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So You Want to Have the Best Possible Waste Rock Dump

M. Russell *DumpSolver Pty Ltd, Australia*

Abstract

Open pit mining waste rock dumps represent very significant structures on most open pit mine sites. If they are not developed well they represent a significant risk to the environment and there are substantial numbers of legacy sites worldwide where waste rock dumps have caused various and severe pollution of the wider environment. Whilst historically this may have been seen as acceptable, it is most certainly not the case today. Legislation, community expectations and corporate governance now demands that mining waste rock dumps have a minimal impact on the external environment whether the mine is developed close to urban populations or in remote locations.

In addition to increasing environmental standards, the waste rock dump represents a significant financial investment costing multi-million dollars to construct with up to half the total truck hours being spent developing the structure. However, with good planning, the waste rock dump represents an opportunity to significantly reduce costs as well as improve the environmental outcomes.

This paper discusses the considerations that need to be undertaken to give the opportunity for a low environmental risk and low cost rock dump to be developed.

1 Introduction

If one asks a member of the public to describe a mine site that they have seen, they would usually either refer to the pit void or the waste rock dump. It is a simple fact that on most open pit mines the pit void and the dump are the largest remnant structures. Improvements in technology over the centuries combined with urbanisation around mines means that waste dumps are larger and that more people see them. Additionally, the extension of road networks and the spread of recreational vehicles mean that a mine that was once in a remote location is now regularly seen by increasing numbers of people.

Many, if not the majority of the waste rock dumps, can also be classed as legacy sites where the dump continues to detrimentally affect the external environment. This may be from its visual amenity through to direct harm on people or the environment. Possibly the most infamous incident is when 144 people were killed in Aberfan in South Wales where the waste rock dump collapsed onto the town.

Figure 1 Aerial view of Aberfan mining disaster (left); and additional view of Aberfan waste dump failure (right)

A line from the inquiry report sums up the cause:

> *"… the Aberfan Disaster is a terrifying tale of bungling ineptitude by many men charged with tasks for which they were totally unfitted, of failure to heed clear warnings, and of total lack of direction from above. Not villains but decent men, led astray by foolishness or by ignorance or by both in combination, are responsible for what happened at Aberfan". (London: HMSO, 1967)*

The last sentence sums up the state of knowledge at the time.

More recently (May 2006) three people died from asphyxiation from gases produced within a waste dump in Canada. Whilst deaths of people from waste rock dumps remains rare, many legacy sites continue to cause harm to the wider environment. Such things as contamination of water courses with acid leachate, heavy metals or siltation with solid particles are common. The effects can be widespread and damaging. What is more there is no foreseeable end to the potential damage. At least one mining company has recognised that waste rock dumps represent one of their major risk factors to their business with millions of dollars being spent annually on treating the runoff and no end in sight.

Figure 2 Surface water damage to dump faces (left); and facility for ongoing treatment of dump runoff (right)

Were these waste rock dumps, with their ongoing issues, created maliciously? No. The results are because of four factors:

- There was no requirement or incentive to do better.
- Historically the science of waste dumps has been weak.
- The construction time for waste dumps in measured in years or decades and so the feedback loop on construction and completion is long.
- Until recently it was a subject insufficiently covered in undergraduate courses.

Now events have been overtaken by community expectations and often statutory requirements. This trend does not only apply to developed countries. International mining companies operating in developing countries also have to address community expectations over all aspects of mining, including the environmental implications. There have been several high profile cases over recent years where mining company activities have been severely criticised in the press. Despite the obvious desire to be good corporate citizens the industry continues to build waste rock dumps that may be severely criticised by future generations.

Modern mine planning, of which waste dump planning is a part, has seen rapid development since the 1980s. This has largely been driven by improvements in accessibility to high speed computing, the associated software and enhanced methodologies largely based on that software. Specifically, software to evaluate the orebody, optimise the economics of the pit and that of scheduling the extraction of the ore has dramatically enhanced the output of the mine planners. However, despite these advances in technology and methodology for mining, there has been only modest and fragmented improvement in methodology for the development of the waste rock dump. This is despite the fact that in most open pit mines the volume of waste significantly exceeds the volume of ore by ever increasing multiples.

So how should a waste rock dump be designed and developed if it is to be:

- Lowest possible cost.
- Least impacting on the external environment.
- Acceptable to the future community?

The first point to make is that there is no single solution to the problem. All waste dumps, even those in close proximity to each other are different and require to be treated differently. Material types, topography, mining sequence and environment means that each is unique.

So how should the evaluation, design, development and closure of the best possible waste rock dump be approached? This should be by understanding the drivers and science of the issues and developing a tailored solution for each unique circumstance.

There are three elements to the development of the best possible waste rock dump which are dealt with in this paper:

- Setting the objectives.
- Understanding the constraints.
- Developing the solution.

2 Setting the objectives

For the best waste rock dump to be developed it is necessary to first understand the objectives since without a target, mediocrity is the best that will be achieved. Broadly, the objective needs to be set cognisant of three influences.

2.1 Legislative framework

Mining in most countries is undertaken within a legislative framework of mining acts and regulations. The trend in most of these regulations is to move away from a prescriptive recipe to an enabling framework where it is the responsibility of the company to undertake whatever studies and testwork is required to ensure that the outcome is both safe and stable. Increasingly mining projects are also being required to overcome environmental hurdles as dictated by government and non-governmental environmental stakeholders. Legislation and regulations change over time and it is to be expected that, what is acceptable practice today, may not be acceptable in the future.

One role of the government agencies should be to provide practical expertise and guidance on mining issues including waste rock dump construction. Unfortunately some government mining departments do not provide guidelines, or where guidelines are provided, view their adherence as mandatory, not advisory.

2.2 Community expectations

Communities and special interest groups now understand that they can have a direct impact upon the behaviour of companies. Not only can they have the direct ability to curtail or affect the security of operations directly (e.g. Bougainville) but can influence the wider ‘licence to operate’ on new projects. Internationalisation of such groups means that communities in very remote locations now have a very powerful voice.

2.3 Corporate goals

Major companies articulate their goals and aspirations for all stakeholders through their vision statement. These are necessarily non specific and high level but do give managers, the planners and operators a framework within which they are to work. It then becomes the goal of management to translate the vision into specific requirements, normally through the development of policies, procedure and guideline documents. Effective guidelines for developing waste rock dumps that meet all environmental goals and allow operations to develop the dump economically and flexibly are complex to develop.

These are then the ‘battery limits’ within which the planners and operators can work.

3 Understanding the constraints

Now that the general outcome and requirements are understood it is necessary to look at the site specific constraints. These include:

- Climate and environment.
- Dump material.
- Surface requirements.
- Locations.
- Mining economics.
- Waste scheduling.

While these are dealt with sequentially below they are very much interrelated and must be considered as such.

3.1 Climate and environment

Three of the ultimate aims for the waste rock dump will be for it to be:

- Safe.
- Stable.
- Able to assimilate into the wider environment.

The first two points are mandatory with the latter point being implicitly included Climate and environment determine the pre-existing productivity and communities of flora and fauna which in turn suggest maximum possible levels for the post-rehabilitated landform. Effectively pre-existing flora and fauna studies form a baseline.

The timeframe for the development of the waste landform also needs to be considered. The existing environment has developed over millennia, based on the integration of climate and geology. This is the timeframe that also needs to be considered in terms of assimilation of the waste rock dump with the wider environment. However, the most crucial period in the life cycle of a waste rock dump is generally seen as during and after construction. Discussing these in turn:

- *During construction*. Often only cursory consideration is given to the behaviour of the dump during the period of construction, which may be many years. Yet this is the period when final slopes and water control methods are generally not in place and deleterious material is exposed to the environment. This can result in off site damage even before completion.
- *At completion*. There is a phase of work at the end of the mine life for completion of the waste rock dump. At that time all major movements of material have ceased and the dump is being finished. The finishing work that is required will be largely determined by the climate.

Clearly there needs to be a good understanding of the environment in which the dump is to be placed. The understanding of flora and fauna is essential. However, climate, and specifically rainfall, is important in the construction of the best possible dump since it is probably the major damaging agent. This is especially so with episodic rain events (e.g. cyclones). Maximum and minimum rain events must be considered (and not only averages) since it is these that cause maximum stress on the waste rock dump.

For the waste rock dump to be assimilated into the environment consideration needs to be given to the topographic structure locally. However, a direct copying of the local surface analogues may not be an achievable solution. For example, concave slopes naturally form on landforms with a harder capping in an area of generally high rain events. However, the caprock effect, and thus the slope behaviour, can not be directly emulated in the waste rock dump.

Figure 3 Natural concave slope

3.2 Dump material

At the planning stage there are generally several fixed criteria, these being:

- The volume of material to form the dump.
- The characteristics of that material.
- The sequence and timing of that material entering the dump.

However, it is uncommon for there to be a complete and adequate understanding of the materials. In particular, there may often be a lack of understanding in:

- *Waste geology*. Through inadequate geological logging, sampling and testing there is often a poor understanding of the characteristics of the waste rock. At the geological investigation stage, all too frequently, the focus is on the ore intersections alone. Inadequate work is done to understand the characteristics of the material which will form the waste rock dump.
- *Waste volume*. Care should be taken in determining the overall dump volume of waste by material type. Frequently a single swell factor is applied which misrepresents the waste rock composition and behaviour. Whilst in many cases it is acceptable to simply over-design a waste dump to allow for unknown factors (e.g. changes in the mine plan, etc.) there are frequent specific cases where this is not a good strategy and these will be discussed later.
- *Sequence of mining*. Whilst scheduling of ore and associated waste is normal practice on every mine, the design of the waste dump rarely takes any cognisance of the timing of the waste material flow. Invariably a waste rock dump is designed solely on the final anticipated volume, not on the progressive flow of material.

A compounding factor may be the inclusion of low grade ore that will need to be stored for an indeterminate period of time. Clearly storage should be at least possible cost but it should preserve future options for the operation. The geochemical characteristics of the low grade ore may also determine the need to be encapsulated to prevent possible environmental impacts.

For quality planning to occur, a good understanding is needed of the following:

- *Material characteristics*. The physical and chemical characteristics of the waste rock units. There is a need to consider evaluation, testing and analysis work to ensure that there is an adequate knowledge of the material that will form the waste rock dump. A phased approach to testing is recommended to ensure that adequate work is done to achieve the required knowledge.

- *Material positioning in the dump*. In an ideal case there will be no deleterious physical or chemical characteristics that require special consideration. However, material characteristics should determine the required positioning of material within the waste rock dump. This may be encapsulation or to create a suitable growth medium on the external surface.
- *Waste material flow by rock type*. The timing of the flow of waste rock, by specific material types, then becomes the primary input data to the effective waste dump construction scheduling.

3.3 Dump surface

One of the most critical structures within the waste rock dump is the surface of the dump, i.e. the thickness and nature of the outer skin. The nature of the rock dump surface is determined by the following:

- *Surface materials*. Which material or combination of materials is potentially the best from a rehabilitation / revegetation perspective? This may be a combination of material as a growth medium for revegetation including blockier material to resist surface erosion.
- *Encapsulation and cover requirements*. Is there a need to specifically encapsulate material due to the chemical characteristics? Generally this will be to reduce / eliminate oxidation and / or leaching of material from the dump. The nature of the deposition of this material needs to be evaluated closely. Consideration may determine that there is also the need for special measures such as:
  - *Volume control*. Restricting the amount of material in any single location may be appropriate, e.g. layers of black shales that could spontaneously combust may need to be separated by benign waste.
  - *Special encapsulation*. It may be appropriate to consider encapsulating the deleterious waste in another material such as clay to further restrict its exposure to the environment.
  - *Co-mixing*. There may be the need to co-dispose of specific waste in order to ameliorate some of the negative characteristics of the deleterious waste, e.g. co-disposing of potentially acid generating waste with an acid consuming unit.
- *Rainfall* / climate. What are the average, peak and minimum rainfall for the location and evaporation rates? This knowledge will assist in determining the waste rock dump surface requirements.

  While the effect of the climate is all pervasive there are some specific influences worth highlighting:

  - The handling of water, particularly peak rain events, will determine the shape of the top of the dump and the need for any specific water handling structures and methodology.
  - Encapsulation requirements at the design stage will determine where ponding should be avoided on the dump surface and benches.
  - If a store-and-release cover is envisaged, the top surface preparation and vegetation to ameliorate migration of water across the benches and enhance transpiration will be important considerations.

  In some instances it may not be practical to develop specific surface layers on steep slopes and as such encapsulation below those slopes is not viable. This may substantially hamper the area available for encapsulation.

- *Surface thickness and* behaviour. The thickness of the surface skin, the type of material and the vegetative requirement will, to a large degree, be controlled by a need to exclude water from the mass of the dump. If there is no reason to exclude water, then the design of the surface layer can focus solely on rehabilitation and erosional implications. However, if there is the need to exclude moisture the nature and design of the surface layer becomes critical. There is then four effects to deal with:

- *Handling of water on benches*. Generally there are two alternatives for how water is handled on the waste rock dump, either encouraging infiltration (store and release) or water shedding. The preferred method will determine the design of the benches / top surface of the dump as well as the water handling structures.
- *Surface materials*. The nature, including the porosity and permeability, of the surface layer is an important factor since it largely determines the rate of infiltration into the dump and the surface layer's ability to hold that water. At the most basic level, water penetrating this layer will ultimately travel through the dump and emerge elsewhere.
- *Slopes*. The conundrum for designers of waste rock dumps lies in the outer slope. The angle of the slope and particularly the behaviour of water on the slope will have a direct and major impact on the stability of the dump. The extent of surface erosion is controlled by the speed and volume of water passing over the material of the slope which in turn depends on the length and steepness of the slope. For a given fall in elevation (waste dump bench height) the steeper slope is shorter and so, to avoid excessive erosion, must minimise the amount of water on it, i.e. be positioned near the top of the dump. Where water volumes increase, towards the bottom of the dump, the slope should be lower to reduce the velocity. This implies that the concave slope system is potentially superior in terms of surface stability to the conversional batter and berm approach to dump slopes. This may be the case since berms can ultimately deteriorate to become structures that actually concentrate water flow rather than control it. However, since there is no hard cap protecting the crest of a concave slope upper face there will be increased erosion. In all cases great care must be taken to ensure that the water does not over-top the face of the dump.

Figure 4 Severely eroded dump face

- *Evaporation / transpiration*. The counter to infiltration is evaporation and transpiration. The shallow influence of evaporation means that transpiration can be the major contributor to the removal of water from the surface layer. Climatic conditions and the surface material itself will ultimately determine the type and extent of vegetative cover and so the extent and depth to which transpiration has an effect.
- *Preferential flow paths*. Within waste dumps there are preferential water flow paths. Understanding of potential flow paths should include the risk of adverse behaviour. Flow paths may be caused by such influences as:
  - Compaction layers from truck operations.
  - Size gradation of dumped material.
  - Dump settling.
  - Surface profile.
  - Machine induced, e.g. deep ripping.

- *Geotechnical stability*. The composition of the surface layer, the slopes employed and the hydrology will have an impact on slope stability. The surface layer of the dump is the most complex within the entire dump and so must be planned for from the very start. Whilst the science of slope stability is well developed, consideration of the following should also be included:
  - Finer materials, which are generally of poorer mechanical strength, will be used as a growth medium and for surface water control.
  - Mining operations will not be able to generate a unified blend of materials on the surface so consideration will need to be given to the risk from poorer mechanical stability material.
  - In addition to the more common circular type slope failure, tunnel erosion from the dump crest or berms, is a significant failure mechanism.

3.4 Potential locations of waste rock dumps

There will often be some choice for the location of the waste rock dump and it is this in part that makes every waste rock dump unique. Economically it is important to consider the waste dump location ahead of installing infrastructure since the landform's general position can have a multi million dollar implication. Whilst it is not all inclusive, the following points should be considered when evaluating dump locations:

- *Proximity to the pit exit*. Economics obviously favour waste rock dumps positioned close to the pit exit (though the selected pit exit location should be incorporated with the overall dump economics).
- *Gradient*. Slopes that allow drainage back into the pit ameliorate some of the potential risks particularly if potentially acid forming materials are present.
- *Drainage*. Care must be taken to ensure that water courses are not blocked by the development of the dump. As needed it may be appropriate to consider flow-through drains below the dump though these should only be used after careful consideration and require precise construction. When rock dumps are tied into topography, special consideration should be given to prevent / control the runoff from the surrounding area damaging the dump structure.
- *Topography*. Aiming to get the waste rock dump to complement the local topography.
- *Stability*. The stability of the dump itself relies on the stability of the underlying material. It may be necessary to relocate weathered rock to provide a firm footing particularly where these are deep, or where there is a slope and water is present.

Whilst not specifically covered in this work there should be a preference for using existing pit voids for the disposal of rock waste. Second-hand holes in the ground do have a value.

3.5 The cost of developing a waste rock dump

An obvious statement is that the mine is in the business of making a profit. For this to occur there are two guiding principles:

- Minimising dump construction costs.
- Minimising closeout cost through 'getting it right first time'.

3.5.1 Dump development costs

The cost of developing a waste rock dump is largely controlled by three factors:

- Haulage economics, i.e. the cost of moving the waste material around the site.
- Land costs, those associated with the pre and post mining activities.
- Ancillary equipment costs, those associated with keeping the haul trucks operating on the waste landform safely and efficiently.

Depending on the size of the trucks, operating costs in excess of A$400/hr are common with fuel burn rates peaking at 500-600 l/hr. When one considers that most open pit mines have high strip ratios it is clear that:

- The construction of the waste rock dump is a very costly part of the mining process.
- Even a minor improvement in unit costs can provide substantial cost savings to the overall operation.

Additionally, reducing the haulage cost will have two further operational benefits. Firstly, scarce truck resources can be used elsewhere on the mine (or stood down) and secondly, sustainability benefits occur from the reduced fuel consumption and so a reduction in the greenhouse gases generated to create the waste landform.

While the minimisation (optimisation) of the overall waste rock dump is reasonably complex, it needs to occur during the planning phase, even it if it is approached at a rudimentary level.

Elaborating on the main cost components for minimising the overall cost of dump construction, the following applies:

- *Variable haulage costs*. This relates to the cost of moving the truck and its payload around the waste rock dump both laterally (across benches) and vertically (to successive benches). To evaluate this it is necessary to understand the main drivers to the cost of haulage which include:
    - Truck capacity and performance (including the application of any site specific controls such as speed limits).
    - The general operating cost exclusive of fuel, i.e. the cost of operator, maintenance and repair, tyres and other consumables.
    - The net unit fuel cost and fuel consumptions on flat and inclined hauls both loaded and unloaded.
    - The capital cost and life of the truck.

  These then enable a cost to be developed for delivering material to all areas of the potential dump.
- *Land costs*. These are the costs associated with the area of the waste rock dump. They include such items as land acquisition, clearing, topsoil removal / storage, rehabilitation, ripping and seeding, etc. Area costs are generally expressed as a cost per hectare.

The derivation of the lowest cost waste rock dump is effectively a minimisation of the above two gross costs.

3.5.2 Closure costs

An interesting point is that few operations, if any, accurately budget for the closeout cost of the mine during the planning and approval phase. Yet multi million dollar costs are often incurred to close out waste rock dumps alone. In the majority of cases, good understanding of the materials and good planning could have avoided a high proportion of these costs. The old adage of 'get it right first time' has no greater truth than in the sphere of constructing waste rock dumps.

3.6 Scheduling of the waste rock dump

An open pit would not be developed without scheduling taking place. The same should be applied for the waste rock dump. Unless the waste dump is to be constructed with a single benign material a detailed understanding needs to be gained of:

- Required / preferred and alternative locations for all materials.
- The timing of the material flow by type.

These need to be combined in a detailed schedule, by period to ensure that a dump plan can be achieved. Empirically, the ease of scheduling by computer will generally dictate the ease with which the plan can be achieved during operation. Scheduling is a useful tool for determining dumping issues before they occur.

Commonly the flow of material that requires encapsulation will peak at the end of the mining schedule where mining of the lower pit benches takes place. It may be necessary to keep aside benign material specifically for capping purposes. Detailed scheduling should enable this deficit to be calculated and so appropriately planned for.

4 The solution

Section 3 discussed the constraints and drivers for the construction of the waste rock dump. In this section the focus is on how this knowledge may be gained in practice and applied to develop the best possible waste rock dump.

4.1 Is there a common ground between economics and the environment?

With appropriate planning there is substantial common ground between dump economics and environmental outcomes. They are most certainly not mutually exclusive and with care can be generally inclusive. However, this will not occur without specific steps and processes taking place. The current methodology where the waste dump design is purely the domain of the mine planning engineer and the development of the dump under the control of mine operations does need to change.

There are a series of steps and considerations that need to be gone through if a low cost, low risk waste rock dump is to be developed.

4.2 The planning process

4.2.1 The team

It needs to be accepted and embraced that the design of the best possible waste rock dump will be a collaborative effort between a series of individuals from different disciplines. While the design of the dump was traditionally undertaken by a mine planning engineer and (generally as they saw fit) and executed by the mine operations department there is now the need to involve a wider set of individuals. As a minimum this will also involve individuals from the environment and geology departments but, depending on the complexity and individual skill sets, may be much broader.

4.2.2 Timing and integration

For the best possible waste rock dump to be designed it must be integrated with the pit optimisation design work. After all, how can a pit and ramp system be designed without consideration for the dump, upon which the majority of its contents is to be placed? By implication the timing of the design work cannot be at the end of the process as an afterthought.

4.2.3 Elements of the planning

Based on the technical work discussed in Section 3 to manage constraints, there is the need to evaluate, assimilate and develop a robust plan based on the following:

- Potential locations for the dump.
- Waste material categorisation.
- Climate and the environment.
- Waste rock dump general structure.
- Surface layer structure requirements.
- Mining waste rock dump economics.
- Hydrology.
- Slope stability.
- Operations.
- Dump design.
- Dump schedule.

4.2.4 The waste dump plan

The team should be able to demonstrate to management that all the above aspects have been covered with the production of a complete waste dump plan. Dump footprints or outline designs are not sufficient. The waste dump plan should include graphical representation of the waste rock dump by period.

4.2.5 Risk assessment

It is rare for a mining plan to go ahead as planned and the same applies to waste rock dumps. A formal risk assessment should be included in the planning process. From experience the major area of risk lies in the volume of deleterious material requiring encapsulation. Often, for several reasons, this volume increases. The design and the dumping plan needs to be robust and flexible to handle this.

5 Closing comments

The multi-disciplinary team has been used to develop the best possible waste rock dump, the myriad of inputs and requirements noted above have been taken into account and it is time to develop the dump. Is the task over? The answer is: most certainly not. The construction of good waste rock dumps cannot be simply planned at the start and then assumed that it will be completed appropriately. Periodically formal audits should take place to ensure that the rock dump development and rehabilitation is on track and that, with potentially differing material types and volumes from updated information, the waste rock dump will get to the desired end point, namely a waste rock dump that is lowest possible in cost and has the least possible environmental impact.

Should it not be possible to comply with all of the set requirements and goals questions need to be asked about the viability of the proposed overall mining project.

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