REHABILITATION PLAN FOR PROPOSED DIVERSION CHANNELS – McARTHUR RIVER MINE OPEN CUT PROJECT

Assessment for: URS Corporation

Prepared by:
Global Soil Systems

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Prepared By:

M. Burns
Principal
Global Soil Systems

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Rehabilitation Plan for Diversion Channels
McArthur River Mine Open Cut Project

1.0 BACKGROUND

As part of the proposed McArthur River Mine Open Cut Project it is proposed to realign the McArthur River, Barney Creek and Surprise Creeks around the proposed pit and flood bund. This realignment will create an altered riverine environment which will require effective, long-term and sustainable revegetation, consistent with existing vegetation communities along these creeks.

A range of revegetation studies and reports (Appendix K of EIS, and various other submissions and reports by Marj King), have been prepared. These reports provide useful information, some of which has been included in the following Plan. This report compliments Appendix K and should be read in conjunction with same. An additional supporting document (The Keys to Sustainable Ecosystem Establishment on Mine Sites, prepared by Mark Burns) has also been added as an Appendix to this report to provide further general information.

2.0 CRITICAL ISSUES AND MAJOR IMPEDIMENTS TO SUCCESSFUL REVEGETATION

High velocity flows during the wet season can dislodge young establishing plants with inadequate root systems. Similarly, if plants are unable to establish deep root systems that can access deep soil water during the dry season, they will die. Quickly establishing deep healthy root systems for both artificial and naturally established native plants will be critical to the ecological success of this project. Conditions must be created, across the range of likely ground scenarios, for this to occur. This need must drive the ecological design of the channels. What are these scenarios?

It is understood that approximately ⅔ of the diverted channels will be cut into hard rock. The balance will be cut into softer fluvial soil. Site preparation requirements, as a prerequisite for vegetation establishment, will be different for each scenario.

For the section of the channel excavated into rock, there is a high risk that shallow rooted plants will be ripped out during high flows or die during the dry season….both due to inadequate root depth which provides anchoring and access to soil moisture. Observations of sections of the existing creek and river clearly show that trees will grow and survive in fractured rock – provided they can get their roots down into fines. This observation provides a key and useful guide to future site preparation along the rocky sections of the channels. (See Section 3.2). In rehabilitation, provided there is a reasonable component of fines, 'rough is good', is a wise maxim. Consequently, the infilling of fractured rock voids with clean topsoil is a key recommendation of this report.

The remaining ⅓ of the diversion channels will be cut into softer fluvial material. This provides a different set of challenges to vegetation establishment. In particular, the instability of created batter slopes can result in young plants being scoured out. Even though soft when wet, batter slopes can also be compacted during construction thus restricting initial root establishment. As for the rock batter scenarios, rapid and deep root development must be encouraged. In addition, it is understood that geotextile will be placed over dispersive soil material before capping with fractured rock. Plant roots cannot grow through most geotextiles. Consequently, restricted root growth will probably result in plants dying from drought during the dry season. To overcome this problem adequate soil depth must be created by adding rock cover to at least 1m depth and infilling with weed free, non-dispersive soil. (Same as for the above rock channel). This depth of rock can be reduced where there is non-dispersive soil and no consequent underlying geotextile.

Other possible impediments to vegetation establishment are weeds. Weeds can quickly out-compete slower establishing native species. Strict weed control, particularly in the stripping, stockpiling and respreading of topsoil will be critical. Basic machinery hygiene must also be maintained.

Grazing animals may also damage newly revegetated areas and these must be excluded (by fencing if necessary).

3.0 PROPOED STRATEGY

3.1 Site Clearing – Topsoil and Vegetation Recovery

Felled Timber

Felled timber represents a valuable resource which should be felled, stored as close as possible to the excavated channel, and then respread over the created rock batters. The correct placement and anchoring of this timber will be important; otherwise it is at risking of washing away. Previous studies have shown that large diameter timber (greater than 30cm diameter) is optimal when placed higher up the batters, while finer branches are best placed partially extending into the floor of the channel where they can trap sediment, baffle high velocity flows and create habitat. Hence, placing a component of the timber debris with the tree heads intruding into the channel is recommended.

Timber must also be placed to ensure the best possible chance of retention during high flow events. The creation of coarse rocky batter slopes l(see Section 3.2.1) will greatly assist anchoring of timber. However, further artificial anchoring may need to be examined and experimented with at the beginning of the project. Attention to detail will be important if the channels are to be satisfactorily rehabilitated.

Topsoil

There are many issues associated with the correct stripping, stockpiling and respreading of topsoil. Separation of dispersive and non-dispersive soil material is one. Minimization of handling and consequent soil structural degradation is another. However, weed management is the key issue which can make or break revegetation success. As such, the weed content of soil along the channel easement must be assessed and managed. Soil from forest areas with likely low weed content needs to be separated from highly weed contaminated material. Only relatively weed free material must be used when infilling amongst rocks on the batter slopes. This may necessitate a number of activities including scalping off the thin weed infested top layer of soil prior to stripping soils. At a later date, carefully scalping off the weed infested top 5 to 10 cm of topsoil dumps prior to re-use may remove up to 95% of weed propagules. In this vein immediate sowing of topsoil dumps immediately after emplacement with a dense sterile cover crop such as millet, will help control initial weed competition, and limit erosion of the topsoil dumps.

There are other day to day topsoil issues which will need to be considered. In summary, the approach to topsoil must not be a 'one size fits all' but a strategic approach to quality and the weed potential within the soil. Without this recognition ,revegetation will be much more difficult.

3.2 Preparation of Slopes

3.2.1 *Channel Construction*

Rocky Section

As previously mentioned suitable soil depth and anchorage must be provided for vegetation to successfully establish.

In the rock sections of the channel it is recommended that initial blasting of the channel be extended to at least 1.5 to 2m below the final depth of the batter slopes. The objective is to create a fractured rocky scree slope with rocks ranging from 200mm to 1000mm diameter. Other considerations will apply in the channel but some fracturing of the channel floor to a shallower depth (say 0.5m) would appear to be appropriate for trapping sediment. Such fracturing of the floor will also create loose rock material which can be pushed up into velocity reducing berms and, in the process, create shallow ponds. Many objectives can be achieved if sufficient attention to detail and supervision is applied at blasting. Some initial experimentation with blasting patterns etc. may be necessary to ensure the best possible outcome. With experienced blasting personnel , it should not be too difficult.

A similar approach will be used to prepare slopes along the softer fluvial section. Rock of appropriate diameter will be placed to at least 0.5m depth on non-dispersive soil. Where the channel cuts through dispersive soil, geotextile will be placed under the rock layer which should be 1m deep on these sections. Correct laying and keying-in of the geotextile will be essential to ensure that the rock embankment is not undercut in high flows (from above and below) and becomes a by-passed "monument'.

3.2.2 *Topsoil Infilling of Rock Batter Slopes*

Following the creation of the rough rocky batters for both types of channel, it is proposed to return suitable, weed free topsoil and spread it over the batters, ensuring it is well worked into the cracks and crevices as much as possible. For this reason, top soil stockpiles need to be close by, weed free and not contain dispersive material. The actual depth of topsoil to be spread will depend on how well it can be worked into the rocky matrix. However, the maximum amount of topsoil should be spread. Rapid settlement is likely to occur following the first rain. The created patches of soil need to be sufficient for tubestock to be planted into. The entire area will also be directly sown with native species immediately after soil emplacement.

Further silting up of the rocky slopes (particularly lower down) is expected from natural sedimentation due to flow velocity reduction at the rocky interface and emplaced timber debris. For the same reason the rough, partially filled rocky batters should also assist trapping and establishment of a range of natural river borne seed such as Barringtonia. Consequently, the natural return of native plant species should be greatly assisted by the coarse textured slopes.

3.2.3 *Replacement of Felled Timber Debris*

Following topsoil respreading felled timber will be respread across the slope and anchored (if considered necessary) as previously discussed. This timber material will further assist sediment trapping, habitat creation and provide shade for aquatic and other fauna. It will also restrict access by grazing animals which have the potential to damage young plants. As mentioned, the results of field observations and past studies should be employed to maximum advantage when strategically replacing timber.

3.3 Revegetation

3.3.1 *Species*

Local species suitable for use in the revegetation program have been identified in other studies. These species can be divided into riparian and the higher riverine species. Marj King has provided the following appropriate species list and comments.

Riparian Species

The following species should be included. These will either be planted as tubestock or direct seeded (or both).

- Melaleuca argentea – planted tubestock and direct seeded
- Melaleuca leucadendra – tubestock and direct seeded
- Eucalyptus camaldulensis – tubestock and direct seeded
- Casuarina cunninghamii – tubestock and direct seeded
- Acacia hemsleyi – tubestock and direct seeded
- Barringtonia actangulata – tubestock
- Nauclea orientalis – tubestock
- Ficus coronulata – tubestock
- Ficus hispida – tubestock
- Pandanus spiralis – direct seeded
- Chrysopogon elongatus – tubestock
- Cyperaceae sp. – tubestock.
- Other locally occurring species may be used after further site investigation

Marj King has provided the following notes on the above.

- Although a number of these species are not present in the channel directly near the mine they do grow in the river both up stream and down stream.

- A key species for this area is Barringtonia actangulata. For this species the intention would be to collect seed from trees that seed early and germinate immediately and propagate these. These would then be of sufficient size to plant late wet.

- Casuarina cunninghamii – this will have to be planted/direct seeded in the wet season of 07/08.

- By planting both seedlings and direct seeding the likely benefits accrue. In this case more is better, at the best it might be necessary to go round and thin out some of the plants.

- Planting should be one at a rate of 1 seedlings per m^2 (see changed recommendation later in report). Usually on mine sites the direct seeding rate is 2.5 kg per hectare, in this case it should be doubled. Germination rates for direct seeding is about 10%.

- Transplanting of larger trees presents a number of logistical problems. The best time to dig up and move is once the early rains have started – this means access with the necessary heavy machinery is not possible given the nature of the soil. If trees are moved before the rains start the transpiration rates are high and the trees will probably die even if they are provided with irrigation.

- By the beginning of the wet season following planting and direct seeding those plants that survive the wet should be about 1m. A ball park figure for growth of trees is 1 metre per year. This is unsubstantiated. The percentage that survive is in the lap of the gods.

Riverine Species

All the species listed would be direct seeded except the two grass species. Chionrachne sp. And Chrysopogon elongatus which would be planted.

- Corymbia bella
- Eucalyptus camaldulensis
- Lophostemon grandis
- Melaleuca leucadendra
- Acacia drepanocarpa
- Hibiscus spp
- Terminalia spp
- Acacia helnsleyi
- Acacia holosericea
- Acacia platycarpa
- Atalaya hemiglauca
- Eucalyptus microtheca

It is proposed that there be a blended interface and overlap of the two groups of plants. The extent of this overlap will be decided when the channel is constructed.

The critical issue at this stage, should the project be given approval to proceed, is the rapid collection of seed and propagation of tubestock to meet the proposed time frames. Marj King has advised that there is currently infrastructure for a small nursery in which plants are being grown for local use. This facility needs to be rapidly upgraded and resourced should approval be received. As such a strategy needs to be quickly developed for both seed collection and tubestock propagation in order to meet expected timeframes. Some additional training of local staff may be necessary in conjunction with this.

Fertilizer Use

It is proposed to place 2 x 21g slow release Agriform fertilizer pills under each planted tubestock. Similarly, it is proposed to apply a N,P, K fertilizer such as Crop King 88 at 100 kg/ha in conjunction with applied seed. The fertilizer will provide the necessary bulking agent for the applied native seed. As applied fertilizer will rapidly stimulate any weeds present, the importance of using weed free topsoil is highlighted.

Maintenance

Revegetated areas (particularly tubestock) may require supplementary watering after establishment. Only clean water should be used. Salt or contaminated water should not be used. A suitable tanker/watering arrangement will need to be dedicated to revegetated areas. This tanker will require an appropriate access track along the edge of the channel. This access should be allowed for in the channel design. While it may sound obvious, correct watering to ensure saturation of the root system is rarely undertaken and correct watering technique for young plants must be ensured.

Maintenance weed control may also be necessary. Only non soil residual herbicides such as Roundup should be used unless otherwise agreed.

The need for careful maintenance fertilizer application will be assessed as vegetation develops. As always there will be a strong need for experienced-based day to day decisions during and after channel construction to ensure the revegetation program is successful.

Vegetation Establishment Above Batter Slopes

In addition to slope revegetation it is also proposed that, where practical vegetation be established along a 20 m wide strip above the batter slopes (as an extension of batter slope vegetation). This will assist the transition of slope vegetation into surrounding undisturbed vegetation. As mentioned, this 20 m wide corridor will also include a 4 m wide easement track at the top of the slope for watering and other maintenance access. This 4 m wide easement will be ripped and sown/planted after 1 to 2 years when surrounding revegetation is safely established.

Direct Seeding Versus Tubestock Planting

Direct seeding of woody native trees and shrubs is widely practiced in tropical Australia and its use is strongly recommended. Assuming a total sowing rate (all species combined) of say 5.5 kg/ha, a lot more seed will need to be collected than is currently available. (35 ha to be revegetated in first stage alone). Consequently, seed collection efforts need to be significantly intensified.

Tubestock planting is much more maintenance intensive than direct seeding but is needed in conjunction with direct seeding, to enhance species diversity across the site (some species don't direct seed well). At this stage an approximate planting density of 1000 tree/ha is proposed but this will vary across the site with more dense plantings closer to the channel proposed.

As a consequence of the rough rocky slope and channel floor significant trapping of water and air borne seed is expected. This process should result in significant numbers of woody trees and other species establishing over time…..particularly on the lower slopes. Assessment of natural recruitment should be included in the monitoring program.

Surface Water Management

Constructed and revegetated batter slopes must be protected from heavy surcharge of run off water from above. A cut-off drain immediately above the slopes with dedicated drop-down structures at regular intervals is strongly recommended. (See Appendix 1 for more comment on this).

Timing

There are many timing issues which need to be considered. The main ones are:

- Collection of appropriate quantity and diversity of seed to meet anticipated needs.
- Construction of a suitable nursery and the early production of at least 35,000 tubestock.
- Direct seeding should be undertaken immediately after soil is spread (or ripped above channel) and before rain and surface crusting occurs.
- Assess what areas will be available for topsoiling/seeding/planting and co-ordination of this with seed/tubestock supply.

- The optimum scheduling of topsoil stripping and respreading on rocky slopes and conversely the optimum scheduling of rock armoring on dispersive soil slopes.

- The co-ordination of all works with the wet season.

<u>Monitoring</u>

Regular monitoring and feed back will be important during revegetation. There is always something to learn and to do better. This can be informal to start with but a formal data collection system to validate results should be set up. Further details can be provided on this if the project gets approved.

<u>Other Issues</u>

There are a range of other issues which will need to be worked through if the project proceeds. However, the above comments highlight the most important initial considerations at this time.

A supporting document titled "The Keys to Sustainable Ecosystem Establishment on Mine Sites" has been attached (Appendix 1). This provides general guidance and expansion of some of the important ecological issues touched on in this report.

Mark Burns
Global Soil Systems
24th May 2006

APPENDIX 1

The Keys to Sustainable Ecosystem Establishment on Mine Sites

THE KEYS TO SUSTAINABLE ECOSYSTEM ESTABLISHMENT ON MINE SITES

Prepared by:
Global Soil Systems

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The Keys to Sustainable Ecosystem Establishment On Mine Sites

Prepared By:

M. Burns
Principal
Global Soil Systems

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THE KEYS TO SUSTAINABLE FOREST ECOSYSTEM ESTABLISHMENT ON MINE SITES

Mark Burns

Global Soil Systems

1.0 ECOSYSTEM RETURN

Rehabilitation of mine spoil has become an important consideration for government bodies, the general public and mining companies. The development of detailed environmental legislation has largely reflected public and, in turn, government concern that mined sites retain at least a pre-mining land capability and that environmental degradation be repaired. On many sites there is an increasing expectation that pre-existing native ecosystems of varying complexity and composition be re-established. Where mining has taken place on land previously used for sheep or cattle grazing there can still be an expectation of a return to a more complex native vegetation system involving native trees, shrubs and ground covers.

Unlike many northern hemisphere countries, Australia has numerous and diverse native woody communities. Many of these have specific soil, topographic, aspect and other site requirements that need to be achieved in order for them to establish and persist. The challenge on all sites where native revegetation is proposed is to create conditions conducive to the establishment of the preferred community and to develop appropriate revegetation techniques that lead to long-term success. The early identification of any potentially limiting factors is critical to success.

At each mine spoil material presents different limitations to plant growth. These limitations may relate to either the physical and/or chemical limitations of spoil material. These may vary considerably within the mine. While plant adaptability and climate responses are generally well documented the suitability of many spoil materials to support growth has generally not been examined. This may necessitate an examination of the suitability and limitations of likely surface materials at each mine. These can then be compared with the requirements of the proposed native plant community.

Despite the diversity of plant communities and indeed the variety of spoil and soil conditions across Australia there is a central core of factors which must be considered. In essence these are a checklist of potentially limiting factors which must be addressed for successful establishment of the preferred native plant community to be achieved.

2.0 DIRECT TREE SEEDING

Many mine sites currently utilize direct seeding techniques to establish plant communities. Direct seeding of native trees and shrubs is now widely used to reafforest coal mines and other disturbed mining sites throughout Australia. In particular, seeding has become the major reafforestation and ecosystem reconstruction technique used in the Hunter Valley coal fields, where up to 50 per cent of reshaped spoil on some mines is now being sown back to trees rather than pasture. This process is having a major positive impact on returning forest to the floor of the Hunter Valley, which had been largely cleared of forest as a result of agricultural clearing over the last 150 years. A similar process is happening on coal mines in the coal fields of central Queensland and on other mine sites throughout Australia. This paper discusses limiting conditions particularly with reference to direct tree seeding.

3.0 IMPORTANT FACTORS THAT NEED TO BE CONSIDERED

Awareness of, and appropriate attention to, a range of factors is necessary to ensure repeated success when establishing native plant communities. Some of these, with particular reference to direct tree seed application, include the following:

- Surface Drainage and Slope Stabilization;
- Limiting Physical and Chemical Soil/Spoil Characteristics;
- Compaction
- Soil Water Availability;
- Weed Competition;
- Species Selection and Seed Pre-Treatment;
- Sowing Rates and Species Proportions;
- Timing;
- Nutrition and Fertilizer;
- Soil Ameliorants; and
- Use of Short Lived Cover Crops.

3.1 Surface Drainage and Slope Stabilization

If revegetated areas are not protected by appropriate erosion and sediment control structures revegetation is likely to be unsatisfactory. Minimization of surface soil movement is critical in direct seeding programs and all revegetation work. Many native eucalypt and shrub species have very small, fine seed. Burial of seed by more than 1 or 2 mm is often sufficient to prevent germination and seedling emergence. Material such as surface rock and remnant organic material, including respread roots and branches, can assist in reducing surface soil movement by armouring the slope and can, in turn, produce superior rainfall infiltration and seed retention.

3.2 Limiting Physical and Chemical Soil Characteristics

Physical and chemical problems cannot be viewed in isolation. Physical problems such as surface crusting may have chemically induced origins e.g. sodicity *(Emmerton 1983)*. Other physical problems can sometimes be ameliorated by chemical treatments such as augmenting nutrient supply *(Fox 1984)*. Conversely, nutrient availability is often related to the physical properties of a soil *(Bachelard 1985*).

Generally, physical changes in spoil have received far less attention than chemical characteristics. With the exception of several limited water-relation studies by the then Soil Conservation Service of N.S.W., *e.g. Elliott (1983)*, there have been few studies on the effects that physical changes may have on plant growth.

3.3 Compaction

Compaction can not only impede root penetration through the soil but also affect plant water availability.

Soil compaction, as measured by bulk density, can be altered considerably during the rehabilitation of mineral workings, being either reduced when the material is deposited by face shovel and dragline or, more usually, increased when heavy box-scrapers and bulldozers are used (*Doubeday 1974, Pederson et al. 1980.)*. The bulk density of dry loam surface soil is about 1.3 g cm^{-3} . Bulk densities below 0.8 g cm^{-3} can lead to excessive drainage and limited water storage because of the high proportion of large pores *(Swain 1983*). Heavy-wheeled box-scrapers can exert a pressure on soil of 2 – 3 kg cm^{-2} *(Downing 1977*), and compactions of the order of 25 per cent on colliery shales have been reported, while 15 per cent was normal *(University of Newcastle-upon-Tyne 1971)*. Shearing of high clay content soils can occur at the blade of the earth-mover. Even tracked vehicles cause disruption of the soil structure due to track slip when turning, uneven weight distribution when loaded, and engine vibration (*Soane et al. 1977*). Bulk densities approaching 2.0 g cm^{-3} have been reported *(Marshall 1983).*

Soil compaction has the effect of reducing the proportion of large pores, and increasing the proportion of small pores due to the rearrangement of soil particles. As a result, the rate of water and gas movement into and through the profile is reduced *(Swain 1983)*, root growth is impaired and rooting depth reduced *(Rimmer 1979)*. Water stored in the soil is held more tightly because of the higher capillary forces present in the narrower pores, and less is thus available to the plants because of the higher resultant wilting point.

3.4 Soil Water Availability

Soil water availability has been identified as the single most important soil parameter affecting plant establishment on mine sites *(Hannan 1979, Kelly 1979, Koch 1980).* A range of factors can affect the amount of water available to tree roots. Some are direct effects and others indirect and several have been mentioned above. Other than through irrigation we cannot change the rainfall we receive but factors such as weed competition, soil water infiltration and soil water holding capacity can be manipulated to advantage. Infiltration is greatly improved by deep ripping and can be affected by slope gradient, rockiness, soil texture, compaction and surface crusting to name a few. The amount of water available to plants can be maximised by simple practices such as deep ripping along the contour thus allowing more water to infiltrate and less to runoff. Smooth sculptured surfaces are not desirable in mine rehabilitation largely because they shed water and do not hold seed and fertiliser as readily as rough surfaces. In rehabilitation (and particularly for tree establishment) "the rougher the better" is a good maxim for successful ecosystem reconstruction. Nature rarely creates smooth surfaces and there are good examples of mine and quarry sites around the world where rough, uneven sites have regenerated successfully over time (often without assistance) due to improved seed trapping, water infiltration and habitat diversity *(Burns 1987).*

3.5 Important Chemical Characteristics of Substrates

On many mines pre-stripped surface soil horizons (topdressing material) have been traditionally respread on reshaped spoil dumps. However, on other mines there are insufficient quantities of good quality topsoil or A horizon material to cover recontoured areas.

The varying quality and often limited availability of suitable topdressing material may necessitate an assessment of lower profile overburden material or other mining waste products for use on the surface as a growing medium.

Surface coal mining projects are generally either dragline or truck and shovel operations. In either case, topsoil is normally stripped and stockpiled if necessary prior to the removal of overburden. At the beginning of an operation, the first overburden removed is usually emplaced adjacent to, but out of the pit. Subsequent workings abut overburden against this emplacement thereby backfilling previously mined areas. This method of mining normally results in the original stratigraphic sequence being inverted and mixed, and large quantities of unweathered, fragmented rock are exposed to the weathering process. This, together with grading and erosion, causes variability in coal mine spoil. The chemical and physical properties of spoils can be highly variable, not only between different spoils, but within individual spoil banks *(Schessler and Droege 1965, Geyer and Rogers 1972, Grandt 1978). Russell (1978)* found the range of nutrient supply and chemical conditions in spoil greater within each of four mines in Central Queensland than between mines. Extremes of chemical conditions may exist only centimetres apart on the spoil surface or within the plant rooting zone *(Riley 1975)*.

On open cut mines in the upper Hunter Valley in New South Wales and in the Bowen Basin in Central Queensland the most common chemical limitations to plant establishment are salinity, sodicity, alkalinity (high pH) and nutrient deficiency. Metalliferous mine spoil can have other problems such as Acid Mine Drainage (AMD), heavy metal toxicity and others.

3.6 Critical Chemical Limits

3.6.1 Salinity

Electrical conductivity indicates the salinity of soil. High levels of solute salts are detrimental to many plant species, and have an adverse effect on soil structure.

High salinity levels have been identified in overburden strata in open cut coal mines in the Hunter Valley (NSW), Bowen Basin (Qld) and at other mines *(Burns 1987).*

Electrical conductivity is measured using a conductivity meter, and standards for interpretation of the results are set out below in Table 1.

Table 1
Standards Use for Interpretation of Results (E.C.)

Electricity Conductivity (mS/cm)	Rating
<1.0	Low salinity hazard
1.0 – 2.0	Moderate hazard
2.0 – 4.0	High hazard
>4.0	Severe salinity hazard

Plants have differing levels of salt tolerance during different stages of growth. Many species are less physiologically susceptible to salt at germination than at later stages of growth.

However, under saline conditions the long term survival of vegetation depends as much on the tolerance of the germinating seed as on the tolerance of the seedlings and adult plants.

The salinity of spoil at the surface is usually a short term problem in humid climates (as exist in the wet tropics) and may disappear after two or three years of leaching. In drier climates the process takes longer and the problem may never disappear. The process can be enhanced by increasing infiltration through spoil. However, the accumulation of leached salts in lower strata has the potential to affect plants whose roots penetrate those strata.

3.6.2 pH

The availability of nutrients, particularly phosphorus is critically dependent on soil pH.

Phosphorus availability is restricted in both acid and alkali soils. If soil pH is suitably adjusted for phosphorus, the other plant nutrients, if present in adequate concentrations will be available in most cases. A pH range of 5.5 to 7 seems to promote the most ready availability of plant nutrients. However, it should be appreciated that rapid adjustment of soil pH is a difficult and expensive operation that is rarely undertaken in alkaline spoil. In acidic material pH can be undertaken using lime or other alkaline amendments.

Standards of interpretation are based on pH measurements in a saturated extract and are shown in Table 2.

Table 2
Standards Used for Interpretation of Results (pH)

Range	Rating	Comments
>8.5	Very High	Alkaline soils
7.0 – 8.5	High	
5.5 – 7.0	Medium	Preferred range
<5.5	Low	Acid soils

3.6.3 Sodicity

Sodicity is a common problem in subsoils and some overburden in open cut coal mines.

Sodicity refers to a condition where a relatively high proportion of readily soluble sodium is present in soil or spoil material. The effects of sodicity on plant establishment has been widely studied in the case of agricultural soils, but limited information is available in the case of mine spoils where active weathering of exposed material can result in rapid charges in ionic conditions of the substrate.

Sodic material is prone to erosion and surface crusting. This can have a range of detrimental consequences on plant establishment as a result of reduced water infiltration and restricted emergence.

Standards used in the interpretation of results are shown below in Table 3.

Table 3 Standards Used for Interpretation of Results (sodicity.)	
ESP*	Comments
2 – 10	Sodicity not a limiting factor
10 – 20	Sodic problems e.g. crusting, becoming evident
20 – 46	Very sodic
40 – 60	Extremely sodic – only tolerant plants will survive
*ESP = Exchangeable Sodium Percentage	

3.6.4 Nutrient Availability

Past experience has indicated nitrogen and phosphorus to be the main limiting nutrients to plant growth in mine spoil. High pH (alkaline conditions) such as that experienced in some mine waste materials can have a profound effect on nutrient "lock-up" and in turn, plant growth.

Other research on both acidic and alkaline mine spoil has shown phosphorus to be the most important nutrient to a stable vegetation cover closely followed by nitrogen *(Burns 1987).*

Only a portion of the phosphorus applied in fertiliser is available to plants. A large proportion may be fixed in relatively insoluble compounds and unavailable to plants. Phosphorus (unlike nitrogen) is also relatively immobile and will move only a short distance in the soil from the point of application.

An efficient fertiliser regime needs to consider the soil factors, which determine the availability of phosphorus and other nutrients. These include pH, texture and drainage characteristics and biological activity. Phosphorus fixation is generally greater in soils with a high clay content, in acid or alkaline soils and in soils high in hydrous oxides of iron and aluminium. The method of application is also important in maximizing nutrient availability to plants.

While in practical terms, many of the factors which influence nutrient availability cannot be readily altered, management of pH through the use of lime (in acid soils) or sulphur based products (in alkaline soils) can assist nutrient availability. Organic material applied in sufficient quantity can also have a buffering effect.

3.7 Weed Competition

In the Australian environment, tree planting is seldom successful if exotic grasses and/or broad-leaved weeds are allowed to compete with the newly planted trees *(Menzies and Chavasse 1982). Boden (1965)* found that, without removal of weeds around newly planted trees, growth was only half to three-quarters that which occurs under weed-free conditions. *Jack (1970)* found that 1-2 years growth of radiata pine (*Pinus radiata)* can be lost due to competition during establishment from herbaceous weeds. This lost growth is not made up later. Mortality of planted tubestock can be high if weed competition is severe *(Burns 1999).*

Early control of weed competition will maximise early growth of desired plant species and improve survival.

Competitive weed species can be introduced in pre-stripped topdressing material or by sowing pasture species. Wind-blown weed contamination may occur over time, but this effect is slower than other sources of weed introduction. Unmanaged topsoil stockpiles can be a major source of weed contamination.

Initially, and prior to topsoil respreading, open-cut coal mining produces a weed-free environment rarely found in nature. Consequently, an ideal situation is provided for the first natural or artificially applied seed or seedlings. Native species introduced under these conditions, at this stage of rehabilitation, suffer little competition from weed species. However, where topsoil is not used plants have to contend with the physical and chemical characteristics of the overburden. On some mines these conditions can be hostile to plant establishment.

Many exotic pasture and weed species are adapted to rapidly utilise available moisture and nutrients at an early stage. The comparatively protracted establishment of many native species from seed, renders them susceptible to competition *(McMurray 1985*). The degree of competition that can be tolerated depends on the limiting factors of the site and the sensitivity of the preferred species to these *(Brown and Hall 1968*). Generally, it has been found that the better the weed control, the higher the percentage establishment of native species from seed *(Venning et al. 1985, Irving 1986*), and the better the growth *(Irving 1986, Wise et al. 1980)* and subsequent survival *(Revell and Deadman 1976)*.

The main ways in which weeds might restrict growth are through competition for water *(Larson and Schubert 1969),* nutrients *(Greenham 1957*) and light *(Strotham 1967)*. Allellotropism can also be a factor *(Jameson 1961*), but this effect is not widely reported. According to *Greenham (1957*), the marked restriction of tree growth by weed competition in the early years of establishment is caused primarily by competition for soil moisture and, to some extent, for nitrogen (N). *Wareing and Phillips (1970)* found that removal of weed competition by herbicide spraying increased the N content in tree foliage and that responses to N and P fertilisers depended on the degree of control of weed competition: in some instances competition, even at low levels, neutralized the effect of fertilizer. Conversely, weed control can substitute for N fertilizer *(Richards 1954*).

Removing competition is therefore essential for establishing native species, either from seed or seedlings.

3.8 Species Selection and Seed Pre-treatment

The selection of suitable species can normally be achieved through a review of species listed in relevant Environmental Impact Statements, flora studies and other reports. Not all species are readily suited to direct seeding. Some species have innate dormancy mechanisms which may be difficult to break or, in some cases, completely unknown. Dormancy mechanisms for the relevant species need to be understood before buying large quantities of seed.

Often a decision has to be made to either collect local provenance seed or buy appropriate species from seed suppliers. The collection of local seed is desirable but requires a relatively long lead time to collect sufficient quantities of a diverse range of species. Many native species flower irregularly and sometimes only every 3 to 4 years. Other species only produce minute quantities of seed and the physical effort and cost of collection of sufficient quantities can be high. Often a compromise between collecting some local seed and buying in the balance is a practical alternative.

Seed collection is a specialist operation and requires appropriate experience in species identification, seed maturity assessment, drying, sieving and storage.

3.9 Sowing Rates and Species Proportions

The sowing rate (grams per hectare) of each species sown is important in terms of both the initial and long term presence of that species in the stand. The sowing rate has to be balanced with the likely aggression and competitive nature of that species. Some quick growing species can quickly dominate the stand and possibly outcompete other slower growing (but important) longer lived species. Determining appropriate sowing rates is an ongoing process and should be constantly reviewed after each sowing and monitoring event. What may be appropriate in the short term may not be in the long term. Long term ecosystem objectives should be considered before commencement of the work.

In addition to specific species sowing rates, the ratio of say understorey to overstorey species is also important. Even the balance of plant groups such as Acacias within the understorey group needs to be considered depending on the principal objective(s).

On most sites there is normally only one chance, immediately after site preparation, to sow and get the native ecosystem away. It is difficult and often expensive to come back and try and oversow, or plant, or interfere with the evolvement of the stand. Stand dynamics over time can vary from site to site depending on soil/spoil characteristics, weather, time of sowing etc, etc. Variation in outcome can occur over short distances, or over time, even though the same seed mix has been applied. Stand dynamics are complicated and often difficult to predict. For this reason it is strongly recommended that past revegetation experience in the region is assessed, initial trials are undertaken on the mine site and that regular monitoring is undertaken to provide a continuous feedback and self-improvement process.

Inherent in all this is initial discussion and clarification and the setting of clear vegetation goals and outcomes, which can then be worked-towards. Once these are set, manipulatable variables can be adjusted to give the best possible outcome. On most sites there is always room for improvement and adjustment. Setting clear objectives and completion criteria is important. Progress can then be assessed through an appropriately targeted monitoring program.

3.10 Timing

The time of sowing or planting is important to revegetation.

Tubestock planting is best done when either conditions are cooler or when there is the greatest likelihood of rain. In the Hunter Valley Coalfields tubestock planting is best undertaken between April to July when stress on the newly planted tree is reduced. In the tropics, planting in the wet season is preferred in order to coincide with summer rain. However, temperatures at this time are also higher as is the consequent water stress on the plant. In all scenarios, backup watering may be necessary until adequate rain falls and plants can establish a self supporting root system.

Direct tree seeding is driven by different forces compared to tubestock planting and is preferably undertaken when the weather is warm and preferably wet. The main requirement is that the soil temperature is high enough to facilitate seed germination. Hence, along the east coast of Australia the preferred sowing period is September to May. In the tropics a narrower time band of October to March is preferred to also coincide with wet season rain. Sowing at the beginning of the wet season is preferred. This allows seed to germinate early and young germinants to receive the full benefit of any follow up rainfall.

Direct tree seeding is considered more flexible and naturally harmonious than tubestock planting. If seed is spread and it doesn't rain it will lay on the soil surface until adequate rainfall and soil temperature occur. If either of these conditions are delayed the two most significant potential problems are ant harvesting and/or burial of seed. On most recontoured mine spoil it takes several years for ant populations to re-establish. Ant predation of seed is therefore only a problem where populations of seed harvesting ants are sufficient to quickly harvest seed.

Excessive seed burial can occur where seed is buried below a critical depth. Many species with small, fine seed such as *eucalyptus, melaleuca, callistemon* and other species will not emerge if they are buried greater than 1 to 2 mm. The depth is even less where surface crusting, (which occurs with many mine overburden types) occurs. Surface crusting is a characteristic of sodic soil/spoil material and occurs after repeated wetting and drying events. Surface crusting provides a physical barrier to hypocotyl emergence. If conditions are not conducive for germination immediately after sowing then seed can be quickly buried. This occurs more rapidly where there is a higher chance of surface soil movement such as on steep slopes, in sodic soil material, and during high intensity rainfall events. Hence, sowing time should occur when conditions (temperature and rainfall) are most likely to permit quick germination. The longer seed sits ungerminated the greater the risk of excessive burial or ant predation. For these reasons sowing should occur immediately after site preparation while there is a fresh tilth on the surface. Seed should also be sown directly onto the soil surface and not buried. Raindrop splash and soil settlement is normally sufficient to adequately cover seed.

It should be highlighted that young direct tree seeded germinants are very drought resistant and much more so than planted tubestock. Once seed germinates *insitu* it can often survive for many months with little water. In contrast planted tubestock may need repeated watering until root systems develop, the plant 'hardens,' and adequate rainfall occurs.

3.11 Nutrition and Fertilizer

This aspect has already been partly discussed in section 3.5.4. Many mine spoils and even topsoils are deficient in many of the key elements and particularly nitrogen (N), phosphorus (P) and sulphur (S) *(Burns 1988*). The addition of nutritional support is often helpful in encouraging the growth of many native species. However, establishing the optimum nutritional requirements for native woody species on mine spoil can be complex and a range of factors need to be considered. Some of these include:

- Growth objectives. How fast do you want plants to grow? If the objective is not a commercial forestry plantation then sometimes slower growth creates hardier and more drought resistant plants.

  Many Australian species are adapted to low nutrient environments and will survive and grow.

- Preferential effect. On some occasions fertilizer addition favours the establishment of one or two species to the detriment of others. The ratio of elements within the fertilizer can also result in preferential effects.

- Drought Effect. In arid areas fertilizer addition can unfavourably affect the root to shoot ratio and the biochemical balance of the plant. This, in turn, can affect its water use efficiency and ability to survive in drought. In very arid areas it may be wise to avoid initial fertilizer application.

- Weed stimulation. If the surface material has a high weed propagule content then fertilizer addition may stimulate weed growth to the detriment of native species.

- Timing. Fertilizer addition can occur as an initial application at the time of sowing/planting and/or as a maintenance application. Experience of the author has shown that the regular application of low rates of fertilizer on a regular basis after plants establish produces superior results compared to infrequent applications at high rates.

Despite the above, fertilizer addition is normally beneficial in promoting rapid native vegetation establishment and soil stabilization. Soil stabilization and erosion control must always be the first and foremost objective in mine revegetation. If soils and slopes are not stable, revegetation efforts will be in vain and possibly temporary. Initial fertilizer rate trials are often necessary to identify optimum regimes in the context of mine objectives. There are no 'absolutes' with fertilizer use and its use must be adapted to each site based on prevailing conditions.

3.12 Ameliorants

Perhaps the most significant ameliorant is time. Changes in the physical and chemical nature of surface overburden have been observed over time due to the processes of weathering, leaching and biological activity. The relevance of any changes in soil characteristics to plant establishment will depend on the initial levels of chemical factors such as salinity and pH and the rate of change. As a general comment, surface spoils tend to ameliorate with time as salts leach down through the profile and as pH modifies. A notable exception would be where acid conditions result from the presence of waste pyrite material. In this situation soil conditions may become more acidic as pyrite oxidises.

The salinity of surface spoil is usually a short term problem in humid climates and may disappear after two or three years of leaching. In drier climates the process takes longer and the problem may never disappear. Salinity can provide a limitation to plant growth where spoil has been recently
re-contoured and where leaching rains are low and water infiltration and internal drainage is poor.

In the Hunter Valley leaching of soluble salts has been noted on alkaline overburden of the Wittingham seam *(Dyson 1987). Elliott (1983*) showed that the distribution of dominant water soluble ions in the overburden appeared to be related to the occurrence of flood rains and there was a consistent accumulation of Na, Mg and C1 at 2.5 – 3m below the material surface in overburden exposed for over 8 years. Leaching by irrigation is rarely practical due to the large areas frequently involved and the volumes of water required. Salinity, and indeed all chemical problems, can be partly overcome by selective placement of a favourable growing medium on the surface eg. topsoil or a suitable overburden. However, as the roots of most plants and particularly deep rooting tree species will eventually penetrate the underlying spoil, the long term success of revegetation work will still depend on the quality of the underlying materials and the tolerance of the species used. A tree whose roots are located in a thin layer near the surface, due to the restrictive effects of hostile conditions lower down, will soon suffer drought effects.

Sodicity may also be alleviated by leaching of Na salts over time. The ratio of Na ions to Ca or Mg ions can also be artificially varied by applying chemical additives (eg gypsum) to change this ratio. Top-dressing material generally in the upper Hunter Valley has favourable sodic properties and is often used to cover overburden material with poor sodic properties. However, its likely weed content must be considered before establishing trees, particularly if it has been stripped from agricultural country.

Although most coal mine spoil is commonly deficient in at least one essential nutrient for plant growth, nutrient deficiencies are not considered a major problem in rehabilitation as fertiliser can be readily (and relatively cheaply) applied at planting or sowing time. Some mines apply maintenance fertilizer annually until soil nutrient levels reach a predetermined level.

The use of organic mulches can reduce salinity affects on some sites. The use of biosolids can also alleviate many soil problems as can the use of temporary cover crops.

3.13 Temporary Cover Crops

Where rapid surface stabilization is required, and where the sown or planted native species crop does not provide this, a joint sowing of a temporary, low competition crop, may be necessary. This approach is often used in direct tree seeding programs and may involve the inclusion of a light sowing rate of oats, millet, rye corn or other temporary pasture species in the tree seed and fertilizer mix. Again, there is a balance to be achieved as all species will compete with each other for soil water, nutrients and light. Initial trials should be established to determine the optimum cover crop species and sowing rate. In so doing an acceptable compromise should be reached which balances the positive and negative effects of the cover crop on native species establishment.

This concept can be extended to include medium term cover crop species such as *Acacias* which can provide medium term surface stabilization and favourable soil amelioration. We are only limited by our own experience and imagination.

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