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Guidelines for Mining in

ARID

ENVIRONMENTS

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DEPARTMENT OF MINERALS AND ENERGY WESTERN AUSTRALIA

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1 Introduction

This Guideline concentrates on the environmental management of mining rather than the administrative processes for obtaining project approval. Information on the preparation of proposal documents (NOIs), and on other government approval procedures, is available in specific Guidelines provided by the Department of Minerals and Energy (Appendix 1).

Mining and mineral processing is a very diverse activity in Western Australia, with different mining methods and processing technologies scattered over a vast State. Mining also takes place in a wide range of environmental contexts which impose particular problems in controlling environmental impacts and constraints on the management and rehabilitation of mined lands.

Approximately 78 percent of Western Australia's land area lies within the arid and semi-arid bio-climatic zones. A variety of minerals including most of the State's gold and nickel and all of its iron ore, copper, manganese and salt is currently extracted from mines in arid areas. Potentially economic uranium and phosphate resources also occur in our semi arid to arid environments.

The challenges to environmental management are best approached from an ecological rather than an 'industry type' engineering perspective. Therefore, this Guideline is focused on the environmental management of mining within the State's vast arid zone.

It is stressed that the information contained within this document is presented as a guideline, and it is expected that individual operators will be innovative in achieving environmental and rehabilitation objectives. As new techniques are developed and information from various case study examples become available, this Guideline will be reviewed.

2 Arid Zone Environments

2.1 GENERAL

Australia is the driest continent and therefore it is not surprising that the majority of mining operations in Western Australia are located in the arid (rainfall <250mm) or semi arid (<350mm) zones. Approximately 388,917 km^2 of Western Australia (15.4 percent of the State) is tropical or Mediterranean semi-desert. A larger 1,593,803 km^2 (63.1 percent) is technically desert. In order to manage projects in these areas it is important to understand the characteristics of Australian arid environments.

As well as being the driest continent, Australia is also the oldest and most eroded. The features of the ancient western shield are erosional, weathered-down lateritic plains and breakaways (shield desert), gibber plains, residual ridges, monadnocks and granite tors. The Hamersley Ranges (Banded Iron Formations) are deep water chemical sediments that have been gently folded and subsequently dissected.

Gravitational processes form colluvium, sediments from erosional processes are deposited by water as alluvium along the drainage lines or by wind as aeolian desert sand dunes.

2.2 RAINFALL/EVAPORATION

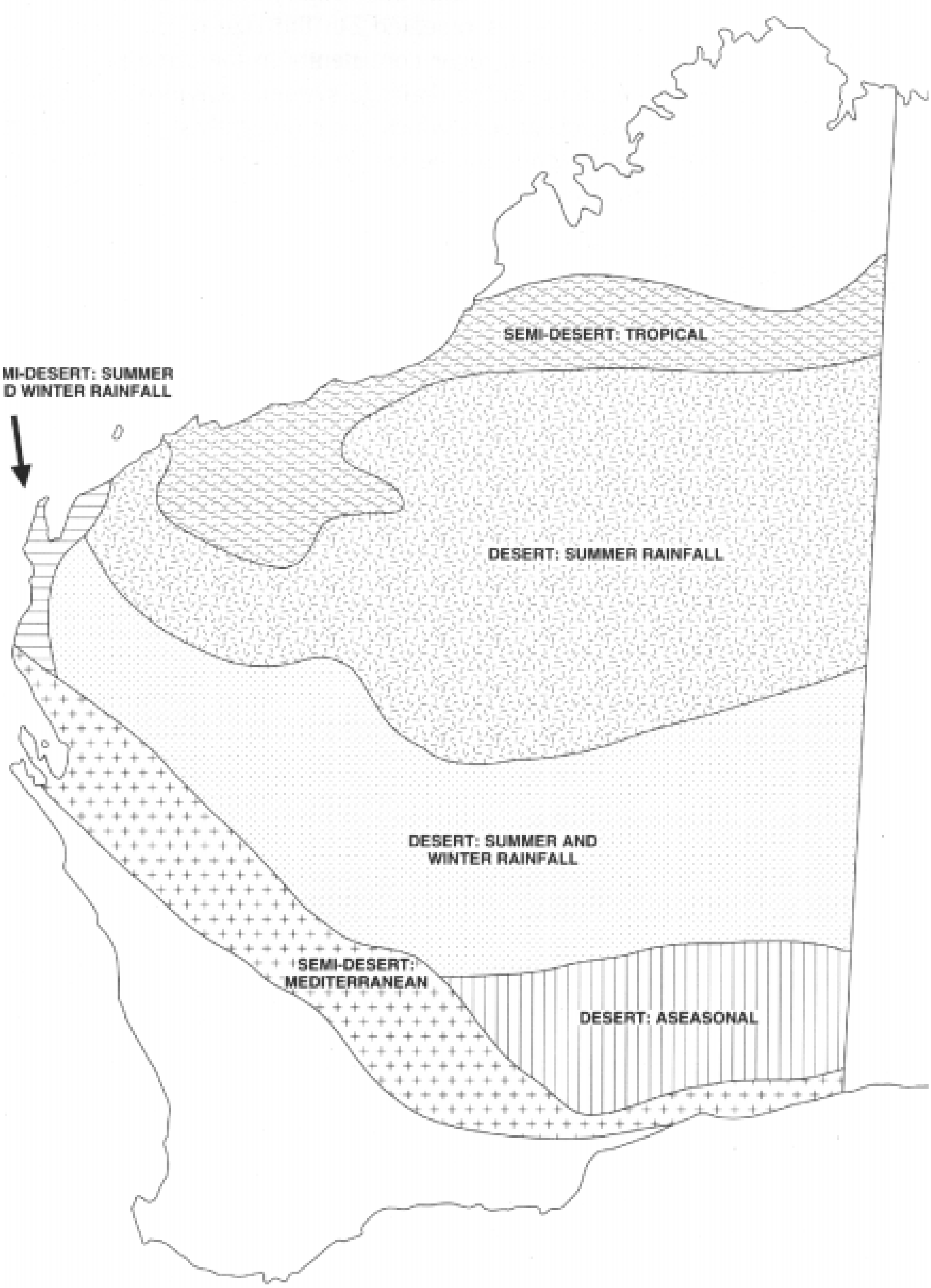
Rainfall in the arid zone is low with large annual variations. Arid environments are nevertheless seasonal with the probability of significant rainfall being higher in particular months. The bioclimates of the arid zone in Western Australia are mapped in Figure 1.1. Broadly, summer rainfall dominates in the Pilbara and central desert areas of Western Australia and winter rainfall in the semi-arid southwest and eastern goldfields. The broad intervening area of mid-western Australia, the mulga zone, is a transition zone between winter and summer rainfall dominance. Within this zone both winter and summer rainfall events contribute significantly to biological productivity.

Evaporation rates of arid environments are many times that of rainfall. A consequence of this is that airborne salt of marine origin (cyclic salt) deposited in rainfall, becomes concentrated in the soil profile, in the weathered geological profile or in groundwater. Many inland drainage lines terminate in salt pans or playa lake systems (which are hypersaline environments).

2.3 SOILS

Soils in the arid zone are generally shallow, often skeletal, and show little vertical structure due to a lack of organic matter. They are heavily weathered, containing mostly insoluble elements such as iron and aluminium (hence the reddish colour) and are of low fertility (often deficient in phosphorous, potassium and trace elements). The red-brown earths of much of the mulga zone are slightly acidic to neutral in pH (6.0-7.5) but basic soils occur near outcrops of calcareous rocks such as calcrete or dolomite (pH 8.0-9.0). Changes in soil type can be clearly identified by their distinctive flora.

FIGURE 1.1 THE ARID AND SEMI ARID ZONES OF WESTERN AUSTRALIA AND THE BIO-CLIMATE OF THE ZONES WITHIN THEM



2.4 LAND SYSTEMS/VEGETATION

Arid zone land systems are clearly defined by the landforms and drainage lines. Creek systems frequently occur in repetitive cycles with each unit consisting of tributary channels, main channels and distributary (outwash) channels. With decreasing elevation the pattern is repeated but the size of the creek systems is magnified. Vegetation types often recur consistently in the same part of the creek cycle but at different elevations in the drainage system. A typical example are the groved stands of mulga, *Acacia aneura,* which occur on gently sloping outwash plains varying in area from less than one square km, in early creek cycles, to hundreds of square kilometres in later ones.

Vegetation density indicates the patterns of water concentration and storage created by the landform. Biological productivity in the arid zone is dependent on drainage effects. Most vegetation survives and grows solely on the water stored in less than a metre of soil beneath the plants, which is replenished by intermittent rainfall events and surface water (sheet) flow.

Phreatic vegetation types, with deep roots tapping groundwater, are generally confined to the gravels of major creek channels (river red gum, *Eucalyptus camaldulensis,* is an example). Therefore, **interference to the surface drainage regime can have far reaching ecological consequences**.

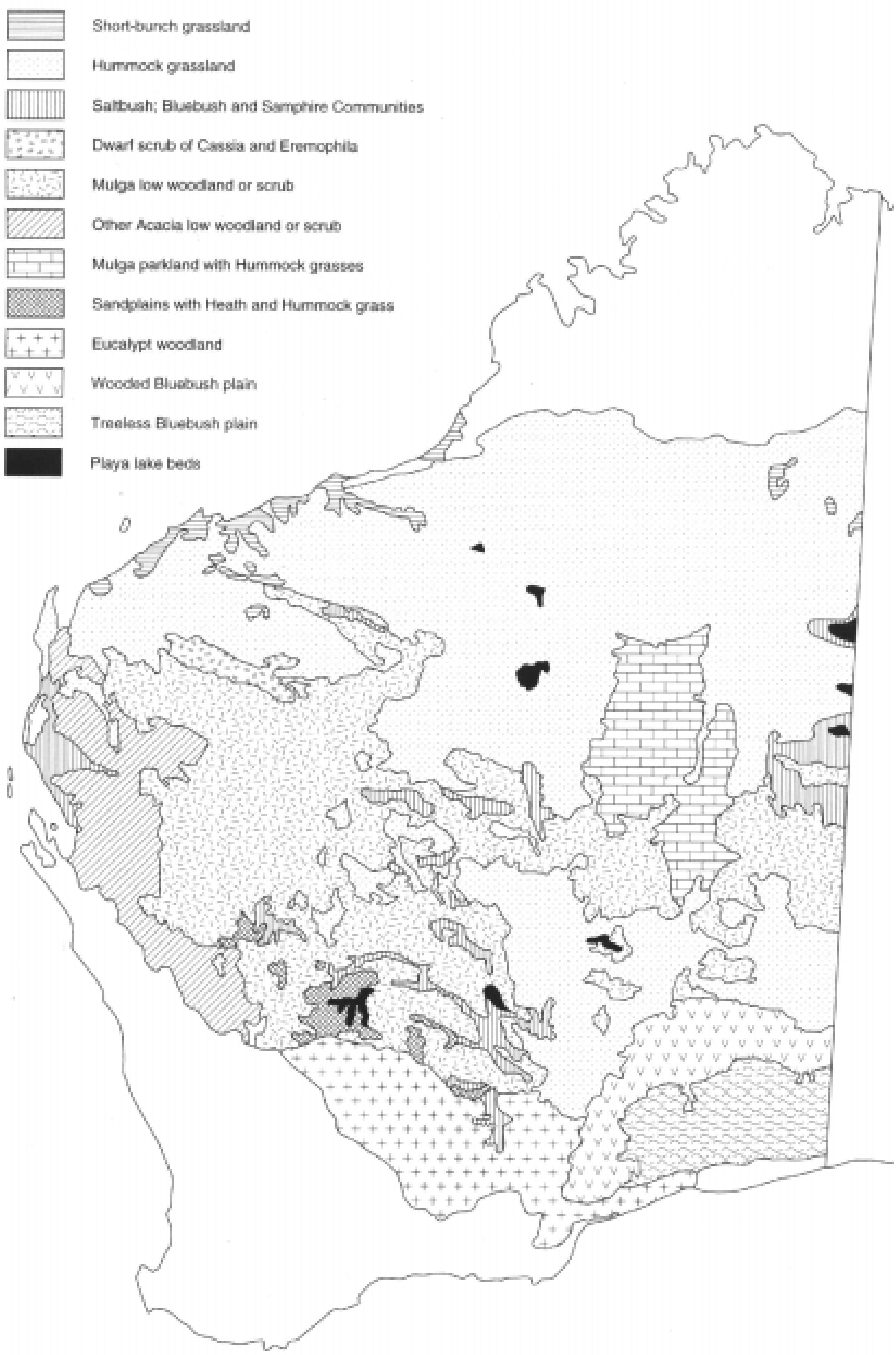
The low water storage capacity (shallow/sandy nature) of many arid zone catchment soils often leads to creek flows after relatively little rainfall, depending on the intensity of the rainfall event. This is important in re-charging semi-permanent pools in creek lines which are pivotal to the behaviour and survival of some desert wildlife such as macropods (kangaroos), large monitors (goannas), bats and seedfeeding birds (pigeons, cockatoos, parrots, finches, bowerbirds). Often, assemblages of artefacts show that such pools were also foci for Aboriginal man. Surface water sources need not be permanent to be of biological, archaeological or ethnographical significance.

The dominant vegetation ‘formations’ of the arid zone are eucalypt woodland, eucalypt scrub or ‘mallee’, mulga (*Acacia aneura*) woodland, *Acacia* scrub (mulga or bowgada *Acacia linophylla*), hummock grassland (*Triodia* or *Plectrachne spp*), bunch grassland and chenopod (saltbush and bluebush) low scrub. Figure 1.2. shows the distribution of the broad vegetation types in arid Western Australia.

Eucalypt woodlands or mallees dominate the semi-arid, winter rainfall zone bounding the sub-humid southwest (e.g. much of the eastern goldfields). The mulga-eucalypt line divides the winter rainfall zone from the winter/summer zone dominated by *Acacia* woodlands and scrubs. The western mulga, dominated by *Acacia aneura,* covers the inland Murchison, Gascoyne and the southeastern Pilbara. Within the mulga zone, spinifex dominates the drier sandplain habitats.

Hummock grassland, or spinifex, gradually replaces the mulga to the north and east where summer rainfall dominates and maximum ambient temperatures are very high. Mulga persists in the sub-tropical deserts only in moister, protected habitats. Bunch grasslands dominated by a range of short, soft, tussock forming grasses occur

FIGURE 1.2 VEGETATION TYPES OF ARID AND SEMI-ARID WESTERN AUSTRALIA



in patches over much of the arid zone, principally over clay pans or on ‘cracking’ (expansive) soils.

Low chenopod scrubs are also widespread in the arid zone. Chenopods are succulent shrubs and herbs most of which are adapted to varying degrees to saline soil conditions. The widespread forms of chenopods are saltbushes (*Atriplex spp*), bluebushes (*Maireana spp*) and samphires (*Halosarcia* and *Sclerostegia spp*) and these are the mainstay for sheep grazing in the arid zone pastoral industry.

2.5 FAUNA

The mosaic of vegetated and open spaces characteristic of arid habitats favours fauna such as ants, termites and reptiles. These are the most abundant and diverse desert animals. Australian deserts are much richer in lizard species than comparable arid environments elsewhere on earth.

Arid zone animals are more mobile than their counterparts in more mesic environments in order to exploit the more scattered and unpredictable food resources.

Particular environmental features may however be vital in the survival of local wildlife populations. In any given area these may include:

a) Stands of denser vegetation where soil moisture is concentrated
b) Stands of denser vegetation protected from fire, particularly mature hummock grassland
c) Gallery woodland with large tree hollows
d) Permanent or semi-permanent surface water
e) Rocky hills, ridges and gorges
f) Breakaways and rock shelters
g) Deep caves, adits or shafts, and
h) Cracking soils.

2.6 CULTURAL

The need for food, shelter and water also influenced the behaviour of Aboriginal man and artefacts can be expected in the vicinity of these resources. Aboriginal ‘quarry’ sites, where stone was extracted for the manufacture of implements, may occur where there are outcrops of fine grained siliceous rocks (such as chert, silcrete, quartz, chalcedony and metabasalt). Ochre was mined from caves in lateritic rocks.

2.7 FIRE

Aboriginal man made extensive use of fire in some parts of the arid zone to modify habitats for hunting. Many of the extinctions of desert mammals, which took place following European settlement, have been attributed to the loss of the Aboriginal fire mosaic. Fire is a particularly important factor in the ecology of the hummock grassland areas and at the interface between the hummock grasslands and the mulga.

3 Baseline Studies

Appropriate pre-mining baseline environmental studies are fundamental to responsible project management. Frequently the information gathered to prepare proposal documents and to obtain government's approval is inadequate for environmental management purposes. In other cases useful information is collected during the pre-development phase but it is not translated into knowledgable operational practices and procedures. This latter failure usually results from a lack of continuity between personnel involved in project planning and development and those with ultimate operational responsibility.

Baseline investigations underpin all the subsequent stages in environmental management and mined land rehabilitation. They are pivotal in making the decision about post-mining land use, in operational site planning, in avoiding unnecessary secondary impacts, in rehabilitation planning and in developing ecologically based monitoring programmes and completion criteria. For any major operation, baseline studies may be expected to span at least one year and should be commenced at the inception of the project and preferably during the latter stages of exploration.

3.1 Site Assessment

The objective of site assessment is simply to determine where things are located in relation to the orebody, the tenement boundaries and the alternatives for the location of mining infrastructure.

The locations of mineral resources are obviously fixed but no decision should be made about mining methods, the tailings structures and the location of processing plants, overburden dumps, haul roads, camps, etc, without reference to their impact on the natural features of the landscape. The following checklist will be useful for site assessments in an arid environment. Relevant features should be mapped onto a base plan to be overlayed later with alternative project layouts:

1. Tenement boundaries
2. Position of orebody
3. Contours and prominent landscape features
4. Drainage patterns, including unconfined sheet flow directions
5. Broad vegetation types
6. Any special environmental features:
   a) Productive environments where moisture is concentrated: creeks; mulga groves; etc.
   b) Locally restricted plant and animal habitats
   c) Localities where rare, endangered or vulnerable species have been found to occur

d) Geological or biological 'type' localities of scientific importance
e) Permanent or semi-permanent surface waters
f) Rock shelters and caves
g) Old and current underground workings
h) Historical buildings, machinery
i) Sites of mythological significance to Aboriginal people
j) Sites with Aboriginal cultural materials or artefacts
k) Pastoral improvements.

The biological resources over much of arid and semi-arid Australia are poorly known. Existing published and unpublished records of plants and animals from many areas will be inadequate for site assessment purposes and the proponent should be prepared to carry out a thorough flora and vertebrate fauna survey. Similar generalisations apply with respect to Aboriginal sites.

3.2 Overburden and Tailings Characterisation

The overburden of topsoil, subsoil and waste rock excavated during open-cut mining operations will ultimately be used to construct the post-mining landforms and to provide a substrate for revegetation. Some shallow alluvial operations may not produce waste rock and there may be little or no soil material available to cover the mullock from underground mines. Understanding the characteristics of the overburden materials is essential for making informed post-mining land use decisions and for planning landform re-construction and revegetation. It also avoids double-handling or poor rehabilitation results in later years. The overburden and tailings may also have the potential to generate Acid Rock Drainage and therefore may require special disposal strategies.

3.2.1 Waste rock

The characterisation of waste rock should be carried out at the earliest opportunity. Frequently this can be done prior to any excavation by looking at the drill hole geology from a geomechanical and geochemical perspective. Bulk sample cuttings, adits and old workings are also useful reference areas for information on waste rock types and the weathering patterns of these materials once they are exposed. Most schistose wastes from the Eastern and Murchison Goldfields weather to friable mine soils with high clay or kaolin content. These can become sodic and waterlogged if not treated correctly. There is rarely sufficient erosion resistant (competent) rock material which is suitable for armouring dump surfaces.

Conversely at Telfer, much of the overburden is blocky, erosion resistant sandstone. Here there is little prospect of retaining moisture on the dumps or developing a mine soil suitable for revegetation but there is a vast source of material for armouring the more erodible waste rock. Physical characterisation of the waste should determine which of the two broad options for surface stabilisation, revegetation or rock armouring, is most appropriate for the given situation.

Saline and sodic (sodium saturated) waste rock is a common problem in arid Western Australia, particularly so in the salinaland areas of the eastern Goldfields and the eastern Murchison. Substrates with E.C. (electrical conductivity) in excess of 400 milliSiemens/ metre are difficult to revegetate. Most of this salt is of atmospheric origin, is interstitial and as such cannot be predicted from the geology. Once dumped with the waste rock it is often quite mobile, leaching and/or washing out of parts of the mine landform and concentrating in others. In most circumstances this salt must be prevented from entering natural surface drainages and it should not be spread over the dump surfaces if revegetation is to be successful in the long term.

Generally, salinity increases with depth within the weathered rock profile but this trend can be complicated by groundwater patterns. Fresh cuttings from drilling programmes can be used to determine salinity levels in waste rock materials prior to mining (Figure 3.1). Although water used in drilling, or intersected within the hole, may make measuring actual salinity levels difficult, relative salinity levels can be determined. This information can then be used to develop overburden dumping sequences which minimise the amount of salt near the surface of the dump, where it could affect revegetation.

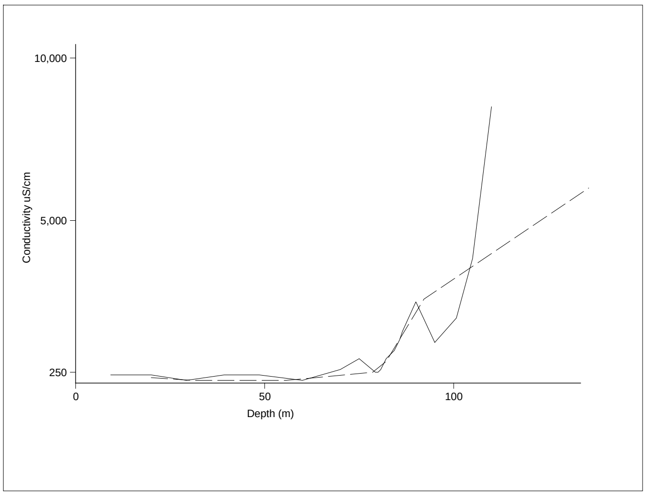


FIGURE 3.1 PROFILES OF INTERSTITIAL SALT IN CUTTINGS FROM TWO DRILL HOLES THROUGH A MURCHISON OREBODY.

Most saline/sodic mine wastes from arid Western Australia range form slightly alkaline to pH levels in excess of 10. Even deep wastes from sulphidic ore bodies tend to be chemically buffered.

Soil pH is an important factor in determining which plant species should be selected for revegetation,. For example, some halophytic (salt tolerant) bluebush plants, which may be useful in the revegetation of saline mine soils, often grow naturally in slightly acidic environments. Mulga communities which dominate so much of central Western Australia generally occupy slightly acidic soils. Alkaline soils generally do not impede nutrient uptake in plants, as do some highly acid soils like coal spoil.

Problems with toxic levels of metals are also unlikely, as at high pH these are not available for uptake by plant roots even though they may be at high concentrations in the waste rock. However, if breakdown of the material occurs and they are released to the environment (through acid rock drainage) they could become toxic contaminants to surrounding soils and vegetation.

Along with salinity and pH, physical characteristics of the waste rock will limit its potential as a growth medium. An analysis of particle size distribution in the waste is useful to predict its capacity to infiltrate and store water, leach salt and provide for plant root penetration. Particle size will also influence the way the material responds to handling and particularly to compaction. Information of this type should again influence the selection of surface materials for the waste dump and the choice of machine handling methods.

Waste rock will inevitably be low in macro-nutrients (N,P,K) but particularly nitrogen and phosphorous. However, nutrient analyses are best undertaken prior to just commencing the revegetation programme, rather than during the pre-development phase. The handling, storage, weathering and exposure to biotic factors of the waste materials will change nutrient levels over time. Nutrient deficiencies are relatively easy to correct at the appropriate time and much of the indigenous vegetation is well adapted to poor soils (albeit with the assistance of mycorrhizae in many species). The leguminous and proteaceous plants are often intolerant of high nutrient applications, but in contrast, eucalypts and saltbushes often respond positively to nitrogen based fertilisers.

3.2.2 Topsoil (“Growth Medium”)

Arid zone soils are frequently shallow and stony (commonly referred to as “skeletal”) with little organic matter to produce well defined horizons. However most desert plants produce numerous, resistant seeds which accumulate in soils. Some seeds are gathered by ants and buried in their nests where they escape the effects of seed predators, desiccation and fire. This appears to be especially important for the seeds of the dominant hummock grasses or Spinifex (*Triodia*) which are harvested by species of *Meranoplus* and *Melophorus* ants. The use of fresh topsoil remains the best way known to regenerate spinifex in mine rehabilitation areas.

Prior to project development all topsoil resources from areas to be mined, cleared, buried or otherwise disturbed should be identified, characterised, mapped and the quantities estimated. Each source should be characterised according to:

a) The composition of the standing vegetation above it

b) Soil texture and depth

and c) pH and salinity.

This information is invaluable for rehabilitation planning. If the available depth of harvestable material exceeds about 15cm, the material should be allocated to topsoil and subsoil classifications. Those two horizons may be utilised in different ways. Material which is excessively sandy (>70% sand or gravel), clayey or saline may not be suitable for waste dump rehabilitation, although it may have useful applications elsewhere.

3.2.3 Mycorrhizal Fungi

Mycorrhizal fungi (both ecto - and vesicular arbuscular mycorrhiza (VAM)) are a natural component of the ecosystem in all soils. Research undertaken over the last 10 years by Dr David Jasper and his associates at the University of WA has indicated that the key plant species used for revegetation at minesites will naturally form associations with mycorrhizae in undisturbed soils.

It has been shown that mycorrhizae are absent or at very low levels in disturbed native soils, topsoil that has been stockpiled, mine wastes and overburden. Even directly returning topsoil to a new area can significantly affect viability of the mycorrhizae.

Mycorrhizae can increase phosphorus uptake and consequently improve growth rates in vegetation. Maximum phosphorus uptake early in the revegetation phase helps establish a substantial pool of phosphorus in the biomass for subsequent recycling.

Encouraging the introduction and/or retention of effective mycorrhizae will ensure maximum plant diversity by increasing the opportunity for highly dependent plants to become established.

Fungi that are effective in increasing uptake in soils can be selected from each minesite and can be prepared into an effective moculum in a form suitable for field application.

To retain the maximum amount of mycorrhizae in stored topsoil, the stockpiles should not be more than one metre in height. Loss of propagules will be greatest in deep stockpiles stored for a long time. Rhizobia can also be severely adversely affected by stockpiling.

The research work has shown that the rate of recovery of mycorrhizae in respread stockpiled soils may depend on the level of mixing with surface soils during the respreading procedure. Spreading of mycorrhizae as an inoculum can be undertaken by growing a small area of cover crop, collecting and cutting root sections and spreading and burying the cuttings over the topsoiled areas. Advice on this should be obtained from Dr Jasper.

3.2.4 Acid Rock Drainage

Most of the greenstone hosted gold mines in Western Australia have limited potential for the development of acid rock drainage. This is due to the extensive carbonate alteration often associated with gold mineralisation in the Archaean greenstone belts. The carbonates present in the deposits often have the capacity to neutralise any acid produced by the weathering of sulphides contained in the ore bodies. While this may limit the potential for classic low pH acid rock drainage, the potential for the release of other metals and contaminants will vary depending on the specific geochemistry and environmental conditions of each deposit.

Polymetallic massive sulphide deposits may have high potential for the development of acid rock drainage and should be carefully scrutinised.

All mineral deposits should be carefully evaluated to assure the potential for acid rock drainage is identified in all waste units to be handled, even where the metals or materials being recovered are not specifically associated with sulphide mineralisation.

The arid to semi-arid climate and topography of WA combine to make it unlikely that widespread problems related to acid rock drainage that accompanied mineral development in the Western United States, Canada, Europe and Scandinavia, and more temperate or tropical portions of Australia will develop. Problems in WA are likely to be restricted to lands adjacent to the site of disturbance. The lack of water to serve as a contaminant transport mechanism means that impacts are likely to be restricted to reclamation success, nearby native vegetation and immediate groundwater supplies (where groundwater is suitable for beneficial use). These impacts can be locally severe and persistent. The limited annual precipitation, extensive periods of drought coupled with rare major precipitation events will likely mean any potential problems will take a correspondingly longer time to develop than is true in a more temperate environment. Consequently, problem sites may not be recognised for many years. This emphasises the need for appropriate waste characterisation work prior to the initiation of mining activity.

The following measures are recommended in order to limit adverse environmental impacts related to acid rock drainage:

1. All NOI's that involve above ground disposal of waste material should include preliminary waste characterisation work as part of the NOI submitted to the Department.
2. Additional waste characterisation will be necessary when the preliminary characterisation work has identified a potential ARD problem. The additional waste characterisation work may include a continuing comprehensive program of static testing.
3. Sites where characterisation work identifies a potential for ARD must be closely evaluated for long term engineering stability and water management of all sulphidic material. Rehabilitation emphasis must focus on the durability of the proposed cover system used to isolate sulphidic materials.
4. Operator monitoring plans should be developed for sites where static or kinetic testing has identified a problematic unit. These plans should focus on the measures to prevent adverse impacts that might result from ARD throughout the project life.

3.3 Ecological studies

In order to meet the requirements of the environmental assessment process proponents often provide inventories of plants and animals recorded from project areas. Such information is of value in assessing the environmental impact of a project. However little of it is particularly useful for environmental management or for the planning, monitoring or assessment of revegetation programmes.

At present in arid Western Australia, mined-out land generally reverts to its original land use. This usually implies return to the natural ecosystem which may or may not be used as rangeland. Management of rehabilitated areas is generally discontinued once mining ceases. Revegetation must be directed towards self-perpetuating systems which will be integrated with the surrounding natural habitats.

There are two lines of local ecological investigation which should be undertaken if self-sustaining vegetation is to be established on mined lands.

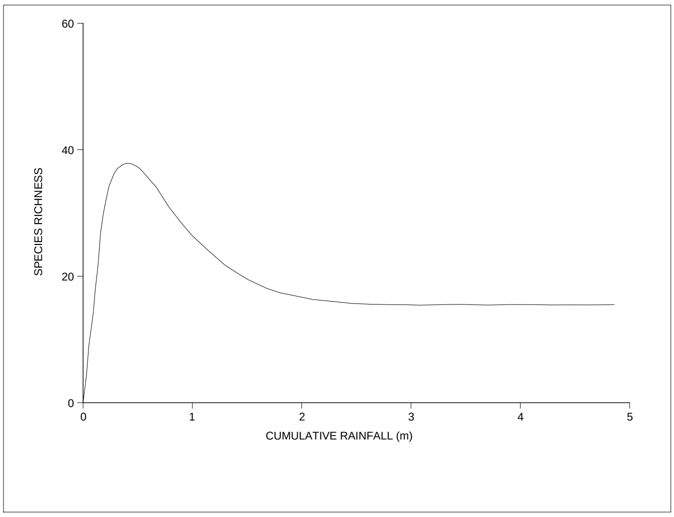
Plant species must be selected from at least the same bioclimatic region and preferably from the local area. Seed should be collected from plant populations which share the same seasonal temperature and rainfall regimes to ensure appropriate growth responses, flowering times, seed set, etc. Mine substrate/soil conditions can be difficult to match with plant species from similar natural environments, especially if the material to be revegetated is fresh rock, mined at depth, and left untopsoiled. One may have to look further afield than the mining tenements to search for suitable species, whilst staying within the same bioclimatic zone. Studies of the soil and moisture conditions controlling the distribution of plant species in the local environment are an important baseline for revegetation planning.

The second important line of investigation is into local natural regeneration cycles or ‘succession’. These provide models for the planning programmes and assessment of revegetation.

In northern and eastern arid areas of the state, hummock or spinifex grasslands dominate the landscape. In these ecosystems the hummock grasses are ‘keystone’ species which influence, directly or indirectly, the distribution and abundance of the vast majority of plants and animals. As a consequence vegetation on most rehabilitated mine environments is unlikely to be sustainable unless it culminates in hummock grassland cover. Unfortunately the hummock grasses Triodia and Plectrachne spp have proved to be difficult to propagate on mining landforms, except where fresh topsoil has been available for spreading. Investigations of local regeneration cycles are important to determine how plant species recolonise in the field and which pathways are involved in developing a self perpetuating vegetation cover. In the hummock grasslands fire is the initiator of most natural regeneration cycles.

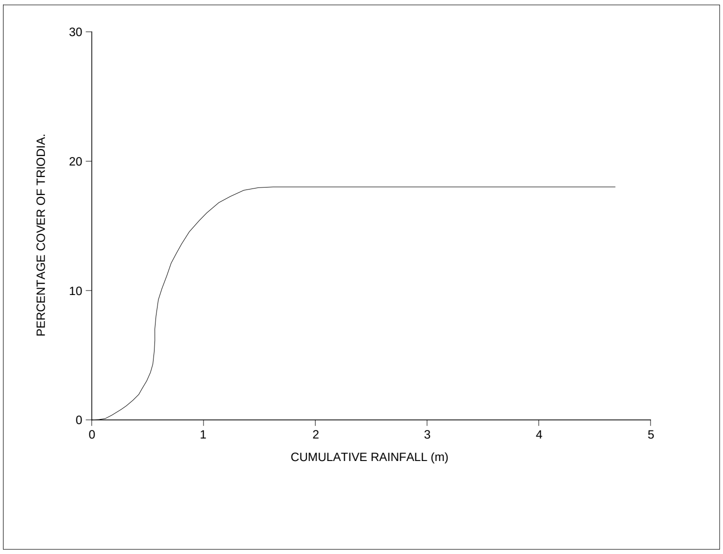
Mine environments should be matched as closely as possible with natural ones, particularly with respect to position in the landform and moisture status. It is important to recognise that rainfall drives the rate of regeneration in arid environments and progress should always be assessed against rainfall rather than on a time scale. It follows that good rainfall records are necessary to investigate local regeneration cycles and to monitor revegetation.

FIGURE 3.2 TREND IN SPECIES RICHNESS IN A TYPICAL HUMMOCK GRASSLAND FOLLOWING FIRE.



The regeneration of *Triodia pungens* communities around Newman in the Pilbara region, has been investigated. It was found that the seasonal timing of fire had little overall influence on the regeneration pathway. The rate of regeneration is dependent on cumulative rainfall. Initially, in the absence of spinifex cover, a relatively large number of plant species contribute to the vegetation. As the cycle progresses, and the hummock grass becomes dominant, most other species disappear although they continue to be represented in the seed bank (Figure 3.2.). Ultimately the hummock grass becomes dominant occupying about 20% of the ground surface (Figure 3.3). Successful revegetation depends on mimicking these trends as closely as possible. The results of these investigations cannot be extrapolated widely, due to variations in the species present, local bioclimates, site types etc. Local regeneration cycles should however provide predictive information for assessing revegetation success including ‘expected’ values which can be developed as objective completion criteria.

FIGURE 3.3 TREND PERCENTAGE COVER OF THE HUMMOCK GRASS IN A TYPICAL “SPINIFEX” COMMUNITY FOLLOWING FIRE.



Similar investigations are equally relevant to rehabilitation programmes in mulga, bluebush or eucalypt woodland. Invertebrate animals play an important part in soil development, pollination, seed dispersal, pest control and other essential processes in a sustainable vegetation system. The presence of some groups, particularly ants, termites, collembula and spiders, are an important indicator of ecosystem development. Studies of local invertebrate and vertebrate animals during the pre-development stage may contribute significantly to later rehabilitation planning, monitoring and assessment.

4. Land Use Objectives

At present, most of arid and semi-arid Western Australia is Crown Land which includes pastoral leases, National Parks and Aboriginal or Nature Reserves. Post-mining land use in these areas generally reverts to maintaining the natural ecosystem or rangeland. However there is no reason why other innovative land uses should not be considered in some circumstances. Mechanisms do exist for converting mining leases to special Land Act leases for the maintenance or sale of managed post-mining enterprises or activities.

The pre-development baseline studies should provide an indication of post mining land capability, although this may be refined later by the experience gained early in the rehabilitation programme. The next step is one of consultation beginning at the local level. Pastoralists, Aboriginal communities, Land Conservation District Committees and other local conservation groups, neighbouring miners or prospectors and Shire Councils may all have an input to select the preferred post-mining land use(s).

Such consultations will probably include safety as well as environmental considerations. Broad agreement at the local community level is most important to arrive at land use/ rehabilitation objectives.

Once potential land use objectives have been established, consultations should begin with the decision making authority to determine if there could be any technical or administrative impediments to the proposals. In most cases the decision making authority will be the DME but in environmentally/socially sensitive areas it will be the Environmental Protection Authority (EPA).

5. Site Planning

Once the environmental features of a project area have been identified and located, the objectives for post-mining land use have been set, then site planning can commence. In arid environments attention to the patterns of surface drainage is an important consideration in the location of facilities. Natural drainage is usually poorly coordinated and vast areas are flooded following intense rainfall events. Valley floor vegetation, mulga in particular, is dependent on subtle catchment characteristics which concentrate water. Groved stands of mulga occur within parts of the landscape which receive water as sheet flow. Poor siting of roads, embankments, trenches or pipelines can interfere with this sheet flow, may lead to drainage shadows and ultimately, the death of stands of vegetation over large areas.

Special attention should also be given to the identification of groundwater systems, both from a resource and an environmental protection point of view. The depression (reduced level) of unconfined aquifers by mine borefields or dewatering programmes can cause the death of creekline (phreatic) vegetation.

In positioning the site infrastructure the following points should be considered:

- Minimise sterilisation of ore reserves
- Minimise transport distance from the pit face
- Minimise impact on any neighbouring residential area including company living areas
- Minimise visual impact
- Incorporate noise screens
- Use wind and dust shields
- Minimise destruction of existing vegetation and natural land forms
- Avoid significant environmental features or areas
- Avoid areas of significance and sensitivity to Aboriginal people
- Avoid areas of other cultural significance
- Minimise rehabilitation costs.

Some facilities such as waste dumps and tailings storage facilities are major permanent changes to the landscape and the design and location of these structures requires special consideration.

The design of the waste dump should include the potential for progressive rehabilitation to ensure a minimum area of disturbance at any one time and to establish final rehabilitation goals at the earliest opportunity. Alternative uses for part of the material, such as in bunding, landfill, tailings storage walls or road construction, should also be considered.

The location of waste dumps should be considered along with siting of tailings storage(s). If possible, dumps should be located adjacent to storages to have materials available for tailings rehabilitation and reduce costs.

The area of land required for waste dumping is an important consideration as it is essential to ensure that sufficient land is available. Adjoining land may have to be pegged or purchased to accommodate all the material moved. Obtaining extra ground may seem expensive, however, it is usually much cheaper than rehandling overburden at a later date.

The following basic objectives for waste dumps need to be considered in the planning phase so that the parameters of final design can be considered early in the life of the operation:

- Where possible (e.g. if open-pit design permits, or more than one open-pit is proposed), waste rock should be returned to previously excavated areas
- The height, area and shape of the waste rock dump should be designed with regard to the area of land available, the general topography of the area and the vegetation in the area
- Waste materials should be handled only once
- All completed surfaces of the waste dump should be stable and able to resist long term erosion
- Topsoil salvaged from the advancing waste dump should be immediately spread on prepared (re-shaped) waste dump surfaces
- Previously stockpiled subsoil and topsoil should be spread on all completed surfaces where practicable and re-vegetated with suitable vegetation
- Design and construction of the waste dumps should be such that the completed outslopes do not exceed 20^{o} from the horizontal
- Surface drainage structures should be constructed to control (and infiltrate) heavy rainfall events. (Provided infiltration will not lead to Acid Rock Drainage or other adverse leachate (saline) in the future).

In meeting these objectives, consideration should be given to the aesthetics of the constructed waste dump. The long distance perspective of the shape and colour of the dump in relation to the surrounding landscape needs to be assessed from the main access ways and viewing points around the site. At close range the view of the dump area should provide the viewer with an impression that the area has been rehabilitated to blend with the natural landform. The view should also indicate that the dump supports a stable vegetative cover similar to the surrounding area.

These factors should be established as long term objectives and planned from the beginning of the operation.

The site selection process for tailings disposal areas requires careful consideration and is discussed in detail in a separate DME Guideline (Appendix 1). However, it is appropriate to present the basic environmental objectives in this section. Tailings facilities are required to be:

- Non-polluting while in operation and following de-commissioning
- Stable in the long term from both an engineering and an erosion view point and be maintenance free
- Compatible with the surrounding landscape following decommissioning and rehabilitation.

There are many ways for these objectives to be met, however it is essential that appropriate design, construction and management of the tailings facilities are carried out.

The location of the other mine facilities such as the plant, workshops, offices and in some cases the accommodation area, all need to be considered. It is stressed that the site conditions and the local environmental factors to be detailed in the site assessment should provide assistance in locating these facilities.

Large aerial photographs are an excellent tool to assist in planning the placement of facilities, structures and showing (tenement) boundaries.

Prior to locating the various facilities in concept form, a clear understanding of the required dimension of each is essential. All the facilities and infrastructure which needs to be developed should then be arranged on a trial and error basis to evaluate the advantages of each. In this way a final conceptual plan can be developed. Figure 5.1 shows a typical site plan at an hypothetical arid zone location.

During this planning process, it is necessary to consider the possibility of preserving buffer strips of vegetation. The buffer strips can be used to separate activity zones and can provide improved aesthetic quality to the site.

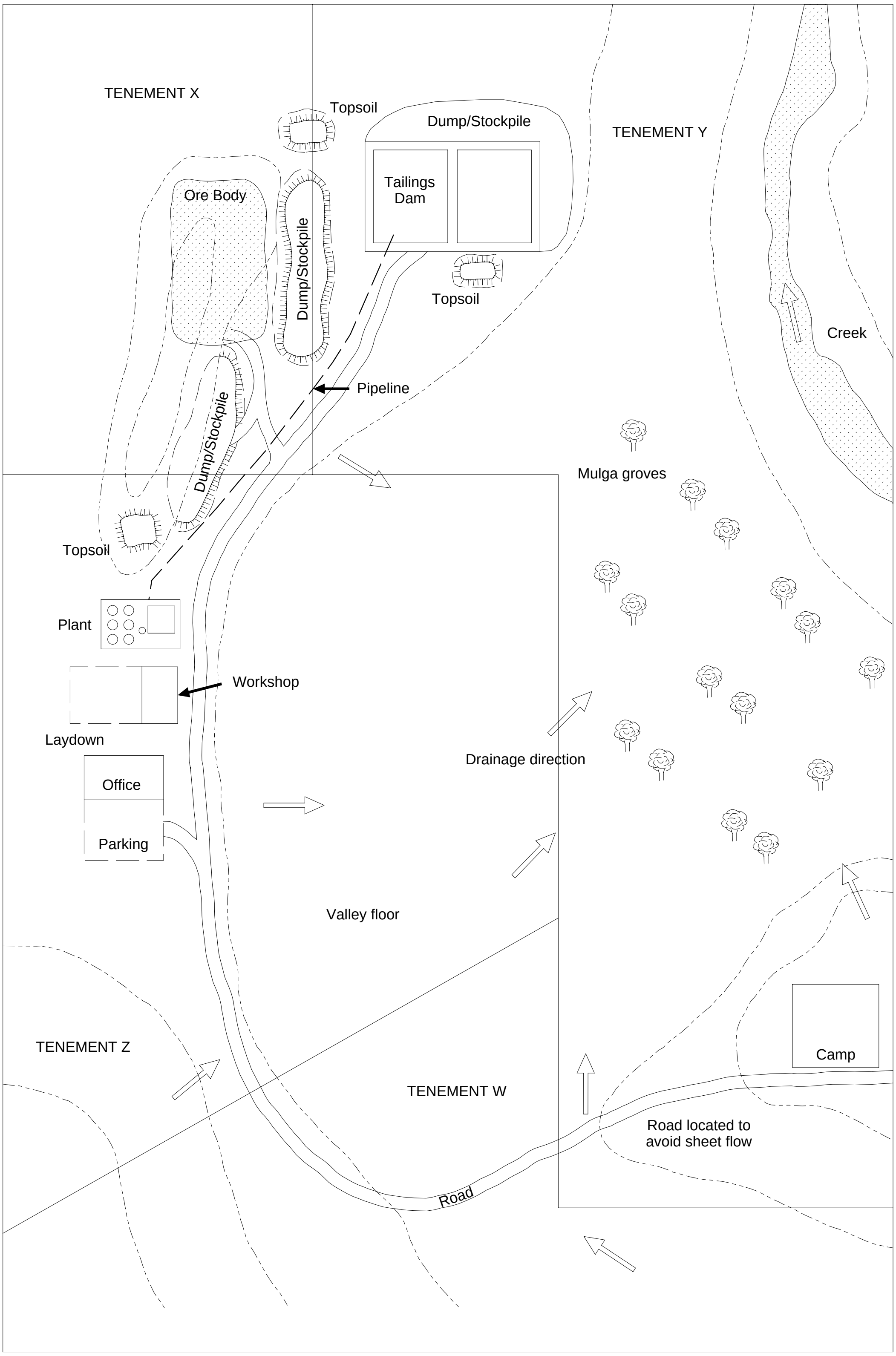
Once the site plan has been refined and finalised it is essential to clearly establish the volume of recoverable topsoil to be pre-stripped from development areas. This figure needs to be compared with the total area of disturbed land which will need rehabilitation during the life of the mine. In addition, the material needs to be characterised as described in Section 3.2.2. A minimum stripping depth of 200 mm is recommended and where possible this depth should be increased. Separate stockpiles of topsoil (including vegetation) and subsoil may be required. Topsoil management will be discussed in more detail later, together with other techniques for rehabilitation.

It is cost effective to integrate environmental and rehabilitation aspects of the operation with daily mine operations. Rehabilitation delayed until mine closure is imminent is not cost effective, the costs will be greater and the rehabilitation options will be reduced. Only the obligations will remain the same.

Other site planning considerations that need to be addressed include water supply, waste water disposal and rubbish disposal. One particularly important consideration is the impact the project will have on neighbours and other landusers of the area, for example, pastoralists. Agreements with pastoralist and Shire regarding road access, fencing and public health matters may need to be established.

In summary, proper evaluation of environmental factors in the planning phase of a mining operation can achieve considerable environmental and financial benefits to both the operation and its final decommissioning.

FIGURE 5.1 A SITE PLAN IN A HYPOTHETICAL ARID ZONE ENVIRONMENT.



6 Operational Management

The construction and operation of the mining operation is often undertaken by personnel not involved in the pre-development studies, the discussion on land use objectives or site planning. It is important that thorough planning is translated into consistent operational management. This requires effective internal communication through all levels in the organisation. It is tempting for managers charged with getting projects operational, or later for maintaining production, to put aside long term land use objectives believing that these can be picked up again at a more convenient time. In reality, land use options are frequently reduced by poor operational management. The rehabilitation costs can escalate significantly if earthmoving is not integrated with the mining operation during the life of the mine. Secondary impacts such as pollution caused by poor operational environmental control may result in long-term liabilities for the company.

6.1 Topsoil Harvesting

The first material to be moved with each new stage of a mining operation is the topsoil. In many situations this material **is the most important resource** in land rehabilitation and it should be handled and stored with this in mind.

6.1.1 Timing of Harvesting.

Potential topsoil resources should have been identified, characterised and quantified during the pre-development site planning phase. As far as possible, topsoil areas should be cleared and harvested as the source areas are required for development. Buffer strips of vegetation should be conserved wherever possible. Topsoil harvesting campaigns which clear areas many months or years in advance, which lead to long storage times and land-surface exposure, should be avoided.

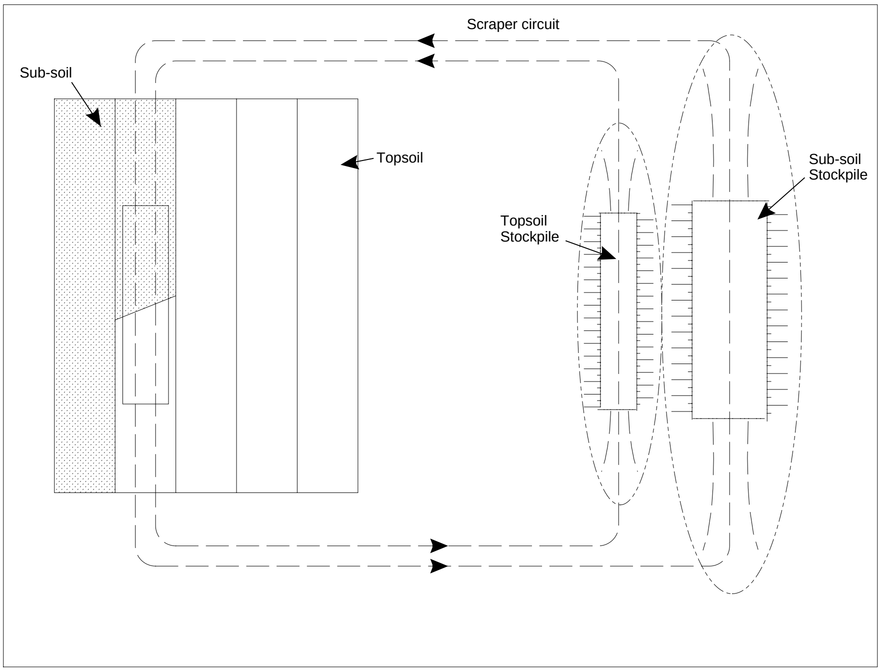
In arid Western Australia there are few shallow strip-mining operations which allow for the sequential harvesting of topsoil from areas to be mined and replacement on backfilled (mined) sites.

Towards the end of the life of the common open pit/dump operations, opportunities may occur for direct topsoil replacement sequences. In most of these operations topsoil harvested at the beginning of operations does have to be stored for varying lengths of time. As a general principle, topsoil should be re-used as quickly as operational constraints permit. Fortunately, if topsoil is stored correctly, the resistant seeds of the arid zone flora can remain viable for relatively long periods of time.

6.1.2 Topsoil Harvesting and Storage Methods

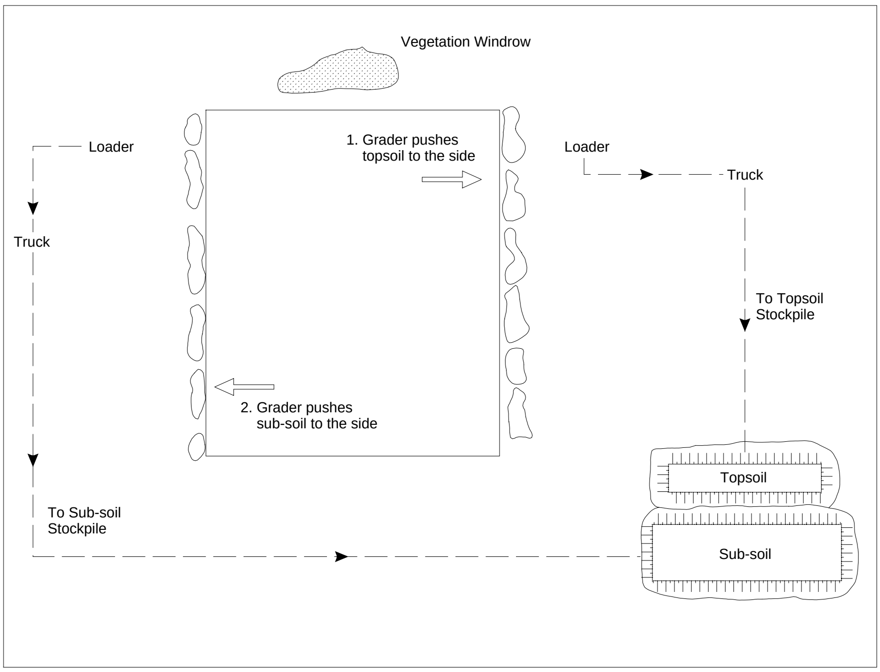
A significant proportion of the most valuable surface topsoil is lost during clearing operations when larger vegetation is incorporated into windrows. If stakes and roots must be removed prior to tyred machinery (scrapers, graders, loaders) harvesting the topsoil, then the clearing bulldozer should be equipped with a rootrake. This will allow the above and below ground woody vegetation to be windrowed without removing the soil.

FIGURE 6.1 HARVESTING TOPSOIL WITH SCRAPERS.



Scrapers are the most efficient earthmoving machines for relocating topsoil but unfortunately these are not a permanent feature of the mining fleet at most open pit/ dump operations. Scraper circuits should be planned to minimise topsoil compaction during harvesting and stockpiling (Figure 6.1). Graders, loaders and trucks may be used together to carry out the operation. Compaction can be avoided using other machinery if topsoil and subsoil is cast to the edges of the source area, loaded and carted from outside (Figure 6.2). On completion of construction the topsoil stockpile should be ripped with a tine to the full depth of the stockpile to assist aeration, drainage and root penetration.

FIGURE 6.2 HARVESTING TOPSOIL WITHOUT SCRAPERS.



The upper 10-20cm of topsoil is biologically active and of the greatest value in revegetating rehabilitated areas. If the soil profile is relatively deep, then a significant volume should be characterised as sub-soil. In valley floor mulga areas for example, there usually is between 0.3 and 0.7m of soil above the siliceous hardpan, ie up to 0.5m of subsoil. It is most important that the topsoil fraction not be diluted, mixed or buried by the sub-soil material (Fig 6.3). Topsoil and sub-soil should therefore be laid out in separate stockpiles (Figure 6.4.). Sub-soil stockpiles can be of any size but as a general rule topsoil should not be stored in stockpiles deeper than 1m. Aeration and a lack of compaction assist in conserving the biological viability of the topsoil. In some strip-mining situations with quantities of available topsoil, the material is laid out in shallow, wave shaped ‘gardens’. This maximises the aeration of the material. Natural re-vegetation of the topsoil should be encouraged to maintain the viability of soil organisms and propagules.

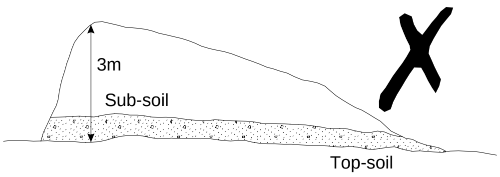


Fig. 6.3 THE INCORRECT METHOD OF STOCKPILING TOPSOIL.

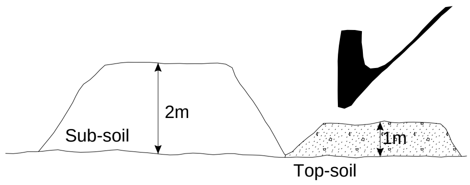


Fig. 6.4 THE CORRECT METHOD OF STOCKPILING TOPSOIL.

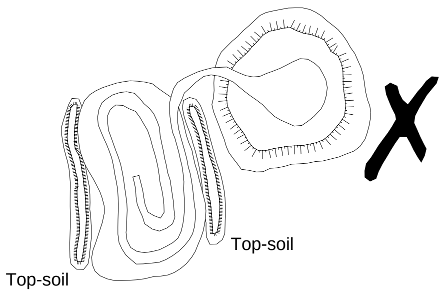


Fig. 6.5 POORLY LOCATED TOPSOIL STOCKPILES.

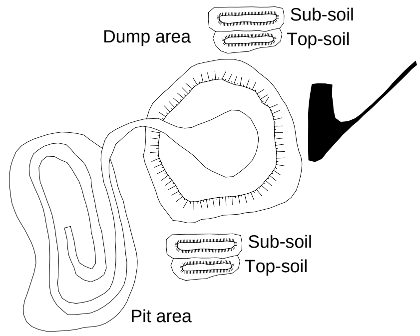


Fig. 6.6 WELL LOCATED TOPSOIL STOCKPILES.

The material stored in topsoil and sub-soil stockpiles is intended to be respread on waste dumps, tailings dams and other areas requiring revegetation. It follows that these stockpiles must be located as near as possible to the areas to be rehabilitated and the material be readily retrievable. Soil material is sometimes used as pit bunding early in a mining operation and is difficult, if not dangerous, to recover when mining is well advanced (Figure 6.5). Such stockpiles are also sometimes isolated by waste dumps again complicating retrieval. The ultimate destination of topsoil resources must be determined at the Site Planning stage and the stockpiles appropriately located (Fig 6.6).

Too often, topsoil is stockpiled in areas where saline water spills or dust suppression sprays can pollute the material rendering it unusable. This must be prevented by careful planning.

Soil stockpiles can become a source of fugitive dust during windy dry season conditions. Dust suppression water should not be sprayed on topsoil stockpiles. Water with very low salinity levels will still result in an accumulation of salt which will greatly reduce the value of the resource for revegetation. If the stockpiles are destined to remain in place for a long period of time they can be lightly sheeted with river gravel or gibber or alternatively sown with a local indigenous grass or groundcover species.

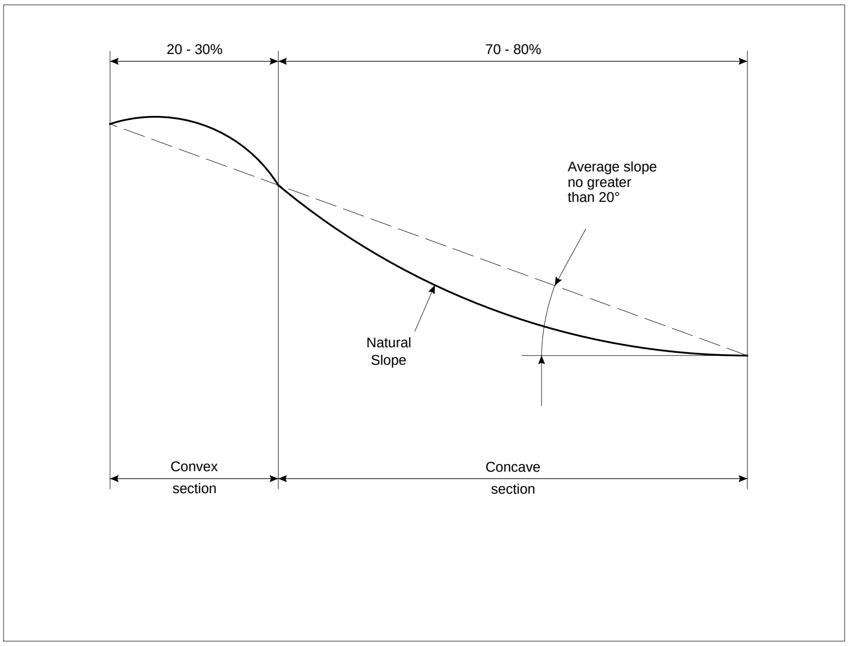
If possible, topsoil and subsoil should not be harvested or respread if it is either very dry or very wet. Moisture conditions may vary between 15 - 20% water holding capacity (depending on the soil texture) and these are the suitable water contents at which to move topsoil.

6.2 Mining Landform Construction

Most mining operations in arid Western Australia produce large quantities of waste rock overburden. If possible, consideration should be given to disposing of waste rock in any suitably located mined out pit as long as sterilisation of ore resources does not occur. In most cases however waste dumps of various sizes will have to be constructed and ultimately rehabilitated to stable landforms.

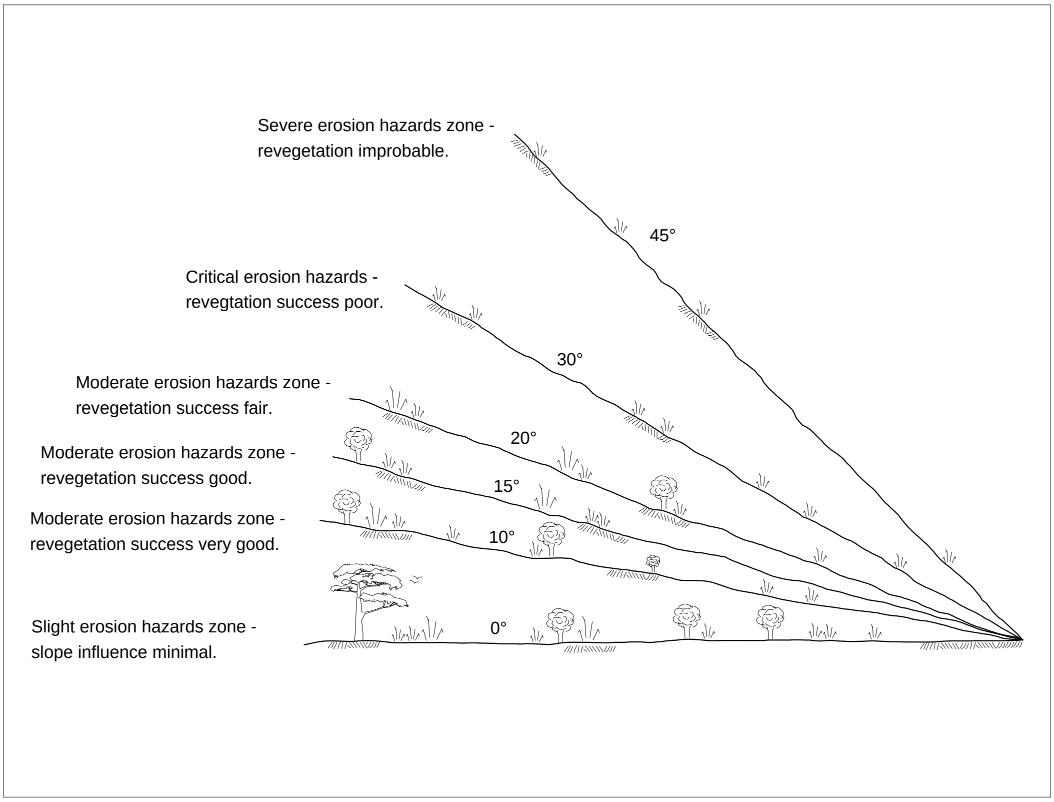
The approximate volume of material required to be disposed of in waste dumps should be known and sufficient land area allocated. The final shape of the dump should be decided upon prior to commencement with the important objectives being to blend the waste dumps as much as possible into the surrounding landscape and to produce stable, non-erodible surfaces in the long term.

FIGURE 6.7 A TYPICAL NATURAL SLOPE PROFILE, WITH AN IDEAL PROFILE FOR A WASTE DUMP.



A number of factors need to be considered in final waste dump design. For instance, when considering final slope angles, it is informative to measure the natural slopes occurring in the particular area as they have evolved as a result of natural erosional processes. Natural slope angles are depicted in Figure 6.7. The final angle and shape should blend with the natural landscape providing that surface stability can be achieved at slope angles greater than 20°.

FIGURE 6.8 INFLUENCE OF ANGLE OF SLOPE ON REVEGETATION AND EROSION.

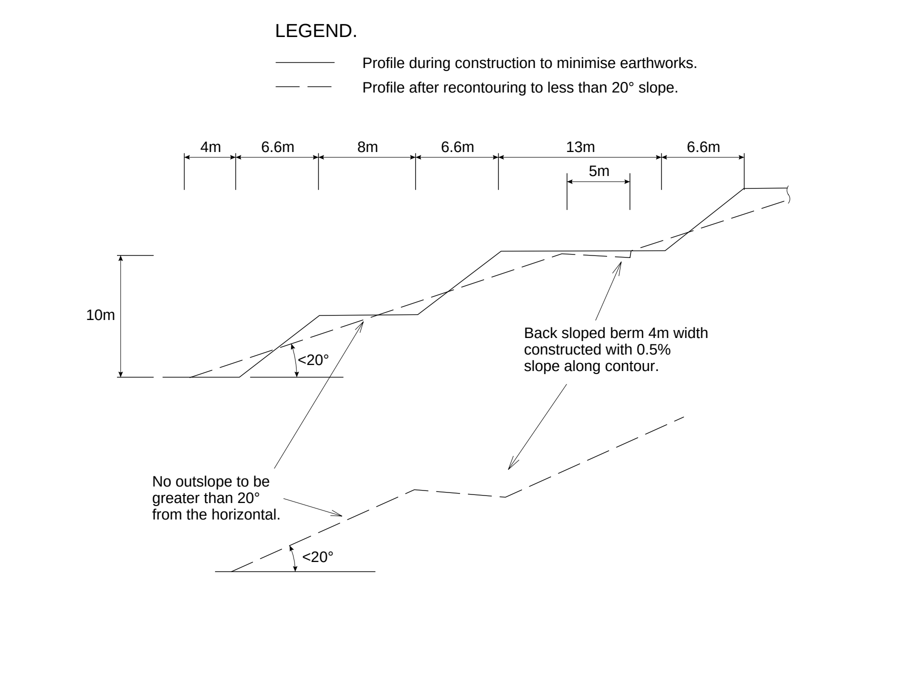


Control of erosion is dependant primarily on two factors, slope angle and slope length. Figure 6.8 shows the influence of slope angles on erosion and revegetation success. Long unbroken slopes allow surface runoff to accelerate and produce rill and gully erosion. For these reasons the DME recommends slopes of no greater than 20°, with benches every 7 - 10 metres of vertical height. Figure 6.9 shows the basic slope profile for most dumps.

Erosion is also influenced by soil characteristics, rainfall/runoff characteristics and the presence of vegetation. Therefore rehabilitation of disturbed surfaces needs consideration of all of these factors.

At present many operators prefer to leave any major earthworks for rehabilitation until the waste dump is nearing completion. This however can be a very expensive exercise. Construction of the final land form as the waste is emplaced is far cheaper than many hours of dozer time at the end of the mine life to batter slopes and construct berms. Figure 6.10 illustrates a waste dump construction technique which aims to minimise earth works.

FIGURE 6.9 BASIC SLOPE PROFILE FOR MOST WASTE DUMPS, DETAIL OF WASTE DUMP CONSTRUCTION TECHNIQUE



For example to re-contour a 380 000 cubic metre waste dump which has 37^o slopes to the recommended 20^o or less slopes, approximately 80 000 cubic metres of material will need to be relocated. The amount of land required to achieve these lower slopes will mean that approximately twice as much surface area will be required. It is thus of paramount importance to design waste dumps in the planning phase of the operation and ensure that sufficient land is available.

One technique highly recommended is to construct the out-facing batters of the waste dump first. Development of the outside faces of the dump can be achieved by initially dumping material around one to two thirds of the boundary. The remaining open area can be used to expand into if the need arises.

The completed outside faces can then be rehabilitated early in the operation when the viability of the topsoil is highest. Figure 6.10 illustrates this concept.

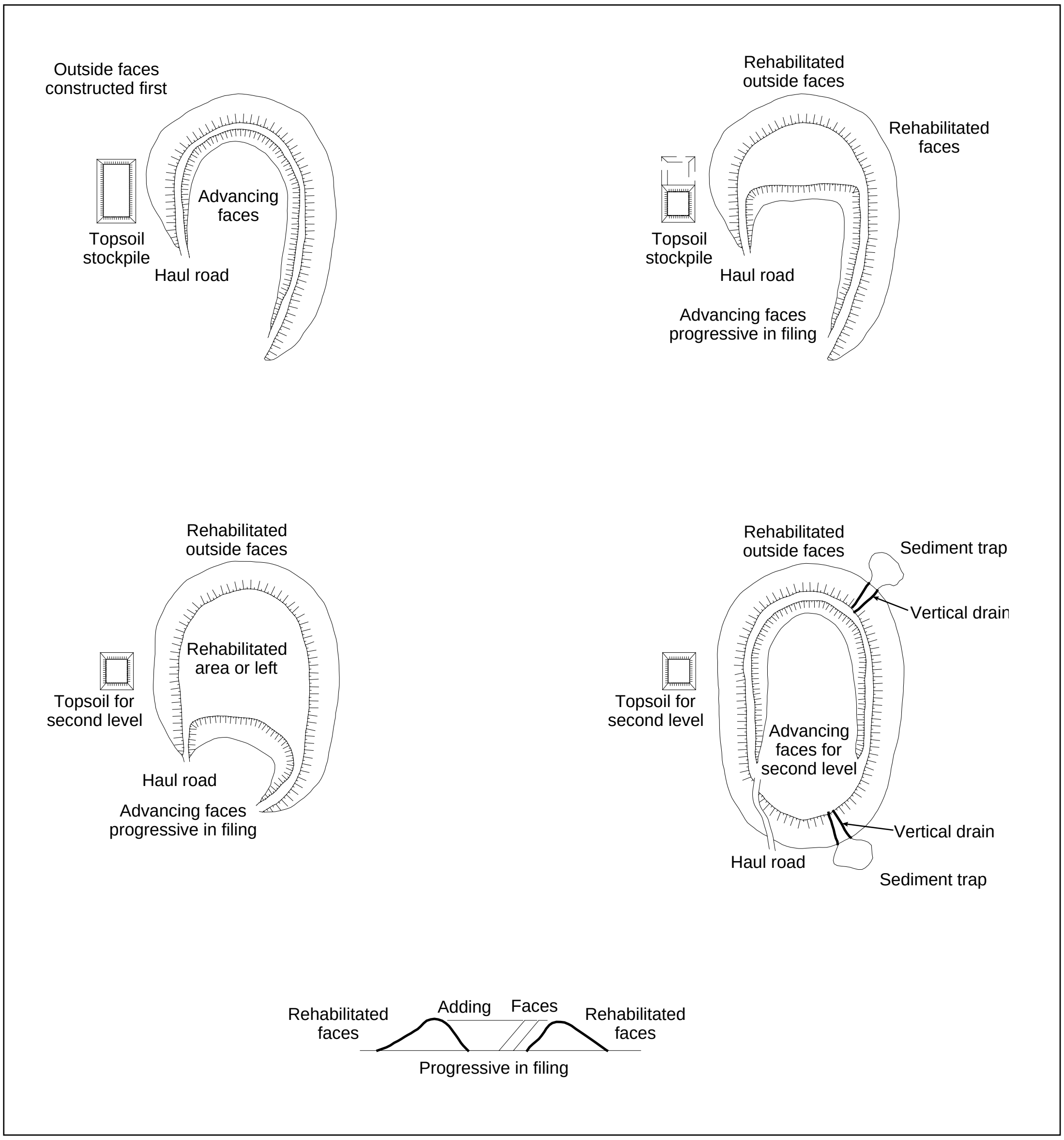
The out-sloping faces should have a maximum angle of 20^o as previously mentioned, however, shallower angles allow machinery to work with greater safety. Shallower angles are also far more stable and, where space is available, shallower angles are encouraged.

Outside faces of the dumps should be built progressively and berms of at least 4 - 5 metres width should be established every 7 - 10 metres of vertical height. The berms allow access for machinery to dump topsoil prior to spreading. These berms act as catchment drains and should be sloped back into the dump (5% grade). The berms require a 0.5% slope along their length to lead the runoff to rock-lined vertical drop-down drains. The vertical drains should be linked to energy dissipating sediment traps. A small bund (30cm high) should be constructed to the outer edge of the berm to reduce overflow over the waste dump wall.

The number of vertical drains required is dependent on final slope angles. On steeper slopes the catchment area for the vertical drains should be smaller to ensure that runoff water does not exceed the design capacity of the drainage system. Individual catchment areas should not exceed 2 hectares on 14^{o} slopes, 1.25 hectares on 18^{o} slopes and 1 hectare on 20^{o} slopes.

It is emphasised that these drainage structures should be maintenance free and designed to last for decades to ensure that no failures occur before vegetation is well established. Waterways need to be lined with rock and not just hard clay material. Alternatives may include meshing secured in place, old conveyor belting, half round pipe or concrete formed chutes. It is important that the drop-down drains be excavated from the waste rock dump so that they are lower in profile than the dump slope after placement of rock material. Wing banks should be constructed to direct runoff to the drain.

FIGURE 6.10 DUMP CONSTRUCTION THAT ALLOWS PROGRESSIVE REHABILITATION



The lateral bank or berm drainage system is widely used as it can be constructed during the building of the dump and requires little re-contouring. It can also produce a land surface which appears similar to the original surface and capable of supporting some future use of the land.

Properly constructed and re-vegetated, the final surface should be self sustaining and able to resist the natural forces of erosion.

In hilly or breakaway country, dumps can be ‘keyed’ into the natural contours to reduce the visual impact. However desert uplands may be important ecological and ethnographic features and the other impacts of this practise should be carefully considered. In other respects the previous recommendations for dump design and construction are applicable.

6.3 Mine Dewatering and Dust Suppression.

In the arid zone, water for mineral processing, dust suppression or human consumption is often in short supply. Typical operations in the eastern goldfields can utilise all of their mine water, most of the time, in dust suppression. However unpredictable heavy rainfall events may necessitate intensive short term pit dewatering campaigns.

In the eastern Goldfields, in-pit water is usually saline to hypersaline and great care needs to be taken in its disposal. Releases into local non-saline drainages in mulga or eucalypt woodland or spinifex can cause vegetation degeneration over large areas. Such water should be pumped to minesite evaporation ponds, tailings structures or piped to the beds of hypersaline playa lakes.

Surplus fresh mine water should, if turbid, be settled in appropriately designed stilling ponds before release into the drainage system.

Saline mine or ground water is most effective for dust suppression on haul roads, waste dumps and other minesite environments. However it should be recognised that this salt load could have long term environmental consequences and may impede land rehabilitation. Saline haul roads should be drained to evaporation sumps to prevent runoff from damaging the surrounding vegetation. The use of saline dust suppression water should be avoided during the latter stages of waste dumping and during topsoil spreading operations. The resulting soil contamination could greatly reduce the success of the subsequent revegetation programme.

7 Land Rehabilitation

Stable mining landforms should be progressively created throughout the period of mining operations. The next stage is to modify the surfaces of these new structures to control erosion and to facilitate revegetation and post-mining land use.

A final assessment of dump surface conditions should be carried out prior to undertaking surface treatment. The predictions about the weathering characteristics of the waste rock, soil salinity and pH levels made during the pre-mining phase, should be re-evaluated. Problem zones of highly erodible material, high salinity or low or high pH should be identified and mapped for preferential treatment.

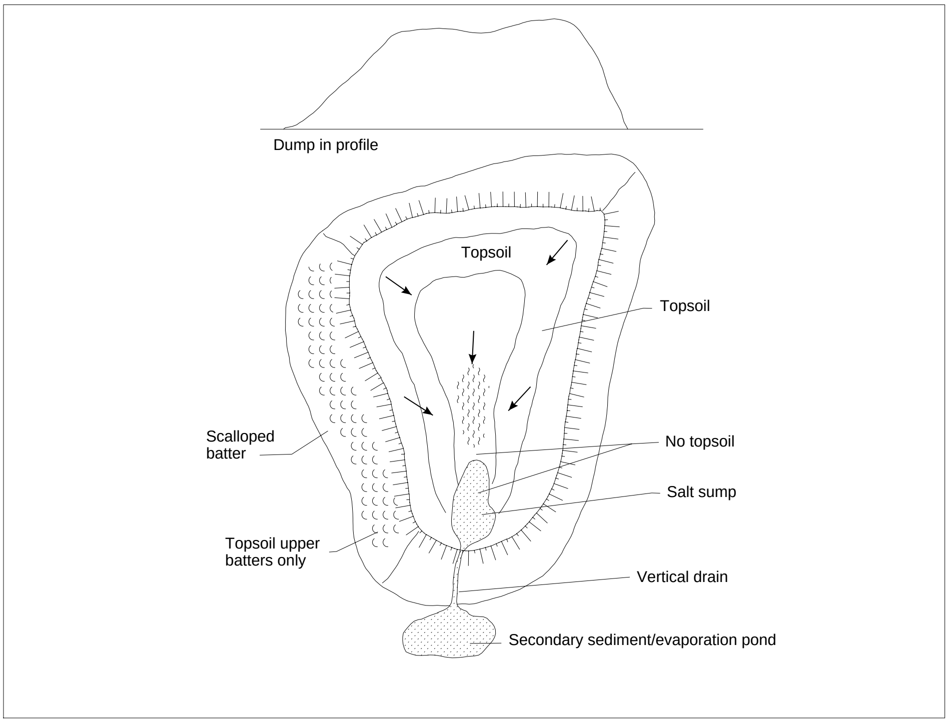
The outer walls of tailings storages are to be treated in similar manner to waste rock dumps.

7.1 Topsoil Utilisation

Prior to any expansion of dump surfaces, the topsoil resources must be moved and placed. These resources will usually be inadequate to cover all dump surfaces, (and other disturbed areas) and decisions will have to be made about the most effective use of the available material.

Where the mine waste rock is saline it is recommended that the dump surface be allowed to receive one significant rainfall event before topsoiling, although ripping or scalloping the surface will inevitably bring up additional saline material. Salt is quite mobile on dump surfaces and this should be managed by the overall surface treatment and drainage design. Scarce topsoil resources should not be used on those parts of the

FIGURE 7.1 SURFACE TREATMENT OF A HYPOTHETICAL SALINE WASTE DUMP.



dump where salts will concentrate and salinity levels are predicted to rise. Conversely topsoil resources should be used where the drainage characteristics have reduced salinity or where rainfall conditions will continue to ameliorate salinity conditions. It is tempting to use most of the topsoil on dump batters for colour/aesthetic reasons, but these zones may become more saline with time and less able to support woody vegetation.

An hypothetical saline waste dump situation is illustrated in Figure 7.1. The upper surface drains gently to a local low point which is scooped out to contain the flushed salt. Topsoil is placed only on slightly more elevated surfaces. The batters are scalloped with topsoil utilised on the upper half of the slope.

Saline, sodic or acid 'hotspots' on waste dumps should be avoided by sheeting the surface with the least hostile waste rock available. In many cases even this may be less than adequate as a substrate for plant growth. A depth of subsoil should then be used as a pad prior to laying down the top cut topsoil material. This will at least insulate the establishing plant roots during the germination phase when most species are most susceptible. Only a thin layer of topsoil (perhaps 5cm) is required over a sub-soil layer. The re-surfacing of mined landforms should be carefully sequenced to ensure that the sub-soil is laid down first before being top dressed with topsoil material.

7.2 Erosion Control and Water Harvesting

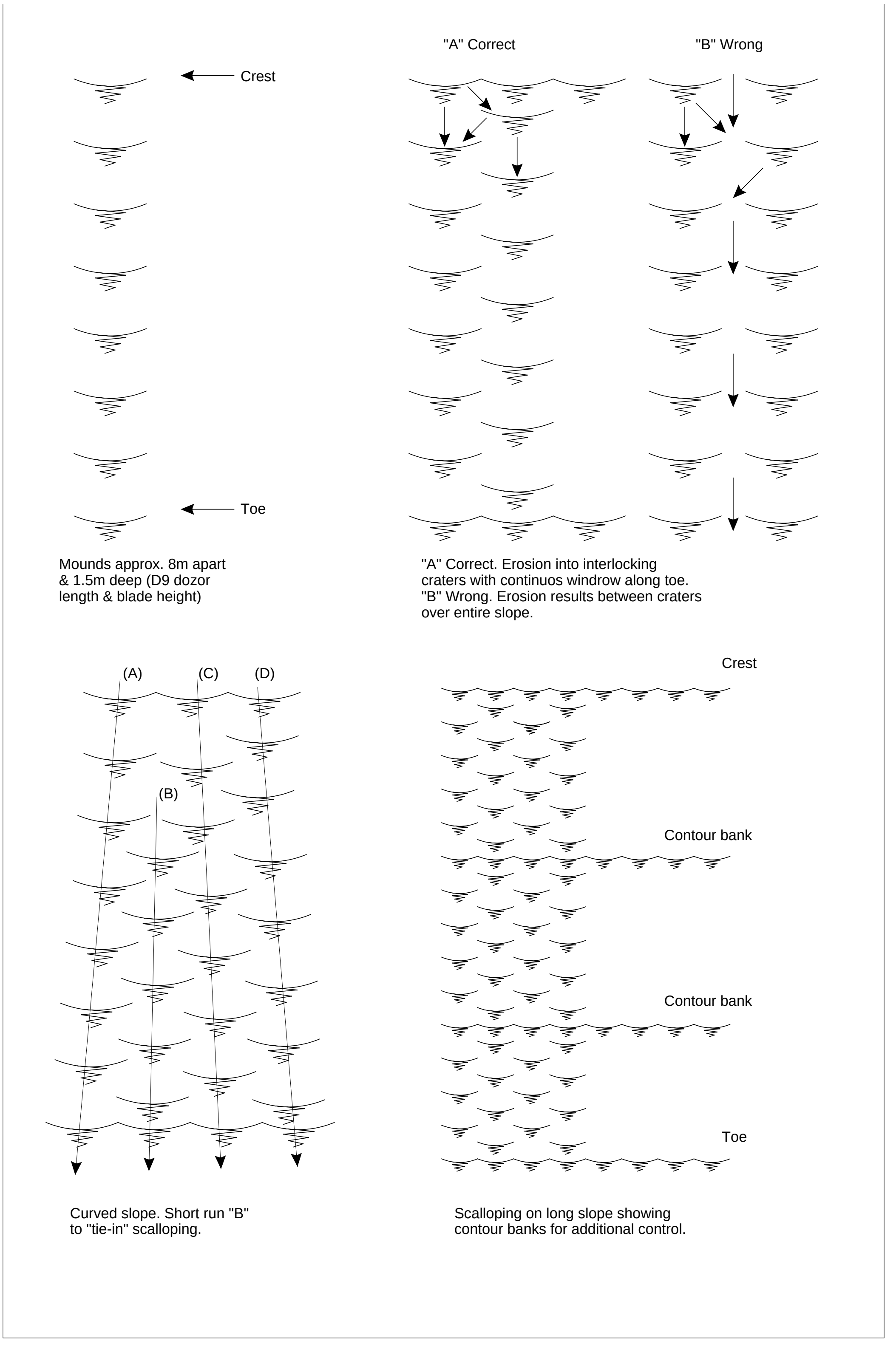
Assuming the waste rock material weathers reasonably quickly to form a 'mine soil' the major rehabilitation strategy will involve revegetation. Some highly erodible or chemically hostile parts of the waste dump may however have to be armoured with competent, blocky rock material in order to stabilise them. Rock armouring is a permitted surface treatment for waste dump and tailings storages. However, few active minesites in WA have competent rock for this procedure. If rock armouring is planned, outslopes may be steepened but should be designed at less than 30°, or lower if required for geotechnical reasons.

Surface treatment for revegetation must break ground compaction in the plant root zone, enhance infiltration and the leaching of salts and, importantly in the arid zone, harvest water from rainfall and runoff. Simply roughening the surface will improve the environment for plant establishment but for most large minesite landforms, deep ripping with the tynes of a bulldozer is required. Ripping to at least 0.7m depth is necessary and the operation should graft the topsoil/subsoil layer into the underlying waste material. On sloping areas these rip-lines must be located on the contour.

Contour ripping is difficult on slopes above about 14° and generally not possible above 20°. On steeper slopes, up to about 27°, scalloping is the preferred option.

Scalloping refers to the development of interlocking banks or blade pushes, the dimensions of which can be varied depending on the slope, waste material and the type of bulldozer available. This technique was developed by Mt Newman Mining in the Pilbara region to stabilise waste dumps in arid, low rainfall environments and is now widely used. It provides an alternative way to stabilise steeper slopes where contour ripping is not possible. It also reduces water and wind erosion and allows small micro-catchments to be created which provide suitable places for vegetation to establish.

FIGURE 7.2 SCALLOPING (MOONSCAPING)



Effectively a dozer is required to push a blade height of material in a downhill direction before backing up the slope and repeating the process. The development of the banks begins at the toe of the slope and works up and towards the crest. It is important to ensure that subsequent runs up the slope should be worked very close to the previous run and offset 50 percent to effectively lock the lattice of banks together. On long slopes continuous contour banks may be required to guard against erosion of the entire face (Figure 7.2).

The dump surface should be concave in slope if non-toxic overburden has been dumped. If toxic materials have been dumped, the surface should be slightly convex to shed water but allow some infiltration for soil moisture and plant availability. A bund wall (minimum 45 cm high) should be constructed on the outer edge of the dump surface to direct runoff to the drop-down drains.

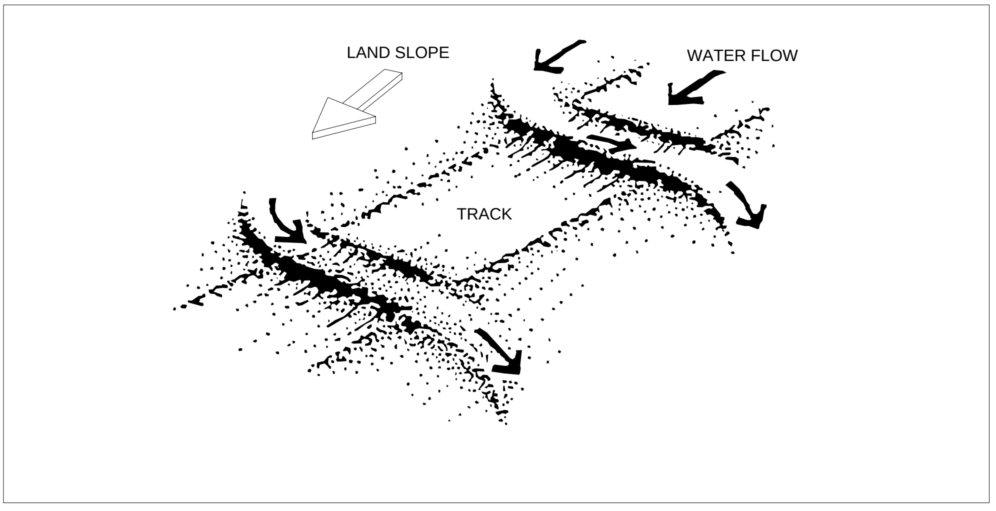
Slope stabilisation techniques such as hydro-mulching are not recommended for arid and semi-arid areas. These systems require relatively frequent rainfall to establish the seeded cover crop. Arid zone plants do not emerge well from thick organic mulches which are the bonding agent used in hydromulching. Hydro-mulching slopes does not create the physical microclimates which desert plants rely on for establishment.

When the need to use access or haul roads is completed, relatively flat sections of roads should be ripped or chisel ploughed on the contour after the windrowed topsoil has been respread. The ripping or ploughing should not be closer than 30 cm.

On sloping sections where runoff is likely ripping is to be carried out across the slope at approximately 30 cm spacing. Water will be directed laterally from the track and not focussed downslope (with the potential to cause gullying). Particular care is needed to restore the natural contours where roads cross drainage lines.

Where roads are worn down or eroded lower than natural ground level, earth blocks (mitre banks) should be used to direct water laterally to avoid channelling and erosion (Figure 7.3). As a guide the banks should be spaced 30m apart on steep slopes (>10%), 50m apart on moderate slopes (5-10%) and 75m apart on gentle slopes (<5%). Mitre banks can also be useful for other worn sites such as pipelines.

FIGURE 7.3 METHOD OF DIVERTING WATER FLOW BY MAKING EARTH BLOCKS.



Disused borrow pits should be deep ripped on the contour to a depth of 30cm. The surface and edges of the pit should be smoothed to a grade of less than 10° and the processes of respreading of topsoil and revegetating followed. All haul roads leading to and from borrow pits should be treated as outlined above.

All abandoned drill holes are to be plugged and rendered safe. Any sumps are to be filled in with subsoil, then topsoiled and revegetated. Particular care is required if toxic materials are present.

Pipeline access roads are to be rehabilitated as outlined for access or haul roads. If subsurface pipeline is scavenged, the trench is to be backfilled with subsoil and then covered with windrowed topsoil. Excess soil should be placed over the trench to allow for subsidence. The crown should not exceed 20 cm in height and care should be taken to ensure that water flows are not generated along the crown. Where necessary breaks in the crown should be utilised to enable flows to travel across the pipeline access.

7.3 Revegetation

The baseline studies conducted prior to the commencement of mining should provide information on the relationships between local plant species and soil conditions, and other environmental variables such as moisture. An assessment of the prevailing conditions on the mined landforms should provide an indication as to those plants which may be utilised in any revegetation programme. The next challenge is to determine how these species can be established on the mined landforms.

Rainfall in the arid zone is broadly seasonal in occurrence but unpredictable in quantity. Even in 'good' years there can be long periods between rainfall events leading to drying out of the soil. The planting of nursery reared seedlings is rarely a successful option because of these climatic factors and the scarcity of high quality irrigation water during establishment. Direct sowing is the most effective way of revegetating arid areas.

By broadcasting seed many propagules ultimately lodge in viable micro-habitats where moisture is concentrated or conserved. The natural dormancy and stratification (variation in germination rate) of native plant seeds ensures that some seedlings appear after early rainfall events, whilst others remain dormant as a hedge against the failure of the initial emergents.

7.3.1. Direct Sowing

The balance between winter and summer rainfall changes across the arid zone with the mulga (*Acacia aneura*) communities straddling the transitional zone (Figure's 2.1 and 2.2). As well as bioclimatic factors, many other environmental and biological variables also change from locality to locality, sometimes over quite short distances. As a consequence the long term success of a revegetation programme may well depend on the use of seed from locally adapted plant populations. Local seed harvesting can be undertaken by company personnel or by contract seed harvesters. If it is undertaken internally, the operator must obtain a Licence to collect flora from the Department of Conservation and Land Management. Contract workers should be operating under a commercial seed pickers licence.

The types and quantities of seed required depend on a range of considerations. These include the:

(1) Plant cover which is required of each species

(2) Viability of the seed before and after storage

(3) Potential germination rates in the field

and (4) Probable survival rates of the seedlings.

7.3.2 Species composition

Diversity is an important characteristic of resilient and self perpetuating vegetation. In arid ecosystems the peak in plant diversity generally occurs early in the regeneration cycle and this trend should be reproduced by the direct sowing strategy.

It is often tempting to collect seed from the one or two species producing an abundant crop. However one of the fundamental rules of ecology is 'never to put all the eggs in one basket'. An effort should therefore be made to collect and trial as wide a range of potential plant species that the **local** environment can provide.

7.3.3 Seed viability

Seed viabilities vary widely between the different groups of arid zone plants. It tends to be low in grasses including the important hummock grass (spinifex) species. It is almost universally high in *Acacias,* but intermediate in other legumes such as *Cassias* (Senna) which are heavily predated by borers. The fresh seed of other groups is generally of high to intermediate viability.

The viability of some seed declines rapidly with time, even if the material is stored correctly. The saltbushes (*Atriplex*) and Bluebushes (*Maireana, Sclerolaena*) do not retain their viability for long and may be useless if stored for more than two years. *Acacia* seeds, by contrast, remain viable for decades if maintained under dry, insect free conditions.

Proper storage procedures are vital to maintain the viability of seed stocks until the optimum time of sowing. There are a number of stages in the accession of material to the operation's 'seed bank'.

Cleaning

The collected material should be cleaned or 'purified' prior to storage. Most mass collecting techniques not only pick up the seed but soil, pods, chaff, twigs and other plant matter or insects. This extraneous material should be separated from the seed itself. Sieving, winnowing, hand sorting and floating (in legumes) can all be used to purify the product. The extraneous material may harbour insects and microbes which would destroy the seed in storage. This waste material also greatly increases the volume to be stored and broadcast, and interferes with the estimation of quantities in the sowing mix.

Quantity estimation

In order to compile sowing mixes for the various rehabilitation areas it is necessary to estimate the number of propagules available. Prior to storage a small sub-sample of each accession should be weighed and the number of seeds counted. All future allocation of seed can then be undertaken by weight. If the viability of the seed is unknown the sample should then be utilised for germination or other viability testing.

Storage

The greatest threats to stored seed resources are moisture and seed-feeding insects. Extremes in temperature should also be avoided and a well sealed, air conditioned storage room is desirable.

All seed must be thoroughly air dried before being placed in sealed insect free containers. These may include screw-top jars or tins, plastic, calico or paper bags. Paper or calico bags take up less space and are best for seeds/fruits which may continue to produce moisture. It is usually prudent to store seed with napthalene crystals to repel any insects which may enter the storage area.

7.3.4 Timing and Methods of Sowing

The optimum timing of sowing will depend on the bioclimatic zone in which the project is located, e.g. June at Coolgardie or Yalgoo, March at Wiluna, or February at Newman.

As rainfall is somewhat unpredictable one should also be prepared for opportunistic sowing programmes during favourable periods.

Seed should not be sown onto the loose surface of freshly prepared topsoil or waste as this can lead to its burial below germination depth. This is particularly so for fine seed such as that of many eucalypts. A treated area should be allowed at least one substantial rainfall event before it is sown. This will also help move excess salt from the germination zone.

If not topsoiled, saline waste still has to be revegetated and it may be necessary to defer sowing until the surface salts have had the opportunity to leach and wash from the material. In some cases this process may take only a year or two, given sufficient rainfall.

Mechanical devices and spreading machines are used for broadcasting seeds in the mining industry. However the waste dump landforms common to most of our arid zone mines are too steep (and hopefully rough) to be amenable to these techniques. (Hand sowing remains the most widespread method of seed dispersal).

It is important that seed mixes and application rates are worked out precisely for the designated area (e.g. 0.25 ha plots). This not only ensures that all areas are covered evenly but provides the basis of subsequent assessment of field germination success and seedling survival. The monitoring of revegetation success must be quantitative if it is to provide the necessary feedback on species performance, rehabilitation treatments and seed application rates.

Seed mixes are generally blended into a bulking material to increase the dispersion of propagules. Fine sand, chaff, sawdust, vermiculite, gypsum and fertiliser can all be used singly or in combination as bulking materials. Both sawdust and vermiculite are hygroscopic and may draw moisture to the sown seeds. Vermiculite has the added advantage of sparkling in the sun thus marking areas that have already been sown.

Appendix 2 provides a broad overview of the handling methods and germination characteristics for the main arid zone seed types.

8 ▸

REHABILITATION

Monitoring and Completion Critera

The rehabilitation programme should be based on post-mining land use objectives established by baseline study and consultation during the pre-mining and early operational phases of the project. At the conclusion of the project it will be necessary for the company, and the decision making authority, to determine whether the land use objectives have been met or will be met without further management intervention. Objective completion criteria must be established to facilitate the release of the mining operator from the environmental obligations. These can be tentatively defined early in the operational phase but must be firmly established before decommissioning.

As some structures, such as the tailings facilities, need to be monitored for stability and seepage after the completion of mining operations, this post-mining monitoring must be considered early in the operational phase - who should do it, why and for how long?

The nature of the completion criteria will depend on the type of end-use which has been selected and the significant environmental factors in the project area. Completion criteria may be as diverse as engineering specifications for structures, water quality standards for runoff or leachate, erosion/sedimentation rates, crop or rangeland productivites, the return of specific plants, animals or biotic communities or the establishment of a self-perpetuating and resilient vegetative cover.

Self-perpetuating Vegetation

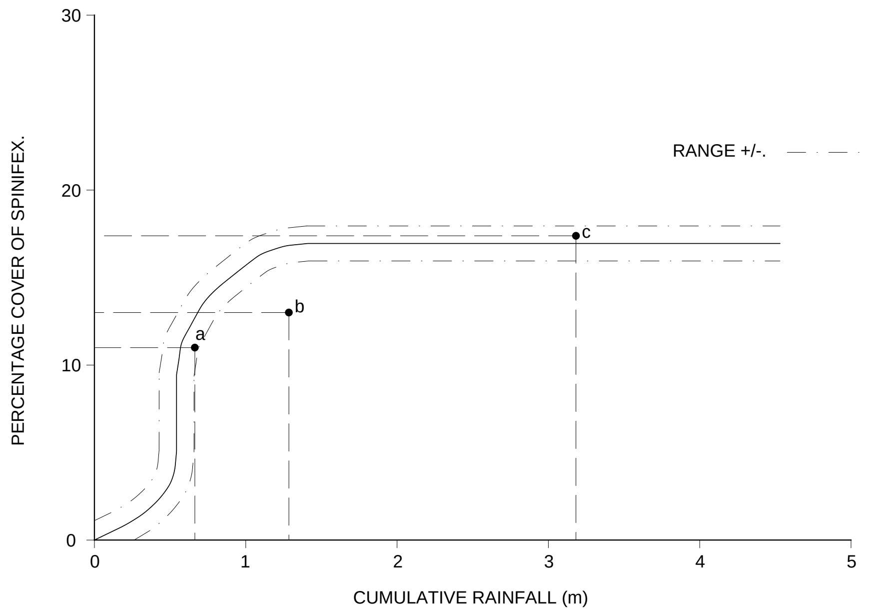
In arid and semi-arid Western Australia the re-establishment of self-perpetuating vegetation, which is integrated with the surrounding ecosystem, is the most common land use objective. This sounds simple in principle but demonstrating that a sustainable plant cover has been established is in practice a complex matter, which hinges on the monitoring of ecological processes.

Rehabilitation monitoring schemes and completion criteria are inextricably linked by the parameters being assessed or measured. Neither can be established without adequate baseline studies, including models of local regeneration cycles. It is not possible to rehabilitate to self-perpetuating vegetation without reference to the surrounding ecosystem on which the constructed one will ultimately depend for stability.

The regeneration cycle of one hummock grass (spinifex) community from the Pilbara was described in Section 3.3. Models like this have application in devising ecologically based monitoring schemes and in determining completion criteria. Figure 8 shows how the dominant hummock grassland stratum would be predicted to regenerate in response to cumulative rainfall.

Rehabilitation site (a) was recently treated and the vegetation is young. However the percentage cover value for this site lies within the predicted range for the cumulative rainfall received and it is therefore predicted that the vegetation will ultimately develop into stable hummock grassland. The completion criterion has been met at site (a). Conversely site (b), which could be of the same age or older, has failed to achieve the required spinifex cover and remedial action is required. Rehabilitation site(c) meets the completion criteria, as it is contained within the percentage cover range for a mature, self-perpetuating hummock grassland.

FIGURE 8 REGENERATION CURVE OF A TYPICAL DOMINANT HUMMOCK GRASS (SPINIFEX) AND ITS APPLICATION AS A COMPLETION CRITERIUM.



It is not possible in this short guideline to describe all the ecological parameters which may be selected for monitoring or developed into valid and objective completion criteria. The development of such criteria must be carried out by using knowledge of the local environment, the constraints of the mining operation and the land use objectives. It follows that it is the province of the operators to develop and propose completion criteria which are appropriate to their own specific situations.

9. Selected References

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1 Appendix

Other Guidelines provided by the Department of Minerals and Energy

- Guidelines for Mining Project Approval in Western Australia.
- Guidelines for Preparation of a "Notice of Intent" - Tailings Dam, Vat Leach, Heap Leach or Extensions to Existing Structures.
- Guidelines on Safety Bund Walls Around Abandoned Open Pits.
- Guidelines for Preparation of an Annual Environmental Report.
- Guidelines on the Safe Design and Operating Standards for Tailings Storages.
- Environmental Management of Quarries: Development, Operation and Rehabilitation Guidelines.
- Guidelines on Open-Pit Mining through Underground Workings.
- Interim Guideline - Noise Control in Mines.
- Interim Guideline - Management of Exposure to Inorganic Mercury in Gold Plants.
- Interim Guideline - Management of Exposure to Arsenic in Mines.
- Guideline - Management of Asbestos in Mining.
- Guidelines for Underground Supervisors and Miners.
- Cyanide Management Guidelines.
- Guidelines on Underground Mine Ground Control Procedures.
- Mine Rehabilitation Handbook. (MCA)
- Code of Practice for the Exploration in Environmentally Sensitive Areas. (CME)

2 Appendix

Seed handling and germination in the main arid zone seed types

SEED TYPE	HARVESTING/COLLECTING METHODS	CLEANING & STORAGE	VIABILITY, GERMINABILITY & SOWING TECHNIQUES
1. Light, dust-like seed. Baekea, Eucalyptus, Melaleuca or Calothamnus Thryptomene Wehlia	Mature unopened nuts are collected by hand and allowed to dry and open in trays. Seed and chaff will collect on the trays.	Seed and chaff can be decanted into clean, dry airtight containers. Some naphthalene crystals should be added and the containers sealed after 48 hours.	Viability varies from 10-100% but is frequently between 60 and 90%. Most species remain highly viable for several years in storage. Rarely any seed dormancy, will germinate when exposed to moisture. Temperature optima at around 15^{o}C in eastern goldfields, 20^{o}C in Murchison and 25^{o}C in Gascoyne and Pilbara. Seed should be mixed with a bulking material such as vermiculite, sawdust or fine sand for sowing. Small seed should not be sown over unsealed dusty or muddy ground surfaces or under windy conditions.
2. Larger, thin walled seed from woody fruits. Casuarina, Grevillea, Hakea, Terminclia, some Eucalyptus	All come from woody nuts or fruit which can be handpicked from the plant when mature and beginning to open. Should be air dried in trays as for 1.	Clean seed can be collected in the trays. Storage as for 1.	Viability is usually high in this group but some Grevillea and Hakea may have special germination requirements. Most germinate readily when exposed to moisture across a wide range of temperatures. Sowing as for fine seed (1).
3. Legumes, seeds with hard coats. Acacia, Clianthus, Cratalaria, Senna, Swainsona, Petalostyles	Dry and splitting pods can be collected from plants or shed seed can be collected from the ground, either by hand or by using a vaccuum harvester.	Seed can be separated from crushed pods or from ground debris or soil by seiving. Most Acacia seed can then simply be stored in dry containers. Senna seed should be floated to remove seed with borers, dried and then stored with naphthalene crystals.	Acacia seed is generally of high viability 70-100% but almost always requires scalding, with boiling water, or scarifying to break dormancy. Seed usually remains viable in dry storage for many years. Senna seeds also require nicking or scalding to promote early germination. Senna tends to have lower viability with 20-50% being typical. Germination in arid zone legumes may be inhibited by low temperatures but most species perform well above 15^{o}C.

SEED TYPE	HARVESTING/COLLECTING METHODS	CLEANING & STORAGE	VIABILITY, GERMINABILITY & SOWING TECHNIQUES
4. Berries and fleshy fruits some with woody seeds. Alyxia, Rhagodia, Enchylaena, Ficus, Owenia Santalum, Nitraria, Pittosporum	Picked from the plants when ripe. Capsules of Pittosporum phylliraeoides will open on the tree to display the seed mass.	Most berries should be dried on trays (preferrably under air-conditioning). They should be stored in calico or paper bags. Fleshy fruits with heavy seeds (eg. Nitraria) should be fermented in a container of water until the seeds drop to the bottom. The fetid brew should then be decanted off and the seed mass seived and dried. The seed should then be stored in dry containers.	Initially seed viability is usually high but declines quickly in storage. Treatment with acidified pancreatin will preserve the seed viability of Pittosporum phylliraeoides. Seed dormancy is not known from Rhagodia, Enchylaena or Pittosporum although it may take one or two weeks for the first germination (15-25 days in Pittosporum). Nitraria and Santalum seeds require cutting or scarifying to break dormancy.
5. Soft seeds with membranous wings, bracts, spines or fluff. Atriplex, Maireana, Scleroleana, Ptilotus	Hand picked from plants when ripe and dry, or vaccuum harvested from or under bushes.	Vaccuum harvested seed should be seived to remove soil and other extraneous matter. The seed should be thoroughly dried and then stored in watertight containers with some naphthalene crystals.	Seed viability is often low and declines rapidly in storage. Bluebush Maireana should be used within two years. Some species are difficult to germinate and may require the removal (or wear) of bracts and wings, leaching, or exposure to cycles of light and darkness.
6. Grasses Triodia, Plectrachne, Aristida, Cenchrus, Chrysopogon, Eragrostis, Ennaepogon, Eriachne, etc.	The dominant hummock grasses (eg. Triodia) rarely set seed in any quantity. Best established with fresh topsoil. Seed from grasses can be collected by hand from the spikes or via scoops mounted on the bull bars of 4 x 4 vehicles. Vaccuum collection is also possible for seed on the ground.	Grass seed should be air dried and then stored in watertight containers with some naphthalene crystals.	Seed viability is very variable and often declines rapidly in storage. Generally endeavour to use grass seeds within one or two years.

Notes

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