REVEGETATION METHODS

1.0 SCOPE

This guideline provides advice on selection of species appropriate to available growth media characteristics and agreed post-mining land use, methods of preparing areas for revegetation, and techniques for establishing new vegetation.

> **This guideline is ADVISORY ONLY and is not intended to prescribe mandatory standards and practices. This guideline is intended to assist the development of project-specific environmental management practices.**

2.0 OBJECTIVE

To ensure that the most suitable plant species and most appropriate techniques are used in the revegetation of mined areas, in accordance with pre-determined strategies and goals for progressive and final rehabilitation.

3.0 RELATED GUIDELINES

- Determining Post-Mining Land Use
- Land Suitability Assessment Techniques
- Progressive Rehabilitation
- Erosion Control
- Growth Media Management
- Assessment of Revegetation
- Housekeeping on Rehabilitation Areas

4.0 INTERPRETATION

For the purposes of this guideline, unless the context indicates otherwise:

"Topsoil" refers to the surface layer of soil which is usually more fertile and better structured than underlying layers. The surface layer may vary in depth depending on soil forming factors, including parent material, location and slope, but generally is not greater than about 300 mm in depth from natural surface. The definition of suitable topsoil should be based on soil chemical and physical properties;

"Subsoil" refers to the subsurface soil material which is below the topsoil.

5.0 BACKGROUND

Revegetation of areas which have been disturbed by mining and subsequently reshaped is a critical aspect of rehabilitation having regard to erosion control, aesthetics and establishing a suitable post-mining land use. Very few disturbed areas will regenerate satisfactorily in a reasonable time without assistance. A properly managed revegetation programme can ensure the effective return of land to an agreed post-mining land use.

6.0 MANAGEMENT PRINCIPLES

(1) The return of disturbed land to a stable, productive and self-sustaining condition may be a long-term process. The revegetation programme should establish a sound basis for the ecosystem to develop and improve over time. Often in the short-term, rehabilitation requires management measures to minimise erosion.

(2) The extent and type of revegetation and the selection of species should be determined by the proposed end land use, landform, climatic conditions, spoil characteristics and soil conditions. These determining factors may vary across different parts of the mine area.

(3) Site specific and/or expert advice should be obtained in relation to the suitability of proposed preparation works, species selection, establishment methods and maintenance.

7.0 MANAGEMENT STRATEGIES

Revegetation should generally involve the following process:

(a) Landform reconstruction to re-establish a stable topographic profile that provides for acceptable drainage patterns. If re-establishment of original native vegetation is the proposed land-use, the rehabilitated topography may need to be similar to that occurring in the surrounding undisturbed landscape. On wetland sites, re-creation of water table/ground surface relationships are critical.

(b) Careful management of topsoil to maintain its structural and biological properties, including its native seed bank. How well the replaced soil profiles are reconstituted will impact on, amongst other things, their water holding capacities, and this too can have a significant effect on the productivity and type of community the new growth media will support.

(c) Appropriate selection and management of other growth media where there is insufficient topsoil available on site.

(d) Surface stabilisation, particularly where native species are to be established. Many native species have small seeds, and germinate and establish slowly.

(e) Direct seeding (especially for native species) is usually the most efficient means of enhancing regeneration from topsoil, both biologically and economically. Seed should preferably be collected from the site to ensure it is genetically adapted to local conditions.

(f) Enhancement planting of nursery-raised stock from local propagules, with emphasis on species that are difficult to propagate using field techniques. This operation ensures the return of species that may be important to the structure of the desired vegetation community.

(g) Monitoring of the development of the vegetation community to ensure its proper establishment and growth. This can range from visual inspection to botanical sampling involving a computerised data base.

All revegetation works should be designed and implemented having regard to regional and site-specific conditions.

8.0 IMPLEMENTATION STRATEGIES

8.1 Surface Preparation

Surface preparation should serve to optimise plant establishment and minimise soil erosion.

Following bulk earthworks (including construction of contour banks, drop structures and other erosion control structures) and reshaping, large surface rocks may need to be removed and/or buried if they would interfere with subsequent cultivation, sowing operations or be incompatible with the post-mining land use. Spoil dumps can then be ripped on the contour to reduce surface compaction, improve water infiltration and provide for topsoil to be keyed into underlying material. Ripping to depths of 0.5m to 1m at 1 m spacing is suitable for many types of spoil but site specific conditions may require a different depth and spacing. If trees are to form a component of the post-mining landscape, a deeper ripping depth will be required if the underlying material is compacted. Ripping can bring large stones and rocks to the surface, and at some sites it may be more appropriate to deep rip after topsoil is spread, particularly if the application of the topsoil is likely to compact the ground.

Logs and rocks may be left in heaps on the surface to provide fauna habitat.

Topsoil should be spread evenly over the surface. The depth of topsoil used will depend on the quantity available and the agreed post-mining land uses with greater depth placed in critical areas such as bunds, drains and contour banks. The application of topsoil in strips along the contour is useful where the topsoil supply is limited or where excessive grass growth from seed already present in the topsoil will hinder the establishment of trees. Trees can be planted in the intervening untreated areas.

Where soil is placed in layers it is important that each layer is keyed into the layer below, as layering can act as a barrier to the penetration of roots even if the subsoil is suitable for plant growth. Layering, especially on slopes and soils with a high clay content, can result in geotechnical instability and the resultant slumping of the soil down the slope. There is a need to adequately address the engineering requirements of maintaining shallow topsoil layers on steep slopes. Deep ripping or tyning should be judiciously used to provide a suitable base on which to apply subsequent layers. Tyning usually involves using 3 to 5 tynes behind a grader or dozer to a depth of 100 to 300 mm.

If topsoil is unavailable, or if the topsoiling operation is inappropriate or impractical for a specific area, the use of alternative growth media options have to be considered.

The control and management of rainfall and stormwater runoff is the basis of erosion control. Any works that concentrate overland water flow can accelerate erosion. Where an area is subject to high intensity storms, rainfall regularly exceeds infiltration and the balance runs off. Contour furrows and/or contour banks are useful in reducing slope length and aid water infiltration. Basin listing, pitting, ponding or moonscaping can be used to trap aerial distributed seed and fertiliser as well as hold rainfall and improve water infiltration. Overtopping of basins can cause severe erosion. These techniques may be particularly useful in areas of low annual rainfall and low intensity rainfall, although they have yet to be proven in moderate to high rainfall areas. By constructing basins of sufficient size to contain most storms, the probability of overtopping is reduced and the risk of failure is less.

All operations should be conducted on the contour with the final land surface left “rough” to aid plant establishment. Access to the site should be prohibited, especially to traffic which can create initiation spots for erosion and introduce weeds. If future access is required, at least 60 percent groundcover should be achieved before access is permitted.

8.2 Fertilisation

For healthy growth, plants require a wide range of elements, most of which are available to some extent in even the poorest soils. Plant nutrients are divided into major and trace (or minor) elements according to the quantities in which they are required by plants. The major elements are nitrogen, phosphorus, calcium, magnesium, potassium and sulphur. The trace elements include zinc, copper, manganese, iron, molybdenum and boron.

Nitrogen and phosphorus are the elements most often limiting to plant growth. Sulphur deficiencies are not as common (although they can occur on some soils, eg. black earths), and potassium deficiencies are more likely to occur in acidic media. Trace element requirements vary depending on the plant species.

Fertiliser application can assist in overcoming some of the elemental deficiencies present in growth media, thereby encouraging plant growth. Whether more than a single application of fertiliser is required depends on whether the fertiliser not taken up by the plants is held in the rooting zone and remains available for uptake (dictated by soil and climatic influences), the nutrient requirements of the plant community and the post-mining land-use. In time, the recycling of nutrients should occur through plant litter production and decay, the latter process itself being dependent on the appropriate complement of nutrient cycling organisms becoming established.

A range of fertilisers are available (eg. urea, ammonium nitrate, sulphate of ammonia, superphosphate, MAP, DAP and Q5), containing either one, two or several nutrient elements, in varying concentrations and ratios. The selection of fertiliser type and the rate of application will depend on:

- existing nutrient concentrations in the growth media (as determined by soil analysis)
- other media characteristics that will influence nutrient availability, such as organic matter content and porosity
- depth of the rooting media
- type of vegetation community to be established

Generally, only nitrogen at 50 to 100 kg/ha and phosphorus at 30 to 60 kg/ha are required (References 1 and 2). However, a review of rehabilitated land following open-cut coal mining in Queensland (Reference 5) found a number of growth media with deficient or marginal quantities of potassium, calcium, sulphur and zinc. Native plants generally have lower soil nutrient requirements than most exotic species.

The simplest means of assessing fertiliser requirements (major nutrients) is by laboratory analysis, but unfortunately, this can only provide a guide to plant response to nutrient addition. Pot or field trials, and monitoring of plant growth may be needed to refine fertiliser needs. Local fertiliser suppliers may be able to assist with the selection of the most appropriate fertiliser in regard to availability, cost, transport and ease of application.

Plants vary in their nutrient requirements. Nitrogen tends to promote vegetative growth (particularly of grasses), while phosphorus, applied on its own at high rates, can be toxic to some native plants. Organic materials, such as sewage (sludge and effluent) and waste from intensive animal husbandry (feedlots and poultry farms), are valuable sources of nutrients and organic matter. Care is needed to avoid inappropriate application rates which can add potentially harmful substances, including heavy metals and excess nutrients.

8.3 Species Selection

Species selection should be appropriate to the agreed post-mining land use. Where the primary intention is erosion control, fast growing grasses and legumes are likely to be most suitable. Where the intention is to establish a native plant community or timber species, grasses can provide undesirable competition.

Where possible, local species should be selected as they are adapted to the local climate and soil conditions, and are more likely to be self-sustaining. Seed should be collected locally.

8.3.1 Grasses and Legumes

A wide range of grasses and legumes is available to suit almost every situation and purpose (Table 1). Almost all of these species are introduced plants which have been further bred and selected to suit Australian conditions. The most useful species for erosion control are the fast spreading stoloniferous species (eg. Rhodes grass) which provide surface cover protection for gentle slopes. Deeper-rooted tussocky species (eg. buffel grass), in addition to the first type, may be useful for stabilisation of steeper slopes.

Broadacre revegetation of mined land has generally used introduced grass and legume species, but in areas where introduced species are not sustainable, native grasses should be encouraged to invade or may need to be established directly. Native grasses may also provide better long term stability. The native *Dichanthium sericeum* (Queensland bluegrass) is proving useful on alkaline cracking clay soils (black earths). *Vetiver zizanioides* (Vetiver grass) also has potential, particularly for erosion control (by spreading concentrated runoff water and trapping sediments) when planted as a hedge on the contour.

Other native grasses that could be useful for revegetation in specific situations include *Themeda triandra* (kangaroo grass), *Heteropogon contortus* (black speargrass), *Bothriochlsa blaolhii (forest bluegrass), Bothriochlsa decipiens* (pitted bluegrass) and *Astrebla lappacea* (curly mitchell grass). These and others are largely untried on mine sites but their use in the future is likely to increase.

Where it is intended to establish native plant communities, exotic species may be regarded as weeds. Sterile annual grass species, especially selections of forage sorghums, or species that will not survive or reproduce in the long term (eg. annual ryegrass or japanese millet), can be used for initial erosion control and to act as a nurse or cover crop for the slower growing native plants. Also Red Natal Grass can be used as a less competitive pioneer.

One of the important differences between grasses and legumes is that grasses obtain their entire nutrient supply from the soil, whereas legumes are capable of obtaining nitrogen from the air, provided they have formed a symbiotic relationship with an appropriate *Rhizobium* bacterium. Death and eventual decay of legumes releases the nitrogen into the soil for use by other, non-leguminous, plants.

To encourage the self-sustainability of the newly establishing plant communities in the longer term, legumes should be included in the seed mix as they provide a cheap and effective means of supplying nitrogen to the soil. The alternative would be to continue to supply nitrogen by means of fertilisers.

Since all commercially available legume pasture species are derived from exotics, and since some of the bacteria/ legume host associations can be specific, it is unlikely that the replaced native soil will contain the appropriate strains of bacteria. It is therefore important that legume seed of introduced species be “inoculated” with the correct *Rhizobia* immediately prior to sowing, a service most commercial agricultural suppliers will provide. Commercial seed suppliers from which pasture grasses and legumes can be obtained include:

- Heritage Seeds Pty Ltd — Brisbane, Toowoomba, Walkamin
- Selected Seeds Pty Ltd — Biolela, Pittsworth, Rockhampton
- Wrightson Seeds. (Australia) Pty Ltd — Brisbane

TABLE 1
COMMON GRASS AND LEGUME SPECIES SUITABLE FOR MINE SITE REVEGETATION
(from Reference 14 and R. Loch, pers. comm.)

Scientific Name	Common Name	Climatic Zone	Soil Types	Comments
GRASSES				
Bothriochloa insculpta cv. Bissett	Creeping bluegrass	600 to 1200mm	loams and clays	good mat former
Brachiaria decumbens cv. Basilisk	Signal grass	1200 to 2200 mm, N of 20°S	acidic	bauxite mines
Brachiaria humidicola cv. Tully	Koronivia grass	800 to 2500 mm, N of 20°S	acidic	tailings dams
Cenchrus ciliaris cv. Biloela	Buffel grass	500 to 850 mm, S of 17°S		
Cenchrus ciliaris cv. Gayndah	Buffel grass	500 to 850 mm, S of 17°S		
Chloris gayana cv. Katambora	Rhodes grass	600 to 1000 mm, S of 20°S		stoloniferous
Chloris gayana cv. Nemkat	Rhodes grass	600 to 1000 mm, S of 20°S		stoloniferous, most speading of cv
Chloris gayana cv. Pioneer	Rhodes grass	600 to 1000 mm, S of 20°S		
Cynodon dactylon or *Cynodon nlemfuensis*	Green couch	600 to 800 mm, S of 17°S		
Melinis repens	Red Natal Grass			pioneer grass
Panicum maximum cv. Gatton	Gatton Panic	600 to 1000 mm, N of 26°S		
Panicum maximum var. *trichloglume* cv. Petrie	Petrie green panic	600 to 1000 mm, N of 26°S		sulphur rich soils
Pennisetum clandestinum	Kikuyu			
LEGUMES				
Macroptilium atropurpureum cv. Siratro	Siratro	600 to 1000 mm, N of 25°S	not acidic	twining, potential problem for trees
Macroptilium lathyroides cv. Murray	Phasey bean	600 to 1500 mm		wetter valleys, drains
Medicago sativa cv. Hunter River	Lucerne			cheap seed
Medicago sativa cv. Trifecta	Lucerne (winter active)	550 to 850 mm, S of 23°S	alkaline, not sandy	
Stylosanthes guianensis var. *intermedia* cv. Common	Fine-stem stylo	S of 23°S	sandy	
Stylosanthes guianensis cv. Cook	Stylo	700 to 2000 mm, N of 20°S	acidic	
Stylosanthes scabra cv. Seca	Shrubby stylo	550 to 850 mm, N of 25°S	sandy to clay loams	slow growing, drought hardy
Stylosanthes hamata cv. Verano	Caribbean stylo	700 to 1500 mm, N of 23°S	sandy	

TABLE 1 (cont.)
COMMON GRASS AND LEGUME SPECIES SUITABLE FOR MINE SITE REVEGETATION
(from Reference 14 and R. Loch, pers. comm.)

Scientific Name	Common Name	Climatic Zone	Soil Types	Comments
UNPROVEN SPECIES WHICH SHOW PROMISE				
Alysicarpus vaginalis ·	Alyce clover	750 to 1500 mm, N of 20°S		grazed swards
Bothriochloa pertusa cv. Dawson	Indian bluegrass			late flowering turf type
Bothriochloa pertusa cv. Keppel	Indian bluegrass			late flowering mat formation
Bothriochloa pertusa cv. Medway •	Indian couch	550 to 1000 mm		
Brachiaria praetervisa ·		800 to 1000 mm, N of 20°S	massive	sward forming, grazing tolerant
Calyptochloa gracillima ·		600 to 900 mm, N of 25°S	acid	stoloniferous, woodland understorey grass with restricted natural distribution
Cassia rotundifolia cv. Wynn	Cassia	550 to 850 mm	prefers sandy loam	low fertiliser needs; semi-annual in dry years
Cynodon dactylon	Bermuda grass			
Desmanthus virgatus			neutral to alkaline cracking clay soils	
Dichanthium sericeum	Queensland bluegrass	550 to 850 mm		low fertiliser needs; semi-annual in dry years
Ehrharta calycina	Mission Veldt grass	350 to 550 mm	sandy to loam	drought tolerant winter growing perennial
Lotus pedunculatus cv. Maku and cv. Sharnae	Lotus	850 to 1500 mm, in cool mountains	clay, acid	puggy wet soils
Panicum coloratum cv. Bainbatsi	Makarikari Grass			salt tolerant but slow to establish
Paspalum plicatulum	Plicatulum	700 to 1200 mm	acid	
Paspalum scrobiculatum ·	Scrobic	750 to 1500 mm, at elevation		seasonally wet areas
Petalostylis labicheoides ·	Butterfly bush	300 to 600 mm	acid, red	arid regions
Setaria incrassata	Purple pigeon pea	600 to 1000mm	clay	
Urochloa mozambicensis cv. Nixon	Sabi grass	700 to 1000 mm, N of 24°S	acid, red	needs regular fertiliser
Vetiver zizanioides cv Monto #	Vetiver grass	> 450mm		Tolerant to Al, salt, pH extremes and waterlogging. Can only be propagated vegetatively.

• Seed not commercially available.

P.N. Truong, pers. comm.

8.3.2 Trees

Rehabilitation commonly seeks to establish pasture grasses and legumes, with some trees for diversity. At some sites, post-mining land use requires the establishment of a native plant community or trees for conservation purposes or commercial timber production.

In the rehabilitation of any land the rapid development of vegetative cover is important to control erosion and provide stability. This rapid cover is most effectively achieved by sowing exotic, improved pasture grasses and legumes. This technique may create problems for the establishment of trees and shrubs due to competition between the grass and tree seedlings. Two methods are available to overcome this problem.

First, if trees are to be planted at the same time as the pasture, sites for tree clumps or windbreaks should be chosen prior to pasture sowing and planted with a tree-only seed mix or tube stock. If a mix of grass and tree seed is sown, the grass seed sowing rate, and probably also the fertiliser rate, should be considerably reduced to minimise competition. Secondly, if trees are to be planted into an established pasture, or at sites where grass competition occurs from seed present in the topsoil, planting sites should be thoroughly cultivated or herbicide applied to destroy the grass prior to tree planting.

Local native tree species should be given first consideration for planting as these would have proven suitability for the local climate and some resistance to local pests and diseases. Re-establishment of vegetation communities that previously existed on the site can also contribute to local and regional conservation corridors and networks, as well as facilitate slope and watercourse stabilisation.

However, within the range of appropriate native species, the selection should take into account site-specific soil conditions, planting purposes and the agreed post-mining land use. The inclusion of nitrogen-fixing tree species, such as those from the genera *Acacia, Casuarina* and *Allocasuarina*, should be considered. Some of the tree and shrub species that have been used in minesite revegetation programs, and their suitabilities (where known) for particular climatic zones and soil types, are shown in Table 2.

The information in this table is assembled from References 3, 4, 5, 6 and 7, as well as a number of site sources. The list is not exhaustive but illustrates the range of species that have been used in either broadacre seeding/planting or have shown promise in specific trial areas. The list does not include species used in rehabilitation programs following sand mining, as local species are used exclusively at these sites.

Mulligan and Bell (Reference 5) reviewed tree and shrub growth on rehabilitated land following open-cut coal mining in Queensland. Their report provides information on the success of the tree species trialled.

Advice on the selection and growing of native plant species for particularly adverse conditions (eg. acidic, alkaline or saline soils) can be obtained from information leaflets prepared by Brookvale Park (PO Box 57, Oakey, Qld, 4401). More generally, Queensland native plant species seeds (and advice on them) can be obtained from commercial suppliers including:

- Forest Services Group, Qld Department of Primary Industries - Brisbane and Regional Offices
- ACEB Seeds - Mareeba
- Australian Tropical Plant Supplies - Dimbulah
- Dendros Seed Supplies   Walkamin
- Earthseed - Mossman
- Ellison Horticultural Pty. Ltd - Nowra, NSW
- Pangea Seeds - Highgate Hill, Brisbane
- Queensland Tree Seeds Pty. Ltd   Moura.
- Turner & Associates - The Gap, Brisbane

8.4 Sowing and Cultivation

The first stage of the sowing operation is to apply soil amendments or fertiliser at the required rate over the area. Application can be by means of tractor-drawn or rear-mounted broadcasters for small areas, or by aircraft or hopper truck for broadacre work.

Immediately after fertilising, the area should be cultivated to incorporate the fertiliser and prevent nitrogen losses through volatilisation. Cultivation should aim to produce a very coarse seed bed with furrows which trap and retain runoff and resist the formation of a surface crust or seal. Cultivation with a tyned implement, such as a scarifier, chisel-plough or chisel-seeder, is useful even though additional rocks may be brought to the surface.

If the area has previously been contour-ripped, the rip lines will serve as a guide to ensure that cultivation is conducted on the contour. Cultivation should aim to simply fill in the areas between the rip lines, while leaving the rip lines themselves intact and undisturbed.

It is important that all cultivation be done on the contour and that drawing the plough or scarifier across the rip lines be minimised.

Seed pelleting or coating involves the application of a layer of material around the seed. This material may be inert or it may contain fertiliser, growth hormones, pesticide and/or *Rhizobia/*mycorrhizal fungi. The benefits of such application can include:

- better seed distribution,
- greater seed to soil contact,
- improved seedling nutrition,
- reduced loss of seed due to fungal or insect attack
- pre-inoculation of legumes or native plants with beneficial micro-organisms, and
- longer “shelf” life of *Rhizobium* - inoculated seed.

TABLE 2
COMMON TREE AND SHRUB SPECIES USED FOR MINE SITE REVEGETATION

Scientific Name	Common Name	Climatic Zone*	Drought**	Clay	Sandy	Shallow	Poorly draining	Waterlogged	Saline	Acid	Alkaline
Acacia auriculiformis	Northern black wattle	1000-1500, N of 16	R		X				X		
Acacia bancroftii	Bancroft's wattle										
Acacia crassicarpa	Spoon tree	1000-1250	R		X						
Acacia harpophylla	Brigalow	450-700, S of 20	V	X			X				X
Acacia holosericea	Candelabra wattle								X		
Acacia leiocalyx	Black wattle	750-1000	V	X	X	X	X				
Acacia macradenia	Zig-Zag wattle	500-750	V		X	X					
Acacia mangium	Brown salwood	1000-1250	N		X						
Acacia pendula	Myall	500-750	V	X			X				
Acacia podalyriifolia	Queensland silver wattle	750-1000	R	X		X			X		
Acacia rhodoxylon	Rosewood									X	
Acacia salicina	Cooba	200-1500	R	X					X		X
Acacia saligna	Golden wreath wattle	500-750	R	X	X	X					
Acacia shirleyi	Lancewood	500-750								X	
Brachychiton rupestris	Narrow-leaved bottletree	500-750	V	X							
Callistemon viminalis	Weeping bottlebrush	750-1000	N	X	X	X	X	X	X		
Cassia brewsteri	Leichhardt bean	750-1000	R								X
Casuarina cristata	Belah	500-750	V	X			X		X		
Casuarina cunninghamiana	River sheoak	1000-1250	R	X	X		X		X		
Casuarina equisetifolia	Beach sheoak	1000-1250	R		X						
Casuarina glauca	Swamp sheoak	750-1000	R	X	X		X	X	X		
Eucalyptus argophloia	White gum	500-750	V	X			X		X		
Eucalyptus camaldulensis	River red gum	250-600	V	X	X		X		X	X	X
Eucalyptus citriodora	Lemon-scented gum	650-1600, S of 17	R		X	X			X	X	X
Eucalyptus crebra	Narrow-leaved ironbark	550-2000	R		X	X			X	X	X
Eucalyptus drepanophylla	Queensland grey ironbark	1000-1250	R			X			X	X	X
Eucalyptus maculata	Spotted gum	750-1750, S of 25	R	X		X				X	
Eucalyptus melanophloia	Silver-leaved ironbark	400-750, S of 17	V	X		X	X				
Eucalyptus melliodora	Yellow box	500-900, S of 24	R	X			X		X		
Eucalyptus moluccana	Gum-topped box	700-1200, S of 17	R	X	X	X	X				
Eucalyptus nesophila	Melville Island bloodwood	1000-1750, N of 16									
Eucalyptus papuana	Ghost gum	250-1500	V		X					X	
Eucalyptus polycarpa	Long-fruited bloodwood	250-1750									
Eucalyptus populnea	Poplar box	250-1000, S of 20							X	X	
Eucalyptus tereticornis	Forest red gum	650-3000, S of 15	R	X	X		X		X	X	X
Eucalyptus tessellaris	Moreton Bay ash	400 - 3500	V	X	X	X			X	X	
Eucalyptus tetrodonta	Darwin stringybark	700-1500, N of 18									
Grevillea banksia	Scarlet grevillea	1000-1250	R		X	X					
Grevillea glauca	Bushman's clothes peg	750-1000	R		X						
Grevillea pteridifolia	Golden grevillea	1000-1250	N		X		X				
Lophostemon suaveolens	Swamp mahogany	750-1000	R	X	X		X	X			
Lysiphyllum hookeri	White-flowered bauhinia	500-750	V	X			X				
Melaleuca armillaris		750-1000	R	X	X		X				
Melaleuca bracteata	Black teatree	750-1000	R	X	X		X	X	X		
Melaleuca leucadendra	Long-leaved paperbark	650-1500, N of 24	N		X		X	X			
Melaleuca quinquenervia	Five-veined paperbark	900-1250	N	X	X		X	X	X		
Melaleuca viridiflora	Broad-leaved paperbark	325-1750, N of 25	R		X		X	X			

mm rainfall/yr. ** Drought tolerance: N = not resistant; R = moderately resistant; V = very resistant. X infers a degree of tolerance to the particular soil characteristics. The absence of X does not necessarily imply the converse.

A review of the range of seed coatings available and their effects on establishment is available in Reference 8. When using coated seeds, it may be necessary to adjust seeding rates to compensate for the amount of coating material present.

Seed quality (ie. % germination, purity, presence of weed or undesirable seeds, hard-seededness) needs to be considered. Useful information on seed testing and germination of hard-seeded species (mainly an issue with legume seeds) is provided in Reference 9 and several brochures available from Greening Australia, and from commercial seed testing laboratories (e.g. Seed Testing Laboratory of Australia Pty Ltd, Agritech Laboratory Services Pty Ltd).

For most commercially available pasture seed, details of seed quality are provided at the time of sale and include minimum standards of purity and germination and the maximum allowable weight of other seeds present. Low germination does not always indicate poor quality seed, but may be due to dormancy. It should be recognised that for some grass species in particular, there needs to be a lag time of 6-12 months between harvest and planting because freshly-harvested seed can initially be dormant.

To ensure the required plant density is achieved, the sowing rates should allow for a high proportion of seed loss and seeding failure during establishment.

Sowing rates will vary according to seed quality, site characteristics and proposed post-mining land-use. Seeding rates of pastures can afford to be much higher in situations where there is no simultaneous direct-seeding of tree and shrub species, and for land stabilisation purposes, oversowing rather than undersowing is required. As is the case for determining fertiliser application rates, site-specific field trials are the best means of assessing the most appropriate seeding rates (and indeed species/cultivars themselves) for a given application.

However, care should be exercised in extrapolating the results from one season's trial and incorporating them into a prescriptive revegetation plan, as the rainfall, and hence soil moisture, characteristics of a region will invariably change from year to year.

Sowing should be completed as soon as possible after cultivation and definitely before further rain is received. Simple broadcasting of seed onto a coarsely cultivated surface has proven to be a reliable and effective means of achieving good establishment.

When topography permits, sowing with conventional agricultural machinery, such as a combine seeder or seed broadcaster, is most economical. On steep slopes, hydroseeding can be used. In some situations, aerial seeding may be the most appropriate.

It may also be appropriate to combine some or all the ripping/tyning, fertilising and seeding operations in a single pass. This can reduce costs, and minimise the time between soil treatment and seeding (thereby avoiding the possibility of soil crusting before seeding).

Depending on seasonal conditions, sowing in the October to April period is preferable. The ideal sowing conditions are when sub-soil moisture levels are high, but not so high as to impede the movement of machinery, and when rain is likely within a few days after sowing.

This will inevitably mean that in some years, sowing may have to be delayed or abandoned altogether. Sowing can still occur into a dry seed bed (seed of many species remain viable for months after sowing and will eventually germinate when rain falls) provided that once germination does occur, there is sufficient follow-up rain (or irrigation) to support the emergents.

Sowing activities on neighbouring agricultural properties can be taken as a guide to correct timing, although some considerations applying to commercial farming activities on natural soils are different to those applying to revegetation on mined land.

8.5 Tree Establishment

For large-scale rehabilitation, trees are most economically established by direct seeding, although planting of seedlings can be used for specific purposes. With seedlings, the most reliable results are achieved with tubed stock, four to five months old, which have been "hardened off" in the nursery prior to planting.

To some extent, the agreed post-mining land-use will influence the density and arrangement of planting. For reconstruction of a native species community, the composition and structure of the pre-mine community, as defined by the initial vegetation surveys of the site, will provide guidance on the planting densities. With grazing as the post-mining land-use, scattered timber lots should contain about 20 to 50 individuals planted in a random manner (not in rows or lines) to give a natural appearance. Trees should be spaced having regard to the final size of the trees. The most natural effect will be achieved by planting along watercourses and adjacent to dams or ponds. Thought should be given to future paddock sizes and possible fence locations to ensure that each future paddock will contain several tree lots.

Windbreaks are best planted along ridge lines or proposed fence lines. The best effect is achieved by planting two to three rows commencing with a row of small trees or shrubs and with successive rows planted on the western side containing species which grow to greater heights at maturity.

To help maintain moisture levels and control weed growth, a mulch, preferably organic material like the mulched original vegetation, old lucerne or pasture hay (not containing seeds of cereal crops such as wheat or oats), can be placed around the base of the seedling.

Trees may be planted by hand or with specialised planters, a number of which have been developed and used for revegetation where large numbers of trees are involved or where the availability of labour is a problem.

If practical, young trees should be securely fenced immediately after planting to give protection from rabbits, hares, cattle and kangaroos. Grow tubes and "recycled" bags are also useful for protecting seedlings and promoting plant growth.

If the rainfall pattern is irregular, and the climate generally hot and dry, seeding survival will be improved by periodic watering through the first summer. If seeding/planting techniques are expensive, watering may prove cost-effective, although it may be more economical to retreat failed areas. Specialised watering techniques, such as slow release water bags, inverted bottles, “leaky” containers, and water retaining/absorbent materials (eg. terra-sorb), may be useful in specific applications. A small basin excavated around each tree will improve collection of both runoff and applied water.

8.6 Maintenance

An effective maintenance programme is essential, especially where seed or plants are placed in a hostile environment.

New vegetation must be maintained in order to ensure proper establishment and long term viability. Application of additional fertiliser may be required depending on initial soil levels and status of plant growth. Areas which fail to establish should be investigated to identify the reason for failure and to implement corrective action.

The use of irrigation may be necessary to encourage vegetation growth at selected areas, especially on steep slopes or in drainage lines. Initially, frequent light applications are desirable, then progressively increasing the quantity applied while reducing the frequency.

Slashing may be useful to remove excessive grass growth and assist the establishment of trees. Further issues relevant to the maintenance of new vegetation communities, such as weed control and the use of fire as a management tool, are referred to the guideline on housekeeping on rehabilitated areas.

Maintenance and repair of water management structures, including contour drains, waterways and sediment control structures, is essential. Where erosion has occurred due to inappropriate design or failure of structures, remedial action must be undertaken promptly and the area retreated.

8.7 Specialised Revegetation Methods

Areas which may require specialised revegetation treatment include:

- very steep slopes and dam embankments,
- spillways, watercourses and drains,
- good quality agricultural land,
- other environmentally sensitive areas.

The choice of method will be based on the nature and extent of the area to be treated, and the cost of the treatment (specialised methods are expensive). Methods available include, but are not limited to, the following:

(a) Site Requirements

More careful final shaping, topsoiling, site preparation, species selection and maintenance.

(b) Nurse cropping.

In rehabilitation areas for which the post-mining land-use is largely incompatible with the presence of perennial exotic pastures, the sowing of a “nurse crop” such as cereal rye (*Secale cereale*) or Japanese millet (*Echinochloa crus-galli*) can be beneficial. Such crop species will not persist in the new ecosystem to out compete the desired final vegetation community or to invade the surrounding native areas.

Cereal rye can be sown at 10-15 kg/ha as a nurse crop, but as a stabilisation crop the seed should be sown at 70-100 kg/ha. The grass protects the soil from erosion, gives shelter to smaller sprouting seeds, and as it dies off a useful mulch is produced. Sowing a mix of native seeds and an annual nurse grass crop can assist in the establishment of a vegetation cover faster than if only native seeds are sown.

(c) Jute mesh and bitumen.

Jute mesh or other suitable matting material is useful for steeper sloping land. The mesh is laid after the land has been shaped and seeded with a stabilising cover which will grow up through the mesh. It is held in place by staples pushed into the underlying soil. Bitumen emulsion or other stabiliser may be sprayed over it to secure the mesh more firmly and to provide added soil protection.

Some of the more commonly used mesh mattings are shown in Table 3. Some common chemical stabilisers are shown in Table 4.

(d) Chemical Stabilisation

Chemicals may also be used on their own to physically protect the soil surface (Table 4). These chemicals are generally expensive and only effective as short-term measures to provide temporary protection while plants become established. Any chemicals used should not be toxic to plant growth and should be handled and applied in accordance with the manufacturer’s specifications.

(e) Mulching

Mulching aids revegetation on very exposed sites by providing germinated seedlings with protection from extremes of heat and cold and drying winds. It also reduces raindrop impact, improves infiltration and reduces evaporative losses. Mulches should be chosen carefully and should not contain any weed seeds which may thereby be introduced into the area. Products, such as straw, bagasse, woodchips or shredded bark, can all be used as mulches. Mulched original vegetation can also contribute plant propagules of the existing vegetation. Straw is commonly spread at 2 to 4 t/ha. Hay should not be used as this contains seeds which may become weeds in the area in which the bales are used.

Where erosion is a particular problem, such as on steep slopes, straw or mulch can be held in place by using either non-galvanised 0.9 mm wire netting with a 50 mm mesh, stapled down at intervals of 1 to 2 metres, or any commercially available erosion control matting.

TABLE 3
SOME OF THE MORE COMMONLY USED MATTINGS AVAILABLE IN AUSTRALIA
(From Reference 10)

Trade Names	Product Description
Surface laid products:	
Natural Fibre:	
Dekowe 700 and 900 (Belton Ind.)	Open mesh long lasting woven coconut fibres
Enviromat	Wood enclosed in fine polypropylene netting
Fibermulch	Coconut fibres with polypropylene backing
Geojute	Open mesh woven jute mesh
Jutemaster	Fine jute fibres stitched on to hessian backing
Terramat	Fine coconut fibre stitched on to polypropylene backing
Soil Saver	Medium mesh of woven jute yarn
North American green	Straw/coconut fibre erosion control blank
Synthetic:	
Rheem Multimesh	Woven polypropylene - bio-degradable
Rheem Oystershade	Knitted polypropylene open mesh - bio-degradable
Rheem Shademesh	Woven polyester with different mesh size - not bio-degradable
Rheem Windguard	Woven polypropylene medium mesh, bio-degradable
Sarlon Conwed Net	Fine polypropylene netting used to cover loose mulch
Sarlon Shade mesh	Woven polyester with different mesh size - not bio-degradable
North American Green	Recycled nylon - flexible channel liners
Buried product:	
Enkamat	Fused nylon monofilament spongy mesh

NOTE: Methods of installation are usually provided with each product.

TABLE 4
SOME CHEMICAL STABILISERS AVAILABLE IN AUSTRALIA
(from Reference 10)

Trade Names (or Common Names)	Application Rate	Solubility
Bitumen* (Anionic emulsion)	10,000 - 50,000 L/ha (1:1 mixture)	Water soluble
E.P. Powder (Earth Protection)	250 kg/ha	Water soluble
Soil LOK	2,500 - 25,000 L/ha	Water soluble
Crustex	1,000 - 4,500 L/ha	Water insoluble
Geotech 804 Geotech II	2,000 - 6,000 L/ha	Water insoluble

* Used in sand mining at 3000 L/ha sprayed in a 1:8 or 1:10 mixture.

(f) Hydro-mulching

The technique known as `hydromulching' is most useful in covering steep areas. This consists of spraying the area with a mix of water, appropriate seeds, fertiliser and mulch, such as paper pulp mixed with indicator dye in a water and glue solution. Mixes can also include bitumen and fibreglass. The mix literally `sticks' wherever sprayed, and the dye enables the sprayer to see what ground has been covered. The fertiliser and mulch assist the establishment and early growth of the seedlings. There are a number of firms which specialise in this field, and will make up seed mixes to suit the site being treated.

This technique is relatively expensive but has proved useful in areas too steep for access with machinery.

(g) Brush matting

One method of revegetation, which is appropriate for use in some sites, particularly where sand areas are to be revegetated, is brush matting. Pieces of seed-bearing tea-tree, or other suitable shrub, are collected (from bushes trimmed selectively and not all cut from one small spot) and laid over the newly spread topsoil. About one piece of brush for each square metre is sufficient. The seeds drop out of the brush, the leaves dry and fall off and form a mulch, and the remaining twigs act as sun and wind protection to the seedlings. This is of course not suitable for every site, and tends to be labour intensive, and therefore expensive. It is nonetheless a good solution to revegetate some sites. Additional seeds and/or fertiliser can be added over the matting after it is laid.

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