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CHAPTER 18

Waste Handling and Storage

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Waste Handling and Storage

This chapter discusses handling and storage of waste, including environmental considerations and the items for costings for waste management.

INTRODUCTION

Wastes are defined generically as materials deriving from human activities that have no perceived present commercial value. Their temporary or permanent storage or disposal is then a cost that must be borne by present production.

The recognition of wastes deriving from mining and mineral processing has been, in the past, quite clear. However, in recent times, this recognition has become more complex through the introduction of the principles of sustainability incorporated in mining environmental policies such as 'Enduring Value' (Minerals Council of Australia, 2005).

Wastes associated with mining and mineral processing include:

- camp and town solid and liquid wastes (garbage, contaminated water and sewage sludge)
- construction and demolition wastes and contaminated soils deriving from site rehabilitation on the cessation of operations
- residues from heap-leaching, water treatment and disposal, which commonly include soluble or unstable salts and potentially contaminating compounds
- tailings, coal washery and sand mining slimes and the red muds deriving from alumina production
- waste rock including overburden and barren country rock as well as mineralised material below cut-off grade.

The generation of waste materials from mining projects is increasing very substantially as the ore grades that can now be mined economically have decreased in parallel with increased commodity prices and as increasingly efficient mining and ore treatment processes. These changes were set out by Mudd (2007a). They are evident when considering the magnitude of the waste generated by operations such as the Argyle diamond mine in Western Australia (Environmental Protection Authority of Western Australia, 2005) or being considered in relation to the future stages at Olympic Dam project in South Australia (BHP Billiton, 2009). All these wastes need to be managed throughout the period of operations and reasonably contained to protect the environment into the future.

It has been normal practice in the past to store mining 'wastes' of subeconomic value to be contained for their inherent value. In fact, by definition, it is incorrect for tailings to be defined as waste until such time as the project that created them becomes non-viable overall. Only at this time should closure and final containment be implemented.

When new technologies and beneficial economics emerge, tailings at least can be recovered for further processing. Containments to facilitate recovery, for the most part, do not involve progressive rehabilitation. Simple storage is acceptable as long as costs associated with minimising risks to the contiguous environment from incomplete containment are acceptable. In the past, final containment has all too commonly only been considered when financial provisions for rehabilitation have become limited by the loss of cash flow and the recognition that funding provisions were inadequate.

Such situations are no longer acceptable. Substantial rehabilitation provisions in the form of bonds or non-redeemable financial assurances are now required by law in all Australian states and in most other countries. These can involve commitments to pay tens to hundreds of millions of dollars, depending on the size and complexity of the rehabilitation required, to permanently stabilise mining residues within the natural environment.

Modern Australian mining regulation is built around minimising the environmental footprint left by mining projects. This objective demands both waste containment and progressive rehabilitation. Achieving these requirements is assisted where the intrinsic value and risks inherent in 'waste' materials is recognised at the project outset (and/or as the project develops).

Intrinsic value of what may be defined as wastes may arise through the physical (size range, shape, geotechnical parameters) or chemical characteristics (exchange, sequestration capacity or reactivity) of the waste, or to the degree that they need to be encapsulated so as not to be a source of environmental degradation in the future.

In most cases, waste rock at least should be used for on-site civil engineering construction. Uses include the usual range of civil engineering demands to support construction, road and rail infrastructure. Uses also include fill, dam and tailings storage construction materials, or to create hydrologically effective lining systems. The parameters dictating suitability for these purposes are fundamentally geotechnical and very well understood. What is less commonly recognised is the need to define the geochemical parameters of the materials to establish their suitability for use in preventing issues such as acid generation and/or acid mine drainage. Equally, the susceptibility of material to decay and lose geotechnical properties when subjected to lithostatic stress release and weathering over the years (wetting and drying, oxidation and erosion) is important. Material susceptibility needs to be taken into account in planning waste rock use and placement during and beyond the project life.

Where mining is close to established communities, local demand should be considered in order to reduce the necessary on-site project footprint (eg the New Bendigo Gold mine). Modern mining projects should consider all wastes and all opportunities for off-site use as soon as managers are confident that they have materials excess to the project demands. In particular, the potential for achieving environmental benefits by incorporating organic (biodegradable) wastes into mine waste systems either progressively or in final capping should not be overlooked, as this can minimise the generation of acid mine/rock drainage (AMD) issues later. Where such strategies apply, retaining biodegradable wastes such as sewage sludges, and food and green wastes can be of special importance in future soil engineering.

It is essential for modern mining projects to evaluate and characterise the above parameters to detect opportunities with reasonable certainty at the project outset, along with the necessary volumetric or mass allowances. This will allow use and/or containment to be rationally planned and costed within project feasibility studies, along with containment of the project's 'environmental footprint'.

Notwithstanding the above considerations, and accepting the need for progressive containment and rehabilitation of materials recognised as having potential resource value, the processes need to ensure that waste containment and use is not such as to sterilise these materials for further processing in the future, should this become feasible and economically preferable to their use in other applications.

It is obvious that costing cannot foresee all these issues at project outset. It is important to make adequate provisions when considering the options available during prefeasibility studies such that a basis exists for refinement as the project is more closely defined from outset to closure. If this is not done at the outset, the overall feasibility of the project can be negatively affected such that the desired returns cannot be achieved. In addition, damage may be done to the project proponent's reputation for responsible project development and implementation. Such results have occurred all too frequently in the past with very damaging consequences for those personally involved, as well as for trusted corporations. Examples include the Ok Tedi (Wikipedia, 2006), Bougainville Copper (Lax, 1986; Brown, 1974; Stephenson, 1978) and Rum Jungle (Mudd, 2004) projects, which gave rise to environmental issues with consequent serious social unrest and cost to the proponents.

WASTE HANDLING

Waste handling for costing purposes should be considered under two headings:

1. dry waste rock and earth
2. wet waste, slurries and sludges.

The geotechnical and geochemical (including radioactive) characteristics of wastes as well as the climatic and social factors around the mine site will be the primary dictators of how and where wastes may be placed. The next most important issues are the geotechnical and geochemical characteristics of the potential sites available. The environmental risks and potential future value will then define the specifics of engineering and management arising from the nature and design of their containment.

Dry waste

Dry waste rock and earth may arise from blasting in open cut or underground mines or from ripping or dragline operations such as are widely practiced in coal, mineral sands and bauxite mining.

Soil is commonly removed separately by scraper and should be stored separately from waste rock for future use in site rehabilitation and capping of other wastes. Soil is a resource and should be stored such that the organic components of the soil, its pedology and seed storage are preserved from degradation as far as possible.

Harder materials from metalliferous mines are commonly placed by dumping from haulage trucks and will be free-draining in waste rock dumps (free moisture content of five to 15 per cent). They will be geotechnically stable in the long-term with internal friction angles for stable dump slopes at 35 - 50°. However, rock fabric decay can reduce the stable angles significantly over time, especially where the waste rock is a claystone or shale and/or where the rock mass is sulfidic.

Softer rocks and weakly lithified materials can be less freely draining. Further, depending on their mineralogy and potential for decay and loss of strength after placement, these materials can be quite unstable even with slope angles <20°. This latter issue is exacerbated where moisture and infiltration drains to and increases hydrostatic pore pressures in deeper layers and towards the toe of the dump. The potential for instability can be offset by selecting dump sites that are naturally contained (eg in-pit placement), or by dump perimeter surcharging with stable free-draining material. With such provisions, stable angles of 20 - 35° can be achieved and maintained.

Removing and placing waste rock will generally involve trucking the material from its source within the mine in a single trip to the waste dump. Depending on the beneficial characteristics of the material, waste rock can also be placed in some specified subsidiary dump that uses those characteristics; for example, for containment of potentially negative characteristics of other wastes, or for civil engineering construction applications.

The preservation of biodegradable wastes is most commonly achieved in windrows for drying and composting, or in layered drained containments where odour is an issue.

Spent leach heaps represent a special variety of mine waste as they are commonly contaminated with residues of the leaching agents (eg cyanide) for long periods after active processing has been terminated. Over this period, they drain to become dry wastes, but may need to be rehabilitated and encapsulated to ensure they do not present a contamination risk in the environment. Cost allowance for this work needs to be provided at the outset unless it can be confidently predicted that post-leaching, spent leach heaps will naturally become environmentally benign or they can be treated to achieve the same condition.

Where the residues of leach heap operations become adequately flushed or degraded of contaminating chemical residues over time, they may be treated as dry wastes. They can then be transferred to waste rock and subgrade ore dumps where their geochemical properties may be beneficial. Alternatively, they may be suitable for civil engineering use, although obtaining permits for such use from conservative regulators can be so difficult and expensive that they may be uneconomic. Elements to be costed in waste handling operations are:

- initial feasibility studies:
  - geochemical and geotechnical characterisation of all waste material types
  - internal management and external specialist costs associated with approvals, permitting and stakeholder liaison
  - site investigations and preliminary design including containment facility location and design based on environmental, geotechnical, geochemical, regulatory and other criteria as appropriate
  - staged development of waste repositories based on waste production schedule (volumes and types)
- design costs including site investigations, analysis and contract document production (drawings, specifications, manuals of operation, etc) of the selected waste containment facility
- construction costs including:
  - construction of the facility and associated assets
  - development of infrastructure including roads to the dump site and any loading or other material handling facilities; this includes facilities required for reuse of materials on- or off-site if applicable
- operational costs:
  - dust suppression watering by sprinkler and wet-down trucks
  - monitoring and regulatory or other reporting
  - provision and operation of appropriate transport mechanism such as conveyor systems or vehicles
  - run-off and drainage provision, including dump drainage collection and any treatment and disposal system provision
- rehabilitation, progressive or otherwise, including:
  - dump surface profiling, drainage, soil development and revegetation
  - provision of sediment traps and run-off mitigation retention works
  - erosion, hydrological and dust monitoring, including release rates, geochemical parameters in surface and groundwater as well as vegetation health and variety, ecological niche re-establishment and airborne dust particle size in some cases
  - ongoing monitoring post-closure as required by the regulatory or other applicable standards as appropriate.

The footprint of the facility may in some cases be reduced by sale or export of waste rock for external civil engineering construction. This may be done by others without creating risks to the long-term waste rock containment required for environmental protection.

Wet waste

Wet wastes such as tailings from base metal, uranium and precious metal mines and heap-leach residues are commonly a consequence of at least substantial combination, if not chemical treatment and/or flotation processes as well. Similar wastes derive from coal washing and from mineral sand separation processes.

Mostly, wet wastes are delivered by pipeline to tailings storage facilities (TSF) as a slurry with a solids content of 20 to 60 per cent. With proper distribution and management of spigot outlets around tailings retention facilities, beaching, evaporation, consolidation under loading and efficient fluid recovery may reduce the moisture content of relatively coarse (>0.1 mm) tailings to less than 20 per cent. Where the main grain size is fine, moisture will commonly remain trapped towards decant points within the mass at between 30 and 40 per cent, especially if clay minerals predominate in mine tailings.

Optimising conditions by thickening and other means can give rise to plasticity indexes between

30 and five per cent and liquid limits between 50 and 30 per cent for coal washery slimes, and a bit higher for the more angular particulates from hard rock/mineral ore comminution circuits. Higher moisture contents may apply where tailings are necessarily placed and maintained beneath water covers, such as in uranium tailings.

Similarly, bauxite beneficiation tailings (red muds) exhibit, at least initially, very low strength when placed. However, depending on their mineralogy, they may gain some strength later as internal precipitation takes place. Geotechnical characteristics may be improved by the use of flocculants and mixing other coagulants and bonding agents into the waste stream to stimulate these processes (Lettermoser, 2003; Wingenfelder *et al*, 2005).

Optimising geotechnical parameters in wet waste containment facilities can markedly affect the capital cost of wet waste facility engineering. Thus, recognising the characteristics achievable with wet wastes after placement is important in the design of tailing repositories. Design of the tailing repositories includes the design of the distribution systems and in the ease or difficulty of handling and encapsulating these materials for later recovery, facility expansion or lift, and facility closure.

The costing of facilities to handle wet waste may incorporate:

- investigations into the geotechnical, hydrological and geochemical characteristics of the wet waste and alternative repository sites; this work will dictate the lengths, materials and performance characteristics required for pipes and pumps in slurry delivery and water recovery
- provision for the diversion of natural stream courses
- construction material selection, source identification and material property documentation
- evaluation of the geotechnical, hydrological and geochemical characteristics and behaviour of the wastes after placement and over time post-closure; this work will dictate the design of repository facilities and the frequency of lateral expansion or lifts, which will be necessary over time
- construction scheduling over the mine life including tailings or waste recovery and reworking options
- construction including quality assurance
- evaluation of environmental impacts, management and monitoring systems necessary to prove that the waste handling operation objectives are being met
- determination of adverse monitoring response triggers and mitigation engineering action
- permitting of the waste handling system and repository
- repository closure planning and implementation including revegetation and site protection and post-closure monitoring
- site closure sign off
- design and modelling of the tailings or waste repository behaviour with respect to:
    - hydrological integrity of the structures
    - contaminant release potential
    - mitigation measures essential to long-term site management and longevity of the performance of enclosure structures against erosion, rainfall run-off and protective vegetation maintenance; the magnitude of necessary work will inevitably vary from site to site and with different climatic environments. These determine the extent of closure engineering and backup facilities required to handle and contain the wastes.

Miscellaneous wastes

Miscellaneous wastes are generated through site camps and offices as biodegradable (putrescible) garbage, commercial and industrial waste and sewage sludges. Other wastes include construction and demolition wastes and contaminated soil revealed when project sites are being demolished, or as facilities are being upgraded.

These wastes seldom represent a significant magnitude of material, but they should be assessed for their value and compatibility with other mine waste streams in environmental terms.

Sewage sludges and garbage can be valuable soil supplements and or as oxygen uptake barriers in waste cappings over net acid-generating wastes. Equally, crushed concrete, even if contaminated, may be used as part of a 'capillary break' layer to prevent contaminated water from wastes being drawn to the surface. Contaminated water may kill vegetation and/or become a source of surface run-off contamination, as occurred over the tailings repositories at Rum Jungle and at other sites (Mudd, 2004).

The costing of the handling of these wastes is usually not material and these matters are addressed in Chapter 19 – 'Rehabilitation and Closure'.

Allowances need to be made especially for the handling of contaminated sludges from mineral processing and run-of-mine stockpile area run-off settling, containment dams and evaporation ponds. The volumes should include all the sludges plus not less than 0.5 m of the containment facility substrate. This material is usually compatible with the wastes sent to tailings repositories.

The final handling of miscellaneous wastes usually occurs immediately before project closure. While it may involve some double handling, any handling prior to that should be considered temporary, and established and costed as such.

HAZARDOUS WASTE

This section describes hazardous wastes generated during mining and mineral processing, and discusses treatment of these wastes.

Description

Hazardous wastes from the mining or mineral processing industries are those wastes which, as a consequence of their chemistry, physical or radiation characteristics, represent a risk to human or environmental health or biodiversity; or there is a risk of fire, explosion or degradation of water or air quality (*Environment and Protection Act* 1970).

These risks may enter the environment through transport in water or in air as a gas/vapour or as dust.

The principal hazards identified as associated with mining and mineral processing wastes include:

- AMD from the oxidation of sulfides, eg sulfuric acid
- dispersible coloured minerals that can cause loss of light penetration in water bodies to the detriment of natural species, eg clay minerals, tannins and phenolic compounds
- dust and fibres, which when released to the atmosphere in excessive concentrations can affect human and animal respiratory systems; these include asbestos or respirable siliceous dust of fibre diameters between probable maximum (PM) 2.5 and 10 μm (Ambient Air Quality – Particles Standard $PM_{2.5}$ – National Environment Protection Measure, 2003)
- flammable or explosive dust or gas at concentrations in mine ventilation discharges, for example, coal dust and methane
- nutrients or biological inhibitors at concentrations that create or exacerbate eutrophic conditions in water bodies or kill fauna, eg nitrate, phosphate and magnesium sulfate
- pathogenically active wastes, eg unstabilised sewage sludges
- radioactive materials and gases, eg radon and radioactive minerals
- soluble heavy metals released as a consequence of acid or extreme alkaline mobilisation, eg iron, copper, lead, silver , zinc and aluminium
- wastes carrying metallurgical treatment chemicals at concentrations that could be harmful if released into the environment, eg cyanide.

The costing of approaches to manage this range of risks involves two approaches: treatment or containment. Treatment is addressed in the following section, while containment is addressed under the section on ‘Waste storage’.

Treatment

Treatment is the approach generally applied to decrease waterborne and airborne risks. Forms of treatment include chemical or biological degradation of the risks at source, such as for cyanide, pathogen and nutrient releases. It can involve vapour scrubbing using water or active filtration media for risks associated with airborne dust and potentially explosive issues. Most other risks are generally alleviated by waste containment with or without some waste stabilisation to immobilise the highest risk contaminants through precipitation as insoluble forms. The generation of tailings into paste form for underground disposal is effective for resolving risks deriving from long-term surface exposure and dispersion by oxidation or erosion.

Issues of light penetration and the effects of nutrients on water bodies can be difficult to handle, but adjusting pH in and through reed beds and wetlands in advance of disposal can be very effective (Hamilton *et al*, 1999).

Critical issues for costing to mitigate hazardous waste risks then comes down to costing the investigations necessary to identify the:

- nature of the risks that can arise – deriving from an understanding of the geochemical characteristics of the material when subjected to exposure to the atmosphere and to mineral processing practices
- extent to which risks have potential pathways to create unacceptable consequences in the short or long-term
- options in treatment or containment that apply to each source of risk or risk pathway
- availability of materials among other wastes or other sources in the mine area or beyond, for mitigating the risks; for example, wastes with significant net acid neutralisation potential can be used to contain or restrict acid mine drainage generation or be used in engineering to prevent moisture and/or air ingress, which could stimulate AMD.

Many of the above issues should have been covered in costings associated with waste handling.

WASTE STORAGE

Approaches to waste storage differ according to whether waste is dry or wet.

Dry waste

Dry waste should be considered a source of construction material or risk mitigation at the outset until evaluation shows it to be a source of risk in its own right, or is likely to be produced in such volumes that it exceeds rational construction or risk mitigation requirements. It follows that generic categorisation of waste rock should include evaluation of geotechnical and geochemical parameters as set out in the ‘Waste handling’ section of this chapter, with the waste rock dumps being developed to maintain the availability of these materials for use as needed.

Dry waste rock dumps will commonly be either above-ground heaps at the outset of mining or backfill in a worked out open cut pit and in some cases as underground stope backfill.

Soils should be preserved whereever possible by being spread and vegetated. This way, soils retain their biological activity for future use in waste rock dump capping or in the rehabilitation of other mine facilities. Garbage, including biodegradable material, should be placed in containment where it is fully drained and subject to aerobic compost degradation.

Wet waste

Depending on the geotechnical and geochemical characteristics of wet waste, this waste will need to be contained. The degree to which containment will be successful without specific engineering will be determined by the hydrological and geochemical characteristics of the natural materials of the containment site (including attenuative or solubility parameters of the rock or groundwater when contacted by fluids deriving from the wet mine wastes). Successful containment also depends on the tailings storage repository design, including the need for liners of compatible materials and drains to improve the *in situ* density in some cases and/or to stimulate fluid release for collection and recycling.

In some cases, the characteristics of wet mine wastes resulting from their grain size, mineralogy and chemistry will prove to be self-sealing and self-protecting. An example is high oxygen uptake of tailings capped with layers including high biological oxygen demand (BOD) or high chemical oxygen demand (COD) material below a soil and vegetative layer. However, beaching of tailings in their repository can mean some areas close to the containing walls have markedly increased permeability. This can be a problem where containing walls act as drains on less permeable material lateral to them.

The areal magnitude and geometry of tailings repositories should be such as to permit rational management to achieve efficient water recovery and geotechnical stabilisation of the tailings. At the same time the design must provide for flexibility in operation and ease in covering of the tailings against exposure, washout and or other failures. These failures could give rise to a loss of containment and/or release of contaminants into the environment in other than an approved and acceptable manner. An example is capillary rise or seepage via the substrate to local springs (Mudd, 2004).

Mitigating these processes will involve engineering containment within:

- capping – depending on the local climate, this may include the placement of significant thicknesses of materials including from bottom to top grading layers (1 - 2 m), capillary break layers (0.5 m of coarse gravel) and soil moisture retention layers (1 - 2 m) underlying soils (0.5 m), which can be expected to provide a substrate for compatible native vegetation
- engineered or possibly grouted substrate to restrict subsurface leakages
- stable bunds or walls, possibly with low-permeability compacted clay liners, preferably of attenuative materials.

These design elements need to be created in a landform that resists erosion from either run-off or flood flows, as well as degradation by burrowing animals. Incorporating loose rocky material helps resist erosion.

Costing of wet waste tailings, coal washery slimes, red muds and dredge pond spoils must include:

- allowance for tailings dewatering or consolidation processes, including decant system construction and post-closure desaturation where necessary (eg by wick drains)
- construction costs for the waste storage, including sourcing of construction materials, materials placement and compaction, construction quality control testing and remediation
- engineering design of containment walls and bunds including subsequent lifts from time-to-time
- erosion protection armouring
- run-off drainage and settlement ponds with overflow to clean water discharge
- tailings repository site substrate identification and characterisation in terms of hydrological, geotechnical and geochemical (attenuative) parameters
- waste storage closure and encapsulation engineering
- waste storage facility works approvals and licensing
- waste storage revegetation and erosion stabilisation.

Some TSF may be water-retaining structures for environmental reasons (eg radioactive or AMD generating tailings for locations where rainfall exceeds evaporation and/or where tailings fluid releases are not permissible).

Any tailings or water-retaining structure built on a mine site will fall within the guidelines issued the Australian National Committee on Large Dams (ANCOLD). Such structures are, for reasons of failure risk mitigation, required to meet much more stringent design and management standards. These guidelines are developed locally and internationally and are used as de facto standards by regulators in approving such structures. The guidelines are updated from time-to-time and are available on the ANCOLD web site. At the time of writing a specific guideline for tailings dams is being prepared.

The consequence of the application of the ANCOLD standards is to materially increase design, construction and monitoring costs of any dam classified as a large dam (http://www.ancold.org.au/images/files/glossary.pdf).

ENVIRONMENTAL CONSIDERATIONS

Sustainability is intrinsically incorporated in the various acts and regulations that dictate work authorities and mining license conditions. These are directed at environmental protection including protection of water resources, land, air quality and biodiversity. The maintenance of human health and safety is simply a subset of this, even though the large dam requirements are particularly focused on downstream consequences of dam failure on human life and activities (eg agriculture, infrastructure, urban development and residential safety).

Providing for environmental considerations is incorporated in the engineering and investigational work referred to in the 'Wet waste' section of this chapter. To a degree, the structures introduced for investigational purposes will provide for environmental considerations and have been costed.

Facilities are necessary to demonstrate that environmental considerations are covered and that the performance objectives set out in licenses or in standards are being met.

The principal environmental considerations can be summarised as:

- air quality, especially dust, vapour and odour issues
- ecological system preservation locally and regionally, including flora and fauna and biodiversity surveys
- land condition including erosion, flora and fauna issues and contamination
- hydrological environment including volumetric and quality constraints dictated by the dependent ecosystems, including down-gradient issues for aquifers that may be affected, and beneficial users and uses.

The issues for costing include four factors:

1. capital and operational elements of monitoring systems, including:
    - dust, vapour, odour and carbon dioxide equivalent releases
    - flora, fauna and ecology
    - ground and surface water monitoring – monitoring water table, geochemical profile and surface water flows upstream and downstream of the project site on the principal proximal stream courses
    - land subsidence and footprint development
    - meteorological monitoring as a basis for tracking water stress, dust distribution and carbon emission issues
    - operational water flows and chemistry
2. costs of remediation of former mining, mineral processing and waste handling facilities, including the third and fourth factors
3. costs of environmental reporting over the project life and post-closure management
4. cost of gaining regulator sign off and relief from ongoing responsibilities.

A further issue is the need for and desirability of R&D expenditure over the project life. Such work should have as objectives optimising and proving efficient means of environmental stabilisation for the facility progressively and post-closure. The lack of such work has been a source of serious failures in environmental performance for many mining projects in past decades, such as the Bougainville copper mine in Papua New Guinea.

COSTING FOR WASTE MANAGEMENT FACILITIES

The aphorism that 'any mining project should not be entered into until there is a costed assurance that it can be closed down without leaving an adverse environmental legacy' should never be forgotten.

Generic costing

It is impossible to produce a generic or unit cost basis for mine waste management and containment facilities. The cost of implementing waste management facilities for mining projects can vary from a few \$100 K to in excess of several \$100 M.

Extreme cost variations derive from differing volumetric requirements, climatic factors, geology and geochemistry as well as from the physical parameters of sites and of the wastes themselves. Thus, the costing of any generic facility design or operation would be misleading to mining practitioners unless derived from specific project data and design detail. In addition, labour and equipment cost and operating factors vary dramatically across Australia. Costs that may be acceptable at one site may be a minor element in the project development costs for resources at another site, where the resources are in high demand or for a project subject to expedient development in order to meet a market peak demand/price period.

For mining companies involved in costing waste containment facilities for their projects it is essential that they develop check schedules that comprehensively list all the characteristics of their site and project. They also need to check the engineering essential to achieving the objectives of waste management facilities both as operational facilities and as long-term elements in the environment, including post-closure and post-closure site management periods.

A useful aid to costing the civil engineering elements associated with waste management facilities is *Rawlinsons Australian Construction Handbook* (Rawlinsons, 2010). This handbook, which is updated annually with quarterly supplements, covers a wide range of the issues that must be addressed, including:

- building price indices showing variations over time and across Australian regions including many mining centres
- civil engineering costs including such relevant matters as the placement and engineering of storage facilities
- contractual planning, administration and management percentages of the capital costs of construction
- excavation unit costs for smaller works.

Rawlinsons does not cost factors such as site investigation, site selection and site characterisation. Equally, there is no basis for costing any necessary substrate grouting operations. Rawlinsons does not cover environmental monitoring or site rehabilitation, albeit means may be found within the book to produce cost estimates by costing analogies to the necessary operations.

There are a great many aspects, as indicated above and in earlier sections of this chapter, that are site- and project-specific. These need to be incorporated into schedules for specific project and waste containment costing.

The range of influence that site-specific project elements can have on an overall project is exemplified by marked differences in costs for example the costs associated with monitoring, waste management and site closure issues for uranium mining and processing, compared with an alluvial gold mine.

For a gold mine, recovery may require only gravity treatment and produce self-draining tailings that are not a source of contaminant release. Indeed tailings may be a saleable commodity in some locations.

For a uranium mine, all wastes are commonly considered by regulators to be environmentally and socially hazardous should there be any release. This perception seems to be applied irrespective of the insensitivity or otherwise of the surrounding country (eg the Beverley *in situ* leach uranium mine in northern South Australia or the Ranger mine within the Kakadu area of the Northern Territory (Fox, 1977)).

A gold mine will likely be subject to many fewer constraints than the uranium mine because the impacts and residues are in most cases considered less environmentally contaminating (eg tailings deriving from the gravity circuit at the Bendigo gold mine in Victoria).

Using Rawlinsons, it is relatively easy to cost simple waste repositories (TSF, waste rock dumps, etc). However, simple structures do not represent the common range of the facility variations implicit in mining projects. The checklists must identify all the additional cost elements that apply and which dictate the design and development of the facilities at each stage.

In simple terms, the additional cost elements needed in the costing schedules can be grouped, in order of a project's progress, as:

- predesign data gathering
- site selection
- site characterisation
- conceptual design and permitting
- detailed design and contract specification
- construction quality assurance (CQA) and auditing
- operational use and management and monitoring
- facility expansion
- closure and rehabilitation
- post-closure monitoring and reporting.

These additions to the straight civil engineering issues are described below.

Predesign data gathering

Predesign data gathering relates essentially to the selection of the sites for waste management facilities. This process is dictated variously by logistical costs, especially proximity to the source of the wastes, the physico-chemical characteristics and flora and fauna around the site options, as well as social factors, geomorphology, climate and hydrology.

Physico-chemical data includes evaluation of:

- geochemical reactivity – pH, net acid generation/net acid neutralisation capacity, solubility, cation exchange capacity of Na, K, Ca, Mg, NH4 and heavy metals
- geotechnical characteristics – engineering capability
- groundwater chemistry baseline conditions – pH, Eh, Na, K, Ca, Mg, Fe_{tot}, Mn_{tot}, P_{tot}, Cl, HCO_3, SO_4, NO_3, F, radionuclides and other elements and ions of significance to the project or the waste chemistry
- hydrogeological – permeability (primary and secondary), water level variations and relationships (unconfined and confined to depth-base plus 10 m minimum)
- substrate mineralogy – clay species, sulfides, feldspars, ferromafic and soluble minerals.

Flora and fauna data include:

- ecosystem identification and critical assemblage relationships (including groundwater-dependent ecosystems)
- migratory species issues
- rare and endangered species identification and distribution.

Collection of the above data will involve site mapping and sampling, and may include some drilling, although existing exploration data and sampling results may reduce specific drilling requirements at the site selection stage. Data will include characterisation of geomorphic niches and their variability across the seasons. It should be noted that environmental factors such as sensitive ecosystems and rare and endangered species can be potentially fatal site flaws in many jurisdictions, or at least significantly expensive issues to negotiate and mitigate.

Social factors include the potential displacement of community settlements or activities, and the development of perceptions of risk to communities or to heritage or amenity values. Exposure of mining facilities within community viewscapes is also an issue that should be considered in site selection, as this can be an expensive problem to resolve during permitting if not addressed at the outset.

Geomorphology is a simple matter of topographic mapping and photogrammetric interpretation to identify spring areas and or karst features and the relationship of geomorphic form to geological structures at a broader scale than simply the area of the waste containment facility.

Climate and hydrology involve documenting and evaluating the frequency, magnitude and intensity of rainfall, run-off and evaporation as these apply to the site and the drainage lines. The occurrence, frequency and direction of wind should be evaluated.

In many locations these data are readily available from existing data collection authorities such as the Australian Bureau of Meteorology or from the World Meteorological Bureau. Local stream hydrology usually involves predictive modelling.

Site selection

Site selection involves the assembly and weighting of the various data to lead to identifying one or more optional sites that could accommodate the waste facility development at the acceptable capital and operating cost.

The process is analytical and inexpensive, but its success depends on the rigour with which predesign data gathering has been done. This work should be undertaken during the prefeasibility phase of the project evaluation.

Site characterisation

Once one or more optional sites have been chosen, they must then be further evaluated considering the same parameters as listed for the predesign data gathering. This will involve specific-purpose drilling, costeaning, sampling, hydrological testing and laboratory analyses and testing. The objective of this work will be to establish the data necessary for conceptual designs in sufficient detail to achieve reliable project costings and bases for successful permit approval by regulators, project finance organisations and by the community stake-holders. All three benefit by undertaking evaluations using the Equator Principles (http://www.equator-principles.com).

Some geophysical evaluation induced potential (IP) of waste facility site perimeter areas can be a cost-effective way of demonstrating the continuity of known conditions. At the same time it provides valuable base-line data for comparison with the conditions deriving as operations proceed. These data can also provide a defensible basis for siting representative monitoring wells. Appropriate geophysical surveys can also be a basis for identifying any necessity for grouting; there is a need for containment facility liners or specific geochemical material zonation in designs to mitigate environmental and geotechnical issues that may arise from water leakage.

Similarly, operational arrangements to provide for uniform and preferred tailings distribution (centre or perimeter spigots) and water recovery, and to maintain water cover, will need to be determined. The possibility of easy facility expansion in the future and facility rehabilitation should also be considered.

Access routes to and from the waste facilities will be determined again with a view to the cost, environmental and social constraints that apply.

Conceptual design and permitting

The outcome of a site characterisation study will be conceptual designs for the facilities in an overall project concept design extending over the life of the project.

Depending on the requirements notified by the regulator, the conceptual design performance will need to be modelled against worst-case scenarios. Design performance will be managed through a monitoring array capable of demonstrating that facility performance is as modelled and is within acceptable parameter (mostly contamination) limits, or if not, then what can be done and when.

Monitoring of geochemical characteristics of waste rock and tailings or other wastes can be very expensive where independent laboratories accredited by the National Association of Testing Authorities (NATA) are required. These costs can be reduced by negotiating with the regulator for only a limited number of off-site analyses to be required (say every three years) with more frequent monitoring of relevant field parameters only. These analyses can be undertaken by trained site environmental personnel using calibrated instrumentation.

Where fractured rock conditions apply and where any leachate is likely to be significantly more or less saline than natural groundwater, repeated IP surveys across fixed traverse lines can be very valuable in demonstrating compliance, as well as in identifying pathways of preferred leachate flow. These results also allow specific remedial action to be better focused and more effective in achieving effective site remediation and closure.

Permitting depends on meeting the requirements of the regulator. The regulator should be involved from the outset to ensure the program of site characterisation work and the proposed design elements are consistent with regulatory requirements. This is not to say that regulators should design the data-gathering program; rather that it is signed off before the conceptual design is delivered with its justification in data and modelling.

It is not desirable to move from conceptual design to detailed design before permitting is achieved. This can result in permit conditions that limit flexibility at the detailed design stage and during the exigencies of operational requirements.

Permits are normally developed around performance parameters rather than design specifics. These are generally based on planning, social, heritage or environmental issues referenced against regulatory standards.

Costing for this element of project development is part of the prefeasibility or bankable feasibility study.

Detailed design and contract specification

Depending on the preference of the project developer, the work of detailed design may be done by the developer or by an equipment procurement contracts management (EPCM) contractor. In either case, a performance specification must be established in which both the regulator and the specific operational requirements over time are specified.

The data in the performance specification must include definitive and reliable waste material characterisation. Where these vary for any reason, the extent, range and duration of variations that may apply need to be presented. These can then be accommodated by the detailed design.

For waste rock dumps it is likely that the material will vary from being oxidised material as the overburden is removed to being chemically reduced material with different geochemical and geotechnical sensitivities as mining proceeds to depth. These changes must be allowed for. Similarly, tailings may also vary significantly as a consequence of changing mineralogy and treatment processes. These changes may have implications for the way in which the tailings need to be managed. The likelihood of change needs to be set out explicitly in the performance specification, which underpins EPCM and other contracts related to these facilities.

Construction quality assurance and auditing

CQA is normally included in both construction and EPCM contracts but is separated here to emphasise that it is becoming more common for regulators to require an independent CQA audit. This results in the need to allow for CQA when costing for the services of the auditor, who reports to the regulator. Costings should also cover any confirmatory testing that the auditor requires to fulfil reporting responsibilities that the essential elements of the design will meet the performance requirements set out in the facility permit issued by the regulator.

The costs of auditing services vary from a few tens of thousands for simple project facilities to several $100 K for more complex facilities where higher risk containment is involved (eg Ranger Uranium).

Auditing of the operational performance of waste containment facilities is now also a common requirement within operational licenses. This work involves review and independent analysis of monitoring data at specific intervals over the project life and during the post-closure period. This should be treated as an operational cost.

Operational use and management

A wide range of costs is associated with operations. Costs include the transfer of the materials to the facilities, the monitoring of the material delivered in terms of tonnage, volume and characteristics and the monitoring of the facility performance. These are all operational costs and should only be made facility-related where project management considers this necessary for their management purposes.

Facility expansion

Costing expansion of waste management facilities may be a foreseen cost or it may be a cost derived through project realignment or operational change. Where the latter applies, most of the foregoing cost elements will be needed but much background data will already exist, making costing relatively much easier.

Expansion may involve raising the level of tailings facilities or waste rock dumps or the development of new facilities. For tailings, ANCOLD requirements will have to be considered in the costs of construction. Equally, for waste rock dumps, if expansion involves raising the height of the facilities, then additional geotechnical analyses and modelling will be required in order for the facilities to be permitted.

Closure and rehabilitation

These issues are considered in more detail in Chapter 19 – 'Rehabilitation and Closure', and only limited comments are provided here.

Closure of waste facilities commonly involves the creation of capping that will withstand erosion and sustain native vegetation to ensure that the moisture flux through the cap is insufficient to leach contaminants into the contiguous environment at unacceptable rates. At the same time, the cap must be able to accommodate the stresses of wetting and drying and ongoing settlement and/or consolidation of the waste mass. It is a challenging engineering design issue that is met by developing the cover over the waste and the capping to commonly incorporate several layers. In some cases, geotextiles and geomembranes are used to 'buy time' for the geotechnical stabilisation processes to take place.

The effectiveness with which the above demands are met is greatly improved where the geotechnical and geochemical behaviour of the wastes are monitored while the project is operational. This provides data on the rate of stabilisation processes, which is recognised in most regulatory regimes only when the final years of the project are defined. Thus the costs of closure and rehabilitation plans derive towards the closing period of the project.

The costs then include:

- design of the capping layers sufficient to prevent both capillary rise of fluids from the underlying waste and the ingress of significant volumes of infiltrating rain or groundwater
- modelling of subsidence rates and the consequences of the process for capping

- monitoring of physical and geochemical characteristics of the waste over years of the project
- placement and quality assurance on the capping layers
- reseeding and vegetation monitoring
- selection of materials to form the stable layer for moisture movement control and vegetation support.

Post-closure monitoring and reporting

Depending on the level of risk that the regulator applies to the facility, the licensee will commonly be required to continue monitoring the facility and its surrounds, including the cap, for between five and 30 years.

Operators may apply for the cessation of monitoring requirements if they can demonstrate that the performance trends for the facility are favourable to the regulator within requirements based on monitoring over the life of the project. However, only when the regulator accepts the results will any financial assurance placed to the benefit of the regulator for rehabilitation be released.

The costs of post-closure monitoring are not usually very significant compared to the opportunity cost of the financial assurance.

CONCLUSION

The costing of the waste facilities for any mining and or mineral processing project demands experience and a great deal of data to be reliable. It is best undertaken by a team of people who are mindful of both:

- the operational logistics and complexities
- the potential issues involved if wastes or contaminants deriving from the wastes are released to the environment.

Releases may be to water via the ground or as direct run-off. Release may be in the air as dust or vapour, due to slumping or exposure as a consequence of erosion or animal excavation, or even through plant uptake and release in organic debris.

The only certain thing about the costing of waste management for mining and mineral processing projects is that it must be thorough and comprehensive. If this exercise is not comprehensively addressed, the economics of the project and the reputation of the project proponent can be very adversely affected.

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