Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Cleaner Production 14 (2006) 285–298
Journal of Cleaner Production
www.elsevier.com/locate/jclepro

Optimisation of the mine closure process

David Laurence *

School of Mining Engineering, University of New South Wales, Sydney 2052, Australia

Received 9 December 2003; accepted 9 April 2004
Available online 10 May 2005

Abstract

The excitement and fanfare that surrounds the opening of a new mine is never present when it finally closes. Closure may be planned but most commonly, it is premature, occurring before ore (or coal) reserves are exhausted. The reasons why mines close are diverse and include economic, geological, geotechnical, regulatory, community and other pressures. Premature and planned mine closures can result in significant adverse impacts on the environment and community and need to be managed appropriately.

The use of risk management techniques can help reduce these impacts. The closure risk model has significant potential as a tool for decision-makers to assess the major closure risks at individual mine sites in a structured, systematic manner both qualitatively and quantitatively. This, in turn, facilitates comparisons between the closure issues at a single site as well as between different mines. A team-based approach is essential to ensure that all of the risks are incorporated, and the use of an external facilitator, as is standard practice in risk assessments, helps to reduce subjective bias. The importance of community engagement during operation and the inevitable mine closure phases cannot be overstated. If ignored, an optimal closure outcome will not be achieved. The consequences of a poor consultation strategy are potentially severe in terms of community impacts. Mining companies that get it right will benefit from the support they receive from employees, landholders, local and state governments, and other stakeholders. Other benefits include significant cost savings and a competitive advantage for future exploration/mining activities.

Even though closure issues are unique from mine-to-mine, it is possible to develop a series of principles to assist the company, government and community involved in the closure process to ensure maximum benefit for all parties involved.

Keywords: Mine closure; Risk analysis; Management tool

1. Introduction

For the past decade or more, the term “mine closure” has firmly entrenched itself into the lexicon of mine operators and regulators. Even “hard nosed” or “old school” mining engineers have come to appreciate that this fourth phase is just as important as the other stages of the mining cycle – namely exploration, development and production.

Although mine closure is recognised as an important component, it still lacks the excitement or prestige surrounding the other phases. When a new mine is opened, often by a local politician, notable excitement and goodwill typically accompanies this “good news story”. The mine operating team is enthused and individuals see the opportunities for building their careers as the mine develops; however, when a mine closes, the opposite usually occurs. There are no politicians to mourn the demise of the mine. Employees, often long serving, have to find other jobs and other places to live. Some of the best and brightest managers leave to pursue careers elsewhere, often in newly opened mines where they can “make their mark.” Reputations are rarely built by closing a mine. The local business community, which once prospered because of its association with the mine, must adjust to leaner times.

* Tel.: +61 2 9385 4597; fax: +61 2 0313 7269.
E-mail address: d.laurence@unsw.edu.au

0959-6526/$ - see front matter
doi:10.1016/j.jclepro.2004.04.011

Local and regional governments, accustomed to taxation, royalties and in many cases, infrastructure provided by the mine, must also learn to adjust. In developing countries, the schools and clinics operated by mine staff become the responsibility of the local community, which is often a problematic scenario. In some cases, environmental impacts are negligible after closure but in other instances, there are pressing problems.

From the 1970s to the mid-1990s, mine operators and regulators mainly emphasised environmental issues in closure plans. Mine rehabilitation techniques improved dramatically as a result [1,2]. However, the increased focus on sustainable development and its application to the mining industry in more recent times has helped put into perspective the need to address the equally important social and community aspects of mine closure [3,4]. Understandably, much of the focus has been on minimising the impacts of large scale mining – particularly sites in the developing world controlled by multinational companies. However, a number of mines have also ceased operation in developed economies such as Australia, USA and Canada, closures which have been challenging for the mining companies concerned and their stakeholders.

In the last five years, considerable work has been done at a global level to minimise the impact of mining on communities under the banner of sustainable development. The final report of the MMSD project, for example, stresses: "For a mine to contribute positively to sustainable development, closure objectives and impacts must be considered from project inception. The closure plan defines a vision of the end result of the process and sets concrete objectives to implement that vision. This forms an overall framework to guide all of the actions and decisions taken during the mine's life. Critical to this goal is ensuring that the full benefits of the project, including revenues and expertise, are used to develop the region in a way that will survive after the closure of the mine". The MMSD North American project analysed the issue of closure in depth in an attempt to "develop a set of practical principles, criteria and/or indicators that could be used to guide or test the exploration for, design, operation, closure, post-closure and performance monitoring of individual operations, existing or proposed, in terms of their compatibility with concepts of sustainability" [5]. Environmental and social aspects were explored in depth, particularly in relation to the following questions:

- Will people's well-being be maintained or improved? and
- Is the integrity of the environment assured over the long term?

Although the environmental and social impacts of mine closure are probably the most significant issues in terms of monetary, human or ecosystem values, other impacts cannot be ignored. For example, there are thousands of abandoned mines throughout the world where safety issues such as open shafts and dangerous structures are numerous. Catastrophic subsidence has taken place in numerous former mining fields such as Timmins, Ontario and Waihi, New Zealand. Technical aspects such as the optimum utilisation of the resource, a classic sustainability goal, must therefore be considered during the closure process; legal and financial issues must also be incorporated into closure plans. Only a small percentage of mines are closed in a planned manner, whilst the majority close prematurely or suddenly for a variety of reasons.

This paper explores the reasons why mines close, and examines the major risks associated with mine closure. The paper furthermore presents a classification system for quantifying mine closure risks for use by mine operators and regulators aiming to minimise the impacts of both premature and planned mine closure. The discussion concludes by further exploring ways in which to minimise the adverse social and community impacts of mine closure.

2. Why do mines close?

Mines close for a variety of reasons. The principal force is likely to be economic – specifically, a continued steady decline in global commodity prices. On the other hand, it may be geological, due, for example, to an unanticipated decrease in grade or size of the ore body. It may be technical, due to adverse geotechnical conditions or mechanical/equipment failure, or regulatory, due to safety or environmental breaches, or, at times, policy changes, which occur from time-to-time, particularly when governments change. Alternatively, a mine may be forced into closure by social or community pressures, particularly from those implacably opposed to mining or some other cause.

In a perfect world, mines close when their reserves are exhausted. In many respects, this is the easiest scenario to manage. In these cases, the various stakeholders are conditioned to the planned closure date. Employees, for example, can plan to find alternative employment either with the company or elsewhere. The community in which the mine operates is furnished with the opportunity to work with the mine to ensure sustainable benefits from its activities, although it should be remembered that communities, and sometimes employees, are often in denial and unprepared for the consequences of closure. This is particularly true in towns such as Broken Hill where mining has taken place for many decades. Governments have no doubt maximised their benefits in the form of taxes and royalties and should be working with the mine to ensure that environmental outcomes are optimum and in line with objectives stipulated within the closure or environmental management plan.

2.1. Closure due to economic reasons

One of the best-known examples of "mass" mine closures occurred in October 1985, when the price of tin dropped dramatically after the collapse of the Internal Tin Agreement at the London Metal Exchange. The price dropped more than 50%, from US$5.40/pound to $2.50; numerous mines could no longer remain in operation. This naturally had an impact on large companies but particularly affected the small-scale tin miners operating, for instance, in Tingha and Emmaville, Australia. The outcomes were significant environmentally (numerous unrehabilitated open cuts and waste dumps) and detrimental economically for mine workers, mine owners and communities. The effects in other countries were even more dramatic, such as in Bolivia, where a reported 50,000 miners lost their livelihoods.

2.2. Closure due to geological reasons

Ore reserves are estimates based on the best available data provided by geological, geophysical, geochemical, and drilling techniques, and by other relevant means. An over-estimation of the grade and tonnage of a deposit is a common reason for a mine to close prematurely. The Mount Todd Mine in the Northern Territory is one such example. Here, head grades were estimated at over 1 g/tonne but averaged a little over 0.8 g for the life of the mine. The mine closed after one year, although the expected mine life was more than nine years. Similarly, Cumnock Coal in the Hunter Valley of NSW closed in 2003 due to "adverse geological conditions". The Chief Executive Officer further indicated, "whilst it is very disappointing to see the underground mine close and employees lose their jobs, I am comforted by the fact that due to Xstrata Coal's financial support to date we have been able to extend the mine's life and ensure the continuity of operations and employment. Furthermore, as a result of this financial support, Cumnock Coal is able to meet all employee entitlements in full" [6].

2.3. Closure due to geotechnical reasons

Mining takes place in a non-homogeneous rock mass, which varies from site to site. Imperfections in the rock in the form of joints, cleavages, cleats, and other planar weaknesses, combined with faults, shear zones and hydrological issues, can lead to failure of the rock mass. Falls in underground workings have caused the premature closure of many mines, including the Tom's Gully Mine in the Northern Territory, where the decline intersected a fault and the development failed to overcome the resultant poor ground conditions. The most spectacular closure in Australia in recent years due to geotechnical reasons was the 1998 hanging wall or stope failure at the Browns Creek Mine in central NSW, and the subsequent inrush and filling of the mine with water overnight; the mine has never reopened. Inrush also caused the deaths of four coal miners and the closure of the Gretley Coal Mine in NSW in 1996. Although there were minimal environmental issues, the social and community fallout has been considerable, with prosecutions of the company and individual managers continuing (December 2003).

Pit slope failures in open pit mines can cause permanent mine closures and most recently caused the deaths of eight workers at the massive Grasberg open cut mine in Indonesia, operated by PT Freeport. The mine closed temporarily after this incident.

2.4. Closure due to equipment or mechanical failure

Mine closures due to equipment failure have been a part of mining history. One of the more notorious cases was the Hartley mine in the United Kingdom, which closed in 1862 when its Cornish Beam pump collapsed into the shaft used to ventilate the mine. As a result, 199 miners perished due to lack of air.

2.5. Closure due to regulatory pressure

Government regulators generally have the power to close mines due to environmental or safety breaches. A recent, highly publicised example is the Baia Mare mine in Romania. This mine also had the pressure of the Australian Stock Exchange suspending trading in its shares. Operations at the Mt Kasi Mine were stopped for over six weeks by the Government of Fiji for failure to contain tailings. The Northparkes Mine temporarily closed in 1999, following an incident resulting in the deaths of four personnel.

2.6. Closure due to government policy

Mineral sand mining on the coasts of New South Wales and Queensland is almost extinct because of government policies, which, in response to community pressure, give land use preference to National Parks over mineral resources. The operations of Dillingham were prematurely closed by the Federal Government in 1976 at Fraser Island in Queensland after the Fraser Island Environmental Inquiry found that mining constituted a significant threat to the island's environment. The re-opening of the Woodsreef asbestos mine in northern NSW was stymied due to the controversy surrounding the mining of asbestos. The author was involved in the regulation of both mineral sand and asbestos mining in the 1980s.

2.7. Closure due to community opposition

The Timbarra gold mine in NSW closed in 2001 due in part to the continued opposition to its operation by an alliance of opposition groups. The low grades sent to the mill and persistent wet conditions during its construction and early operations also contributed to its premature closure. The Jabiluka Uranium Mine operated as a development operation only (i.e. no production of uranium) in the face of highly organised opposition from environmental and community groups for almost two years before operations halted. The owner, Rio Tinto, has indicated it will not recommence mining at Jabiluka until the traditional owners are supportive of mining.

2.8. Closure due to other reasons

Occasionally, mines close before their reserves are exhausted due to reasons other than those indicated above. For example, the coal mining operations at Catherine Hill Bay in NSW closed after the company was sold to a buyer who wanted to develop the area for its prime real estate appeal.

Examples of premature mine closure and their implications are illustrated in Table 1.

3. What are the major mine closure risks?

The following checklist of the issues involved in mine closure is based on extensive experience gained from mines throughout Australia, the Pacific, Africa and South America. It should be stressed that this classification is intended as a guide, and is not meant to be fully inclusive of all of the issues involved at every mine site. Due to the dynamic and diverse nature of the industry, new issues will appear from time-to-time. Each mine will have a unique classification. The major risks are identified as environmental, safety, community, final land use, legal, and financial and technical. These are further divided into broad risks, sub-issues, and specific events (Tables 2–7).

4. Analysing the risk

Risk management is recognised as one of the most powerful tools available to reduce the impact of potentially catastrophic events in mining [7]. Previous research indicates it also has potential for application in the area of mine closure [4,8].

The Closure Risk Model was developed by the author as a new tool to aid decision-makers in the complex area of mine closure. It uses a simple analytical technique that allows the decision maker to simplify what is often a complex mine closure process into more easily managed sub-components. This systematic approach ensures that critical factors in the closure process are not overlooked. It also allows the most important issues to be highlighted (4).

The model can also be used to produce quantitative estimates of risk to produce the Closure Risk Factor (C_{RF}). A comparison of closure risk factors from various sites will be particularly useful for the larger company with a stable of sites to allow appropriate resources to be dedicated to the locations posing the highest risks. Correspondingly, a government department regulating numerous sites will find the tool useful in applying its limited resources for the best outcome. The technique will assist industry and government personnel to achieve the optimum closure outcome in the knowledge that all factors – not solely environmental components – have been adequately considered.

The Closure Risk Factor (C_{RF}) is simply a qualitative and quantitative measure that captures the various significant risk components of mine closure. These components can be broadly divided into environmental risks (R_E), safety and health risks (R_{SH}), community and social risks (R_C), final land use risks (R_{LU}), legal and financial risks (R_{LF}) and technical risks (R_T). The Closure Risk Factor is the sum of these individual risks and the relationship can be expressed by the following linear equation:

$$C_{RF} = \sum (R_E + R_{SH} + R_C + R_{LU} + R_{LF} + R_T)$$

The C_{RF} allows the closure risks at each mine site to be broken down into as many individual components as considered appropriate by the decision-maker. For example, some of the "non-negotiable" outcomes that a mine manager in consultation with a corporate office may wish to achieve are as follows:

- that environmental objectives are achieved in line with best practice and the company's policies and guidelines;
- ensuring sufficient funds are available to cover closure;
- that employee entitlements are protected;
- the best personnel are in place to manage and implement the closure process;
- the community is positive about and participates in the process;
- that resource extraction has been optimised in line with the economic model so as to provide optimum benefit for shareholders;
- ensuring public safety issues will be addressed; and
- that the company will be released from liability on the site as soon as possible after operations (and cash flows) cease.

Table 1
Examples of premature mine closure

Mine	Commodity	Date	Reason	Main closure implications
Subera	Sapphire	1993	Price, grade	40 job losses, future success of company compromised
Woodcutters	Zn	1998	Price, even though reserves at depth	Loss of 200 jobs
Tingha, Emmaville	Sn	1985	Price dropped (LME)	Massive environmental legacy – waste dumps, open pits, sedimentation etc.
Browns Creek	Au	1998	Mine filled with water due to inrush	Loss of 250 jobs, potential human catastrophe
Mt Todd	Au	1998	Grade lower than model; mineral processing and metallurgical issues	Environment, indigenous j/v threatened; 300 job losses
Horn Island	Au			Environment – $5 million to rehabilitate, taxpayers dollars
Woodlawn	Cu, Zn		Reserves at depth, ownership change	Employees demand entitlements – media headlines
Mt Carrington	Au	1988	Grade, metallurgy	Acid mine drainage, pollution of rainforest streams
Timbarra	Au	1999	Grade, environmental conditions (constantly wet)	Sensitive wetlands environment, difficult to rehabilitate, victory for opponents of mine living downstream
Jabiluka	Uranium	2001	Traditional owner objection and commodity price	Ore and waste returned to mine; possible end to all uranium mining in that region
Rustlers Roost	Au	1997	Mine owner financial difficulties during mine expansion phase	Mineral resource remains to be mined; loss of shareholders investments; 80 job losses
Tom's Gully	Au	1996	Poor ground conditions in access decline	Rehabilitation required. Massive acid rock drainage legacy
Hartley Platinum	Pt group minerals	1997	Technical difficulties in mining phase	Loss of 1000 jobs, major negative global impact on BHP
Fraser Island	Beach sand minerals		Closure due to government policy – national parks	Loss of jobs and end of a once flourishing industry
Oakdale	Coal	2000	Company financial difficulties	Employee protests in the media; poor advertisement for the mining industry
Baia Mare	Au	2000	Cyanide spill	Major environmental issues including fish kills from cyanide pollution; major social impact; resulted in delisting of company's share and end of business; major setback for European mining industry
Summitville	Au		Leak AMD	Massive environmental (AMD) and general industry damage
Hillgrove	Au, Sb	2002	Commodity price, expansion and finance difficulties	150 job losses, impact on local community
Mt Kasi	Au	2000	Mineral processing, insufficient ore reserves, lack of mine planning	Environmental degradation from nuisance to severe, loss of 200 jobs and credibility in community
Gretley	Coal	1996	Inrush from adjacent, abandoned workings	4 deaths
Cumnock	Coal	2003	Adverse geological conditions	No major environmental or social issues – employees receive entitlements

Table 2
Classification of environmental risks (R_E)

Broad closure risk	Sub-issue	Specific event (options)
Water	Surface waters	Sedimentation
		Effluent
		Drainage
		Acid Mine Drainage (AMD)/heavy metals
		Salinity
	Ground waters	Contamination (ARD, NMD and processing chemicals)
		Drawdown
	Downstream usage	Agriculture
		Drinking
		Aquatic ecosystem
Air	Gas	Greenhouse gas emissions
		Other emissions (e.g. SO^2)
	Dust	Tailings
		Stockpiles
		Rehabilitated areas
Land systems	Aesthetic values	Close to population centre or main roads
		Remote
	Infrastructure	Buildings, equipment, camps
		Roads
		Stockpiles, dumps, dams, sumps
		Borrow pits
	Soils	Contamination
		Topsoil availability/suitability
		Erosion potential
	Reshaping/earthworks	
	Flora reestablishment	Simple
		Complex
		Rare/significant
	Fauna reestablishment	Terrestrial
		Avian
		Aquatic
	Voids	Open
		Backfill (using waste rock)
	Subsidence	
	Exploration	
	Management/ monitoring	
Wastes	Dumps	Reshaping
		Covers
		AMD
		Topography
		Seismicity
		Climate
	Tailings	Reshaping
		Covers
		AMD
		Toxicity
		Stability
		Landbased
		Riverine
		Submarine
	Hazardous materials	Chemicals including cyanide
		Fuels, lubricants
	Other	Sanitation
		Tyres, machinery etc.
		Garbage
Heritage	Indigenous	
	Non-indigenous	

The regulator, such as a State Department of Mines and Energy, may require that:

- there is a sufficient security bond to enable final rehabilitation and closure to be carried out should the company default on its commitments;
- the site will not be added to the list of orphaned or abandoned mines to be rehabilitated at public expense;
- the resource has been utilised for optimum benefit for the community;
- it will not be embarrassed or "caught out" by releasing securities back to the companies too early; and
- public safety issues are addressed.

The above approach is consistent with sustainability reporting guidelines published by the Global Reporting Initiative (GRI) in reference to indicators of an organisation's sustainability performance. The "GRI recognises the value of both qualitative and quantitative information, and views both as complementary and necessary to presenting a balanced and reasonable picture of an organisation's economic, environmental, and social performance. Where possible, GRI employs quantitative indicators. However, certain topics, particularly in the field of social performance measurement, do not readily lend themselves to quantification" [9].

5. Quantifying the risk

The science of risk management is continually evolving. Australian Standard (4360) defines risk as

Table 3
Classification of safety and health risks (R_{SH})

Broad closure risk	Sub-issue	Specific event
Openings	Shafts, raises, winzes	
	Adits, drifts	
	Open pits	Backfill
		Fencing
		Bunding
		Reducing batters
	Trenches, costeans, drill holes	
	Dewatering	
Subsidence	Coal or mineral extraction	
	Crown pillar collapse	
	Caving	
Infrastructure	Buildings, equipment	
Security	Increased security	Theft
		Unauthorised access
Emergency response preparedness		
Radiation source disposal		

Table 4
Classification of community and social risk (R_C)

Broad closure risk	Sub-issue	Specific event
Employees	Provision for entitlements Retraining, relocation Workers compensation claims	
Management	Improved communication Safety awareness – increase in injuries as closure approaches Keeping team together particularly key personnel	
	Contractors	Can be used to soften the blow of retrenching employees Potential for cost blow outs
Unions/employee representatives		
Landowners	Indigenous Non-indigenous	
Affected residents		
New settlers		
Local government		
General community impact	Local	Fly-in, fly-out or mining town One company town Isolation Mining tradition in area High local unemployment Single industry town Residential property value impact Impact on family values Diversification or decline Return to subsistence Health issues – alcohol, drugs
	Regional National International	

"the chance of something happening that will have an impact on objectives". It is measured in terms of the probability of an event occurring and the consequence of that event, or Risk = Probability × Consequence [10].

One of the more important tools for quantifying risk in mining is the Workplace Risk and Control or WRAC technique. The method requires a team of key personnel to generate a number of possible hazards or events with a process or piece of equipment and quantifying the likelihood or probability and the consequence of that event occurring. The team will usually consist of mine site personnel familiar with the process/equipment, as well as external participants, including a facilitator. Quantification of risk allows a decision maker to prioritise risks and decide to eliminate control or tolerate the risks. The risks are calculated in a risk matrix such as that shown in Fig. 1.

The closure risk model enables the risks from the various broad closure issues to be compared and combined to enable an overall Closure Risk Factor for a particular mine site to be estimated. It does this by quantifying the probability and consequence of each potential event.

Unlike the typical WRAC matrix, in which the highest probability and consequences are usually allocated the smallest numbers, in the model, the higher the probability or consequence, the higher the number. In other words, if an event has a probability of 10, then, unless timely intervention occurs, the event would certainly occur; conversely, if determined to have a probability of 1, it is unlikely to occur. If the consequence of an event is 10, then the outcome could be catastrophic in the form of a multiple fatality, a major environmental incident, major equipment damage, a major loss to the

Table 5
Classification of final land use risk (R_{LU})

Broad closure risk	Sub-issue	Specific event
High value ($/ha or conservation values)	Premium agricultural land Industrial/commercial/residential National park/heritage	
Medium value	Return to pre-existing ecosystem Forest Grazing	
Low value	Previously disturbed mine site Heavily degraded arid land	

Table 6
Classification of legal and financial risk (R_{LF})

Broad closure risk	Sub-issue	Specific event
Government	Regulatory compliance	
	Title	Retain
		Sell
		Relinquish
	Security/bond	Large
		Small
	Documentation	
Creditors	Employees	
	Contractors	
	Businesses	
	Government	Taxes
		Royalties
Provisioning for rehabilitation	Provision made	
	No provision	
Salvage		
Potential for adverse publicity and impact on business		

Table 7
Classification of technical risk (R_T)

Broad closure risk	Sub-issue	Specific event
Closure plan	Plan exists and up to date	
	Plan not up to date	
Rehabilitation progress against plan		
Closure team	Management	
	Community liaison	
	Environmental	
	Planning	
	Electrical/mechanical/financial etc.	
Resource/reserves	Exhausted	
	Not exhausted	Accessible for future extraction
		Potential for new reserves
		Sterilised permanently

business, or a ruined community standing. If a consequence of 1, there is an insignificant chance of injury, or a health implication, environmental damage or ongoing liability to the business. The risk matrix is illustrated in Fig. 2.

An example of the use of the model as applied to an Australian mine is shown in Fig. 3. In this case, the author has assigned the risk to each event. At a mine site, however, this would be carried out by a team of key personnel.

In a similar manner to environmental and occupational health and safety risk management, individual closure risks can also be classified or prioritised. In the case study identified above, the highest risks and their scores are as follows:

- Environment – aesthetics due to the mine being surrounded by a world heritage national park (100).
- Land use – need to rehabilitate to the standards of the surrounding environmentally sensitive wetlands (100).
- Community – hostility to both operation and closure of mine by indigenous landowners (100).
- Financial – adequate provisioning for the cost of rehabilitating to these standards (90).

This particular mine should be classified as a *very high to extreme risk* because of the numerous environmental, community and legal issues identified. The mine is surrounded by a world heritage listed national park, there is considerable indigenous and general community

	Consequences				
Likelihood	Very Low **1**	Minor **2**	Moderate **3**	Major **4**	Catastrophic **5**
A (Almost Certain)	**15** *(Significant)*	**10** *(Significant)*	**6** *(High)*	**3** *(High)*	**1** *(High)*
B (Likely)	**19** *(Moderate)*	**14** *(Significant)*	**9** *(Significant)*	**5** *(High)*	**2** *(High)*
C (Moderate)	**22** *(Low)*	**18** *(Moderate)*	**13** *(Significant)*	**8** *(High)*	**4** *(High)*
D (Unlikely)	**24** *(Low)*	**21** *(Low)*	**17** *(Moderate)*	**12** *(Significant)*	**7** *(High)*
E (Rare)	**25** *(Low)*	**23** *(Low)*	**20** *(Moderate)*	**16** *(Significant)*	**11** *(Significant)*

Fig. 1. Calculation of risk using the risk matrix [7].

Probability	10 (certain)	9	8	7	6	5	4	3	2	1 (rare)
Consequence										
10 (catastrophic)	100	90	80	70	60	50	40	30	20	10
9	90	81	72	63	54	45	36	27	18	9
8	80	72	64	56	48	40	32	24	16	8
7	70	63	56	49	42	35	28	21	14	7
6	60	54	48	42	36	30	24	18	12	6
5	50	45	40	35	30	25	20	15	10	5
4	40	36	32	28	24	20	16	12	8	4
3	30	27	24	21	18	15	12	9	6	3
2	20	18	16	14	12	10	8	6	4	2
1 (insignificant)	10	9	8	7	6	5	4	3	2	1

Fig. 2. Mine Closure Risk Assessment matrix.

opposition to operations, and the commodity being mined is uranium.

This discussion that follows describes the results of field trials at several mines in the Northern Territory of Australia on which the model was tested. As a result of the trials, an improved version of the model was developed.

6. Field trials

6.1. Background

Mine closure questionnaires were distributed to the following five mines in the Northern Territory of Australia. The questionnaires consisted of eight questions. The first question asked each respondent to prioritise or rate the relative importance of the major mine closure issues (such as environment, community, safety, etc). The remaining questions asked them to list or rate the most important sub-issues under the classifications of environment, community, safety and so on. Additional comments were invited. The main characteristics of the mines surveyed are as follows:

- Mine A – major alumina producer, employing over 1000 personnel. Responses from eight managerial personnel received.
- Mine B – major zinc and lead producer, two responses.
- Mine C – medium-scale open cut gold mine, three responses.
- Mine D – medium-scale open cut gold mine, one response.
- Mine E – small-scale industrial minerals producer, one response.

The manager of each mine was requested to engage key personnel to complete the survey, including:

- the mine manager (or resident manager or general manager);
- the environmental manager (and environmental personnel);
- the technical services manager (or mine planning engineer);
- the community liaison coordinator; and
- other key personnel, including mill manager, financial controller, and/or production superintendent.

Embracing the views from this broad cross-section of senior staff ensures that as many of the major issues are captured as possible.

6.2. Discussion of results

The main purpose of the survey was to enable a risk classification or rating to be achieved. It is acknowledged that the responses represented a very small sample and may not be statistically significant. However, this was not considered to be a fatal flaw in the investigation, given the aim of obtaining the views and a risk rating from key personnel in a variety of roles within each mine.

6.2.1. Mine A

The results from the eight respondents from Mine A show good consistency on environmental issues but

CALCULATION OF CLOSURE RISK - URANIUM MINE, NORTHERN TERRITORY						
			P	Q	QUANTITATIVE	
BROAD CLOSURE ISSUE	SUB-ISSUE	EVENT	prob	conseq	RISK	SUBTOTALS
ENVIRONMENT	WATER	DOWNSTREAM - POTABLE	8	10	80	
		RADIATION/HEAVY MET.	8	9	72	
		SEDIMENTATION	8	3	24	
	AIR	DUST (RADIOACTIVE)	9	9	81	
	LAND SYSTEMS	AESTHETICS - WORLD HER.	10	10	100	
		INFRASTR. - BUILD., EQUIP	9	3	27	
		REVEG. - TROPICAL	8	6	48	
		FAUNA REESTABLISHMENT	7	4	28	
		VOIDS	9	7	63	
	WASTES	DUMPS - RESHAPING	8	8	64	
		TAILS	9	9	81	
		HAZARDOUS	7	7	49	
		DOMESTIC	6	3	18	
						735
SAFETY/HEALTH	UNSAFE OPENINGS	OPEN PITS	8	8	64	
		TRENCHES/COSTEANS	5	5	25	
	INFRASTRUCTURE	BUILDINGS/EQUIP	9	3	27	
	SECURITY	SABOTAGE THREAT	4	9	36	
	AIR	GAS (RADON)	9	7	63	
						215
LAND USE	HIGH VALUE	WORLD HERITAGE	10	10	100	
						100
COMMUNITY/SOCIAL	EMPLOYEES	ENTITLEMENTS	9	6	54	
		RETRAINING, RELOCATION	2	2	4	
	UNIONS	HEALTH ISSUES	6	7	42	
	LANDOWNERS	INDIGENOUS HOSTILITY	10	10	100	
	COMMUNITY IMPACT	LOCAL	9	9	81	
		REGIONAL	9	7	63	
		NATIONAL	9	6	54	
		INTERNATIONAL	9	5	45	
						443
LEGAL/FINANCIAL	GOVERNMENT	RETAIN TITLE	9	6	54	
		SECURITY	9	8	72	
	CREDITORS	EMPLOYEES	7	7	49	
		CONTRACTORS	7	5	35	
		BUSINESSES	7	4	28	
		GOVERNMENT	7	3	21	
	PROVISIONING FOR REHAB	EXPENSIVE REHABILIT.	9	10	90	
	ADVERSE PUBLICITY	PROTESTS, CORPORATE PR	8	8	64	
						413
TECHNICAL	CLOSURE PLAN	COMPLEX	8	7	56	
	REHAB PROGRESS	GOOD PROGRESS	5	3	15	
	CLOSURE TEAM	MANAGEMENT	4	4	16	
		ENVIRONMENT, PLANNING	4	6	24	
	RESERVES/RESOURCE	EXHAUSTED	7	3	21	
						76
CLOSURE RISK FACTOR						1982

Fig. 3. Application of the Closure Risk Model in an Australian mine.

variable results thereafter. The main closure risks at the mine are tailings, water management, final land use, and impacts on indigenous landowners and the local community. This is reflected in the risk scores, with Environment "leading" by a long margin, followed by Safety and Community, and the remaining issues. The overall Closure Risk Factor was estimated at 1040 and therefore, classified as a high risk.

6.2.2. Mine B

The responses here were remarkably consistent in all areas, with the exception of the Technical issues. Environment was considered the biggest risk, followed by the equally weighted Community and Safety issues. The major concerns identified by the team were tailings and waste dump rehabilitation, public access, the use of a realistic closure plan and employee entitlements. The Closure Risk Factor was estimated at 740 for this mine.

6.2.3. Mine C

The responses varied significantly for this mine in all of the broad closure issues, except for final land use. Unlike other mines, safety and health issues were considered the most significant, followed closely by technical and environmental issues. This in itself is significant, as it confirms that mine closure is multi-factorial and one cannot assume that environmental issues are the only issues requiring focus from senior management. The major issues were considered to be the adequacy of funds to cover closure, employee entitlements, open voids, and acid mine drainage. The average C_{RF} score was 1368.

6.2.4. Mine D

"Other" issues scored the highest, followed by environment and safety. The respondent indicated under "other" that internal and external communication is a top priority as well as understanding stakeholder requirements prior to closure. Unsafe open pits, stakeholder requirements, and capping of tailings and waste rock dumps also scored highly. The C_{RF} score was 1315.

6.2.5. Mine E

This is a small mine, with few environmental issues associated with its closure planning. Ensuring the area is safe for gem-seeking tourists after closure is the major issue, along with dismantling infrastructure and stabilising pit walls. Environmental issues dominate, followed by technical, end use and safety issues. The score of 470 confirms that there are minor closure issues at this mine.

6.3. Analysis of results

The field trials illustrated that useful results are achievable, particularly when used to brainstorm the qualitative broad closure issues and individual risks faced by a mine site. As one of the managers stated:

"I held a workshop with my managers today who all filled in the questionnaire independently. We then discussed and allocated the important issues. (It is) a good searching questionnaire."

Table 8 summarises the scores from each of the mines, and Table 9 relates the scores to typical mines throughout the developed and developing worlds.

6.4. Comments from managers

Mine A

"It is important to ensure that an operating company has both the intention and financial capability to complete closure obligations. An agreed closure plan and the demonstrated capability to meet the plan are important. In the absence of clear intent/capability a closure bond or trust account may be required."

Mine B

"Issues with closure are two fold. Traditionally companies do not devote adequate time or technical expertise to developing properly constructed closure plans and then implementing them. Also, regulatory agencies are not developing/encouraging novel approaches to mine closure and the future direction of legislation in this area does not indicate that they are likely to."

Mine C

"My view has been to leave the bare minimum behind so that half-baked heritage issues don't come back to haunt the industry in 40 years time. I guess I liked the Shay Gap closure, which left behind only one small plaque to show where it had been."

Mine E

"Companies and individuals can now be held responsible for environmental damage. Whether the DME or government have the resolve or the resources to chase is another matter. DMEs are reluctant to take responsibility for mine sites because of the costs of recovery. Many sites are on caretaker status and the damage has been done."

Table 8
Comparison of the Closure Risk Factor at the trial mines

Mine	CRF	Classification
Uranium Mine	1982	Extreme
A	1040	High
B	708	Moderate
C	1368	High
D	1315	High
E	470	Minor

6.5. Potential uses of the model

Apart from improving the operational outcomes for mine site personnel, there are a number of other potential uses for the model, including the following:

1. Corporate governance – the risk assessment process will help the Boards and senior executives will crystallise the longer term needs of the mining company and its operations in parallel with its short-term needs.
2. Long-term planning and budgeting – the model will assist the Board, senior management, consultants, financiers and contractors.
3. Induction – the model will help build awareness among staff and contractors (if they participate in the survey and/or results are disseminated to them).
4. Performance review – the analytical approach to the issues will assist in providing components of input into the key performance indicators for the Board, senior management and site personnel. It could also form a part of a peer review process.
5. Regulators or other government departments may find the tool useful to benchmark operations.

6.6. Limitations in using the model

In its present form, the model suffers from a number of limitations, including the following:

1. It is based on a limited number of sites and the input of a limited number of respondents at those sites. Thus, responses are based on the perceptions of respondents and may vary from person to person and from day-to-day.
2. The personnel involved in the risk assessment process are mine site employees but there is no reason why the process should not be broadened to include outside stakeholders.
3. Caution needs to be exercised in the selection of personnel involved in the risk assessment process to ensure that political issues such as vested interests are not allowed to deleteriously impact on the process.
4. High consequence, low probability events such as tailings storage failures as a result of seismic activity

Table 9
Relationship between CRF and complexity of mine closure

C_{RF}	Closure Risk Rating	Typical Characteristics	Examples
> 2000	Extreme	Environmentally and socially sensitive locations; subjected to past, extensive environmental abuse	OK Tedi, Grasberg or other large scale open cut mines in Pacific, Indonesia, using riverine or deep sea tailings disposal
1500–2000	Very high	Proximity to extremely sensitive areas e.g. world heritage; long established mining towns; sensitive commodities such as uranium, asbestos	Arnhem land uranium mines; Butte; Broken Hill; Wittenoom blue asbestos
1000–1500	High	Large surface mines in proximity to settled areas; mines in developing countries; gold or other mines with acid mine drainage potential; any mines where mine is only employer in local community	Hunter Valley strip mines; Pine Creek geosyncline gold mines; Zambian copperbelt
500–1000	Moderate	Underground coal mines with pillar extraction; hard rock mines using caving methods; suspect crown pillars; gold mines in remote, semi-arid regions	Lake Macquarie underground coal mines; Northparkes block cave mine
< 500	Minor	Alluvial strip mines using chemical-free gravity treatment; underground coal mines with first workings only; clay quarry near regional centre – to be used as landfill or other purpose on closure; small extractive operations	New England sapphire mines; sand extraction in any capital or regional city

need to be accounted for in the risk assessment process as much as the higher frequency but lower consequent events.

5. The outcome of the process is a "snapshot" at a particular mine – the process should be repeated at regular intervals (e.g. annually, biannually, etc.) to track the changes in mine closure risks over time.
6. A logical extension to the model may be a built-in scenario capability and the calculation of potential cumulative impacts. This could be accomplished in a similar facilitated manner to the risk assessment.
7. A useful extension to the model would be for the numerical risk factor to be related to a dollar value.

All of these limitations can be overcome, and improvements can be achieved as the database is extended.

7. Addressing social and community impacts

Ensuring the best outcome for the community is one of the many challenges confronting a mining company and its management team as they attempt to optimize shareholder value. As Humphreys [11] explains, "getting it right will make for bottom line business success. Getting it wrong will be costly, even terminal". Given the community's increasing emphasis on "doing it right", it is appropriate to address the issues in some detail.

Failing to involve the community during the mine closure process can result in numerous adverse outcomes, including [12,13]:

- unnecessary expenditure of management and employees time;
- mining as a future land use in an area that may be threatened;
- social ills, including crime and alcoholism, may escalate, an increasing problem in developing countries;
- local businesses could dramatically collapse;
- real estate values could plunge;
- breakup or elimination of communities could occur (although this may be inevitable);
- inappropriate or non-existent rehabilitation could create long-term problems for the community; and
- a negative corporate and industry image is likely to result due to a media thriving on stories such as these.

7.1. Lessons for the company

Community consultation or engagement should be a life-of-mine principle. If consultation is working well during the mine's operations, it is unlikely that there will be problems experienced during the closure process. The management of a company should always be honest and transparent in its dealing with the community, and should always provide it with appropriate notice of closure. If a closure is planned rather than unexpected, notice should be given to the community. There is an optimum amount of notice that should be given, dependent on many of the factors outlined above. At Pasminco's Broken Hill Mine, which is scheduled to close in 2006, the community has been on notice for some time. A task force is addressing closure in a systematic manner, even though there is another five years of mine life. It should be noted that mining at Broken Hill has continued without serious interruption for almost 120 years. At mines with a considerably shorter lifespan, 12 months is considered optimum. The risk of too long a notice could result in the loss of key employees and a low morale, which could lead to safety and environmental problems, and even sabotage.

The challenges for the company are to maintain morale during the latter stages of operation, and to monitor safety and environmental performance throughout. It should assist employees in job search/retraining/relocation, provide a fair redundancy package, use its network to place employees, and should use incentives to retain key employees. An employee closure fund will facilitate redundancies, relocation assistance, and workshops on useful topics. Outsourcing certain final works or using contractors for jobs normally performed by employees will soften the final blow.

Company homes should be progressively released into private ownership rather than at closure, in order to preserve local real estate markets. The company should also think about providing seed funding for new industries. This works especially well in developing communities, where the cost of this initiative is small but the potential gains in terms of sustainability are significant. The company should establish a closure committee/advisory panel comprising relevant stakeholders, and seek input from stakeholders regarding decommissioning plans.

Effective public relations will assist the company, and public meetings or "open days" can mollify the community. The media is powerful in Australia and has been quick to illustrate to the public environmental and safety problems in mining. However, it can and should be used to the advantage of the industry.

7.2. Lessons for employees

Employees must acknowledge that mines have a finite life and closure is inevitable. They should take advantage of assistance from the company and remain focused. Lower morale often means more accidents. Employees should recognise that closure is a challenge and maybe positive for their careers.

7.3. Lessons for unions/employee representatives

Trade unions need to ensure that they are fully aware of the impending closure. Their immediate focus may be to assist members in obtaining entitlements such as long service leave. They should work with the company to prolong mine life and ensure continued profitability (thus providing more benefits for members). They need to work to ensure that safety will not be compromised and work to encourage accreditation and skills development to facilitate employment options for retrenched miners. It should be recognised that it will be difficult to ensure placement of all members at other mines, particularly older members.

7.4. Lessons for local government/councils

This lowest tier of authority has often been a major beneficiary of mining operations and would therefore suffer a significant loss of benefit such as rates and indirect spin-offs when the mine closes. It should take advantage of federal government initiatives, must ensure awareness of impending closure, plan for the effects of closure, be realistic in expectations, and explore any diversification options.

7.5. Lessons for state/federal governments

State governments play an important role in planning and overseeing mine closure. They can, for example, implement a subsidisation plan to prolong mine life. This may provide the company with royalty or other taxation relief to give an incentive to mine lower grade or deeper ore bodies. It should be realistic in expectations; offer job search services to employees; ensure awareness of impending closure; ensure that the community is protected by the imposition of environmental securities; establish a task force/committee if necessary; and explore retraining, diversification (private and public sectors), use of infrastructure, and investigate the potential for mine tourism. The government should establish a contract between itself and the company regarding arrangements for decommissioning, which should emphasise giving adequate notice, severance payments, relocation costs, etc.; establishing a trust fund for decommissioning; and establishing a security deposit for rehabilitation.

7.6. Lessons for landholders/occupiers

It needs to be recognised that indigenous and non-indigenous landholders can have common and different needs. They need to:

- ensure that rehabilitation is on-target and is being carried out as agreed;
- ensure decisions as to what infrastructure is to remain are made early; and
- ensure clarity on royalty/compensation issues.

7.7. Lessons for local business operators

Local businesses generally flourish when a mining company is operating in their locale. However, business operators must acknowledge that closure is inevitable and mine-induced prosperity will come to a halt following closure.

7.8. Lessons for local residents/other groups

In every community affected by mining, there are a number of interest groups that are either in favour of, or in opposition to, the mine. Mine managements needs to ensure that these groups are made aware of impending closure in order to optimise outcomes for them.

8. Conclusions

This paper has analysed the multiple reasons why mines close. Premature and planned mine closures can result in significant, adverse impacts to the environment and the community, and therefore, must be managed appropriately. The use of risk management techniques can assist in this transition. The closure risk model has significant potential as a tool for decision-makers to assess the major closure risks at individual mine sites in a structured, systematic manner, both qualitatively and quantitatively. This, in turn, facilitates comparisons between the closure issues at a single site, as well as between different mines. A team-based approach is essential to ensure that all the risks are incorporated, and the use of an external facilitator, as is standard in risk assessments, will assist in reducing subjective bias.

The model was shown to have a number of uses at not only operational mine sites, but also in corporate offices and government departments. A number of limitations to the model were discussed but can be overcome with further refinement.

The importance of community engagement during a mine's operations and its eventual, inevitable closure cannot be overstated. If it is not implemented in a timely and appropriate manner, an optimal closure outcome will not be achieved. The consequences of a poor consultation strategy are severe in terms of human and other costs. Mining companies that "get it right" will benefit from the support they receive from its employees, landholders, local and state governments, and other stakeholders. Other benefits include significant cost savings and a competitive advantage for future exploration/mining activities.

Even though closure issues for every mine are unique, this paper has shown that it is possible to develop a series of principles to assist the corporate, government and community players involved in the closure process to "get it right" for the benefit of all, and which demonstrate that sustainable mining development is achievable.

References

[1] ACMER. In: Asher CJ, Bell LC, editors. Proceedings of the workshop on environmental issues in decommissioning of mine sites. Brisbane: ACMER; 1998.

[2] Australian and New Zealand Minerals and Energy Council/ Minerals Council of Australia. Strategic framework for mine closure 2000.

[3] MMSD. Breaking new ground – minerals mining and sustainable development final report. Earthscan Publications Ltd, ISBN 1 85383 907 8; 2002.

[4] Laurence DC. Classification of risk factors associated with mine closure. Mineral Resources Engineering 2001;10(3):315–31.

[5] International Institute for Sustainable Development (IISD). MMSD seven questions for sustainability. Canada: Manitoba, ISBN 1-895536-54-5; 2002.

[6] Xstrata Coal, 2003. Press release available at: http://www.xstrata.com.

[7] Thompson SD. Risk assessment for mines. In: Proceedings of the Queensland mining industry health and safety conference; 1999.

[8] Laurence DC. Reducing the risk of mine closure – a team based approach. In: Proceedings of the mining risk management. Sydney: AusIMM; 2003.

[9] Global Reporting Initiative. Sustainability reporting guidelines. <http://www.globalreporting.org>; 2002.

[10] Australian/New Zealand Standard for Risk Management 4360; 1999.

[11] Humphreys D. A business perspective on community relations in mining. Resources Policy 2000;26(3):127–31.

[12] Laurence DC. New developments in community consultation in mine decommissioning. In: Proceedings of the workshop on environmental issues in decommissioning and temporary closure of mine sites (unpublished). Townsville: ACMER; 1999.

[13] Laurence DC. Optimising mine closure outcomes for the community – lessons learnt. Minerals and Energy, Raw Materials Group 2002;17(1):27–34.