pathway and/or direct ingestion of the tailings (Bruce et al., 2001).

Figure 1 **Aerial view of the Kidston gold mine in September 2005 showing sites monitored on the tailings storage facility and location of the Airstrip analogue site. The Copperfield analogue site is located approximately 20km to the south of the mine, en route to Copperfield Dam**

3 METHODOLOGY

3.1 Planting and Seeding

Building on the knowledge base from the preliminary species trials, the facility was progressively planted and seeded over the period from 1998 to 2001. The revegetation process began on the main TSF with the laying of irrigation tubing to supply water for the seedlings. The initial planting in March 1998 covered an area of approximately 46 ha at the south-western end (known as area TD40). This was later expanded from December 1999 to May 2000 to another 56 ha site on the north-western side of the TSF (TDNA) and an area at the eastern edge (TDNB), with planting occurring from February to July 2001. Finally, due to eventual accessibility to the central tailings area (CTD), an area of 65.5 ha was seeded and planted in December 2001.

For most of the sites, tubestock were planted directly into irrigated tailings material at a density of one plant to every 50 m^2. Tubestock of native tree and shrub species were planted out when 4 months old and each seedling was fertilised with 20 g of Tropical Osmocote. The trickle irrigation system was supplied by water from the Copperfield Dam freshwater pipeline and after 3 to 4 months, the rate and frequency of irrigation was reduced. The species used during the planting campaigns varied over the years and with location. Species from the *Melaleuca* and *Casuarina* genera and other species tolerant of moist conditions were planted in the wet areas of the TSF where finer grained tailings such as slimes predominated. In the drier, sandier areas closer to the edge of the facility, the *Eucalyptus*, *Corymbia*, *Acacia*, *Callistemon* and *Grevillea* species were dominant. Some species such as *Acacia auriculiformis*, *Callistemon viminalis* and *Eucalyptus camaldulensis* were able to be planted in both the wet and dry areas of the TSF. A total of at least 50 tree and shrub species and 8 native and improved pasture species were used at some time during the TSF revegetation program (Table 1).

Table 1 Tree and grass species used on the tailings storage facility. Species are compiled from lists of tubestock and seed received from suppliers

Native tree and shrub species		
Acacia ampliceps	*Eucalyptus clarksoniana*	*Hakea persiehana*
Acacia aulacocarpa	*Eucalyptus cloeziana*	*Hakea plurinervia*
Acacia auriculiformis	*Eucalyptus crebra*	*Melaleuca alternifolia*
Acacia crassicarpa	*Eucalyptus dallachiana*	*Melaleuca argentea*
Acacia holosericea	*Eucalyptus dichromophloia*	*Melaleuca citrolens*
Acacia leptoloba	*Eucalyptus drepanophylla*	*Melaleuca leucadendra*
Acacia mangium	*Eucalyptus miniata*	*Melaleuca linariifolia*
Acacia melanoxylon	*Eucalyptus moluccana*	*Melaleuca quinquenervia*
Acacia rhodoxylon	*Eucalyptus nesophila*	*Melaleuca* sp. Oak Creek
Acacia salicina	*Eucalyptus pachycalyx*	*Melaleuca* spp. mixed
Acacia saligna	*Eucalyptus peltata*	
Allocasuarina inophloia	*Eucalyptus phoenicea*	
Callistemon pachyphyllus	*Eucalyptus robusta*	**Native and exotic pasture species**
Callistemon spp. mixed	*Eucalyptus setosa*	
Callistemon viminalis	*Eucalyptus shirleyi*	*Chloris gayana*
Casuarina cunninghamiana	*Eucalyptus staigeriana*	*Cynodon dactylon*
Casuarina equisetifolia	*Eucalyptus tereticornis*	*Dichanthium sericeum*
Casuarina glauca	*Eucalyptus* spp. mixed	*Echinochloa crus-galli*
Casuarina obesa	*Grevillea glauca*	*Heteropogon contortus*
Corymbia citriodora	*Grevillea parallela*	*Melinis repens*
Eucalyptus acmenoides	*Grevillea pteridifolia*	*Stylosanthes scabra*
Eucalyptus camaldulensis	*Grevillea* spp. mixed	*Urochloa mosambicensis*

At the northern end of the TSF where dust generation was problematic, introduced pasture grasses and legumes were seeded across a 120 ha area as a necessary control measure in December 1998. The seeding rates for each of the pasture species ranged from 10-15 kg per hectare and fertiliser was applied at 200 kg of Di-ammonium Phosphate (DAP) per hectare. These application rates resulted in a healthy, even coverage that minimised the wind-borne mobilisation of dry surface tailings but subsequently impacted on the early growth rates and survival of seedlings which were later planted in those areas. As a part of the ongoing refinement of the revegetation strategy, trials using native grasses such as *Dichanthium sericeum* and *Heteropogon contortus* were undertaken with the purpose of both providing a potentially less competitive environment for the trees and shrubs, and also gradually allowing the improved pasture species to be replaced with those that may require less future maintenance from a fertility perspective. Despite this however, the faster establishing pasture grass and legume species were generally used, and in those areas of the TSF where the planted tubestock were allowed to establish first, *Chloris gayana*, *Cynodon dactylon*, and *Stylosanthes scabra* were typically sown in between the rows of trees. An initial application of 200 kg per hectare of Crop King 55 (CK55) NPK fertiliser was applied and in the older areas at least, this was often followed by a further application (380 kg per hectare) within the following two years.

On those areas across the TSF that were planted later in the revegetation process, pastures were established using aerial seeding and seed spread using a quad bike, all terrain vehicle (ATV). The use of the ATV became essential to access the swampier, poorly drained sections of the TSF. As these areas took considerable time to dry out, it was also possible to direct plant tubestock without the use of irrigation.

3.2 Monitoring

A manual for monitoring the rehabilitation at Kidston was developed by Bowen (2001). It was proposed that a number of parameters be monitored, including measures of plant species composition, cover and density, together with assessments of microbial and invertebrate activities, and plant and soil health. Also included in the procedures was the use of the Landscape Function Analysis (LFA) approach developed to assess aspects of ecosystem functioning (Tongway and Hindley, 1995). The approach had been tested at Kidston at the end of the wet season in early 2000 (Bellairs and Gravina, 2000), and further assessments were conducted during the monitoring campaigns of 2001-2003. Following a study by Tredwell *et al.* (2003) that compared the LFA-derived nutrient cycling index [LFA(N)] with alternative biological and chemical indicators of soil health (soil C pools, soil total N, available P, microbial biomass C and mineralised C) at a number of rehabilitation sites and five nearby unmined reference sites at Kidston, this approach was not continued as a part of the regular program. The LFA procedure was found to be relatively inconsistent in reflecting actual nutrient pools and cycles in both mined and unmined sites, with the number of patches and site heterogeneity directly affecting relationships between the empirical measures and LFA(N), with subjective patch border determinations adding to these inconsistencies.

Each TSF site was divided into three areas of roughly equal size for the placement of a 100m long transect. Three permanently marked transects, orientated down slope, were randomly located at each of the four TSF sites and each analogue site (although only two transects were able to be monitored at the Copperfield site in 2005). Over the course of the period being reported, monitoring comprised two groups of assessments including:

- Vegetation-related measures, termed primary order measurements, covering plant health, growth rate and herbaceous and woody species richness, cover, density and diversity parameters.
- More intensive secondary order measurements including soil chemical analyses, microbial biomass analyses, mycorrhizal assessments and invertebrate surveys.

3.2.1 Primary order measurements

In order to monitor the primary order measurements a measuring tape was extended along each 100m transect. The composition and foliage projective cover (FPC) of groundcover species was recorded for 11, 1 m x 1 m quadrats spaced at 10 m intervals along each transect. Visual assessments were made of the proportions of grass, forb, litter cover or bare ground (including rock). FPC measurements were also made for both ground cover and, where applicable, upper canopy cover, at 1 m intervals along the transect tape.

Total species richness was assessed for 1200 m^2 at each site, comprising 3 x 400 m^2 areas. Weed species present in any of the transect areas were also recorded separately. Species diversity was represented by the calculation of Simpson's Diversity Index which provides an indication of species dominance (with relatively little weight given to rare species and more weight to common species). The index ranges from 0 (an infinite number of non-dominating species) to 1 (only one species present) thus the higher the index is, the higher the dominance by individual species (Krebs, 1985).

For each transect the number of woody tree and shrub species were recorded in 10 m sections in an area of 400 m^2 extending 4 m out to the side of the 100 m tape. Additional herbaceous species present were also recorded in this way. Heights and basal diameters for *Eucalyptus* and *Corymbia* spp. in this 400 m^2 area were also measured.

3.2.2 Secondary order measurements

Some more intensive secondary order measurements have been used to assess more detailed aspects of the functioning of the community. This enables the generation of valuable baseline data on plant nutrition, microsymbionts and invertebrate population levels in the rehabilitation. In the context of this paper, only reference to aspects of substrate chemical attributes that may influence the success of direct revegetation will be presented.

Surface soil samples (0-10 cm) were collected at 10 m intervals along each transect and bulked to provide a single composite sample per transect. Samples were air-dried and sieved to ≤2 mm prior to analysis. Sub-samples were analysed for pH and electrical conductivity on 1:5 soil:deionised water suspensions. Total C and total N were determined by combustion in an automated LECO 2000 CNS analyser. Organic C was also determined this way, following pre-treatment with 5 M HCl to remove soluble carbonates (non-organic carbon). Available P was determined by UV-Vis Spectrophotometer following 0.5 M NaHCO3 (1:10) extraction, and exchangeable cations (Ca, Mg, K and Na) by ICPAES following NH_4Cl extraction. Cation exchange capacity was determined by separate assay. Chloride was analysed by UV- Vis using 1:5 aqueous extracts and SO_4-S was analysed by ICPAES after 0.01 M mono-calcium phosphate extraction.

4 RESULTS

4.1 Vegetation Characteristics

In 2005, the age of the rehabilitation on the main TSF ranged from three to seven years, and up until that time, each of the sites had been monitored on three or four occasions. In parallel, the analogue sites Airstrip and Copperfield, have also been monitored. The 2005 data presented in this paper are mean values of the replicated transects at each site and variability was found to be high for density data across all sites.

Rainfall for the period between the 2004 and 2005 assessments was below the long-term average data for every month except for November 2004 through to January 2005. Rainfall in February and March 2005 was 155 mm and 112 mm below the long term averages for those months, respectively. At both the Airstrip and Copperfield native analogue sites, the drought-affected vegetation characteristics reflected the poor season. Most of the grasses were dry and many of the evergreen trees had sparse foliage. Total live vegetative cover was about 40% at both sites (Table 2), most of which was contributed by native grasses. The surface cover contributed by litter was 15% for both sites, with bare ground contributing 43% and 51% cover at the Airstrip and Copperfield sites, respectively.

Most of the woody stems at the analogue sites were of trees and shrubs other than *Acacia* and *Eucalyptus* spp. although proportions of eucalypts were 14% and 21% for the Airstrip and Copperfield sites, respectively. Over a quarter of the contribution to the 'other' component was from introduced shrubs such as *Stylosanthes scabra* although several other woody genera were recorded at each of these sites including *Carissa lanceolata* and *Petalostigma* spp. at Airstrip and *Melaleuca* and *Terminalia* species at Copperfield. Nearly half of the *Eucalyptus*/*Corymbia* species were found to be in the smallest height class, indicating a large seedling/sapling component at the Airstrip and large component of resprouting at Copperfield. Despite this, all tree height classes were represented at the Airstrip and all but trees >10m were recorded at Copperfield.

Table 2 Vegetation characteristics for Airstrip and Copperfield sites in 2005

Native species richness	**Airstrip**	**Copperfield**
Number of trees/shrubs	14	16
Number of tree/shrub genera	11	12
Number of *Eucalyptus*/*Corymbia spp.*	4	2
Simpson's diversity index	0.14	0.18
Woody species density (no./ha)		
Eucalyptus/*Corymbia*	158	237
Acacia	0	75
Other (native & introduced)	908	813
Total	1067	1125
Ground cover (%)		
Vegetation (native & introduced)	42%	36%
Litter	15%	13%
Bare	43%	51%

The monitoring manual of Bowen (2001) presents a set of interim targets for various plant and soil parameters which were developed based on averages from a number of unmined communities in the surrounding local and regional landscapes. These values were developed for the TSF in addition to the tops of the waste rock dumps where oxide material was the surface substrate for supporting the establishment and growth of the vegetation (Williams *et al*., 2006). The generation of such targets is useful as a means of assessing "success" and community progression and stability but it is recognised that it is an iterative process, and these 'targets' are currently being reassessed in light of the validation that has occurred as a result of the monitoring over time.

A summary of some of the primary measurements for each TSF site, and comparisons against the interim targets are presented in Tables 3-6. The oldest site, TD40 (Table 3), was dominated by *Chloris gayana* with a denser understorey than other areas (though still patchy), up to 1.5 m high. Tree species were mainly acacias and eucalypts but *Callistemon*, *Melaleuca* and *Casuarina* species were also present. Some of the older acacias were dying and there were areas of high litter accumulation.

Table 3 Vegetation characteristics for TD40 in 2005, 7 years after establishment

Native species richness	**Value**	**Target**	**Target met?**
Trees and shrubs	10	10	yes
Tree and shrub genera	6	7	no
Eucalyptus/*Corymbia*	3	3	yes
Simpson's diversity index	0.60	0.15	no
Woody species density	**No. per ha**	**Target**	**Target met?**
Eucalyptus/*Corymbia*	67	>15% of total	no
Acacia	1633	<30% of total	no
Other (native & introduced)	425	>30% of total	no
Total	2125		
Ground cover	**%**	**Target**	**Target met?**
Vegetation (native & introduced)	34	>30%	yes
Litter	34	>15%	yes
Bare	32	<30%	no

Pasture cover at TDNA (Table 4) was also dominated by *Chloris gayana* but *Urochloa mosambicensis*, *Cynodon dactylon*, *Heteropogon contortus* and *Cenchrus ciliaris* were also present. The densities of woody species in this area were less and were mainly acacias, eucalypts and casuarinas. Surface crusting and salt accumulations were noted in patches. TDNB (Table 5) was *Chloris gayana* dominated as well but there was also considerable *Stylosanthes scabra* present. Trees were sparse and the grass was generally patchy with areas of bare sand.

Table 4 Vegetation characteristics for TDNA in 2005, 5 years after establishment

Native species richness	**Value**	**Target**	**Target met?**
Trees and shrubs	10	10	yes
Tree and shrub genera	5	7	no
Eucalyptus/*Corymbia*	3	3	yes
Simpson's diversity index	0.39	0.15	no
Woody species density	**No. per ha**	**Target**	**Target met?**
Eucalyptus/*Corymbia*	25	>15% of total	no
Acacia	92	<30% of total	yes
Other (native & introduced)	458	>30% of total	yes
Total	575		
Ground cover	**%**	**Target**	**Target met?**
Vegetation (native & introduced)	35	>30%	yes
Litter	20	>15%	yes
Bare	45	<30%	no

Table 5 Vegetation characteristics for TDNB in 2005, 4 years after establishment

Native species richness	**Value**	**Target**	**Target met?**
Trees and shrubs	8	10	no
Tree and shrub genera	5	7	no
Eucalyptus/*Corymbia*	2	3	no
Simpson's diversity index	0.37	0.15	no
Woody species density	**No. per ha**	**Target**	**Target met?**
Eucalyptus/*Corymbia*	67	>15% of total	no
Acacia	42	<30% of total	yes
Other (native & introduced)	3333	>30% of total	yes
Total	3442		
Ground cover	**%**	**Target**	**Target met?**
Vegetation (native & introduced)	29	>30%	no
Litter	13	>15%	no
Bare	58	<30%	no

The CTD had couch in patches but remaining areas were dominated by dense *Chloris gayana*. Tree and shrub layers consisted mostly of mixed acacias but also *Casuarina*, *Melaleuca* and *Callistemon* species. Trees were no greater than 3 m tall in this youngest site, and there were few eucalypts (Table 6). Ground cover was generally good but there were particular sections devoid of vegetation where salt crusting occurred.

At the time of the 2005 assessment, the TSF was generally a pasture-dominated landscape with scattered trees, mainly acacias and eucalypts. However, as a reflection of the varying ages and planting/ seeding mixes and techniques, there remained considerable structural and compositional differences in the vegetation assemblages across the 310 ha.

Overall, the live vegetation component of cover was close to or greater than the interim target set for the rehabilitation (although patchy at TDNA and TDNB in particular), the majority being contributed by introduced grasses. This contrasted with the situation occurring in the analogue sites where native grass species dominated. The litter target coverage was also reached, or at least close, for all rehabilitation sites across the tailings. The bare ground component for TDNB and TDNA was higher than the target percentage, although in this season, the analogue sites also displayed a high proportion of bare surface.

In terms of woody plant densities, TDNA and TDNB were well below the target for both acacias and eucalypts, with tall shrubs and trees generally found to be sparse at these sites. Eucalypts were also scarce at CTD. Most of the individuals found at TDNA and TDNB fell in the smallest height class which could either indicate recruitment or stunted growth. TD40 showed more structural development with most eucalypts occurring in the 5-10 m height range and with over 30% higher than 10 m.

Table 6 Vegetation characteristics for CTD in 2005, 3 years after establishment

Native species richness	**Value**	**Target**	**Target met?**
Trees and shrubs	9	10	no
Tree and shrub genera	4	7	no
Eucalyptus/*Corymbia*	1	3	no
Simpson's diversity index	0.19	0.15	no
Woody species density	**No. per ha**	**Target**	**Target met?**
Eucalyptus/*Corymbia*	8	>15% of total	no
Acacia	100	<30% of total	no
Other (native & introduced)	58	>30% of total	yes
Total	166		
Ground cover	**%**	**Target**	**Target met?**
Vegetation (native & introduced)	68	>30%	yes
Litter	18	>15%	yes
Bare	14	<30%	yes

4.2 Soil Characteristics

The average pH of the surface 10 cm of tailings in each of the four tailings areas is alkaline (Table 7). The pH range determined from the 2004 TSF sample was between 7.8 and 8.2 thus has not changed over time. The background soils at the analogue sites were near neutral and non-saline. The $EC_{1:5}$ values showed the TD40 and TDNB sites to be of medium salinity, TDNA was high and CTD was very high. However, it is worth noting that there had been an overall reduction in salinity over the previous year, with EC at CTD reduced from approximately 5 dS/m in 2004.

Soil organic carbon levels were very low at all tailings sites, including the Copperfield analogue, with the Airstrip site somewhat higher, but still low. Total N was low to very low (the exception being the Airstrip site) and the carbon/nitrogen ratio, which provides an indication of the likely source and state of decomposition of soil organic mater and its potential contribution to plant-available soil nutrients, was also very low. Available P was generally not much lower than exists in the surrounding unmined landscapes, and was maintaining moderate levels in the older TD40 area.

With the exception of Ca and Mg, concentrations of exchangeable cations were very low to moderate across the tailings but not dissimilar to the background levels in the analogue sites. The elevated Ca at TDNA and CTD, and Mg at CTD is likely to be residual from the lime dosing that occurred in the process plant during operation. As was the case on previous sampling occasions, chloride concentrations were higher in the CTD area than elsewhere, and sulphate levels at this site were again very high.

Table 7 Surface soil chemical properties at the TSF and analogue sites in 2005

Site	pH	EC	Org.C	Tot.N	Avail.P	SO4	Cl	K	Mg	Ca	Na	CEC
		dS/m	%wt		mg/kg			cmol(+)/kg				
TD40	8.1	0.56	0.36	0.04	18.4	180	153	0.26	0.38	7.16	0.09	2.07
TDNA	8.2	1.00	0.14	0.02	5.3	480	209	0.38	0.88	12.14	1.67	1.94
TDNB	8.3	0.34	0.08	0.01	6.0	215	158	0.21	0.28	4.52	0.07	1.61
CTD	8.0	4.00	0.34	0.04	5.6	4050	747	2.34	13.48	41.17	13.95	4.12
Airstrip	6.9	0.05	1.07	0.14	8.3	15	48	0.50	1.10	2.90	0.10	2.80
Copper	6.8	0.01	0.49	0.07	5.0	5	22	0.26	0.49	1.59	0.04	2.19

5 SUMMARY

This paper reports some of the history and more recent monitoring outcomes from the tailings research program at Kidston. Building on earlier trials testing the possibilities of directly revegetating the tailings without the need for a surface cover, over 300 ha of Kidston gold mine tailings was successfully revegetated over the period 1998 through to 2001.

The long-term monitoring program of the TSF was initiated to determine whether the established vegetation communities are developing in a positive direction. Current monitoring results show that some of the interim targets have been met at most TSF sites. While species composition and density results do not directly reflect a native and self-sustaining community, this is mainly a result of the original seeding and planting regime undertaken on the tailings dam. To ensure rapid soil stability, exotic, fast growing and more drought/saline tolerant species are often used. The higher proportions of introduced grasses and pasture legumes in the rehabilitation sites is a result of this, however native grass, forb, tree and shrub species are continually being recorded on the TSF indicating that progression towards a more native community is occurring. Besides the interest in returning areas of post-mined land at Kidston into self-sustaining native communities, there is also scope for the inclusion of cattle grazing in some areas. In this instance, higher proportions of pasture species are appropriate.

These recent findings, in addition to data collected over a five year period, have lead to a need for a more intensive study of the TSF. To identify more problematic areas, a comprehensive soil sampling campaign was undertaken in 2006. Data will be compared against associated vegetation data to identify whether appropriate practical management strategies are required to ensure the area is moving towards a self-sustaining system. The generation and effective management and modelling of long-term data such as has been acquired through this project is an invaluable tool for determining management requirements, further defining success criteria, fine-tuning indicators of those criteria and building a defensible case with regulators to allow a suitable time-frame for eventual relinquishment of the site.

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