INFOMINE E-BOOK

# Mine Closure

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# MINE CLOSURE - INTRODUCTION

As we progress into the twenty-first century, there is increasing awareness of the need to provide for 'sustainability' of ecological and social settings in which mines are developed, operated and closed. The 'six tenets for sustainability of mining' provide the foundation for sustainability planning at a mine site. This gives rise to the need to do more than '**Design for Closure**', requiring that we also prepare '**Post Mining Sustainable Use Plans**' for the mine site and affected area. This concept is described by Robertson et al., 1998 and Robertson and Shaw, 1999. It also requires that all stakeholders, including the succeeding custodian, be consulted in the preparation of mine development, operations, closure and post closure sustainable use plans.

An example of innovate post mining land use development is the redevelopment of an abandoned mine in Cornwall called the Eden Project.

In planning for closure, there are four key objectives that must be considered:

1. protect public health and safety;
2. alleviate or eliminate environmental damage;
3. achieve a productive use of the land, or a return to its original condition or an acceptable alternative; and,
4. to the extent achievable, provide for sustainability of social and economic benefits resulting from mine development and operations.

Impacts that change conditions affecting these objectives are often broadly discussed as the 'impacts' or the environmental impacts of a site or a closure plan. It is convenient to consider potential impacts in four groupings:

1. Physical stability - buildings, structures, workings, pit slopes, underground openings etc. must be stable and not move so as to eliminate any hazard to the public health and safety or material erosion to the terrestrial or aquatic receiving environment at concentrations that are harmful. Engineered structures must not deteriorate and fail.
2. Geochemical stability - minerals, metals and 'other' contaminants must be stable, that is, must not leach and/or migrate into the receiving environment at concentrations that are harmful. Weathering oxidation and leaching processes must not transport contaminants, in excessive concentrations, into the environment. Surface waters and groundwater must be protected against adverse environmental impacts resulting from mining and processing activities.
3. Land use - the closed mine site should be rehabilitated to pre-mining conditions or conditions that are compatible with the surrounding lands or achieves an agreed alternative productive land use. Generally the former requires the land to be aesthetically similar to the surroundings and capable of supporting a self-sustaining ecosystem typical of the area.
4. Sustainable development - elements of mine development that contribute to (impact) the sustainability of social and economic benefit, post mining, should be maintained and transferred to succeeding custodians.

Clearly the assessment of these types of impacts and closure requirements must address components of the site as well as the region and must select measures and allocate resources to address the major issues of impact. In order to minimize the various impacts, risks and liabilities, it is necessary to anticipate, as early in the process as possible, potential future liabilities and risks, and to plan for their elimination or minimization. In many areas, much of the liability or risk is associated with the uncertainty of the requirements for closure and rehabilitation from the succeeding custodian (be it a government agency, community organization or corporate entity). Early identification of the succeeding custodian, and their involvement in the development of the closure plan enables the closure requirements to be established and agreed and considered in the closure plan development. This allows the mining company to determine, and provide for, the requirements of the succeeding custodians, gain their support for the closure plan and minimize the risks and liabilities that may derive from succeeding custodian rejection or objection to the closure measures at the time of mine closure.

# MINE CLOSURE - STEPS IN CLOSURE PLAN DEVELOPMENT

The typical steps for closure planning are shown in Figure 1. These steps also provide a logical order in which to develop and present the various sections of a Closure Plan Report. They provide the reader with a progressive description of the material required to understand the need for, nature of, effectiveness of, and cost the Closure Plan.

Any closure plan must consider the long-term physical, chemical, biological and social/land-use effects on the surrounding natural systems (aquatic, groundwater, surface water etc.). Therefore there must be an understanding of the pre-mining environment **(step 1)** and the effects of past and future mine development **(step 2)** on the pre-mining environment. Operational control measures must be selected **(step 3)** for implementation during mining in order to minimize the impact on the surrounding ecosystems. Impact assessments **(step 4)** must be done prior to measures selection as well as periodically during operations in order to determine the success of the measures implemented. Alternative mine closure measures are developed **(step 5)** and assessed **(step 6)** during mine design to ensure that there are suitable closure measures available to remediate the impact of the selected mine development.

If suitable remediation or closure measures cannot be identified or achieved, then it may be appropriate to revise the type of mine development proposed **(return to step 2)**. Once a technically acceptable mine development and closure plan has been developed it is necessary to prepare a monitoring and maintenance plan **(step 7)** that will monitor the system performance during operations and post closure and provide for the maintenance necessary to ensure the long term functionality of the system components. Throughout this process, costing and scheduling evaluations **(step 8)** are completed, if the costs are too onerous, or if fatal flaws in the design are identified, the process returns to the design phase **(step 2)** and alternative measures are evaluated

Once an acceptable plan is completed, an acceptable form of financial assurance is developed and provided **(step 9)** in order to cover the costs of plan implementation, long term operations, monitoring and maintenance of the site post closure. The final stages of the closure plan process involve the application for **(step 10)** and approval by **(step 11)** the regulatory agencies of the Closure Plan, and implementation **(step 12)** at the end of mine life.

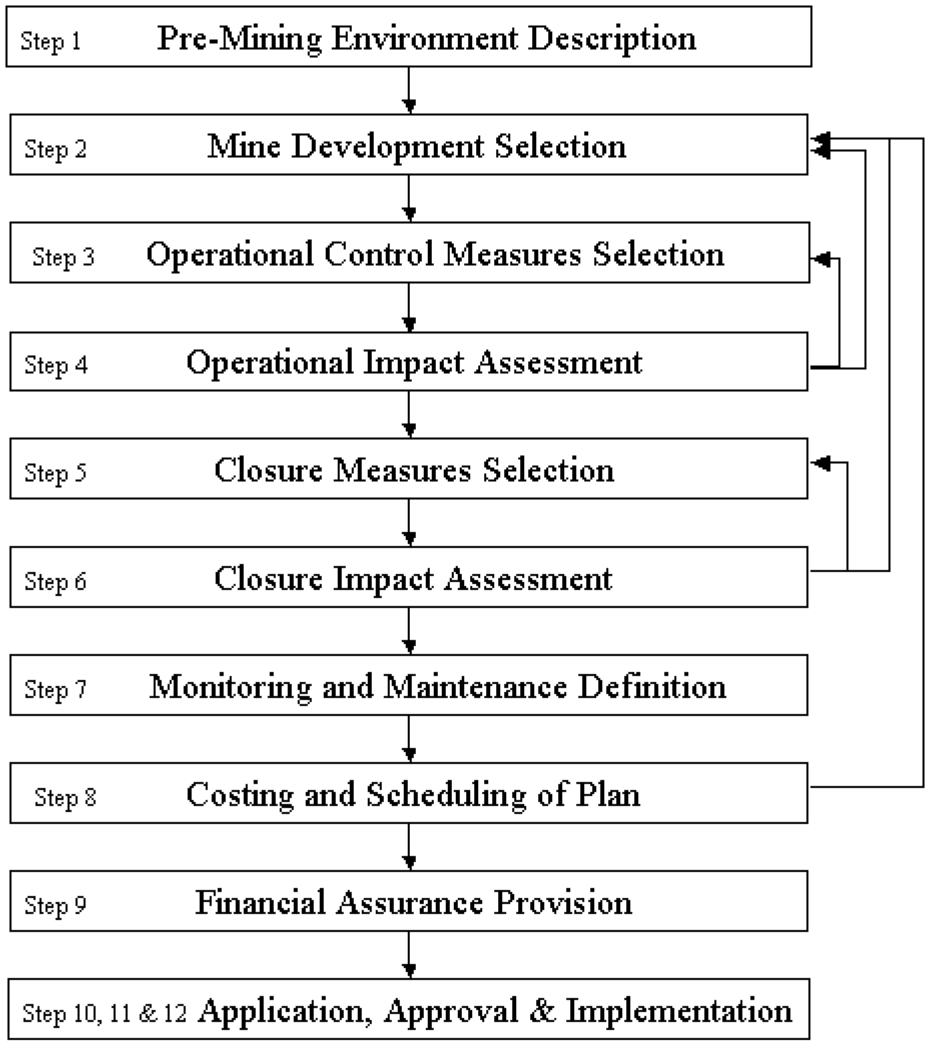



Figure 1. Typical Steps in the Closure Plan Development Process.

The Closure Plan document itself, must be completed in a logical manner which will provide the reader with a description of the area from pre-mining through to closure. The Closure Plan should also provide a discussion of the impacts (positive and negative) of mining on the surrounding environment, socio-economics, land use, health and safety etc. during operations, at closure, and over the long term as the reclaimed site responds to on-going natural processes of soil and vegetation evolution, erosion, sedimentation, chemical and physical weathering, frost action, biotic activity and during extreme events of floods, fire and earthquakes. This long term response is essentially an assessment of the sustainability of the site post closure and defines the need for long term monitoring and maintenance required by the site, i.e. the 'burden' placed on succeeding generations. The detailed description of the closure plan measures and the anticipated mitigated impacts can then be provided. A typical Table of Contents for a mine closure plan is provided in pdf form here.

# MINE CLOSURE - CYCLIC EVALUATION OF PLANS AT VARIOUS STAGES OF A MINE'S LIFE.

Each development, operating and closure plan comprises a design with drawings; specifications that define what will be constructed, and an operating plan which describes how the constructed facilities or machines will be operated. The design is completed to satisfy a number of design criteria and the operating plan specifies a number of operating constraints. Sometimes the permit conditions specified by the regulatory authorities include certain design criteria and operating constraints.

During the development of the design, the design engineer is continually doing informal risk assessments (or failure mode and effects analyses - FMEAs) to check that his/her design will meet operating requirements. If the current design has unacceptable risks of not meeting the design objectives, either the design or the operating procedures are modified until adequate performance characteristics are achieved (this evaluation process is represented by the upper half of the top circle on Figure 2). It is becoming more common for large mine developments to appoint Boards of Review to provide an independent check (audit or review) of the designs and operating manuals to ensure the appropriate 'International" standards of safety and environmental impact (risk or liability) are achieved. In effect these Boards perform FMEA's within the scope of their audits or review.

The FMEA primarily addresses the risk of designs and operating procedures not achieving the design intent. There are a number of other assessments that are important in deciding if a particular mine development or closure option is appropriate and represents a reasonably optimized plan. These assessments include impacts on the environment, the local and distant communities, costs etc (represented by the bottom half of the top circle on Figure 2). All significant stakeholders may need to participate in all or part of these evaluations and accounts must be taken of their values and concerns. A methodology, termed the multiple accounts analysis (MAA) has been developed as one of the tools (together with EA's, EIS's or ERA's) to perform such assessments (see Robertson and Shaw, 1998; Robertson and Shaw, 1999; and Shaw et al., 2001 for more details). The end result is the selection of a preferred Closure Plan.

Closure plans should be re-evaluated as the mine site development progresses since the initial plans are based on projected conditions which are expected to change in response to additional ore discoveries, changing conditions of product and mining economics, advances in technology and new regulatory requirements. Once the initial plan has been developed and is accepted, periodic, iterative re-assessments and revisions should be completed to ensure that the plan remains current, relevant and optimized. This results in a cyclical development of the plan and mine design over various stages of a mine's life as illustrated in Figure 2.

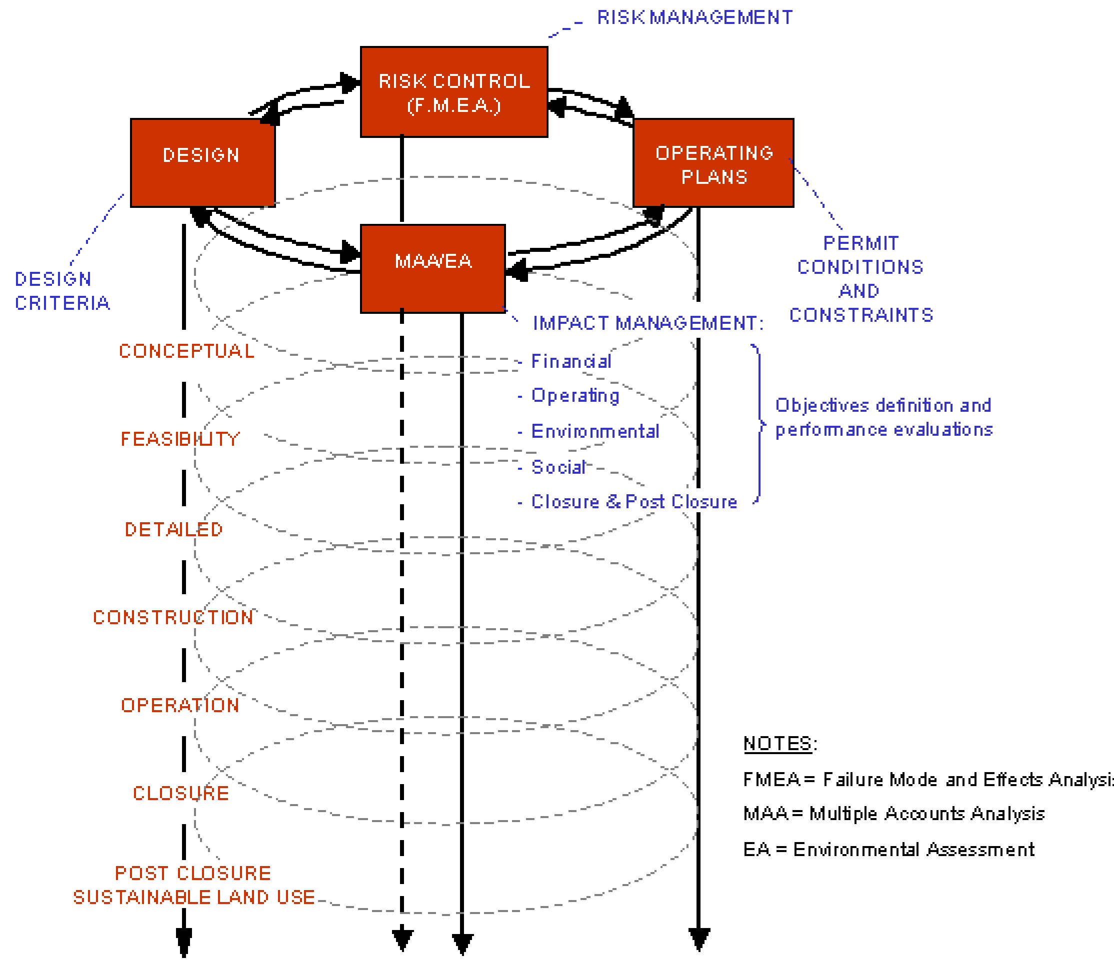



Figure 2. Cyclic Development of Plans and Designs at Various Stages of a Mine's Life.

Figure 2 provides an illustration of the successive activities at various stages of a mine project's life. The mining process, and the mine closure planning process, involve stages that evolve from conceptual to feasibility to permitting to operating to closure and finally to a post closure stage. These stages are shown on the figure down the left hand side. The circle at the top of the figure illustrates the decision-making activities as discussed above that are typically involved at each stage.

During the period of design, operating plan development and FMEA and MAA evaluations of a Closure Plan, there will be iterative modifications to the designs and operating procedures until a revised plan is agreed. The entire process is typically repeated periodically at intervals of about 5 years to ensure that the plans always remain relevant and current.

The FMEA is intended to minimize risk (financial as well as environmental) associated with complex, long duration engineered systems as represented by the closure measures. The MAA provides a basis for the evaluation of impacts and tradeoffs where large, high economic value projects also have high, and potentially long term, social and environmental impacts. The MAA provides the mechanism for communication of stakeholder values, as well as the accounting system by which they can be taken into consideration in the development of control and closure plans that address concerns from all stakeholders.

# FAILURE MODES & EFFECTS ANALYSIS (FMEA)

Often the effects of a failure can have impacts of different severity with respect to economic impacts, environmental impacts, impacts on health and safety of humans, regulatory impacts or violations and impacts of public concern and censure. Risk concerns exist with regard to all of these potential impacts. The objective of an FMEA is to identify and quantify these risks in order to either avoid, or mitigate them.

**FMEA** is an acronym for **F**ailure **M**odes and **E**ffects **A**nalysis, and is a methodology for the assessment of 'risk', which is a combination of likelihood and consequences of failure. The goal is to provide a useful analysis technique that can be used to assess the potential for, or likelihood of, failure of structures, equipment or processes and the effects of such failures on the larger systems, of which they form a part, and on the surrounding ecosystem, including human health and safety. The environmental community often uses this type of process for conducting environmental risk assessments and engineers use this type of method to assess the risk of engineered systems. Mining companies can use this assessment method to evaluate the risk that their Closure Plans impose on the surrounding environment, workers and the public. This analysis methodology has been adapted for many applications over numerous industries including 'systems' approach and 'criticality' analysis.

### Use of FMEA's for Risk Management

The FMEA provides the evaluators with the ability to perform a systematic and comprehensive evaluation of potential failure modes of the design/plan in order to identify the potential hazards. The technique is not limited to this but is applied as such in this instance. The FMEA can be used to evaluate the potential for failures of the Closure Plan measures that could result in Biological/Land Use Impacts, Regulatory Impacts/Censorship, Public Concern/Image and Health and Safety Impacts. A risk profile can be developed for each of these concern areas. Once the failure modes and measures with the highest risk have been identified, it is possible to consider mitigation or alternative designs to reduce risks. FMEAs are therefore an essential part of any risk and liability reduction program.

### Evaluation of 'Risk'

**Risk is a function of Likelihood and Consequence**

The term 'risk' encompasses the concepts of both the likelihood of failure, or the 'expected frequency of failures, and the severity of the expected consequences' if such events were to occur. Because predictive risk assessment involves foreseeing the future, it is an imprecise art. There is a difference between the risk of a failure, and uncertainty in the estimate of that risk. There are also separate uncertainties associated with both the expected frequency and expected consequences.

Mine closure plans include complex natural and engineered systems involving geology, geotechnics, hydrogeology, hydrology, geochemistry, biology, ecology and social systems. Failure modes exist for each of these systems and as a result of interaction between these systems. Methods for failure risk analyses for geotechnical/geochemical/hydrogeological/biological engineered systems are in the early stages of development in comparison to failure risk analyses used in some other fields of engineering where the potential for failures have been more precisely determined from statistics of equivalent system performance or from probability analyses of deterministic systems. This lack is partly due to the heterogeneous nature of natural geological/geochemical/biological systems and partly due to the lack of any established databases for failures of components of such engineered/natural systems. Often the 'best' estimate of the likelihood of failure of such complex systems is made based on the opinion of suitably qualified and experienced professionals. In essence, such estimates are empirical values based on experience and informed judgment of the appropriate 'expert' familiar with the design, operations and site conditions. The reliability of the estimate is substantially dependent on the available information, expertise, skill, experience and good judgment of the experts. The scope of the FMEA should be broad to cover the effects of relevant modes of failure, including engineered system failures and natural failures (avalanches, floods, droughts etc.). Factors, to account for the confidence in estimates of the likelihood and consequence, should be included to provide readers with an understanding of the analyst's opinion of the reliability of the estimate.

**Detailed Approach**

This type of FMEA is a top down/ expert system approach to risk identification and quantification, and mitigation measure identification and prioritization. Its value and effectiveness depends on having experts with the appropriate knowledge and experience participate in the evaluation during which failure modes are identified, risks estimated, and appropriate mitigation measures proposed. It is therefore essential that the evaluation team include representatives who understand the geotechnics, hydrology, environmental impacts and regulatory requirements applicable to the engineered and natural systems and their surroundings, as well as the past history of the mine's design, construction, operation and performance.

An example of an FMEA worksheet including a few example failure modes is provided here in pdf form. This FMEA worksheet illustrates the methodology's structured approach for identifying failure modes leading to undesired events. This may be modified depending on the assessment objectives. The worksheet is organized in columns with the headings 'Mine Area/Component', 'ID', 'Failure Mode', 'Effect', 'Project Stage', 'Likelihood', 'Consequences', 'Level of Confidence' and 'Mitigation/Comments'. Each of these headings is described in the following sections.

**Mine Area/Component**

This column provides an area for a description of each area or component of the mine site is being evaluated. This can be an open pit, rock pile, spillway, dam, pipeline etc.

**ID**

This is a simple alpha-numeric code that makes ready, quick reference to specific failure modes for each component certain line items much simpler later on. For instance, often the alpha-numeric codes for each failure mode of each component are plotted within the Risk Matrix graphic (discussed further below) in order to provide a summary of the entire FMEA.

**Failure Mode**

A failure mode can be naturally initiated (e.g. an 'act of God' such as an earthquake which is greater than the design event) or it can be initiated by the failure of one of the engineered subsystems (e.g. instability of a dam) or result from operational failure (e.g. failure to close a valve releasing contaminating fluids). Because of the large number of potential failure modes that could be included in an FMEA, it is often necessary to confine evaluations to those that represent a significant risk. Failure modes can also be combinations of events where a small trigger event sets off a chain of events resulting in substantial or large consequences.

The examples provided in the worksheet relate to the generation of acid rock drainage from facilities such as open pit mine walls, tailings facilities and mine rock piles. Some of the failure modes are simply acts of nature (e.g. acidity generated from a pit wall) whereas others may be failure modes related to ineffective or inadequate control measures (e.g. inadequate blending of non-acid and acid generating materials).

**Effects or Consequences**

The assessment of the magnitude of the Effects (or Consequences) of specific failure modes should be based on evaluations or analyses of the systems responses following failure. Adverse effects may have physical, biological or health and safety consequences. It is often necessary to make first estimates of consequences based on a professional judgement of the anticipated impact of that failure. The examples related to acid generation provided in the sample FMEA worksheet would have an effect on the requirements for collection and treatment, or the appearance of contaminated seepage in unexpected areas. The classification of the severity of effects (i.e. the consequences) are discussed under the heading 'Consequences' below.

**Project Stage**

Some 'risks' have a different likelihood of occurring or a different consequence if they occur during operations (O) or post closure (PC). The column 'Project Stage' is included to indicate the time frame(s) in which the risk was considered. Some risks increase with the period over which the risk is assessed. I.e. the potential of a 100 year recurrence interval flood occurring is much greater during the long post closure period than it is during a, say, 10 year operating life of a mine. Risk of some facility failure (e.g. a spillway) may be greater post closure when there is not an operating staff to provide monitoring and maintenance. The time frame is also important when assessing risks to human health and safety where there are likely many more people at risk during operations than post closure.

**Likelihood**

The likelihood of the failure mode leading to the effects has been classified here using a 5 class system, ranging from not likely to expected (see Table 1). Two separate likelihood distributions have been adopted: one for safety consequences, and another for environmental and public concern consequences. The reason for this is that we have found that, in general, the public tolerance for safety consequences is much lower, and therefore the acceptability of risk of a safety event compared to an environmental event is lower. The number of classes, can be adapted to best suit a specific site.

Table 1. Likelihood of Risk

| Likelihood Class | Likelihood of Occurrence for Safety Consequences (events/year) | Likelihood of Occurrence for Environmental and Public Concern Consequences (events/year) |
|---|---|---|
| Not Likely (NL) | <0.01% chance of occurrence | <0.1% chance of occurrence |
| Low (L) | 0.01 - 0.1% chance of occurrence | 0.1 - 1% chance of occurrence |
| Moderate (M) | 0.1 - 1% chance of occurrence | 1 - 10% chance of occurrence |
| High (H) | 1 - 10% chance of occurrence | 10 - 50% chance of occurrence |
| Expected (E) | >10% chance of occurrence | >50% chance of occurrence |

**Consequences**

For each Effect, the consequence can be assessed separately in each of four different concern areas. For each concern area, there are various scales and thresholds that may apply, such as scales based on the severity of injury, community well-being, environmental impact, operational impact etc. The scales that we have found most applicable for mine closure assessments are provided on Table 2 below.

For mine closure purposes, the authors have found it useful to have separate consequence categories for each of the following concern areas:

1. Biological Impacts/Land Use
2. Regulatory Impacts and Censure
3. Public Concern and Image Impacts
4. Health and Safety

Regulatory impacts have been found to have a profound influence on risk. Changes in regulation or regulatory enforcement practices following failures, or perceptions of potential failures can have severe consequences. Public concern and activism following failures have also had severe impacts, including impacts on public company share value and abilities to permit new mines.

The consequence ranking, or severity, is typically also classified using a 5 class system. We have found ranking from negligible to extreme consequences to be effective and intuitive. The class intervals for each of the categories are outlined in table 2. Again, these are suggested classifications that have been found useful in the past, but could be adapted to best suit the site or plan being evaluated at the time.

Table 2. Severity of Effects

| Consequences Severity | Biological Impacts and Land Use | Regulatory Impacts and Censure | Public Concern and Image | Health and Safety |
|---|---|---|---|---|
| Extreme | Catastrophic impact on habitat (irreversible and large) | Unable to meet regulatory obligations; shut down or severe restriction of operations | Local, international and NGO outcry and demonstrations, results in large stock devaluation; severe restrictions of 'license to practice'; large compensatory payments etc. | Fatality or multiple fatalities expected |
| High | Significant, irreversible impact on habitat (large but reversible) | Regularly (more than once per year) or severely fail regulatory obligations or expectations - large increasing fines and loss of regulatory trust | Local, international or NGO activism resulting in political and financial impacts on company's 'license to do business' and in major procedure or practice changes | Severe injury or disability likely; or some potential for fatality |
| Moderate | Significant, reversible impact on habitat | Occasionally (less than one per year) or moderately fail regulatory obligations or expectations - fined or censured | Occasional local, international and NGO attention requiring minor procedure changes and additional public relations and communications | Lost time or injury likely; or some potential for serious injuries; or small risk of fatality |
| Low | Minor impact on habitat | Seldom or marginally exceed regulatory obligations or expectations. Some loss of regulatory tolerance, increasing reporting. | Infrequent local, international and NGO attention addressed by normal public relations and communications | First aid required; or small risk of serious injury |
| Negligible | No measurable impact | Do not exceed regulatory obligations or expectations | No local, international, or NGO attention | No concern |

## Level of Confidence

There is uncertainty regarding both the likelihood of failure and consequence estimates based on a number of factors, including: lack of data; lack of system understanding; uncertain future operating conditions or uncertain maintenance; and, regional development post closure. Thus confidence in the risk estimates may range from low to high. It is useful to reviewers of the FMEA if the evaluation team provides their assessment of their confidence in any risk rating that they conclude.

We have found that a three interval classification system of low, medium and high confidence in the risk ratings is usually adequate and appropriate. Where there is low confidence in a high risk assessment value, this clearly indicates a need to further evaluate the risk in order to more reliably predict both the risk and the mitigation measures to reduce such risk.

**Mitigation/Comments**

For each of the risks, safeguards that are already in place through design or operating procedures can be listed (usually as a separate column). Safeguards act to prevent, detect, or mitigate a risk from reaching its worst results, and can be applied to both the failure mode and the resulting effects. The existing safeguards reduce the likelihood of the risk from occurring.

Similarly, if a particular failure mode and effect is rated a 'high' or 'expected' likelihood and a 'high' or 'extreme' consequence in any of the categories evaluated, additional mitigation measures may be sought to reduce this risk. In this manner, the FMEA worksheet can act as a template from which risk management measures or procedures can be prioritized.

**Representation of Results**

Given the likelihood and severity, a risk rating can be determined and displayed by plotting the results on a two dimensional risk matrix (see Figure 3a below). This procedure is often referred to as 'binning'. A failure mode which is 'expected' and would result in an 'extreme' consequence plots in the red 'bin'. The risk ratings are shown as colors alone, to indicate that this is not a mathematically precise representation of risk. The level of 'risk' increases moving from the bottom left to the top right. The warm colors (yellow through red) indicate failure modes with significant and increasing risk ratings. These are the failure modes in most urgent need of determination of mitigation measures. The cold colors (green through dark blue) indicate the failure modes with moderate to low risk.

For ease of communication, the alpha-numeric codes (ID) of the various failure modes can be plotted within the risk matrix easily flagging those ID codes with their associated risk ratings. The resulting plots are called 'Risk Matrices'. Separate matrices are plotted for each of the concern areas. The four risk matrices represent the 'risk profile' for the closure plan being evaluated. A typical profile is provided as Figures 3b to 3e. Comparison of these matrices indicates that for the example given, the matrix for Regulator Impacts and Censure has the highest risk ratings. These risk matrices (the risk profile) is an excellent tool for illustration to management, regulators and the public the risk profile for a project or its alternatives, as well as for planning risk management programs. In addition, the authors typically color-code the FMEA worksheet using the same color combinations as in the risk matrix, providing a tool with which the reader can scan a long list of evaluated risks and easily pick out those of most concern.

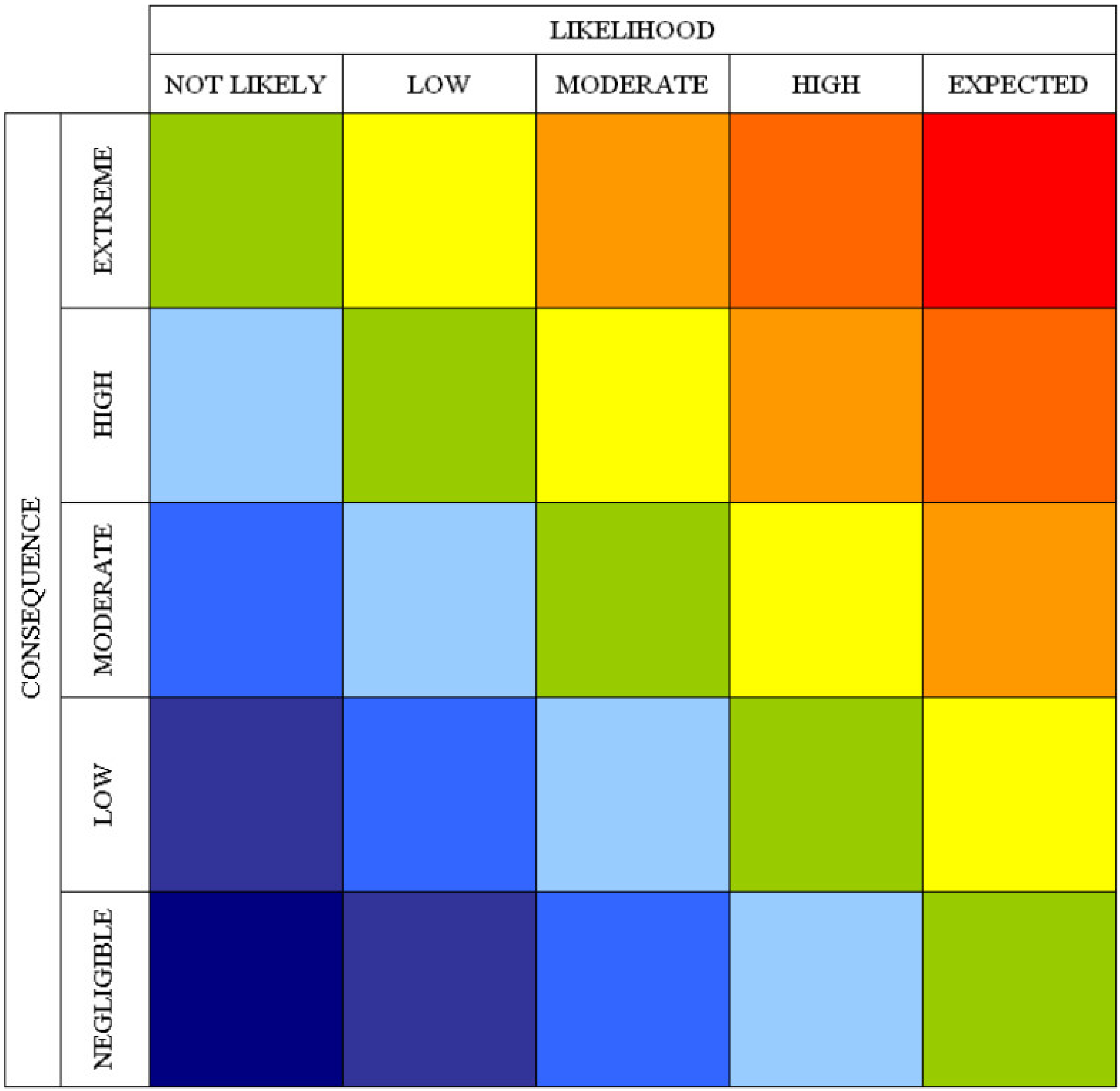



Figure 3a. Risk Matrix

| CONSEQUENCE | LIKELIHOOD: NOT LIKELY | LOW | MODERATE | HIGH | EXPECTED |
|---|---|---|---|---|---|
| EXTREME | B14.1, B15.2, B16.2 | A61.1, B14.1, B15.2, B16.2 | A12.3, A61.2, A62 | | |
| HIGH | | A41.7, A42.2, A101.3, B21.1, B31.5, B31.6, B33.6 | B11.2, B11.3, B32.2 | A55.1, B11.1, B15.1, B16.1 | B21.2 |
| MODERATE | | A13, A22.2, A61.5, A81.6, B22.1, B23.1, B31.4, B33.4, B92.2 | A21.1, A21.2, A22.1, A41.6, A52, A81.2, B12.1, B13.1, B13.2 | A53.1, A55.2, A61.4, B12.2, B31.3, B33.3 | A14.1, A41.8, A42.1, A92.1, B22.2, B23.2, B32.1 |
| LOW | B17 | A41.2, A41.4, A57, A92.2, A92.5, A101.2, A101.6, B14.2, B17, B31.2, B34.1, B37.1 | A41.5, A63.3, A101.4, A63.5, B18, B31.1, B33.1, B36.1 | A12.2, A41.1, A41.3, A53.2, A56, A61.6, A63.4, A71.1, A71.2, A81.4, A81.5, A92.3, B33.2 | A11, A12.1, A14.2, A54, A61.3, A63.1, A63.2, A81.3, A92.4, A92.6, A101.5, A101.7, B34.2, B35.1, B36.2, B37.2, B53.2, B51, B52, B53, B71.1, B71.2, B94.2 |
| NEGLIGIBLE | | B41.1, B41.2, B41.3, B41.4, B85, B91.2, B91.3, B92.1, B93.1 | A81.1, B92.3, B93.2, B93.3 | B91.1 | A91, B81.1, B81.2, B81.3, B81.4, B94.1 |

Figure 3b. Example Risk Matrix for Biological Impacts and Land Use

| | | LIKELIHOOD | | | | |
|---|---|---|---|---|---|---|
| | | NOT LIKELY | LOW | MODERATE | HIGH | EXPECTED |
| CONSEQUENCE | EXTREME | B14.1, B15.2, B16.2 | A22.2, A41.7, A61.1, A101.3, B14.1, B15.2, B16.2, B41.1, B41.2, B41.3, B41.4, A42.2, B92.2 | A61.2, A61.6, A81.1, B11.2, B11.3, B12.1, B13.1, B13.2, B18 | A81.4, B11.1, B12.2, B15.1, B16.1 | A92.6 |
| | HIGH | B17 | A13, A57, A61.5, A81.6, A101.2, A101.6, B17, B31.4, B31.5, B31.6, B33.4, B33.5, B33.6, B91.2, B91.3 | A12.3, A22.1, A41.5, A41.6, A52, A63.3, A81.2, B32.2, B92.3, B93.3 | A53.1, A55.1, A55.2, A56, A61.4, A63.4, A92.3, B31.3, B33.3, B91.1 | B32.1, B94.2 |
| | MODERATE | | A92.2, B14.2, B21.1, B85, B92.1, B93.1 | A101.4, B93.2 | A12.2, A41.1, A41.3, A53.2 | A12.1, A14.2, A42.1, A54, A63.2, A92.1, A101.5, A101.7, B21.2, B81.1, B81.3, B81.4, B94.1 |
| | LOW | | A41.2, A41.4, A92.5, B22.1, B23.1, B31.2, B34.1, B37.1 | A21.1, A21.2, A63.5, B31.1, B33.1, B36.1 | A71.1, A71.2, A81.5, B33.2 | A14.1, A41.8, A61.3, A63.1, A81.3, A92.4, B22.2, B23.2, B34.2, B35.1, B35.2, B36.2, B37.2, B51, B52, B53, B71.1, B71.2, B81.2 |
| | NEGLIGIBLE | | | | | A.11, A91 |

Figure 3c. Example Risk Matrix for Regulatory Impacts and Censure

| CONSEQUENCE | LIKELIHOOD: NOT LIKELY | LOW | MODERATE | HIGH | EXPECTED |
|---|---|---|---|---|---|
| EXTREME | B14.1, B15.2, B16.2 | A22.2, A41.7, A61.1, A81.6, A101.3, B14.1, B15.2, B16.2, B41.1, B41.2, B41.3, B41.4, B92.2 | A61.2, A62, A81.1, A81.2, B11.2, B11.3, B12.1, B13.1, B13.2, B18 | B11.1, B12.2, B15.1, B16.1 | |
| HIGH | B17 | A13, A57, A61.5, B17, B31.5, B31.6, B33.5, B33.6, B91.2, B91.3, B92.1, B93.1 | A12.3, A41.5, A41.6, A63.3, B32.2, B92.3, B93.2, B93.3 | A56, A61.4, A63.4, B91.1 | A54, A92.1, B32.1, B94.2 |
| MODERATE | | A92.5, A101.2, A101.6, B14.2, B21.1, B31.4, B33.4 | A22.1, A52, A101.4 | A12.2, A41.1, A41.3, A53.1, A53.2, A55.1, A55.2, A81.5, B31.3, B33.3 | A12.1, A14.2, A42.1, A63.2, A92.4, A92.6, A101.7, B22.2, B94.1 |
| LOW | | A41.2, A41.4, A92.2, B22.1, B23.1, B31.2, B34.1, B37.1, B85 | A21.1, A21.2, A63.5, B31.1, B33.1, B36.1 | A61.6, A71.1, A71.2, A92.3, B33.2 | A11, A14.1, A41.8, A61.3, A63.1, A81.3, A101.5, B22.2, B23.2, B34.2, B35.1, B36.2, B37.2, B51, B52, B53, B71.1, B71.2, B81.1, B81.2, B81.3, B81.4 |
| NEGLIGIBLE | | | | | A91 |

Figure 3d. Example Risk Matrix for Public Concern and Image

| | | LIKELIHOOD | | | | |
|---|---|---|---|---|---|---|
| | | NOT LIKELY | LOW | MODERATE | HIGH | EXPECTED |
| CONSEQUENCE | EXTREME | B14.1, B15.2, B16.2 | A42.2, A57, A81.6, B14.1, B14.2, B15.2, B16.2, B91.2, B91.3 | A81.2, B92.3, B93.2, B93.3 | A56, B15.1, B16.1, B91.1 | |
| | HIGH | | A101.3 | A12.3, A63.3, B11.2, B11.3, B13.1, B13.2, | B11.1 | B81.1 |
| | MODERATE | B17 | B17, B92.1, B92.2, B93.1 | A63.3, B12.1, B18 | A63.4, B12.2, B55.2 | B81.3, B81.4, B94.1, B94.2 |
| | LOW | | A13, A22.2, A61.5, A92.2, A92.5, B85 | A101.4 | A53.2, A55.2, A61.4, A61.6, A71.1, A71.2, A81.4, A81.5, A92.3 | A14.1, A54, A63.1, A63.2, A81.3, A92.1, A92.4, A92.6, B51, B52, B53, B71.1, B71.2, B81.2 |
| | NEGLIGIBLE | | A41.2, A41.4, A41.7, A42.2, A61.1, A63.5, A101.2, A101.6, B21.1, B22.1, B23.1, B31.2, B31.3, B31.4, B31.5, B31.6, B33.4, B33.5, B33.6, B34.1, B37.1, B41.1, B41.2, B41.3, B41.4 | A21.1, A21.2, A22.1, A41.5, A41.6, A52, A61.2, A62, A81.1, B31.1, B32.2, B33.1, B36.1 | A12.2, A41.1, A41.3, A53.1, A55.1, B31.3, B33.2, B33.3 | A11, A12.1, A14.2, A41.8, A42.1, A61.3, A91, A101.5, A101.7, B21.2, B22.2, B23.2, B32.1, B34.2, B35.1, B35.2, B36.2, B37.2 |

Figure 3e. Example Risk Matrix for Health and Safety

The reader may also find of interest the Risk Analysis - Event Probability Assessment tool available on EduMine. This tool determines the number of events likely to occur during the lifespan of an operation such that probability of exceedance is limited to a specified value. It was created by Dr. F. Oboni who has also written an on-line course for EduMine called Risk Management in Mining that takes a slightly different approach to the FME

# MULTIPLE ACCOUNTS ANALYSIS (MAA)

As was shown on Figure 2 (cyclic development of plans and designs), the MAA is utilized as part of a plan development and evaluation process dealing primarily with value assessment and impact management; focusing on operational, financial, environmental and socio-economic issues.

A detailed course on how to complete a multiple accounts analysis is available on Edumine. A summary of the MAA process, and a description of how it can be utilized in closure planning are provided here.

### Introduction

The MAA is a multi-stakeholder, multi-disciplinary tool that provides the means by which evaluators can select the most suitable, or advantageous alternative, from a list of alternatives, by weighing the relative benefits and costs (or losses) of each. The method involves three basic steps:

1. Identify the impacts (benefits and costs) to be included in the evaluation;
2. Quantify the impacts (benefits and costs); and
3. Assess the combined or accumulated impacts for each alternative, and compare these with other alternatives to develop a preference list (ranking, scaling and weighting) of the alternatives.

In mining, the diversity of impacts that must be considered makes integrated (combined and cumulative impacts) assessment difficult. How does one compare the 'apples and oranges' in one fruit basket with the 'plums and bananas' in another to decide which is the preferable. To a large extent, any comparison is subjective and depends on the flavor preference (value basis) of the analyst. It is not possible, and probably not desirable, to remove this subjectivity as each analyst seeks to have his/her value basis applied in the analysis. It is therefore an advantage if the evaluation methodology is systemized and transparent, allowing the various analysts to clearly indicate their value basis and results. If the results of analyses from two analysts are similar, despite differences in value basis, then there is likely to be consensus on the alternative selected. If results are materially different, then the root cause of the difference can be identified and discussions and/or additional studies can be focused on the material, value basis, issues to determine if a consensus resolution can be reached.

An example MAA worksheet is provided here in which a series of mine closure plans were evaluated for the Zortman mine site in north central Montana. This worksheet has been termed the MAA ledger and the text provided here will utilize this ledger in order to describe the MAA methodology. For a description of the specific alternatives assessed at Zortman, the reader is referred to the Bureau of Land Management website.

### MAA Ledger of Accounts

The Ledger of Accounts is the template within which all the participants can register, or 'voice' their issues. The authors have found that structuring the 'ledger' into four broad categories, or '**accounts**', under the headings of *technical, project economics,* *environmental* and *socio-economics*, works well for the evaluation of mining-related projects. All the various stakeholders' issues (termed '**sub-accounts**') can be grouped within these main '**accounts**'.

The term '**sub-account**' has been defined here as any material impact or issue (benefit or loss) associated with any of the alternatives being evaluated. Examples of issues or impacts are 'dust, noise, contamination of surface water, employment opportunities' etc. Within each sub-account, indicator values of that particular issue are then defined in order to give a clear, understandable description of the impacts. An '**indicator value**' is a measure or descriptor that provides the reader with some concept or 'picture' of the degree of impact, allowing the reader to measure or compare impacts between alternatives. Note that some sub-accounts have more than one indicator while others have just one.

Some **indicators** are straightforward and quantitative (e.g. costs can be expressed in dollars), however many indicators, particularly environmental and socio-economic indicators, are difficult to accurately describe or quantify without an enormous amount of investigation and analysis. For example, within the environmental account, the sub-account 'surface water quality protection' was identified in the example provided. The predictive values for long term water quality 'protection' are difficult to quantify since it varies in concentrations over both time and location. Therefore the indicator and measure of the surface water protection value is often, by necessity qualitative or semi-quantitative. The authors have found a classification system of 5 categories is often ideal for this type of qualitative assessment. In this example, values of '*high*', '*somewhat high*', '*intermediate*', '*somewhat low*' or '*low*' were used to describe surface water quality protection. Each classification is associated with a general description of how water quality will be effected over time and at various locations about the mine site. Those closure alternatives that included measures such as installation of higher quality (infiltration barrier) covers over acid generating material, and effective seepage capture systems were given higher qualitative values than closure alternatives with less rigorous covers or capture systems based on the assessed effectiveness of the installed measures.

As a result of issues, such as long term water quality and/or stability of structures, which are difficult to quantify and predict, much of the assessment in this type of evaluation is necessarily based on judgement rather than deterministic analysis. This 'judgement' is often based on tools such as modeling and predictive analyses as well as on the experience of experts in the specific topic. The anticipation of behavior and assessment of performance of engineered structures, natural processes at work and environmental impacts require a sound understanding of the current technologies as well as considerable experience on a wide variety of similar projects in order to recognize and identify potential impacts, issues and risks. Therefore, having participants who are experienced with similar projects and/or dedicated to understanding and learning the realistic benefits and limitations of certain measures (e.g. cover performance) are critical to the success of these evaluations.

One of the real benefits of developing the 'Ledger of Accounts' comes from the information transfer and understanding gained during the task of filling out the ledger. It is during this stage that the determination of alternatives that may be obviously fatally flawed (i.e. do not meet threshold values such as water quality standards or cost limitations) can be identified and the alternatives either dropped from the evaluation or modified so as to preclude detailed analyses of alternatives with fatal flaws.

Once the ledger is complete, the numerical evaluation can take place. This involves the ranking, scaling and weighting of indicator values in each of the sub-accounts. The numerical evaluation includes a normalization process that allows the evaluators to compare the indicators equally, amongst themselves and between different sub-accounts.

## Ranking, Scaling and Weighting

The numerical evaluation of the Zortman MAA is provided to show the Ranking, Scaling and Weighting assessment of the ledger discussed above.

Each of the alternatives being assessed is first **ranked** in order from best to worst with respect to each indicator being evaluated. Ranking is a simple ordered list and makes no attempt to distinguish how great the difference in impact is between alternatives on the list. In practice, there may be very little, or very large, differences in the impact from the best to the worst alternative.

Since the separation of the best alternative from the worst may be either very small or very large, a **scaled value** is then assigned to each alternative for each indicator. The authors have found that a 9-point scale is readily understandable and typically provides the range and discretion well suited to this type of evaluation. The best alternative for any indicator is always given a scalar value of '9'. If the second best alternative is only half as good as the best alternative, it would be given a value of '5' and so on. As an example, on the numerical evaluation worksheet for the Zortman mine, the line item assessing the stability of the North Alabama Open Pit gives scalar values ranging from '9' for Alternatives Z4 and Z5, a value of '5' for Alternatives Z1 through Z3 and a value of '7' for Alternative Z6.

To enable each evaluator or stakeholder the opportunity to introduce their value bias between individual indicators, a **weighting factor** is applied to each indicator (as well as to each sub-account and account). On the example worksheet, the indicator weights are shown in orange, the sub-account weights are in green and the account weights are in blue text. The process of assigning weights to the various indicators on the ledger often serves to inform all parties involved in the evaluation on two levels. First, it serves to clearly identify those issues that are most critical to each of the stakeholders. For instance, while aesthetics might be of utmost importance to one stakeholder, capital cost might be most important to another. The second level of understanding achieved in this process is that each evaluator is provided the opportunity to defend his/her weightings and more often than not, a compromise between extremes is reached as part of the assessment process. An overall understanding is achieved by all participants as the complexities of the mine sites are evaluated issue by issue and the issues assessed relative to each other.

The cumulative 'score' of one alterative compared to another, in any one sub-account, is obtained by adding together the products of the scalar values and weights for each indicator within that sub-account category and is normalized by dividing by the sum of the weights for all the indicators in that sub-account (equation 1 below). The higher the score, the more favorable that alternative is in any one category.

$$\text{Sub-Account Score} = \frac{\text{sum of Scalar Values x Weights (for each indicator in the sub-account)}}{\text{sum of Weights for indicators in the sub-account}}$$

The process of adding together the sub-account scores to obtain the account scores for the four main accounts and the overall MAA score follow the same procedure of weighting and normalization.

## Results

For the example provided, the relative scores for the alternatives evaluated can be assessed on an account by account basis or by total MAA score. In summary, the scores were as follows:

| | Alternative Z1 | Alternative Z2 | Alternative Z3 | Alternative Z4 | Alternative Z5 | Alternative Z6 |
|---|---|---|---|---|---|---|
| Technical Account | 7.5 | 6.7 | 6.5 | 8.1 | 8.8 | 7.1 |
| Project Economics | 5.7 | 8.7 | 7.9 | 4.9 | 4.2 | 6.7 |
| Environmental | 8.1 | 6.5 | 6.9 | 7.9 | 8.0 | 8.1 |
| Socio-economics | 6.0 | 6.1 | 6.1 | 7.0 | 7.5 | 6.8 |
| **MAA Score** | **6.9** | **6.9** | **6.8** | **7.1** | **7.3** | **7.3** |

While the individual account scores show some significant differentiation between alternatives, the overall MAA scores are fairly similar. While this is not always the case, it is often that at least two of the alternatives result in relatively similar scores. In order to differentiate the scores from one another somewhat, a **discrimination value** filter can be applied. This value is shown in the 'grey' columns on the numerical evaluation worksheet. In this example, the discrimination value has been set to 20% so that for any one issue or indicator, if the difference between the 'best' and 'worst' alternative's scalar value x the weight for that indicator is less than 20% of the maximum difference, then the issue is deemed 'non-discriminating' or ND and can be 'zero-ed' from the numerical evaluation (i.e. applied a weighting of '0'). As can be seen on the worksheet, a number of indicators can be flagged as non-discriminating, in particular within the technical account in which engineering standards are typically applied to all alternatives and therefore the differences are often limited.

This 'filtering' was applied to the Zortman example, with the following results:

| | Alternative Z1 | Alternative Z2 | Alternative Z3 | Alternative Z4 | Alternative Z5 | Alternative Z6 |
|---|---|---|---|---|---|---|
| Technical Account | 7.3 | 6.5 | 6.2 | 8.1 | 8.8 | 6.8 |
| Project Economics | 5.7 | 8.7 | 7.9 | 4.8 | 4.3 | 6.7 |
| Environmental | 7.9 | 6.1 | 6.6 | 7.6 | 7.6 | 8.1 |
| Socio-economics | 6.0 | 6.1 | 6.1 | 7.0 | 7.5 | 7.0 |
| **MAA Score** | **6.8** | **6.7** | **6.6** | **7.0** | **7.2** | **7.2** |

Again, the results show that Alternatives Z5 and Z6 score higher than the other alternatives. Both of the sets of scores shown above are those numerical results when costs are not considered a limitation. However, as is often the case, the costs between alternatives are large and generally the more money that is spent, the better the alternative is likely to be. A **cost-benefit** type evaluation can be completed using the MAA to determine if additional expenditures provide commensurate improvements. The MAA score (excluding costs) can then be plotted against the cost of the alternative resulting in a cost-benefit graphic. Figure 4 below is such a plot for the Zortman example.

It becomes clear that while alternatives Z5 and Z6 scored very similarly in the complete MAA scores, the cost difference is substantial. In this type of a graphic, it is often seen that a significant benefit, or increase in MAA score can be achieved with any of the reclamation and closure alternatives. Occasionally, a more costly alternative results in a less desirable result (such as Z1 in the example). The red dot in the upper left of the plot was included to show where the ideal alternative would plot, i.e. that which resulted in a perfect MAA score for the cost of the available bond money. Alternative Z6 plots closest to this 'ideal alternative' and would be a logical selection for the preferred alternative. The options with higher scores (Z4 and Z5) are only marginally better and involve reclamation/closure costs which are several times higher. For more details about the reclamation at the Zortman mine, the reader is referred to the Bureau of Land Management website.

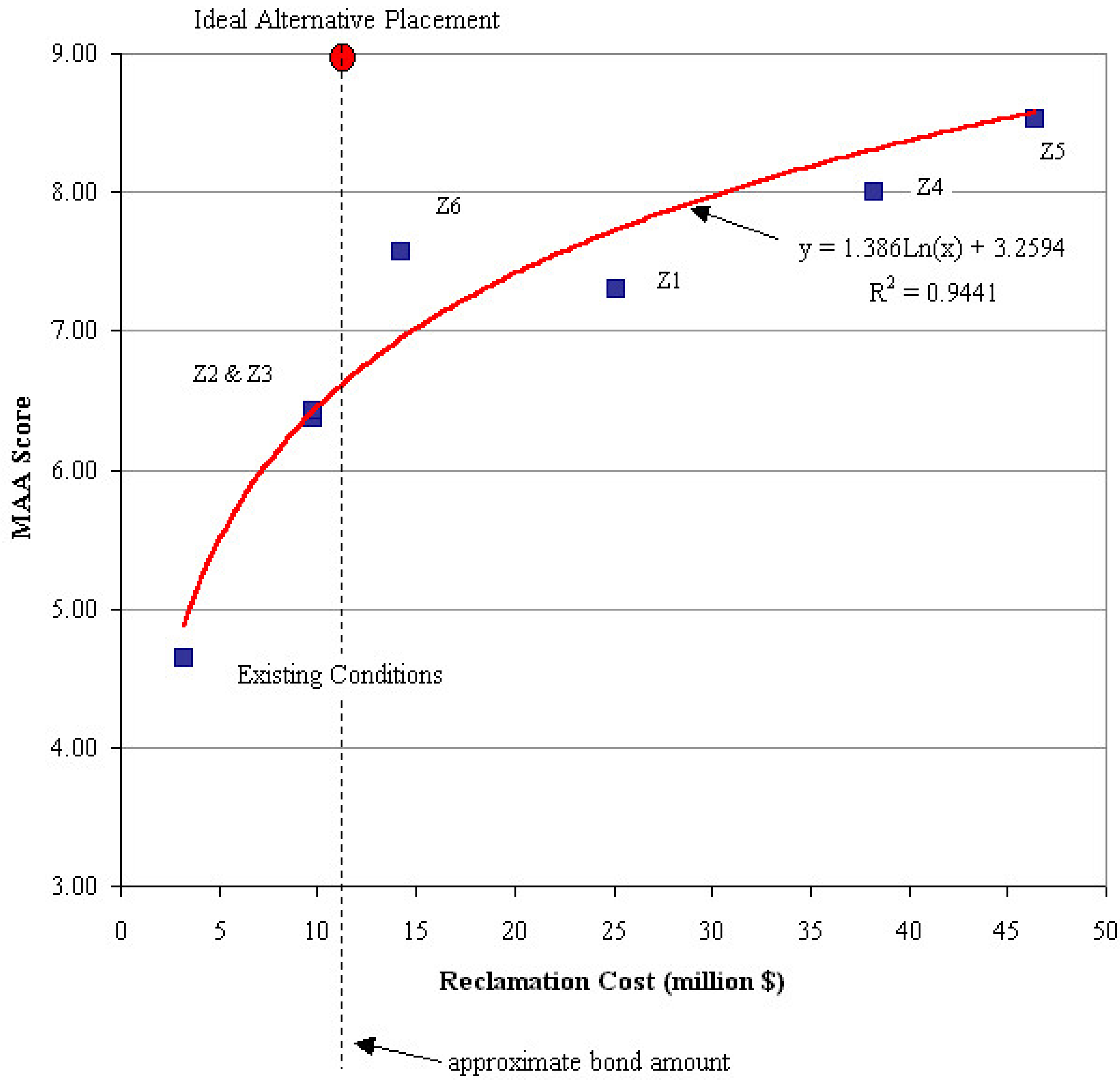



Figure 4. MAA score versus total cost for the Zortman reclamation alternatives.

## Utilization of the MAA

The MAA process described briefly here, has been utilized for a number of purposes in practical applications, including:

- identification of information gaps and data needs from which studies can be developed;
- provides a framework in which all stakeholders can identify and discuss the issues of importance to them;
- provides an objective and simplified basis on which sensitive issues can be discussed;
- provides a defensible and transparent tool with which decision makers can evaluate the positive and negative impacts of available alternatives; and,

- can provide a framework for describing alternatives considered, evaluation basis and conclusions for inclusion in other documents (e.g. EIS, EA, permit applications etc.).

The perspective view of the MAA process completed at the Zortman and Landusky mines, from other stakeholders, in the form of the project manager, regulatory agency and technical advisor to an adjacent Indian Tribe, is provided in the paper by Shaw et al., 2001. An overview paper for using the MAA with regards to sustainability optimization is also available (Robertson and Shaw, 2004)

The reader may also complete his/her own MAA using the MAA management tool provided on **EduMine**. A described here.

# MINE CLOSURE - CLOSURE CRITERIA AND INDICATORS

In order for regulators, mining companies and society to evaluate the success and reliability of closure measures and the relative and cumulative impacts of a mine post closure, criteria are typically applied to 'test' the performance of those measures. The assessment criteria, as to what constitutes 'a reasonable level of post closure social, environmental and aesthetic impact, land use, active and/or passive care, costs and environmental risk' will differ for the various stakeholders with interests in the mining operations and the surrounding impacted region. Definition of appropriate indicators and assessments of the appropriate criteria, for each of these indicators, must be made during closure planning in order to form a basis for decision-making. The rapid changes that are being experienced world-wide in the increase in the number of indicators (for air and water quality, aesthetics, land use, re-vegetation, ecosystem restoration, social impacts etc. and the application of ever more stringent environmental standards for mining projects results in considerable uncertainty as to the acceptability of many criteria, particularly those involving on-going active care and risk of environmental impacts.

For most decision-making processes, there are a number of decision 'drivers', i.e. issues that are so important they tend to determine the conclusions of the decision process. These are often related to:

- Surface and groundwater quality and impacts on the receiving environment,
- Long term stability and erosion of structures that will remain on the site,
- Land use and post closure aesthetics,
- Social and economic impacts related to a potential reduction in economic potential of an area and the potential long term burden placed on future generations related to post mining maintenance,
- Economic consequences to both the mining company and financial stakeholders of closure costs.

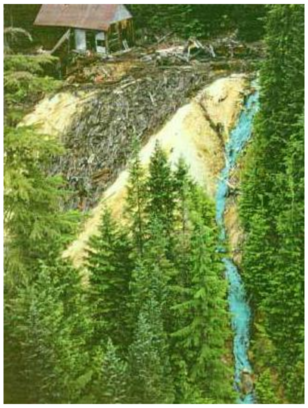
At a minimum, indicators, with associated criteria, are required to describe and test these driving issues. The use of indicators was described in the previous section on multiple accounts analysis.

Selection of inadequately 'low' criteria may result in the rejection of a Closure Plan or the imposition of additional and stringent closure requirements in the permits. Selection of 'high' criteria may result in closure costs that are not economically achievable or result in incremental costs which are out of proportion relative to the gain or improvement in performance. Unjustifiable closure cost expenditures waste fiscal resources that may otherwise be available for other local or national needs. The selection of criteria is therefore a balance between costs and benefits of reducing requirements for future active care and of future risk to the environment. Minimum criteria are those that just meet regulatory 'standards' and are protective of the environment, health and safety.

During mine planning and operations, it is often difficult, if not impossible, to predict, with the degree of confidence required, the precise impact on the environment and the resulting ability to meet closure objectives or standards. Regulatory criteria are likely to change over time ('moving goalposts'), and criteria selected for the purposes of Closure Planning early in operations, may not be applicable at the time of closure. Therefore, it is not necessarily appropriate during mine planning, development or early operations to select quantitative closure criteria which may or may not be realistic or valid at the time of mine closure. Early in the mine's life, it may be more appropriate to discuss closure objectives, or indicators for such issues as surface water quality, groundwater quality, stability and erosion, land use, revegetation etc. in more general terms. Thus the 'tests' by which the anticipated effects of various closure measures are judged typically range from quantitative values (believed to be most realistic for long term criteria values), to semi-quantitative or qualitative (descriptive) indicators of impacts or benefits.

Typical indicators for some of these areas are provided here.

**Surface and Groundwater Indicators:**
Typically, criteria or standards are applied to surface and groundwater quality whereby water being discharged, or at some compliance point within the receiving stream or aquifer, must be of a quality equal to or better than a defined chemistry. Some typical water quality objectives (taken from some provincial, state and federal water quality standards) have been tabulated in a water quality periodic table, however sometimes site specific criteria are selected. Such standards or objectives are threshold indicators (not to be exceeded) in a scalar value of concentrations. Because of total assimilative load limitations for receiving streams and aquifers, the permissible discharges are sometimes specified as loads and not as concentrations. Other 'indicators' of surface water include seep coloration, odor and taste. While this is more often an aesthetic issue, colored seeps on mine sites are often indicative of certain chemical signatures.



Secondary Copper Minerals Precipitation (Furry Creek Drainage, Britannia, B.C.) (from Price et al., 1995)

Dark greenish-black drainage from a mine adit indicative of ferrous iron ($Fe^{2+}$) (Gilt Edge, South Dakota)
(Photo taken by S. Shaw, 2000).

Rusty red water from underground indicative of ferric iron ($Fe^{3+}$)
(Photo taken by A. Robertson).

Milky water in a stream often indicative of aluminum (Red River, Questa, New Mexico)
(Photo taken by S. Shaw, 2001).

**Stability and Erosion Indicators:**
Indicators and criteria are also typically applied to ensure the integrity and long term stability of structures. Typically civil engineering safety standards (such as a factor of

safety of 1.5 for slope stability) applies during the operating life of the mine. Durability of structures, post closure, is dependent on the durability of the materials the structure relies upon for stability. Wooden support in underground openings, bridges, dams and buildings will fail over time resulting in failure of the supported structure. Not so obvious is the long term deterioration of other materials such as geomembrane liners or covers, reinforced concrete and corrosion protected steel structures. Yet less obvious is the long term weathering of rock, including tunnels, pit walls and waste rock, resulting in strength deterioration and failures. Rip-rap protection on a dam face or lining a ditch will last only for the period over which the rock from which it was quarried is durable.

Structures are under the continual attack of both perpetual 'forces' such as weathering and corrosion, erosion by wind and water, sedimentation, biotic action by roots and burrowing animals and frost action.

Structures are also subject to extreme events, which, because of the long period of post closure interest have a much greater probability of occurrence than during the operating period of the mine. Further, the consequences (economic, environmental and socio-economic) of structural failures of, for instance mine rock piles, tailings dams etc., are also oftentimes large. Therefore, it is typical for long term closure planning, that measures will consider larger events where the consequences of failure would be catastrophic, i.e. 1:10,000 year or maximum credible earthquake (MCE).

The selection and computation of design floods is another important part of many mine closure plans for features associated with water management (e.g. spillways, ditches, tailings dams, diversions, ARD capture and transport facilities, water treatment plant storage ponds etc.). Non-critical structures are typically designed to accommodate the 1 in 100 year flood event while structures that would cause large, but not catastrophic impacts, or are critical to the operations of specific facilities would require design to accommodate the 1 in 1000 year event. Those structures for which failure could result in casualties or cause catastrophic environmental impacts should be designed for the probable maximum flood (PMF). The provision for long term post closure operation of water management structures is often one of the most challenging aspects of closure measures design.

**Land Use and Socio-economic Indicators:**

The post mining land use and socio-economic impacts are extremely important issues for consideration in closure planning. Mine site development is often responsible for significant changes in the local social and economic conditions in an area. In industrialized and highly developed countries, the priority for rehabilitation of mine sites located remote from population centers is usually to return the site to the conditions that existed prior to mining, or an agreed equivalent. In industrialized countries, large mines have often been the catalyst around which a larger industrial and urbanized community has developed (i.e. the Witwatersrand of South Africa; Bingham Canyon/Salt Lake City, Utah; Berkley Pit/ Butte, Montana). A return to pre-mining socio-economic conditions is sometimes not contemplatable, in particular in regions with very little previous industry development (e.g. areas of Peru, Indonesia, Papua New Guinea etc.). To the extent reasonably achievable, mine closure must address the facilities and conditions that should be maintained post mining, to sustain the social and economic benefits generated during mining. While it is not possible to select closure criteria for all these issues, comparative assessments using indicators such as maintenance of access and power, on-going protection of health and safety, on-going job opportunities, sustainability of tax revenue etc. should be completed.

The cumulative assessment of the various benefits and impacts of all the closure measures can be completed on this basis using the MAA methodology (also see Robertson and Shaw, 2004). The resulting evaluation of all stakeholder issues, including water quality, stability and erosion, land use, socio-economics and economics, provides a comparative 'test' of success of a Closure Plan without necessarily applying or committing to closure criteria too early in the closure planning process. This type of a comparative 'test' was utilized for the reclamation planning of the Zortman and Landusky mines in north central Montana and was used in writing the EIS document.

# REHABILITATION OBJECTIVES AND MEASURE

One of the leading documents published on the topic of mine closure and rehabilitation is the Ontario Ministry of Northern Development and Mines' report entitled ***Rehabilitation of Mines, Guidelines for Proponents***, published in 1995. The content provided in this section is based on information in Appendix B of that report and is intended to serve as a series of guidelines or checklists for mine closure.

Mining projects are typically divided into components or facilities during closure and rehabilitation planning. These components are typically things such as open pits, tailings facilities, underground features, rock piles etc. A series of rehabilitation objectives and measures have been summarized in table format for the components listed below and discussed in the three broad categories of (1) Physical Stability, (2) Chemical Stability, and (3) Land Use.

Typical Mine Site Components Include:

- **Underground Mines,**
- **Open Pits,**
- **Ore, Concentrate and Development of Rock Piles,**
- **Tailings Impoundment Systems,**
- **Water Management,**
- **Buildings and Equipment,**
- **Landfills and Other Wastes,**
- **Infrastructure.**

The physical stability of structures such as crown pillars, pit slopes, underground openings, tailings dams, spillways, diversion structures, rock pile slopes etc. must be stable to eliminate any hazard to public health and safety.

Surface and groundwater must be protected against adverse environmental impacts resulting from mining and processing activities.

In a closed out condition, the rehabilitated site should be compatible with the surrounding lands.

The general rehabilitation measures for each of the above mine site components aimed at achieving these objectives has been provided in a series of tables attainable by clicking on the specific component in the list above.

# AUDITS AND REVIEWS

Technical Audits and Reviews are completed in order to review the safety, stability and environmental liability of mine facilities such as tailings systems, sediment dams and waste dumps; to identify the safety, stability and environmental liability risks of each structure; and, to provide recommendations for the improvement of safety measures and procedures to enable appropriate international standards to be achieved.

These Audits and Reviews are typically completed by professional specialists and consist of:

- Information collection, review and analysis of all site investigation (geotechnical, hydrology, hydrogeology, geochemistry, environmental and socio-economic), design and 'as-built' plans and reports;
- Field inspection of the sites and structures;
- Review of the operating history and compliance of the structure/facility, operating plans, management systems, emergency response plans and closure plans;
- Identification of the relevant risks for each of the structures;
- Development of recommendations to mitigate the risks and address issues identified; and
- Preparation of a report summarizing the work.

There are various levels at which an Audit and Review can be completed. At a minimum, a level sufficient to determine the current status of safety, stability and environmental liability of the subject structures is completed. Also included in the Audit and Review is a definition of a path forward for the implementation of measures that would ensure achievement of international standards of good practice and to prioritize the items of an action plan. Recommendations for remediation or improvements are typically provided, in which the levels of concern or risk that are associated with deficient items are indicated. For this purpose review ratings that describe the assessment of where current structures or operational procedures meet appropriate standards, or should be improved, are provided.

The description which follows provides an outline of the practice of audit and review as implemented by the authors. This practice is continually changing in response to increased requirements for assessment of additional environmental and social impact and liability concerns..

## Definitions for Audit and Review Levels and Terminology

**Audit level:** At this level the auditor performs sufficient investigation, documentation and analysis review to develop an independent opinion on both the general principles of designs, construction and operations and on the validity of the key elements of the design analyses, construction control and operating methods. For dams and critical mining structures, Audits are typically conducted at fairly widely spaced intervals of about 5 years. More frequent Audits may be appropriate if the structure and designs are undergoing rapid and substantial change. Generally an audit level review is required on initiation of the review process for any major structure. An Audit Report is produced which documents, generally against a check list, the reviewer's observations as to adequacy of the designs, construction and operations and indicates any recommendations that flow from these. The adequacy of the design is based on its achievement of a set of standards as defined below.

**Review level:** At this level the reviewer generally reviews all key documents and does at least 'reasonableness of results' checks on key analyses, design values, and conclusions. Design, construction and operational procedures are reviewed at a level sufficient to develop an independent opinion of the adequacy and efficiency of the designs, construction and operations. The reviewer generally relies on the representations made to the reviewer by key project personnel, provided the results and representations appear reasonable and consistent with what the reviewer would expect. A review report is produced which documents the reviewer's observations as to adequacy of the designs, construction and operations and indicates any recommendations that flow from these.

**Review at Discussion level:** At the discussion level the reviewer is not provided with all the relevant data required to perform an independent assessment or develop an independent opinion. Generally, only selective information is presented, often in meeting presentation form, and there is insufficient time to absorb and digest all the pertinent information and develop a through understanding of all pertinent aspects relating to the design, construction and operation. The reviewer relies on information selected by the presenter and substantially on the observations, interpretation and conclusions of the presenters. While discussion level reviews are valuable in that the reviewer can question results, conclusions and design aspects that raise issues in the mind of the reviewer, and make recommendations when applicable, the reviewer is often unable to develop an in depth understanding of all the issues that may arise or an independent opinion.

**Interim Reviews:** Interim reviews are conducted between more formal regularly spaced reviews. They are generally conducted during periods when there is rapid change in the designs or construction of major geotechnical structures and may be focused on only those parts of the design or structure which are undergoing change. They form a basis for regular exchange of information between the design/construction/operating personnel and the reviewer and for reviewer comments during the process of design/construction or operation.

## The Audit or Review Process

The auditor and/or reviewer generally evaluates each structure and facility of a mine development and makes an assessment of the adequacy of the design, construction, operation and closure provisions for that facility according to some check list. Examples of checklists are available from a number of sources such as the MAC Guide to the Management of Tailings Facilities and the tables shown in Table 1 and Table 2 which are adoptions from a checklist provided in M.B. Szymanski, 1999 (***Evaluation of Safety of Tailings Dams***, BiTech Publishers Ltd., pp. 100). Additional checklists will be added to this section in due course.

For each structure or facility, the various design, construction, operation and closure elements are reviewed and an assessment made of the adequacy of standards achieved. This results in the assignment of a Review Rating as described below. Many reviews are concluded once the Review Rating is complete. The author recommends that in addition, a risk assessment be completed to enable a program and a prioritization of risk reduction to be implemented. The risk that is associated with any structure or facility that does not achieve appropriate standards is dependent on the likely consequences. The reviewer therefore assigns a Consequence Category in addition to the Review Rating. A definition of Consequence Categories is provided below. Finally, the reviewer considers both the Review Rating and the Consequence Classification and makes a judgement decision of the risk and assigns a Risk Management Rating as defined below. This rating allows the prioritization of actions required to reduce and manage risk.

## Review Ratings

The review rating is an assessment of the extent to which the current status of design, construction, operation or closure measures meet typical international standards of good practice and design standards. The review is completed using the following ratings:

**Blank** - Undone, or inadequate information for a rational assessment
**NA** - Not applicable
**I** - Improvement needed to meet current international good practice or standards
**$I^-$** - Large and urgent improvement needed to meet required practice or standards
**$I^+$** - While inadequate against international standards, there are mitigating circumstances reducing concerns.
**P** - Passes test of adequacy (generally reasonable international standards)
**$P^-$** - While passing there are substantial concern issues
**$P^+$** - Passes well to consistent high standards
**O** - Has been optimized to beyond standards, to minimize risk
**$O^-$** - Optimization is preliminary or not well done
**$O^+$** - Optimization is extensive and risks have been minimized.

Review ratings do not include the assessment of the failure risks associated with the current state.

## Consequence Classification Category

Consequence categories consider only the severity of the potential impacts should failure occur. They provide some indication of the importance of applying an appropriate level of design, construction, operation and closure engineering and management to the particular element or system being evaluated. High levels of risk management must be applied to avoid failure where there are severe consequences.

The consequence is similar to the 'hazard ranking' and may include for financial, investor and public relations consequences in addition to human health and safety and environmental impacts.

The scale is a 1 to 5 scale as follows:

1. very low impacts: No injuries or identifiable health effects, insignificant property damage or environmental impact
2. mitigatable low to moderate impacts: only minor injuries and minor property damage, small temporary environmental impacts
3. moderate impacts: injuries anticipated, reversible health and environmental impacts of moderate extent and moderate property damage.
4. severe impacts: severe injuries, possibly a fatality, large property damage, substantial but reversible environmental impacts or irreversible but moderate environmental impacts.
5. extreme impacts: multiple fatalities, extensive property damage, and extensive environmental impact

There are numerous other hazard and consequence category scales that may be used to obtain a ranking which may then be used assigned a 5 point scale as listed above.

## Risk Management Ratings

The risk management ratings provide an assessment of the current and future failure risk that exists for the current state of the element or system. It is the objective of a risk management program to reduce risks to levels consistent with regulatory requirements and corporate objectives.

For the purposes of risk management a Risk Rating is required. In the conducting of Reviews and Audits the authors have found the Concern/Risk Rating provided below to be useful for conveying to the mining company or stakeholders an understanding of the level of risk and concern, and the urgency for risk reduction. Such a risk rating, provided for each major element of the tailings pond, indicates to the operator and stakeholders the reviewers opinion of the degree of concern/risk and provides a priority list and time scale for correction.

The following risk rating is bases on the assumption that risk is proportional to:

- Site specific or inherent risk;
- Application of Internationally accepted criteria, standards, guidelines and methods;
- Demonstrated precedent;
- Capability, ability and commitment of design, construction and operating staff;
- Monitoring for unexpected behavior;
- Available response time and methods; and
- Operational and risk management

At the most comprehensive level of risk assessment, a conventional risk assessment (considering likelihood of occurrence, consequences and potential mitigation for each identified failure mode, see FMEA) can be performed for elements of the facility to determine site specific or inherent risk. This establishes the appropriate design, construction and operating criteria, standards and methods. In the absence of a formal risk assessment, an experienced practitioner makes a judgment of risk.

### Level 1: Low Risk/Concern

General criterion:

Failure has only very low impacts, or
Design, construction and operations are to appropriate high standards.
Only normal care and management are required to maintain low risk.

Detailed criteria:

Failure of the facility will not result in significant injury, loss of life or environmental damage: or risk is low as determined by all of the following evaluation criteria:

1. Site specific and inherent risks have been identified and provided for in design, construction and operations.
2. Design, materials, construction and operating methods are in accordance with internationally accepted design criteria, standards, guidelines and methods for facilities of this type.
3. The facility is designed, constructed and operated by personnel with appropriate experience, training, commitment and authority.
4. There is precedent for all facility elements (size, materials, performance levels, etc), construction and operating conditions.
5. Facility performance is monitored, and detection of unexpected behavior is expected with a high level of confidence.
6. Potential instability or unexpected behavior will develop sufficiently slowly to allow reliable corrective measures to be implemented.
7. A reliable, informed management structure and procedures are in place to implement and control all aspects of facility design, construction and operation.

Risk Management

This is the lowest level of risk. Risk management is primarily aimed at maintaining this level while optimizing opportunities for further reduction.

**Level 2: Small Risk/Concern**

General criterion:

Failure would result only in mitigatable low to moderate impacts, or
Design, construction and operation have minor deficiencies that are correctable.
Some increased risk management is required during period of correction.

Risk Management

Risk reduction to level 1 is desirable and should be implemented as part of the on-going design, construction and operating optimization program for the facility.

**Level 3: Medium Risk/Concern**

General criterion:

Failure would result in only moderate impacts, or
Design, construction and operation have moderate deficiencies that are correctable with directed management.
Committed risk management is required during period of correction.

Risk Management

Continued implementation of design, construction or operation should proceed under a specific risk management plan that ensures risks can be managed to acceptably low levels while corrective measures are implemented. Reduction to Risk Level 1 should be planned for.

**Level 4: Substantial Risk/Concern**

General criterion:

Failure could result in severe impacts, or
Design, construction and operation deficiencies are major but correctable with directed management.
Comprehensive and committed risk management is required during period of correction. Correction is required urgently but not on a crisis level.

Risk Management

Continued implementation of design, construction or operation should proceed under a specific risk management plan. It may not be feasible to manage risks to acceptably low levels while corrective measures are implemented. Aspects for which acceptably low levels of risk cannot be achieved should be delayed or ceased until corrective measures are implemented. If this is not feasible (due to facility conditions) then specific risk minimization measures must be defined and implemented. Reduction to Risk Level 1 should be planned for.

**Level 5: High Risk/Concern**

General criterion:

Failure could result in extreme impacts, or
Design, construction and operation deficiencies are major and it is uncertain if they are correctable with directed management.
A high level of focused and committed risk management is required during period of correction.
Correction is required on a very urgent, possibly crisis level.

Risk Management

Continued implementation of design, construction or operation should proceed under a specific risk management plan. It may not be feasible to manage risks to acceptably low levels while corrective measures are implemented. Aspects for which acceptably low levels of risk cannot be achieved should be delayed or ceased until corrective measures are implemented. If this not feasible (due to facility conditions) then specific risk minimization measures must be defined and implemented. Reduction to Risk Level 1 should be planned for.

# CUSTODIAL TRANSFER

**Introduction**

Mining is a temporary use of the land. A mining company's interest in the land usually terminates with the implementation of the Closure Plan. The succeeding custodian's (and associated stakeholder's) interest is in the continued sustainable use of the land and commences only when the Closure Plan is completed. '**Mine Closure Plans**' while an advance on '**Mine Abandonment Plans**' suggest a short term planning perspective that appears shortsighted to the Succeeding Custodian. Custodial transfer of mined land, post mining, requires an extension of the concept of '**designing for closure**' and the development of a '**Post mining Sustainable Use Plan**' as part of the '**Closure Plan**'. Inclusion of the succeeding custodian in the closure planning as well as periodic technical review and audit, throughout a mine's life (feasibility, design, construction, operation and closure stages), will provide a basis for minimizing the risk development of an accepted Closure Plan. However, defects in the Plan, which may become apparent only after a time, become the liability of the Succeeding Custodian.

Poor experience with the success of Closure Plans, as well as the recognition that many defects are not apparent (or not recognized) at the time of custodial transfer has resulted in reluctance by the Succeeding Custodians to accept transfer of mined lands. This applies particularly to mine sites where significant risk of physical instability (tailings dams which could breach) or chemical instability (leaching of contaminants) could result in substantial liability. The potential for sustainable land use, including sustained revenue generation and sustained custodial care, becomes particularly important when the reclaimed mining lands require sustained or perpetual care and maintenance (active or passive). The mining industry can do much to limit the liabilities associated with operating a mine by actively participating in, or leading efforts to define the custodial transfer process, and by developing sustainable post mining land uses.

'*People do not plan to fail - they fail to plan*'. Planning initial mine development in a manner that fully considers final closure and post mining sustainable land use is an essential step in limiting future liability and in identifying the concerns and requirements of the future custodian of the land. In so doing, the mining industry can also provide motivation and guidance to assist in the rationalization of the often widely disbursed, largely uncoordinated administration and control of post mining sustainable land use.

The objective of this section of the Mine Closure section on EnviroMine is to discuss the concept of Custodial Transfer and present an approach for the development of sustainable land use post mining. Definitions for the terms used here are provided in pdf form.

**Changing Perspective**

In many parts of the world, much of the mine development has occurred on essentially undeveloped land. Prior to mining, the land was essentially 'self sustaining' in that it required no intervention by man to maintain this use. There has been a tendency to require mining companies to return mine sites to this condition post closure (to reclaim lands to achieve a land use equivalent to or better than that which existed prior to mining). Figure 6a illustrates this cycle. If the land had been developed prior to mining then the options would include reclaiming to the prior usage, to either an alternative usage, or to self sustainable use as illustrated in Figure 6b. A developed use may require either passive care, such as would apply to rangeland or forestry, or active care, as would apply to any industrial site.

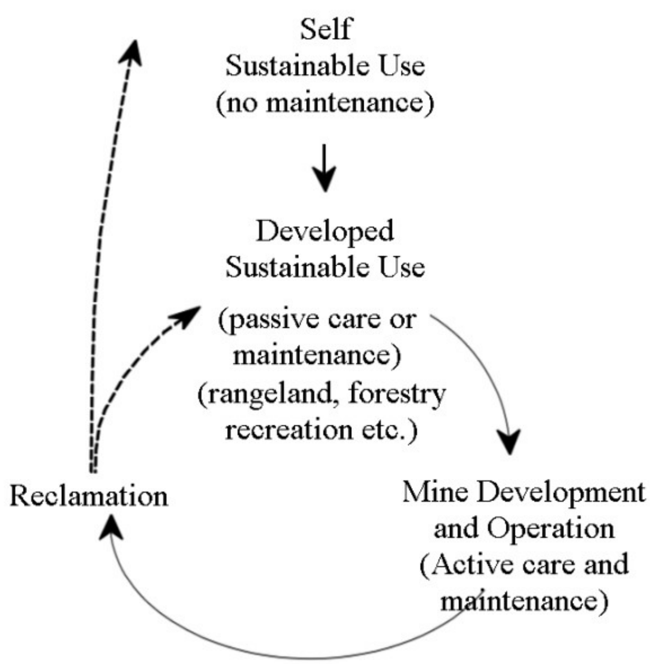




Figure 6a. Reclamation to self sustainable use. Figure 6b. Reclamation to a developed sustainable use.

Figure 7 provides an illustration of successive cyclic use of land and its reclamation. If, on completion of mining, the site can be returned (economically) to a sustainable land use then the cycle illustrated for Active Developed Use 1 is achievable. If, on mine closure, it is found that passive or active care must be maintained then it may be necessary or appropriate to reclaim to an alternative developed land use such as illustrated for Active Development Use 2. Mining, since it depletes a finite resource is inherently a temporary use of the land. The alternative (active or passive) development may be sustainable over a much long period if the activity involves renewable resources, such as a nature or recreational park, forestry or similar.

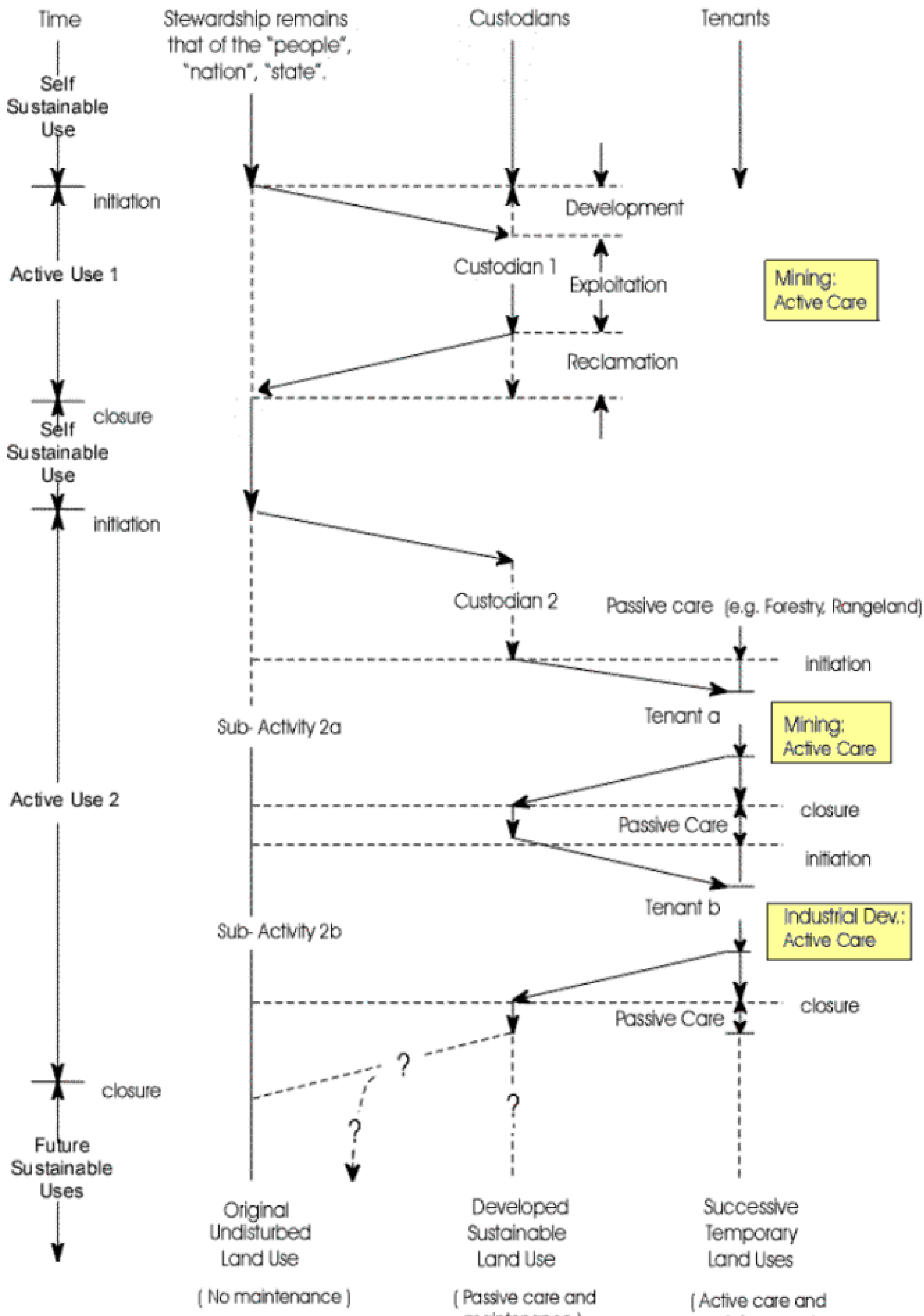

Time
Stewardship remains that of the "people", "nation", "state".
Custodians
Tenants
Self Sustainable Use
initiation
Development
Active Use 1
Custodian 1
Exploitation
Mining: Active Care
Reclamation
closure
Self Sustainable Use
initiation
Custodian 2
Passive care (e.g. Forestry, Rangeland)
initiation
Tenant a
Sub- Activity 2a
Mining: Active Care
Active Use 2
closure
Passive Care
initiation
Tenant b
Sub- Activity 2b
Industrial Dev.: Active Care
closure
Passive Care
?
?
?
closure
Future Sustainable Uses
Original Undisturbed Land Use
( No maintenance )
Developed Sustainable Land Use
( Passive care and
Successive Temporary Land Uses
( Active care and

Figure 7. Land use and custodian succession.

The willingness of a New Custodian to undertake the responsibility of a reclaimed site, which requires continued interaction, will be much greater if the long term sustainability of the site under the alternative development can be demonstrated. If the alternative development is fiscally not of itself sustainable then the development plan should include an appropriate endowment (trust fund) to finance continuing maintenance. The ultimate acceptance of a Post Mining Sustainable Land Use Plan may come more readily than for a Closure Plan, and the ultimate cost of long term interaction and/or custodial transfer terms may be significantly less if a suitable long term use plan can be demonstrated.

In order to minimize the various risks and liabilities a mining company faces, it is in the mining company's as well as society's best interest to consider all the impacts, both positive and negative as early in the process as possible and anticipate, to the degree possible, potential future liabilities and risks. This should involve, at least at a conceptual level, the development of potential post mining sustainable land use options at the feasibility stage of a mine's development. By so doing, the mining company can begin to identify post closure land use and hence potential succeeding custodians and seek their input. This will allow the mining company to gain the confidence of the succeeding custodian, and visa versa, and minimize the risks and liabilities that may be transferred with the land.

Progressive reclamation and custodial transfer, as reclamation units become available for reclamation, has the advantages that terminal closure liability is reduced, closure technology can be demonstrated and the potential of discovering 'hidden defects' and correcting them, prior to terminal closure, is increased. The risk to both the mining company and the successor custodian is reduced. Progressive reclamation and transfer provides a 'test' of the succeeding custodian's willingness to accept custodial responsibility and risk. If a successor custodian cannot be realized during the period when the mining company is operating (and is able to negotiate with economic and political strength) then the mining company's potential for negotiating conditions for transfer will reduce.

Financial assurance provisions for terminal and premature mine closure has become a standard for hard rock mines for most Canadian provinces and the United States of America. To provide the company owners with the technical and financial information they need to make such provisions, it is appropriate for the closure planning to also address premature closure liability.

**Achieving Custodial Transfer.**

The following steps are proposed in order to help achieve successful custodial transfer.

**Establish project (Closure Plan) goals:**

The overriding goals for the closure plan development and implementation are:

- Operate in an economical, safe and responsible manner
- Reclaim the landscape on an on-going basis; progressive reclamation
- Provide a landscape that will be physically and chemically sustainable for the long term
- Provide a healthy sustainable ecosystem suited to an agreed land use
- Achieve closure and custodial transfer in an economical, timely and secure manner

**Establish a procedure to screen options:**

Mining companies should review and formalize their approach to screening closure options. The screening process should involve:

- Knowledge of the relevant factors;
- Involve multi-disciplinary input;
- Involve all stakeholders to identify option selection and design objective criteria (see MAA webpage, and related papers);
- Address the full life cycle of all interacting components;
- Identify work and cost vs. time for each option;
- Have the ability to demonstrate viability, monitor (verify) performance, take corrective action if necessary, and to achieve an early reclamation certificate;
- Include a probability and risk analysis (see webpage on Failure Modes and Effects Analysis);
  - Of work to be performed,
  - Of cost,
  - Of probability of success.
- The methods, procedures, and criteria should be documented clearly and concisely to provide a 'transparent' view of the process to the stakeholders and concerned public.

**Establish a closure path:**

Establish, early in the life of the project, the project closure path - knowing that it will be adjusted with time. To the maximum extent, broaden the group that will establish this path to those likely to be involved in the final path definition (regulatory authorities and stakeholders) such that there is increased probability of the path being correct and durable.

**Establish success indicators for closure and custodial transfer:**

Seek binding agreement with stakeholders and the final custodian on what will be considered success in closure. Developers are entitled to know what the rules of the game are, use what political/financial leverage the operator has to have the rules defined and adhered to.

**Establish economic evaluation tools:**

Standards exist for conducting normal economic evaluations. However, they do not exist for situations that involve potential environmental liabilities - especially if it is possible to defer corrective action for a decade or more. The operator should establish procedures to conduct economic evaluations of different reclamation/remediation options. The procedures should be shared with, and be vetted by, key stakeholders.

**Realize public partnership:**

There needs to be better understanding of how the public benefits from a profitable operation and why it is in the public interest to seek responsible and economical solutions for closure.

The public is a major benefactor from a profitable operation project. A large percentage of each profit dollar flows to the public (as circulating wages and supplies payments, company tax and through income tax). In a similar manner the public pays a large percentage of the cost of reclamation through foregone tastes on profits. It is very much in the public interest that the project be profitable and that it be operated and reclaimed in a manner that is responsible and economical.

Realization of the public partnership is needed to facilitate progress on other issues required to achieve satisfactory closure.

**Identify the next Custodian and mechanism for custodial transfer of reclaimed land:**

The mechanism to transfer land ownership (and responsibility), when a site has been reclaimed, but will require perpetual care, is not always well defined. It should be. This may require that mining companies work actively with stakeholders to define the regional post mining land use as well as the custodian(s) that will manage that land use.

**If necessary, establish an endowment for residual care:**

Perpetual care is one closure option. It may be the only option for some sites.

Economic evaluation should determine if it is the preferred option or not.

This cannot be done until the post mining land use, succeeding custodian and mechanism to establish an endowment to fund perpetual care is understood. If the current laws discourage this option (e.g. by taxing money earned by the endowment), the problem should be identified and the laws changed.

Some stakeholders, mining company owners included, may insist that reclaimed land be maintenance free. Mining companies should be prepared to educate them about the impracticality and cost of the maintenance free option.

**Establish a mechanism to identify and transfer residual assets and liabilities:**

There is a need to establish the 'value' of any residual assets/liabilities

- To identify requirements for financial assurance (to ensure that liabilities are addressed);

- To identify the asset value of a project (when sold to a new owner- even during the operating phase);
- To identify funding needed to carry on perpetual maintenance (i.e. to establish sustainable land use

An agreed upon mechanism should be established to identify and to transfer full custodian responsibility, including potential liabilities, to the succeeding custodian.

**Establish a mechanism for independent technical review:**

Independent technical review and audit should be part of the entire mine development, operation and closure process and would facilitate the acceptance of closure and custodial transfer. Key focus areas include:

- Adequacy of plans for closure and custodial transfer;
- Adequacy of success indicators;
- Appraising if conditions for satisfactory closure have been met;
- Identifying residual liabilities and plans to deal with them;
- Determining if economic evaluations of options are realistic;
- Establishing the 'value' of residual liabilities;
- Establishing the amount that should be entered into an endowment fund to provide perpetual care - if needed;
- Determining that a property is ready for custodial transfer and that terms associated with it are reasonable;
- Suitability of the plan to the objectives of the receiving custodian.

In the future, it may be difficult to achieve agreement on closure and custodial transfer without an independent review (audit) in the same manner as corporate financial auditors have become an essential component of corporate fiscal governance and assessment.

# RECLAMATION/CLOSURE BONDING PRACTICES AND GUIDELINES

For many mine sites, the requirement of long-term interception, collection and treatment of the ARD and on-going continuous care and maintenance for dam safety, spillways, diversions and covers etc. necessitates long-term custodial care, management and associated funding (i.e. closure bond).

The size of the required bond is generally the amount that the appropriate regulator(s) accept as a realistic estimate of implementation of the accepted Closure Plan by a third party contractor. If the Closure Plan indicates that water collection, treatment, and sludge disposal will be required indefinitely then the financial assurance amount should include the provision of an invested sum that will yield sufficient annual revenue to cover these costs indefinitely (in perpetuity).

Generally a real rate of return of about 3% is used for the calculation of such funds. i.e. a $10 million fund will generate $300,000 of annual (present value) dollars in-perpetuity. The basis for costing work typically assumes that work is done by a third party contractor (normal commercial rates) and allows for all overheads such as design, quality control, administration etc.

The amount of the bond is usually independent of the company size and financial strength. The nature of the bond that a regulatory agency will accept does however depend on the financial strength of the company. To date many companies have been able to 'self bond' by providing a corporate guarantee. There is increasing reluctance for regulators to accept such corporate guarantees and mostly they now insist on a bond from an independent third party financial institution (such as a Bank or bonding company) or the establishment of a separate trust fund.

Some useful links on the topic of bonding can be found below.

- Cost Data Center
and other costing services by Western Mine Engineering Inc..

- Environmental Guidelines for Mining Operations, including a small section on financial assurance, prepared by United Nations Department of Economic and Social Affairs (UNDESA) and United Nations Environment Programme Industry and Environment (UNEP) , undated.

- Financial Assurance Guidelines.
Steps in reviewing and approving financial assurances from the Office of Mine Reclamation, California.

- Financial Assurance for Mining Activities.
Part of a series of publications related to environmental management of mining activities prepared and distributed by the Environmental Protection Agency, Queensland Governement in Australia. , written December, 2003.

- Financial Assurance for Mining Activities.

Part of a series of publications related to environmental management of mining activities prepared and distributed by the Environmental Protection Agency, Queensland Governement in Australia. , written December, 2003.

- Financial Provisioning for Mine Closure: Developing a Policy and Regulatory Framework in the Transition Economies, a paper written by M. M. Nazari with the European Bank for Reconstruction & Development, May, 1999.

- Hardrock Reclamation Bonding Practices in the Western United States.

A report prepared by J. Kuipers for the National Wildlife Federation, February, 2000.

- Nevada Mining Bonding Task Force Report.

Hosted on the Mining Life-Cycle Center website, written March, 2003.

- Research on Mine Closure Policy, including a section on Economic and Financial Considerations, prepared by the Mining, Minerals and Sustainable Development (MMSD), January, 2002.

- Mining and the Vanishing Surety Bond Market

An article by Lisa A. Kirschner and Edward B. Grandy posted on the FindLaw website, written October, 2003.

# MINE CLOSURE EXAMPLES

## *California*

***Item 1.*** In December 2004, Paul Etner and his family discovered an unmarked mine shaft the hard way: they nearly backed their SUV into it. After gingerly pulling all four wheels back onto solid ground. It was established that the 53-foot mine shaft was located on property owned by the California State Lands Commission. Toe close the shaft soil and rock was pushed into the mine shaft. Now four-wheelers are back and welcome and safe.


AFTER

***Item 2***. The following are examples of successful mine reclamation projects in California:

- One mining company in Ventura County reclaimed its mining pit to a strawberry field.
- A gravel extraction area at Mississippi Bar in Sacramento County was returned to a riparian (water) wildlife habitat.
- An aggregate mine on agricultural land in Yolo County operates in four phases. The intent is that not more than 95 acres is out of agricultural production at any time during the project's life.
- Other mined lands have been reclaimed to grazing and production of crops such as alfalfa, corn, grapes and tomatoes.

***Item 3***. The full text, for free download of the 240-page volume REHABILITATIONS OF DISTURBED LANDS IN CALIFORNIA: A MANUAL FOR DECISION MAKING. This is a superb piece of work, chock full of useful information.

These ***Items*** are from the California Department of Conservations Office of Mine Reclamation. There is a lot more on this site that make a visit worth your while regardless of where you are: Of course it is not as good as a visit to Disneyland or the Huntington Gardens or the Getty. Well maybe it is better than a visit to the Getty—just how many old marble statues can you admire in a day?

## *Iron Mountain, California*

From the 1860s through 1963, the 4,400-acre Iron Mountain Mine (IMM) site was mined for iron, silver, gold, copper, zinc, and pyrite. Though mining operations were discontinued in 1963, underground mine workings, waste rock dumps, piles of mine tailings, and an open mine pit still remain at the site. Historic mining activity at IMM has fractured the mountain, exposing minerals in the mountain to surface water, rain water, and oxygen. When pyrite is exposed to moisture and oxygen, sulfuric acid forms. This sulfuric acid runs through the mountain and leaches out copper, cadmium, zinc, and other heavy metals. This acid flows out of the seeps and portals of the mine. Much of the acidic mine drainage ultimately is channeled into the Spring Creek Reservoir by creeks surrounding IMM.

The Bureau of Reclamation periodically releases the stored acid mine drainage into Keswick Reservoir. Planned releases are timed to coincide with the presence of diluting releases of water from Shasta Dam. On occasion, uncontrolled spills and excessive waste releases have occurred when Spring Creek Reservoir reached capacity. Without sufficient dilution, this results in the release of harmful quantities of heavy metals into the Sacramento River.

Approximately 70,000 people use surface water within 3 miles as their source of drinking water. The low pH level and the heavy metal contamination from the mine have caused the virtual elimination of aquatic life in sections of Slickrock Creek, Boulder Creek, and Spring Creek. Since 1940, high levels of contamination in the Sacramento River have caused numerous fish kills. The continuous release of metals from IMM has contributed to a steady decline in the fisheries population in the Sacramento River. In 1989, the National Marine Fisheries Service took emergency action to list the Winter Run Chinook Salmon as threatened under the Endangered Species Act and to designate the Sacramento River from Red Bluff Diversion Dam to Keswick Dam as a critical habitat. In January 1994, the National Marine Fisheries Services issued its final rule reclassifying the Winter Run Chinook Salmon as an endangered species.

As an emergency action, a lime neutralization process was installed at the site to treat acid mine discharge from the Richmond Portal prior to discharge to the reservoir. This system was operated by the EPA during the winter rainy season of 1988 until 1989. Rhone- Poulenc, Inc., a potentially responsible party, operated a similar system during the 1989 to 1994 rainy seasons.

In late 1986, the EPA selected cleanup remedies addressing several parts of the Water Management area. Cleanup activities include: capping selected cracked and caved ground areas; diverting clean Upper Slickrock Creek water around waste rock and mine tailing piles; diverting Upper Spring Creek; diverting clean surface water in South Fork Spring Creek to Rock Creek; enlarging the Spring Creek debris dam; and performing hydrogeologic studies and field-scale pilot demonstrations to better define the feasibility of controlling acid mine drainage formation.

In 1989, the EPA completed capping cracked and caved ground areas and the open pit mine on Iron Mountain. The EPA completed the diversion of Slick Rock Creek in early 1990. Rhone-Poulenc completed construction of the Upper Spring Creek diversion in early 1991.

In late 1992, the EPA selected an interim remedy to treat the acid mine drainage discharges from the Richmond and Lawson tunnels by constructing a treatment plant. The treatment plant has been built and is operating. Treatment will continue, until an alternate remedy is developed to recover metals or control the discharges, to assure meeting all cleanup goals.

The EPA has studied the nature and extent of contamination that discharges from the mine seep that originates from the Old Mine and No. 8 Mine. In the fall of 1993, the EPA selected an interim cleanup remedy, which included collecting and treating the acid mine drainage discharges. A treatment system has been built and is in operation.

The installation and operation of the full scale neutralization system, the capping of areas of the mine, and the diversion of Slickrock Creek have significantly reduced the acid and metal contamination in surface water at the Iron Mountain Mine site. The diversion of Upper Spring Creek has greatly increased the ability of the EPA and the Bureau of Reclamation to manage the continuing release of contaminants from the site to minimize harm to the Sacramento River ecosystem until a final remedy can be selected and implemented.

This fascinating story is from the EPA website and really needs no comment even though it invites a torrent of opinions. Send me yours and I will post it.

## *Mine Closure Missouri*

Mining began at the mine near Fredricktown, Madison County, Missouri in 1843 and continued to 1961. The mine produced copper, lead, cobalt, nickel, iron, and small amounts of zinc and silver. The stabilization program consisting of grading the tailing piles to reduce slopes, capping of the tailings to prevent distribution by wind and precipitation, establishing vegetation above the cap, and routing storm water runoff around the tailings area.

A new sedimentation structure was constructed. To deal with continuously flowing discharge from the mine decline, plugging of the decline was determined to be the most cost effective method for controlling the discharge. Construction of the decline plug was completed at a cost of approximately $335,000.

Ongoing work includes screening of potentially mine-affected residential yards and city parks using an X-Ray Fluorescence unit, collection of soil, sediment and surface water samples and coordination of access and screening of over 150 properties.

This interesting case history is from the site of Terranext, a small, woman-owned business enterprise (WBE) providing environmental consulting and engineering services to government and private sector clients nationwide. I hope we hear more from them about their mining projects.

## *South Africa et al.*

Here are examples of post-closure uses of reclaimed mine sites:

- ***Elandsrand Gold Mine, South Africa***. For five years bricks were made from tailings and waste rock. The bricks were used to build low-cost housing. The venture failed because of conflicts between the partners.
- ***Kimberly, South Africa***. Underground mine tunnels are used as a nice cool, dark place to grow mushrooms. De Beers uses this as an "empowerment vehicle."
- ***AngoGold, South Africa***. Fish are raised in old mine ponds, thereby avoiding a seven-million Rand closure costs.
- ***Wildwood Coal Remining Project, Pennsylvania***. Fifty acres of burning coal were remined and the area restored to parkland.
- ***Baggaley Quarry, Pennsylvania***. An industrial site and wildlife areas were established; trout steams were restored.

These are the only technical details in a 120 pages examining the philosophies and desiderata of mining with closure in mind. The aims of mining with closure in mind are stated thus:

- Future public health and safety are not compromised.
- Environmental and resources are not subject to physical and chemical deterioration (sic).

- The after use of the site is beneficial and sustainable in the long term.
- Any adverse socio-economic impacts are minimized.
- All socio-economic benefits are maximized.

I read this volume quickly. I have also read a number of papers recently on similar topics. None of them tell me what I want to know: how do you design and operate a mine for closure. The answer of course lies in the answer to the question: how do you close a mine to achieve the ideals of responsible mining? Now the only way I know to close a mine for the long-term is to do what we did on the UMTRA Project, or to turn the mine into an industrial area (as was done at the mine where I grew up), or turn the area into a tourist attraction (as has beguiled me on long trips up the Continental Divide), or pass legislation demanding that you backfill the pit and stop off-site migration of contaminants (the California approach and keep in mind California generally paves the way in fashion).

These thoughts are prompted by the 2005 volume *Mining for Closure Policies and Procedures for Sustainable Mining Practice and Closure of Mines*. It is worth downloading free even if only to see the amazing photos of mining practices in south eastern Europe—the volume is written to form "a basis for action" in this part of the world. I cannot help but feel we still await a definitive statement on how to design and operate a mine for closure. If you disagree and have the answer please contact me and I will post your writings.

# MINE CLOSURE - RECOMMENDED READING & USEFUL LINKS

## Recommended Reading

### papers related to **Alternatives Analysis**

- Final Environmental Impact Statement, Zortman and Landusky Mines - provides an example of reclamation alternative assessments and impact evaluations completed for closure of gold heap leach facilities.
- Review of the Multiple Accounts Analysis Alternatives Evaluation Process Completed for the Reclamation of the Zortman and Landusky Mine Sites. paper by Shaw et al.
- A Multiple Accounts Analysis for Tailings Site Selection paper by Robertson and Shaw.
- Alternatives Analysis for Mine Development and Reclamation paper by Robertson and Shaw.

### papers related to **Risk Analysis and Technical Review**

- Assessment and Management of Risks Relating to Covers for Metal Leaching and ARD Mitigation presentation by Robertson and Wels.
- An adaptive Fuzzy Model for Risk Assessment of Mercury Pollution in the Amazon paper by Veiga and Meech.
- Application of Fuzzy Logic to Environmental Risk Assessment paper by Veiga and Meech.
- Technical Flaws in Bankable Documents paper by B.J. Guarnera
- Risk Management in Mining course by F. Oboni.
- MAC Guide to the Management of Tailings Facilities

### papers related to **Mine Closure and Financial Assurance**

- Pre-Mine Closure BAT Survey and Inventory Techniques. a paper by Altenbach et al.
- Counting What Counts paper by F. Solomon.
- The Concept of Custodial Transfer of Mined Land paper by Robertson and Shaw.
- Post Mining Sustainable Use Plans vs. Closure Plans paper by Robertson et al.
- Financial Provisioning for Mine Closure: Developing a Policy and Regulatory Framework in the Transition Economies - a paper by M. M. Nazari.
- Hardrock Reclamation Bonding Practices in the Western United States paper by J.R. Kuipers (large file).
- Hardrock Reclamation Bonding Practices in the Western United States (Executive Summary) paper by J.R. Kuipers (small file).

## Useful Links

- Mackay School of Mines - closure of heap leach facilities.
- InfoMine's Publication Database - search for papers related to mine closure.
- Kelian Mine Closure Steering Committee - an example of a website utilized for mine closure information dissemination at the Kelian Mine.
- World Bank Group - IFC: Mine Closure - discussion of mine closure from the World Bank perspective.
- Australian and New Zealand Minerals and Energy Council - Strategic Framework for Mine Closure.
- Mining, Minerals and Sustainable Development (MMSD) - Mine Closure Policy.
- Manitoba Mines Branch: Mine Closure Regulation
- Queensland Mining Council: "Mine Closure".
- Mineral Resources: Rehabilitation and Mine Closure.
- The Center for Mine Land Redevelopment.