

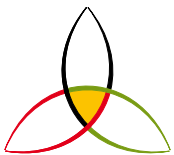
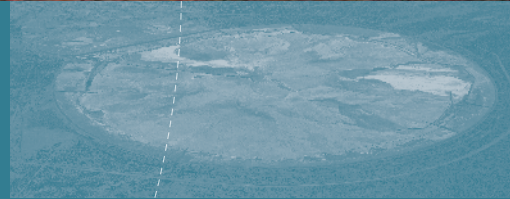
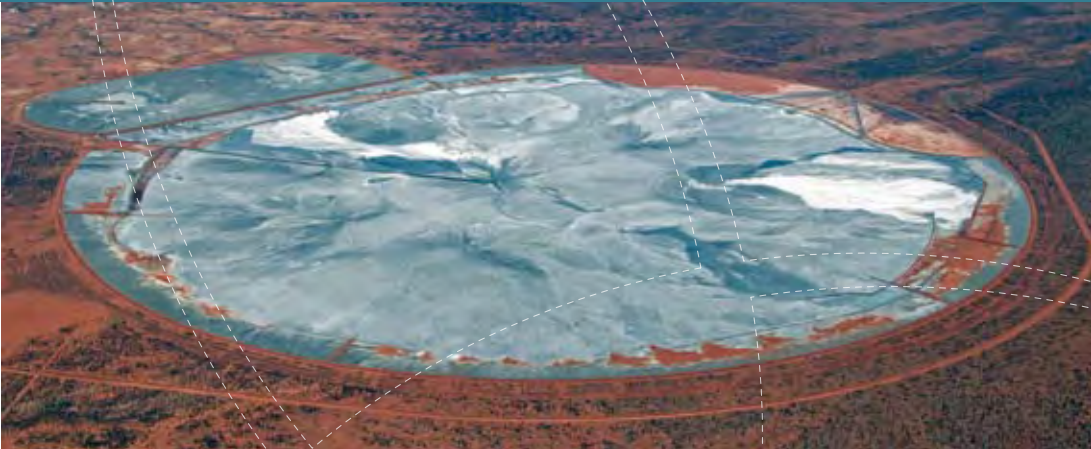


Australian Government

Department of Industry  
Tourism and Resources

# TAILINGS MANAGEMENT

LEADING PRACTICE SUSTAINABLE  
DEVELOPMENT PROGRAM FOR  
THE MINING INDUSTRY



SOCIAL  
ECONOMIC  
ENVIRONMENTAL



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LEADING PRACTICE SUSTAINABLE  
DEVELOPMENT PROGRAM FOR  
THE MINING INDUSTRY



FEBRUARY 2007

#### **Disclaimer**

Leading Practice Sustainable Development Program for the Mining Industry

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Cover image:

Aerial view of Mt Keith Nickel Operation's Tailings Storage Facility, Western Australia

Photo courtesy of BHP Billiton

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February 2007







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## FOREWORD

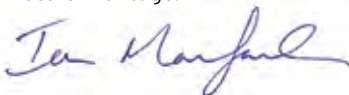
The Australian mining industry is well aligned to the global pursuit of sustainable development. A commitment to leading practice sustainable development is critical for a mining company to gain and maintain its 'social licence to operate' in the community.

The handbooks in the *Leading Practice Sustainable Development Program for the Mining Industry* series integrate environmental, economic and social aspects through all phases of mineral production from exploration through construction, operation and mine site closure. The concept of leading practice is simply the best way of doing things for a given site. As new challenges emerge and new solutions are developed, or better solutions are devised for existing issues, it is important that leading practice be flexible and innovative in developing solutions that match site-specific requirements. Although there are underpinning principles, leading practice is as much about approach and attitude as it is about a fixed set of practices or a particular technology. Leading practice also involves the concept of 'adaptive management', a process of constant review and 'learning by doing' through applying the best of scientific principles.

The International Council on Mining and Metals (ICMM) definition of sustainable development for the mining and metals sector means that investments should be: technically appropriate, environmentally sound, financially profitable, and socially responsible. Enduring Value, the Australian Minerals Industry Framework for Sustainable Development, provides guidance for operational level implementation of the ICMM Principles and elements by the Australian mining industry.

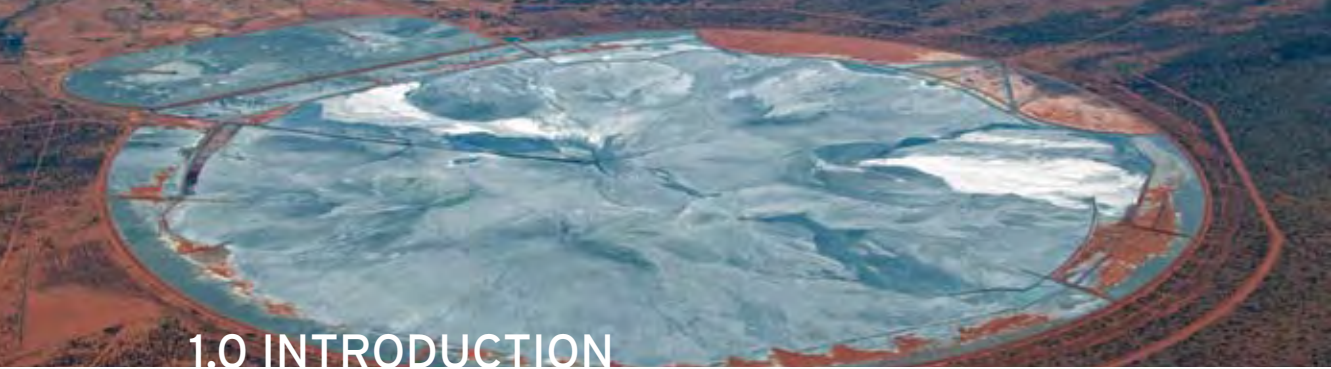
A range of organisations have been represented on the steering committee and working groups, indicative of the diversity of interest in mining industry leading practice. These organisations include the Department of Industry, Tourism and Resources, the Department of the Environment and Heritage, the Department of Industry and Resources (Western Australia), the Department of Natural Resources and Mines (Queensland), the Department of Primary Industries (Victoria), the Minerals Council of Australia, the Australian Centre for Minerals Extension and Research, and representatives from mining companies, the technical research sector, mining, social and environmental consultants, and non-government organisations. These groups worked together to collect and present information on a variety of topics that illustrate and explain leading practice sustainable development in Australia's mining industry.

The resulting publications are designed to assist all sectors of the mining industry to reduce the negative impacts of minerals production on the community and the environment by following the principles of leading practice sustainable development. They are an investment in the sustainability of a very important sector of our economy and the protection of our natural heritage.



**The Hon Ian Macfarlane MP**

**Minister for Industry, Tourism and Resources**



# 1.0 INTRODUCTION

## 1.1 Context

This handbook addresses the theme of Tailings Management in the Leading Practice Sustainable Development Program. The aims of the program are to identify the key issues affecting sustainable development in the mining industry and provide information and case studies that illustrate a more sustainable basis for mining operations.

There are a number of historical mine sites in Australia that carry a negative legacy of environmental and social impacts, and risks arising from tailings storage facilities (for example, Mt Lyell, Mt Morgan and Rum Jungle). The impacts relate to poor disposal practices, contaminated seepage and associated impacts to surface and ground waters, and the erosion of tailings and outer batters. These historical legacy sites do not reflect current leading practice tailings management as outlined in this handbook.

Tailings is a combination of the fine-grained (typically silt-sized, in the range from 0.001 to 0.6 mm) solid material remaining after the recoverable metals and minerals have been extracted from mined ore, and any remaining process water. The physical and chemical characteristics of the tailings vary with the nature of the ore. Tailings management is a mineral processing waste management issue.

Tailings may be stored in a variety of ways, depending on their physical and chemical nature, the site topography, climatic conditions, and the socio-economic context in which the mine operations and processing plant are located. Tailings are most commonly stored in surface facilities, which can represent up to half the area of disturbance at mining operations, and these are the main focus of the handbook. The basic requirement of a tailings storage facility is to provide safe, stable and economical storage of tailings presenting negligible public health and safety risks and acceptably low social and environmental impacts during operation and post-closure.

This handbook discusses a systematic, risk-based approach to tailings management. It provides examples of tailings containment, disposal and rehabilitation, and points to future trends in tailings management. It does not provide specific consideration of riverine, shallow submarine or deep submarine tailings placement methods. Such methods are not supported by the Australian regulatory environment or bathymetric conditions.

## 1.2 Audience

The primary audience for this handbook is onsite mine management, the pivotal level for implementing leading practice at mining operations. The handbook is also relevant to people with an interest in leading practice in the mining industry, including environmental officers, mining consultants, governments and regulators, non-government organisations, mine communities and students. All readers are encouraged to take up the challenge to continually improve the mining industry's performance in the area of tailings management by applying the principles outlined in this handbook.

## 1.3 Handbook structure

The scope of the handbook encompasses all phases of tailings management including planning, design, construction, operation, closure, rehabilitation and aftercare. It is important to cover all aspects of the life of a tailings storage facility, since operational mine management is responsible not only the operation of existing tailings storage facilities, but also for their extension and the development of new facilities where additional ore reserves are discovered.

Section 2 highlights the importance of applying a broad sustainable development framework to tailings management. Section 3 presents the need for a life-of-mine risk-based approach to tailings management, and briefly describes this approach. Section 4 provides an overview of the key elements of management systems that are applied throughout the life of a tailings storage facility to ensure operating and closure objectives are met. Section 5 presents aspects of leading practice tailings management relating to the design, operation and closure of the various physical components of a tailings storage facility. Section 6 discusses future directions for leading practice tailings management, and Section 7 presents a brief conclusion.



## 2.0 SUSTAINABLE DEVELOPMENT AND TAILINGS

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### KEY MESSAGES

- Enduring Value, encompassing sustainable development principles, underlies the social licence to operate.
- The failure or poor performance of a tailings storage facility can have a profound impact on the corporate bottom line.
- The main causes of reported tailings incidents are a lack of control of the water balance or construction, and a general lack of understanding of the features that control safe operations.
- Early and ongoing consultation, information sharing and dialogue with stakeholders is required.
- Compliance with government regulations establishes a minimum performance platform in relation to tailings management for the mining industry.

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To provide a framework for articulating and implementing the mining industry's commitment to sustainable development, the Minerals Council of Australia has developed *Enduring Value – the Australian Minerals Industry Framework for Sustainable Development* (Minerals Council of Australia 2004). Enduring Value supports the uptake of policies to ensure that current activities in the minerals sector do not compromise the ability of future generations to meet their own needs. It is specifically aimed at supporting companies to go beyond regulatory compliance and to enhance their social licence to operate. Enduring Value's risk-based continual improvement approach is reflected in this handbook.

#### **Enduring Value Principles for Tailings Management:**

- implement an environmental management system focused on continual improvement to review, prevent, mitigate or ameliorate adverse environmental impacts
- provide for the safe storage and disposal of residual wastes and process residues
- rehabilitate land disturbed or occupied by operations in accordance with appropriate post-mining land uses
- consult with interested and affected parties in the identification, assessment and management of all significant economic, public health and safety, social, and environmental risks associated with our activities
- inform potentially affected parties of significant risks from mining, minerals and metals operations and of the measures that will be taken to manage the potential risks effectively.

## 2.1 Business drivers

The business case for applying leading practice in tailings management is compelling. The failure or poor performance of a tailings storage facility can have a profound impact on the corporate bottom line. In extreme cases, tailings storage facility failures have severely eroded share value as the market anticipates the cost of cleanup, suspension of operations and possibly mine closure. This is in addition to the loss of company reputation and the loss of a social licence to operate. The cost of leading practice tailings management systems is more than offset by the reduced risk of a major incident.

Conventional economic analysis can lead to minimising initial capital expenditure and deferring rehabilitation costs. Net present value analysis discounts the current cost of future expenditures on closure, rehabilitation and post-closure management. Therefore, if this short-term economic perspective is taken, without taking into account the longer-term social and environmental costs, there is little motivation to invest more substantially at the development stage to avoid or reduce expenditures at the closure stage. There is a number of reasons, however, for applying leading practice at the earliest stage of development, and in designing and operating the tailings storage facility to optimise closure outcomes. Designing and operating for closure can avoid significant earthworks expenditures to re-establish stable landforms and drainage systems. Progressive rehabilitation, where possible during operations, enables rehabilitation work to proceed while there is an operational cash flow, and management and resources available. Progressive rehabilitation can also reduce the cost of financial assurance required by regulatory agencies. Leading practice tailings management will also minimise the time required for post-closure monitoring and maintenance.

### CASE STUDY: Business approaches

#### **Minimum effort and minimum initial capital cost approach**

The tailings storage facility may be undersized to handle an increased mine throughput, resulting in an under-consolidated, low-density, low-strength tailings deposit. A larger storage volume will ultimately be required for the tailings. The tailings will continue to consolidate for a long period of time after closure, resulting in the possible need for groundwater recovery wells to capture contaminated seepage for a lengthy time after closure. Access to the tailings surface for rehabilitation purposes will be delayed until the tailings gain sufficient strength for trafficking, and ongoing settlement will delay the placement of cover systems. Major earthworks may be required to control surface runoff. As a result, the mining company will be regarded with suspicion by regulators and other stakeholders and its reputation will be affected.

### **Leading practice approach**

Consideration of the final landform will dictate the siting, layout and tailings deposition strategy. At closure, the tailings storage facility would be shaped for natural surface drainage and erosion rates similar to those of natural landforms in the area. Leading tailings management practices using thickened or paste tailings, good water management and adequate under-drainage and liners, where appropriate, would result in fully-consolidated tailings. This would allow access to the surface for rehabilitation purposes with the minimum delay. Adequate operational control over seepage would remove the need for long-term groundwater collection. The tailings storage facility would be a showcase for responsible tailings management, building credibility for the mine owners with stakeholders, a reputation for sustainable mining practices, and assisting future proposed mining developments.

## **2.1.1 Lessons learnt**

The international mining industry has learnt many lessons over the last decade that have helped to develop leading practice tailings management in Australia. The International Commission on Large Dams (ICOLD) Bulletin 121 (2001) provided a comprehensive report of these lessons, drawing from a range of tailings storage facility failures and incidents.

The main causes of failures and incidents identified were:

- lack of control of the water balance
- lack of control of construction
- a general lack of understanding of the features that control safe operations.

Tailings containment wall failures were (in order of prevalence):

- slope instability
- earthquake loading
- overtopping
- inadequate foundations
- seepage.

Tailings incidents appeared to be more common where upstream construction was employed, compared with downstream construction (see Section 5.3). Tailings containment walls constructed using the downstream method performed similarly to water-retaining embankments.

ICOLD Bulletin 121 (2001) also concluded that successful planning and management of tailings storage facilities could benefit greatly from:

- the involvement of stakeholders
- thorough investigations and risk assessments
- comprehensive documentation
- tailings management integrated into mine planning, operations and closure.

The lessons learnt are reflected in the leading tailings management practice described in this handbook.

## 2.2 Community values

A key challenge for mining companies is to earn the trust of the communities in which they operate and to gain the support and approval of stakeholders to carry out the business of mining. A 'social licence to operate' can only be earned and preserved if mining projects are planned, implemented and operated incorporating meaningful consultation with stakeholders, in particular with the host communities. The decision-making process, including the technical design process, should involve relevant interest groups, from the initial stages of project conceptualisation right through the mine's life.

Stakeholder consultation, information sharing and dialogue should occur throughout the tailings facility design and operating stages, so viewpoints, concerns and expectations can be considered for all aspects of planning and execution. Regular, meaningful engagement between the company and affected communities is particularly important for developing trust and preventing conflict.

The 'precautionary principle' should be drawn on when considering the impacts of mine operations, including tailings storage facilities. The principle states that where there is a clearly identified threat of serious or irreversible harm to people or the environment, the lack of full scientific certainty should not be used as a reason for postponing measures to prevent harm to people or environmental degradation. A proactive approach to risk mitigation should be taken where there is significant uncertainty in relation to the consequence or likelihood of risk scenarios.

Principles and leading practices for stakeholder engagement are addressed in the Leading Practice *Community Engagement and Development* and *Working with Indigenous Communities* handbooks in this series.

## 2.3 Regulatory context

The primary responsibility for tailings and tailings storage facilities regulation in Australia rests with state and territory Governments. While the regulatory requirements vary between jurisdictions, common principles apply. In all jurisdictions:

- responsibility for tailings deposition and management (including rehabilitation and closure) regulation rests with the mining department or environmental protection agency
- responsibility for pollution control and tailings storage facility water discharge regulation rests with the environmental protection agency
- the focus of the regulation is on ensuring that tailings management methods, including tailings storage facilities, are safe, stable and non-polluting.

In some states the regulation of tailings storage facility design, construction and ongoing management may be covered by specific legislation. In New South Wales, for example, the Dams Safety Committee oversees tailings containment regulation under the *Dams Safety Act, 1978*. Different jurisdictions may also issue their own tailings management guidelines (see References and Web sites and links).

Where tailings management actions are likely to have a significant impact on a matter of National Environmental Significance, they are subject to a rigorous assessment and approval process under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Matters covered by the EPBC Act include national heritage, threatened species and wetlands of international importance.

Compliance with government regulations establishes a minimum performance platform for the mining industry in relation to tailings management.





## 3.0 LIFE-OF-MINE RISK-BASED APPROACH

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### KEY MESSAGES

- Tailings storage facilities must be designed, operated, closed and rehabilitated to ensure negligible operator and public health and safety risks, and acceptably low community and environmental impacts.
- A risk-based design approach provides a framework for managing the uncertainty and change associated with tailings storage facilities.
- The risk-based approach applied to tailings management must have sufficient flexibility to allow changing circumstances to be managed.
- Alternative tailings management, storage and closure strategies can usually be accurately costed, for incorporation into a cost-effectiveness analysis to reduce identified risks.

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The principles of leading practice tailings management are underpinned by a risk-based approach to planning, design, construction, operation, closure and rehabilitation of tailings storage facilities. In taking this approach, plans need to be tailored to manage a tailings storage facility effectively over its full life, with sufficient detail to manage the potential risks within acceptable limits.

A low height (10 m) earth-fill containment wall in a dry, semi-desert climate (250 mm average annual rainfall), for example, is not likely to require the same level of detailed planning and design as a 100 m high valley containment wall in a high rainfall environment (> 3 m/year). Tailings storage facilities with higher risk ratings will require more rigour at the design phase, greater quality control during construction, and closer attention to risk management, emergency action planning systems, and documentation during the operation phase.

### 3.1 Concept of acceptably low risk

Tailings storage facilities must meet operator and public health and safety, community, and environmental protection objectives. These objectives can only be met if tailings storage facilities are designed, operated, closed and rehabilitated to a level of risk that is acceptable to stakeholders for the full operating life of the facility and beyond.

A systematic approach to effective tailings management is therefore advocated. Management strategies need to be risk-based and account for the viewpoints and expectations of the communities in which companies operate. The principal tailings-related risks to people and the environment can be characterised for the operational and closure phases.

### 3.1.1 Operational risks

The principal objective of a tailings storage facility is for tailings solids and any stored water to remain contained. Failure modes and risks to public health and safety, the community, and the environment during operation of a tailings storage facility could include:

- rupture of the tailings slurry delivery pipeline or decant water return pipeline
- rainfall-induced erosion or piping of the outer tailings face (image 1)
- geotechnical failure or excessive deformation of the containment wall (image 2)
- overfilling of the tailings storage facility with tailings, leading to overtopping of the containment wall by water
- seepage through the containment wall, potentially leading to tree deaths (image 3)
- contaminated seepage into the foundation impacting on the groundwater
- particulate (dust) or gaseous emissions (for example, radon, hydrogen cyanide – see Environment Australia (1998) and proposed *Cyanide Handbook* in this series, sulfur dioxide and hydrogen sulfide) (image 4)
- exposure of birds, wildlife or livestock to potentially contaminated decant water that ponds on the surface of the tailings storage facility
- exposure of wildlife or livestock to soft tailings in which they may become trapped.



### 3.1.2 Closure risks

Failure modes and risks after closure of a tailings storage facility could include most of the operational failure modes and risks, apart from failure of the tailings delivery or return water pipelines. Additional post-closure failure modes and risks could include:

- rainfall-induced erosion of the outer face of the containment wall, which may expose and mobilise tailings (see image)
- failure of the spillway, (if provided)
- overtopping by rainfall runoff, causing erosion of the containment wall
- failure of the cover system placed over the tailings surface.



## 3.2 Design approaches

The traditional design approach is based on a 'design life' for the facility, together with a design 'factor of safety'. While the design life of a tailings storage facility can be reasonably well defined, its design life after closure is more contentious, with the implications that this is in perpetuity. The use of a design factor of safety implies that providing this is achieved, uncertainties can be ignored. The high level of uncertainty that is often associated with tailings storage facilities requires a high factor of safety to ensure an acceptably low probability of failure. This approach can lead to an inefficient design.

A risk-based design approach provides a framework for managing the uncertainty and change associated with tailings storage facilities and has a number of benefits (Williams 1997), including:

- improved quantification of the magnitude and costs of exposure to hazard
- provision of a defensible argument for the adoption of the optimum strategies
- identification and elimination of low risk hazards
- highlighted significant risks that need to be reduced by appropriate treatment measures
- facilitation of cost-effective solutions that achieve an acceptably low risk.

## 3.3 Risk analysis methods

There are many definitions of risk. *Best Practice Environmental Management in Mining (1999)* defines hazard as a potential cause of harm, describes risk as having two dimensions – likelihood and consequence, and defines risk as the likelihood of actual harm.

Risk analysis allows quantification of the options, and of the likelihood, consequences and costs of failure. The 'risk rating is obtained by the product of the likelihood and the consequence.

AS/NZS 4360:2004 recommends the following risk assessment process:

- establish the context – geographically, socially and environmentally, and decide on the design criteria
- identify the hazards – what can happen, where and when, and how and why
- analyse the risks – identify existing controls, determine the likelihoods and consequences, and hence the level of risk
- evaluate the risks – compare them against the design criteria, carry out sensitivity analyses to highlight both the key and unimportant risks, set priorities, and decide whether the risks need to be addressed
- address the selected risks – identify and assess options, prepare and implement treatment plans, and analyse and evaluate the residual risk.

Overarching this process is the need to communicate and consult with stakeholders, and to monitor and review.

A variety of risk analysis methods is used by different mining companies, depending on the scale of the mining development and company approaches adopted. The main types of risk analysis methods are:

- qualitative risk charts – including hazard identification, its likelihood, its consequence, the risk ranking, and remedial action
- semi-quantitative and quantitative methods – lending themselves to well-defined and quantifiable hazards
- computer analysis – requiring large amounts of data that need to be collected for design of major industrial facilities.

The quantitative method relies on assigning numerical values to likelihoods and consequences. The most commonly used quantitative method is the probabilistically-based fault/event tree method, which is set up as a series of connected boxes, typically in a spreadsheet. In applying the method, the key event or outcome must first be identified, such as failure of the tailings storage facility. This forms the top of the event tree. The causes or failure modes that might lead to this key event are then identified. These form the tops of the branches of the fault tree. Each of these causes has a variety of contributing sub-causes, some of which contribute to more than one cause.

### 3.4 Managing change

The risk-based approach applied to tailings management must have sufficient flexibility to allow changing circumstances to be managed. These changes could involve routine and anticipated tailings storage facility raisings, unforeseen expansions, or bringing on-line completely new facilities and/or new disposal methodologies. Managing such change should be a core consideration in the planning, design, construction, closure and rehabilitation of tailings storage facilities.

Changing circumstances and possible responses include:

- increases in processing plant throughput and/or the mine life – requiring raising and/or expansion of existing tailings storage facilities, and/or the construction of new facilities. Increased tailings production rates will require the permitting and construction of storage facilities to be brought forward
- changes in the nature of the ore and/or a lowered cut-off grade – possibly requiring a finer grind, increasing the tailings storage requirement and resulting in a wetter, softer tailings deposit. Loss of a fines processing circuit will have a similar effect
- the depletion of water resources – possibly requiring greater thickening of the tailings prior to disposal to recover more water for reuse
- changing regulatory requirements and community expectations – subject to change over time
- premature closure resulting in an incompletely utilised facility with tailings spread to a relatively thin depth over a large footprint – deposit tailings into a smaller footprint to reduce the area to be managed and rehabilitated.

### 3.5 Cost-effectiveness

Alternative tailings management, storage and closure strategies can usually be accurately costed, for incorporation into a cost-effectiveness analysis. Such an analysis allows the costs of different strategies to be compared and to be weighed against the extent to which they lower the overall risk (including the geochemical risk) of the selected tailings management, storage and closure strategies.

The highly technical approach to risk analysis and design, combined with uncertainties and the subjective nature of some factors, such as aesthetic values and loss of amenity, results in such an analysis meaning very different things to different people. Stakeholder consultation is used to help decision-makers understand different perspectives, expectations and concerns. These viewpoints can be considered in the generation of options, analysis and decision-making.

The attractiveness of reducing the costs of tailings management in the short-term must be carefully weighed against the possibility of increasing environmental and social costs at closure and beyond. This requires a robust and flexible risk-assessment model and associated cost-effectiveness analysis to aid the decision-making process throughout the mine life cycle. Public health and safety risks and broad social and environmental impacts need to be considered, including situations where contaminants could be released to the environment over the long-term.



## 4.0 TAILINGS MANAGEMENT SYSTEMS

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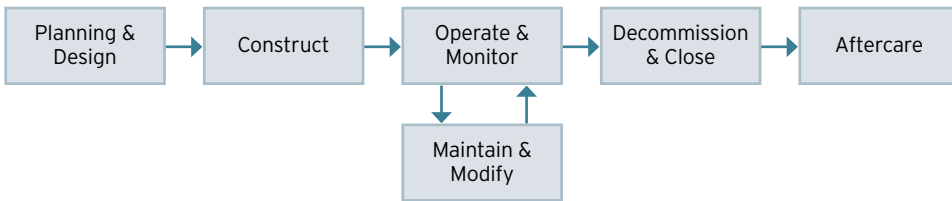
### KEY MESSAGES

- Tailings storage facilities should be designed, operated, closed and rehabilitated to ensure performance that meets or exceeds the criteria agreed to through consultation with key stakeholders.
  - Each stage in the life of a tailings storage facility, from concept design to rehabilitation and aftercare, needs to be fully considered and documented in a series of reports within a tailings management plan, which is a 'living' document.
  - The scale of the tailings management plan should match the scale of the project.
  - Early and ongoing consultation, information sharing and dialogue with stakeholders is an integral part in the ongoing development of the tailings management plan.
- 

Leading practice tailings management requires that a tailings storage facility is designed, operated, closed and rehabilitated to ensure performance that meets or exceeds the criteria agreed to through consultation with key stakeholders. A number of very good guidelines is available that describe the elements of tailings management systems (see References and Web sites and links). These guidelines provide a sound foundation for the development of customised tailings management systems. They include a framework of management principles and policies, and checklists for implementing the framework through a tailings storage facility's life cycle. The key elements and approaches of a leading practice tailings management system from planning to closure are outlined in this section, with acknowledgement to the *BHP Billiton Tailings Management Guideline (BHP Billiton 2006)*, on which the section is largely based. This guideline reflects leading practice tailings management systems used across the mining industry.

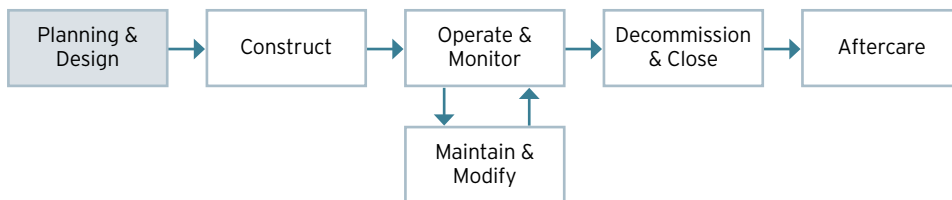
This section describes the key elements of tailings management systems, while Section 5 describes leading practice tailings management under these systems.

## 4.1 Life of a tailings storage facility



The fundamental principle underlying responsible and effective tailings management is to design and operate to achieve effective closure (refer to the *Mine Closure and Completion Handbook* in this series). This is an important objective because it addresses the longer-term liability aspects of tailings storage facilities. If these aspects are not adequately considered early, they can add significant ongoing clean-up and maintenance costs to a project after revenue from mineral production has ceased.

## 4.2 Planning and design



Leading practice requires alignment between the tailings storage facility planning and the mine plan. Tailings storage facility planning must also be reviewed in response to any changes to the mine plan, and revised, if necessary. This will ensure that any staging or sequential raising requirements are adequately financed and scheduled, and that operation and management activities strive to achieve closure objectives throughout the project life.

Consideration should be given to:

- integration with the mine plan and schedule in developing the tailings disposal methodology. For example, utilising or stockpiling topsoil and waste rock for construction of containment wall raises and/or caps and covers
- location of the tailings storage facility to avoid sterilising mineral resources or contaminating water resources
- availability of suitable embankment construction materials and surface capping materials
- geochemical characterisation of tailings to assess their potential for acidic and metalliferous drainage during operation and after closure (refer to the *Managing*

*Acidic and Metalliferous Drainage Handbook* in this series). The selection of tailings placement method and the type of embankment construction can both be influenced by the level of geochemical risk. Samples for characterisation can be obtained from the metallurgical testwork typically carried out as part of the economic pre-feasibility phase of a new mining project

- change management – increases in processing plant throughput impact storage requirements for tailings and water. The rate of rise of the tailings surface can also have implications for tailings strength and stability
- reprocessing of tailings – some tailings may contain valuable minerals and therefore a management objective may be to provide interim storage until economic recovery becomes feasible. However, this should not be used as a justification for leaving tailings in a geochemically unstable or reactive state for prolonged periods of time.

#### **Components of a tailings management plan:**

- life-of-mine tailings storage facility plan – how and where tailings will be stored over the life of the operation, the estimated budget (and schedule), and how construction will be staged (stage schedule, see Section 4.2.1)
- design criteria – production, geotechnical, geochemical, operational and closure public health and safety, community and environmental performance objectives that the tailings storage facility is expected to achieve, at each stage in the mine life (see Section 4.2.2)
- design report(s) – detailed designs for each structure or stage of the tailings storage facility, including drawings, to achieve the specified design criteria. This will include geotechnical and other investigations carried out in support of the design (see Section 4.2.3)
- construction report(s) – a detailed report on the construction of the tailings storage facility as measured against the drawings and construction quality plans. This should contain as-constructed drawings and photographs which assist in the identification of risks going forward, and in the back-analysis of issues arising (see Section 4.3)
- operating manual – operating principles, methodology and associated resources and training (see Section 4.4)
  - safety (or risk) management plan – surveillance and monitoring plans including inspections, monitoring, water balance and performance reviews (see Section 4.4.1)
  - emergency action and response plan – the steps to be taken in case of an emergency to minimise public health and safety, community, and environment related risks, and impacts if an incident occurred (see Section 4.4.2)
- closure plan – the closure strategy that forms the ultimate objective of the tailings management plan (see Section 4.5).



The operating plan, safety management plan and emergency action and response plan are likely to be substantial and detailed for a high-risk tailings storage facility, but brief (a single document incorporating all aspects) for a simple, low-risk facility.

#### 4.2.1 Life-of-mine plan

A life-of-mine tailings storage facility plan is necessary to ensure operational and public health and safety, community, and environmental objectives are met over the entire life of the operation. This would normally involve major updates on about a five-yearly basis, with annual reviews. The criteria for this plan are derived from the life-of-mine plan.

Where a tailings storage facility is developed in stages to satisfy production requirements, a detailed schedule needs to be prepared that includes:

- timing of the start-up of new stages or modifications
- schedule required for designs, investigations and approvals
- estimated costs annually and for each stage.

Such planning will ensure an adequate budget for the work, that the investigations and design are performed in time, and that there is adequate time for construction (including a contingency for weather and other factors) to complete and commission the new stage or modification.

#### Background and baseline conditions

Commencing at the pre-feasibility or environmental impact assessment stage, it is important to continuously measure the nature, quality, level or quantity of any environmental feature that may be impacted by the presence of a tailings storage facility prior to it being constructed. Background conditions that need to be defined will normally include:

- groundwater levels and quality
- water content and geochemistry of foundation soils and rocks
- air quality
- fauna and flora population and density
- natural and background radiation levels where radioactive materials are to be stored.

It is important to identify the background data required through a public health and safety, community, and environmental risk assessment well before the commencement of operation.

In addition, baseline tailings parameters need to be defined, including:

- tailings or ore geochemistry
- tailings liquor, stored water, or leachate water quality.

These background and baseline conditions are important – it is the difference between the background and the tailings and water parameters that assist in defining the lead indicators to be used to detect contaminants that could impact on soils or groundwater resources. This process is also required to enable the regulator to draft applicable operating licence conditions for the facility.

Should the tailings parameters change during the tailings storage facility's operating life, the changes should be noted alongside the original data, noting the date that the change occurred. These changes may result in modifications to the design and the management plan.

### **Community values**

Community values such as health, aesthetics and the environment must be included throughout the decision-making process of a tailings storage facility from planning to closure. This will involve meaningful, ongoing, regular consultation with the relevant interest groups, including information-sharing and dialogue with stakeholders (see Section 2.2).

### **Risk assessment**

Tailings storage facilities require a formal risk assessment to identify and quantify the risks that need to be managed. Tailings storage facilities are normally rated high, significant or low-risk facilities, in accordance with a set of ranking criteria. The risk rating is used to determine the design, construction, risk management, inspections and reporting requirements.

The higher the risk rating, the more stringent the design, construction supervision, risk management, and emergency action and response planning requirements. High-risk tailings storage facilities are often auditable by government regulatory agencies.

Suitable methods for ranking a tailings storage facility's risk are contained in the Australian National Committee on Large Dams (ANCOLD) *Guidelines for Tailings Dam Design, Construction and Operation*, and the state and territory guidelines for the design of tailings storage facilities (see References and Web sites and links).

#### **Identification and Evaluation of Options – Conceptual Stage**

Options for tailings management are all too often predetermined due to:

- engineers relying on their previous experiences – disregarding new technologies and the particulars of the project
- advice being sought from a limited number of internal and external experts.

The most important step in developing a conceptual tailings management system for a project is to assemble a multi-disciplinary team capable of assessing the life-of-mine implications of the site's tailings management. The project team should follow the steps:

### 1. Define operating parameters

The conceptual study must be based upon data. These data should include the life-of-mine plan; site topography; hydrological catchment areas; historical rainfall and evaporation data; the projected volume and rate of production of tailings, and their physical, chemical and rheological characteristics; the availability, quality and price of water; the geotechnical parameters of available construction materials and the foundation; and seismic data.

The project team also needs to:

- collate all previous tailings studies
- identify and quantify the key performance drivers. For example, fresh water demand, minimising acid and metalliferous drainage or salinity generation, or reducing the noise and visual impact experienced by a nearby community
- identify all regulatory requirements and laws governing the design, operation and closure of a tailings facility in the project jurisdiction
- identify community concerns.

### 2. Identify all possible tailings storage sites

Possible tailings storage sites may include green field sites, existing tailings storage facilities, current and future mine voids, and waste rock storage areas. When reviewing the tailings storage options, the project team should consider:

- options to maximise water recovery and tailings consolidation
- tailings discharge rotation between multiple storage cells to reduce the rate of rise and maximise the consolidated density
- orebody sterilisation
- potential acid and metalliferous drainage or salinity, and visual, noise and dust issues
- the impact of a tailings containment or pipeline failure
- site rehabilitation.

This step will produce a risk assessment, a storage capacity versus time graph to assess whether the possible storage volumes are adequate, a minimum tailings density specification, and a short-list of recommended tailings storage sites.

### 3. Carry out a site water balance

While mines on Australia's east coast are currently experiencing water storages, other sites in Australia need to deal with excess water issues. A site water balance is required to evaluate the impact of different tailings disposal and storage options as a function of various water supply and rainfall scenarios.

This step will recommend a conceptual tailings storage facility design and provide a risk assessment of the various tailings dewatering and storage options.

#### 4. Dewatering options

There is a range of mechanical and in situ tailings dewatering options that can be applied at a particular tailings operation. These include conventional, high rate and paste thickeners, vacuum and pressure filters, centrifuges and cyclones. There is no single rule-of-thumb for selecting the appropriate tailings dewatering method. At the conceptual stage it is recommended that the team reviews:

- current and future tailings requirements. After several years of mining, for example, voids may become available for tailings storage which would require a different dewatering method to that used in a constructed tailings facility. More than one tailings dewatering method, therefore, may be required over the life-of-mine and its location may need to be a compromise
- technologies employed at similar mining options
- new technologies
- novel technologies.

The various dewatering options can be initially screened using the site water balance and tailings density targets established in the previous steps. Typical dewatering equipment performance data can be collated from other operating sites, expert advice from equipment vendors, and/or bench top laboratory tests.

This step will produce a risk assessment of the various dewatering options and a recommended short list that meets the water and tailings density design specifications.

#### 5. Net present cost and value assessment

The various tailings dewatering and storage options can now be ranked from a financial viewpoint by calculating the net present cost and value. At this stage, costs associated with the location of the dewatering equipment and storage site, tailings transportation options (that is pumping, hauling and conveying) and price-sensitivity of consumables (that is reagents and water) can be assessed.

#### 6. Final assessment

Combining all of the above steps, the conceptual project team can rank the options and recommend the optimal tailings dewatering, transportation and storage options. The conceptual project team's recommendations will also provide guidance in the selection of appropriate external vendors and consultants for more detailed studies.

It should be remembered that this assessment may be strongly influenced by non-numerical parameters such as community concerns. The conceptual project team therefore must engage the community and carefully document and communicate their findings to the mining company and to the community.

## 4.2.2 Design criteria

It is important for the key design criteria for the tailings storage facility to be defined by the mine project team, and provided to the facility designer.

Key design criteria include:

- minimum, maximum and average tailings production rates at which the delivery system will operate (m<sup>3</sup>/hour)
- geochemical characteristics which may influence the selection of the most appropriate design for operation and closure
- range of solids concentrations and the average solids concentration (as a percentage by mass) over which the production rates are applicable
- annual and life-of-operation tailings tonnages for which the tailings storage facility must be designed
- the rated maximum capacity of the return water system (m<sup>3</sup>/hour)
- the range of rheological characteristics of the tailings slurry
- public health and safety, community, and environmental compliance targets, as defined in consultation with stakeholders, including seepage, ground water quality, decommissioning, rehabilitation and closure requirements, air quality and radio-activity compliance levels
- operating and maintenance requirements, for example, unmanned, low maintenance.

## 4.2.3 Design report

Tailings storage facilities and associated components must be designed by suitably competent and experienced persons.

The design report describes the basis of the design, including all design parameters, and the key performance criteria. It is critically important to determining the safety controls, operating procedures and maintenance programs that are necessary to ensure the safe operation of the tailings storage facility. The design report provides easy and quick reference when evaluating a proposal to modify the operation or design. It also provides details in the event of an emergency. A comprehensive design report contains:

- minimum design standards
- background and baseline conditions (see Section 4.2.1)
- community values (see Sections 2.2 and 4.2.1)
- risk assessment of the tailings storage facility and associated design requirements (see Section 4.2.1)
- geotechnical and geochemical investigations, seepage analyses, containment wall design, and liner and under-drainage system design, if required
- tailings storage facility water balance, tailings pump and pipeline system design, and decant and return water system design.

The design report should fully describe the design standard, process and methodology adopted. For tailings storage facilities designed for Australian mine sites, minimum design standards are prescribed by state and territory regulators and proponents should familiarise themselves with these requirements from the outset. The *ANCOLD Guidelines on Tailings Dam Design, Construction and Operation* (ANCOLD 1999), supported by applicable ICOLD design guides and standards (see References and Web sites and links), also provide authoritative advice and should be used as appropriate.

### **Geotechnical and geochemical investigations**

Geotechnical and associated investigations, tailored to the complexity of the project and the risk rating of the tailings storage facility, are required to provide information for detailed design and project decision-making. The design report should contain all investigations conducted during the design of the tailings storage facility, comprising (but not limited to):

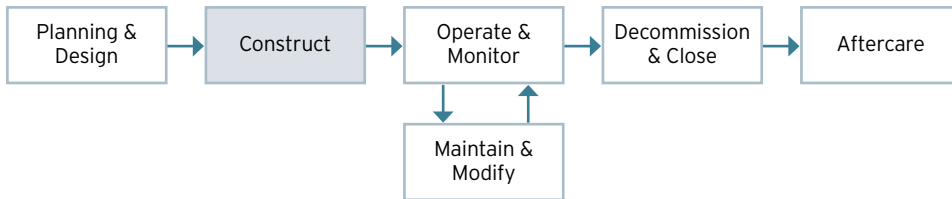
- geotechnical investigation – for each proposed structure and its critical components
- seismic assessment of the site
- physical and chemical characteristics and engineering parameters of the tailings – in particular, the potential for acid and metalliferous drainage, salinity and other contaminants to be generated by the tailings (refer to the *Management of Acidic and Metalliferous Drainage Handbook* in this series)
- hydrogeological investigation – conceptual groundwater model including background water quality within the projected zone-of-influence of the tailings storage facility.

### **Water management planning**

Water management is a key design consideration and will have a major influence on the design, operation and closure of a tailings storage facility. The design report should include:

- hydrology data – including the site catchment area, identification of all water sources and derivation of design rainfall and flood events
- tailings water balance modelling – involving freeboard selection, the estimation of losses, and managing water deficit or surplus
- tailings delivery system design – including pump and pipeline selection and sizing
- return water system design, including decant, pump and pipeline selection and sizing
- consideration of water quality issues, leading to a plan to control contaminant release.

### 4.3 Construction



It is important that the construction report maintains an accurate record of the construction works in order to:

- ensure the tailings storage facility was constructed by a competent contractor, with an appropriate level of supervision and quality control of construction materials, and techniques to show they were in accordance with the design drawings and specifications
- provide a detailed record and description of geo-technically critical aspects such as the preparation of foundations, treatment of cracks in key and cut-off trenches, or the compaction of backfill around outlet works. This record assists in the design and construction of remedial works if any post-construction issues occur
- provide as-constructed drawings that:
  - provide an accurate representation of the detailed construction works
  - particularly where design changes may have occurred during construction
  - assist in improved designs for further stages
  - provide details and dimensions for remedial works so that these do not impact the integrity of existing structures
  - provide details for back-analyses should these be required.

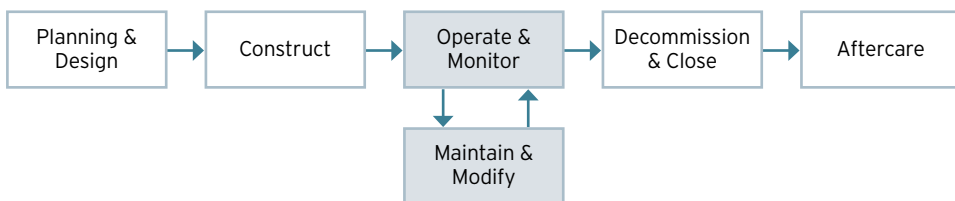


**Tailings storage facility downstream containment wall in a dry climatic setting**



**Tailings storage facility downstream containment wall in a wet climatic setting**

## 4.4 Operation



Leading practice tailings management will demonstrate clear operational accountability at a senior mine management level, with a thorough understanding of the design, operating and closure objectives. The implications of not operating in accordance with the design intent and design criteria must be clearly understood.

A tailings operating manual is required for each tailings storage facility. This manual must be aligned with the design objectives of the facility. Its intention is to guide and assist the tailings storage facility operators with the daily operation, as well as with forward planning of the facility's operation and maintenance. Using suitable reference drawings and sketches to illustrate important operating features, principles and limitations, the operating manual should describe, and the operators should receive training in:

- the principles of good tailings deposition and beach development – thin layers with maximum drying to maximise strength and minimise seepage
- the correct management of the decant pond and efficient water recovery to maximise stability





- examples of poor tailings management practices, and their negative impacts
- the facility's daily operation and the frequency and correct method of changeovers
- operational procedures which require specific precautionary measures, such as the correct order of valve opening/closing to avoid blockage of tailings pipelines
- the procedures for changing and flushing tailings pipelines
- key lead indicators used to monitor the facility's successful operation, and each operator's role and responsibilities in support of the tailings management plan
- scheduled and preventative maintenance to keep critical equipment operational
- the importance of recording and storing monitoring and performance data
- the need to report any exceptional, untoward or unexpected observation to a supervisor, and to follow through with emergency and risk management actions.

#### 4.4.1 Safety management

Many regulatory authorities require a safety management plan for high or significant risk tailings storage facilities (refer to, for example, the *Queensland Dam Safety Management Guidelines 2002*).

The tailings storage facility safety management plan relates to the:

- risks identified for the facility
- public health and safety, community, and environmental risks and necessary controls to ensure the integrity of the operation
- surveillance and maintenance program to ensure the ongoing integrity of the various structural components.

#### Monitoring

Monitoring of tailings storage facilities should include:

- the installation of piezometers to monitor groundwater mounding beneath and surrounding the facility
- surface and groundwater quality sampling both upstream and downstream of the facility
- the trialling and monitoring of closure strategies, including slope treatments and covers.

Monitoring reports should be prepared annually and reporting should be accessible, easily understood and transparent to stakeholders.

#### Regular inspections

All tailings storage facilities and associated pumping and pipeline systems should be inspected on a daily basis at a minimum. Observations should be recorded. Any extraordinary observations or maintenance requirements must be documented and appropriate action taken, including reporting to regulators and the community. The inspections should include:

- position of the decant pond and observations relating to freeboard requirements (water levels with respect to dam crest levels)

- visual and operating checks of lead indicators, such as damp, seepage and erosion
- status of leak detection systems
- status of secondary containment systems
- status of automatic flow measurement and fault alarms
- condition of pump and pipeline systems
- assessment of impacts to birds, wildlife or livestock, particularly birds that may be affected by tailings water consumption.

## **Performance reviews**

The performance of the tailings storage facility should be reviewed annually by a geotechnical engineer experienced in tailings management. The review should critically assess the actual performance against the design and make recommendations for improvements and risk mitigation actions. Such reviews are mandated by some regulatory authorities. The review should consider:

- stage construction performance against design – crest and beach levels, tailings tonnage stored and volume occupied
- confirmation of assumptions used in design – the assessment of stability under normal and seismic loading and design meteorological events, in situ tailings parameters (density, strength and permeability) and position of phreatic surface
- performance of seepage control measures such as under-drains (for seepage control), or internal filters (which control internal erosion or piping)
- liner condition, where used
- performance of surveillance and monitoring system – the status and condition of the monitoring systems, their performance in detecting changes in lead indicators (environmental and/or structural), and the analysis and evaluation of monitoring data against predicted trends
- groundwater monitoring results – comparison of the groundwater levels and quality against the ‘baseline’ data and against design and closure criteria, considering:
  - near-surface lateral seepage which may stress vegetation or destabilise a containment wall
  - vertical seepage which may cause localised mounding beneath the storage
- operational performance – tailings deposition practices (thin layer) and surface water control (minimum stored water and maintenance of required freeboard)
- assessment of operational incidents, and recommendations for improvements or modifications to rectify and to carry lessons learned into future design and operation.

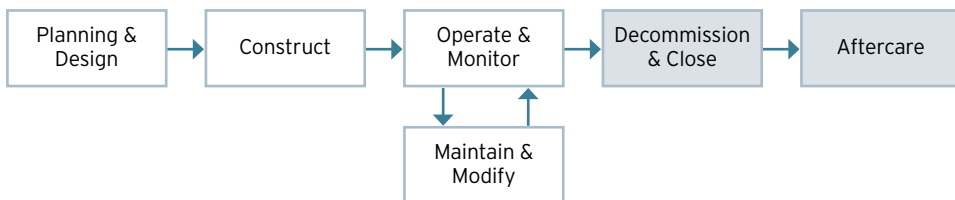
#### 4.4.2 Emergency preparedness

All tailings storage facilities should have an emergency action plan. This will ensure that in the unlikely event of a failure, appropriate actions can be taken to minimise the safety risk to people on and off the site, and to minimise the impacts by responding to the incident in an organised and systematic manner (UNEP 2001).

The emergency action plan:

- identifies conditions that could result in an emergency situation, such as severe storms
- describes procedures to isolate people from hazards, including the warning and evacuation of downstream communities
- identifies response plans to mitigate impacts, such as clean-up plans
- identifies the resources required to implement the emergency action and response plans
- identifies emergency response training requirements for key people
- documents the location of emergency warning alarms and their maintenance requirements to ensure serviceability at all times.

#### 4.5 Closure planning



The closure of the tailings storage facility should be carefully considered as part of the mine closure plan, to ensure that appropriate public health and safety, community, and environmental criteria can be established for the design (refer to the *Mine Closure and Completion*, *Mine Rehabilitation* and *Community Engagement and Development* handbooks in this series).

Closure criteria for the tailings storage facility should be reviewed in consultation with the community during the operating phase, and the tailings management plan revised (including design modifications) accordingly.

The leading practice approach to closure planning clearly defines, at the earliest possible stage in the design, the post-closure land use and the final closure landform, and then demonstrates the commitment to achieve these goals, through regular transparent reporting against lead indicator criteria and community consultation. Leading practice will also

demonstrate a commitment to achieving stable and self-sustaining landforms by testing closure engineering concepts well before closure occurs, so that the closure design can be confidently and cost-effectively engineered.

Critical closure-related design considerations relate to geotechnical and landform surface stability and pollution control through the design and construction of effective surface covers and treatments.



#### **Rock armouring and vegetation of outer face of a tailings storage facility**

Careful consideration must be given to:

- post-closure land use and final landform – consideration must start in the design stage, and continue throughout the life-cycle through to stakeholder consultation during closure planning
- financial provisioning – experience has shown that unless an appropriate probabilistic financial model is developed which fully considers possible ranges of costs, dimensions (for example, cover thickness), events (such as storms and earthquakes), schedule (design, construction, and post-closure monitoring and maintenance), and project risks (for example, more stringent criteria than assumed), then the provision is likely to be significantly underestimated
- post-closure monitoring and maintenance plan – listing all post-closure criteria, and scheduling tasks and activities required to measure key lead and lag post-closure impact indicators. This may include quantities and rates of release of solutes and vegetation regrowth (species, density and weed management). The post-closure monitoring period will be site dependent, but will be determined by the period required to confirm that no measurable detrimental impacts are occurring, and/or are unlikely to occur post-completion. The plan must also detail post-closure accountabilities, responsibilities, schedules and financial provisioning for monitoring activities, reporting, consultation and maintenance, if required.



## 5.0 LEADING PRACTICE TAILINGS MANAGEMENT

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### KEY MESSAGES

- Tailings storage facilities are among the most visible legacies of a mining operation. Following closure and rehabilitation they are expected to be stable and produce no detrimental effects on the environment in perpetuity.
- Poorly designed or managed tailings storage facilities lead to increased closure costs, ongoing environmental impacts, and a perpetual risk to public health and safety.
- Key considerations for leading practice tailings management are siting of the tailings storage facility, geochemical characterisation of the tailings, selection of the optimal tailings disposal method, containment of the tailings and design and construction of the containment wall, seepage control, tailings delivery, water management, dust control, and closure, decommissioning and rehabilitation.
- Leading practice tailings management requires the involvement of qualified professionals, acting in accordance with sound geotechnical and hydrological engineering principles.
- The principal objective of tailings storage facility closure, decommissioning and rehabilitation is to leave the facility safe, stable and non-contaminating, with little need for ongoing maintenance.

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Tailings storage facilities are among the most visible legacies of a mining operation and after closure and rehabilitation are expected to be stable and produce no detrimental effects on the environment in perpetuity. Poorly designed or managed tailings storage facilities lead to increased costs of closure, ongoing impacts to the environment, and a perpetual risk to public health and safety.

Tailings storage facilities need to be designed, constructed and operated to the highest standards, taking into account the eventual need for closure and rehabilitation. Closure and rehabilitation plans are increasingly influencing the location of tailings storage facilities and the selection of tailings disposal methods, so as to minimise the costs of closure, the future risks to the environment and the legacy for future generations. As described in Section 4, the design of the tailings storage facility should be integrated with the life-of-mine plan so that the most cost-effective solution for closure can be developed.

Optimum strategies for tailings management are very much site specific. For these reasons, a range of tailings management approaches is presented in this section. In particular, key technical aspects of siting, disposal design, construction and closure are highlighted and discussed.

The tailings storage facility location, disposal method, approach to water management and long-term closure objectives need to be defined. Financial and technical analysis of options must accommodate social and community concerns about environmental, aesthetic and cultural issues. As well as initial siting and disposal design decisions, the proposed tailings management, storage and closure strategies must be communicated to regulatory authorities and the community.

## 5.1 Siting considerations

A siting study aims to identify and evaluate locations and disposal methods for the safe and cost-effective storage of tailings. The study should consider a broad range of options, including using tailings for underground or pit backfilling, and methods for developing integrated tailings and waste rock disposal facilities, as well as the more conventional surface storage facilities. A siting study should consider:

- site setting – climate, mine site layout, topography, potential for orebody sterilisation, storage volume requirements, public health and safety risks, and potential social and environmental impacts
- fatal flaw evaluation – for example, not locating the tailings storage facility directly up-gradient of populated areas, and avoiding areas of significance such as wetlands, areas underlain by karst terrain, heritage sites and floodways
- type of tailings – particle size distribution, rheology and potential to contaminate
- proximity and elevation of the proposed site in relation to the processing plant, affecting the tailings delivery method
- appropriate disposal method and storage type for the proposed site and tailings
- available storage volume and potential for expansion
- expected footprint (area of disturbance)
- potential surface drainage and groundwater impacts
- closure issues – long-term tailings containment, outer batter and surface stability, seepage and water quality, public health and safety risks, and potential social and environmental impacts.

## 5.2 Tailings disposal methods

Tailings are usually pumped as a slurry in a pipeline and discharged sub-aerially into a surface tailings storage facility. The consistency of the slurry (percentage solids by mass) depends on the type of tailings, the particle size distribution and specific gravity, and the extent of thickening at the processing plant. Tailings slurries are typically pumped at 25 per cent solids (for low specific gravity coal tailings) to over 50 per cent (for hard rock metalliferous tailings).

Tailings are often thickened at the processing plant prior to pumping to the storage facility. This enables process water to be directly recycled back to the mineral processing plant, reducing water losses and reducing processing plant water demand. A range of thickening technologies is available and the most commonly applied are outlined in Table 1 (Williams & Williams 2004):

**Table 1: Commonly applied thickening technologies**

TAILINGS CONSISTENCY	THICKENING EQUIPMENT REQUIREMENTS
Slurry	Conventional or high rate thickener
Thickened	High compression thickener
High slump paste	Deep bed thickener
Low slump paste or filter cake	Filters

Thickening tailings reduces the quantity of water delivered to the tailings storage facility. This in turn reduces the risks of overtopping, and reduces seepage and evaporation losses. Thicker tailings discharge also enables better control of the decant pond and return water system. Where tailings are discharged into surface storage facilities, depositional beach angles will steepen as the tailings are discharged at a thicker consistency, and the reducing water content will, in turn, reduce the containment requirements. Typical relationships between placement consistency and beach angle for pumped tailings are presented in Table 2 (Williams & Williams 2004).

**Table 2: Typical relationships between placement consistency and beach angle**

PLACEMENT CONSISTENCY	BEACH ANGLE (per cent)
Slurry	1 to 2
Thickened	2 to 3
High slump paste	3 to 6
Low slump paste	6 to 10



**Conventional tailings slurry disposal**

Conventional tailings disposal methods and storage facilities include:

- slurry disposal to a valley storage – tailings discharge downstream towards a water-retaining containment wall where the decant to collect the supernatant water is located, or upstream away from the containment wall with a decant facility located at the upstream end
- slurry disposal to a ring containment wall on relatively flat ground, usually with a centrally-located decant facility
- slurry disposal to a series of cells with tailings deposition cycled between the cells to facilitate consolidation and desiccation
- central thickened discharge (CTD) on relatively flat ground, with supernatant water collected behind a water-retaining perimeter containment wall or in a water-tight perimeter channel (Williams, 2000)
- down valley discharge (DVD) of thickened tailings towards a containment wall, located at the head of a catchment
- disposal of thickened tailings to cells, possibly in combination with mechanically-enhanced evaporative drying, as used for red muds in the alumina industry
- in-pit placement of tailings as a slurry, as thickened tailings or combined with waste rock
- underground backfill of mined-out stopes, in the form of hydraulic fill, rock-fill or cemented paste tailings backfill.



**In-pit tailings disposal**



**Rehabilitated in-pit tailings**

Some advantages and disadvantages of conventional tailings disposal and storage are summarised in Table 3, which should not replace the need for the engagement of appropriate engineering expertise.



**Table 3: Conventional tailings disposal and storage advantages and disadvantages**

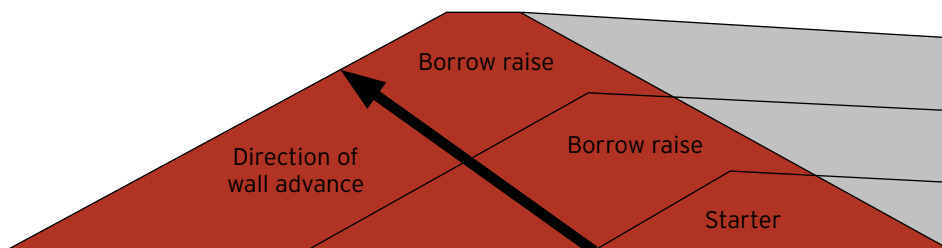
DISPOSAL	STORAGE	ADVANTAGES	DISADVANTAGES
Slurry – discharge towards wall	Valley	<p>Maximises storage volume for a given wall height</p> <p>Water return system can be fixed</p>	<p>Natural valley flows will be disrupted</p> <p>A water-retaining containment wall is required to limit seepage</p> <p>Deposition of tailings fines against the wall could affect its stability</p> <p>Potential for overtopping by water and/or tailings (including under seismic action)</p> <p>Will require a final spillway</p>
Slurry – discharge away from wall	Valley	<p>A water-retaining containment wall may not be required</p> <p>With proper management, overtopping should not occur, and a final spillway may not be required</p>	<p>Natural valley flows will be disrupted</p> <p>Water return system will have to move upstream ahead of the tailings beach</p>
Slurry	Ring	<p>With a central decant, a water-retaining containment wall is not required</p> <p>Footprint is minimised by continued raising of the ring containment wall</p>	<p>Natural drainage channels will be disrupted</p> <p>Proper closure of the central decant is required to stop ongoing seepage</p>
Slurry	Cells	<p>With central decants, a water-retaining containment wall is not required</p> <p>Cycling between cells allows consolidation and desiccation of the tailings and may reduce seepage</p> <p>Total footprint can be minimised by raising the cell containment walls</p>	<p>Natural drainage channels will be disrupted</p> <p>Proper closure of the central decants is required to stop ongoing seepage</p>

<b>DISPOSAL</b>	<b>STORAGE</b>	<b>ADVANTAGES</b>	<b>DISADVANTAGES</b>
Thickened	CTD, DVD or cells	<p>Thickening will reduce water and process chemical losses, reduce the supernatant water volume, and reduce seepage</p> <p>Thickening allows accelerated access for rehabilitation</p> <p>CTD creates a low-profile, self-shedding landform, often in keeping with the surrounding natural landforms</p>	<p>Thickening and pumping incurs additional costs over slurry disposal</p> <p>Due to the low beaching angle of the thickened tailings, the CTD footprint area will be large, with implications for rehabilitation</p> <p>CTD may require a water-retaining perimeter embankment or channel</p> <p>Mechanically working the surface of cells requires some desiccation for traffickability and is expensive</p>
Slurry	Underground	<p>Eliminates the need for a surface tailings storage facility</p> <p>Can be delivered under gravity</p> <p>May improve the stability of underground workings</p>	<p>Supernatant water is difficult to recover</p> <p>Only partial backfilling and partial utilisation of the available storage may be achieved</p> <p>Adjacent active underground operations may be flooded</p>
Slurry	In-pit	<p>Eliminates the need for additional surface tailings storage</p> <p>Can be delivered under gravity</p> <p>Supernatant water recovery is possible by pumping</p>	<p>Tailings consolidation rate is reduced, and surface desiccation is reduced or eliminated (if underwater)</p> <p>Failure to recover the supernatant water and process chemicals leads to high losses</p> <p>Supernatant water recovery requires that in-pit pumps be maintained and the pumping head must be overcome</p>

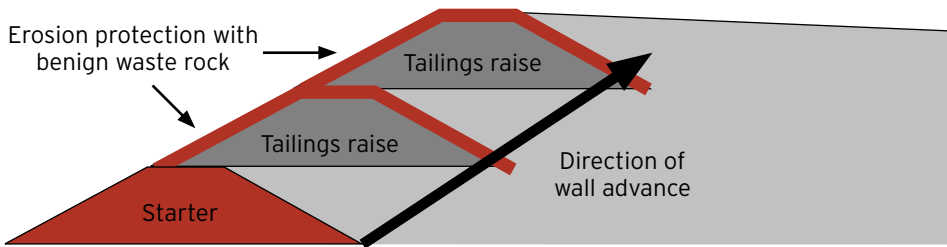
DISPOSAL	STORAGE	ADVANTAGES	DISADVANTAGES
Thickened	In-pit	Eliminates the need for additional surface tailings storage Can be delivered under gravity The reduced supernatant water may not require recovery	Thickening incurs an additional cost Tailings consolidation rate is reduced, and surface desiccation is reduced or eliminated (if underwater)
Cemented paste	Underground	Can be delivered under gravity Little supernatant water is produced, allowing rapid backfilling Provides stability for subsequent mining of adjacent stopes	Paste production and cement addition incur high costs

### 5.3 Tailings containment

For the storage of tailings slurry in surface facilities, the containment walls are normally constructed in a series of lifts or wall raises using the downstream, centreline or upstream methods. They are so called because they involve the crest advancing downstream, vertically upwards or upstream, and progressively less containment wall earthworks. Figures 1 and 2 show schematic diagrams of downstream and upstream raising, which highlight the much greater volume of borrow material required for downstream raising compared to upstream raising. The diagrams do not include details about internal drainage or clay cores within the containment walls, which may be required to ensure geotechnical stability and/or to control seepage.



**Figure 1: Downstream construction using borrow**



**Figure 2: Upstream construction using desiccated tailings**

Centreline raising is midway between the two extremes of downstream and upstream raising, and is not commonly used in Australia. In all cases, the initial starter containment wall is generally constructed using borrow material, often benign (non-acid forming) waste rock. Downstream wall raises are also generally constructed using borrow material, while centreline and upstream wall raises are often constructed using a combination of the coarse fraction of the tailings and waste rock or borrow material.

For upstream raising using tailings, material is excavated from the tailings beach and used to construct an upstream lift over deposited tailings. It may be necessary to place benign waste rock on the downstream face and crest (and sometimes on the uncovered upstream face) to prevent the erosion of tailings by water or wind. Upstream lifts can also be constructed by placing waste rock or borrow material on top of deposited tailings, if the tailings foundation has sufficient strength. For centreline raising, tailings may be separated into coarse and fine fractions using cyclones, with the coarse fraction directed downstream to form the wall and the fine fraction directed upstream. In this case, no erosion protection is applied to the downstream face during operation. The downstream face may be dozed to reduce the slope angle, increase density and improve the geotechnical stability of the wall.



**Downstream construction**



**Upstream construction using tailings**

Some advantages and disadvantages of using the downstream and upstream methods of progressive tailings containment wall raising are highlighted in Tables 4 and 5. These should not, however, replace the engagement of appropriate engineering expertise.

**Table 4: Advantages and disadvantages of downstream construction**

<b>ISSUE</b>	<b>ADVANTAGES</b>	<b>DISADVANTAGES</b>
Borrow material	A wide benign encapsulation is provided	Large borrow volumes are required
Construction cost	Starter embankment section is no larger than that required for upstream construction	Subsequent wall raises are increasingly costly
Footprint	Starter embankment footprint is no larger than that required for an upstream starter embankment	Subsequent wall raises increase the footprint Increasing footprint of the containment wall reduces the volume available for tailings storage
Geotechnical stability	Will likely be enhanced by the borrow material	Use of fine-grained borrow material may result in a high phreatic surface on further tailings deposition, which will reduce geotechnical stability
Seepage	Seepage control measures can readily be incorporated within successive wall raises	Coarse-grained waste rock borrow would increase wall seepage
Contaminants	Encapsulation limits exposure of tailings to oxidation	Encapsulation maintains tailings water content and the potential for the transport of contaminants
Erosional stability	Wide encapsulation will likely prevent the exposure and erosion of tailings	Fine-grained borrow material or weathered rock on the surface may be prone to erosion
Rehabilitation	Wide encapsulation should allow reshaping of the outer batter	Any additional reshaping for rehabilitation purposes may increase the footprint

**Table 5: Advantages and disadvantages of upstream construction**

ISSUE	ADVANTAGES	DISADVANTAGES
Borrow material	After construction of the starter embankment, only small volumes of borrow material are required for raises	Above the starter embankment, only limited cover over the tailings wall raises is provided
Construction cost	Subsequent wall raises with tailings involve little borrow material, negligible hauling of tailings, and haulage only of the facing material	Subsequent wall raises require the tailings to be sufficiently desiccated to be traffickable and suitable for wall building
Footprint	Subsequent wall raises do not increase the footprint  Initial starter embankment requires the same footprint as that required for downstream construction, but allows a greater storage footprint	Excavated tailings have greater exposure to oxidation
Geotechnical stability	Will likely be reduced by the use of tailings for wall raises	Use of tailings in wall raises may result in a high phreatic surface on further deposition of tailings, which will reduce geotechnical stability
Seepage	Tailings used for wall raising will have a relatively low permeability, limiting seepage	Seepage control measures cannot be incorporated within successive wall raises
Contaminants	Drying of the tailings and their elevation in wall raises reduces the water available to transport contaminants	Excavation of the tailings and their use for wall building exposes potentially acid forming tailings to oxidation
Erosional stability	Cover over the tailings wall raises is specifically intended to provide erosion protection	Limited cover over the tailings wall raises may be prone to erosion loss in the longer-term
Rehabilitation	Relatively flat outer batter slopes of the tailings wall raises will lend themselves to rehabilitation by the placement of additional borrow material at the same slope angle	Limited cover over the tailings raises places limitations on future reshaping options  Additional borrow material is likely to be required to achieve the optimal cover depth, final profile and surface treatment  Reshaping for rehabilitation purposes will likely increase the footprint

## 5.4 Containment wall design and construction

Tailings containment structures are designed and constructed in accordance with sound geotechnical engineering principles, such as those provided by ANCOLD (1998, 1999, 2000a, 2000b, 2003), using the systems described in Section 4. The principal considerations for design of a tailings containment structure are:

- foundation conditions
- zoning of the containment wall and geotechnical parameters of the construction materials
- geotechnical slope stability
- seepage and the need for internal drainage or clay cores and cut-offs into the foundation beneath the containment wall
- staged construction, either by progressive wall raising, addition of containment cells or construction of new facilities over time
- selection of construction materials, including excavated tailings or run-of-mine waste rock where appropriate
- selection of construction techniques and equipment requirements
- quality assurance of construction process, including control of water content, compaction and survey.

## 5.5 Seepage control

For tailings slurry deposition there is a high risk that seepage will occur through the containment wall and into the foundation. During the operation of a conventional tailings storage facility, a perched water table will typically develop within the deposited tailings – held in place by the low hydraulic conductivity of the unsaturated foundation beneath the tailings and maintained by ongoing wet tailings deposition and any incident rainfall. Water will slowly seep from the tailings into the foundation. Some of the seepage will go into storage within the foundation, increasing its hydraulic conductivity, and some will infiltrate to the groundwater table causing it to mound. Some tailings water may also seep from the toe of the tailings containment wall. The seepage water is likely to transport contaminants.

If there is a risk that tailings seepage will cause groundwater contamination that could lead to public health risks and environmental damage or impact, the following aspects need to be considered in the design to adequately control seepage:

- hydraulic characteristics of the foundation beneath the tailings storage facility, including the presence and value of groundwater, and the need for a liner
- hydraulic characteristics of the containment wall, including the need for a clay core and cut-off into the foundation beneath the containment wall
- the impact of seepage from the tailings on surface and ground water

- prevention of low permeability lenses or layers forming on the tailings beach that could cause future seepage or stability concerns
- under-drainage to remove gravity drainage from the deposited tailings
- decant systems designed and operated to limit the storage of supernatant water and incident rainfall off the surface of the tailings, and hence limit seepage.

Liners are not usually placed beneath tailings storage facilities. However, there is a growing requirement for the provision of liners to minimise the risk of groundwater contamination. New mining projects are being asked to justify why a liner is not required. This may be because the foundation has an acceptably low hydraulic conductivity (a saturated value of say  $< 10^{-9}$  m/s) or the groundwater has no beneficial use (for example, it is hyper-saline).

In the absence of a foundation of very low hydraulic conductivity, a compacted clay or geomembrane liner may be considered. A compacted clay liner would normally be expected to achieve a saturated hydraulic conductivity of  $< 10^{-8}$  m/s, requiring suitable clay soil, appropriate compaction equipment and good compaction control. A geomembrane, placed using good quality control, would be expected to achieve an equivalent hydraulic conductivity of about  $10^{-10}$  m/s, however, its life might be limited to between 50 and 100 years. A geomembrane would therefore normally be used in combination with a compacted clay layer.

If contaminant plumes have developed beneath existing tailings storage facilities, remedial measures include interception trenches and/or seepage recovery bores installed around the tailings storage facility perimeter, or downstream if the facility is a valley fill type.

Post-deposition, the entrained water within the tailings can lead to ongoing seepage – usually at a diminishing rate as the perched water table within the tailings disappears. Rainfall on the tailings surface can recharge the tailings, leading to further seepage over time. Where seepage is a risk to public health or environmental impacts, a key closure consideration is to limit infiltration into the surface of tailings and to control the flow of seepage from the tailings storage facility.

In extremely dry climates, such as those in the Western Australian goldfields region, closed tailings storage facilities desiccate strongly, reducing the likelihood of seepage after closure, even after prolonged heavy rainfall. In addition, much of this region's groundwater is hyper-saline and of little economic value other than as mineral processing water.

The use of hyper-saline groundwater for mineral processing, and the processing of saline ores, leads to hyper-saline tailings. These form a hard surface crust that can limit infiltration and dusting, but also restrict evaporative drying. Interception trenches or recovery bores may be required around the perimeter of these facilities during operation and for a period post-closure, to control the drain-down of hyper-saline water. Once the water table mound has subsided, the risk of seepage to, and impact on, the surrounding environment is usually low.



## 5.6 Tailings delivery

Tailings are normally pumped as a slurry along a pipeline, although in some situations it may be possible to convey tailings, under gravity, to the storage facility. The pumpability of a tailings slurry is a function of its rheology and the capabilities of the pumping systems considered. The higher the solids concentration of the tailings slurry, the higher its yield stress and the more difficult it is to pump, for a given pump type.

Typical tailings pumping equipment requirements for different tailings consistencies are given in Table 6 (Williams & Williams 2004). The increasing power and line pressure requirements with increasing tailings solids concentration correspond to a significant increase in pumping costs.

**Table 6: Typical tailings pumping equipment requirements for different tailings consistencies**

TAILINGS CONSISTENCY	PUMPING EQUIPMENT REQUIREMENTS
Slurry	Centrifugal pump (low line pressure)
Thickened	Centrifugal or piston/diaphragm pump (high line pressure)
High slump paste	Piston/diaphragm pump (higher line pressure)
Low slump paste	Dual piston positive displacement pump (high line pressure)

Along the tailings pipeline corridor there is a need to protect the environment against tailings spills due to possible pipeline leaks and breaks, and the clearing of pipeline blockages.

Methods for controlling the discharge of tailings if such incidents occur include:

- construction of containment drains or sumps along the pipeline corridor
- sleeving of the pipeline with a larger diameter pipe for situations where the tailings pipeline is traversing sensitive environments (for example, a river crossing) or crossing transport routes
- regular inspection of pipeline route for leaks
- use of differential pressure sensor or flow measurement instrumentation and alarm system to alert operators in case of pipeline failure.

## 5.7 Water Management

The effective management of water quantity and quality is a key driver for responsible tailings management. Key water related considerations in the design, operation and closure of a tailings storage facility are:

- the availability of water of acceptable quality
- competing water users and the value the community places on water
- the need for water and reagent recovery

- pumping flow-rates and distances
- reducing evaporative losses (where water balance is in deficit) or encouraging evaporation (if water is in surplus)
- minimising the generation of acid and metalliferous drainage and salinity
- controlling the discharge of processing chemicals with the tailings
- managing water treatment (if required) and discharge to the environment (of surplus water)
- reducing seepage to groundwater
- reducing the risks associated with the storage of water on tailings storage facilities, which could involve perimeter fencing, minimising the area of ponded water, netting or intermittent noise to distract birds.

### **Water quantity**

Mines often compete for water resources with other users such as agriculture, domestic and industrial water supply, and the environment. It is important that the mining industry be seen as good stewards of water to ensure continued access to a limited resource.

At many mine sites across Australia, water is scarce or of poor quality. The recovery of additional water from tailings can augment a mining project's water resource, reduce water drawn from natural water resources, and recover valuable reagents (for example, cyanide in the case of gold processing).

### **Water quality**

As the surface desiccates, tailings containing sulfides have the potential to oxidise, and also potentially produce acid and metalliferous runoff and seepage. Rainfall infiltration may leach the oxidation products, releasing contaminants to the groundwater. Tailings and/or tailings water may contain high salinity levels, due to the saline nature of the tailings and/or the processing water used. Tailings water will contain residual processing chemicals, such as cyanide, and may be rendered alkaline or acidic for processing purposes. Potential contaminants will be transported in any runoff and seepage emanating from the tailings storage facility. These risks to the environment are controlled by effective operating, closure and rehabilitation strategies (refer to the *Managing Acid and Metalliferous Drainage* and *Mine Closure handbooks* in this series).

### **Cost of water**

It is important that the true cost of water be used in the economic evaluation of water recovery options. These include:

- capital and operating costs of developing, operating and maintaining water supply systems
- the environmental costs, taking into account the value of receiving natural wetlands, streams, lakes and associated ecosystems

- the cost to displaced users
- cost implications of production disruption due to supply shortfalls.

## Water balance

The water balance of a tailings storage facility is the key tool used to quantify inputs, outputs and stored water volumes. A clear understanding of the water balance enables the facility to operate to design objectives and lower the risk of water-related incidents. A schematic of a tailings storage facility water balance is shown in Figure 3.

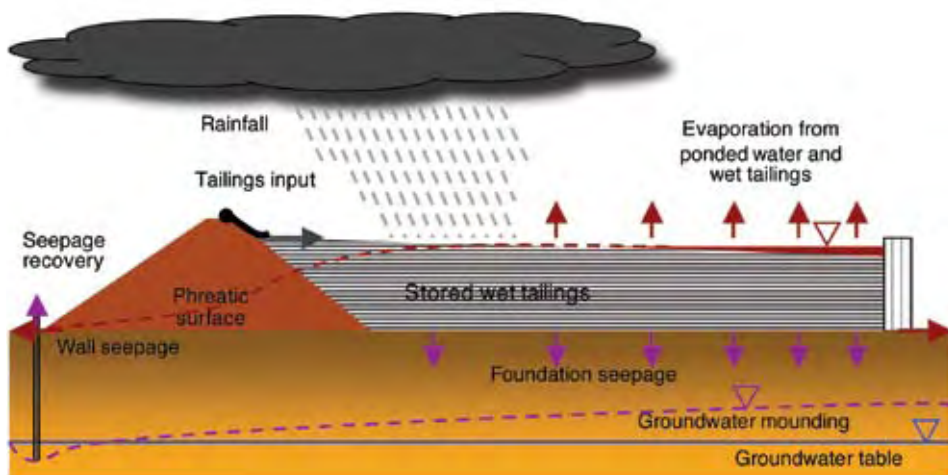
During operation, inputs to the tailings water balance are:

- the tailings water discharged
- incident rainfall and catchment runoff.

The outputs are:

- water recovered for reuse in the processing plant, including water stored in process water dams
- water extracted for treatment and discharge to the environment
- water entrained in the settled tailings
- evaporation from ponded water, recently-deposited wet tailings, and desiccating tailings
- seepage through the containment wall and into the foundation.

The total volume of tailings water and the recovered water volume are the only quantities known with certainty, while the rainfall and the evaporation from ponded water can be estimated from climatic data for the site. The runoff, entrained water within the tailings, the surface storage of water, and the evaporation from wet, desiccating and dry tailings can be measured. Seepage losses through the wall and into the foundation are difficult to determine, and are usually estimated numerically.



**Figure 3: Schematic of tailings storage facility water balance**

The level of water recovery from a tailings storage facility will depend on the tailings placement consistency and the extent of losses from the tailings storage facility. Table 7 gives an indication of the total water recoveries possible, depending on the level of thickening of the tailings prior to discharge (Williams & Williams 2004).

**Table 7: Total water recoveries possible in relation to tailings thickening level**

<b>TAILINGS CONSISTENCY</b>	<b>POTENTIAL TOTAL WATER RECOVERY (per cent)</b>
Slurry	50 to 60
Thickened	60 to 70
High slump paste	~ 80
Low slump paste	85 to 90

After closure, there is no further tailings water input, however, rainfall and catchment runoff may need to be controlled by diversion to a spillway.

## 5.8 Dust control

Dust generated from the surface of tailings storage facilities may be a public health risk and cause environmental impacts from airborne particulates and contaminants. It may be a key concern of neighbouring communities, which could include mine workers and their families. Unbound silty or sandy tailings are likely to cause dust problems during periods of high wind. Dust can be controlled by:

- spraying with chemical dust-suppressants
- covering the tailings with a thin veneer of gravel
- use of silt trap fences
- discharge tailings to maximise wetted surface (although this increases evaporative water loss).

Tailings that hardpan due to a high salt content may not create dust problems, unless disturbed by traffic. However, the long-term breakdown of salt crusts should be allowed for and may require a cover of benign material.

## 5.9 Closure, decommissioning and rehabilitation

The dominant mine-related risks to public health or the environment are from tailings storage facilities (Envec 2005). This is reflected in the high level of community concern about their closure, decommissioning, rehabilitation and aftercare. Contaminants can be mobilised from these facilities through a number of mechanisms, including airborne transport (tailings dust can contain heavy metals and toxic compounds), mass movements of tailings in liquid or semi-liquid form, and waterborne transport as suspended solids and dissolved materials (Lacy & Barnes 2005).

### 5.9.1 Objectives

The principal objective of tailings storage facility closure, decommissioning and rehabilitation is to leave the facility safe, stable and non-contaminating, with little need for on-going maintenance. In some cases it will be possible to enhance the value of mined land, to create a modified landscape that offers recreational, commercial or natural value that can be enjoyed in the future. To achieve such outcomes, it is essential that post mining land-use objectives are developed and agreed to with regulators, the local community and stakeholders prepared to accept ongoing responsibility for the land.

The *Strategic Framework for Tailings Management* (MCMPR & MC 2003), considers the following objectives when planning the final tailings storage facility landform:

- containing/encapsulating the tailings to prevent their escape to the environment
- minimising seepage of contaminated water from the tailings storage facility to surface and ground waters
- providing a stabilised surface cover to prevent erosion from the tailings storage facility
- designing the final landform to minimise post-closure maintenance.

### 5.9.2 Factors to consider

Factors to be considered when planning the closure, decommissioning and rehabilitation of a tailings storage facility are:

- ore type and geochemistry, which will dictate the potential for the tailings to contaminate, taking into account the variable nature of the ore
- crushing, grinding, and the process and process chemicals used for ore extraction
- process water quality
- tailings disposal technique
- operating the tailings storage facility in preparation for closure, for example depositing benign tailings or discharging centrally to create a water shedding surface
- environment and climate in which the tailings storage facility is located
- post-closure land use
- closure cost estimation
- long-term landform stability, including geotechnical and erosional stability
- managing surface runoff and ponding, and the need for a closure spillway
- long-term seepage to the environment of potentially contaminated tailings water
- potential for dust generation both before and after rehabilitation
- the need for, desired function and selection of cover systems
- surface treatment and vegetation of the top of the tailings storage facility
- profiling, surface treatment and vegetation of outer batter slopes.

Each site will have specific commitments relating to closure of a tailings storage facility, based on the outcomes of technical studies, and agreements with landowners and regulatory agencies. These commitments should be reviewed before finalising the closure design. Active stakeholder engagement is an important part of the process, enabling the mining company to present closure plans, listen to feedback from key stakeholders, and refine plans to a point where community acceptance and government endorsement is achieved.

Technical closure issues generally relate to geotechnical, geochemical, hydrological and environmental aspects, requiring a multi-disciplinary team approach. Examples of common issues encountered and possible closure options are provided in Appendix A of the *Mine Closure and Completion Handbook* in this series. Tailings storage facility closure, decommissioning and rehabilitation requires a staged approach, involving:

- stakeholder engagement (discussions, site visit and document review)
- sampling, investigations and research required to define tailings and rehabilitation materials – this knowledge is then used to resolve closure issues
- preparation of the draft decommissioning plan for submission to regulators
- decommissioning and rehabilitation of the tailings storage facility and preparation of a final decommissioning report
- monitoring and sign-off (Lacy & Campbell 2000).

## **CASE STUDY: Planning for Tailings Storage Facility Closure at Mt McClure, WA**

Mt McClure Mine is located in the arid climate northern goldfields, 80 km north-east of Leinster in Western Australia. The Mt McClure gold operation commenced in 1991. The site was owned and operated by four different mining companies before coming under the control of Newmont Australia Ltd in 2002. The mine was bought by View Resources in 2005, after decommissioning works were completed by Newmont.

A carbon in leach (CIL) plant processed ore at a rate of 1.2 Mtpa. The oxide and fresh rock ore (with some pyritic shales) was sourced from multiple pits and tailings were placed in two storage facilities (TSF 1 and TSF 4). (Only TSF 4 is discussed.) TSF 4 is circular in shape with a radius of approximately 325 m and a surface area of 33 ha. It is surrounded by run-of-mine waste from 70 to 300 m thick. Discharge of tailings ceased in March 1999.

The decommissioning program for TSF 4 involved a staged program that identified future closure issues early in the mine life, and management options to overcome these issues. Considerable attention was given to investigating and understanding the facility pre-decommissioning and this led to an appropriate final closure design which included engineered covers and concave profiled embankment slopes.



The five-step decommissioning approach described earlier was implemented. A principal component of effective decommissioning is to identify present and potentially long-term risk issues. This information provides the foundation material and can guide the TSF decommissioning process towards an appropriate closure strategy. It requires a multi-disciplinary approach to ensure all significant risk areas are investigated. Four primary technical disciplines were identified: geotechnical, hydrological, geochemical and environmental.

#### **Aerial view of Mt McClure integrated Tailings Storage Facility 4**

The geochemical parameters of the tailings were found to be a key factor for closure of TSF 4. The tailings were found to be acid-producing, which could lead to long-term impacts to the surrounding environment and groundwater system.

The following risk mitigation strategies were developed in response:

- a 2 m oxide/saprolite tailings cover overlain by 0.5 m of laterite/cap-rock/topsoil. Field test work and column testing predicted that the water holding capacity of this cover would be sufficient to restrict the majority of rainfall from deep infiltration
- the upper surface was designed with numerous individual smaller cells to contain rainfall within each cell. Much of the water that infiltrates into the cover is later released via evaporation and evapo-transpiration
- angle of repose slopes were battered to a 20°/14°/8° concave slope engineered to reduce runoff and minimise embankment erosion. A 0.5 m thick laterite/caprock cover was placed as an armour, followed by a thin topsoil layer, cross-rippled on the contour and seeded.



**Plan showing surface cells to capture rainfall and to minimise erosion on slopes**



**Concave slope after topsoil had been applied in 2006**

The earthworks were complete in 2004, and the facility is now at the monitoring and sign-off stage. During 2006, View Resources applied to the Department of Industry and Resources for, and received, a performance bond reduction. The application was submitted on the basis of demonstrated stability and continuing success in vegetation establishment and growth.

### 5.9.3 Tailings cover options

Uncovered tailings may present risks to human health, and social and environmental impacts, particularly if the tailings are prone to dust generation, rainfall runoff is allowed to pond directly over the tailings or the tailings surface remains soft. Possible tailings cover systems, in approximate order of increasing technical complexity and cost, are (Williams 2005 and the *Mine Rehabilitation Handbook* in this series):

- direct vegetation of the tailings
- a thin layer of gravel placed directly over the tailings surface for dust mitigation
- a vegetated, mono-layer cover, aimed at shedding rainfall runoff in a humid climate
- a vegetated, non-shedding store/release soil cover, aimed at minimising percolation through it by the release of stored seasonal rainfall by evapo-transpiration during the dry season
- a capillary break layer, overlain by a non-shedding, vegetated growth medium, aimed at controlling the uptake of salts into the growth medium to sustain vegetation, for application in a dry climate
- combinations of the above.

Some of the advantages and disadvantages of the different cover systems are summarised in Table 8.



**Table 8: Advantages and disadvantages of cover systems**

<b>COVER SYSTEM</b>	<b>ADVANTAGES</b>	<b>DISADVANTAGES</b>
Direct vegetation	Low cost, if it works	May not be sustainable due to lack of nutrients and/or fresh water
Thin gravel	Low cost, if dust suppression is the key aim	Will not vegetate Will not limit rainfall infiltration and resulting seepage
Shedding mono-layer	Provides a vegetated cover in a humid climate	May deform due to consolidation of the underlying tailings, or desiccate in a dry climate, resulting in seepage of rainfall infiltration
Store/release	May limit percolation to the underlying tailings	Requires a significant thickness of cover including a sealing layer at the base May fail if inappropriate and unsustainable vegetation is selected
Capillary break	May limit the uptake of salinity into the overlying growth medium allowing vegetation	An inappropriate or too thin a capillary break material will allow salt uptake into the growth medium in an evaporative climate Too thin or too coarse-grained a growth medium will not support vegetation

## CASE STUDY: Direct Revegetation of Tailings Storage Facility at Kidston Gold Mine, QLD

Kidston Gold Mine is located 260 km south-west of Cairns in north Queensland. The climate is characterised by pronounced wet and dry seasons. On average, over 80 per cent of annual rainfall (averaging 719 mm) falls between November and April, comprising high intensity storms and monsoonal events. Mean daily temperatures are 18°C and 33°C in winter and summer, respectively.

A closure objective for the Kidston Gold Mine was a self-sustaining savannah woodland vegetation of native trees and introduced and native ground cover species. The 310 ha tailings storage facility (TSF) contained approximately 68 Mt of tailings deposited between 1985 and 1996. Early revegetation trials conducted in the early to mid 1990s demonstrated the capacity of the tailings to support vegetation growth directly, without the requirement for a capping layer of soil or other cover material.

The TSF was decommissioned at the end of 1997 and, as the accessible area on the surface of the facility became progressively available (from March 1998 through to December 2001), planting and seeding of over 50 native tree and shrub species and eight introduced and native pasture species was undertaken. With the support of drip irrigation over the first few months and initial fertilisation, the alkaline tailings were proven to be a substrate conducive to the establishment of vegetation.

Early studies demonstrated that the use of tubestock was likely to be a successful means of initially establishing the middle and upper-storey components of the vegetation community on the tailings. In March 1998, broadcast seeding trials of native species on tailings were instigated and proven to be successful, indicating that it was possible to establish woody species, particularly local ironbark species, from seed. Numerous other research trials and monitoring campaigns were conducted to build confidence in the robustness of the strategy to directly revegetate the tailings, and to support the presence of cattle.



**Kidston tailings storage facility before (left), and a few years after (right), implementation of the direct revegetation program**

The vegetation communities will continue to develop in a positive direction, contribute to a reduction in deep drainage and thus the overall seepage water management strategy for the TSF and hence the site. They will provide a stable and safe environment for subsequent land use. These factors were drivers for the company's investment in the research that has underpinned the closure strategy for the facility.



**Older section of revegetated Kidston tailings storage facility, seven years after planting and seeding**



## 6.0 FUTURE DIRECTIONS

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### KEY MESSAGES

- Leading practice tailings management and the compelling business case associated with it are driving the design, operation, closure and rehabilitation of tailings storage facilities towards available thickening, paste and enhanced dewatering technologies.
- Co-disposal and integrated tailings disposal with coarse-grained wastes, and the potential use of paste rock as a cover seal, are also expanding in their application.
- Underground and pit backfilling need to be considered as alternatives to the surface storage of tailings, where possible. These alternatives act to reduce the mining footprint.
- Ideally, surface tailings landforms should mimic surrounding natural landform analogues, in terms of their geometry, surface cover and texture, and stability.

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Tailings management, based on the principles of sustainable development and the compelling business case (see Section 2), are driving the design, operation, closure and rehabilitation of tailings storage facilities towards:

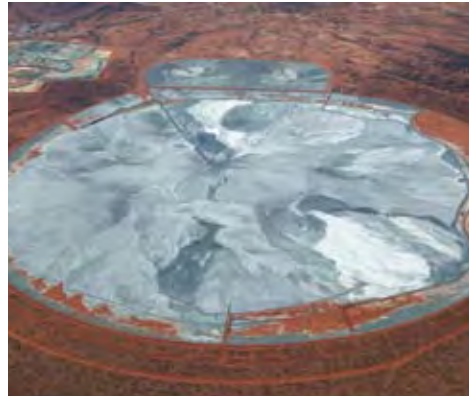
- thickened and paste tailings disposal, to reduce water use and the seepage, and to produce a more stable tailings deposit
- dewatering of tailings to a filter cake for wet or dry stacking, with obvious benefits
- co-disposal and integrated tailings disposal with coarse-grained wastes, to make better use of the available storage volume and produce a more stable deposit
- paste rock for use as a cover seal (see Section 6.1.4 for description)
- secure tailings storage as underground and pit backfilling
- tailings landforms aligned with natural analogues and community expectations
- tailings minimisation, recycling and reuse.

### 6.1 Improved tailings disposal

A state-of-the-art tailings storage facility is a safe, stable landform that does not require ongoing management post-closure and blends in with the surrounding landscape. It provides an opportunity to showcase social and environmental management commitments – positioning the mining company as committed to sustainable development when proposing future developments.

There are many challenges that must be overcome to achieve a state-of-the-art outcome. Traditional tailings disposal methods create environmental problems as they can:

- take up large surface areas
- be highly visible
- entrain and possibly store large volumes of water
- seep contaminated water into the ground
- release contaminated drainage into surface streams
- cause dust problems.



### **Large, visible tailings storage facilities**

Avoiding these issues, and the associated risks, requires a commitment to rigorous planning and application of leading practices over the full mine life cycle. Such outcomes also require foresight and recognition that tailings facilities can incur environmental and social costs in the long-term if leading practice principles are not heeded.

More efficient and economical tailings preparation and disposal techniques are being introduced at Australian mine sites. Some of these systems achieve greater efficiency and economy by removing excess water from the tailings at the processing plant before transport. This maximises the recovery of water and process chemicals for re-use and minimises the discharge of water and contaminants to the tailings storage facility, thereby reducing the risk of seepage or release to surface waters.

### **6.1.1 Thickened and paste tailings**

There are now many mining operations that employ thickened and paste tailings, and this will become more widespread in the future. Past limitations to successful thickened tailings disposal were either cost or the lack of suitable thickener technology. Today, thickener technology has developed well beyond the conventional thickener to produce high underflow densities, close to the filtration limit, and costs have reduced. These thickeners range from deep bed thickeners (typically used for red muds) through to paste or deep tank thickeners developed for the production of cemented paste tailings backfill for underground application (Potvin et al. 2005).



**Cemented paste tailings underground backfill    Surface paste tailings disposal**

The solids concentrations achieved vary for different tailings, since particle size distributions, clay content, particle shape, mineralogy, electrostatic forces and flocculant dosing vary considerably. Table 9 gives some typical slurry and paste solids concentrations for a range of tailings types (Williams & Williams 2004).

**Table 9: Typical slurry and paste solids concentrations**

<b>TAILINGS TYPE</b>	<b>SLURRY PER CENT SOLIDS</b>	<b>PASTE PER CENT SOLIDS</b>
Bauxite red mud	25	45
Base metal tailings	40	75
Coal tailings	25-30	-
Gold tailings	45	72
Mineral sands slimes	15	24
Nickel tailings	35	45

Due to the highly variable solids concentration of tailings slurry, thickened tailings and paste tailings from different sources, the consistency of tailings is better measured in terms of their physical behaviour. Initially, this was described with the slump cone test used to assess concrete slump. Physical characteristics of tailings can be described quantitatively by their yield stress, as described in Jewell & Fourie (2006).



**High density slurry**



**10" (250 mm) slump paste**



**7" (175 mm) slump paste**

Tailings slurry segregates, settles and produces supernatant water on placement, accompanied by significant curvature of the beach profile (becoming flatter further down the beach). High slump paste tailings have a non-segregating, non-settling consistency that releases only small quantities of water after placement. Thickened tailings show some segregation, settlement and bleed on placement, accompanied by some curvature of the beach profile.

The advantages of using thickened or paste tailings include:

- improving water and process chemical recovery at the processing plant
- minimising storage volume
- reducing seepage
- production of a more stable landform.

These are key considerations for sustainable development and reflect community expectations. Jewell & Fourie (2006) provided a comprehensive and definitive reference on these technologies.

## CASE STUDY: Central Thickened Discharge at Sunrise Dam Gold Mine, WA

Sunrise Dam Gold Mine, located 55 km south of Laverton in Western Australia, commenced operation in 1997. A 'paddock style' tailings storage facility (TSF) for conventional medium-density tailings slurry was commissioned for the design throughput of 1.5 million tonnes per annum (Mtpa). One downstream raise was carried out in 1998 prior to decommissioning in 1999. Design throughput was scheduled to increase from 2 Mtpa in 2000 to 3 Mtpa in 2003, and a decision was made to thicken the tailings to a higher density and change to the central thickened discharge (CTD) method of tailings disposal in a new location.

The site was located in a regional drainage line with a catchment area of 60 km<sup>2</sup>. Groundwater was unconfined and typically within 5 m of the surface. Runoff diversion channels were required to manage the substantial flows from cyclonic rainfall events. The site slopes gently at a gradient of about 0.2 per cent. The design area of the CTD TSF in 1999 was 300 hectares and by 2005 had increased to 330 hectares.

The CTD TSF comprises a tailings storage area and a storm storage pond (SSP). Other features include an earth-fill ramp from the perimeter to the centre of the TSF, where multiple tailings discharge points are located, and a small lined pond located within the SSP for collecting tailings bleed water. Water is pumped from the lined pond back to the plant.

The shape of the CTD TSF is a low profile cone, and the height at the crest in 2005 was about 15 m. The present annual tailings production is 3.6 Mtpa. The current design will continue to 2009, however, the future expansion of the CTD will provide disposal capacity to the end-of-mine-life.

The processing plant uses gravity separation and carbon-in-leach technology to extract gold from the ore. The tailings are thickened to about 64 per cent solids using two high rate thickeners (24 m in diameter), and two pairs of centrifugal pumps transport the tailings a distance of 3 km. A seepage collection drain was constructed around the southern half of the TSF for the purposes of intercepting and lowering the water table adjacent to the facility.





**Plan view of CTD TSF**



**View along ramp from CTD TSF perimeter**

The parameters of the tailings are as follows:

Specific gravity:	2.85	Liquid limit:	23 per cent
Shrinkage limit density:	1.47 t/m <sup>3</sup>	Segregation threshold:	39 per cent solids
Initial settled density:	1.2 t/m <sup>3</sup>	D <sub>80</sub> :	0.075 mm
Soil classification:	Sandy silt (ML)	Salinity bleed water:	> 200,000 µS/cm

The tailings are deposited as very thin layers and evaporative drying is significant, although it is somewhat inhibited due to the hyper-saline nature of the tailings water. As a result the phreatic surface remains at or slightly above the original ground surface. Seepage is most prevalent around the perimeter of the CTD cone where tailings bleed water and storm runoff can accumulate, necessitating additional internal drainage measures.

The tailings beach slope is close to the original design value of 1.5 per cent. However, operational variations have led to a concave beach development; the upper third being 2 per cent, the middle third 1.5 per cent, and the lower third 1 per cent.

A strategy was adopted in 2005 whereby multiple discharge points were placed around the crest of the CTD cone. The purpose of this was to reduce the discharge flow rate and thereby increase the beach slope and improve the efficiency of storage.

Thickened tailings can usually be pumped using centrifugal pumps, however, paste tailings require the increased power of positive displacement pumps and high pressure piping. Gravity flow is used to deliver cemented paste tailings for underground backfill, and could be used to deliver paste tailings to surface storages, by locating the thickeners at elevated locations. While the capital cost of positive displacement pumps are higher than the equivalent capacity centrifugal system, the paste system may provide life-of-system cost benefits that support its adoption.

## 6.1.2 Dewatered tailings

Centrifuges and filters are widely used to dewater mine product (concentrates or fine coal) before transportation. In a very few instances in Australia they are being used to dewater tailings before disposal, typically at mines where land for a tailings storage facility is not available or where transportation limits preclude pumping. Tailings dewatered to a wet or dry filter cake consistency allows dry transportation and disposal, offering considerable long-term economic, social and environmental benefits.

Historically, tailings dewatering by centrifuges and filters has been the most costly method available for removing water from the tailings prior to their disposal. Pressures such as the cost of mine stoppages due to water shortages, future limits on processing make-up water, or the environmental legacy of a plume of acidic seepage, make dewatering a cost-effective method.

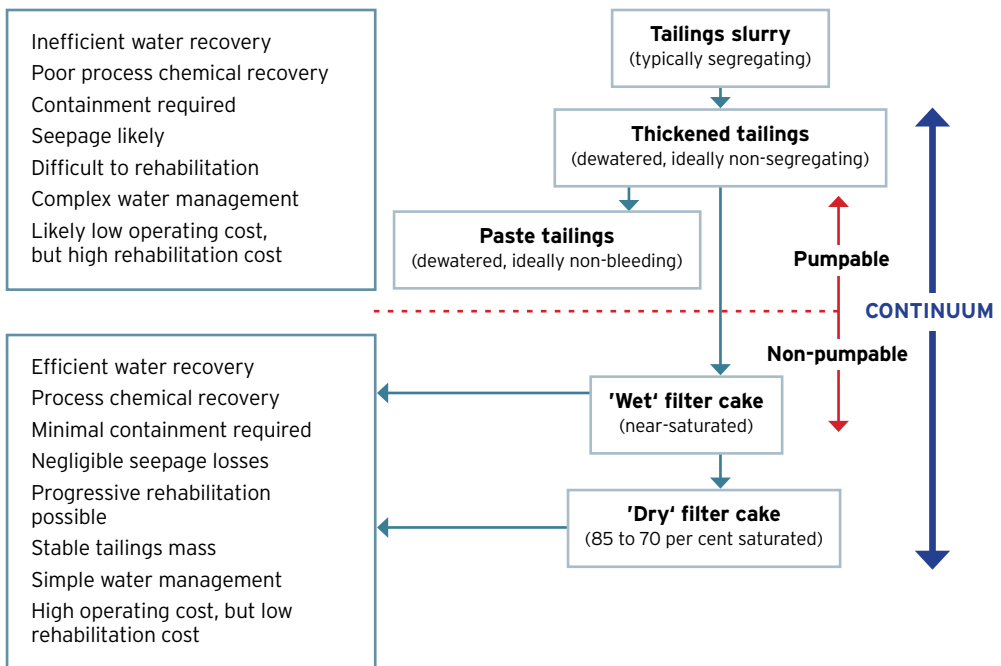
Improvements in the design and operation of centrifuges and filters, and most especially in the flocculants needed to prepare the tailings, have improved the efficiencies of the equipment and reduced the costs of dewatering.

Dewatered tailings can be trucked, conveyed or pumped to storage locations or can be used in mine backfilling as a means of controlling the water content of the fill material.

Historically, power station fly ash, which is produced dry, has been sluiced from the bottom of the boilers and pumped as very low solids concentration slurry to disposal. This practice consumes large quantities of water and can cause considerable environmental harm.

Many power stations are now collecting and transporting the fly ash dry, using trucks or conveyor systems. This has reduced the storage volume requirement by as much as 50 per cent, minimised the potential for seepage, and enabled a more flexible dump design. The one draw-back of dry disposal is the higher risk of dust problems.

Figure 4 illustrates the full range of pumpable tailings thickening and non-pumpable tailings filtration options. Where it is cost-effective to dewater tailings to a wet or dry filter cake, the tailings may be transported by conveyor or truck to the tailings storage facility, where it can be 'stacked', or combined with coarse-grained waste disposal.



**Figure 4: Tailings Continuum (Conrad Tailings Seminar, AMEC Earth and Environmental 2004)**

### 6.1.3 Co-disposal

The co-disposal of the coarse and fine wastes from a mine provides the means to reduce the volume or footprint required to store the separate waste streams, and produce a more stable deposit, with obvious economic, social and environmental benefits. A key challenge with co-disposal is to find a safe method of mixing the two waste streams economically. Logistically, it can be difficult to mix the two operations of large haul trucks dumping waste rock and slurry pipeline discharge, particularly as the dump face is moving continuously. One successful co-disposal operation involved the filling of a completed open pit by the end-dumping of benign waste rock from the crest at one end and the deposition of thickened benign tailings from the other (Williams 2002).



### **Co-disposed waste rock and thickened tailings in a completed open pit**

In coal mining, it is possible to combine the coal washery coarse and fine rejects, and pump and co-dispose this stream. The co-disposal mixture provides a coarse-grained upper beach, which is trafficable and forms a stable outer perimeter containment wall for the balance of the segregating fines. While pumped co-disposal requires a large volume of transport water, the system does not lose any more water than slurry tailings disposal alone.



### **Co-disposed coal washery wastes**

#### **6.1.4 Paste rock**

Paste rock is defined as an integrated mixture of paste tailings and waste rock, which can potentially be used as a sealing material in covers over potentially contaminating mine wastes. For this application, the tailings and waste rock selected must be benign. The waste

rock is typically limited to 100 mm top size by crushing and screening. This size restriction facilitates mixing and ensures a good mixture consistency. The waste rock can be combined with tailings slurry, with dried tailings and mixed mechanically, or mixed with paste tailings to form the paste rock.

Paste rock achieves a high density and low hydraulic conductivity, making it well-suited for use as a sealing material. It has particular application at mine sites where supplies of natural clays for sealing purposes are limited or absent, and achieves a hydraulic conductivity at least comparable, and often lower, to that achieved by compacted natural clay.



**Paste rock**

### 6.1.5 Void backfill

Mining creates voids and it would seem that the most environmentally responsible place to store tailings would be in these voids. A review of leading practice in the use of paste tailings underground backfill and the backfilling of open pits is provided in Povtin et al. (2005). While underground mines create voids that can be used to store tailings during the life of the mine, it is rare that an open pit mine will complete a void before the end of the life of the mine, and in-pit tailings disposal may sterilise future pit reserves.

In Western Australia and the Northern Territory it has been shown that it can be economical for a mine to remove its tailings storage facility and place its tailings in the completed open pit, especially where these tailings pose a future risk to the environment (for example, from acid and metalliferous drainage). See the Woodcutters Mine case study in the *Managing Acidic and Metalliferous Drainage Handbook* in this series. Typically, in these cases the tailings would be re-mined, conditioned to a paste consistency and then pumped or gravity-fed into the pit. Shovel and truck rehandling can be used for those tailings which have undergone sufficient dewatering and consolidation.

## CASE STUDY: In-Pit Tailings Storage at Granites Gold Mine, NT

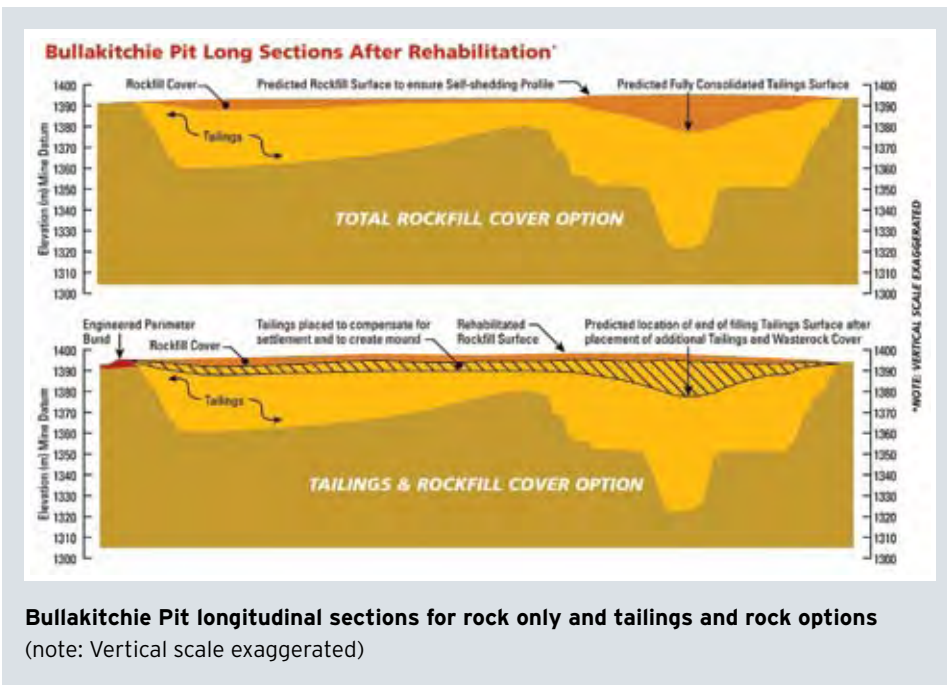
Granites Gold Mine, operated by Newmont Australia Ltd, has a number of worked out pits which are being progressively filled with tailings. Bullakitchie Pit was the first pit to be filled.

The traditional landowners and the Central Lands Council require pits to be backfilled where possible. The adopted strategy has been to rehabilitate them to a self-shedding landform. A number of consultations were held on site with the key stakeholders to gain agreement on closure strategies prior to their implementation. The quantity of waste rock required to form a suitable cover, allowing for future settlement, was estimated at 350 000 m<sup>3</sup>. To reduce costs and waste rock requirements, the pit was periodically topped up with tailings discharged from the centre, compensating for ongoing settlement and forming the self-shedding landform. Tailings were discharged intermittently from 2000 to 2002, and the final tailings surface desiccated to form a trafficable crust. Seepage from the deposited tailings has been closely monitored via perimeter monitoring bores. Impacts from in-pit tailings placement, while measurable, have been closely confined to an immediate halo around the pit.



### **Creating a self-shedding profile by central discharge of thickened tailings into Bullakitchie Pit**

Tailings were discharged at a slow rate from a series of central standpipes. A low perimeter containment bund was created at low points to minimise the risk of stormwater escaping from the site during rainfall events. The use of tailings reduced the amount of waste rock used by about 150 000 m<sup>3</sup>. The cost saving of using tailings instead of waste rock was of the order of \$350 000. Future pits will be rehabilitated using similar principles. The final landform blends with the surrounding landscape as a slight rise over what was the pit.



There has historically been some disposal of tailings slurry to underground workings, and the inclusion of coarse-grained tailings in cemented hydraulic backfill for underground stopes to allow the complete extraction of the orebody. More recently, cemented paste tailings has gained increasing use for the backfilling of underground stopes.

## 6.2 Improved final tailings landform

The majority of tailings storage facilities are constructed on the surface and therefore form an elevated landform, making them highly visible and also providing the potential for erosion. Tailings storage facilities should therefore be planned, designed, constructed and rehabilitated with aesthetics and erosion potential clearly in mind. The likelihood that the tailings storage facilities will expand during the operation of the mine and processing plant should also be carefully considered. The final tailings landform should be aesthetically acceptable, present negligible public health and safety risks, and present an acceptably low risk of future harm to the environment.

There is increasing pressure for tailings storage facility final landforms to be less visible, and for progressive rehabilitation and underground or in-pit disposal to occur, where possible. In cases where mining is advanced as a series of pits, the progressive filling of mined-out pits with mining wastes should be favourably considered.

### 6.2.1 Integrated final landform design

Mine sites naturally tend to separate the different elements involved – open pits, underground workings, waste rock piles, tailings disposal facilities, the processing plant and the office complex.

It is necessary to separate the processing plant and office complex, but these do not generally involve extensive earthworks and are readily rehabilitated on closure. It is also generally necessary to operate open pits and underground workings unencumbered by other elements. The mining and processing of an orebody naturally involves the separation of materials according to their mineralogy and particle size, and the waste streams of different mineralogy and particle size tend to be disposed of separately. However, it may not be necessary nor desirable to completely separate waste rock piles and tailings storage facilities, and completed open pits and underground workings can be used to store mining and processing wastes.

Waste rock piles and tailings storage facilities may well be able to share a common wall and the two final landforms may be integrated. Waste rock can be cost-effectively pushed into wet or desiccated tailings during dumping operations, creating a stable platform over the tailings on which the final cover may be constructed. This outcome will ensure that community and environmental interests and concerns can be better met.



**Waste rock pushed into desiccated tailings**

### 6.2.2 Mimicking natural analogues

Ideally, surface tailings landforms should mimic surrounding natural landform analogues, in terms of their geometry, surface cover and texture, and stability. Tailings storage facilities on flat terrain, such as the geologically old, arid to semi-arid inland of Australia, are relatively shallow and cover a relatively large area. However, even in a naturally flat topography there is some vertical relief, and this typically involves relatively low mounds extending over large areas, a product of the long periods of weathering and erosion that sculpt the flat landform.



It is therefore possible to design and construct tailings landforms to mimic natural landforms in flat terrain.



### **Shallow, extensive tailings and natural elevated landforms**

In a dry climate, where vegetation cover is naturally limited, the sustainability and erosion-resistance of slopes is dependent on a rocky surface texture which is vegetated, at best, by sparse shrubs. For semi-arid conditions, the dished tops of tailings landforms may be revegetated, either directly or after the placement of a suitable cover. In arid conditions, the dished tops of tailings landforms will resemble elevated saltpans, analogous to natural saltpan depressions that are covered by fine-textured soils and vegetated only by sparse salt-tolerant species. However, consideration must be given to the possibility of dust entraining metals emanating from uncovered or poorly-vegetated tailings surfaces.



### **Direct revegetation on tailings in a semi-arid climate**



### **Salt-tolerant vegetation on an arid saltpan**

In an arid climate, closed tailings storage facilities will de-saturate, and are likely to maintain a net upward flux of water, driven by evaporation. Any downward water flux following high rainfall is likely to be limited (unless significant ponding occurs), with evaporation driving a return to upward water flux before any significant percolation through the tailings occurs.

This is analogous to the water flux of natural salt pans, which give rise to very limited and slow recharge to the ground.

In a wetter climate, to avoid the percolation of potentially contaminated tailings water to the toe of the tailings storage facility or to the ground, it may be necessary to provide a permanent spillway to remove runoff from high rainfall events. The spillway should, where possible, be excavated through natural rock or a concrete-lined spillway provided. The runoff will need to have sufficient residence in a sediment pond to allow any suspended solids to be collected, and may need treatment to ensure acceptable water quality prior to release.

All landforms erode over time. Tailings storage facilities are no different. As a consequence, stored tailings should be encapsulated by a thick surround of benign material, covered by rock and/or vegetation that limits erosion loss. Further, run-off from the top of the tailings landform should not be directed over the outer slopes, but either evaporated and/or transpired by vegetation, or directed to a purpose-built spillway.

### 6.3 Tailings Minimisation, Recycling and Reuse

The most efficient hierarchy is to first reduce tailings production, and then to recycle and reuse the tailings where possible. The aim should be for cleaner and more targeted mineral processing that minimises tailings production. Every opportunity for their recycling and reuse should also be explored. In many instances, tailings have inherent value, through reprocessing or via other industrial uses. For this reason, the disposal of tailings in a way that will make tailings recovery or re-treatment uneconomic, or prevent future mining activities is often actively discouraged. Extreme examples of this would be underground and pit backfilling.

Historical gold tailings are the prime example of changing technology providing a means to make re-processing viable. This is also the case for a range of other types of mine tailings.

There is an opportunity to use some tailings for industrial or environmental purposes, thus reducing the storage requirement. These include:

- the finer portions of fly ash used as a pozzolanic in the manufacture of cements
- power station bottom ash used as inert building fill
- red mud from the alumina industry used as a soil conditioner and to clean polluted water streams
- power station ash used to fill coal mining voids
- coal tailings used as a low grade fuel.

Where mineral processing, refining or smelting operations are located within industrial regions, synergistic opportunities may exist where waste streams from one industrial process may become a valued input to other industrial process. This industrial ecology approach (also termed regional synergies) is being undertaken at the Gladstone (Queensland) and Kwinana (Western Australia) industrial areas (refer to [www.csrp.com.au](http://www.csrp.com.au)).

## CASE STUDY: Thickened Red Mud Residue Disposal at Kwinana, WA

Alcoa World Alumina Australia (Alcoa) has three alumina refineries in WA, at Kwinana, Pinjarra and Wagerup, with a combined capacity of around 7.8 Mtpa of alumina.

During the refining process, a caustic soda solution is added to the bauxite to dissolve the alumina, allowing separation of the alumina (in solution) from the un-reactive solids. Although the solids are washed to recover and recycle caustic, the final residue still contains a residual level of caustic, or alkalinity, and the solution entrained with it has a pH of around 13.5.

Since the mid-1970s, Alcoa has moved towards more sustainable residue storage practices. This commitment has seen a transition from traditional wet disposal to thickened tailings disposal, developed and implemented at Alcoa's three Western Australian refineries through the late 1980s.



### **Kwinana area red mud residue storage facility**

Alcoa's worldwide operations now use thickened tailings disposal, and this technique has subsequently become accepted as industry best practice as it increases the volume of residue that can be stored within a given footprint, and significantly reduces the potential for impacts to the surrounding environment.

Alcoa has also continued to search for ways to neutralise the residue, decreasing the pH of the deposit to further lessen its potential for environmental impact. Residue carbonation (treating the residue with waste CO<sub>2</sub>) has been developed, tested and subsequently piloted at the Kwinana refinery, and has been shown to significantly decrease the alkalinity of the residue. This in turn reduces its potential for environmental impacts and opens possibilities for reuse of the more benign residue in other processes.

The process has been adopted at the Kwinana refinery, and the potential to progressively implement the technology at Alcoa's other refineries in WA and throughout the world is being evaluated. It is anticipated that residue carbonation will become the new best practice benchmark for residue treatment and storage in the alumina industry worldwide.

However, the ultimate aim in terms of sustainability of residue management, and in turn the sustainability of bauxite refining, is to have no residue to store. The move to thickened tailings disposal was a critical step along the pathway toward reuse, as it produced a readily accessible residue (through excavation from the drying beds) at a relatively low cost. Neutralisation of the residue is seen as a similar step along this same pathway, as the more significant hazard associated with the residue (its high pH) has been removed.

Alcoa continues to support a large amount of research into potential beneficial uses of residue.



## 7.0 CONCLUSION

A broad sustainable development framework must be applied to the initial design of tailings storage facilities, tailings management and tailings storage facility closure. Management systems incorporating a life-of-mine risk-based approach are needed to ensure that operating and closure objectives are met. There are many examples of leading practice available to assist mining companies achieve a responsible outcome, and a number of these have been documented in this handbook.

Tailings storage facilities should provide safe, stable and economical storage of tailings in such a way that presents negligible public health and safety risks, and acceptably low social and environmental impacts during operation and post-closure. A systematic approach to effective tailings management is advocated, which includes the implementation of risk-based management strategies that account for the viewpoints and expectations of the communities in which companies operate. Short-term cost savings aimed at minimising the costs of tailings management, storage and closure must be weighed against the potentially high social and environmental risks, and associated high remediation costs if failure occurs.

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## WEB SITES AND LINKS

- Department of the Environment and Heritage, [www.deh.gov.au](http://www.deh.gov.au)
- Department of Industry, Tourism and Resources, [www.industry.gov.au](http://www.industry.gov.au)
- Leading Practice Sustainable Development Program [www.industry.gov.au/sdmining](http://www.industry.gov.au/sdmining)
- Ministerial Council on Mineral and Petroleum Resources, [www.industry.gov.au/resources/mcmprr](http://www.industry.gov.au/resources/mcmprr)
- Minerals Council of Australia, [www.minerals.org.au](http://www.minerals.org.au)
- Enduring Value, [www.minerals.org.au/enduringvalue](http://www.minerals.org.au/enduringvalue)
- Australian Centre for Geomechanics, Curtin University, [www.acg.uwa.edu.au](http://www.acg.uwa.edu.au)
- NSW Dams Safety Committee, [www.damsafety.nsw.gov.au](http://www.damsafety.nsw.gov.au)
- International Commission on Large Dams (ICOLD) bulletins, [www.icold-cigb.net](http://www.icold-cigb.net)
- Tailings information, [www.tailings.info](http://www.tailings.info)
- Infomine, [www.infomine.com](http://www.infomine.com)
- Mining Association of Canada, [www.mining.ca/www/Public\\_Policy\\_Issues/Tailings.php](http://www.mining.ca/www/Public_Policy_Issues/Tailings.php)
- United Nations Environment Programme, Mining [www.unep.org/pc/mining](http://www.unep.org/pc/mining)
- International Council on Mining and Metals, Good Practice Library, [www.goodpracticemining.com/tailings](http://www.goodpracticemining.com/tailings)

### Guidelines

- *Guidelines on the Safe Design and Operating Standards for Tailings Storage 1999* Department of Minerals and Energy, [www.natural-resources.org](http://www.natural-resources.org)
- *Guidelines on the Development of Operating Manual for Tailings Storage 1998*, Department of Minerals and Energy, [www.natural-resources.org](http://www.natural-resources.org)
- *Management of Tailings Storage Facilities 2004*, Victorian Department of Primary Industries, [www.dpi.vic.gov.au](http://www.dpi.vic.gov.au)
- *Queensland Dam Safety Management Guidelines 2002*, Queensland Department of Natural Resources, [www.nrw.qld.gov.au/compliance/wic/guidelines\\_refer\\_dams.html](http://www.nrw.qld.gov.au/compliance/wic/guidelines_refer_dams.html)
- *Guidelines on Tailings Dam Design, Construction and Operation 1999*, Australian National Committee on Large Dams, [www.ancold.org.au](http://www.ancold.org.au)
- *Guidelines on Dam Safety Management 2003*, Australian National Committee on Large Dams, [www.ancold.org.au](http://www.ancold.org.au)

## GLOSSARY

Acid and metalliferous drainage	Acid and metalliferous drainage, traditionally referred to as acid mine drainage or acid rock drainage, includes both acidic, metalliferous drainage, and near-neutral but metalliferous drainage.
Adaptive management	A systemic process for continually improving management policies and practices by learning from the outcomes of operational programs. The ICMM Good Practice Guidance on Mining and Biodiversity refers to adaptive management as 'do-monitor-evaluate-revise'.
Bund	An earthen retaining wall.
Capillary break	A coarse-grained material with a limited capillary rise, intended to limit the uptake of contaminants.
Cemented paste tailings	Tailings with the consistency of a paste, to which cement is added to enhance strength for underground stope backfill.
Centreline method, construction or raising	Construction of the tailings containment walls above a fixed crest alignment, using waste rock, borrow materials or tailings.
Central thickened discharge	The discharge of thickened tailings from one or more towers or discharges located within the body of the facility, with only a nominal perimeter wall where any supernatant water is recovered.
Centrifuge	A device that dewateres a slurry through the application of centrifugal force against a drainage surface.
Coarse (coal) reject	The coarse fraction of the mineral matter removed from run-of-mine coal by washing.
Co-disposal	The combined disposal of coarse and fine-grained mine wastes, such as the pumped co-disposal of coal washery wastes.
Community	There are many ways to define 'community'. In mining industry terms, community is generally applied to the inhabitants of immediate and surrounding areas who are affected by a company's activities. 'Local community' usually indicates a community in which operations are located and may include Indigenous and non-Indigenous people.
Community impact	Detrimental harm to the neighbouring community.
Consolidation	The expulsion of water from settled slurry.
Consultation	The act of providing information or advice on, and seeking responses to, an actual or proposed event, activity or process.

Containment wall	A structure providing outer encapsulation for tailings.
Decant or supernatant water	Body of process water that has separated from the tailings solids (supernatant water) in the tailings storage facility, plus any rainfall runoff collected on the facility.
Decant pond	Body of supernatant water that has separated from the tailings solids (process water), plus any rainfall runoff collected on the tailings storage facility.
Deep bed thickener	A thickener relying on a lifting action to minimise the likelihood of bogging and allowing a deep bed of slurry to be thickened and delivered on demand.
Desiccation	Drying, shrinkage and cracking of the tailings surface by solar evaporation.
Dewatering	Removal of water from a slurry by thickening, filtration or centrifuging.
Dewatering in situ	Drain-down of deposited wet tailings as they undergo sedimentation, consolidation and desiccation.
Down Valley Discharge	Discharge of thickened tailings down a valley towards a containment wall, located at the head of a catchment.
Downstream method, construction or raising	Construction of the tailings containment walls in a downstream direction, generally using waste rock or borrow materials.
Downstream or outer face	External perimeter of a tailings storage facility exposed to the environment.
Embankment	A term describing a tailings or water containment wall.
Encapsulation	Surrounding a reactive waste by benign materials that isolate the reactive waste material from oxygen ingress and/or water flow.
Environmental impact	Detrimental harm to the environment.
Factor of safety	The factor by which the resisting actions exceed the disturbing actions.
Failure modes	The mechanisms by which a tailings storage facility may fail.
Filter cake	The semi-solid structure formed on the application of pressure during filtration of a slurry.
Filter press	A device that dewateres a slurry to the consistency of a filter cake through the application of pressure across two drainage surfaces between which the slurry is passed.
Fine (coal) reject	The fine fraction of the mineral matter removed from run-of-mine coal by washing.

Flocculants	Chemical additives that facilitate the agglomeration of tailings particles to aid and speed up their sedimentation and consolidation.
Freeboard	The elevation of the crest of the containment wall above the tailings surface, which provides for the storage of storm water.
Geomembrane	A manufactured low permeability sheet such as high density polyethylene (HDPE).
Geotechnical	The engineering of the ground and or earthen structures.
Hazard	A potential to cause of harm.
High compression thickener	A high rate thickener, with added compression derived from the configuration of the rakes to increase the density achievable.
High rate thickener	A thickener through which a slurry is passed at a high rate, with limited residence time, allowing a high flocculant dose.
Hydraulic conductivity	Otherwise known as (water) permeability; a measure of the ability of a porous material to pass water.
Hydraulic backfill	Fill that is placed as a fluid.
Industrial ecology	Synergies between industrial processes.
Infiltration	The ingress of water into a porous material.
Leading practice	Best available current practice promoting sustainable development.
Liner	A low permeability base comprising compacted clay, and/or a geomembrane or geosynthetic (clay in a geotextile “sandwich”).
Natural analogue	An unmined landform to which a mined landform may be compared to develop sustainable post-mining landforms.
Paste tailings	Tailings slurry thickened to a paste consistency, with a high yield stress, and reduced slump and bleed water. Cement is added to produce cemented paste tailings backfill for underground mine stopes.
Percolation	The seepage of infiltration to the receiving environment.
Piezometers	Sensors used to monitor groundwater mounding beneath and surrounding a tailings storage facility.
Piping	The formation of an erosion tunnel through an earthen structure due to the induced flow of water through it.
Power station ash	A by-product of the production of electricity from coal-fired power stations.
Public health risk	The likelihood of harm to public health.
Quality assurance	Ensuring the quality of a process, for example construction, including the documentation and reporting of test work.
Reagent recovery	Capture of processing chemicals from the tailings stream.

Red mud residue	A by-product of the production of alumina from bauxite.
Rehabilitation	The rendering of a safe, stable and non-polluting tailings storage facility in the long-term, taking into account beneficial uses of the site and surrounding land.
Return water pumping and pipeline system	Designed to return supernatant process water back to the mineral processing plant (recycling).
Rheology	The study of the deformation and flow of tailings slurry under the influence of an applied stress.
Risk	The likelihood of actual harm.
Personal safety	Preserving the safety of mine site personnel and the general public in the face of mine site risks of injury.
Sedimentation	The separation of solids from an aqueous slurry.
Seepage control system	May include a compacted foundation or liner (compacted clay or geomembrane), and an under-drainage collection system.
Slope	Refers to the angle of the tailings containment walls and of the tailings beach.
Social impact	Detrimental harm to society.
Social licence to operate	The social licence is the recognition and acceptance of a company's contribution to the community in which it operates, moving beyond meeting basic legal requirements towards developing and maintaining the constructive stakeholder relationships necessary for business to be sustainable. Overall, it comes from striving for relationships based on honesty and mutual respect.
Spigot	A branch off the main tailings delivery pipeline from which tailings are discharged from the containment wall of a tailings storage facility.
Spillway	A structure constructed at the perimeter of a tailings storage facility, designed to pass excessive rainfall runoff.
Stakeholder	A person, group or organisation with the potential to affect or be affected by the process of, or outcome of, mine closure.
Starter wall	The initial containment wall of a tailings storage facility.
Store/release cover	A vegetated, non-shedding soil cover, aimed at minimising percolation through it by the release of stored seasonal rainfall by evapo-transpiration during the dry season.
Supernatant water	The water ponded on a tailings surface following the sedimentation of the deposited tailings slurry.

Tailings	A combination of the fine-grained solid material remaining after the recoverable metals and minerals have been extracted from crushed and ground mined ore, and any process water remaining.
Tailings beach	The delta that forms on discharge of a flowable slurry.
Tailings containment	Usually constructed initially as an earthen starter embankment, with wall raises constructed using borrow material and/or tailings. Construction may be downstream using borrow material, or centreline or upstream using borrow material or predominantly tailings.
Tailings management	Managing tailings over their life cycle, including their production, transport, placement, and storage, and the closure and rehabilitation of the tailings storage facility.
Tailings pumping and pipeline system	Designed to deliver tailings slurry from the mineral processing plant to the tailings storage facility.
Tailings slurry	Tailings solids embedded in process water that are produced in the processing plant at a low density, which beach at a flat slope, segregate down the beach, and produce considerable supernatant water.
Tailings storage facility	An area used to contain tailings; its prime function is to achieve solids sedimentation, consolidation and desiccation, and to facilitate water recovery or removal without impacting the environment. It refers to the overall facility, and may include one or more tailings storages.
Thickened tailings	Tailings thickened to a high density, which beach at a steeper slope and segregate less than tailings slurry, producing far less supernatant water.
Thickener	A device for increasing the density of a slurry.
Under-drainage	The provision of drains beneath a tailings deposit to facilitate their drain-down.
Upstream method, construction or raising	Construction of the tailings containment walls in an upstream direction on top of consolidated and desiccated tailings, using waste rock or tailings.
Water balance	The sum of the water inputs, including process water and rainfall runoff, and outputs, including evaporation, return water, water entrained in the tailings and seepage, in a tailings storage facility.

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