

RISK MANAGEMENT FOR MAJOR GEOTECHNICAL STRUCTURES ON MINES

By

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Abstract

Any performance of a geotechnical structure that is outside the expected and design intent for that structure, which results in consequences that are undesirable to the owner or stakeholders of the mine, is considered to be a failure. The potential for failure together with the severity of the consequences determine the risk of such failure. Risk management for major geotechnical structures is a process that involves:

- a) assessments of the risk of failure, and
- b) implementation of a program of risk mitigation and risk control.

Failure may occur in many forms, ranging from physical failure resulting in collapse, displacement or erosion, chemical failures resulting in contaminant generation and migration, biological failures, resulting in poor vegetation growth or impacts on fish and terrestrial fauna, or social failures resulting in dissatisfied public or regulatory agencies.

Risk assessments are done on a periodic basis, involving processes for the identification of the likelihood of a failure and of the consequences of failure in a process often termed a Failure Modes and Effects Analysis (FMEA). The output from an FMEA can be used to prioritize and manage the implementation of risk reduction measures. For sustained risk management a program of risk assessment and risk mitigation is required under a management structure that provides for adequately skilled and experienced personnel to perform the program and independent internal and external review and audit of the processes.

The paper describes both an FMEA methodology and a risk management program and structure that have been applied by the author on numerous mines.

1.0 Need for FMEA's

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 Analysis, 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.

2.0 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. The incorporation of FMEA's into a formal audit and review process is further discussed in the second half of this paper.

3.0 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 judgement 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 judgement 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 analysts opinion of the reliability of the estimate.

4.0 Detailed Approach

4.1 Overview

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 in Figure 1. This FMEA worksheet illustrates the methodology's structured approach for identifying failure modes leading to

FAILURE MODES AND EFFECTS ANALYSIS (FMEA) WORKSHEET - SAMPLE MINE (POST CLOSURE)													
PLAN / AREA	ID	FAILURE MODE	EFFECTS	PROJECT STAGE	LIKELIHOOD	CONSEQUENCES					LEVEL OF CONFIDENCE	HIGH CONCERN ISSUE	MITIGATION/ COMMENTS
						BIOLOGICAL IMPACTS & LAND USE	REGULATORY IMPACTS & CONCERNS	PUBLIC CONCERN & IMAGE	HEALTH & SAFETY				
TAILINGS DAM		Physical Stability											
	A1	Deep seated failure due to drainage pipe failure (not plugged by concrete)	Embankment sloughing or non breaching failure - no fatalities	PC	H	L	L	M	L	H			Concrete plug drainage pipe.
	A2.1	Deep seated and or piping failure due to any reason including liner degradation and eventual failure (drain plugged with concrete)	Embankment sloughing and breaching failure - possible fatalities	PC	L	M	H	H	H	M			Liner expected to deteriorate slowly with numerous small leaks allowing draindown of impoundment without high phreatic surface in dam
	A2.2		Embankment sloughing and non-breaching failure - no fatalities	PC	L	L	L	M	L	M			
	A3.1	Diversion failure; pond flooding; dam overtopping	Breach of dam and discharge - possible fatalities (assuming PMF capacity in dam)	PC	NL	M	H	H	H				Must check dam capacity to store PMF
	A3.2		Breach of dam and discharge - possible fatalities (assuming PMF cannot be stored in dam)	PC	H	M	H	H	H				Must check dam capacity to store PMF; Need to upgrade the diversion or raise dam and upgrade spillway to avoid failure
	A4	Face Erosion; deep gullies; leading to dam sloughing	Sample mine liable for repairs	PC	E	L	M	M	N	H	H		Requires long-term minor but regular maintenance. Waste rock cover reduces erosion potential. Crest berm reduces erosion.
	A5	As above but with failure of custodial care	Gullies not repaired leading to massive gully causing dam breach - no fatalities	PC	L	M	L	L	L				Assumes that new custodian will be told by sample mine of maintenance needs and new owner undertakes responsibility for such.
	A6	Diversion spillway erosion	Breach and discharge of tailings - no fatalities	PC	L	L	M	M	N	H			Upgrade ditch to take 1:1000 year flood. Assumes that a concrete chute spillway will be constructed.
		Chemical Stability											
		Salt leaching - pond becomes toxic to livestock (with and without oxidation)	Sick animals - Sample mine sued	PC	E	M	H	H	L	H	H		Increased tailings cover placement over uncovered and thin areas; Investigate oxidation and leaching potential of tailings.
		As above but with cover extended over entire back area	Sick animals - Sample mine sued	PC	L	M	H	H	L	H			
		Surface water does not meet regulatory standards	Fails regulatory standards	PC	E	L	L	L	N	H			Current results have been reviewed by regulatory authorities. Check why regulatory authorities have not expressed concern
		Salt leaching - toxic to plants	Loss of vegetation quality	PC	E	L	N	N	N	H			
		Ground water drainage quality inadequate	Fails regulatory standards	PC	E	H	H	M	L	M	H		Check why, review monitoring results. Regulatory authorities have not expressed concern

Figure 1. FMEA worksheet

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.

4.2 *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, tailings dam, pipeline etc.

4.3 *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 as illustrated in Figure 2 (discussed further below) in order to provide a summary of the entire FMEA.

4.4 *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 (Figure 1) relate to the stability of a tailings dam but later parts of the same FMEA relate to other failure modes such as generation of acid rock drainage from the tailings dam as well as facilities such as open pit mine walls 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 control of erosion or inadequate blending of non-acid and acid generating materials).

4.5 *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.

4.6 *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.

4.7 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

4.8 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 is 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.

4.9 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.

Table 2. Severity of Effects

Consequences Severity	Biological Impacts and Land Use	Regulatory Impacts and Censure	Public Concern and Image	Health and Safety
Extreme (>\$10M)	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 'licence to practice'; large compensatory payments etc.	Fatality or multiple fatalities expected
High (\$1-\$10M)	Significant, irreversible impact on habitat or large, 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 'license to do business' and in major procedure or practice changes,	Severe injury or disability likely: or some potential for fatality
Moderate (\$0.1-\$1M)	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 (\$0.01-0.1M)	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 (<\$0.01M)	No measurable impact	No measurable impact	Do not exceed regulatory obligations or expectations	No local/international/ NGO attention

4.10 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.

5.0 Presentation 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 Figure2 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 by plotting the risk matrices for each of the concern areas. 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.

6.0 Risk Management through Audit and Review

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;
- Completion of an FMEA for the structure/facility;
- Development of recommendations to mitigate the risks and address issues identified;
- Prioritization of the mitigation measure into a 'Risk Management Plan'; 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 a risk reducing 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.

		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 2. Example Risk Matrix for Health and Safety (ID's for various failure modes are plotted in the corresponding matrix locations).

7.0 Definitions for Audit and Review Levels and Terminology

Four levels of Audit and Review are defined:

1. **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.

2. **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.
3. **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.
4. **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.

8.0 The Audit or Review Process

8.1 Overview

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 in M.B. Szymanski's (1999) Evaluation of Safety of Tailings Dams. Modified tables/checklists for review used by the authors are provided in Tables 3 and 4.

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 using the FMEA process 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, and the definition of Risk Management Plan.

8.2 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.

8.3 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. The authors recommend the performance of an FMEA for this purpose.

8.4 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 based 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 behaviour;
- Available response time and methods; and
- Operational and risk management

At the most comprehensive level of risk assessment, a conventional risk assessment (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.

9.0 Risk Management Program

A Risk Management Program involves: (i) the systematic application of current international standards of good engineering practice for the investigation, design, construction, operation and closure of mining structures, as well as (ii) the implementation of a regular program of inspection, supervision, and monitoring to well defined operating and performance objectives documented in design, operating and closure manuals, and (iii) a regular program of Audit and Review resulting in the definition and implementation of a Risk Management Plan.

10.0 References

Szymanski, M.B.: Evaluation of Safety of Tailings Dams. BiTech Publishers Ltd., 1999.

The Mining Association of Canada. A Guide to the Management of Tailings Facilities. September 1998.
<http://www.mining.ca/english/publications/tailingsguide.pdf>

Table 3. Dam Safety and Environmental Liability Review Checklist

TAILINGS DAM REVIEW	REVIEW RATING	RISK MANAGEMENT RATING	REVIEW COMMENTS	RISK MANAGEMENT COMMENTS
General Information				
Name of Dam				
Location				
Type of dam:				
Consequence Classification Safety				
Consequence Classification Environmental				
Review Background				
Inspected by:				
Reviewed and approved by:				
Inspect. date and weather conditions:				
Site investigation (Geo, Hyd, Geochem, Geohyd)				
Materials characterization (Physical Chemical)				
Design report & standards (Floods, Stability, Containment)				
Design/as-built data available:				
Operating manual/Training				
Emergency response				
Closure plan & financial ass.				
Inspection & review plan				
Reviewed by authorities				
Compliance Record				
Review Record				
Purpose of dam:				
Date of last DSI:				
Date of last DSR:				
Initial dam construction date:				
Original dam engineered:				
Type of dam:				
Relation to tailings basin:				
Watershed and diversions:				
Typical dam section:				
Approx dam length and max. height:				
Tailings pond adjacent to dam:				
Typical tailings pond length/size:				
Freeboard at time of DSI:				

Table 3. Continued

TAILINGS DAM REVIEW	REVIEW RATING	RISK MANAGEMENT RATING	REVIEW COMMENTS	RISK MANAGEMENT COMMENTS
Minimum past freeboard:				
Discharge structure:				
Emergency discharge structure(s):				
Date of last raise of dam:				
Future dam raise planned:				
Dam instrumentation/conditions:				
Volume and type of solids stored:				
Tailings disposal method:				
Tailings production rate, capacity				
Operating data review				
Environmental monitoring review				
Special 'as-built' features:				
New developments d/s of dam:				
Dam failed since last DSI:				
Overall Review Conclusions				
General condition of dam:				
Next DSI or DSR recommended:				
Overall Risk Rating				

Table 4. Inspection of Dam Structure

Observed Features	Yes	No	Photo No.	Comment / Note No.
1.0 (visible part of) Upstream Slope				
1.1 Erosion protection				
1.2 Evidence of erosion				
1.3 Evidence of movement				
1.4 Evidence of sloughing				
1.5 Evidence of cracking				
1.6 Mark of high pond level				
1.7 Taikings adjacent to dam				
1.8 Vegetation				
1.9 Slope visually uniform				
1.10 Other unusual conditions				
1.11 Evidence of repairs				
2.0 Crest				
2.1 Breach / wash-out				
2.2 Lateral movement				
2.3 Evidence of settlement				
2.4 Evidence of cracking				
2.5 Shoulder erosion				
2.6 Reduced width				
2.7 Crest visually horizontal				
2.8 Other unusual conditions				
2.9 Evidence of repairs				
3.0 Downstream Slope				
3.1 Erosion protection				
3.2 Evidence of erosion				
3.3 Evidence of movement				
3.4 Evidence of sloughing				
3.5 Evidence of cracking				
3.6 Signs of phreatic surface				
3.7 Evidence of seepage				
3.8 Seepage clear				
3.9 Evidence of contamination				
3.10 Vegetation				
3.11 Slope visually uniform				
3.12 Other unusual conditions				
3.13 Evidence of repairs				

Table 4 (continued)

Observed Features	Yes	No	Photo No.	Comment / Note No.
4.0 Left and Right Abutments				
4.1 Evidence of seepage				
4.2 Seepage clear				
4.3 Evidence of contamination				
4.4 Evidence of erosion				
4.5 Evidence of cracking				
4.6 Evidence of movement				
4.7 Evidence of settlement				
4.8 Other unusual conditions				
4.9 Evidence of repairs				
5.0 Downstream Toe				
5.1 Toe drain exists				
5.2 Toe drain working well				
5.3 Toe ditch exists				
5.4 Flow in toe ditch				
5.5 Evidence of seepage				
5.6 Seepage clear				
5.7 Evidence of contamination				
5.8 Evidence of vegetat. kills				
5.9 Soft toe condition				
5.10 Evidence of sloughing				
5.11 Evidence of boils				
5.12 Other unusual conditions				
5.13 Evidence of repairs				
6.0 General				
6.1 Associated tailings dams				
6.2 SCF(s) at this dam				
6.3 Decant structure at this dam				
6.4 Embedded/buried structures				
6.5 Spillway at/next to this dam				
6.6 Pipelines at this dam				
6.7 Evidence of AMD				
6.8 Tailings next to dam inspected				
6.9 Crest accessible by truck				
6.10 Public access to dam				
6.11 Any unusual conditions				