BEST PRACTICE ENVIRONMENTAL MANAGEMENT IN MINING

Tailings Containment

EPA
Environment Protection Agency

Tailings Containment

One module in a series on

BEST PRACTICE ENVIRONMENTAL MANAGEMENT IN MINING

Environment Protection Agency

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FOREWORD

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

Representatives of the mining industry in Australia and the Environment Protection Agency, an agency of the Australian Department of the Environment, have worked together to collect and present information on a variety of topics that illustrate and explain best practice environmental management in Australia's mining industry. This publication is one of a series of modules aimed at assisting all sectors of the mining industry — minerals, coal, oil and gas — to protect the environment and to reduce the impacts of mining by following the principles of ecologically sustainable development.

These modules 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 mining 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 modules integrate environmental issues and community concerns through all phases of mining from exploration through construction, operation and eventual closure. The concept of best practice is simply the best way of doing things.

The case studies included in these modules demonstrate how best practice can be applied in diverse environments across Australia, while allowing flexibility for specific sites. They achieve this by including practical techniques, recommendations, guidance and advice from Australia's leading mining practitioners.

I encourage mine managers and environmental officers to take up the challenge to lift performance in environment protection and resource management, and to apply the principles in these modules to their mines.

Barry Carbon
Executive Director,
Environment Protection Agency,
and Supervising Scientist

EXECUTIVE SUMMARY

Tailings storage areas are deposits of fine grained sediments containing various contaminants from mining and processing operations. These storage areas have to be engineered to optimise the amount of tailings stored, while avoiding potential environmental impacts to the satisfaction of government regulatory agencies, local interest groups, residents and the community generally (all stakeholders). Tailings storage can be highly contentious and a source of concern and conflict involving community, industry, and government. It is often a difficult task to resolve this to the satisfaction of all stakeholders.

The primary aim in the past has been to provide a well-engineered structure into which the tailings can be deposited without a great deal of attention being given to closure requirements or issues related to long term management of the storage facility and the contaminants, particularly the environmental concerns. Increasingly mine operators are looking for alternative storage techniques to avoid the high initial construction costs and the post operational problems associated with the conventional dams. They are also concerned to avoid unfavourable environmental impacts.

This module has been prepared to provide advice on Best Practice Environmental Management (BPEM) through the various stages of planning, design, operation and closure of tailings storage facilities. It is recognised that all tailings storage facilities will need to be designed and operated to accommodate site-specific constraints. Each situation is different and there is no simple means of ranking factors such as tailings and site selection characteristics, tailings dam construction and operational techniques to give a 'best' answer for tailings containment. The discussion in this module outlines these various aspects to consider in avoiding both short and long term environmental problems and achieving the best environmental results.

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INTRODUCTION

Tailings are the waste products from industry. Different industries produce a wide variety in types of tailings.

Tailings from the mining industry are most commonly finely ground material left over after the valuable metal has been extracted.

Tailings containment areas are usually of short term public concern. The three major concerns are:

- the structural stability of the dam and the possible release, should failure occur, of a large volume water and semi-fluid tailings (such an event would not only cause extensive downstream pollution, but could also pose a threat to life and property depending on the dam's location);
- the impact the tailings operation might have on the lifestyle of people living in the immediate area (this might include nuisance from dust, noise pollution, radiation, the visual impact of a large engineered structure and the effect on local property values); and
- the pollution potential for ground and surface water — both short and long term.

Long term management of tailings is also a concern in that expensive on-going maintenance is not desired by either the operators, regulators or the community. The development of the best processing technology, the physical design of the tailings structure, and the operation of the facility should all minimise any long term environmental impacts.

While this module focuses on tailings containment, it should be recognised that tailings pipeline routes, and provision to control and contain other spillages are other significant environmental factors that need to be considered.

By adopting Best Practice Environmental Management (BPEM), many potential short and long term environmental problems can be avoided. Tailings management needs to cover a broad spectrum of activities. Important factors in establishing BPEM in tailings containment include:

- selection of an appropriate site;
- delineation of the most appropriate method of storage and management of tailings deposition;
- effective implementation of this method;
- monitoring of the operation; and
- developing an appropriate rehabilitation and closure strategy.

1. OBJECTIVES OF TAILINGS STORAGE

In most cases the basic requirements of a tailings facility are to store the tailings in such a way that the impoundment structure remains stable, the operation has little impact on local residents, environmental impacts are minimised, and the storage facility can be rehabilitated once closed. The major short term and long term environmental problems associated with tailings storage relate to:

- water pollution (including groundwater)
- dam safety and stability
- air pollution by dust
- visual impact
- reclamation and restoration

Tailings storage can be highly contentious and a source of conflict involving community, industry, and government. To resolve this to the satisfaction of all stakeholders is often a difficult task. It is probably best to think of tailings storage areas as landfills, or deposits of fine grained sediments containing various contaminants from the mining and processing operations. These have to be engineered to optimise the amount of tailings stored, while avoiding the potential problems of environmental impact to the satisfaction of all stakeholders.

Most world practice has tended in the past towards constructing conventional water storage-type tailings dams. This is probably because:

- many designers have a background in water dam engineering;
- regulatory officials require such an approach due to their own background in water dam design;
- there is a need in wet climates to store large volumes of water covering the tailings; and
- many mines produce very fine-grained or oxidised tailings which have poor consolidation characteristics.

The primary focus has been on providing a well-engineered structure into which the tailings could be deposited. Little attention was given to closure requirements or long term management of the storage facility, particularly regarding environmental concerns.

Increasingly mine operators are looking for alternative storage techniques that provide better environment protection and avoid the high initial construction costs and the post-operational problems associated with conventional dams.

In meeting these objectives the following factors need to be considered.

1.1 TAILINGS CHARACTERISATION

TAILINGS VARY CONSIDERABLY IN THEIR PHYSICAL, CHEMICAL, AND MINERALOGICAL CHARACTERISTICS

Tailings vary considerably in their physical, chemical, and mineralogical characteristics. Particular characteristics can affect tailings behaviour in a storage area and ultimately affect any drainage water from the storage area seeping into either surface water or groundwater systems. For example highly saline groundwater, used for mineral processing in the arid gold mining areas of Western Australia, causes poor consolidation of tailings because evaporation rates are reduced by more than 90% by even moderate levels of salinity. In addition the continual supply of saline water to the surface of the tailings makes revegetation work very difficult.

- Physical properties
  The physical properties of the tailings are important in determining how the material will behave in the storage area, its resistance to wind and water erosion, and the extent to which the tailings themselves can be used for construction.

POTENTIAL FOR SEEPAGE FROM THE TAILINGS INTO GROUNDWATER IS A MAJOR ISSUE WITH MANY TAILINGS DISPOSAL OPERATIONS

- Mineral content
  The mineral content of the tailings will determine the specific gravity of the tailings particles which will in turn have an impact on particle segregation and consolidation. Oxidised tailings can also have poor settling and consolidation characteristics.
- Chemical composition
  Chemical properties of tailings need to be determined in order to define the characteristics of the waste and the nature of potential contaminants. This is needed to assess the potential for drainage waters to affect the beneficial uses of ground and surface waters, and to assess limits to revegetation of the tailings storage area after closure. High sulfide minerals present in the tailings are often a potential source of acid mine drainage, a topic covered in a separate mining module.

1.2 STABILITY

The stability of a tailings dam embankment is vital for the permanent storage of the contained effluents and solids. The main factors influencing dam stability are the embankment height and slope, and the nature, strength and degree of compaction of foundation and embankment materials. The main threats to the stability of a constructed embankment include:

- overtopping from flood waters;
- high groundwater pressure levels resulting from high water table levels within the embankment;
- piping of fine grained materials during seepage; and
- liquefaction of saturated sands during earthquake loading.

Assuming that the dam was designed with adequate initial stability, the easiest way to maintain embankment stability during operation is to keep the decant pond as small as possible and as far from the containing embankment as practical.

1.3 SEISMICITY

Determining the stability of a tailings structure under earthquake loading is a critically important to tailings dam design. Mines often produce loose, saturated sands. These are highly susceptible to liquefaction under earthquake loadings. Liquefaction of tailings in the impoundment places an additional sudden shear force on the dam embankment which does not occur in conventional water storage dams. The result is an increase in pore pressures along each failure surface as well as an additional internal force against the dam. Consequently all dynamic analyses for tailings dams, including pseudo-static, simplified, and complex state-of-the-art analysis, must account for this extra shear force. Procedures used for the analyses of a conventional water dam must be adjusted.

Historical earthquake records and the influence of faulting or other tectonic features on the estimate of probability of occurrence, magnitude and location of possible seismic activity should be carefully examined to evaluate seismic potential in the region of the planned tailings dam.

1.4 SEEPAGE AND GROUNDWATER POLLUTION

Potential for seepage from the tailings into groundwater is a major issue with many tailings disposal operations. It is often necessary to carry out extensive studies of the hydrogeological and geochemical regimes prior to selecting a site and designing a storage area in order to predict and minimise its impact, and to develop a monitoring program to assess performance during and after the operating life of the mine.

1.5 SURFACE WATER POLLUTION

Surface water streams can be polluted by spillages (usually associated with pipeline ruptures), seepage through the embankments of storage facilities, and inadequate provision for control of excess water during extreme wet conditions.

When developing a strategy for the protection of surface waters, it is important to first establish the environmental values of the possible receiving waters, and then, knowing the physical and chemical properties of the tailings, determine how these receiving waters might be affected by the tailings storage. This will allow an assessment of the potential threat to the environmental values of the receiving waters. A management strategy can then be designed to balance the containment provisions with the risks posed by the tailings storage and to achieve desirable environmental outcomes.

1.6 DUST GENERATION

Because many tailings are fine grained, they can be easily eroded when dry and the storage areas become dust. This can be managed by retaining a wet surface to prevent wind erosion. However, a minimum pool of water on the surface and creating a beach against the retaining embankments aids consolidation of the tailings via evaporative drying which in turn maximises the storage efficiency and increases the strength of the deposit.

Often a compromise is adopted. This involves frequent rotation of discharge points around the perimeter of the area. A wetted surface can be maintained while achieving the benefits of a minimum water pool and a beach against the retaining embankment. Other dust control measures can be adopted in critical locations such as the use of irrigation sprinklers and the application of surface mulch or binders.

2. SITE SUITABILITY

Site selection is probably the most important aspect affecting tailings impoundment design. Each site will have certain advantages and disadvantages that must be considered in conjunction with the various storage options for the tailings. Availability of suitable sites that maximise environment protection is also part of both environmental impact assessment and mine planning; these are topics covered in separate modules.

2.1 FACTORS TO CONSIDER WHEN ASSESSING SITE SUITABILITY

During the initial investigations into the general suitability of a site for tailings storage, the following should be considered.

Regulatory requirements

The local regulatory requirements covering all aspects of the planned future storage area should be included in the assessment of an area. These might include:

- water quality requirements for water release;
- cultural and heritage significance of a site — including significance to indigenous people;
- specific design requirements such as earthquake loadings, probabilities of occurrence of flooding;
- dust emissions and noise pollution;
- plans of various authorities including transport, urban development, utilities (power transmission, water supply lines etc); and
- zoning of the tailings storage area and the surrounding area (allowable activities permitted by the authorities), and possible changes to current zoning.

Meteorology

Various aspects of the operation's water balance should be based on a thorough understanding of the meteorological conditions of the local area. Information which should be gathered includes:

- rainfall data (monthly averages for various return periods — 1:10, 1:20, 1:50, 1:100);
- rainfall intensity/duration data;
- evaporation measurements (class A evaporation pan);
- humidity, temperature, and solar radiation measurements;
- wind strength/direction for various times of the year; and
- knowledge of past or infrequent events (typhoons, floods).

Topography and Mapping

The topography of the long term construction and buffer areas to a distance of around 1km from the boundaries of the future storage areas should be examined. This information will allow the potential social and environmental impacts of the proposed facility to be assessed in the very early stages of the planning.

The information should include:

- surface contours at 1m intervals;
- drainage patterns (streams, springs, lakes, wetlands);
- land boundaries;
- roads and services;
- dwellings and other structures;
- cultural or heritage sites; and
- current land use.

Photography

Photography can be an important tool to help assess the overall aesthetics and potential environmental impact of a proposed storage area. These include:

- aerial photographs of the land holding and surrounding area;
- photographs at ground level from various vantage points; and
- historical photographs.

Surface water

If the tailings storage area is to be sited in an area close to rivers or areas which could be subject to flooding, the potential impact of low frequency storm events needs to be considered. Information required includes;

- flows in natural water courses (hydrographic data such as rainfall runoff characteristics);
- flood records and possible flood plain identification;
- background water quality; and
- upstream and downstream water use including environmental flows to maintain habitats for flora and fauna.

Groundwater

An understanding of the general hydrogeology of the site will assist in the evaluation of the potential impact of the tailings storage on the groundwater. Essential information includes:

- hydrogeology of the site (depth to water, flow directions, flow velocity);
- presence of preferred flow paths;
- background water quality;
- upstream and downstream water use; and
- zone of groundwater discharge.

Geotechnical

The initial tailings impoundments are usually constructed from local soils. In such cases availability and suitability of soils must be assessed early in the development and should include:

- foundation conditions (soil types at various depths, particle size distribution, percentage fines, Atterberg Limits (soil plasticity), soil strengths, permeability characteristics, mineralogy);
- availability of construction materials such as clay, sand, gravel;
- presence of rock, structure of any rock formations;
- seismic risk data.

THE INITIAL TAILINGS IMPOUNDMENTS ARE USUALLY CONSTRUCTED FROM LOCAL SOILS

Geochemical

If tailings leachate contacts the natural soils, a number of geochemical interactions may occur. Undertaking long term assessment is good practice because it builds up information to aid understanding of these interactions.

Tailings properties

The properties of the tailings need to be known when designing new facilities, particularly in relation to possible groundwater seepage and water release. They include:

- mineral and chemical constituents of solids;
- heavy metal content;
- radio-nuclide content;
- solids specific gravity;
- settling behaviour;
- permeability vs density relationships;
- soil plasticity (Atterberg Limits);
- consolidation behaviour;
- rheology (flow of liquids with suspended particles)/viscosity characteristics;
- strength characteristics;
- pore water (water in between the pores of the soil) chemistry; and
- fresh water leaching properties.

2.2 DETAILED SITE INVESTIGATIONS

Prior to the construction of a new facility, a detailed site investigation of the proposed site should be carried out. This investigation might include the following elements.

Soil profile

A detailed investigation of the soil profile across the proposed construction area should be carried out to determine the homogeneity of the various soil strata. The investigation should include boreholes and test pits at intervals determined by the variability of soil types. (A typical investigation might include boreholes on a 200m X 200m grid, with test pits on a 100m X 100m grid. Closer spacing might be required if there is doubt about the continuity of certain soil layers). Soil types should be classified based on texture, colour, particle size, and Atterberg Limits (soil plasticity and permeability). This information can help to determine the capacity of the site to contain tailings without leakage. Care should be taken when backfilling boreholes and test pits to ensure a future seepage pathway has not been created.

Water table

It is important to determine the level of any surficial water table as it can influence both the design of a facility and the construction methods employed. During the site investigation the location of areas where the water table is at the surface should be recorded. Any seasonal variation should be determined, particularly if it could limit time available for construction. Several of the boreholes used during the soil profile investigations should be left with standpipes installed to allow measurements of the water table over a reasonable time period (say 12 months). Pump tests should also be carried out to determine aquifer hydrogeology.

In-situ materials

Where ever practical, construction materials should be obtained from within the impoundment area to both reduce haulage distances (and hence costs) and increase the storage efficiency of the impoundment through increasing total storage space. The investigation should determine the suitability of the in-situ soils for construction of the proposed facility. The following parameters should be measured as they will be used in stability checks during the design stage of the project:

- strengths of the various soil layers within the profile (unconsolidated undrained, consolidated undrained, and direct shear triaxial tests);
- in-situ permeabilities;
- dispersion properties; and
- samples for geochemical analysis.

Construction materials

The source of construction materials should be defined and the properties of these materials determined. The source may be from internal excavation (cut-to-fill), from a local external excavation, or may need to be carted from a remote excavation area. Properties important to the construction of the facility include:

- in-situ moisture contents;
- compaction criteria (maximum dry density, optimum moisture content);
- remoulded strengths (unconsolidated undrained, consolidated undrained, and direct shear triaxial tests);
- remoulded permeabilities; and
- dispersion characteristics.

For sites which contain highly permeable foundation soils, best practice requires suitably impermeable clay or synthetic liners to minimise tailings-water loss through seepage.

Rehabilitation materials

Topsoil may be a valuable commodity for rehabilitation, especially if it can be used directly after removal from the site. The potential utilisation of such materials should be assessed carefully during the mine planning stage. More details can be found in a separate module on rehabilitation and revegetation available in this series.

3. DESIGN OF TAILINGS FACILITIES

Many factors that affect site selection, storage area design and tailings discharge methods must be considered when designing tailings impoundment areas. Site selection factors are discussed in Chapter 2. However, the location of a potential site relative to the mine and/or the processing plant is often an over-riding consideration. Economic constraints may mean the tailings storage area will be located close to the processing plant and the design may need to compensate fully for a less than optimum location. Any economic analysis should, however, consider all aspects of the tailings facility from the initial construction, through the operating stages, to the decommissioning and rehabilitation of the area, particularly the environmental impacts of various options. Table 1 describes the preliminary design and investigation process. Table 2 describes the detailed investigation, final design and construction sequence.

3.1 TYPES OF STORAGE FACILITY

It is important when designing the tailings storage area to consider the various types of impoundment and select the most appropriate for the preferred site. Tailings storage structures fall into three main categories. These are dumps, impoundment dams and storage in existing mine pits.

Storage dumps

These are often constructed by hydraulic methods and do not impound large volumes of water. They usually have a downstream catchment dam (reclaim pond) to pick up runoff and drainage waters to protect the downstream environment. Water return from the tailings is commonly via cyclone separation at the point of discharge in conjunction with water return from the reclaim pond.

An alternative approach is to thicken the tailings in a large settler, and discharge the thickened slurry onto a sloped bed where solar drying of the tailings improves the overall rate of consolidation while reducing likely environment impacts from water runoff and leaching. Figure 1 shows the conical dump produced by the so-called Robinski method of 'Thickened Central Discharge'.

Storage dams

Impoundment dams are constructed of mill tailings, mine wastes, or imported borrow, and are expressly designed for the retention of slurry and the reclamation of water. In some

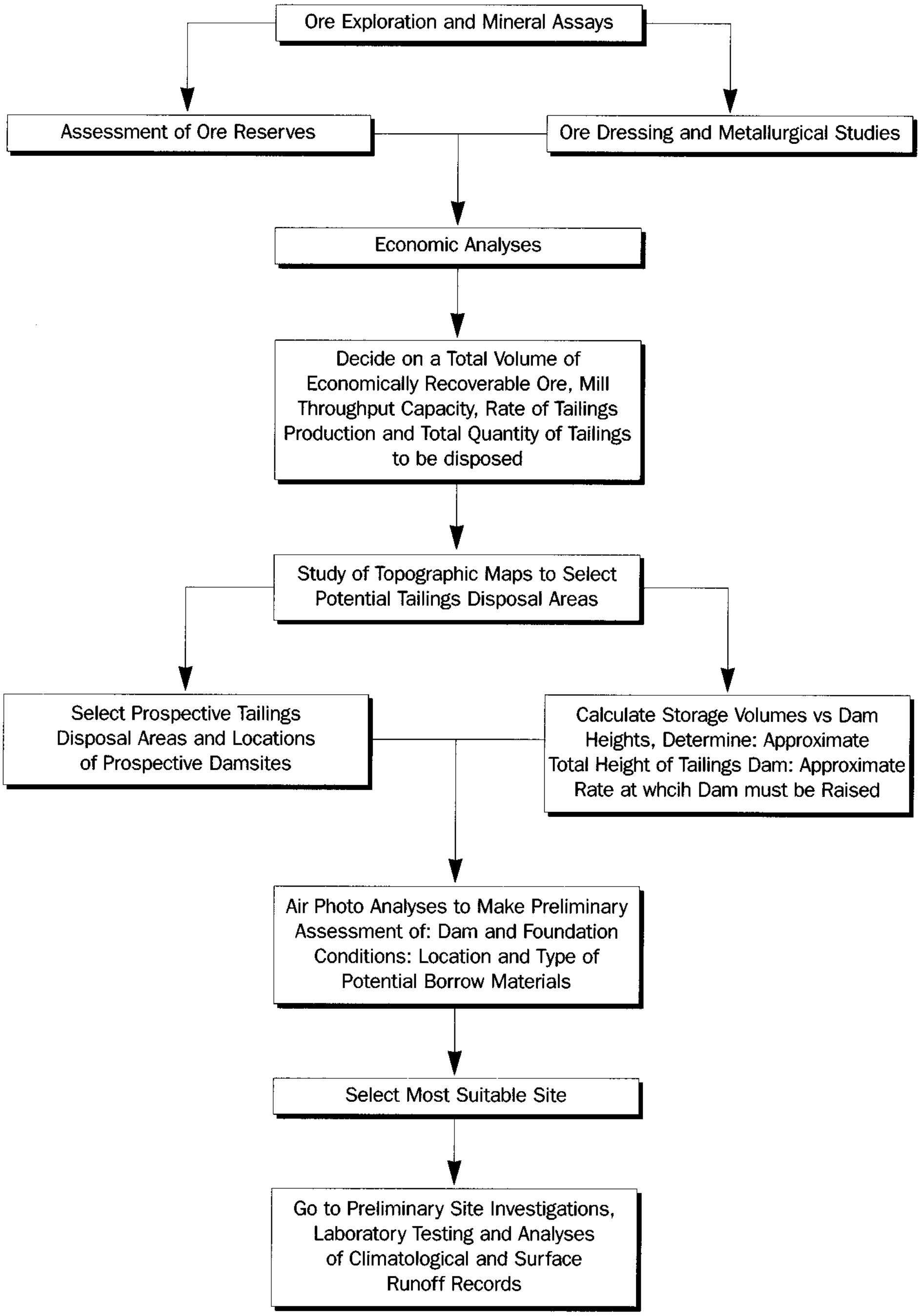


Table 1: Preliminary Design and Investigation Process (Lewis, 1994).

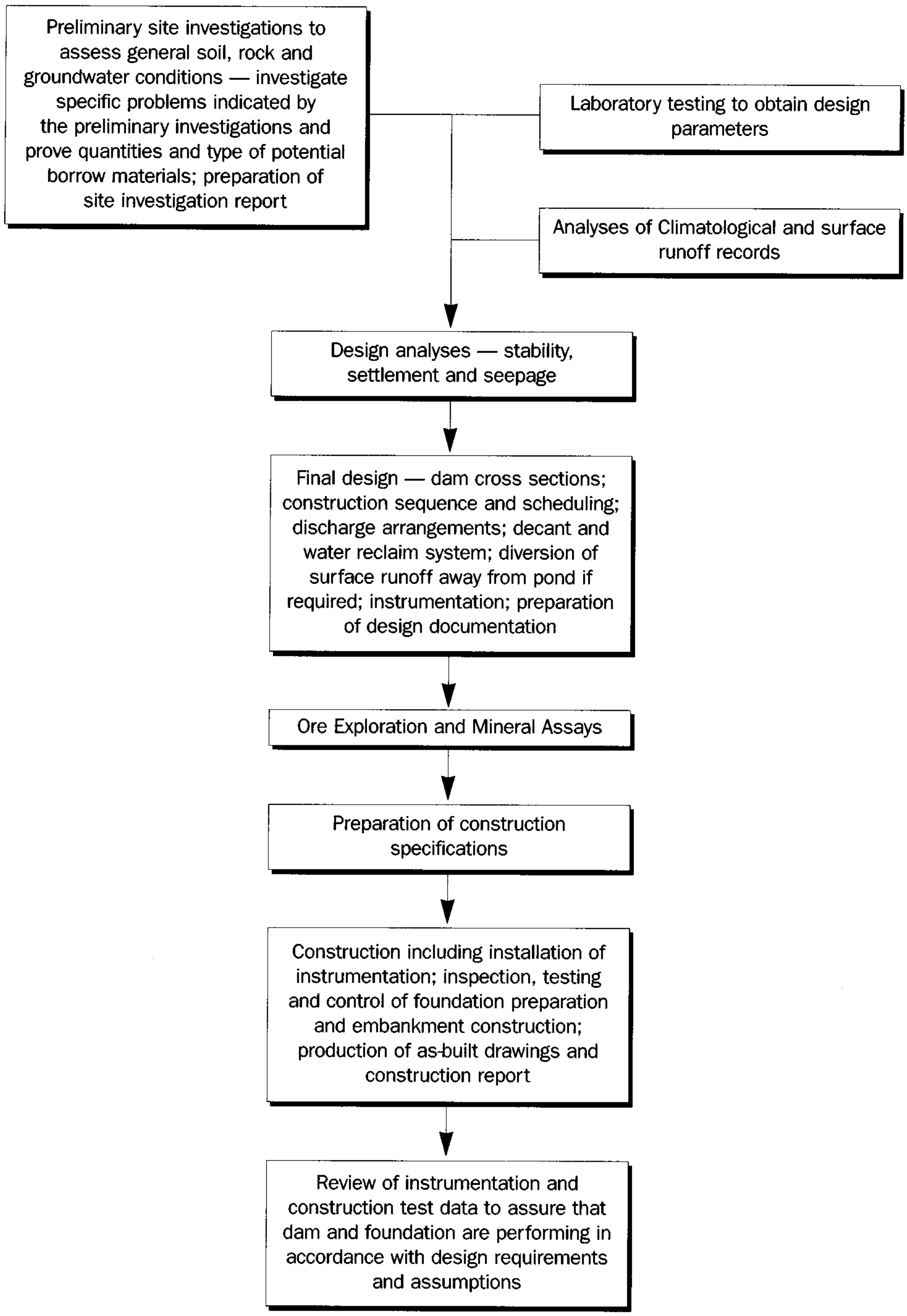


Table 2: Detailed Investigation, Design and Construction Process (Lewis, 1994).

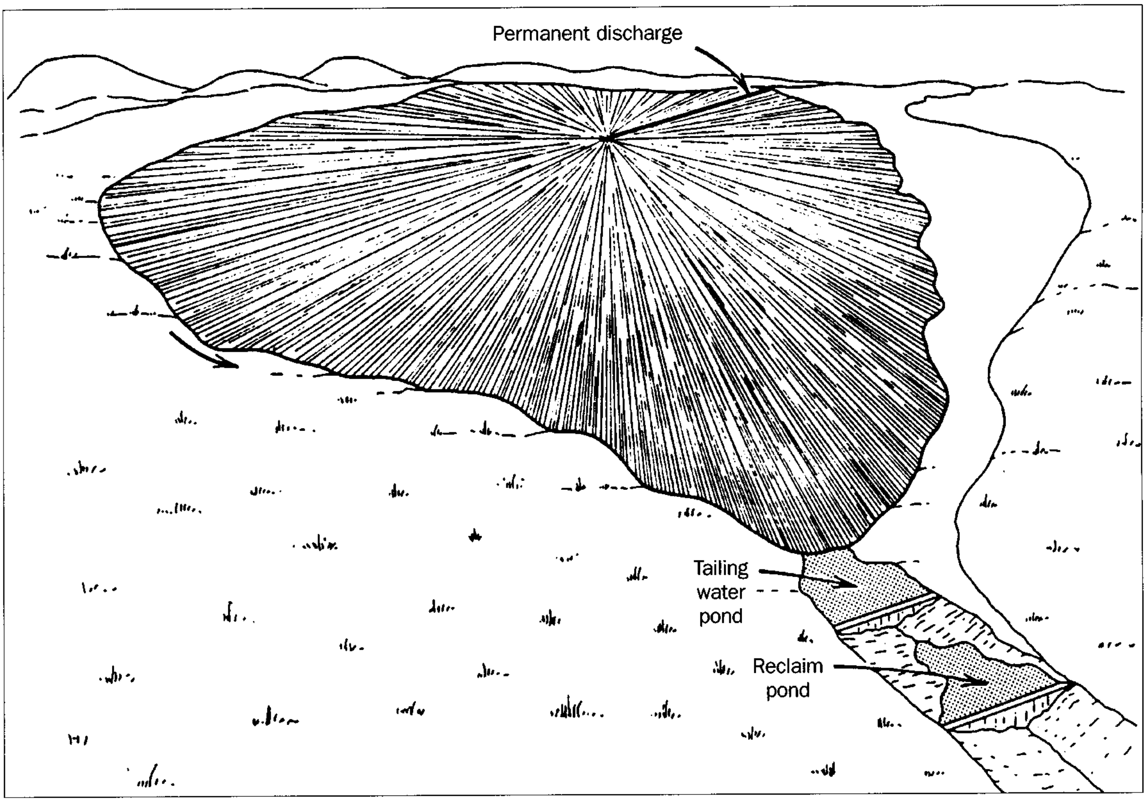


Figure 1: Tailings Dump Produced by the Thickened Central Discharge Method (after Vick, 1983).

cases of open cut mining, the tailings are recycled into an open pit. There are a number of types of dam, usually dictated by the natural topography. These include paddock (or 'turkey nest') dams which are generally four sided impoundments constructed on flat land, cross valley impoundments in which a single embankment is constructed across a valley, or sidehill impoundments.

Tailings are often used as a construction material for dam walls and banks for the obvious reason that they are the cheapest material available. If the tailings are to be used, the dam design must include environment protection from any undesirable physical and chemical properties of the tailings. This includes the following considerations:

- separation of the coarse and fine tailings, with only the coarser materials being used for construction (this segregation of materials might be by mechanical separation [eg using cyclones], or by low velocity discharge through multiport spigots onto a tailings beach);
- control of the sand separation process to ensure the sand produced meets specified gradation and permeability requirements;
- installation of internal drains and filters to maintain low phreatic surfaces (soil water saturation levels) within the embankments;

CASE STUDY 1

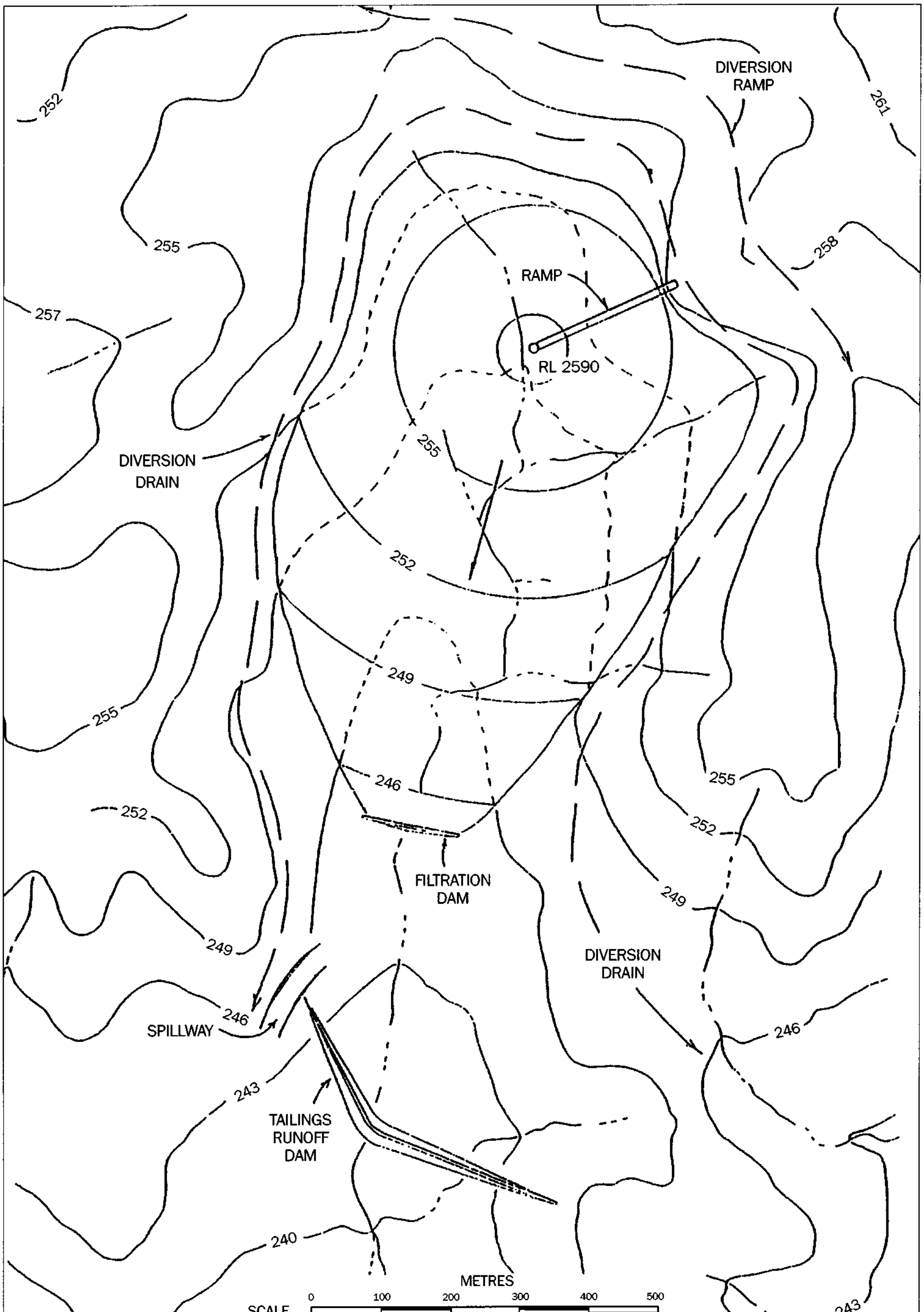
Gold Tailings
Peak Gold — central thickened discharge

The Peak Gold Mine is located at Cobar in New South Wales. It is an underground mine that produces gold as well as a copper/lead/zinc concentrate. The mine was established in 1992, with a predicted mine life of 11 years. The minerals extraction produces on average a fine tailings product for disposal at a rate of 300 000 tonnes per annum.

The topography around the mine is fairly flat. A shallow gully about 1km to the west of the processing plant was selected as the preferred tailings storage area. Preliminary studies showed that substantial embankments would be required for conventional paddock style containment. Only a small amount of waste rock would be generated in the absence of open cut mining. Large borrow areas for construction materials would therefore be required for the initial and ongoing earthworks. The central thickened discharge method of disposal was eventually adopted as an alternative that was cheaper to construct and could be operated with less environmental impact.

The central thickened discharge method involves thickening the tailings slurry to the point where a natural beach angle can be formed by sub-aerial discharge, creating a stack with an essentially conical formation. In this way the need for retaining embankments can be eliminated, or at least minimised. This method, therefore, leads to considerable economies in both initial and ongoing construction costs. Operating costs are also reduced as there is no requirement to keep rotating the spigot outlets or, periodically, to raise and relocate the tailings delivery line. The tailings self-manage their own distribution. Another key advantage of the system is that the decantation pond is not located on the tailings but in a separate impoundment downstream. Evaporative drying of the tailings and slow rate of build up of the cone mean that the tailings quickly achieve high density and high strength. Such reduction in volume and the increased stability of the tailings both provide benefits in increased storage capacity and easier rehabilitation.

Thickened tailings are required as they are non-segregating, ie there is little tendency for the sequential deposition of coarse particles at the point of discharge followed by finer and finer particles progressively down the beach. Rather, the slurry has sufficient viscosity and shear strength that it remains a homogeneous mixture of particle sizes at all points on the beach. As a result the conical beach slope has a uniform gradient over most of its length. The resulting conical land form will be in keeping with the surrounding topography, will be erosion resistant and, in the absence of steep embankments will be relatively easy to rehabilitate.



Layout of the Central Thickened Discharge tailings stack, Peak Gold Mine, Cobar, New South Wales. (see Cover Photo).

- compaction of the coarse material used to construct the embankments to increase its density (this will increase the resistance of the material to liquefaction under earthquake loadings. An alternative is to accept a lower degree of compaction, use flatter slopes, and ensure positive internal drainage to prevent saturation of the sand);
- protection of highly erodible surfaces with vegetation, coarse gravel or waste rock (this is necessary to deal with the susceptibility of tailings to both wind and water erosion).

Storage in open cut and underground workings

A desirable method of tailings storage is to discharge the tailings into an old open cut or worked out underground mine. This is a low cost method of storage. However, there are several potential problems. In most cases the pits are deep with a relatively small surface area. This results in sub-aqueous discharge and a high rate of rise of solids in the pit. This in turn leads to very poor consolidation of the tailings and low strengths, making reclamation of the surface very difficult. It can also be difficult to prevent groundwater contamination from these areas. Backfilling of open cut mines has found a level of acceptance in some industries, particularly in mineral sands mining. This is because these tailings usually comprise the original material chemically and physically unchanged, except for the removal of the desired mineral particles by non-chemical processes.

3.2 LINER SYSTEMS

Liner systems are designed to restrict the downward seepage of leachate through the base of the tailings storage area. All liner systems will have a leakage rate, and this rate will depend on the following:

- the magnitude of hydraulic head above the liner;
- the thickness and effective hydraulic conductivity of the liner material (the hydraulic conductivity is dependent on the properties of the liner material, plus the size and frequency of defects or discontinuities which may exist in the liner and the underlying base material);
- the length of time the hydraulic head is applied to the liner.

These factors (head, liner hydraulic conductivity, and time of application) can be controlled for most tailings deposits and should be considered when designing a project specific containment system. Other factors which need to be considered when a liner system is being designed for a tailings area include:

- a good knowledge of geotechnical, hydrogeological, and geochemical conditions in the vicinity of the proposed storage area;
- physical and chemical characterisation of the tailings, effluent, construction materials used as liners, drainage and embankment

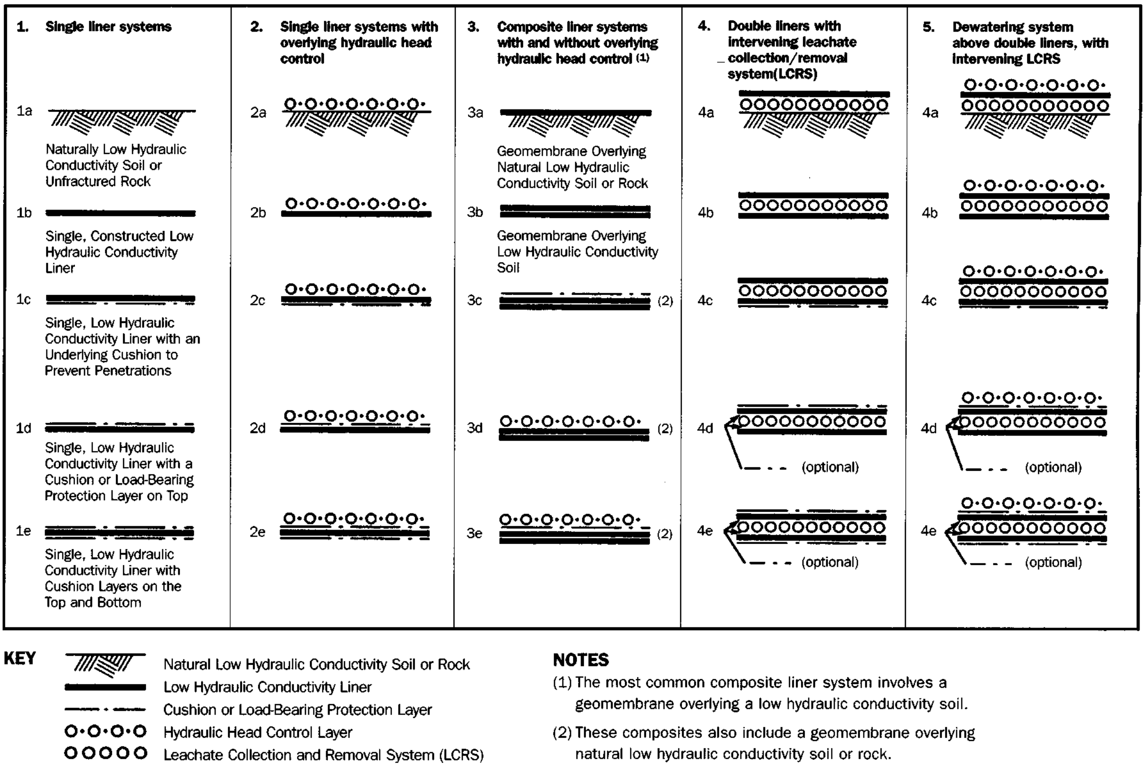


Figure 2: Types of liner systems potentially applicable to mine tailings (after Hutchinson et al, 1992)

materials, and an understanding of the geochemical interactions that may occur as the effluent seeps through various soil types;

- the benefits of a base drainage system in both reducing the hydraulic head on the base of the deposit and improving the consolidation of the tailings within the deposit (improved consolidation increases the storage efficiency within the area, and increases the strength of the tailings. The collected leachate may also contain valuable material).

The design should select a control method which maximises environment protection from effluent seepage due to liner leakage. Liner selection criteria should include possible long term impacts of leakage from tailings storage areas.

All such evaluations should involve suitable specialists with a knowledge of geology, hydrogeology, geochemistry, tailings engineering and environmental risk assessment.

3.3 CONSTRUCTION TECHNIQUES

Tailings dams can be built as conventional water dams and then filled, or built progressively using the tailings in their construction. There are three main approaches when considering the progressive

CASE STUDY 2

Alcoa of Australia
Bauxite Tailings — Wet storage
(seal design with base drainage for seepage collection)

Alcoa of Australia currently produces six million tonnes of alumina annually at its Western Australian refineries located at Kwinana, Pinjarra and Wagerup. All these refineries utilise bauxite mined in the nearby Darling Range. This ore is low grade by world standards as two tonnes of residues are produced for every tonne of alumina extracted.

Disposal of these residues poses some major environmental problems. The refineries are located close to major population centres and adjacent to some of the State's most productive agricultural lands, the volume of waste produced is very large, and the alkalinity of the waste has the potential to infiltrate valuable surface and groundwater resources.

Alcoa of Australia has undertaken a number of development projects aimed at lessening both the potential environmental and economic impacts of the residue disposal operations. This development work commenced in the early 1970s, with the primary focus coming from the discovery of groundwater contamination below the Kwinana disposal areas.

The original containment areas were constructed on the sandy coastal plain and therefore relied upon a 380mm thick clay blanket to prevent contamination of the underlying aquifer. While the clay seal prevented general seepage, there were a number of defects in the blanket placed on the embankment. These were thought to be the result of either cracking due to drying out or erosion caused by rainfall.

As a result of the groundwater contamination, the main design issue was the base seal requirements. New containment areas were constructed with a composite clay/synthetic membrane seal, and a drainage layer was placed above this composite seal to reduce the hydrostatic head at the base of the residue, further reducing the potential for seepage. The drainage layer had the added advantage of increasing the consolidation of the residue, improving the storage efficiency of the area, and recovering alkaline drainage water which was returned to the refinery.

Clay/synthetic membrane line being installed at Alcoa's Kwinana refinery, Western Australia. The dark grey material is the 380mm thick clay seal, the blue is the 0.76mm PVC liner, and the yellow is the sand drainage layer being installed above the composite liner.

construction of a dam. These are called upstream, centreline, and downstream construction. These methods allow for staged construction of the embankments which minimise start-up capital costs, and have the potential to improve the overall mining economics. Table 3 shows a comparison of various aspects of their construction and use.

It is recognised that all tailings storage facilities will need to be designed and operated to accommodate site specific constraints. Each situation is different and there is no simple means of ranking factors such as tailings and site selection characteristics, tailings dam construction and operational techniques to give a 'best' answer for tailings containment. The overriding approach aims to avoid both short and long term environmental problems and achieve the best environmental results.

Upstream construction

This method involves advancing the crest of the embankment progressively upstream as the impoundment is raised. The embankments are lifted by either periodically constructing new bunds using mechanical techniques, or alternatively raising the walls semi-continuously using hydraulic techniques (eg using cyclones). Figures 3 and 4 illustrate typical examples of embankments constructed using the upstream method.

Upstream construction relies upon the bearing strength of the tailings beach adjacent to the peripheral wall to support each successive lift. Beach strength in turn relies at least in part on the drainage and drying practices. The more important features of this approach are:

- the starter dam is essentially a containing embankment and a support for the tailings

Table 3: Comparison of construction techniques (after Vick, 1983)

Embankment type	Mill tailings requirements	Discharge requirements	Water storage suitability	Raising rate restrictions	Embankment fill requirements	Seismic resistance	Relative embankment cost
Water retention	Suitable for any type of tailings	Any discharge procedure suitable	Good	Entire embankment constructed initially	Natural soil borrow	Good	High
Upstream	At least 40-60% sand in whole tailings. Low pulp density desirable to promote grainsize segregation	Peripheral discharge and well controlled beach necessary	Not suitable for significant water storage	Less than 5m/yr most desirable	Natural soil, sand tailings or mine waste	Poor in high seismic areas	Low
Downstream	Suitable for any type of tailings	Varies according to design details	Good	None	Sand tailings or mine wastes if production rates are sufficient. Otherwise natural soil.	Good	High
Centreline	Sands or low plasticity fines	Peripheral discharge of at least a normal beach necessary	Not recommended for permanent storage. Temporary flood storage acceptable with proper design details	Height restrictions for individual raises may apply	Sand tailings or mine waste if production rates are sufficient, otherwise natural soil	Acceptable	Moderate

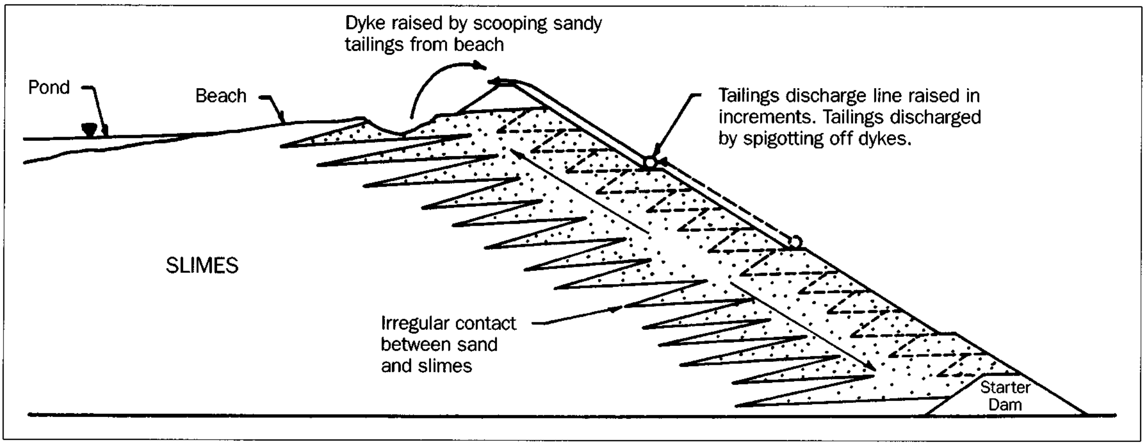


Figure 3: Upstream Construction using Mechanical Techniques (after Klohn, 1980)

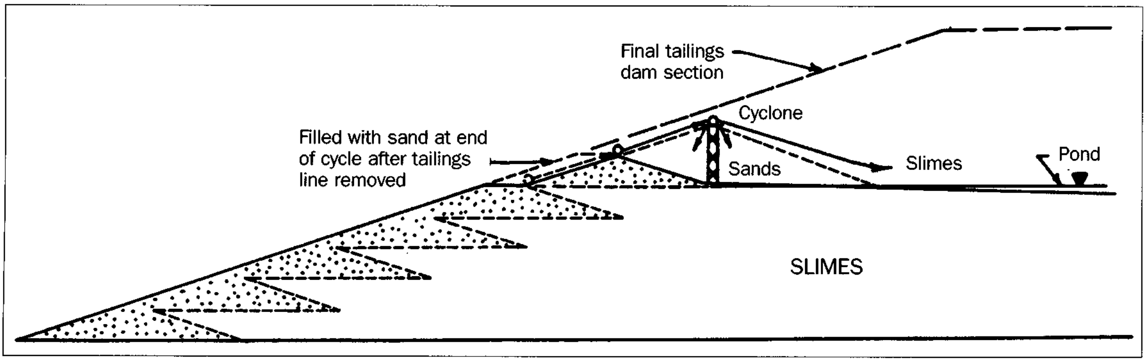


Figure 4: Upstream Construction using Hydraulic Methods (after Klohn, 1980)

discharge line, rather than a dam in itself (the starter dam is best constructed from rock fill or mine waste to allow drainage of seepage water and to control erosion);

- successive lifts are commonly constructed using dried, compacted tailings from the beaches, however waste rock and imported borrow materials are also used (it is again preferable to use relatively coarse materials for the control of seepage pressures);
- tailings discharge must be carefully controlled by spigotting to ensure that the coarser sandy tailings are deposited near the starter bund (this is essential to control seepage pressures on the embankments, and also provides the strongest materials near the walls for stability. It also provides a source of permeable borrow for later embankment lifts);
- the water pond must be kept well away from the edge of the storage area (if the decant water [or ponded rainfall] is allowed to come close to the walls the piezometric level in the outer slope may rise which will lead to slope instability and potential failure of the wall); and
- the coarse tailings may be at relatively low density. If they become saturated, and an earthquake occurs, they may liquefy leading to slope failure.

CASE STUDY 3

Bauxite Tailings
Alcoa of Australia — dry stacking of tailings

Case Study Number 2 describes improvements in the type of seal used to contain the tailings at Alcoa's Kwinana Refinery in Western Australia. However, there are a number of environmental and process reasons why the storage of low density 'wet' tailings in large impoundments is not the preferred technique for future tailings storage.

Development work began in the early 1980's on alternative techniques and in 1985 'dry stacking' was adopted for Alcoa's Western Australian refineries. Dry stacking uses mechanical equipment to de-water the fine tailings, which are then spread in layers over the storage areas to de-water through a combination of drainage and evaporative drying. By using the coarse fraction of the tailings for construction of drainage layers and upstream perimeter embankments, the storage area can be constructed as a progressive stack, thus avoiding the need for full height perimeter dykes and allowing continued stockpiling on areas that were previously 'wet' impoundments.

The initial costs of establishing dry stacking at Alcoa's three Western Australian refineries exceeded $150 million. However there were many benefits:

- a higher density deposit can be achieved reducing the overall volume of stored tailings;
- the progressive stacking allows the deposit to be taken to a height which would not be economic with conventional wet impoundments;
- the higher density and increased deposit height means less land is used;
- the exposure of less land area to tailings and the drained condition of the dry stack significantly reduce the risk of groundwater contamination;
- improved surface stability and drainage mean that completed areas can be reclaimed and revegetated quickly; and
- safety hazards to people and wildlife are reduced.

Figure 5 describes the overall stacking process. The coarse particles (size greater than 150 micron) are separated from the fine tailings. This separation is done using cyclones and counter current wash towers and results in roughly equal portions of coarse and fine tailings. The fine tailings are pumped to a thickener vessel where they are flocculated and settled producing a high density underflow slurry of around 50% solids (by weight). This slurry is pumped to one of a number of beds where it is placed in layers of 0.5m depth and allowed to dry in the sun. The final dry density of the tailings is around 70% solids. This compares with the final density of 60-65% solids that was being achieved in the wet disposal areas.

PHOTO: ALCOA

Dry stacking area, Alcoa of Australia's Pinjarra Refinery, Western Australia. The tailings storage area in the foreground shows the thickened flurry being deposited on a dry stacking area. In the background are wet tailings storage impoundments and water storage facilities.

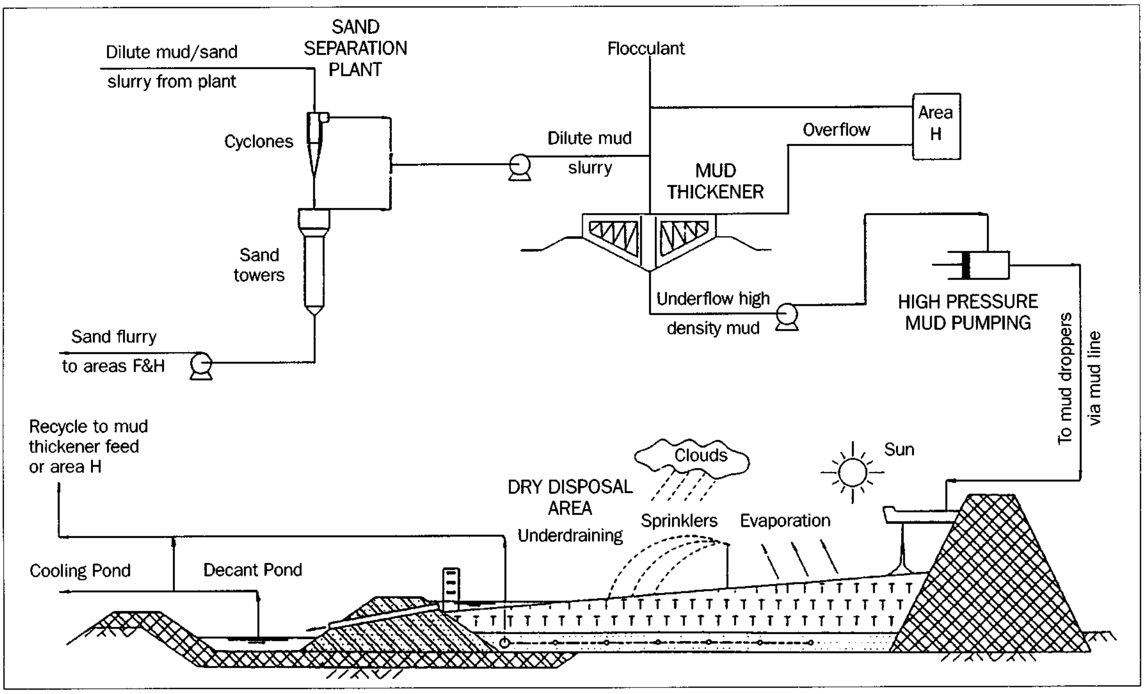


Figure 5: Schematic of the dry stacking process, Alcoa of Australia, Western Australia.

Upstream construction

In general, upstream construction techniques are best suited to hard rock mining which produces silt-sand tailings that are readily spigotted to classify into a sandy beach. In all cases wall stability will depend on allowing the finer tailings to dry out between lifts and to develop a significant dried strength. This method of construction is the most commonly used tailings dam building technique in the Western Australian gold fields. While it is generally the cheapest environmentally benign construction method, it probably requires the highest level of operator skill in tailings management to maintain a stable deposit of tailings.

Downstream construction

There are various types of tailings dams constructed by the downstream technique. They are illustrated in Figures 6, 7 and 8. The technique requires moving the crest of the wall progressively downstream as the impoundment is raised. The walls can be lifted using either waste rock, imported borrow material, or coarse sand tailings.

The important features of downstream construction are:

- the embankment should be constructed of selected fill;
  (In Figure 6, a water storage dam type of cross section has been used, with an upstream impervious zone and internal drainage control. This allows water to be stored adjacent to the embankment. Alternatively, the downstream shoulder could be constructed progressively using cycloned sand tailings. In this case the stability depends on the water pond being kept away from the wall to control the position of the phreatic surface [level of

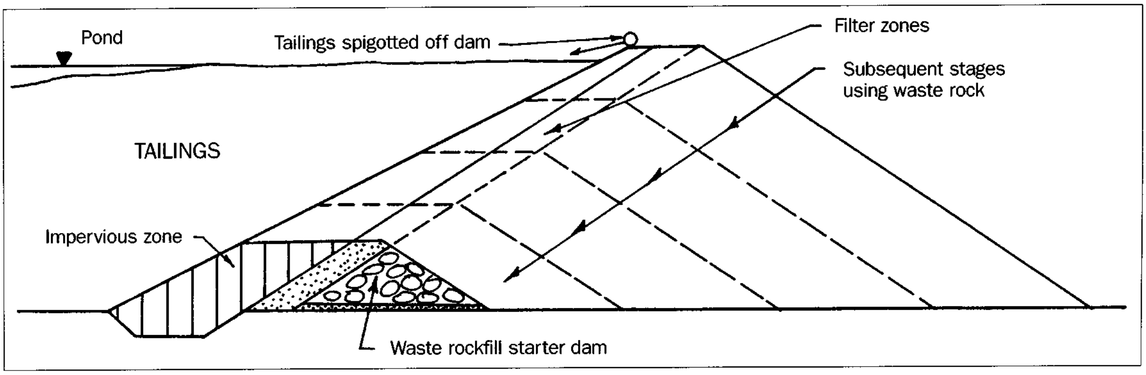


Figure 6: Downstream construction using waste rock (after Klohn, 1980).

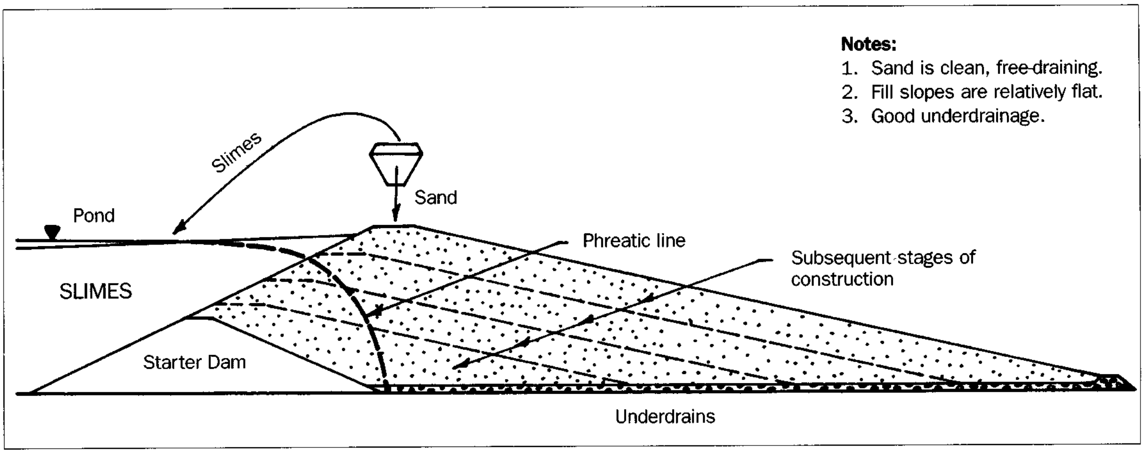


Figure 7: Downstream construction using free draining cycloned sand (after Klohn, 1980).

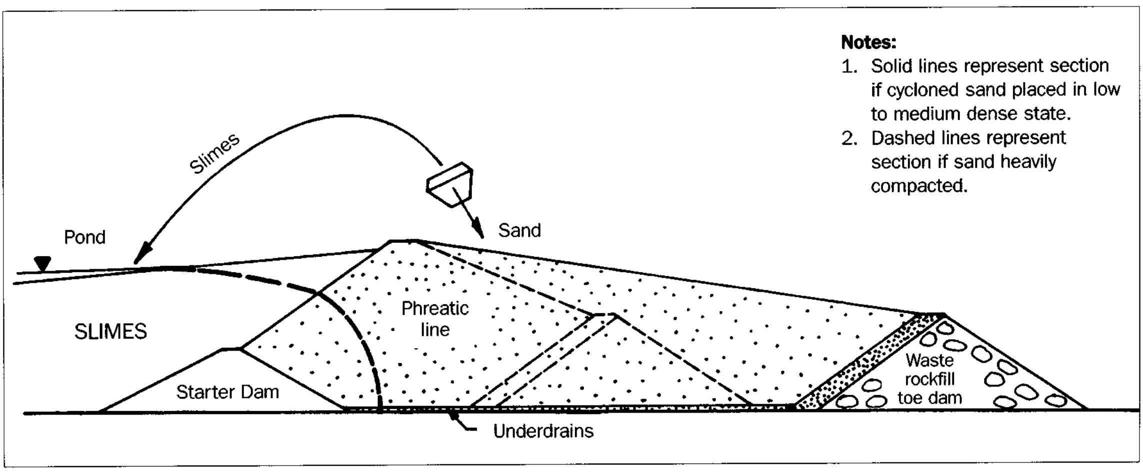


Figure 8: Downstream construction using cycloned sand and waste rock toe (after Klohn, 1980).

the water table]. Cyclones require continual positioning and can be susceptible to changes in the tailings feed rate and gradings. For these operational reasons Australian miners prefer spigotting for depositing tailings. A more common approach is to use mine overburden to construct the embankment.)

- for traditional water dam construction, no real deposition control is necessary, while for a cyclone constructed embankment, it is important to spigot or cyclone the tailings to form a relatively sandy beach adjacent to the wall.

Downstream construction may be cost effective where suitable waste rock is available from the mine and there are similar haul distances to both the waste dumps and tailings area (ie no additional cost is incurred by hauling the waste rock to the tailings area despite the large volumes required).

Centreline construction

Figures 9 and 10 illustrate centreline construction techniques using cyclones and mechanical methods. This technique involves the crest of the wall remaining central on the starter wall with progressive lifts. Construction materials may either be waste rock, imported borrow or coarse tailings or a combination of these.

The important features of centreline construction are:

- the embankment must be constructed at least in part from permeable materials to allow control of piezometric pressures;
- the water pond must be kept away from the edge of the embankment to prevent build-up of excessive piezometric (groundwater) pressure; and
- it is essential that the tailings placement is controlled to keep the ponded water well away from the outer embankment through maximised beaching.

Co-disposal

Traditional tailings disposal practice involves separate disposal of fine and coarse wastes. Mixing and co-disposing of the fine and coarse material is being encouraged, particularly in the coal mining industry. Mixing improves the drainage properties of the tailings and hence increases the rate of consolidation and strength build-up. However, there are often significant problems associated with controlling the deposition strategy in such a way that optimum mixing of coarse and fine rejects is achieved.

3.4 CLOSURE SYSTEMS

There are a number of objectives that need to be considered when planning the closure of a tailings storage area. They include:

- containing/encapsulating tailings to prevent leaching into ground and surface waters;
- providing surface drainage and erosion protection to prevent surface water transporting tailings from the storage area;
- providing a stabilised surface cover to prevent wind erosion; and
- designing the closure to minimise post-closure maintenance.

The physical characteristics of the tailings generally determine the type of erosion protection required, while the chemical characteristics, the amount of rainfall, and the tailings containment features and liners will determine the need for and requirements of a surface cover. Low infiltration covers will be

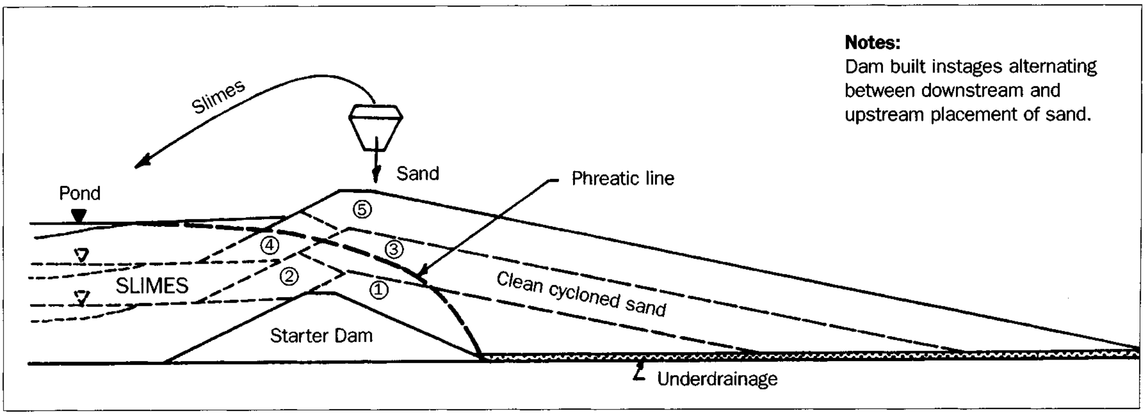


Figure 9: Centreline construction using cycloned sands (after Klohn, 1980).

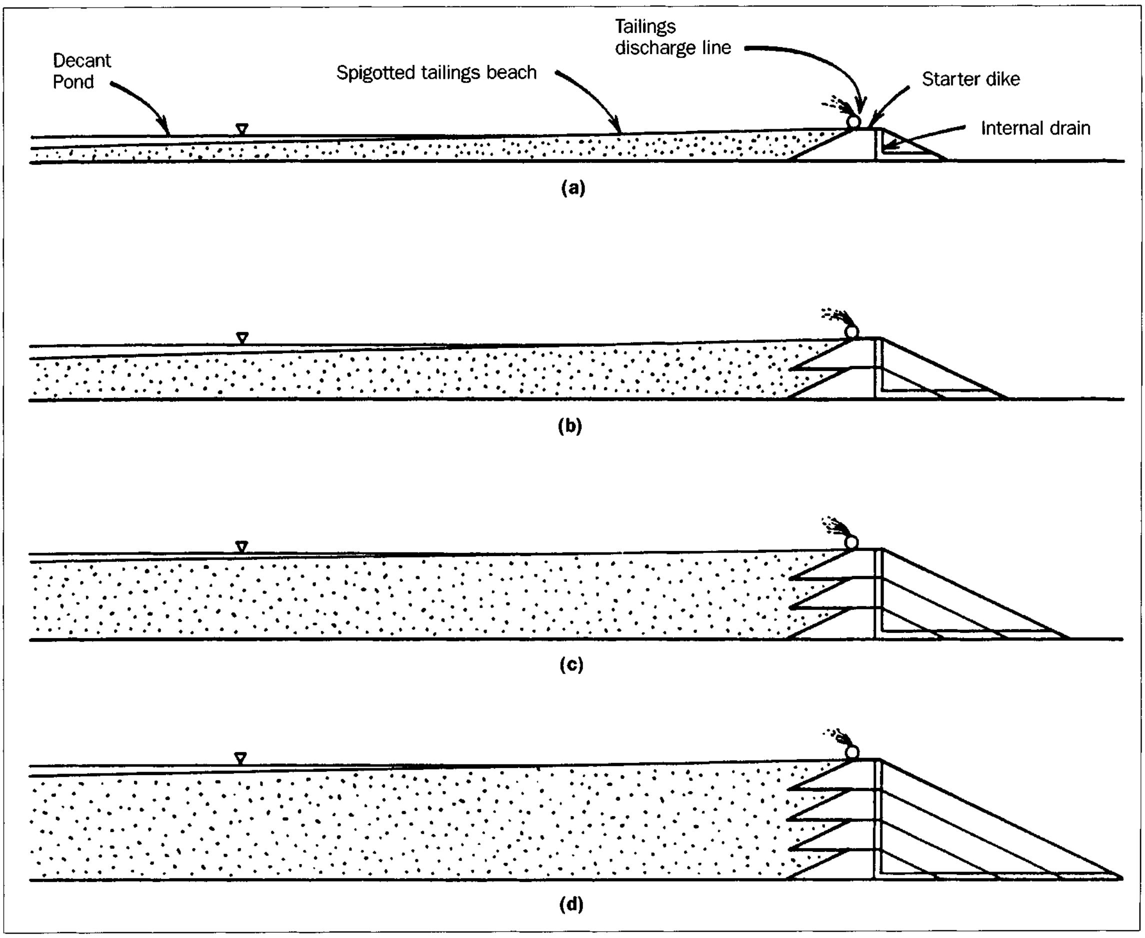


Figure 10: Centreline construction using mechanical methods (after Vick, 1983).

CASE STUDY 4

Coal Tailings
Jeebropilly Colleries — co-disposal of coarse and fine tailings

Jeebropilly Collieries Pty Ltd operates an open cut steaming coal mine in the West Moreton Basin approximately 18 km west of the City of Ipswich in Queensland. The mine produces over one million tonnes of coal per annum for both export and local markets and is a multiple thin seam truck and shovel operation. The Company has implemented the first full production co-disposal system in Australia, which has now been in operation for four years. The operation produces around 700 000 tonnes of reject material per annum. The reject material consists of stone and clays which are present in the coal seams. Of this, approximately 45% consists of fine material (less than 2mm) and the remainder is coarse material with particle sizes up to 100mm.

Traditional methods of disposal required that all coarse reject material be transported by truck to the open cut mine, while the fine tailings are pumped to settling ponds.

CASE STUDY 4

Coal mines face several problems with this type of disposal:

- tailings storage areas can occupy large areas of land and render them useless for future productive use;
- tailings impoundments are generally unsightly and difficult to rehabilitate due to poorly consolidated deposits;
- truck haulage of the coarse rejects requires dedicated equipment and labour, with high operating costs; and
- coarse rejects can be prone to spontaneous combustion if they are not handled correctly.

It was realised that there were benefits if the coarse and fine materials could be mixed together in a common area, utilising old mining voids remote from the active mining area. Mixing reduces environment impact through decreasing the overall volume with smaller particles filling spaces otherwise left between larger particles. At the same time pumping combined waste material offers large savings in operations, equipment and manpower.

The Jeebropilly Reject Co-disposal System has shown that it is possible to pump a combination of coarse and fine rejects over distances of more than a kilometre at commercial production rates and produce a final landform which is both geotechnically stable and capable of rehabilitation to a productive future land use.

required when the climate is sufficiently wet to cause free liquids to accumulate in the tailings, and where the chemical constituents contained in these free liquids pose a threat to the environmental values of water. It is usually good practice to design the cover with an effective infiltration rate which is equal to or less than the seepage potential through the bottom liner system or natural soils underlying the tailings. When using low infiltration cover rehabilitation should include planting shallow rooted vegetation such as grasses so that the cover is not breached by infiltrating roots.

Storm types and patterns will determine the potential for surface erosion from a closed facility. Where these are capable of causing surface erosion and subsequent dispersion of the tailings in the environment, it will be necessary to include components in the cover design to prevent this from occurring. This may include vegetation and/or provision of coarse gravel layers that are erosion resistant. Closure may also require regrading surface and embankment slopes to reduce erosion potential.

In some cases a drainage layer will be required below a topsoil cover to prevent saturation of the topsoil layer, and to function as a capillary barrier. The material used requires a grain size distribution sufficiently coarse to prevent the upward migration of fluids by capillary action, thus preventing constituents from the tailings migrating to the root zone of the vegetated top layer.

Further details on rehabilitation and revegetation are available in a separate module.

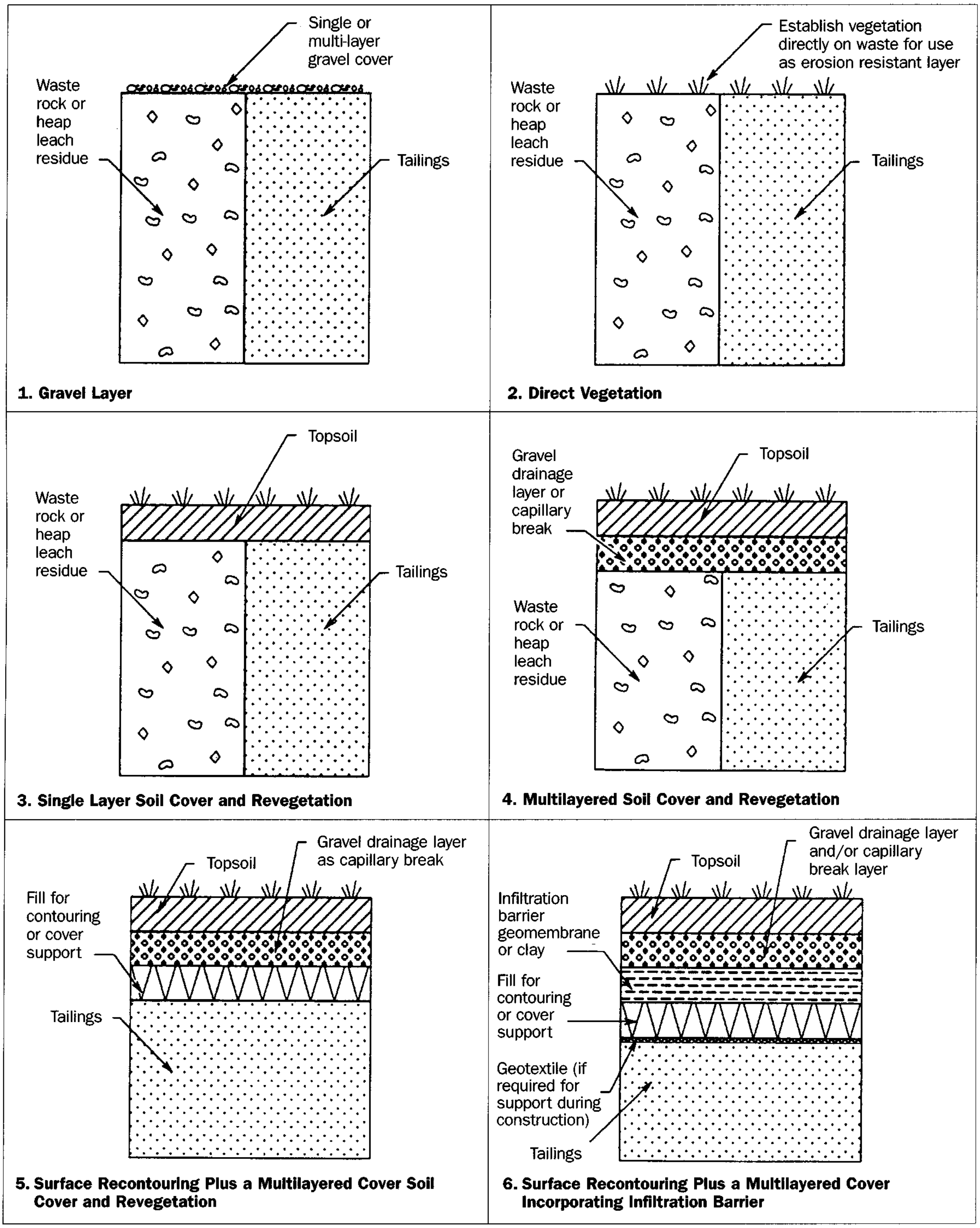


Figure 11: Typical covers for tailings storage areas (after Hutchinson et al, 1992).

4. OPERATING AND MONITORING

4.1 DEPOSITION METHODS

Currently acceptable deposition methods for process tailings include:

- terrestrial impoundment; and
- underground disposal.

Terrestrial impoundment is more common as the tailings are easily accessible condition allowing pollution monitoring and control. In addition, the tailings can be reclaimed as a resource, or mined and reprocessed if required.

Most tailings are pumped to the tailings disposal area as a high water content slurry. They are then discharged into the storage from single or multiple discharge points called spigots. If the tailings contain mostly fine grained, clay sized particles, additional spray bars may be attached to each spigot to deposit them over a larger area while ensuring they form a uniform beach in the dam. This uniform deposition through spigots is the best method for sorting and drying the tailings. It is known as sub-aerial deposition. It is desirable in most circumstances, as it allows the greatest drying or dessication, which produces higher dry densities, lower compressibility and higher shear strength. Additionally, the process sorts the various size fractions on the tailings beaches resulting in high permeability near the discharge point decreasing towards the pond, thus producing a lower phreatic surface (groundwater level). This process is illustrated in Figure 12.

When tailings are beached, they do so at a slope which is dependant on the particle size distribution, density of the discharged slurry, and the discharge rate. Because the coarser tailings settle out more rapidly than the finer slimes, the beach slopes can vary with distance from the discharge points. Typically, beach slopes are between 0.5% and 2% close to the discharge, reducing to as low as 0.1% in the centre of the impoundment.

Tailings deposition that occurs below the ponded water is known as sub-aqueous deposition. When fine, high clay content tailings are deposited sub-aqueously, they will usually have low settled densities, very low strength and will present major problems when trying to reclaim the surface for rehabilitation.

Another type of tailings discharge that is gaining popularity in Australia and offers significant environmental advantages is thickened discharge resulting in a cone or stack of dried tailings. This technique has been described earlier in Case Studies 1 and 3. The basic concept is to discharge thickened tailings onto a bed where they drain and dry, with all excess water, including rainfall runoff, being removed from the bed and either stored in a separate pond or released.

4.2 INSTRUMENTATION

An impoundment design should include a monitoring system for assessing on-going stability of the impoundment structures. The monitoring system design should determine frequency of monitoring, critical parameters within the design that the monitoring will be tracking, and the relevance of these parameters to overall stability and environmental impact assessment.

The operations phase of the tailings facility should include monitoring in accordance with the design requirements as well as on-going analysis of the monitoring data.

The most common design parameters requiring on-going monitoring are:

i. the phreatic surface in the down-slope retaining embankment;

(a) effect of pond water location;

(b) effect of beach grain size segregation;

(c) effect of foundation permeability;

(d) effect of decreasing tailings permeability with depth;

(e) effect of slimes layers;

(f) effect of underdrains.

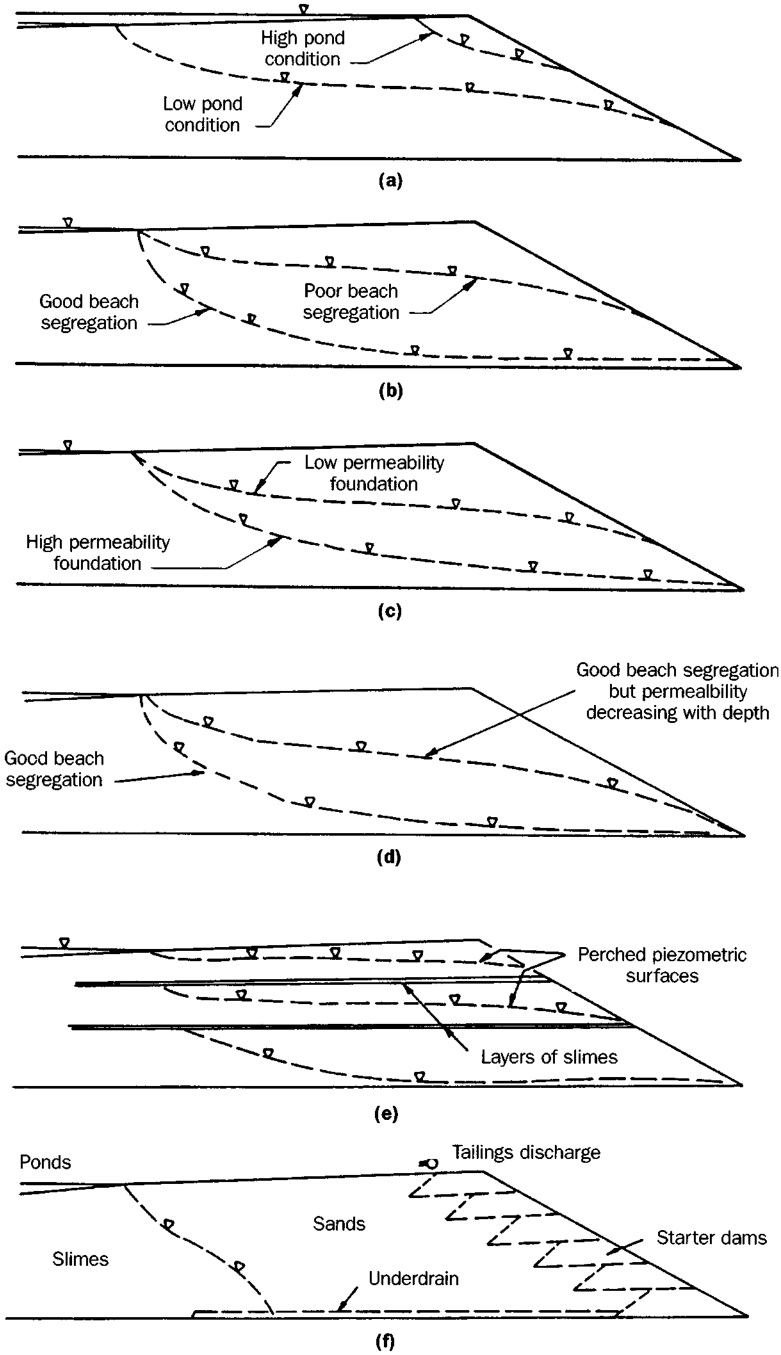


Figure 12: Factors influencing the location of the phreatic surface for upstream embankments (after Fell et al, 1992)

(The assessment of stability will assume a phreatic surface, and slope stability will be calculated based on material strengths and bulk densities. These values can change if the phreatic surface rises, saturating materials that have been assumed to have moisture contents similar to those at the time of construction.)

ii. excess pore pressures below an upstream embankment.
(The size and rate of rise of an upstream embankment is usually linked to the strength of the underlying tailings. This strength is in turn related to the release of excess pore pressures generated by the loadings of tailings deposited and upstream dyke construction.)

The phreatic surfaces and excess pore pressures are monitored through the installation of piezometers.

4.3 WATER MANAGEMENT

Minimising the quantity of water escaping from the tailings dam will be necessary to avoid pollution, and is good environmental practice. This can be achieved by recirculation of process water and control of seepage. Measures used to control seepage from a tailings dam might include:

- use of clay liners and synthetic liners;
- foundation grouting and the use of cut-off trenches;
- controlled placement of tailings; and
- inclusion of toe drains and under drains to collect and treat or recycle seepage.

A tailings deposit is generally subjected to two different types of water balance cycles. The first is the artificial or mining related cycle, which includes water addition or subtraction as part of the mining or metallurgical extractive process. The second is the natural cycle and includes rainfall, runoff, and infiltration.

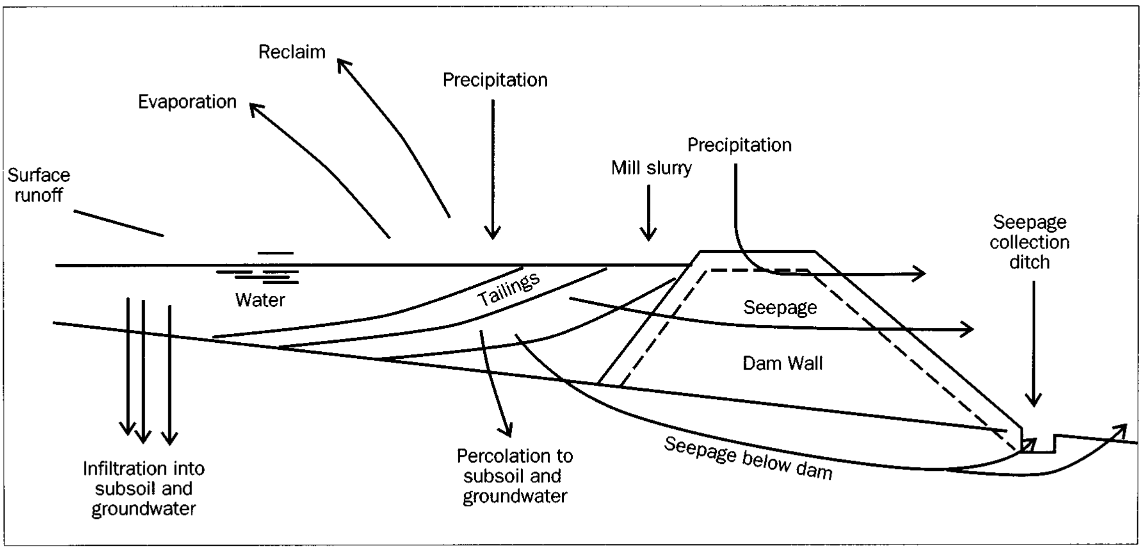


Figure 13: Water gains and losses at a terrestrial impoundment.

In most mining operations it is common practice to discharge all contaminated effluents from the ore processing facility to the tailings deposit. This action, coupled with the fact that water is one of the most important commodities in the processing of ores, means that most tailings operations have a closed water circuit (except for evaporation) with water recycled to the processing plant. When developing a water management strategy, a complete water balance for the operation should be made considering both the artificial and natural water cycles. Also, the potential impact of extreme climatic conditions, such as flood and drought, should be considered to ensure that tailings disposal areas are designed to cope with these extremes — the aim being to achieve best practice environmental management.

4.4 GROUNDWATER MONITORING

Fundamental to the design of an effective groundwater monitoring system is an understanding of the tailings being stored, the design of the facility, seepage migration potential, groundwater flow conditions, potential interaction of the leachate with the soils and the most probable and significant pathways of potential migration of leachates. The monitoring system is then designed to provide sampling points along these likely pathways as detection locations. For comparative purposes sampling should also be conducted at baseline points before tailings storage occurs, and at background points in areas not expected to be affected by leachates.

It is also important to know what the potential impacts of leachate may be, including the extent of the influences and the migration times. These factors need to be incorporated in the design of the monitoring system.

The factors which should be considered when designing a monitoring network are therefore:

- baseline and background conditions;
- waste characteristics;
- the degree and nature of tailings containment;
- disposal environment (climate and local geological, hydrogeologic and geochemical conditions);
- potential migration pathways and likely migration times; and
- potential impacts of leachate.

Best practice also includes biological monitoring and statistical analysis of pre-operation and post-operation data. In this way the effects on pre-operation ecosystems can be determined accurately by any auditing or regulatory mechanism.

4.5 GENERAL SURVEILLANCE

Once a year the tailings storage areas should be inspected and reviewed by the original designer or an engineer experienced and competent in the construction and management of tailings impoundments.

CONCLUSIONS

Tailings storage areas can cause a number of short and long term environmental problems if not well designed and managed. These problems will usually relate to contamination of surface and groundwaters, dam safety and stability, dust, visual impact, and long term management problems with reclamation and restoration of the area.

By adopting the principles of best practice environmental management during the planning, design and operational stages of a facility, and using effective environmental monitoring and auditing, relatively inexpensive tailings storage methods can be practised, while avoiding the many pitfalls that can lead to short and long term environmental problems.

More details on monitoring are available in a separate module *Environmental Monitoring and Performance*.

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The series illustration of the koalas by Christer Erikson was commissioned by BHP Transport in 1988. Reproduced courtesy of BHP Transport.

Front Cover Photo: Aerial photograph of Central Thickened Discharge tailing stack, Peak Gold Mine Cobar, New South Wales (see case Study 1).

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