BEST PRACTICE
ENVIRONMENTAL
MANAGEMENT
IN MINING

Landform Design for Rehabilitation

Environment Australia
Department of the Environment

ACKNOWLEDGMENTS

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The series illustration of the Koalas by Christer Eriksson, commissioned by BHP Transport 1998. Reproduced courtesy of BHP Transport.

Cover photo: Two photographs capture rehabilitation on a grand scale. Left: mining in progress at the Hunter Valley Number 1 Mine, owned by Coal and Allied Industries in 1982. Right the same area after rehabilitation.
Photo: Coal and Allied Industries Limited and John Hannan

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FOREWORD

Environment protection is a significant priority for our society. A major role for government is setting environment standards and ensuring that individuals and organisations meet them. Increasingly, however, government, industry and community organisations are working as partners in protecting our environment for present and future generations.

Representatives of the minerals industry in Australia and Environment Australia, (the environment arm of the Federal Government), are working together to collect and present information on a variety of topics that illustrate and explain best practice environmental management in Australia's minerals industry. This publication is one of a series of booklets aimed at assisting all sectors of the minerals industry—minerals, coal, oil and gas—to protect the environment and to reduce the impacts of minerals production by following the principles of ecologically sustainable development.

These booklets include examples of current best practice in environmental management in mining from some of the recognised leaders in the Australian industry. They are practical, cost-effective approaches to environment protection that exceed the requirements set by regulation.

Australia's better-performing minerals companies have achieved environmental protection of world standard for effectiveness and efficiency—a standard we want to encourage throughout the industry in Australia and internationally.

These best practice booklets integrate environmental issues and community concerns through all phases of mineral production from exploration through construction, operation and eventual closure. The concept of best practice is simply the best way of doing things for a given site.

The case studies included in these booklets demonstrate how best practice can be applied in diverse environments across Australia, while allowing flexibility for specific sites. Each booklet addresses key issues by presenting:

- basic principles, guidance and advice;
- case studies from leading Australian companies; and
- useful references and checklists.

Mine managers and environmental officers are encouraged to take up the challenge to continually improve their performance in achieving environment protection and resource management and to apply the principles outlined in these booklets to their mining operations.

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EXECUTIVE SUMMARY

It is no mistake that mine planning is the first topic mentioned in Land Design Procedures in this booklet. Landform Design for Rehabilitation requires a holistic view of mining operations, where each operational stage and each component of the mine is part of a plan which considers the end-use of the site as much as the immediate need. This plan needs to be flexible, to accommodate changes in method and technology.

Maximising planning reduces site disturbance and ensures that material such as waste rock is close to its final location. The emphasis is on gaining and analysing as much information as possible about the site. Such research has two main uses—it provides baseline data for mine planning and essential information for the rehabilitation and closure phase, when the site is being restored to an agreed post-mining use.

Key factors which need to be considered in pre-mining studies include legal requirements, climate, topography, soils and community views. Community views are clearly most important in deciding the final land use, as they are the most likely site users. Their knowledge and expertise can also be invaluable in understanding aspects of the site.

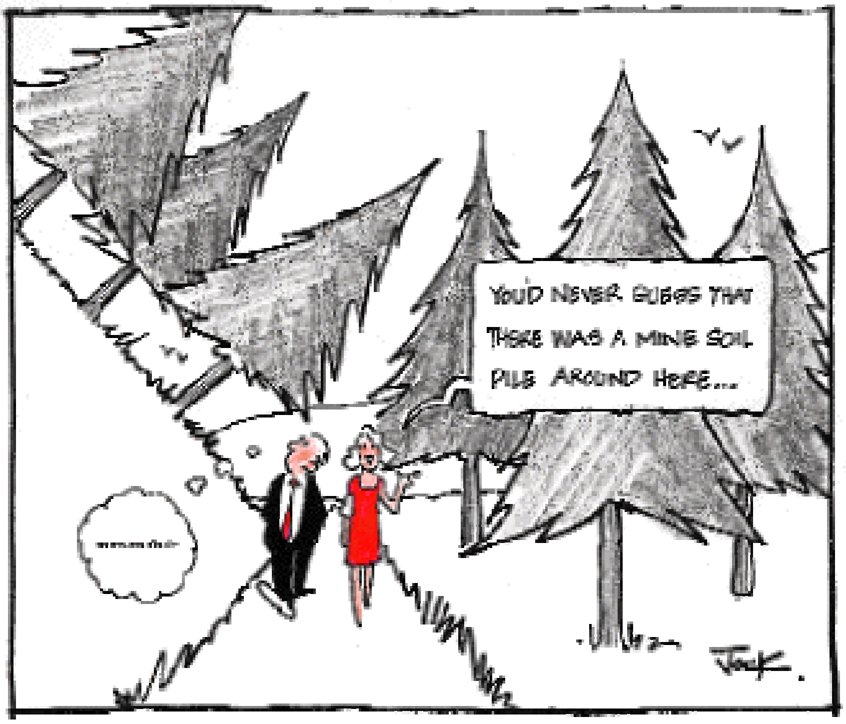
Understanding the site, including its drainage characteristics, is also required when designing and siting components of the mine operation. By transferring this information to mining software, the mine planners have detailed computer modelling of the original site and its drainage patterns to make decisions about restoration or alteration in its final design.

Like all computer-related technology, developments occur and become outdated quickly. Therefore, the principles involved in digitising and analysing the data are more important than the specific software packages used.

End uses for the final void resulting from mining operations also require consideration, and planning. Backfilling may be uneconomic in some operations but in others planning might avert creating any void. Three options are absorbing urban or industrial waste as fill, designing the void for recreational or similar functions or making it a water storage area to enhance regional water resources or provide additional retarding buffers against flooding. Safety is also crucial and substantial obstacles and warnings are needed.

Economic factors may also play a part. Where marginal land is mined (for example, in parts of Western Australia) for a marginally profitable commodity, it can be uneconomic to restore the original marginal land values. Community views may be critical in deciding what the achievable final landform is, or whether to proceed at all.

Landform design for rehabilitation is about planning for the immediate and long term future in tandem. It is about optimising post-mining land capability and minimising the costs in achieving optimal land use. It is also about sustainable development.


YOU'D NEVER GUESS THAT THERE WAS A MINE SOIL PILE AROUND HERE...
JACK.

CONTENTS

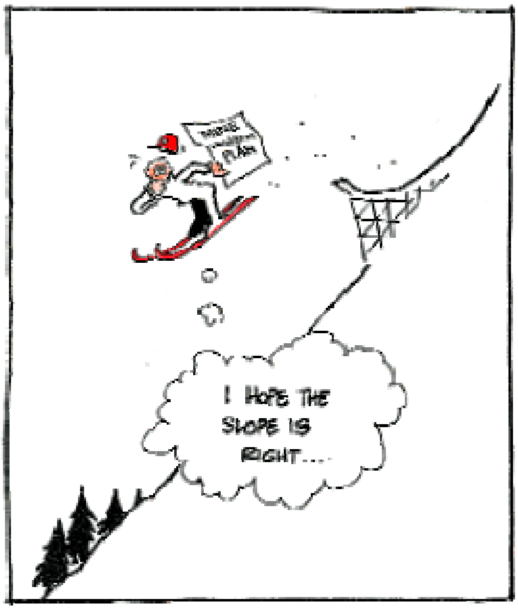
1 INTRODUCTION

This booklet describes why designing the eventual landform and progressively and efficiently managing the mine, rock dumps and tailings facilities to achieve it, must be part of the mine planning process. In the past, land reshaping was only considered at the completion of mining when rehabilitation was beginning. The need to extensively reshape areas disturbed by mining and waste disposal can be minimised through effective mine planning and management. The advantages are that the optimal post-mining land use is readily achieved, and that the cost of rehabilitation to the miner can be dramatically reduced.

This booklet demonstrates how mine planning can integrate an ongoing process of landform reshaping enabling progressive rehabilitation at minimal cost to the operator. The booklet outlines the steps from pre-mining to the decommissioning stage which make land reshaping part of the normal day-to-day operations of the mine.

The planning and the physical processes revolve around the final land use for the site. There must be agreement on the long term post-mining land use objective for the area with the relevant government authorities, local government councils, and where applicable traditional owners or the private landowner.

The final land use must be compatible with community needs, any legal requirements, climate, soils, and the local topography, and the degree of management available after rehabilitation. This aspect is covered in detail in the booklet in this series entitled *Rehabilitation and Revegetation*. Because of its impact on mine planning, it is critical to determine the final land use early in the mine design.



2 LAND DESIGN PROCEDURES

2.1 MINE PLANNING

It is essential that minesite rehabilitation planning starts early in the life of any mine. This includes the plans for reshaping landforms. There is a need to identify those factors that will impinge on the final landform. These may be legal, for example where the initial location of a waste dump is too close to a mineral title boundary and reshaping of the dump will result in material spilling onto a neighbouring tenement. Alternatively, poor placement of waste rock may result in rock spilling over the edge of and into the open pit or void at the reshaping phase. Another factor may be economic, where insufficient geological investigation is undertaken and a waste dump site is not "sterilised" (i.e. was not drilled sufficiently to ensure that ore was not located beneath it). This usually results in either ore not being mined or additional cost being incurred because the waste needs relocation.

The final landform must be safe, stable, non-erosive and be restored to have those environmental characteristics that will support the final land use agreed between stakeholders and the company. Consequently, the most appropriate option for land reshaping will vary between minesites, depending on a range of factors including climate, geology, soils, local hydrological patterns, topography and the adopted final land use.

A reshaped waste dump design must also consider the presence of materials that may later cause intractable problems, particularly acid forming, saline or highly alkaline materials. Any design needs to incorporate features to minimise the risks associated with these materials. Neutralising or encapsulating techniques, for example, for managing potentially acid-generating waste are described in the booklet in this series entitled *Managing Sulphidic Mine Wastes and Acid Drainage.*

2.2 PRE-MINING STUDIES

Landform and land uses are closely inter-related. A clear understanding of the desired post-mining land uses expected by the various stakeholders is an essential pre requisite to planning acceptable landforms. Likewise, landform may affect the types of revegetation processes and species used to ensure long term stability and erosion control.

Conditions in mining approvals often imply that the land be returned to its original use or capability. The philosophy of returning land as closely as possible to its original landform and use applies to mining throughout the world and with good reason. There are many factors, such as community expectations, compatibility with local land use practices and regional infrastructure or the need to replace natural ecosystems and faunal habitats, which all favour the return of mined land as closely to its original appearance and productive capacity as possible. In most cases, however, it is up to the mining company to propose a final landform and land use. These should be submitted at the time of preparing the environmental impact statement for a new project and subsequently, when submitting more detailed plans in satisfaction of lease conditions or as part of an environmental management plan for the site.

Both physical and social components of the pre-mining environment have a strong influence on the rehabilitation program and on the freedom to modify or diversify from the type of use the land has seen in the past. Added to this are the effects of mining in altering the elevation, topography, surface and sub-surface drainage and soil characteristics. It is also important to recognise that in its pre-mining state the area occupied by the lease probably comprised a number of landforms and (possibly) land uses. Planning for rehabilitation needs to be sensitive to these small scale variations and should allow reinstatement of various parts of the site to their optimum landform and use.

Factors that need to be taken into account are:

Legal requirements

Conditions attached to approvals, mine leases and various subsidiary licences and permits may specify certain limits on maximum slope angles, provision for surface drainage, salvage and use of topsoil and the choice of vegetation species to use which will set minimum parameters for landform design.

Restrictions in government planning instruments such as state, regional and local environmental plans and council zoning may limit the range of uses available. In particular, planning instruments may restrict visual impacts of mined land, require preservation of items of cultural and heritage value, and dictate the vegetation species which can be used for rehabilitation.

Climate

The annual rainfall, its type and distribution, has perhaps the greatest influence on the design of stable landforms and drainage systems and, together with the temperature regime, determine the type of vegetation which can be grown successfully.

Monsoonal weather systems, dominated by high intensity storms, may dictate the need for special attention to drainage and early stabilisation of exposed slopes.

Winter or summer dominance of the rainfall has an obvious effect on the type of vegetation grown and the timing of revegetation. The reliability of rainfall has perhaps the strongest climatic influence on vegetation and land use. As the Australian climate is extremely unpredictable, this often dictates the use of drought-tolerant species for long term ground cover and stability. The increase in elevation caused by swelling of excavated material or out-of-pit dumping on the natural land surface will in most cases enhance surface and subsurface drainage, leading to a drier regime which may exacerbate drought conditions. This should be taken into account in selecting appropriate vegetation species.

Topography

The important components of topography are slope gradient, elevation, and drainage density (ie. the total length of natural watercourses per unit area). Aspect, or the direction in which slopes face, also has a pronounced effect on localised temperature and moisture regimes, both of which influence vegetation growth. While little can be done to alter slope aspects, these may dictate slight changes in land use, species selection for revegetation, or management for various parts of each mine site.

The angle and length of natural slopes within and surrounding the minesite will influence the degree of reshaping necessary to achieve visual blending of spoil piles. Slope angle and the degree to which the land is dissected by drainage channels, affect suitability for alternate uses. For example, slopes above 8° (14%) are generally unsuited to regular cropping due to high erosion hazard. Slopes over 20° (36%) should not be subject to intense agriculture or grazing and are more suited to native species and a low intensity land use.

Drainage density is an important attribute in achieving long term stability. The natural drainage pattern has evolved over geological time and is in equilibrium with the environment. The pre-mining drainage density provides a useful benchmark for the design of new landforms. However, changes to elevation, slope angles and lengths brought about by excavation, dumping and reshaping may render the new land surface susceptible to erosion. This may require changes from the pre-mining drainage density in order to achieve long term stability.

Photo: Niugini Mining (Australia) Ltd

Red Dome Mine, Chillagoe, Far North Queensland. After recontouring to "S" profile landform 16° overall slope, installing breaks in slope on 50m high Southern Waste Dump.

Soils

The distribution and quality of soil types over the lease area will influence the volume of topsoil and suitable subsoil available for topdressing of spoil and waste rock materials. Past land uses, the extent of historic erosion damage, salinisation and the presence of weeds and other undesirable species will affect the rehabilitation value of the soil.

As a general rule, topsoil should be preserved for rehabilitation use wherever possible, as it can be a valuable source of seed, nutrients and micro-organisms. The physical properties of topsoil can also be an advantage in providing a suitable micro-environment for seed germination and in mitigating problems of clay dispersion and surface crusting. Topsoil must be used as soon as possible after collection. Long term storage degrades its value substantially. The booklet in this series on *Rehabilitation and Revegetation* provides more details on the usefulness of topsoil and its application.

However, an intelligent approach is needed in the selection and use of topsoil or other topdressing materials. An assessment should be made of the relative advantages of topsoil, compared to the material to be covered, in terms of its physical and chemical properties. Where topsoil is in short supply, preference should be given to first topdressing those areas which are most susceptible to soil erosion. These critical areas include newly formed watercourses, and areas where dense, high quality vegetation is required. The need to separately strip topsoil and subsoil and replace them in their proper sequence needs consideration for areas of prime agricultural land where subsequent productivity is important.

Community Views

Finally, and most importantly, the views and expectations of the community and especially of people in the local area, need to be taken into account when deciding post-mining landforms and uses. In particular, attention should be paid to people with a special interest, such as neighbours whose land may be affected by the mine and community groups (such as local botanical and historical societies and Aboriginal communities) who may have strong preferences on the landforms and future uses of the site. The local expertise of these people may be valuable for such things as advice on flood frequency and behaviour, collection of seed of native species, as well as weed and feral animal control.

Community views on landform and land use should be sought in the consultation program during the early phases of project planning and design. The booklet on "Community Consultation and Involvement" in this series gives useful guidance on establishing and managing a community consultation program.

2.3 COLLECTING DATA PRIOR TO MINING

The pre-mining condition of the land is often the yardstick by which the success or failure of rehabilitation is judged. It is thus in the interest of both the mine operator and the regulating authority to have an accurate and objective record of pre-mining conditions.

It is not sufficient to compare the mine site rehabilitation against the condition or productivity of land surrounding the mine, as there may have been good reasons why the lease area, or parts of it, were significantly better or worse than the adjoining lands.

This information should form part of the base-line data collected for the environmental impact statement (EIS), although more detailed investigations may be needed as mining progresses. Mapping scales will depend to some extent on mine site size and the degree of variability of various land characteristics. Mapping at a scale of 1:20 000 is usually adequate for preliminary analysis of the site and for EIS preparation.

More detailed mapping (at a scale of around 1:5 000) for topography and drainage, topsoil stripping depths and vegetation distribution, is usually necessary for rehabilitation planning.

It is recommended that the following site plans be prepared during the collection of base line data for EIS preparation. It is quite appropriate to maximise the level of information collected by interpretation of satellite imagery or aerial photography followed by ground truthing or the use of available maps. Quite often, maps of these attributes are available at a scale of perhaps 1:50 000 or 1:100 000 from government agencies such as mapping authorities, the CSIRO or state soil conservation, agricultural and national parks agencies. These can provide a valuable base for more detailed data from site surveys. Information required for collection includes:

1. **Land ownership information** including property boundaries, location of roads and other service corridors, etc. This can be enhanced by providing detail on current land uses, either on the plan itself or in a separate report.

The location and extent of significant areas of land degradation, such as that due to severe soil erosion, salinisation and weed invasion should be identified on the map if possible. Likewise, particularly valuable attributes, such as areas of undisturbed native vegetation, wildlife habitat and corridors, areas of prime agricultural land, should be recorded. Where prime agricultural land is to be disturbed and subsequently reinstated, it is worthwhile to gather some information on agricultural productivity. Regional data on historical production levels from the range of local agricultural activities can often be obtained from state agriculture departments.

2. **Topography** in the form of a contour plan which clearly shows the drainage system and complete details of ephemeral and permanent watercourses. These will provide the key to designing a drainage system for reshaped land which is compatible with the surrounding drainage network. Contour spacing will depend on the degree of relief and may range from one metre or even 0.5 metre spacings for flat areas, up to 10 metres or more for very rugged terrain.

   Special features such as cliffs and wetlands should be shown clearly and major catchment boundaries marked. In some situations, an additional plan showing slope classes at 5° (11%) intervals can be useful for planning a future landform which will blend visually with its surroundings.

3. **Land Capability** maps are useful in areas where the land will return to agricultural use. This system of classification is commonly used by soil conservation, agricultural and planning agencies. It allocates land to one of a number of classes according to its ability to support sustainable agricultural and grazing activities at various intensities. It takes into account a number of factors, including slope, soil type, vegetation and climate, together with the effects of past land use practices, soil erosion, drainage and salinisation. If similar land capabilities are to be restored after mining, then reshaped landforms will need to be compatible with the proposed capability on each part of the site.

   Land capability mapping is a specialised activity and should only be undertaken by a person who is competent in the use of the classification system and also has an intimate knowledge of the local soils, climate and land use.

   In the eastern Australian states, sub-regional land capability maps, at a scale around 1:100 000, are often available from local soil conservation or agriculture departments. While these may not be sufficiently detailed for rehabilitation planning, they can form a useful base plan on which to add greater detail from site surveys. **Figure 1** shows a typical land capability map, based on the classification system used by the NSW Department of Land & Water Conservation.

4. **Soils** should be surveyed by examining profile exposures in roadside cuttings, erosion gullies, etc. and supplemented by coring to sufficient depth to penetrate subsoil or weathered parent rock. The objective should be to clearly establish the boundaries between different soil types and gather data on the depth of material suitable for stripping and subsequent use in rehabilitation. Soil identification should preferably be made using the Northcote (1984) coding system, rather than Great Soil Groups or engineering classifications, as the former provides much more detail on textural and structural properties, pH, drainage and the existence of bleached or hard-setting horizons.

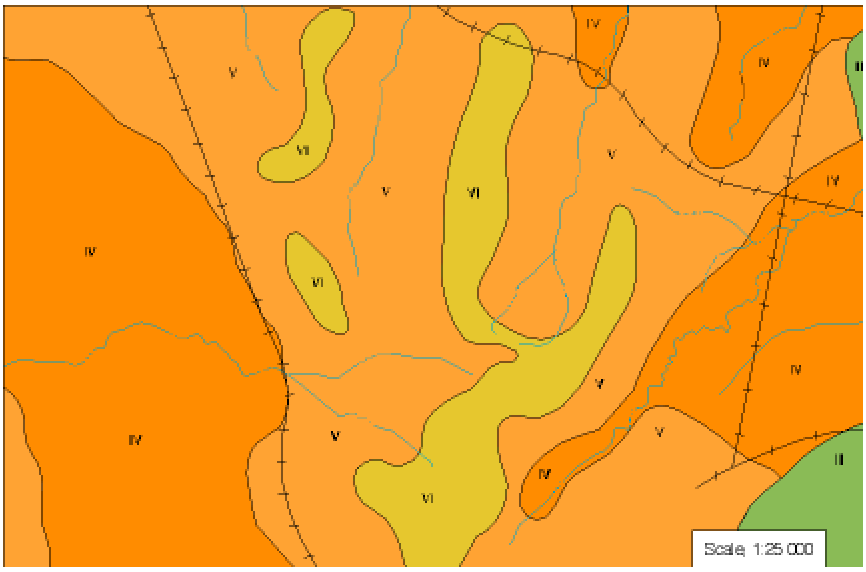


Figure 1 Proposed Surface Mine Lease Area Land Capability Classes (after Hannan, 1995)

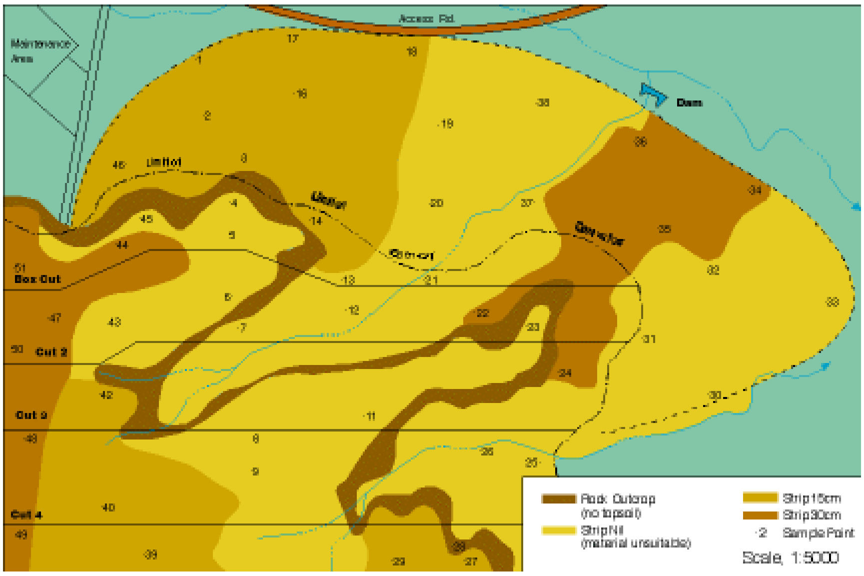


Figure 2 Proposed Open-cut Mine Topsoil Stripping Map (after Hannan, 1995)

5. In many situations there is a strong correlation between soil type boundaries and vegetation distribution. Where the aim is to restore pre-mining vegetation communities, it can be very important that they are re-established on their matching soil types.

6. There is often a close relationship between soil types and landform or topographic position, which can be used to advantage in locating the boundaries between different soil types. For example, ridge crests and steep slopes are frequently covered by thin, stony or light sandy soils. Creek flats and floodplains often consist of deep and fertile alluvial soils, though a check should be made for possible effects of waterlogging and salinisation, which may negate their value for topdressing.Where the parent rock materials are fairly uniform, the boundaries between soil types often roughly follow the contour and this feature can be useful in quickly locating soil type boundaries during field surveys.

7. Representative samples of topsoils and subsoils likely to be used for topdressing should be analysed for a range of physical and chemical characteristics, including clay dispersibility, macro and micro elements and field examination and analysis has been used to determine optimum stripping depths, for the guidance of plant operators.

8. Guidelines on survey and sampling procedures and analytical methods for a range of parameters are usually available from state soil conservation and agriculture departments. The results should be compared with those for spoil and waste rock materials when determining the suitability of soils for topdressing purposes.

9. **Vegetation** surveys are a subject in their own right. They are mentioned here in relation to landform desi cation exchange capacity. **Figure 2** shows a soil map of part of a minesite, where the data fromgn, not only because of the obvious relationships between landform, moisture regime and vegetation, but also because of the need in some situations to re-establish habitat corridors and vegetation along streams.

   When mapping vegetation groups, account should be taken of their topographic position, associated soil types and moisture characteristics, so that similar micro-environments can be created during reshaping and topsoil replacement.

Even in areas dominated by agriculture, remnant stands of trees along ridge lines and watercourses may provide essential wildlife habitat and corridors. New landform designs should as far as possible link corridors on adjacent lands.

3. NEED FOR LANDFORM DESIGN

The following are a number of basic principles for landform design which apply to mine rehabilitation work regardless of location.

3.1 THE NEED FOR A WHOLE-OF-MINE APPROACH

Since most mining operations take place progressively and areas of spoil and waste rock become available for rehabilitation periodically, there can be a temptation to design landforms in small units to suit each individual area. This approach can be satisfactory for small, isolated out-of-pit dumps, where the entire area can be designed and reshaped in a single operation.

In cases where annual or seasonal rehabilitation operations form a seamless part of ongoing programs, there is a continual need to be aware of the size and location of future dumps and adhere to an overall drainage plan for the site. Otherwise there is a risk of draining everything to some low point from which further drainage is impossible or, alternatively, a sudden increase in gradient may be needed in order to reach the level of surrounding undisturbed land. This highlights the need for close integration between plans for mining and rehabilitation. Best practice requires that where a change becomes necessary to mining operations, this must be reflected in corresponding changes to landform design.

Photo: Goldfields (Tasmania) Ltd

The Henty Gold Mine, 30 km NW of Queenstown, Tasmania. The site was chosen in the planning stage as it used an existing disturbed area (Hydro construction site) for most of its processing, water treatment and administration areas.

Photo: Goldfields (Tasmania) Ltd

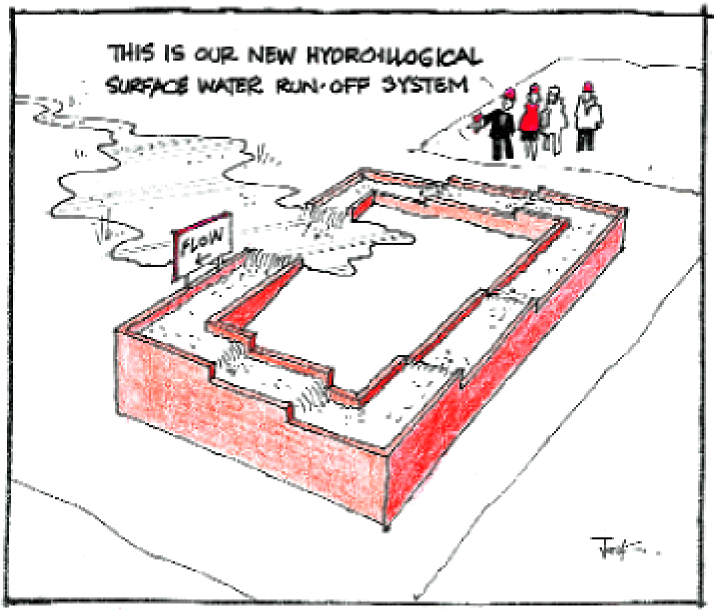
The Henty Gold Mine, near Queenstown, Tasmania. Wilderness values are particularly high in Tasmania. Shaft hoisting equipment is underground (foreground) to minimise visual and landform impacts. The area beyond the ridge is part of the South West Tasmania Conservation Area.

3.2 HYDROLOGIC COMPATIBILITY WITH SURROUNDING LAND

The final discharge points for surface runoff are dictated by the location of suitable watercourses on surrounding land. Reshaping must ensure that all runoff reaches these points in volumes and at velocities which will not cause erosion or sedimentation. The catchment area feeding each of these discharge points should not significantly exceed the pre-mining catchment area. This avoids the risk of downstream channel erosion and overloading of culverts and other infrastructure beyond the minesite. State laws concerning the diversion of water through property boundaries and the wishes of neighbouring land owners should also be taken into account when selecting final discharge points.

3.3 FORMATION OF AN INTEGRATED DRAINAGE SYSTEM

This is perhaps the most difficult aspect of landform design. It demands a whole-of-mine approach and identifying (in the early stages) sites for locating the new major watercourses that can be connected to natural streams on surrounding land. Quite often, haulage ramps leading into the pit or leading down from waste rock emplacements can be chosen as the final watercourses. These roads often form natural depressions easily converted to watercourses with a minimum of reshaping. They are also fairly permanent features while the mine is operating. The task then becomes one of designing landforms which incorporate smaller "feeder" watercourses to intersect with the haulage roads, while temporarily diverting runoff until roads can be decommissioned and converted to their ultimate use.



3.4 DRAINAGE DENSITY

Drainage density describes the number of watercourses draining a catchment area. It is expressed as the total length of all watercourses, per unit of catchment area. The pre-mining drainage density is a useful benchmark for designing a new system, but changes brought about by mining to features such as elevation, slope angles, vegetation cover and the resistance of the new surface to erosion may dictate changes from the pre-mining drainage density.

The post-mining land use may also influence the desirable drainage density. For example, land intended for cropping on fairly low slopes should have a low drainage density, so that reasonably large areas can be cultivated without interruption. The first 100 metres or so of steep slopes can also have a low drainage density, as runoff tends to occur by overland flow, rather than becoming channelled. **Figure 3** illustrates drainage density and stream ordering principles.

Photo: Goldfields (Tasmania) Ltd

The Henty Gold Mine, near Queenstown, Tasmania. The landform at the mine collects all carpark, stores and admin area runoff in the secondary settling pond. The containment booms are in case of a hazardous material accident.

Photo: Goldfields (Tasmania) Ltd

The Henty Gold Mine, near Queenstown, Tasmania. All pad runoff and drilling waste water at the Mine are directed into three or more sumps for treatment before discharge.

Stream ordering is a simple mathematically derived ordering of stream tributaries commencing with first order being the smallest identifiable stream, with the second order from the confluence of two first order streams, third order from the confluence of two second order streams, and so on indefinitely down the catchment. The purpose of stream ordering is to index size and scale but also to give an approximate index of the amount of streamflow which can be produced by a particular stream network (Gregory and Walling 1973).

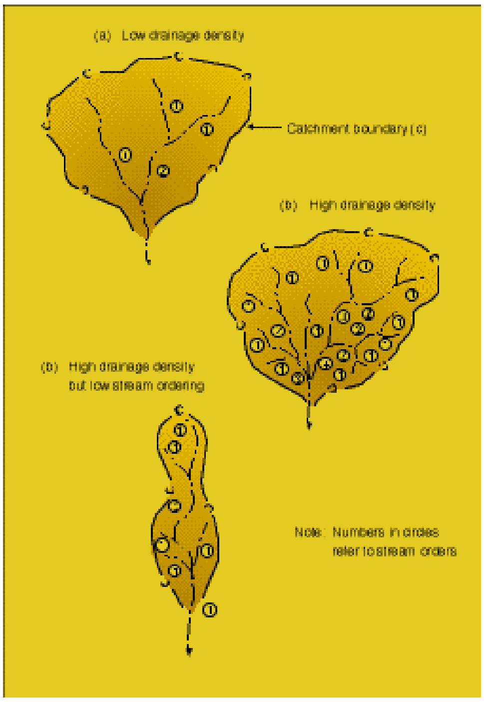


Figure 3 Principle of Drainage Density and Stream Ordering (after Hannan, 1995)

3.5 SLOPE DESIGN

Reshaping aims to produce slopes with angles, lengths and shapes compatible with the surrounding landscape, suitable for the proposed land use and not prone to an unacceptable rate of erosion. Over geological time the forces of erosion and deposition have acted on natural slopes to create an angle which, for a given soil type, is in equilibrium with the catchment area, runoff volume and vegetation. This results in a slope that is initially convex (the upper 2030% of its length) and later concave (the lower 7080%). Combinations of slope angles and vegetation usually maintain runoff velocities at roughly constant, non-erosive values.

With strip coal mining, slopes with the correct profile will form naturally when reshaping the more extensive area of spoil (waste) piles. This is particularly the case between the top of the box-cut and the start of the slope towards the final void of the open-cut and the top surface of large out-of-pit waste rock dumps. Here, the regular creasing of slopes by depressions and watercourses will tend to produce the correct profiles. However, extreme care is needed with small out-of-pit dumps and the outer faces of spoil piles where they adjoin surrounding undisturbed land. Unless closely supervised, the usual practice of flattening spoil piles by dozing from the top downwards will result in slopes with a convex profile.

Where site constraints prevent correct profile formation, the slope should at least be made straight, ie. at a constant angle over its entire length. Consideration should also be given to the formation of a bench in the middle of the slope to divide the runoff path into two shorter segments (see **Figure 4**).

There are a number of factors that determine satisfactory slope angles. Apart from the obvious requirement of blending with surrounding terrain, conditions attached to mining leases and other approvals may specify limits to slope angles. The potential for accelerated soil erosion is subject to the combined effects of slope angle, length and shape.

Photo: Goldfields (Tasmania) Ltd

The Henty Gold Mine, near Queenstown, Tasmania. A recycled timber platform at the mine minimises creating muddy water at the rig. The pad is contoured to direct runoff into sumps. This is important at the mine, where average rainfall exceeds 3.5m a year.

The longer the slope, the larger the catchment area and the volume of runoff. For any slope angle, its length should not exceed that of similar slopes on undisturbed land. Long slopes can be broken by shaping to provide watercourses at the appropriate drainage density, i.e. by directing the flow diagonally across long slopes towards a series of roughly parallel small watercourses. Conversely breaking the slope into shorter segments can be achieved by constructing contour banks or back-sloped benches at intervals down the slope. Where site constraints make it essential to have steep slopes, these should be kept as short as possible and artificial erosion control measures such as "moonscaping", stone pitching or hay mulching may be needed.

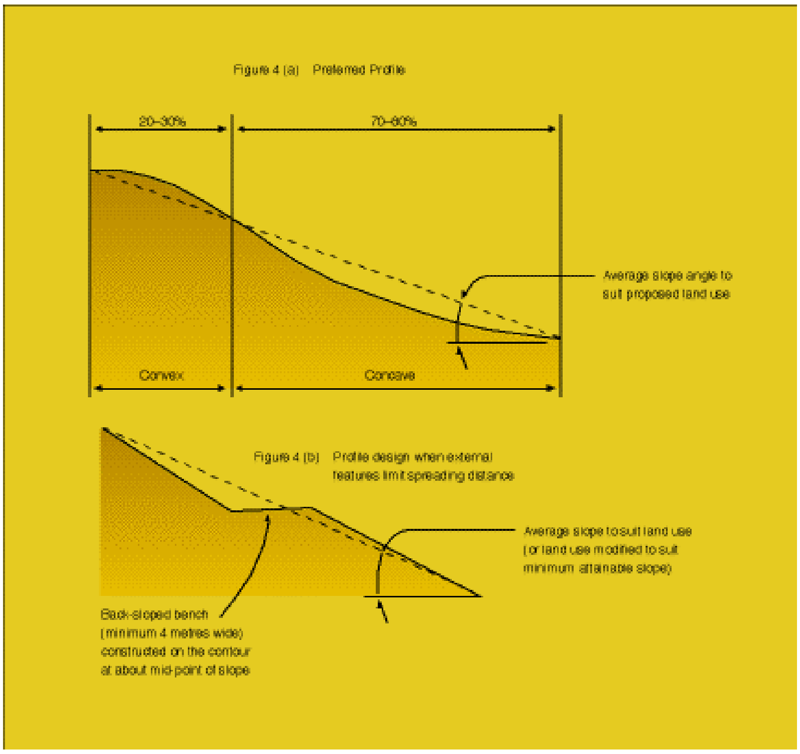


Figure 4 Design of Slope Profiles (after Hannan, 1995)

3.6 RELATIONSHIP BETWEEN LANDFORM AND LAND USE

Pre-mining surveys of land use and land capability provide a useful benchmark for planning post-mining landforms and uses. However, it is unlikely that the pre-mining uses or capabilities will be reinstated in the same proportions or locations. The effects of mining on altering elevations, slopes, moisture regime and soil characteristics will invariably impose changes, perhaps to the extent that none of the land can return to its pre mining use. It is more important that the post-mining landform, drainage and vegetation associations are stable and self-sustaining, visually compatible with the surrounding land and meet community expectations.

In most cases the area occupied by mining is insignificant in terms of regional land use and productivity and the opportunities for developing a land use which is more sustainable and more suited to community needs should always be borne in mind. For example, returning land which has been used beyond its agricultural capability (and has suffered erosion or salinisation as a result) to natural forest and wildlife habitat may better meet community expectations. Mines close to urban areas may have opportunities to provide landforms suited to industrial, recreational or residential development. Creating new or enhancing existing wetlands may provide community benefits and wildlife habitat, as well as providing a sink for nutrients and a buffer for flood flows. Some minesites have successfully been converted to urban subdivisions featuring challenging golf courses.

The opportunities to establish new landforms and uses, less prone to erosion than the pre-mining situation and more valuable to the community, should always be exploited. Any substantial change from the pre-mining landform should be contemplated only after full consultation with the local community, regulatory authorities, and research has been undertaken. This consultation and research gives reasonable confidence that the proposed landform/land use combination will be stable and self-sustaining at management levels applicable to the same land use in other locations.

Photo: Coal and Allied Industries Limited & John Hannan

Two photographs capture rehabilitation on a grand scale. Top, mining in progress at the Hunter Valley Number 1 Mine, owned by Coal and Allied Industries in 1982. Below, the same area after rehabilitation.

Photo: Coal and Allied Industries Limited & John Hannan

4. LANDFORM DESIGN

4.1 IN-PIT SPOIL & WASTE ROCK EMPLACEMENTS

Survey Methods

The type and extent of surveying needed to design a satisfactory landform depends very much on the size and shape of the pit area being backfilled. It also depends on whether back-filling is a progressive process, as the pit expands or moves, or a once off operation at the end of the pit's life.

For small open pits where back-filling is a once-off operation, very little detailed surveying may be needed, apart from calculating volumes of the void and material available for filling. This will determine whether the final land surface will be lower or higher than the adjacent land, ie whether the pit will end up as a depression or a hill. For small, isolated pits, very little landform design may be necessary or possible. The main objective will be to achieve an appropriate drainage scheme that is compatible with the surrounding land, as discussed in Section 3.

The need for proper slope profiles (ie. convex in the upper 2030% and concave in the lower 70-80%) should be borne in mind during volume calculations and field surveying. These profiles tend to form naturally during reshaping backfilled pits and are thus much easier to achieve than with the reshaping of the outer faces of box-cut and out-of-pit spoil and waste rock dumps.

In strip mines and large open-pit or bench mines, where back filling and rehabilitation are carried out progressively (as the pit expands or moves across the landscape), much greater attention is needed to overall landform design and to surveying of each incremental area of reshaping. This is necessary as the volume of material increases (swells) when the natural compaction (density) of the material is released. The volume of a waste dump or spoil pile will decrease over time as the density increases after placement. This attention to design is to ensure that each increment forms an integral part of the overall landform design for the site. This is particularly true of drainage design. Advice on the use of digital terrain maps and computer applications to assist with landform design are given in Section 5. The following notes provide suggestions on criteria which need to be taken into account when designing landforms that will be stable and compatible with the chosen post-mining use, as these form the essential inputs into computer-aided design systems.

Regardless of the area of spoil or waste rock dumps, ultimate success in achieving the planned landform depends very much on close liaison and co-operation between the rehabilitation planner, surveyors and field supervisors.

Transferring the landform plan into the field can be one of the most difficult aspects of rehabilitation work, at least until such time as surveyors and plant supervisors have gained experience with what is required. It is important that field supervisors understand the importance of achieving correct slope angles and profiles and of producing the required channel gradients and cross-sections in watercourses and drains.

Best practice also requires that all personnel supervising and conducting the work are advised of the acceptable range in these parameters and of the importance of ensuring that those values are maintained. The final stages of reshaping need control through regular surveying and checking, using elevation pegs and profile markers to guide the plant operators.

The need for finesse in earthmoving operations is probably greatest in flat or low lying land, where insufficient attention to detail can result in poor drainage and waterlogging. In coastal heath and wetland areas, a difference in surface elevation of even a few centimetres can alter soil moisture regimes to the extent that re-establishing the original vegetation becomes impossible. In these situations, there can also be a very close association between elevation, drainage and soil type, which needs careful consideration when stripping and replacing topsoil to ensure the correct material is applied to each area.

Post-mining land capability and land use

Visual and land use compatibility of rehabilitated mined land is the single most important consideration in designing a combination of landforms and revegetation processes. While there can be occasions where a change to a completely different land use is beneficial, for example from previous agriculture to industrial real estate, these opportunities are rare and explain why most rehabilitation programs are designed to return the land to its pre-mining use.

It is also important to recognise that in many cases, agricultural practices in Australia have not been sustainable, resulting in land degradation. The extensive land disturbance caused by surface mining can thus create opportunities to repair past damage and to return the land to a more sustainable condition. Examples are reafforestation of land that has been over-cleared and the replacement of exotic tree and pasture species with native vegetation.

Photo: John Hannan

Landform design must consider the final land use and whether it is planned to support other uses such as grazing.

As discussed in Section 2.3, land capability is the ability of the land to sustainably support agricultural practices at various intensities and is assessed on a range of factors. These include slope, soil type, vegetation and climate. Reinstating the pre-mining capability may not always be possible or appropriate, especially if the post-mining land use is not related to agricultural production.

However, if the original capabilities are to be restored, a pre-requisite is the formation of appropriate slope angles and lengths. Conversely, topsoil selection and placement, plus the selection of vegetation species, should match the land capability that can be achieved on the slope angles formed during reshaping.

For example, land capability classes I and II are normally regarded as prime agricultural land, where the combination of low slopes, good drainage and fertile soils will permit sustainable crop production (**Table 1.0**). To restore this capability, close attention must be paid to achieving similar slopes and adequate drainage to prevent ponding of water on the soil surface. Both subsoil and topsoil layers must be replaced in the correct sequence and at sufficient depth and care must be exercised to avoid over-compacting soil layers while respreading. Classes IV to VI comprise steeper slopes and/or the influence of climate and soil type renders them suitable only for grazing.

In the south-eastern States of Australia, any slope over about 5° (8%) is unsuited to cropping, given the risk of soil erosion if it is regularly cultivated. In monsoonal areas, slopes over about 3° (5%) are probably best returned to pastures or to permanent native vegetation.

For land Classes IV to VI, the tolerance in reshaping landforms is greater and topsoil replacement can be less critical. In some cases, satisfactory revegetation can be achieved using better quality spoil materials as a soil substitute, especially if topsoil is in short supply and can be put to better use in drainage lines and on lower slopes. Capability Classes VII and higher generally comprise steep and rocky areas or wetlands, which are unsuited to agriculture. Where this type of landform is developed on mines, the appropriate native vegetation should be re-established, as this will provide the best erosion protection and long term sustainability.

Table 1.0 Land Capability Classes (after Hannan, 1995)

Class	Soil Conservation Practices	Interpretation and Implications
I	No special soil conservation works or practices	Land suitable for a wide variety of uses. Where soils are fertile, this is land with the highest potential for agriculture and may be cultivated for vegetable and fruit production, cereal and other grain crops, fodder and forage crops and sugar cane in specific areas. Includes "prime agricultural land".
II	Soil conservation practices such as strip cropping, conservation tillage and adequate crop rotation.	Usually gently sloping land suitable for a wide variety of agricultural uses. Has a high potential for crop production on fertile soils similar to Class I but increasing limitations to production due to site conditions. Includes "prime agricultural land".
III	Structural soil conservation works such as graded banks, waterways and diversion banks, together with soil conservation practices such as conservation tillage and adequate crop rotation.	Sloping land suitable for cropping on a rotational basis. Generally used for the production of the same type of crops as listed for Class I, although productivity will vary depending on soil fertility. Individual yields may be the same as for Classes I and II but increasing restrictions due to erosion hazard will reduce the total yield over time. Soil erosion problems are often severe. Generally fair to good agricultural land.
IV	Soil conservation practices such as pasture improvement, stock control, application of fertiliser and minimal cultivation for the establishment or re-establishment of permanent pasture.	Land not suitable for cultivation on a regular basis owing to limitations of slope gradient, soil erosion, shallowness or rockiness, climate or a combination of these factors. Comprises the better classes of grazing land and can be cultivated for an occasional crop, particularly a fodder crop, or for pasture renewal. Not suited for the range of agricultural uses listed for Classes I to III. If used for "hobby farms", adequate provision should be made for water supply, effluent disposal and selection of stable and safe building sites and access roads.
V	Structural soil conservation works such as absorption banks, diversion banks and contour ripping, together with the practices listed for Class IV.	Land not suitable for cultivation on a regular basis owing to considerable limitations of slope gradient, soil erosion, shallowness or rockiness, climate, or a combination of these factors. Soil erosion problems are often severe. Production is generally lower than for grazing lands in Class IV. Can be cultivated for an occasional crop, particularly a fodder crop or for pasture renewal. Not suited to the range of agricultural uses listed for Classes I to III. If used for "hobby farms", adequate provision should be made for water supply, effluent disposal and selection of stable and safe building sites and access roads.
VI	Soil conservation practices including limitation on stock numbers, broadcasting of seed and fertiliser, prevention of fire and destruction of vermin. May include some isolated structural works.	Productivity will vary due to soil depth and soil fertility. Comprises the less productive grazing lands. If used for "hobby farms", adequate provision should be made for water supply, effluent disposal and selection of stable and safe building sites and access roads.
VII	Land best suited for green timber. Generally stock should be excluded.	Generally comprises areas of steep slopes with shallow soils. Clearing of timber from these sites is not recommended. Where clearing has occurred, the area should be allowed to return to timber.
VIII	Cliffs, lakes or swamps.	Land unsuitable for agricultural or pastoral uses. Recommended uses are those compatible with the preservation of natural vegetation, namely, water supply catchments, wildlife refuges, national and state parks and scenic areas.
U	Urban areas.	
M	Mining and quarrying areas.	

Note:
I, II, III Suitable for regular cultivation
IV, V Suitable for grazing; Occasional Cultivation

VI Suitable for grazing; No Cultivation
VII, VIII, U, M Other.

Landform design criteria

Visual requirements

The first criterion for landform design is visually blending mined land with the surrounding undisturbed land. As a general rule, slope angles within the range of natural slopes in the vicinity are best. This not only ensures visual compatibility, it emulates slopes that are in harmony with local conditions of rainfall, soil type and vegetation cover, thus favouring long term stability. In flat country, the production of similar slopes may not be possible, though this constraint applies more to out-of-pit emplacements than to backfilled pits. If compatible slopes cannot be achieved, attention should be given to visually softening steeper areas by avoiding straight "engineered" ridges and sharp changes of angle and by judiciously planting trees to break up skyline views.

Drainage and interface with surrounding land

The second essential criterion is deciding whether surface drainage should be directed towards the final void, or away from it. In most cases, drainage towards the void is easier to design, but can create problems in keeping active mine areas dry during the mine life. It is not acceptable to direct runoff water to the void if the water quality is low. Runoff water quality must be the same as if the runoff was to be discharged to the general landscape.

Drainage away from the void overcomes this problem. However, it can be difficult to select gradients for drainage lines compatible with the elevations of reshaped spoil piles as the mine develops. When draining runoff away from the final void, the following principles are worth considering:

- Select suitable points around the perimeter of the spoil piles where runoff can be safely discharged into existing watercourses. Bear in mind the need to match catchment sizes to avoid overloading individual streams.
- Be aware that differential settlement of backfilled areas may reduce their elevation and result in ponding at the junction between backfilled and undisturbed land. If knowledge is available about the anticipated amount of settlement, this can be factored into the design of new watercourses, by adding the anticipated amount of settlement to the initial elevation of reshaped stream channels. If such information is not available, be prepared for additional filling and reshaping after several years of settlement or alternatively, construct well-designed dams and ponds at the junction between backfilled and undisturbed land.
- When starting to construct new watercourses on the backfilled material, use the lowest possible channel gradients in the downstream sections, near the junction with undisturbed land. Gradients should be progressively increased as the watercourse is constructed further back into the backfilled area. This provides a degree of flexibility to match channel gradients with the elevation of land on either side as they climb further into the backfilled areas. It also mirrors stable natural landforms, where watercourses become progressively steeper as one moves upstream. It will also compensate for a certain amount of settlement, without the risk of reversal of channel grades.

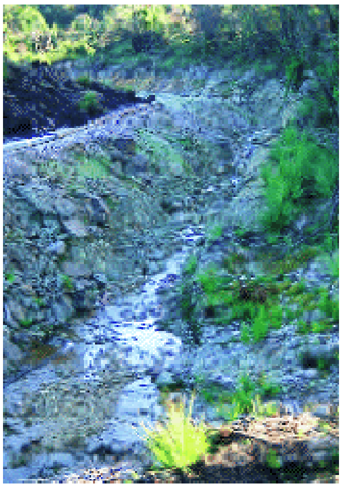


Photo: Goldfields
(Tasmania) Ltd

The Henty Gold Mine, near Queenstown, Tasmania. Construction of diversion drains diverts clean rainforest runoff water into the Henty River. Determining pre mining drainage density provides a useful benchmark for landform design.

Overburden swell factors will almost always result in an increase in volume and a higher elevation than the pre-mining landform as the floor of the final void will nearly always be lower than the surrounding land. Therefore the potential usually exists to drain the entire backfilled area into the void. While this type of drainage pattern is simpler to plan, there are several factors to consider before adopting it.

The most obvious is a need to keep active mine workings dry. This means building a temporary runoff diversion system to drain water away from the mine, which is subsequently removed during decommissioning at the end of the mine's life. Such large scale diversions may be difficult to construct and the cost may tip the balance in favour of a permanent drainage system leading runoff away from the void.

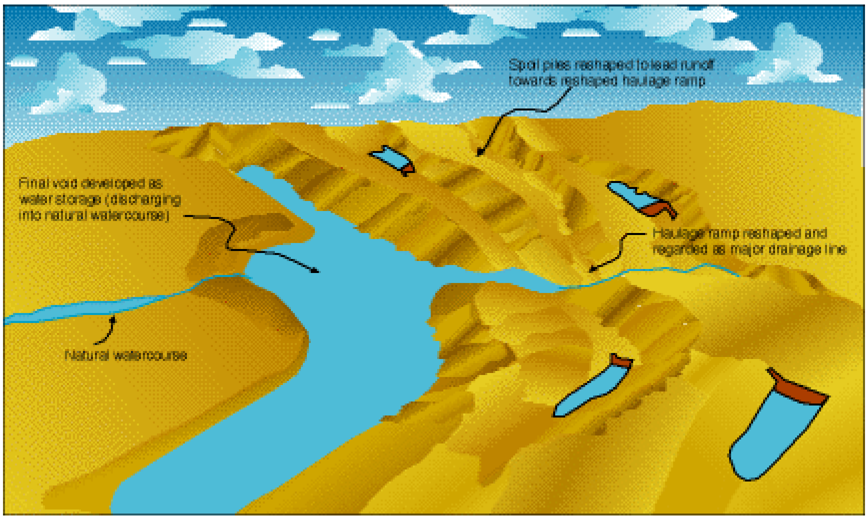


Figure 8 Reshaping of Strip-mine Spoil Piles for Drainage Towards a Final Void (after Hannan, 1995)

The most common reason for drainage towards the void is the intention to create a large water storage in the void at the end of the mine's life. Haulage ramps that lead through backfilled areas into the cut form convenient locations for major watercourses. Reshaping of the areas to either side of the ramps should aim to create secondary watercourses that drain towards the ramps.

At the end of mining, ramps can be backfilled to create the required channel grades and cross sections and any temporary diversions on the secondary watercourses can be removed. Further advice on planning of water storages in final voids is given in Section 6. **Figures 8** and **9** show how a large area of spoil piles at a strip-mine can be reshaped to achieve drainage either towards (**Figure 8**) or away from (**Figure 9**) the final void.

Slope angles and lengths

Over geological time, the forces of erosion and deposition act on natural slopes until an angle is reached which, for a given soil type, is in harmony with the effects of catchment area, runoff volume and vegetative cover. This results in slopes which become progressively flatter towards the bottom, so that runoff is kept at a roughly constant, non-erosive value.

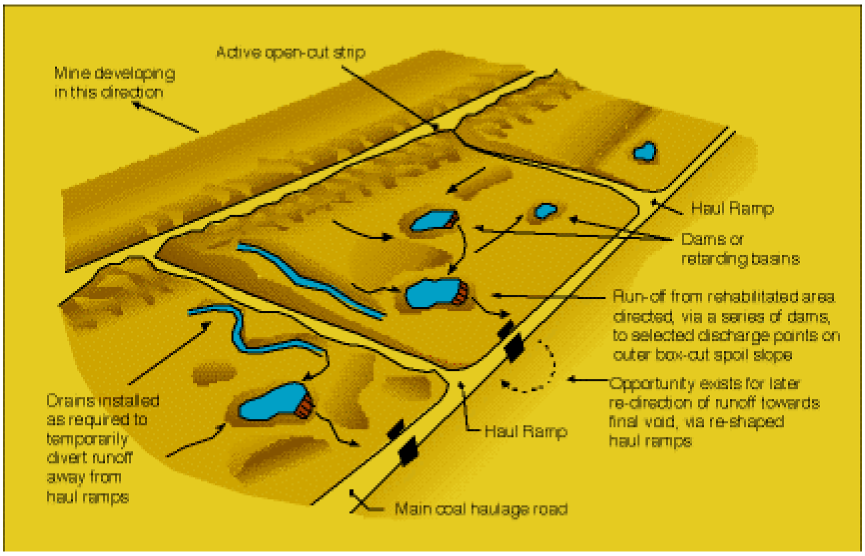


Figure 9 Reshaping for Drainage Away From a Final Void (after Hannan, 1995)

Disturbing any of these factors will upset the balance and lead to further erosion and deposition, until a new slope angle and profile is created which is again in equilibrium. Surface mining clearly upsets all of these factors, with the exception of climate. The task is to try to emulate the original balance as closely as possible, particularly the surface soil properties and vegetation cover.

If topsoil is stripped before mining starts in a manner determined from a properly conducted soil survey, the material should have properties (in terms of texture, structure and erosivity) approaching the pre-mining state when replaced over re-shaped spoil and waste rock. If new slopes are created with the proper sinusoidal profile, and with angles similar to surrounding land, the one can be reasonably assured the reshaped slopes will be stable, provided that effective and permanent vegetation is established.

Within backfilled areas, slope length is closely related to drainage density. The greater the number of channels draining a given area, the closer together they will be and slope lengths will be correspondingly shorter. The benchmark in this regard should be the pre-mining drainage density, as this and the corresponding slope lengths were in equilibrium with the environment. For example, if the pre-mining drainage density was 0.03, then each one-metre length of channel was draining 300 m^2 of catchment, or a slope length of roughly 150 m to either side of the watercourse. This gives a guide on the optimum lengths of reshaped slopes and the distance between adjacent new watercourses.

On no account should the drainage density on reshaped land be any lower than the pre-mining density. In fact, since backfilled areas are usually elevated as a result of swelling or bulking of the spoil after excavation, it is safer to adopt a higher drainage density that reduces the volume of runoff each new watercourse must handle.

Separating and minimising the volume of contaminated water at a mine site may also impose constraints on the design of a drainage system.

4.2 OUT-OF-PIT SPOIL AND WASTE ROCK DUMPS

Survey Methods

All sites chosen for spoil or waste rock dumps must be acceptable for environmental and commercial reasons. From a commercial viewpoint, the sites must not obstruct future mining. That is, the dumps must not be located over orebodies so as to prevent open pit mining of the ore or result in relocating the waste rock, incurring additional costs through "double-handling" the waste. Sufficient exploration is required to ensure that areas to be covered by mine infrastructure, including dumps, are not prospective for resource extraction.

The potential sites should then be surveyed to determine whether any environmental parameters are present which would prevent the site being used for waste rock dumping. The surveys should include searching for rare and endangered speciesand communities of flora and fauna, examining drainage patterns and searching for historic or heritage sites. These surveys, along with topographic surveys, should have been completed during the mine planning phase.

If there are no obstacles to the chosen sites and all environmental impacts can be addressed and mitigated, then the waste dumps can be designed. Design must incorporate allowances for swell with ultimate compaction factors, consideration of local topography and aspect, climatic factors, soils and drainage. Design can be standard dumps which satisfy the minimum requirements of the legislation or the authorities, or innovative using computer-aided design to have the dumps blending in, as much as possible, with the local topography.

Post-mining land capability and land use

The final landform design for any waste dump must ensure that the rehabilitated dump is compatible with the surrounding land and useable by the following land user. This means that the final landform must be accessible, have slope gradients that allow the selected post-mining land use, and is stable and non-erosive in the long term.

Landform design parameters

The principles outlined in Section 4.1.3 while applying to out-of-pit waste rock dumps, require some practical adaptations because of the constraints imposed by the physical addition of mass to the landscape.

Slope Angles and Lengths

With out-of-pit dumps or reshaped tailings dam walls, the slope lengths generally should be less than 50 m. Constructing backsloping berms that are either level or have a gentle slope gradient to divert runoff flows to a stable drop-down structure breaks long slopes. In arid areas, waste rock slope gradients may remain at steeper angles if the dump is built mainly of competent (non-erosive) rock. If erosive material forms the outer slopes of the reshaped dump, then lower angles (not greater than 20° (36%) from the horizontal) should be constructed. This is the maximum angle for safe operation on the contour by a dozer on the sideslope of a dump (see **Figure 10**).

Photo: John Hannan

Part of the landform rehabilitation work needs to consider innovative use of voids for water storage or other uses.

Of particular concern (especially in areas that have high or intense rainfall) is that lowering the batter slope gradients will increase slope length and the area to be rehabilitated. The longer slope lengths will result in a higher potential for erosion that will require additional breaks in the slope by using soil conservation banks or berms to control water runoff volumes and velocities.

Drainage and Interface with Surrounding Land

The top surfaces of waste dumps can be either concave or convex in shape. Differential settlement can have an impact on the final shape of the top surface. Concave surfaces should never be used if a dump contains any materials which have the potential to produce pollutants over the long term, ie acid generating sulphide leachates or where there are doubts about the geotechnical stability of the material in high rainfall areas or intermittent wet years. The use of a convex surface will assist with reducing infiltration and diversion of the runoff to the outer slopes of the dump.

A concave surface, used with chemically stable waste rocks, increases rainfall infiltration and also acts as a temporary water storage to improve infiltration or to assist evaporation. Consequently, the reduction in runoff will lower the potential for erosion of the side slopes.

Wherever possible, the dumps should blend into the surrounding landscape. Many mine sites continue to construct square or rectangular dumps with right-angled corners that are incompatible with natural surroundings. The angles on the dumps should typify those of the surrounding landscape. The sideslopes should be variable in angle around the dump (not down the dump slope) and gentle hollows should copy local hillsides.

Dump heights should never exceed the surrounding hillsides. In areas of low relief, waste dumps of low height at as low an angle as possible is least visually intrusive on the landscape.

Photo: Goldfields (Tasmania) Ltd

The Henty Gold Mine, 30 km NW of Queenstown, Tasmania. The White Spur waste rock storage facility, is part of the mine. The hill are being progressively reformed and covered with stored peat and revegetated with local species. All levels are benched and contoured to direct runoff to a central point.

Innovation is important. In areas where isolated buttes are the local landforms, the final waste dumps can copy those landforms.

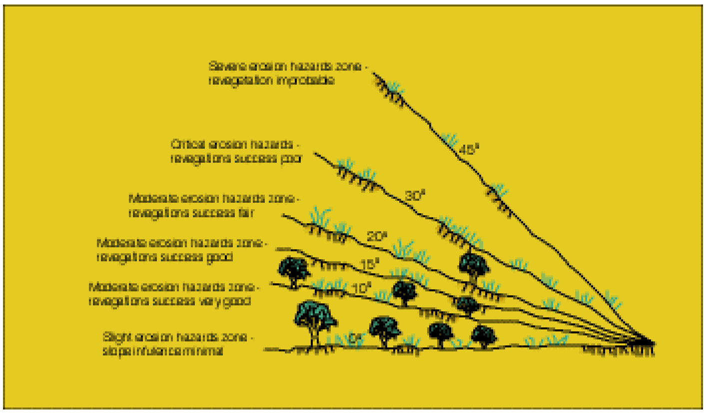


Figure 10 Influence of Angle of Slope on Revegetation and Erosion (after Department of Minerals and Energy, WA 1996)

5. COMPUTER ASSISTED PLANNING AND DESIGN METHODS

One of the greatest difficulties in designing new landforms is ensuring that volumes of cut and fill are precisely matched. In addition, the distances over which waste rock is shifted by dozer or haul truck must be optimised to keep costs down. The task is easier at mines using shovels and trucks as the rough outline of the desired landform can be created by correct selection of waste dump location and elevations.

At mines using draglines major reshaping of spoil piles is required to create the final landform. This requires balancing cut and fill volumes more accurately. At these mines, spoil reshaping can account for up to 90% of the total rehabilitation cost. Clearly, any savings made during earthmoving to build essential slope features, stability and drainage are well worth the time and effort involved.

A number of computer packages now available can assist landform design. Although none are perfect, they can greatly reduce the time required to produce a cost effective landform design. All of the programs rely on digital terrain modelling data for their primary inputs. Mining companies using on-site digital surveying or other digital recording of pre-mine conditions should consider ways to incorporate this information into their computerised terrain modelling.

5.1 DIGITAL TERRAIN MODELS

Minesite digitised terrain models are now readily available through specialised contracting firms or commercial software. These models produce three-dimensional plots of the landscape from either stereographic aerial photography or from site survey data.

5.2 COMPUTER MINE DESIGN APPLICATIONS

Several conventional open-cut mine planning programs have been adapted for landform reshaping. Their usefulness is limited as they rarely produce slopes with the correct profiles and have little capacity for accommodating watercourses and drainage patterns. Because mine planning systems have been designed for use with relatively regular geometric shapes (basically oval or rectangular cuts and triangular or rectangular waste dumps), the programs have problems accommodating the complex three-dimensional shapes required for reshaped landforms. They can therefore be subject to quite large volume errors.

5.3 COMPUTER LANDFORM DESIGN APPLICATIONS

One of the first landform design packages was developed for the AMAX Coal Company in the USA in the early 1980s. This package was quite ambitious as it combined both mine planning and waste dump reshaping functions. It started with the pre-mining topography and simulated the mining phase, including the swell effects of excavation and dumping. The program was useful in preparing conceptual landform and drainage designs for use in environmental impact statements but the cumulative volume errors limited its usefulness for detailed and cost effective planning.

A recent and comprehensive package produced by the Australian Coal Industry Research Laboratories Limited (ACIRL) under the name of "ARGUS" operates in the Windows environment. ARGUS has the advantage of being purpose designed as a program for landform reshaping and is able to handle quite complex three-dimensional shapes with accurate calculation of volumes. It also produces sinusoidal slope profiles, which is valuable from the stability viewpoint. The package can also design drainage, but this can be laborious and care is needed to avoid creating excessive slope angles on valley sides.

In common with most design packages, ARGUS uses digital terrain modelling data imported from a mine planning package such as "MINDRAFT", "SURPAC" or "VULCAN", or as an ASCII file. The data are manipulated by creating a series of nodes (or points in space representing the three-dimensional co-ordinates of the landform surface. The larger the number of nodes created, the closer the landform surface will be to reality and the more accurate the calculations for the cut and fill volumes. As with all computing packages, computing time will increase with higher levels of data input.

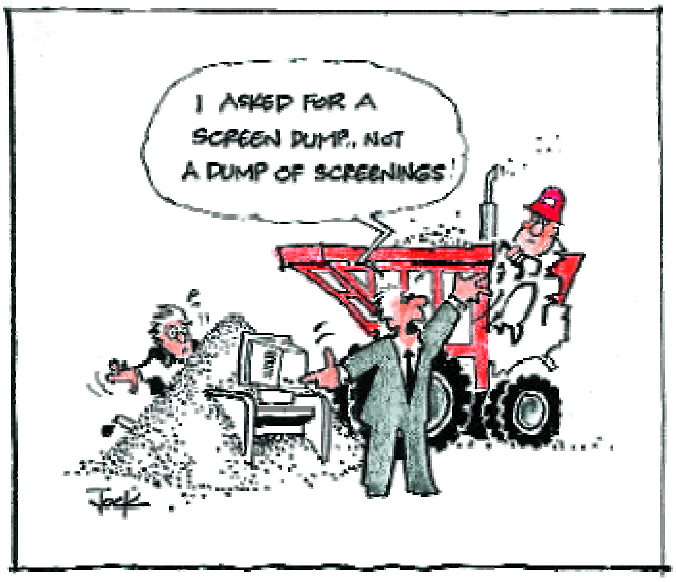
Topography can be displayed in various forms. The most useful is a contour plan displayed as a "wire-frame" or "solid" perspective drawing which can be rotated and viewed from any angle. A plan view which depicts different slope angles in different colours can also be produced which is very useful for highlighting areas of unacceptably steep slopes which would need further design attention.

There can be a "surface warping" feature which enables the user to select a cross-section through any series of nodal points and to progressively reshape the profile by using a maximum of 400 iterative steps. Real-time information is provided through the screen window throughout this process, giving the results of each step in terms of plan or cross-section views, as well as cut and fill volumes. These are particularly useful when designing watercourses.

A unique feature of ARGUS is a transportation analysis model that can help determine the most cost effective equipment selection for reshaping. The module uses the mine's data on the equipment available for reshaping and its performance in terms of earthmoving rates. When these data are applied to the designed landform, ARGUS will produce a plan view of the area overlaid with arrows showing the directions and distances over which material must be dozed or hauled to achieve the final landform. Different colour shadings on the plan assist in selecting optimum equipment by indicating the different types of equipment best used for reshaping on that specific area of the reshaped dump.

5.4 PITFALLS AND PRECAUTIONS

Landform design packages need to be used with common sense. Their output is only as good as the basic information that the program manipulates. In relation to digital terrain data, limiting parameters include slope angles and lengths, drainage density, and more. Their real value is in greatly reducing the volume error in calculating cuts and fills and in the enormous time saving they offer in contrast to older manual calculation and drawing techniques. It is important to substantiate the design parameters by surveying existing dumps to assist with input on swell factors rather than relying on textbook numbers.



6. FINAL VOIDS

The existence, ultimate shape and size of a final void at the end of an open-cut mine's life depends on a range of factors. These include mining method, the resource size and extent, physical constraints (such as roads, railway lines, rivers, lease boundaries, etc.) government regulatory requirements and economics, both in terms of resource amounts that can be viably extracted and the cost of backfilling voids. Any of a range of outcomes is possible. These range from situations where no void remains at the end of mining, as can occur with some bauxite and mineral sands mines, through to situations where virtually all of the material extracted is a marketable resource (such as in quarrying operations) where no material remains for back-filling. Most common, with the majority of gold, base metal and coal mines, is that a sizeable void remains at the end of the mine's life which in most cases is uneconomic to backfill.

Determining the end use for final voids is undoubtedly the most difficult aspect of rehabilitation planning, especially during the early phases of mine planning and development. Not only is the creation of the residual void many years or perhaps even decades into the future, but variations in mining methods, technology and economics during a mine's life can mean that the ultimate location, size and configuration of the void can only be an educated guess.

Perhaps the best strategy, although one not always compatible with EIS procedures, that can be taken towards planning the use of final voids is to adopt a progressive approach. In this approach, pit location and size, together with potential uses, are reviewed at regular intervals throughout the mine's life, with these reviews becoming more detailed and focused as the time of mine closure approaches.

Early planning stages should take account of the following issues:

- Is it possible to design the mine to eliminate a final void? For most conventional hard-rock and coal mines, this may not be an option. However, there are occasions when the mine can be designed to develop in a circular manner, which places the final void adjacent to the initial box-cut spoil dump, thus facilitating back-filling.

- This approach has been successful at a number of mineral sands operations, including the Bridge Hill Ridge mine on the NSW north coast (see pages 9 & 11 of Overview booklet in this series). In some open cut mines, new resources are situated within economic waste haulage distance of previously mined open pits. Rather than construct a new waste dump, many mine sites use the abandoned open pit to dispose of waste rock from the new mine. This only occurs, however, where a resource is not "sterilised" (ie. was not drilled sufficiently to ensure that ore was not located beneath it) in the old pit.
- What is the potential for further underground mining at the end of the open-cut phase? Where the deposit or ore body continues at economic grades to depths beyond open-cut technology, there may be a firm intention from the start to use the void to provide access for underground mining. In this case, the decision on the ultimate fate of the void, ie on final mine decommissioning, may be deferred for many years beyond the open-cut phase.
- If a void is to remain, what needs to be done to ensure safety, what plausible options are available for beneficial uses and what studies need to be carried out to assess both the economic and environmental viability of those options?

Safety aspects

In many remote parts of Australia, it may be clear from the start that the void will have no beneficial use. Provided that the remainder of the mine site is satisfactorily rehabilitated, and the presence of the void is environmentally acceptable, the area occupied by the void itself is probably insignificant in terms of land use and regional economic effects. Therefore the first priority is to render the void safe in terms of access by humans, livestock and wildlife. Factors to consider are:

- In open cut coal mines, the instability of the highwall and low wall can induce failures or mass movement. It may be necessary to bench the highwall and reshape the low wall to a stable slope angle.
- In open-cut coal mines, it will be necessary to cover exposed coal seams with several metres of inert material to prevent ignition either from spontaneous combustion, bushfires or human interference. Exposed base metal ore should also be sealed and covered to minimise oxidation and leachate production.
- A form of barrier at a safe distance from the perimeter of the void to discourage human access, or at least to warn of the void's existence. While fencing may be a suitable temporary measure, it is not reliable for long term protection. It is better to surround the void with a sizeable ditch or steep bund wall to prevent inadvertent vehicle access.
- Build a sump in a suitable location in the floor of the void, where seepage and surface runoff will drain and be ponded. The sump floor should be hard rock rather than backfilled material so that wildlife and livestock will not become bogged and trapped as the pond dries out.
- As much as possible, surface runoff from land surrounding the void should be diverted from it to prevent flooding of the void and potential development of instability of the walls.
- The void surroundings should be made as aesthetically pleasing as possible by appropriate revegetation and tree planting on the low wall and adjacent to the highwall.

Potential end uses

Possible end uses in remote areas essentially fall into two categories, either water storage or back filling with a waste material. However, there are alternative uses where quarried sites have been turned into recreational facilities (golf courses, concert amphitheatres, parks and gardens, abseiling areas, Olympic standard rowing courses), educational (geological and soils) resource and heritage sites, or have been excavated for ultimate development of high rise buildings. While these options deserve careful consideration, they need thorough investigation before a decision is taken. Some of the more significant issues are:

Water storage

The main concern with using final voids for water storage is the quality of the stored water, especially during periods of drought when replenishment may be minimal and evaporation losses are high, leading to elevated levels of dissolved salts. The effects of the void on the surrounding groundwater regime, in terms of potential contamination and inflows/outflows must be investigated, both to assess contamination effects and also to determine the seepage losses.

Determining the suitability of a void for water storage is essentially no different to selecting a site for a major in-river storage reservoir. The principal considerations are:

- Is there a catchment of sufficient size and adequate water quality to fill the void within a reasonable time and to provide for periodic flushing sufficient to prevent a build-up of dissolved salts in the stored water? In this respect, studies of runoff volumes from the catchment under average, drought and flood conditions are needed, together with calculations of seepage and evaporation losses, to determine whether the water balance will be acceptable. Computer modelling will evaluate the filling time for the void, fluctuations of water level under a range of rainfall years and the quality of the stored water. In most cases, mine areas and rehabilitated spoil piles provide an insufficient catchment. However, diverting a nearby creek into the void, will increase the catchment area. Any such diversions will, of course, need to comply with laws relating to water diversion and will need the agreement of neighbouring landowners and the local community. Diversion of flood flows only may be one way to provide sufficient catchment without detracting from riparian water uses during lesser flows.
- Does the likely water quality measure up to its beneficial use? If modelling shows the water will be of low salinity and the void is reasonably close to productive farmland, irrigation uses are an obvious option. Good quality water may also be suitable as a supply for nearby townships, provided the catchment is adequate and quality will not deteriorate in times of drought. The storage may also provide process water for local mining operations and other industry, in which case high quality may be a lesser consideration. Using a void as a retention basin for major flood flows may considerably benefit a community, while at the same time providing useful water storage for use at other times. There may also be opportunities to create amenity uses, such as for water sports and fishing, though these are likely to be secondary to some other, more economically beneficial uses.

Domestic Waste disposal

Waste disposal into final voids is an appealing option, but one that must be approached intelligently and with some caution. The main factors to consider are the physical and chemical nature of the waste, its volume, the distance of the void from the source of the waste and transport requirements. The volume of a typical mine void is such that it can absorb an enormous quantity of urban garbage and fill material, but the potential leachate affects on the local water systems must be considered, and managed.

For example, it has been estimated that the aggregate volume of present coal mine voids in the Hunter Valley would accommodate the total solid waste disposal needs of Sydney and the Hunter region for more than 180 years. Clearly, only one or two voids in the region might fill this purpose.

Disposal of industrial and mining waste can however be a realistic option and is probably the most common use for voids. The disposal of mill tailings, coal wash rejects and power station fly-ash are all current uses for voids. The volume of these materials is usually sufficient to ensure that the void is filled within a reasonable time span. Moreover, filling with these materials achieves two benefits. The wastes are concentrated, which facilitates later recovery should they assume some economic value and the void, after back-filling and capping, can be returned to productive land use.

Caution needs to be exercised, however, when considering any waste disposal option. State and Federal laws relating to waste disposal in landfills are becoming increasingly stringent, due to concerns for subsequent effects on community health and the environment. For preference, only homogeneous waste material should be accepted and the material should be thoroughly tested for leaching characteristics and potential groundwater contamination before it is accepted. If the waste material is combustible or liable to spontaneous combustion, exposed seams in coal mine voids should be sealed with several metres of inert material, to prevent ignition.

7. SURFACE WATER CONTROL

7.1 CAUSES OF SOIL EROSION

Soil erosion occurs when the energy of moving water or air exceeds the forces binding soil particles together. Particles detach from the soil surface and are removed by the moving fluid. Sedimentation occurs when fluid flow decreases to the point where it is no longer sufficient to hold the particles in suspension.

Wind erosion is initiated primarily by coarser particles moving and bouncing across the surface under the action of wind (called "saltation"). At each bounce, finer material is dislodged from the surface and is carried in the air stream. Wind erosion is insignificant on minesites in terms of actual soil loss, but gives rise to air pollution (dust), that may be a particular problem where a mine is located near, and upwind of, residential areas. Another booklet in this series will deal in detail with the topic of dust. Damage caused by sandblasting to newly establishing vegetation can also be a problem.

Water erosion occurs in two main ways: by raindrop splash or as gully or sheet erosion by flowing water. A raindrop striking an unprotected soil surface forms a small crater with particles thrown in a roughly circular pattern around the hole. A vertically falling raindrop striking a sloping surface will throw more material to the downhill side. In this way, quite large volumes of surface soil may be transported down slope during rainfall. In addition, the energy of raindrop impact pulverises and compacts the soil, causing the surface to seal and reducing infiltration. This in turn promotes gully or sheet erosion, by increasing the proportion of rainfall that flows over the surface.

Gully and sheet erosion are related to the velocity of surface water flow and the cohesion or detachability of the soil particles. Sheet erosion is not as obvious as gullying, as it occurs when the flow is widespread rather than concentrated or channelled. However, its effects on the soil and its contribution to sediment loads in streams can be just as severe.

The depth of flow, the angle and length of the slope and the retardance or surface roughness of the soil determine flow velocity. The cohesion of soil particles is affected by the soil type (grain size and degree of aggregation) and by the binding effect which organic matter and plant roots have on the soil.

7.2 CONTROLLING SOIL EROSION

By far the best protection against all forms of erosion is a dense cover of vegetation. This protects the soil surface against wind and raindrop impact, while surface litter and plant roots help bind soil particles together and promote water infiltration, reducing the volume of surface flow.

For undisturbed parts of the mine lease, satisfactory erosion control is generally achieved by management and fire control strategies to maintain an adequate cover of vegetation. This may involve careful control of grazing, removing feral animals and limited access to prevent the formation of vehicle tracks. Any areas of active erosion should be treated with structural control works and revegetated.

During early rehabilitation work, however, it is inevitable that the newly formed surface will be exposed and very susceptible to erosion. Failure to provide adequate control will not only increase the need for water treatment to remove suspended solids, but the loss of replaced topsoil can make the job of revegetation significantly more difficult and delay the return of land to a self-sustaining condition, all of which add to costs.

The principles of landform and drainage design to minimise long term erosion have already been discussed. To minimise the risk of serious erosion during the early stages of rehabilitation work there are a range of management methods and structural controls that can be applied.

Photo: Niugini Mining (Australia) Ltd

Red Dome Mine, Chillagoe, Far North Queensland. Southern Waste Dump after three years with over 40 native species planted at 6-800 stems/ha in alkali waste rock when ground temperature less than 32°C with overcast conditions.

7.3 SURFACE WATER MANAGEMENT

It is common practice to divide surface water on mine sites into five categories or streams, depending upon their source, level of contamination and the need for treatment prior to discharge or use. The five categories are:

- **Runoff from undisturbed land**, the quality of which is little different to that from surrounding, non-mined land. This should be diverted around and away from disturbed areas and mine infrastructure, to minimise the volume of contaminated water needing treatment. Diversion and storage of this water in strategically located dams can provide a significant portion of the mine's processing water supply.
- **Runoff from disturbed areas**, including spoil and waste rock dumps, access roads and partially rehabilitated areas is likely to be contaminated with suspended solids and usually requires treatment by settlement or removal of fine silt and clay particles, before discharge or use. A system of drainage and diversion banks or channels should collect this in settlement dams. After settling, this water may be a useful supply of process water and for dust suppression.
- **Runoff from workshop "hardstand" areas, vehicle washdown facilities, etc** is often contaminated with oils and greases that need separation. After treatment through an appropriate oil separator, the water can be combined with treated effluent from the site sewerage treatment plant and then disposed of by irrigation on nearby rehabilitation areas or by watering lawns and gardens surrounding administration buildings.
- **Decant overflow and seepage from tailings dams** should be retained in a closed circuit and kept separate from other water categories, since it often contains chemicals, residual metals and potential toxins used in the processing plant. This water should be treated to remove solids, adjust pH, etc., and then be recycled through the processing plant.

- **Inflows of saline groundwater,or the dissolving of soluble minerals** can chemically contaminate runoff and seepage collected within the mine pit. This water should be collected in sumps within the pit, then pumped to storage dams, separating it from other water. In most cases, this water can be used on site for process supply and dust suppression. Offsite discharges are usually subject to licence conditions that may impose limits on the quality, volume and/or timing of such releases. It is good practice to minimise ground water entering the pit from uncontaminated sources nearby and becoming contaminated. Techniques using dewatering bores and selective grouting are used to achieve this.

A detailed discussion of mine site water management is beyond the scope of this booklet and further information can be obtained from another booklet in this series entitled *Water Management*, or from various textbooks. There is, however, a close relationship between landform and drainage design and the control of soil erosion. Soil erosion control for reshaped landforms is briefly described later in this booklet. In this respect it is important to remember that a poorly designed and executed drainage system can give rise to greater erosion than if the area had been left without the imposition of these measures.

7.4 EROSION CONTROL MEASURES

The final landform design of the waste dumps should be part of the mining contract for the earthmoving contractor (the civil engineering contract), or planned and operated by the mining engineers if owner-operated earthmoving equipment is used. This ensures maximum usage and efficacy of earthmoving plant, and minimises double handling of waste rock or spoil.

For waste dumps with convex upper surfaces, a small bund (or graded bank) is built at the interface of the top surface and the sideslope (see **Figure 11**). Attention should be payed to the channel gradient so water does not pond in the channel. This may lead to mass movement in the form of block or cyclic (slip circle) slumping of the upper section of the dump. This bund leads runoff flows to constructed drop-down drains stabilised with competent rock or by other means (jute mesh and bitumen, concrete, conveyor belting, etc) (see **Figure 12**).

Erosion control works on waste dumps aim to maximise infiltration, to create an ideal situation for revegetating and to restore the dump to its final land use. This does not apply to the top surface of waste dumps that contain chemically unstable materials.

For waste dumps with concave top surfaces, the bund around the edge of the surface is not required unless it has been calculated that the storage area on the top surface is insufficient to hold the likely rainfall events (see **Figure 13**). Best practice in most cases should provide a "designed" point of discharge from the top surface of the waste dump down a suitable point on the outer slope rather than allowing excess stored water to find its own way down the outer slopes.

Berms should be constructed every 710 vertical metres of a waste dump. The berm must backslope into the dump at a gradient of less than 5% (3°) and with a longitudinal gradient of less than 0.5% (see **Figure 14**). This will vary according to the competency of the material, soil type and local climatic factors. Each berm is to drain a maximum area of one hectare or less according to the design factors. Each berm drain is to discharge to stable drop-down drains. These design criteria are the minimum required and should not be exceeded without support of completed research work.

Each drop-down drain should incorporate an energy dissipation structure to prevent erosion away from the dump and at the base (toe) of the dump.

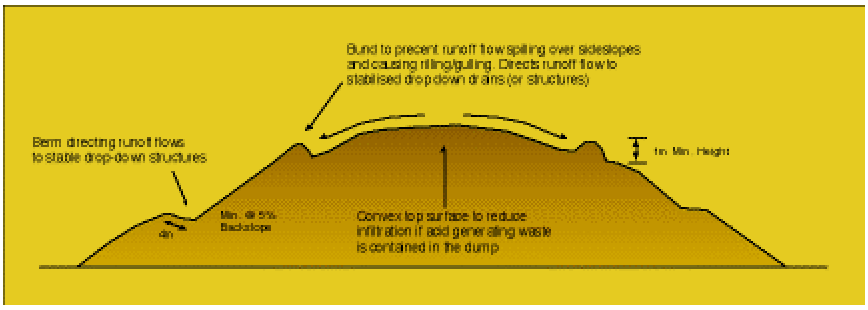


Figure 11 Waste Dump Reshaping for Dump Containing Acid Generating Material or Other Unstable Waste

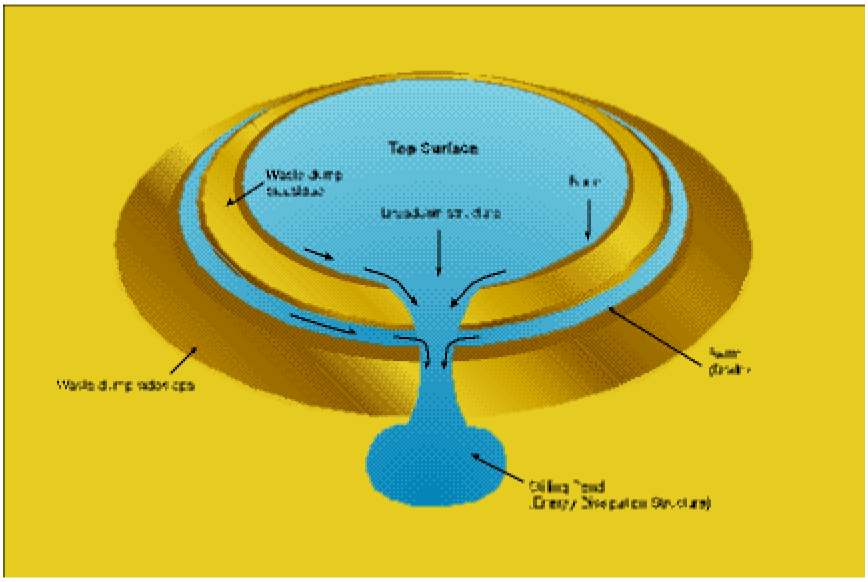


Figure 12 Waste Rock with Berm Drop-down Drain and Silting Pond

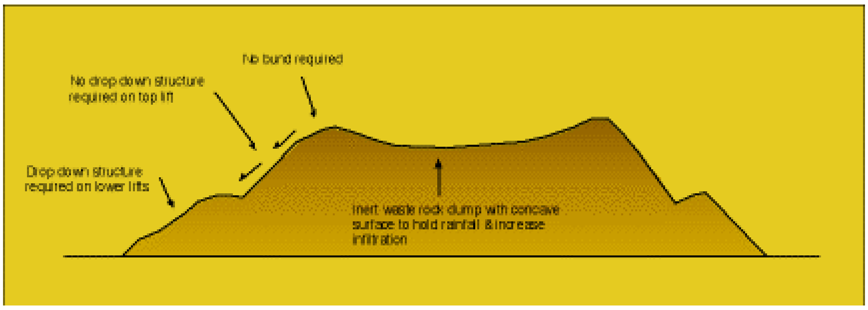


Figure 13 Waste Dump Profile for Inert Waste Rock

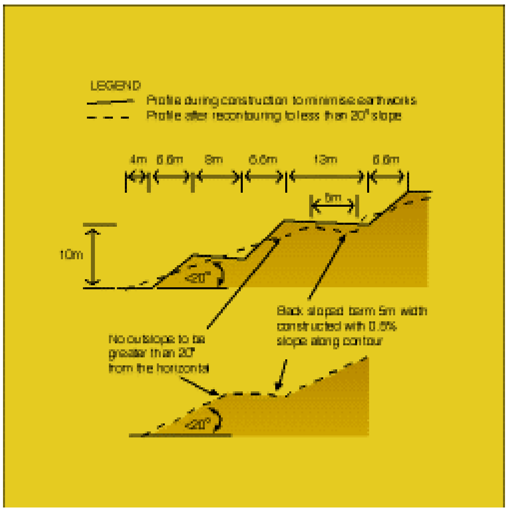


Figure 14 Basic Slope Profile For Most Waste Dumps, Detail of Waste Dump Construction Technique (after Department of Minerals and Energy, WA 1996)

Photo: Niugini Mining (Australia) Ltd

Red Dome Mine, Chillagoe, Far North Queensland. Terraced landform on Western Waste Dump with closely spaced breaks in slope.

Structural erosion control methods

Contour cultivation, with a chisel plough or similar tyned implement, is by far the most common form of structural erosion control on minesites, as it simultaneously provides some measure of erosion protection and cultivates the surface for sowing. However, the usefulness of contour cultivation alone is limited to slopes below about 5° (8%). On steeper slopes, the water-holding capacity of the individual plough furrows becomes extremely limited.

Contour deep ripping or "contour furrowing", in conjunction with contour cultivation, can provide a reasonable degree of erosion protection for a limited time. It should not be relied on as the sole structural treatment for slopes over about 100 (18%) and for slope lengths greater than about 200 metres. Contour ripping consists of simply ripping to a depth of 60 to 90 cm with a conventional single or multi-tyne ripper, drawn by a heavy bulldozer. Best results are achieved if two tynes are used, spaced about 1 m apart, with individual rip lines spaced 2 to 6 m apart, depending upon slope angle.

Contour banks are essentially a much larger version of contour furrows, with a proportionately greater capacity to store runoff and/or drain it to some chosen discharge point. There are essentially three types of banks, although two or more types may be employed in the one continuous line to suit particular design requirements. True contour, or level, banks are constructed precisely along the contour and may be designed to discharge at either or both ends. Absorption banks are also constructed along the contour but have both ends turned uphill to a pre-determined height so that they pond a desired depth of water along their length. Graded or "diversion" banks are constructed away from the true contour, at a designed gradient, so that they drain water from one part of a slope to another, for example towards a watercourse or a dam.

As slope angle increases, the erosion control value of even these larger structures diminishes until, at about 150 (26%) of slope, they need to be so close together that they are of doubtful benefit. In addition, on steep slopes there is a high risk of gully erosion starting in the back or upslope batters of the channels, then rapidly progressing uphill into the areas between the banks. On very steep slopes, basin listing or "moonscaping" can be used to trap and promote infiltration of as much surface runoff as possible (see **Figure 15**). It is important that the basins do not overtop as it will result in serious erosion downslope.

Although contour and graded banks have been used with great success on agricultural land, their value on reshaped mine spoils is somewhat limited. One of the main factors against their use is the lack of suitable construction equipment at most operating mines. The ideal construction plant is a small bulldozer in the 75 to 100 HP class, equipped with a multi-tyne, rear-mounted ripper and a front angle and tilt blade. On slopes up to about 5° (8%), broad-based banks can also be constructed with a road grader. (see **Figure 16**).

Most mining equipment however, is too large for the job and is unable to work to the exacting tolerances needed to produce satisfactory channel shapes and gradients. A further disadvantage is that while the banks may be surveyed and constructed correctly, later differential settlement of the spoil material may alter channel gradients and bank heights. This leads to scouring of the channel or overtopping of the bank at low spots. Where settlement is likely to occur, the channel depth and/or bank height should be increased, so that a certain amount of settlement can occur without the risk of overtopping.

Nevertheless, contour banks have an important part to play in retaining or diverting runoff from undisturbed parts of the site to enable better control of the flow. Their principal use is in separating clean and contaminated runoff, in diverting runoff away from disturbed areas, and directing flow into settlement ponds and water supply dams.

Wherever possible, graded banks should be located so that they discharge onto well vegetated, undisturbed land or stable, well vegetated watercourses. Where this is not possible, provision will need to be made to safely convey runoff directly down the slope, to a suitable discharge point. The spillways of banks, dams or drains are the most critical points in any erosion control scheme, since the water collected from a relatively large catchment is concentrated onto a small area of land and the risk of erosion damage is increased proportionately. The detailed design of banks and spillways is beyond the scope of this booklet and reference should be made to the many textbooks on the subject, or advice should be sought from specialists in government agencies.

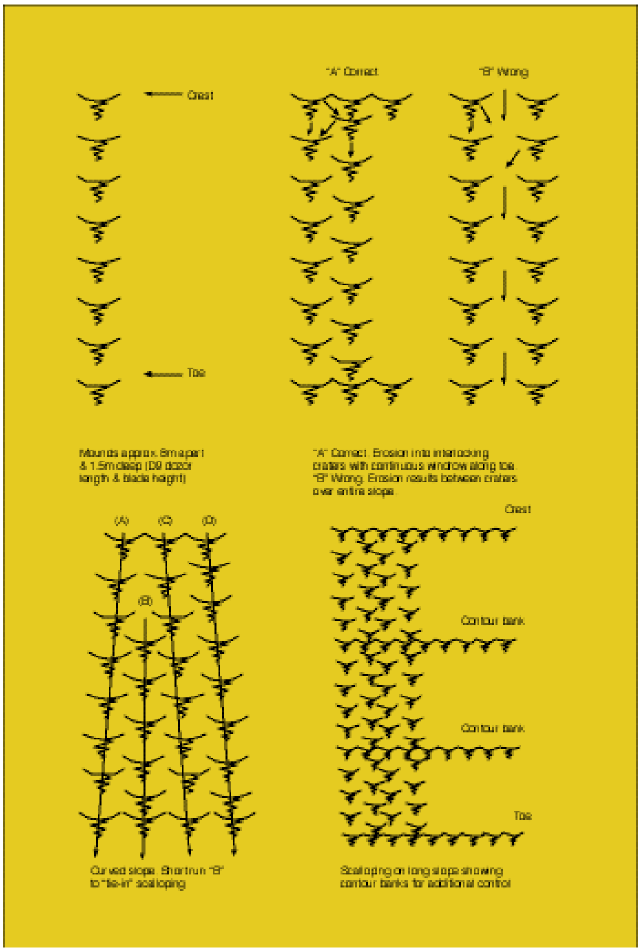


Figure 15 Scalloping (Moonscaping) (after Department of Minerals and Energy, WA 1996)

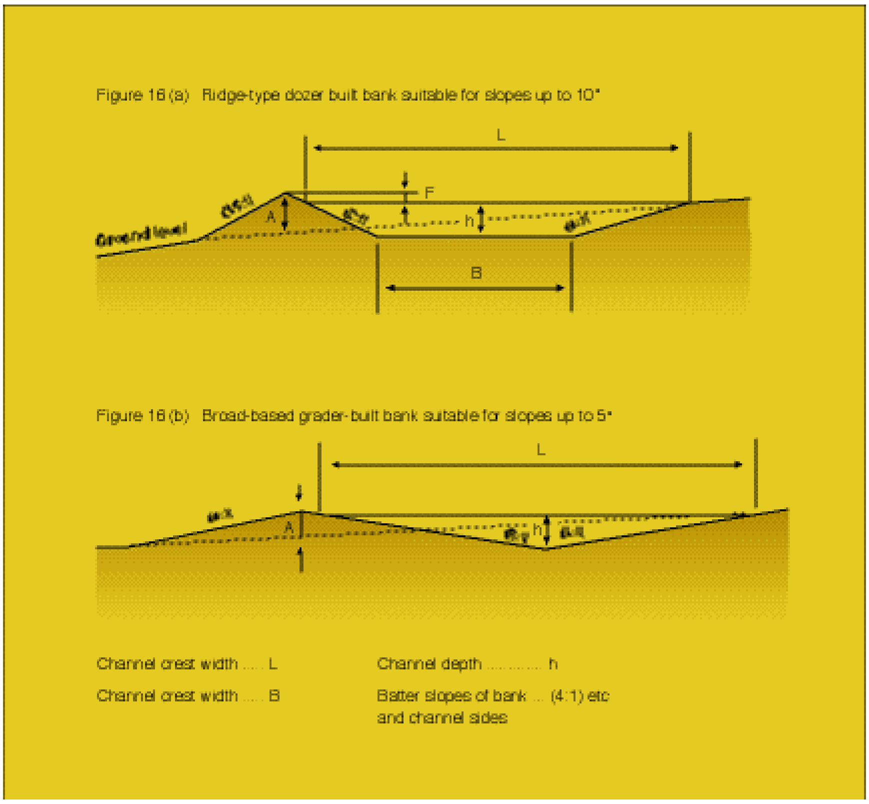


Figure 16 Typical Cross-sectional Shapes for Graded and Level Banks (after Hannan, 1995)

On short, steep slopes, such as the outer faces of tailings dams, roadside cuttings, etc. temporary erosion protection while vegetation is becoming established can be effectively achieved by the use of hydro-seeding, hay mulching, or "Finn" mulching in those areas with suitable climatic conditions. The latter is applied by a specialised machine which applies seed, fertiliser and chopped hay, to which a small amount of bitumen is added to form a binder. A successful method in areas not subject to high intensity storms, is to place vegetation cleared ahead of the mine operations in windrows roughly along the contour at about 20 metre intervals down the slope. The intervening areas are cultivated and sown to the appropriate species. If vegetation clearing is carried out at the right time, this method has the advantage of providing a substantial source of native seed. Also, wherever possible, freshly salvaged topsoil should be "direct" placed onto newly prepared areas of reshaped spoil to enhance the success of return of vegetation to the rehabilitated area.

Areas susceptible to wind erosion, such as deep sands, can be afforded temporary protection during the vegetation establishment phase. Such protection measures include brush matting (essentially the spreading of a layer of vegetation removed ahead of the mining operation), or by erection of artificial barriers consisting of woody vegetation material, jute mesh or similar materials along the contour at intervals of 2030 metres down the slope. A cost effective method in areas of reliable rainfall is to sow a cover crop of a hybrid cereal or row crop such as sorghum or millet which will protect the germinating seedlings, but not set seed to compete with the establishing species in later years.

If it is compatible with the post-mining land use, even the application of a surface layer of coarse rock, around 100-150 mm in size, will provide protection and create a suitable micro-environment for germinating seedlings. The objective of each of these methods is to trap coarser sand grains moving in saltation and prevent entrainment of fine material into the air stream.

Photo: John Hannan

Deep ripping along the contour prior to seeding promotes infiltration on rainfall, reduces erosion and provides a better micro-environment for seed germination.

Vegetative control of erosion

From the preceding discussion, it is obvious that the best means of long term erosion control is a dense, permanent vegetation cover. One of the objectives of revegetation work is to produce this dense cover as quickly as possible. Nevertheless, there is a period between final shaping and topsoiling and the establishment of vegetation, during which the surface is highly susceptible to erosion. Some erosion during this period is almost inevitable, although surrounding land should not be affected if the runoff and sediment collection scheme is adequate. The period of susceptibility and the degree of erosion damage can be reduced by appropriate management methods, as follows:

- Delay topsoiling and cultivation until as close as possible to the anticipated sowing date.
- Sow when soil moisture and weather conditions are most favourable for the rapid germination and establishment of vegetation.
- The seed mixture should include at least one species that will grow quickly to provide early groundcover, even if that species will not form part of the final, permanent vegetation.
- Cultivation, by whatever method, should be carried out on the contour. The use of a tyned implement, such as a chisel plough, ripper or tool bar, will create small furrows to retard runoff and promote infiltration. Naturally, traffic over the area, particularly up and down or diagonally across the slope, must be avoided after cultivation.
- Cultivation should be deep enough to penetrate the underlying spoil material and should be completed in a single pass. The creation of a coarse seedbed promotes infiltration and resists the formation of a surface crust.
- Mulching can act to retain moisture and resist erosion. Sewerage sludge has been a successful mulch where it is readily available and can be mechanically spread.

These techniques will enhance the success of revegetating the waste dumps. This process is contained in the booklet in this series titled *Rehabilitation and Revegetation*.

CONCLUSION

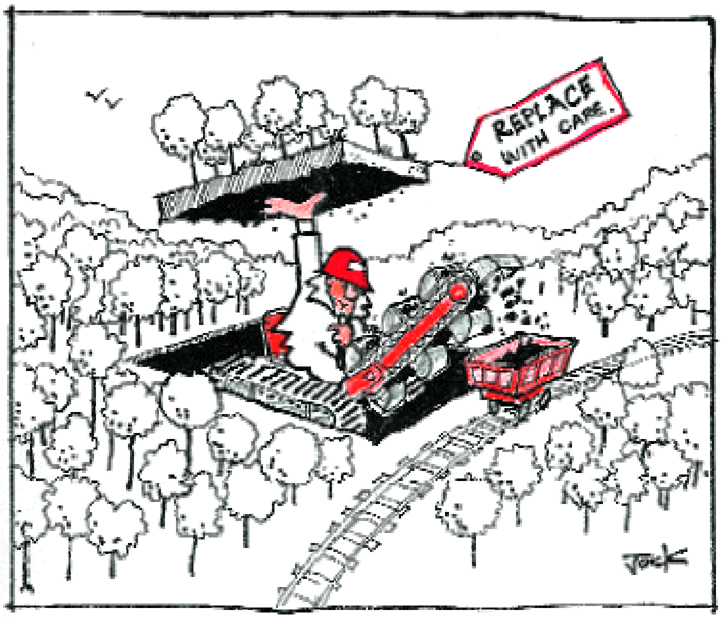
Planning for land re-shaping utilising best practice will result in the optimal post mining land use. Planning post mining land use should start as early as possible in the life of the mine and should incorporate pre-mining investigations including legal requirements, climatic, topographic and soils factors as well as community views. Planning involves interpretation of the pre-mining data into a land capability assessment.

Landform re-shaping criteria include visual requirements, drainage, and slope angles and lengths. Planning can be enhanced by the use of computer-aided design in conjunction with accurate collection of data relevant to each site.

The final land uses for voids and spoil or waste dumps can involve a range of options that must be examined and the final land must be selected before mining starts.

The use of best practice in land shaping and water control gives optimal post mining land capability and land use and minimises the cost to achieve the aim of optimal land use.

A significant aspect of the use of best practice by the mining industry is that it results in sustainable development.



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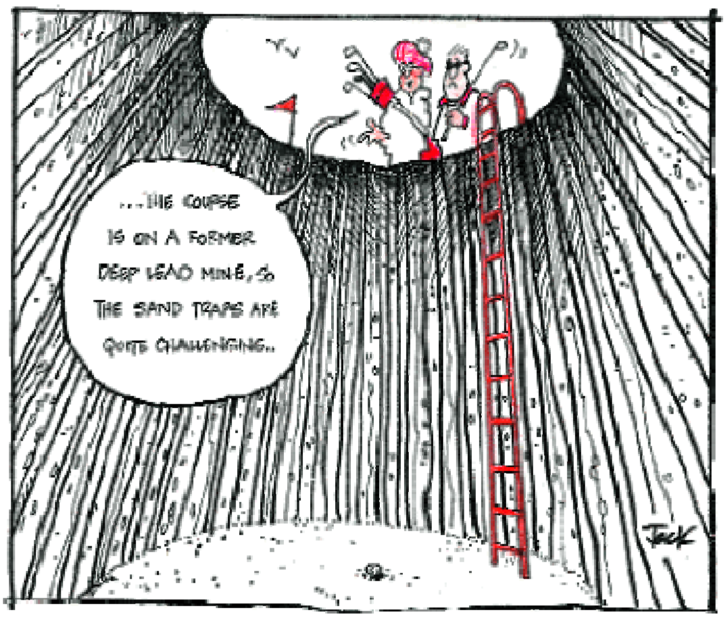
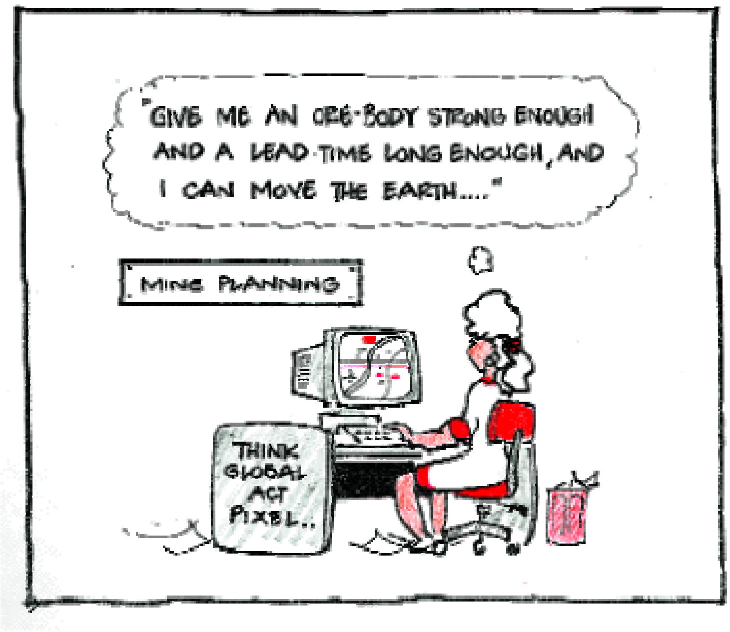


GLOSSARY OF TERMS

Cyclic slumping:	a mass movement of earth and rock, fast or slowly sliding under the influence of gravity on a rotational plane, when water penetrates and saturates subsurface soils or rock debris.
Culvert:	a drain or channel crossing under a road.
Deep ripping/contour furrowing:	techniques to assist water erosion control, usually prior to final landforming and vegetating.
Drainage density:	the number of watercourses draining a catchment area (the total length of all watercourses per unit of catchment area).
EIS:	Environmental Impact Statement, which in Australia is required by law for many projects, particularly large scale developments, which may have significant environmental impact.
Environmental value = beneficial use:	particular values or uses of the environment conducive to public benefit, welfare, safety or health and which require protection from the effects of pollution, waste discharges and deposits. They are often called beneficial uses in the water quality literature. Five environmental values are: ecosystem protection; recreation and aesthetics; drinking water; agricultural water; industrial water.
Finn mulching and hay mulching:	both techniques spread straw over a site to prevent erosive raindrop impact, control erosion and usually to assist germination promote vegetation. Finn mulching adds bitumen emulsion to help maintain cover.
Moonscaping:	a technique using dozer blades to scallop a pattern which helps prevent erosion. See diagram in section on Structural Erosion Control.
Retention/detention:	retention is designed to retain runoff water for absorption into the soil. Detention is designed to release water at a preset rate.
Salinisation:	salt deposition from several sources, including evaporation, groundwater flow or rise, the nett affect of which is a man-induced change from good to poor soil.
Saltation:	movement of sand/dirt particles by wind in intermittent waves.
Stakeholders:	someone potentially affected by a decision which affects their well-being. In mining, this may include residents/landholders (community), government/s, company, traditional owners and environment groups.
Stone pitching:	placing stone or rock to channel water, esp. down a steep slope or batter.
Surface warping:	the feature of some landform design models which allows the profile of spoil or waste rock dumps to be altered to achieve desired slopes and contours while accurately preserving the volumes of cut and fill.



CASE STUDY 1

DRAYTON COAL MINE, NEW SOUTH WALES - SHELL COAL PTY LTD

Recognition, Prevention and Management of Self Heating in Coal Mine Spoil

The Drayton Coal Mine operated by Shell Coal Pty Ltd is located southeast of Muswellbrook in the Hunter Valley of New South Wales.

In open cut coal mining, large volumes of coal and carbonaceous material are exposed to oxygen in air. Once exposed, the materials oxidise and liberate heat. If the heat is not dissipated sufficiently rapidly, the temperature rises. This drives the oxidation and heat generation process at a faster rate and if unchecked, spontaneous combustion may result.

The consequences of spontaneous combustion in spoil piles may be significant. For example, open fires and smouldering combustion can give rise to toxic fumes such as carbon monoxide, carbon dioxide, nitrogen dioxide and sulfur dioxide, as well as the 'tarry' emission products associated with incomplete coal combustion. Further consequences arise from the danger of fire spreading to surrounding land, the destabilisation of the landform with possible subsidence, landslides and the death of vegetation in the vicinity of the "hot" spoil.

Final landform design provides the fundamental solution in preventing self heating in coal mine spoil. Planning spoil dumps and the ongoing management of spoil prevents outbreaks of spontaneous combustion.

Photo: Shell Coal Pty Ltd

Final rehabilitation showing effective grass cover to stabilise slope and minimise erosion. A series of diversion banks assist runoff control.

Best Practice Principles

- Define all fuel sources, ensuring the correct placement of carbonaceous materials
- Minimise the quantity of fuel (carbonaceous materials) going to spoil
- Reduce oxygen pathways in spoil piles
- Avoid dumping carbonaceous or hot materials over dump batters
- Prevention is better than cure

Best Methods for Control

Self heating management practices for dragline and truck-shovel operations follow. Truck dumping practices which can be effective in prevention of self heating include:

- Controlled placement of carbonaceous overburden and partings within inert "pockets"
- Limiting lift height to 15 m maximum
- Covering all final surfaces with a 5 m layer of inert material
- Compacting final surfaces, as well as intermediate surfaces wherever possible.
- Spreading out and track rolling carbonaceous material to prevent heat buildup and oxygen ingress
- Sealing hot spoil with a cover of clay is an effective technique to control heating. Long term seal integrity then becomes an important issue (measures that reduce the development of gully erosion such as drainage backs, drop structures and prompt revegetation may be required. For this to succeed, careful planning, execution and commitment to seal maintenance over many years are keys to successfully reducing soil temperatures below acceptable levels (below 70° C)
- Grouting with inert material such as flyash may be an alternate technique for fire control. The objection is exclude air from the fire by filling the voids between the spoil particles. The advantage of this over sealing is that it creates an insitu barrier to air transport rather than a potentially unstable surface barrier, This has been trialled and although successful to date, the final outcome is not yet conclusive.

Guiding management and fire control principles

- Close oxygen pathways into spoil piles by surface capping or bulk void reduction.
- Maintenance of surface seals
- If it is not possible or practical to seal an area, spreading our the material will prevent heat buildup.
- Promote cooling by encouraging rainwater ponding.
- Early intervention is the key to preventing longer term problems.

Photo: Shell Coal Pty Ltd

Drayton Coal Mine, SE of Muswellbrook NSW. Reshaping dump levels using dozers. Slopes are restricted to 10° but not exceeding 14°.

CASE STUDY 2

LEIGH CREEK, SOUTH AUSTRALIA - OPERATED BY OPTIMA ENERGY

Top Soil Grafting Averts Self Heating

The Leigh Creek Coalfield has been one of the largest open-cut operations in Australia. Located 550 km north of Adelaide in the Northern Flinders Ranges, the site covers a total area of 70 sq km.

Owned and operated by SA Generation Corporation, trading as Optima Energy, it has produced 2.6 to 2.8 million tonnes per annum of sub-bituminous hard brown coal to fuel the Northern Power Station (NPS), supplying 40% of the State's electricity. In April 1998, the South Australian Government announced it intention to sell the site.

Lobe B was the largest of five basins in the site, with up to 1500 m of predominantly fine grained mudstones and siltstones. The coal reserve occurred in three isolated coal horizons referred to stratigraphically as the lower, main and upper series. Initial estimates indicated a resource of more 520 million tonnes. Leigh Creek coals are low rank (Lionite A to Sub bituminous C).

Site operators sought to control self heating in spoil at Leigh Creek, by compacting the final surface and the placing freshly stripped topsoil over the compacted material. Observations indicate this has prevented self heating. Topsoil was stripped from areas to be mined and placed immediately over the compacted overburden material. This "top soil grafting" method has also led to very early natural regeneration of suitable native plants.

Providing the surface runoff water is prevented from causing fresh erosion, a thin layer of—only about 50 cm—has provided good results. Operators believe the key to successfully preventing self heating has been the integrated planning of spoil placement, water management and revegetation.

Unlike other areas of Australia, where 5 m layers of inert material might be available in dealing with self heating problems, arid inland areas of Australia often do not have such quantities of inert materials. A well established vegetation of suitable native plants can use up most of the moisture in the soil and can prevent self heating of the sub-strata.

Photo: Optima Energy
Spoil heaps before rehabilitation.

It is essential that every fire is reported early and that fires are controlled as soon as possible, preferably that day. Good fire reporting procedures needed to be explained and understood by all employees. Every case of self heating on site was recorded.

The use of infra red cameras can also provide early discovery of potential "hot spots" and can help prioritise works designed to prevent self heating.

Well-planned, progressively implemented revegetation of overburden dumps during landform design will prevent most spontaneous combustion of those dumps. In most cases progressive reshaping of slopes and revegetation also helps. A primary consideration is that this work is more economic, as it prevents costly and highly disruptive "fire fighting".

The principal advantages of the methods used were:

- a major reduction in overburden removal costs due to significantly reduced haul cycle times;
- the ability to optimise the mining envelope based on average as opposed to incremental stripping ratios;
- a more consistent level of output over the site's economic life, and
- a more efficient and environmentally sensitive rehabilitation program.

The key to successful post-mining land use was sustainability. Several end land uses were proposed for Lobe B, the main one being a native flora and fauna reserve. Key components of this initiative were:

Photo: Optima Energy
Page dragline adjusting dump slopes and cover with topsoil.

Creating sustainable water bodies and wildlife habitats; controlling feral predators and competitors, including grazing animals; introducing native and endangered flora and flora; minimising visual impact by blending the overburden dumps with the surrounding landscape; limiting surface dumps by maximising in-pit dumping; controlling off site impacts, such as surface water run-off and dust and sustainability through an alternatively generated revenue.

Photo: Optima Energy
Using old page dragline to adjust slope and cover with topsoil (note smoke on left side of photograph).

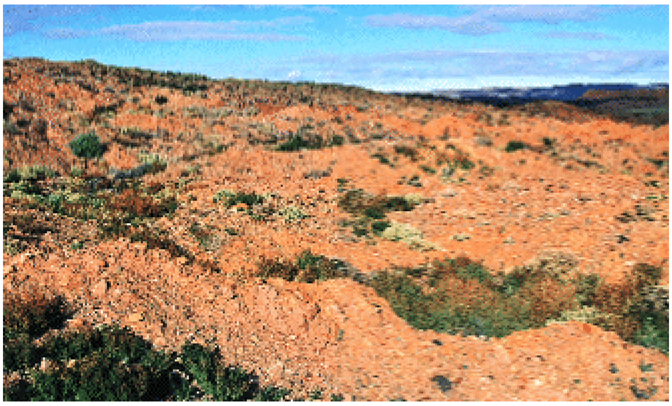


Photo: Optima Energy
Vegetation becomes established on reshaped slopes (topsoil cover with dragline).

CASE STUDY 3

BOW RIVER, WESTERN AUSTRALIA - NORMANDY MINING LTD

The Bow River diamond mine is located 90 km south of Kununurra in the Kimberley region of Western Australia. Mining of alluvial diamonds commenced in 1988 and is currently under care and maintenance. The mine is situated on the floodplain of Limestone Creek, a tributary of the Bow River, which joins the Ord River and flows into Lake Argyle, the largest man-made water body in Australia.

Mining of alluvial diamonds involved the extraction of diamond bearing gravels from ancient creek beds that had become covered by new deposits. Prior to mining, the land use for the area was pastoral cattle grazing and the aim of rehabilitation was to return the land to the former land use. The mining method used involved the removal of overburden, (the overlying soils and gravels) to extract the diamond bearing gravels. As the mining was conducted in a series of pits, the overburden was used to progressively back-fill and shape the mined out pits. Topsoil, which was removed in front of the advancing pit, was then placed directly on the reshaped overburden, eliminating the need to stockpile and store topsoil. Seeding of rehabilitated areas was undertaken using a combination of grasses, shrubs and tree species.

The main environmental concern at Bow River was to ensure that the water quality in Lake Argyle was not affected by the mining operations. Water management was therefore, an important consideration to prevent sediment entering the Lake. To ensure that the mining operation was not a source of sediment, rehabilitation of mined areas involved the shaping of pits to enable all storm water to be collected internally in the pits. As a result of this strategy, the final landform consists of a number of depressions that fill with water during the wet season.

In addition to the rehabilitation of completed pits, mining was also undertaken through a section of Beefwood Creek, an ephemeral creek. About 530 m of the creek was disturbed to enable mining. Following the completion of mining, the creek was rehabilitated to similar dimensions and levels prior to mining. In areas where the original sides of the creek bank were steep, rehabilitation involved reducing the angle of the slope and increasing the width of the creek to reduce the flow velocities of the water. Armouring of the slopes with sorted gravels was also undertaken to prevent erosion. The area was revegetated with trees similar to those that originally occurred in the area, such as the Boab (Adansonia gregorii), Bauhinia (Lysiphylum cunninghamii), and Wild Plum (Terminalia platyphylla).

The diamondiferous gravel was transported by haul truck to the treatment plant where the diamonds were separated by scrubbing and screening. The finer material was discharged to a tailings storage facility and the coarser materials conveyed to the oversize stockpile. The tailings did not contain any reagents and vegetation has naturally colonised the surface. The tailings storage facility was constructed from the oversize material and built in a series of lifts. Placing topsoil and seeding with grass, shrub and tree species has revegetated the berm of each of these lifts.

The oversize stockpile is approximately 30 m high, with the upper 15 m battered to an angle of 20° (32%). A 5 m wide berm has been constructed at the base of the battered upper slope and the remaining (lower) 15 m remains at the angle of repose. The highly porous nature of this material has made revegetation difficult. Soil was placed on the surface of the dump and the area has revegetated with grasses and shrubs while the outer slopes have been left to vegetate naturally.

Monitoring of revegetated areas has been undertaken over the last seven years to determine the success of rehabilitation. Permanent monitoring points have been established and each year data are collected on ground cover, plant height, and species richness. This information has indicated that the rehabilitated areas compare favourably with areas that were not mined.

The creation of the undulating landform has also provided a habitat for many species of wildlife, especially birds that frequent the water holes. During the period of operation of the mine, from 1988 until 1996, approximately 1,120 hectares were mined, with all areas now being rehabilitated. The final landform has achieved its objective of preventing sediment entering Lake Argyle, while also providing suitable grazing for cattle as well as habitat for wildlife. Low intensity grazing of the rehabilitated areas has been undertaken, however it is not planned to allow grazing on mined areas until vegetation is well established.

Photo: Normandy Mining Limited

Bow River, 90 km south of Kununurra, Western Australia. To ensure that mining was not a source of sediment in Lake Argyle, rehabilitating mined areas involved shaping pits to capture stormwater. These provide habitats for many wildlife species, especially birds.

CASE STUDY 4

GREGORY COAL MINE, CENTRAL QUEENSLAND - BHP AUSTRALIA COAL

Basin Listing—an Alternative to Contour Ripping

In the Bowen Basin coalfields north-west of Rockhampton, Central Queensland, the regraded mine spoil has traditionally been ripped on the contour to create a suitable microtopography and seed bed for vegetation.

Usual practice is to deep rip the spoil (at least 0.3 m to 1.0 m or more) on the contour. This creates a microtopography which limits erosion of the spoil and creates a rough seed bed to help germination and vegetation growth. To ensure erosion is minimised, it is critical to maintain the ripping strictly on the contour. Any deviation off the contour tends to initiate erosion.

Where topsoil is returned to the regraded spoil, the deep contour ripping also ensures the topsoil is "keyed" into the spoil. This means topsoil is less likely to erode or slip en masse off the surface of the regraded spoil. Gregory Mine near Emerald has developed an innovative system called "basin listing". It creates a microtopography similar to an agricultural basin listing used to break up hard setting clay soil surfaces.

This innovation uses reciprocating tynes rather than offset discs to create the scalloped surface. A set of three hydraulically controlled tynes was constructed to lift and rip alternately. As one tyne rips, the other two are lifted, then as the two rip the third lifts with the hydraulic system controlling the alternation of rip and lift.

Photo: BHP Australia Coal

BHP Australia Coal, Gregory Mine, 60 km north east of Emerald, Queensland. Rehabilitation of mine spoil in foreground with strip mining in background.

The tynes in the final machine are flat-faced, rather than the traditional narrow-face. This emphasises the scalloping action and creates a patterned microtopography.

Basin listing achieves the same outcomes as deep ripping, creating an erosion-limiting spoil or soil surface and a seed bed. However, as the ripping is not continuous, it is not essential that ripping is strictly on the contour. Further, as the basins tend to overlap across the slope, the potential for causing erosion is limited should a basin overflow.

Basin listing achieves the same result in terms of keying topsoil into regraded spoil. Consequently, mass erosion or slipping of topsoil is minimised.

The basins or scallops tend to retain water after rainfall much better than rip lines. Therefore, the basin listed reclamation creates a micro-environment which aids seedling germination and establishment better than traditional ripping.

Basin listing has proved very successful in finishing mined area rehabilitation. It minimises erosion initiation compared to traditional ripping.

CASE STUDY 5

NABARLEK MINE, NORTHERN TERRITORY - SUPERVISING SCIENTIST GROUP, ENVIRONMENT AUSTRALIA

The Nabarlek uranium mine operated from 1970 until 1989 by Queensland Mines Pty Ltd. Rehabilitation was carried out in the dry season of 1995. Several features of the Nabarlek story are unique and offer interesting approaches for possible consideration in other mine rehabilitation programs.

The Nabarlek ore body was mined in a single 143-day campaign during the dry season of 1979. Ore was stockpiled on a specially prepared site while the mill was constructed. The ore was processed over the subsequent 10 year period.

Topsoil from the mine and mill construction was placed in a stockpile and allowed to stand until required in the final rehabilitation. Tailings from the milling operation were returned directly to the mined out pit. The waste rock was placed to the south of the site and planted with an exotic grass species to provide erosion control.

During the mine planning process, the final decommissioning and rehabilitation program was developed as a series of specific component plans including an earthmoving and revegetation document. Throughout the life of the mine, these components were reviewed at intervals and updated to take account of changes in mine development as well as incorporating the results of site-specific research and new technology.

During preparation for final decommissioning, the site topsoil dump was investigated. It was found that, due to its 14 years in store, the material was of little value to the rehabilitation process. The soil had lost much of its micro flora and faunal populations, it had been leached of nutrients and had become a source of weed seeds. Few viable propagules of potentially "useful" plants had survived. The topsoil was used in the rehabilitation work but not as a final cover as this would have spread undesirable weeds across the site.

The waste rock dump had been untended during the life of the mine and had become well vegetated with a wide range of native species of trees and shrubs. This material was selected for the final cover for reshaped and rehabilitated landforms.

The rehabilitation objective, as agreed with the traditional owners and the supervising authorities, was to establish a landscape that matched the surrounding areas as closely as possible and would permit traditional hunting and gathering activities to be pursued.

The earthmoving plan placed all mine wastes in the mined out pit together with scrap metal etc. This was then covered with a layer of waste rock up to 15 metres thick and the final landform left as a mound over the pit to allow for subsidence and to still provide a water shedding cover. The original cover design was of great importance as it was required to act as a barrier to radon gas and to contain the tailings and radioactive waste for thousands of years.

A contractor carried out earthmoving for the final landform shaping during the dry season of 1995. Apart from demolishing earthworks, including substantial pond walls, the work also required the land surface over most of the site to be returned to approximately its original contours. The ponds were filled in and the waste rock was spread and incorporated the degraded topsoil lower down the soil profile.

One concern while completing the rehabilitation earthworks was the amount of compaction caused over the site as a result of the constant passage of trucks and other mobile plant. At the end of earthmoving, a large bulldozer fitted with a winged deep ripping tyne was used to rip the whole site to loosen the surface and provide improved conditions for seed germination. During this operation some oversize rocks were brought to the surface. These were collected into piles and spread randomly across the site to provide refuges for small animals and reptiles that were anticipated would re-colonise the site.

The final domed cover over the pit was designed following research and shaped to provide shorter runoff paths and so reduce runoff water velocities. A single, low, central ridge was established to facilitate these shorter flow paths as show in the attached figures. (See Riley 1994 & 1995 in Further Reading).

Seeding was carried out at the end of earthmoving, immediately before the onset of the monsoonal rains of the 1995—96 wet season. Previous work on site had shown that this was likely to be the most successful revegetation approach. Trials involving tubed tree stock was shown to be generally less successful.

The rehabilitation of the site is progressing well and continued monitoring is in place to establish when the site can be returned to the traditional owners.

Photo: Environment Australia

Progress with rehabilitating Nabarlek mine site: Aerial view (top) of the mine site in February 1992 before work started and in February 1996 (centre) following decommissioning earthworks, including the waste rock dump (mid picture) then the mine pit and beyond it the evaporation ponds. Refer to diagram. Bottom photo shows ground view of vegetation growth on former pit in July 1996.

Photo: Environment Australia

Photo: Environment Australia

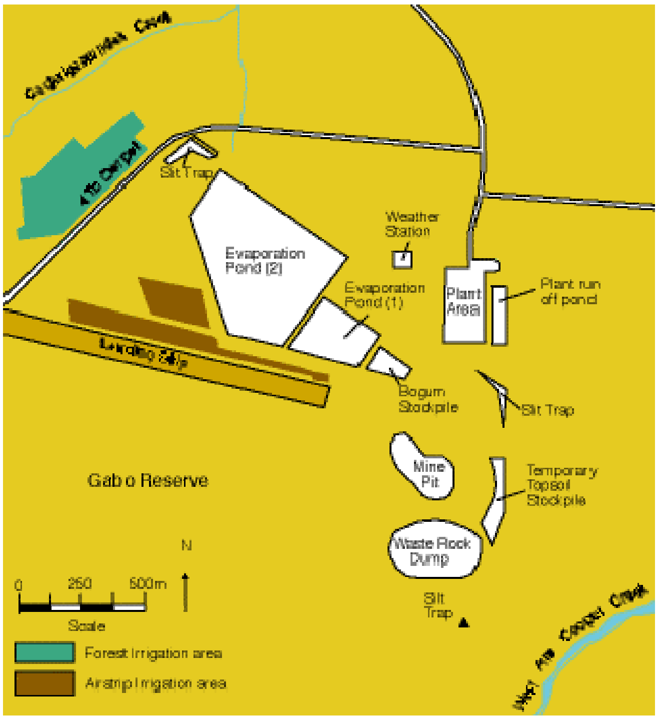


Figure 5 General Layout of Operation at Nabarlek

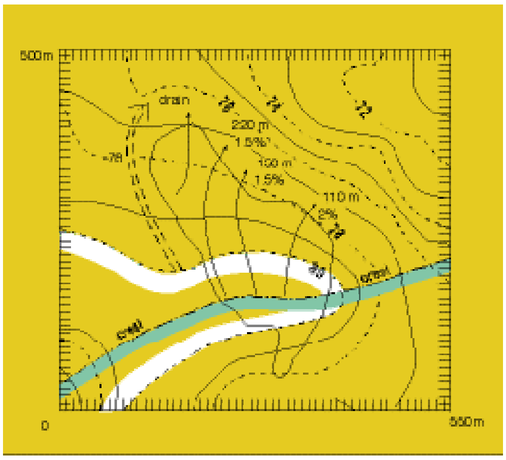


Figure 6 Nabarlek: As Designed (after Riley, 1994)

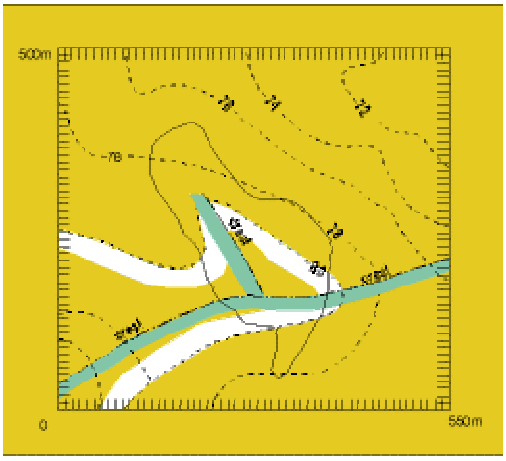


Figure 7 Nabarlek: As Constructed Showing Final Landform After Research (after Riley, 1994)

CASE STUDY 6

RAVENSWORTH MINE, NEW SOUTH WALES - PEABODY RESOURCES PTY LTD

Large scale open cut coal mining began at Ravensworth in 1972. Located 20 km northwest of Singleton in the Upper Hunter Valley, New South Wales, the coal produced is transferred via conveyor to the adjacent Bayswater and Liddell power stations.

Ravensworth Mines produces 6 MTPA of product coal, equal to almost 30% of the coal required for power generation in NSW.

The mining method involves a combination of prestrip and dragline operations to remove overburden which uncovers coal and partings for extraction. Eight coal seams are mined which range in thickness from 0.3m to 8m, and up to 120m below the natural surface.

The overburden removed by the draglines is deposited into the void of the previous cut. The coal is removed progressively as the seams are exposed with 13m^3 electric shovels, 15m^3 front end loaders and a fleet of 109 tonne capacity rear dump trucks.

At Ravensworth, Peabody Resources has recognised that mining is an interim land use and mine rehabilitation is therefore an integral component of the mining process.

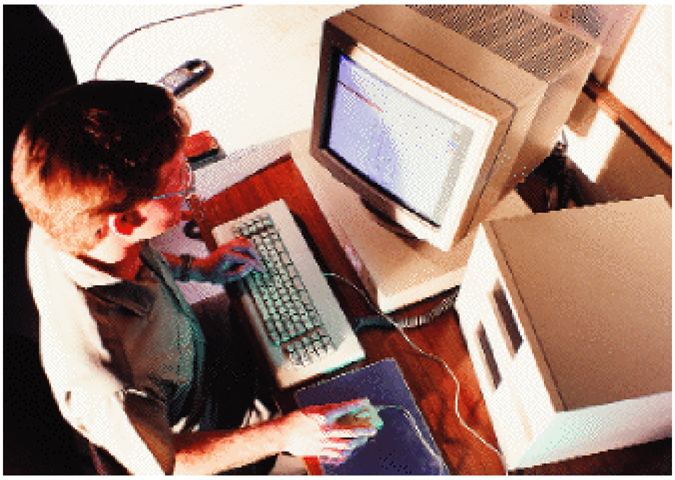


Photo: Peabody Resources Pty Ltd

Computer aided design provides an opportunity for substantial savings, quicker site planning and redesign.

Rehabilitation of disturbed land is carefully planned and implemented. This process starts well in advance of active mining, with premining land capability and suitability assessment, and soil and drainage density surveys. Also prior to mining, a geological model is produced using computer software after an exploration drilling program is completed.

This model enables engineering staff to determine the coal resource in any one mining area. Mine resources and strip layouts are determined based on the geological model and block data is transferred into XPAC, a mine scheduling software package. Among other things, for each mining block, XPAC calculates strip quantities to move to uncover predetermined coal reserves.

Ravensworth is overflown and photographed annually to generate a digital terrain model (DTM) and orthophotos. Orthophotos create maps using aerial photos. These are used to compare actual rehabilitation profiles to those planned and allow for further overburden dump planning to conform with final rehabilitation profiles. The DTM is used with a third software package, CivilCad, to generate working plans.

CivilCAD computes the quantities of cut and fill required to meet final rehabilitation landform design criteria. The preferred final landform design is then adjusted to suit available prestrip and to optimise the amount of reshaping required by bulldozer.

The CivilCAD model is then transferred to AutoCAD, 1:2000 scale working plans. The plans guide appropriate survey control and earthworks. Supervisory staff use them when they oversee the strategic placement of prestrip material and any required dozer reshaping operation.

All landform design parameters have to meet specified slope gradients and slope length and drainage density criteria, and typically are consistent with adjacent natural landforms.

This landform design technique is a semi-automated system, purpose developed at Ravensworth using commercially available software packages. The system has enabled the company to reduce its rehabilitation costs by maintaining a constant awareness of the required post mining landform. Placement of pre-strip material has been optimised, which has reduced the need to re-handle spoil materials and has also cut down on dozer time required for final reshaping.

CASE STUDY 7

KAMBALDA, WESTERN AUSTRALIA - WMC RESOURCES LTD

Computer Assisted Design

This case study outlines the assistance provided by computer aided design for waste rock and overburden handling and rehabilitation at WMC's gold and nickel operations at Kambalda, 50 km south of Kalgoorlie in the Eastern Goldfields.

Historically, waste rock dumps at Kambalda's underground nickel mines were flat topped, composed of fresh rock, rarely exceeded 10 ha in area and generally did not extend above the surrounding tree tops. Topsoil recovery was not practiced. In contrast, the later waste rock and overburden dumps from the gold operations covered six times the area, were substantially higher and contained a greater percentage of oxidized material.

In total, waste rock dumps at Kambalda cover an area of more than 800 ha of which more than 70% are in advanced stages of rehabilitation. The objectives for rehabilitation at Kambalda require that post mining landforms are: safe, stable, non-polluting, suitable for the proposed end land use, compatible in appearance with surrounding landforms, revegetated with a mix of local species representative of similar habitats and are self sustaining.

Waste dumps in the Goldfields were typically left as flat-topped mesas with the side slopes usually around the angle of repose (3738°). Many mines still practice top dumping of waste rock followed by slope reprofiling at the completion of mining. WMC investigated the use of the SURPAC, or other mine survey packages, to aid waste dump design by treating the dump as an inverted open pit. Improved computer aided planning capability supported realistic opportunities to trial progressive rehabilitation of waste rock dumps.

Further investigations resulted in the following steps to produce the required waste dump profiles for pre-mining waste dump planning:

- Feasibility Phase—obtain aerial photography, digitize available contour information and map the vegetation, drainage and terrain types/units within the proposed dump area onto the topographic base and generate original surface cross-sections and contour overlays
- Volume Measurement Phase—calculate the total waste volume from the mine planning data ensuring to account for the swell factor. Undertake a site visit to select visual and geotechnically sound crest and toe contour positions and drainage requirements.
- Final Design Phase—generate dump contours with the available waste to "fill in" the existing landform profile, noting the optimal locations for special features such as slope drains, silt traps, haul roads and placement sites for rock wastes containing deleterious materials.
- Produce 3D mine schematics to display pre and planned post mining landforms for mine personnel use.

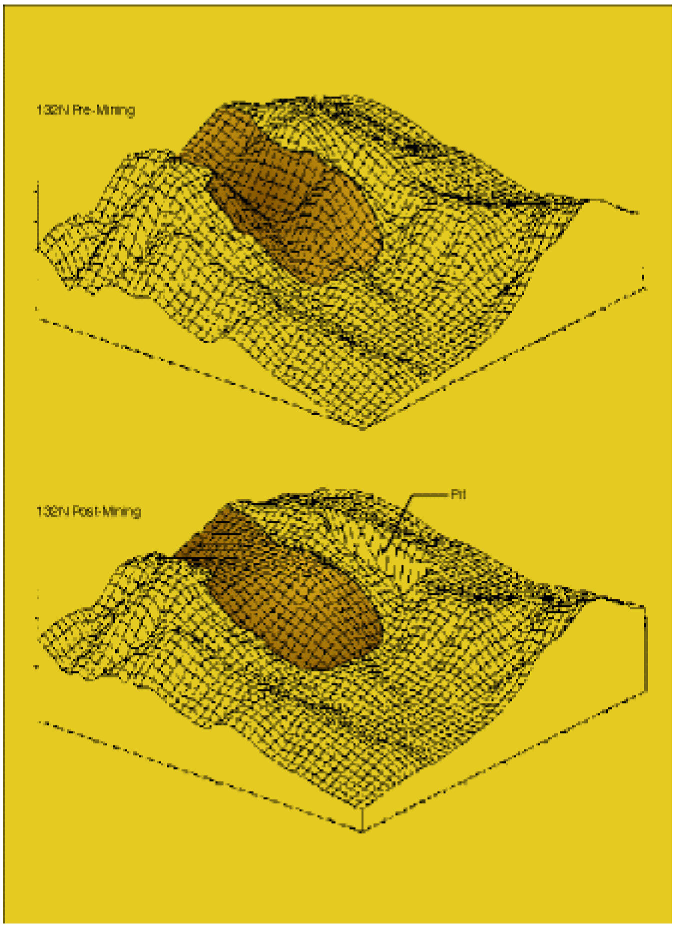


Diagram 1.0 An example of computer aided design used to give a three dimensional model of a proposed mine site.

Further advances of computer software have resulted in an in-house package called SURDUMP. This program is used to assist with designing existing waste dumps that require reprofiling. This package, a two directional block stacking routine, reshapes existing dumps to nominated slope gradients and toe positions. Several commercially available mine design packages now offer similar modelling tools.

The final step in the process is for a surveyor to peg the modeled dump contour positions in advance of the waste rock dumping. Properly coordinated topsoil panel stripping can take place in front of the waste dumping and be progressively placed on completed sections of the dump. In addition to avoiding double handling of topsoil, stored seed and topsoil viability is little affected, resulting in reduced seeding costs and enhanced rehabilitation success.

This approach was applied to the modeling of the 132 North nickel deposit. In addition to the traditional mine planning activities (ie. pit optimization, volume calculations) pre-mine modelling of biophysical inputs including catchment, infiltration and erosion potential assessment, soil quality and availability and visual amenity. The dumping strategy employed was to:

- maintenance of upslope remnant vegetation stands where possible to enhance natural recolonisation and seed dispersal.
- drape the waste rock over a shallow valley and reconstruct drainage lines
- strip vegetation and topsoil along the contour in panels and dump waste rock to nominated final crest and toe positions
- progressively uplift topsoil/vegetation from strips in front of the advancing dump and complete upslope rehabilitation to final grade with fresh soil.
- identify the larger drainage lines and leave these intact with a 20 meter greenbelt buffer zone to the final dump toe.
- drainage and downstream siltation control was done using a single long slope rock drain which:
- was linked to contour rip lines;
- was constructed with a dozer such that it formed a series of small siltation ponds before entering existing drainage.

Rehabilitation of the 132 North site was completed in September 1992. An assessment of the rehabilitation success was undertaken in December 1997 as part of the CSIRO Minesite Rehabilitation Research Program—Indicators of Ecosystem Rehabilitation Success. This program utilized Land Form Analysis and a series of indicators to provide an overall assessment of ecosystem rehabilitation success. While monitoring is ongoing, the results to date suggest the rehabilitated site is approaching values similar to those observed in the control site.

The 132 North results show an integrated mine planning approach is capable of removing much of the guesswork associated with dump planning, selective placement of materials, reprofiling costs and area of disturbance calculations. Modelling techniques which pay close attention to reconstructing natural features can help achieve improved rehabilitation.

A waste dump that eventually blends in with the surrounding landform is consistent with the view that mining is only an interim use of the land, not an end use. By cutting out guesswork, better end uses and efficiences (during mining) are achievable.