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Three "R's" for mine closure – responsibilities, regulations and results

H. Jones *Golder Associates Pty Ltd, Australia*

Abstract

The paper outlines an evolution of attitudes of governments and the mining industry to the concept of sustainable development with particular reference to mine closure. It considers the role professional associations have in promoting responsible attitudes to environmental management and mine closure.

Focusing on the development of mine waste landforms the author briefly outlines the drivers of regulations and considers the process of regulation drafting together with the role of guidelines as de facto regulations. The paper then outlines the "prescriptive" and "enabling" approaches to legislation and discusses how they can impact on setting and attaining mine closure objectives. The application of regulations and the requirement of resources including skilled and experienced regulators is discussed together with the responsibilities of government should its regulations increase, rather than reduce environmental harm at closure. The concept of environmental compliance is briefly discussed including the potential technology restricting aspects of strict compliance with regulations. Does this promote a lowest common denominator approach to mine closure?

With particular reference to the closure requirements of waste dumps and tailings structures the author gives illustrations of good and less than good examples of what regulations and industry performance have so far achieved. The time frame within which closure objectives attainment can be evaluated is discussed, highlighting the different time frames required to assess geomorphological and biological post closure performance at a mine. The site specific nature of mines means that one approach to waste landforms cannot fit all situations and the fairness of having a solution acceptable in one operation, but not in another is considered.

The author concludes by outlining ways in which responsibilities and regulations could work together to improve the mine closure performance of our industry and demonstrate to the broader community that the term "sustainable development" is not an oxymoron when applied to the mining industry.

1 Responsibilities

We live in a world where many people place great importance on their individual or collective rights. Hence we have Bills of Rights in many countries and even Miners' Rights in some jurisdictions. These rights that we enjoy usually include an unwritten contract that we exercise our rights in a responsible manner.

In the mining industry there has historically been miss-match between the miners exercising their rights and those same miners conducting their operations in a responsible manner. This was true when Georgius Agricola (1556) (real name Georg Bauer) penned his book on mining (*De Re Metallica*) in the sixteenth century and was still the attitude of most miners when I lived in a small mining village in the mid twentieth century, when mine closure was simply a case of walking away and letting nature take over.

In the second decade of the twenty first century I'm pleased to observe a significant change with most mining companies now recognising their responsibilities for mine closure and taking them seriously.

1.1 Government and industry approaches to sustainable development

Responding to concerns about environmental management the General Assembly of the United Nations established the World Commission on Environment and Development (WCED) in 1983 to formulate "a global agenda for change". Chaired by a former Prime Minister of Norway, Gro Harlem Brundtland, WCED conducted a wide ranging investigation into many issues. In 1987 it reported to the General Assembly and this report was published as a book, 'Our Common Future' (UNWCED,1987), which became a non-fiction best seller and is generally considered as the starting point of general awareness of the concept of sustainable development.

The initial terms of reference for the WCED intended for it to develop long term environmental strategies for achieving sustainable development by the year 2000 and beyond. During its investigations and preparation of its report the Commission recognised that social, economic and environment issues were all very tightly bound together, meaning that changes in one would have real impacts on the other two.

The report defined sustainable development as “*sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs*.”

The mining industry is clearly an exploiter of resources, definitely makes significant investment, is responsible for significant technological development and has the ability to change institutions. Using this definition it is clear that applying the term “sustainable development” to the mining industry is not an oxymoron.

In the report, mining is specifically identified three times; twice in positive terms as both a contributor to Gross National Product (GNP) in developing countries and as an energy supplier, and once negatively as an industry that needs to either prevent environmental damage, or invest in restoring unavoidable damage.

The subsequent 1991 Heads of Government (HoG) Summit in Rio de Janeiro addressed the issues raised by the WCED and published Agenda 21, a document that set out the requirements to attain sustainable development on a world-wide basis.

In 1999 the World Business Council for Sustainable Development (WBCSD) contracted the International Institute for Environment and Development (IIED) to identify the state of the mining industry in addressing Agenda 21 and to highlight areas where challenges remained and, where possible, develop plans that addressed those challenges.

The IIED created the Mining, Minerals and Sustainable Development Project (MMSD) (IIED, 2002) to conduct a participatory analysis of how the mining industry could contribute to the global transition to sustainable development. This project identified nine major challenges “across-the-world” which were seen as nine opportunities to tackle important issues in the broadest possible multi-stakeholder effort.

One of the nine challenges, “How can environmental management in the mining and metals industry be improved?” was sub-divided into three aspects of the industry namely large volume waste, abandoned mines and closure.

During the main seminar addressing these three aspects one delegate put forward the concept that public perceptions of the industry were defined by the closure outcomes, which the delegate nominated as being in three phases (Table 1).

In 2002, the MMSD project report ‘Breaking New Ground’ was presented to the Johannesburg HoG Summit. In the lead up to that Summit, Dr Bjorn Stigson, then President of WBCSD, enunciated a very clear understanding of what sustainable development means in the context of the mining industry, namely “Leaving a positive legacy while exploiting the resource”.

Table 1 Perceptions and outcomes

Perceptions of Mining	Closure Outcome
The mine of the past was regarded as an intruder	Abandoned derelict areas
The mine of today has, in many cases, progressed to being a good neighbour	Greened geometric structures
The mine of the future will be an agent of development	Ecologically and geomorphologically integrated landforms

1.2 Approach to sustainable development by professional organisations

Many professional organisations have codes of conduct or standards that all members of the profession in question are encouraged or even required to follow, if they wish to retain membership of that organisation. Common features in the various organisations include the requirements that members will continue their professional development, act honestly and work within their areas of professional expertise. Several of the mining industry related professional organisations contacted (three Australian based, one U.K. based and one North American based) in the development of this paper conduct professional development audits of their members, but do not specifically audit the actual professional work done by members. All organisations contacted actively promote seminars, conferences and workshops that address sustainable development matters, including mine closure.

Codes of Ethics are continuously evolving documents that largely reflect current social standards and increasingly include specific references to sustainable development, environmental management and discrimination. However, the application of these Codes is very much a personal issue for the individual members, even though the Codes often require members to bring non-ethical activities carried out by fellow members in the course of their duties to the attention of the organisation. Notwithstanding, none of the professional organisations contacted reported any cases of "environmental" unprofessional conduct being brought to the attention of their disciplinary committees.

2 Regulation

2.1 General aspects

Mining legislation is a balance between the requirements of the broader community (and the broader community's perception of or understanding of mine developers) and the wish of the mine operators to not be constrained by regulation. This relationship can be considered as a simple "control/trust" relationship (Table 2).

Table 2 Relationship between legislative mechanisms and community requirements

Legislative Mechanism	Community Requirement
Total prohibition	Maximum "control"
Prescriptive regulations	High "control"
Code of practice	General "control"
Specific guidelines	General "trust"
Generic guidelines	High "trust"
No regulations or guidelines	Maximum "trust"

Most mining industry legislation is drafted as a reaction to a specific event, rather than a pro-active device to avoid an event occurring (Jones, 2008a). The resulting documents focus on these events and sometimes result in unintended consequences, some negative and some positive.

At its lowest impact on operators there is no legislation (no control, maximum "trust" of the miners) while the final form of control is, of course, total prohibition of a given activity (total lack of trust). The type of legislation is determined by community expectation or requirements and generally speaking starts at the maximum trust end of the scale.

When new technical issues arise in the mining industry they are often addressed by progressing through the different forms of "control" as outlined in Table 2.

It should however be noted that there are real differences in legal status between Guidelines, a Code of Practice, ministerial conditions and regulation in countries that have a common (British) law basis for their legislation (Jones, 2008a).

It is noted that all of the regulatory mechanisms mentioned above are manmade and therefore transitory. An important point is that; if they have been developed quickly and/or are applied to natural processes that take a considerable time to reach maturity.

2.2 Legislative styles

Legislation can either be directed at processes (prescriptive) or towards outcomes (enabling). For mine waste facilities, prescriptive legislation may dictate how the landform can be built, while enabling legislation defines the outcomes the landform must attain, without constraining the means by which those criteria can be met.

Generally speaking, prescriptive legislation is a poor method of addressing the long term environmental requirements of waste landforms because it is imposed on all mine sites, irrespective of site specific conditions. This actively discourages the development of an optimal solution for any particular mine because it effectively dictates the final design and the method of attaining that design (Howard et al., 2010).

An example of this legislative style is some mining tenement conditions in Western Australia that require dumps to be constructed with batters of "*not more than 20^o with 5m berms every 10m vertically*", giving rise to the flat-topped, uniform sloped landforms with sub-horizontal berms (terraces) constructed at regular intervals on the side slopes, similar in appearance to the Step Pyramid of Djozer. Such shapes have a high propensity to develop deep, incised gullies (McPhail and Rye, 2008). McPhail and Rye modelled the erosion of various slope configurations and concluded *"There is no merit in adopting guidelines that indicate a final abandoned slope profile made up of a series of benches. It would be better to terrace the slope then doze the terraces out to form a contiguous slope."*

Enabling legislation is more likely to result in acceptable post-mining landforms by setting outcomes for the new landforms without constraining the designers. This approach requires the mining company to consider the site specific conditions and arrive at a design much closer to the optimum for that site than the application of a set, one-size-fits-all design.

One example of enabling legislation is the Government of Québec's publication, "*Guidelines for preparing a mining site rehabilitation plan and general mining site rehabilitation requirements*", which nominate a Factor of Safety for stable landforms rather than nominating a slope angle or configuration (Gouvernement du Québec, 1997). Such an approach gives the mine a clear outcome to meet while enabling the mine to develop an optimum solution.

The potential problem of a one-size-fits-all approach to regulation is illustrated (Jones, 2008b) by the application of the same rainfall run-off management technique ("moonscape") at two different mine sites. The intent of the technique is to harvest the incident rainfall by delaying run-off from the slopes, so enabling the build up of near surface moisture and assist the establishment of vegetation.

In Figure 1 the hard banded iron formation (BIF) waste material making up the dump weathers very slowly, is physically strong, heavy and is not displaced should the "pond" overtop.

The more friable materials in Figure 2 weather rapidly, with larger fragments breaking down and being more susceptible to rapid erosion when the "ponds" overtop.

Figure 1 Banded iron formation waste

The more friable materials in Figure 2 weather rapidly, with larger fragments breaking down and being more susceptible to rapid erosion when the "ponds" overtop.

Figure 2 More friable waste

2.3 Cost-effectiveness

Implementing legislation is a costly undertaking, but policing mining waste landforms is not a main stream political issue, therefore the resources allocated to this task by most governments is very small. Paucity of resources means that government regulators are forced to use systems to assess environmental compliance that are simple, require minimal man power (both numerically and experience-wise) and administratively cost-effective. Many regulators with mine closure responsibilities also have other concurrent responsibilities such as project approval. The challenge for the regulator is to have a resource effective system that attains the legislative objectives.

Prescriptive legislation is usually cheaper to administer because it can use technically relatively inexperienced regulators. One potential drawback of this approach is what happens if the regulator's prescription is wrong and the company follows that prescription. Can the regulatory authority avoid future liability for that landform?

Enabling legislation is more expensive to administer as it requires the regulators to have a higher level of technical competency. Nevertheless, being outcome based this type of legislation provides the best chance of an acceptable long-term environmental outcome at any specific mine site and has less potential risk for the regulator.

3 Results

One very difficult aspect of determining closure results is the very different time frames that the natural biological and geomorphological processes acting on the closed mine site take to evolve to final maturity.

When can we be reasonably certain that both a sustainable ecology and a stable landform have been achieved at a particular site?

The only practicable method currently available is an inexact combination of natural analogues, computer models and observation of historical man-made structures.

3.1 Geomorphological considerations

The natural analogues for waste dumps and tailings structures are not common, while man-made structures on the scale of modern waste dumps and tailings are extremely rare (Blight and Amponsah-Da Costa, 1999). However, modern modelling techniques have made considerable progress in predicting probable erosion outcomes on slopes by simulating erosion based on the physical properties of the material forming those slopes (Willgoose, 2000; Howard et al., 2010). These models allow the erosion potential of various slope and land form configurations to be compared at the design stage enabling the best probable slope design to be selected. The models do not give actual outcomes, but they allow the comparison of slope configuration options (Loch and Lowe, 2008; McPhail and Rye, 2008).

A natural hill attained its current stable configuration over many thousand (or even millions) of years, while mine closure requires that man-made waste dumps become stable in a much shorter timeframe. Waste dump designers (mine planners) should therefore be faced with the challenge developing landforms that emulate (not replicate) natural hills, while at the same time keeping mining costs low. My observations of mining operations all over the world indicate that very few operations could claim to have shaped their waste dumps to emulate natural hills, and many of the resulting landforms show significant erosion which could have been reduced if consideration had been given to the long-term stability of the landforms.

The very long-term geomorphological performance of any landform depends on its composition as well as the general and specific configuration of its surfaces and any protective cover. These elements have been generally summarised below (Table 3) as a comparison between a typical flat-topped, uniform-sided, truck built waste dump and a natural hill from the same climatic region.

Table 3 Comparison of man-made dumps against natural hills

Element	Man-Made Dump	Natural Hill
Construction material	Loose, unconsolidated run-of-mine waste	Rock core with (usually thin) regolith cover
Voids	c. 20%	>1%
Top surface	Large, flat	Very small, domed
Slope angle	Uniform (c. 20°)	Concavo-convex
Slope configuration	Regular horizontal steps	Smooth
Drainage	Poorly defined	Well developed, clearly defined
Vegetation	Initially uniform age	Mature, varied ages, co-evolutional with the landform

The element with the greatest impact on the long-term development of the man-made dumps, from their initial construction to mature landform, is the nature of the construction material. Unconsolidated run-of-mine waste with a high void ratio can never withstand the long-term weathering and erosive forces to the same extent as bed rock; however many of the other elements listed in Table 3 can be modified during waste dump construction, thereby reducing the time required for the dump to attain a high degree of maturity. Top surface, slope angle, slope configuration and drainage are all elements that can be adjusted through enlightened mine planning design and operations.

The top surface of any dump should be as small as practicable and domed, rather than flat.

Figure 3 Erosion gully on a flat topped waste dump

This is because a large flat surface at the top of a dump acts as a temporary pond for incident rainfall. Eventually the accumulated water will find a low point on the rim where all the ponded water could potentially discharge; causing the formation of deep erosion gullies (Figure 3). Limiting the size of this upper surface to the minimum practical area will reduce this potential. Other possible means of managing accumulated water, which depend on the climatic regime, include specially designed store/release caps and extreme surface roughness.

Three factors that have a major effect on the rate of erosion of any slope are the slope length, the slope angle and the surface shear strength of the slope material. While the surface shear strength of the slope is not changeable in most mining operations (Figures 1 and 2), both slope angle and length can be varied.

Most natural hill slopes that are not bed-rock outcrops have a concavo-convex ("S" shaped) cross section, with hills shedding the majority of incident rainfall through progressively reducing slope angles.

3.2 Hydrology and hydrogeology

The water moving down a uniform slope will commence to flow as a sheet, until it reaches a certain volume, at which point the flow will generally develop into a series of channels (Figure 4).

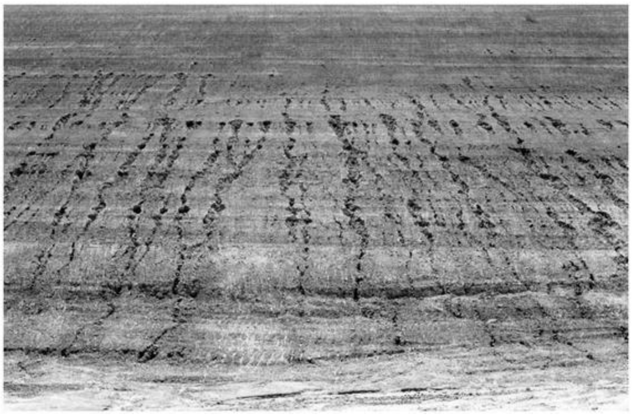

Figure 4 Sheet flow developing into channel flow

Managing sheet flow through variations of slope angles works to a certain point beyond which it is necessary to manage the run-off water using defined drainage channels. Robust landform drainage design approaches such as using the maximum probable flood as the design event and using deliberate landform shaping to produce a drainage pattern analogous to those on hillsides, with careful consideration to the relationship between catchment area and the size of drainage channel, should be adopted.

Engineered chutes are often unsuccessful in the long-term, because inadequate design/construction leads to bypassing and rapid gullying. It is important that these channels are appropriately sized and the angle of the channel bed designed to accommodate the expected volume of water. The design of the drainage pattern should roughly mimic the natural drainage systems (Myres et al., 2001) on hills in similar climatic regions, with the added proviso that because the dumps are constructed from unconsolidated materials, rather than bed rock, the individual catchments should generally be smaller than the natural ones.

Most practitioners now accept that narrow, horizontal or low-gradient berms (terraces) constructed across the slope are of negligible long-term benefit for reducing erosion through breaking up slope length. They actually exacerbate erosion, because they concentrate down-slope flow at overtopping points, leading to rapid gully development (Willgoose, 2000; McPhail and Rye, 2008).

Replicating natural hill hydrogeology is a difficult process, partly because there are no natural analogues for the very substantial, stand alone landforms, constructed out of run-of-mine waste and tailings.

The hydrogeology of dumps and tailings facilities is markedly different from natural hills. In natural hills the hydrogeology is controlled by the geology of the rock core, with the different lithologies and rock structures influencing the configuration of the unsaturated and saturated zones within the hill. The various lithological units will each have different porosity and permeability, while the geological structure of the hill will often influence the distribution of aquifers. The geological forces that create natural hills generally result in hills having a low void ratio. Waste dumps have a considerably higher void ratio than hills (swell factor of one bank cubic metres to 1.2 loose cubic metres for many waste materials) and a generally high permeability.

This means that the majority of waste dumps are relatively free draining, allowing incident rainfall to report to the ground footprint on which the dump is constructed. The rainfall exits as seepage, which is largely influenced by the pre-existing surface drainage. Notwithstanding this fact, many regulations and guidelines do not appear to consider this aspect of waste landforms, which can have considerable implications if any leachable, potentially harmful elements are contained in the waste or tailings.

3.3 Ecological considerations

The ecological aspects of closure (Brearley et al., 2000) are probably considerably better understood than the geomorphological aspects, in part because the time frames over which biological changes naturally occur are several orders of magnitude shorter than those required for natural geomorphological change and well within the timeframe of human experience. The ecological function analysis system (Tongway and Hindley, 2004) developed by various researchers appear to offer companies and governments tools to better assess the complex ecological processes than simple plant density or indicator species approaches that have been historically adopted as closure compliance measurements.

The challenge of recreating the vegetative cover on waste landforms was the first area tackled by the industry using the very cost-effective technique of seeking natural analogues in the form of areas disturbed by other activities. This required an understanding of the ecological cycles for existing disturbed lands and enabled the mining industry to conduct research into such things as plant succession and develop practical methods of replicating natural processes.

However, the vegetation on the majority of waste dumps is still often the result of a single successful planting, with a resulting uniform aged "crop", unlike the mixed ages of natural vegetation. This makes the vegetation susceptible to natural events, such as fire and excessive removal by grazing.

3.4 Closure and completion

The Australian Commonwealth government's 2006 handbook "Mine Closure and Completion" in their Leading Practice Sustainable Development in Mining series defines a completed mine as one that has reached a status where mining lease ownership can be relinquished and responsibility for the land accepted by the next land user.

This means that such a mine is demonstrably "environmentally compliant" but when this status is reached will very much depend on the perspective of the persons doing the "environmental compliance" assessment.

To be considered as being environmental compliant waste structures are required to be geomorphologically stable in the long-term, without the need for further maintenance. Similarly the vegetation established on the waste structures needs to be ecologically sustainable in the long term (Jones, 2010).

Some people hold the opinion that meeting standards set by government of the day is environmental compliance. Others consider that government standards are transitory and sometimes found wanting in developing sustainable ecologies and geomorphologically stable landforms at specific sites. They prefer to develop site specific solutions some of which can sometimes conflict with government “standards”.

Over the period I have been involved with environmental aspects of the mining industry, community aspirations, industry attitude, many guidelines and legislative requirements have changed dramatically. It is highly probable that such changes will continue, potentially posing a significant risk to those companies that choose to simply “meet the current pass mark” and government officers who believe they can dictate designs. Change is certain, but progress is not!

Having a current pass mark in the form of prescriptive legislation (e.g. slope angle for a waste dump or plant density for rehabilitation) is an environmental risk, as it encourages a lowest common denominator approach rather than an optimal solution for a specific site. Should that prescription be wrong or result in some adverse unintended consequences how is the remedial work funded?

4 Conclusions

Closure of a mine is the only aspect of that operation that is certain. All professionals working in and around the mining industry should take responsibility to plan and execute this certainty to the highest practicable standard.

Closed mines are epitaphs to the operators, the regulators and the guidelines at the time those sites were closed. In the spirit of sustainable development we should all endeavour to close our mines in a manner that is “*consistent with future as well as present needs”*.

Every mine is unique! No guideline or regulation can be a substitute for local knowledge of site conditions and the surrounding environment.

The design life of a closed mine is almost infinite and therefore the acceptable design standards adopted should be similarly long-term, such as maximum probable flood and maximum credible earthquake.

Ecological and geomorphological processes require different timeframes to reach maturity. An understanding of these processes is an essential part of designing an acceptable mine closure.

While almost all miners have a strong wish to leave their sites in a safe and acceptable condition the time and intellectual investment in closure matters is still low.

Disclaimer

The views expressed in this paper are the personal views of the author and do not necessarily reflect the views of any organisation the author is, or has ever been, associated with.

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