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FINAL REPORT

FAILURE MODES AND EFFECTS CRITICALITY ANALYSIS MODEL FOR RISK ASSESSMENT
(REVIEW BASIS FOR MINE RECLAMATION AND CLOSURE PLANS)

Submitted to:

Government of Yukon
Energy Mines & Resources
Minerals Development Branch

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1. INTRODUCTION

1.1 Background

The Mineral Development Branch of Energy Mines & Resources, Yukon Territorial Government (YTG), is developing a Mine Reclamation and Closure Policy with the following key objectives:

- mine site restoration;
- efficiency and cost-effectiveness; and
- risk management.

A Technical Guidelines document is planned to assist with the implementation of this policy. The YTG is considering a risk assessment approach for evaluating mine closure plans in a comprehensive and effective process. This risk assessment evaluation approach would be included as one element of the Technical Guidelines document for industry, government and public use. Including risk assessment in the evaluation process offers both government regulators and the public an improved understanding of the advantages, disadvantages and uncertainties associated with a mine project. The government is encouraging mine development in the Yukon and a risk assessment approach to mine closure planning would help ensure that reasonable controls are in place using a timely approvals process that will not impede development.

The YTG has commissioned Golder Associates Ltd. (Golder) to assist in the development of a suitable risk assessment approach for inclusion in the Technical Guidelines for the Mine Reclamation and Closure Policy. Golder has prepared this report to assist with the decision to incorporate a risk assessment approach and to describe the application of a Systems Failure Modes and Effects Criticality Analysis (FMECA) methodology.

1.2 Risk Assessment Objectives

A risk-based approach to evaluating mine reclamation and closure plans is being considered by the YTG in order to implement a systematic and documented process that achieves the following objectives:

- identification of site-specific risks;
- estimation of risks in terms of their likelihoods and consequence severities;
- identification of uncertainties; and
- consideration of risk management measures where appropriate.

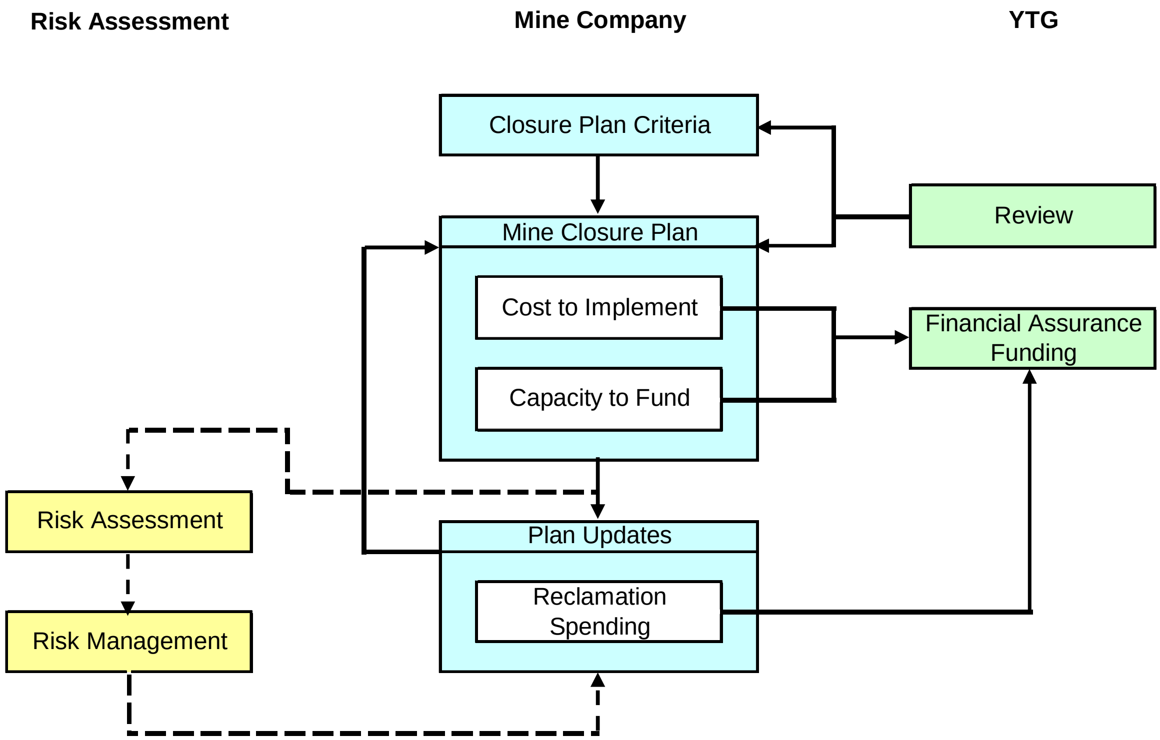
The objectives for the present study were defined as follows to assist the YTG:

- outline the Systems FMECA process;
- detail the advantages and disadvantages of the FMECA for evaluating mine reclamation and closure plans;
- identify where alternative risk assessment methodologies may be appropriate;
- provide guidance on common hazards for northern mine closure plans and criteria for evaluating risks;
- develop a risk matrix suitable for YTG evaluations;
- review previous risk application documentation from the YTG;
- estimate costs for introducing a risk assessment program at the YTG;
- provide recommendations for implementing a risk assessment program at the YTG; and
- document study results in a report.

1.3 Risk Assessment Context

The context for developing a risk-based approach to evaluate mine reclamation and closure plans is illustrated in the schematic presented in Figure 1.1. This schematic divides mine closure activities between the proposed risk assessment, the mine company and the YTG. The YTG Mine Reclamation and Closure Policy objective to ensure efficient and cost effective mine closures requires planning to begin before mine operations and continue with updates throughout the mine life. A risk-based approach is being evaluated as an added element of the current review process and is shown through the dotted flow lines in Figure 1.1. The responsibility for this risk assessment element may be delegated to an appropriate third party but is not addressed in this study.

Figure 1.1
Risk Assessment Context Schematic



As shown in Figure 1.1, the criteria for closure provide the basis for developing a plan. These criteria address issues such as implementing the most current engineering practises (minimizing environmental risks), defining post-closure land use (and addressing community expectations) and achieving long term environmental standards for air and water quality. An implicit criterion is acceptable risk and this would be addressed explicitly if the risk assessment element were included. The criteria for risk assessment are further described in Section 5.2 of this report.

Closure plans are developed by the mine company and reviewed by the YTG. In order to ensure the current closure plan is implemented, the YTG secures financial assurance funding from the mine company. This funding may be negotiated in many forms from cash to bonding. Funding may also be renegotiated as various reclamation activities are completed or conversely as new liabilities are determined throughout the mine life.

Environmental risk assessment provides a tool for more effective management of these risks associated with mine closure. The assessment process improves understanding of risks, the risk profile provides a tool for improving risk management decisions and the complete activity promotes communication among the stakeholders. Objectives for the risk assessment are to estimate the frequency and consequences for closure events that do not meet criteria (or new criteria in the future). Risk assessment may not directly impact financial assurance funding but it may provide a basis for alternate risk management strategies for a revised closure plan that may impact financial assurance funding.

The closure plan updates element in Figure 1.1 (with or without results from a risk assessment) flows back to the revised closure plan element in an iterative process that continues throughout the mine life.

An environmental risk assessment is applicable to all elements of a mine closure plan. For example, understanding the risk associated with a stream or river diversion may be an important element of planning and managing risk during the operation and then closure phases of a mine. During operations, the element (stream diversion), may have a low consequence of failure as there is reasonable or continuous monitoring and effective management controls in place that limit the impact of any damage due to a potential failure during the life of the mine. The element may however have a higher risk at closure as the design storm event may be larger than initially planned for, based on data collected during the operational mine life. Thus, risk minimization based on a risk management approach may require different design criteria for the operation and closure phases of the mine. A risk management process would help identify the impact of designing to different standards at the start of the permit process.

1.4 Report Outline

Following this introduction, the report is organized first to introduce the terminology associated with risk and the risk management process in Section 2. Then the Systems FMECA risk assessment methodology is described in Section 3. Sections 2 and 3 provide general background for completeness; however, some readers may wish to move directly to Section 4 describing the specific application for evaluating mine closure plans. Finally, a program for introducing risk assessment at the YTG is recommended in Section 5.

2. RISK MANAGEMENT PROCESS

2.1 Risk Terminology

Risk has been studied by the YTG for a number of years as a potential basis for evaluating mine reclamation and closure plans. The terminology to describe risk is important as risk is all around us and we tend to describe risks in many ways according to our experience in life and work. Different definitions have been more formally developed over the past number of years to manage risk in different industries and for different applications. Many definitions are now becoming similar as shown in the following excerpts from three internationally recognized guidelines: (CSA, 1997), (AS/NZS 1, 2, 2004) and (ISO/IEC, 2002). The CSA definition was used previously by the YTG as presented in their reference (Steve Jan 2004).

RISK

(CSA, 1997) the chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property, the environment, or other things of value.

(AS/NZS 1, 2, 2004) the chance of something happening that will have an impact on objectives.

Note 2) Risk is measured in terms of a combination of the **consequences** of an **event** and their **likelihood**.

Consequence -outcome or impact of an **event**

Event –occurrence of a particular set of circumstances (can be uncertain)

Likelihood –used as a general description of probability or frequency (chance of something happening)

Note 3) Risk may have a positive or negative impact

Residual Risk –risk remaining after implementation of risk treatment (measures to modify *or mitigate* risk)

(ISO/IEC, 2002) combination of the probability of an event and its consequence.

Notes similar to those for (AS/NZS, 2004).

The more recent definitions allow for managing positive opportunities in addition to negative consequences and for the evaluation of mine closure plans, the (AS/NZS 1 2004) definition above should be considered in addition to the (CSA 1997) definition. Although the definitions for risk are becoming similar, the terminology for assessing risk often varies with types of risk assessment applications. Decision makers must understand that the general term “risk assessment” may be used in practice to imply a specific analytical method such as a HAZOP, a Human Health or Ecological Risk Assessment, an FMECA or any number of other methods described in Sub-section 2.4.

2.2 Risk Management

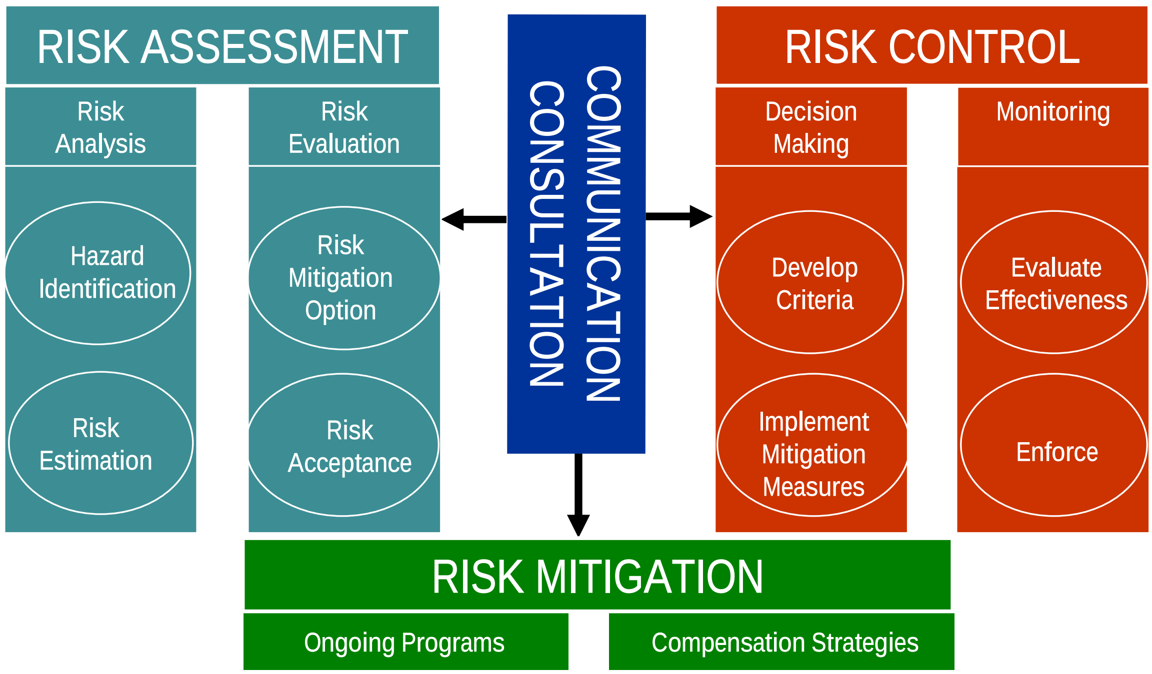
As previously mentioned, risk terminology varies in the risk literature and current practice and the same is true for the activities involved with risk management. Specific definitions for Risk Management are available in the guidelines identified previously in Sub-Section 2.1. More generally, we are always managing risk because it is always around us; and how we manage risk depends on the process we adopt. This process may range from intuition to more systematic processes with varying degrees of effort. However, there is a general expectation for industries such as mining to systematically manage their risks in a competent approach that demonstrates due diligence for the owners, the public and the environment. “The alternative to risk management is risky management” (AS/NZS 2, 2004).

A more systematic approach to managing risk allows decision makers to increase the likelihoods of achieving their objectives and making informed decisions. In addition to managing threats, risk management provides opportunities to improve performance. These objectives may be summarized as follows:

- achieve acceptable levels of risk , where benefits flowing from a particular action or decision outweigh the potential loss or damage (Golder, 2003);
- avoid unacceptable levels of risk, where the risk outweighs the expected benefits or where the magnitude of potential consequences is too great regardless of its likelihood (Golder, 2003); and
- maximize opportunities to improve performance (AS/NZS 2, 2004).

Schematics of the Risk Management process are included in (CSA, 1997) and (AS/NZS 1, 2004) and an overview of the main elements is provided in Figure 2.1.

Figure 2.1
Risk Management Process



There are different adaptations of these process schematics and the following overview of the main elements is based on (AS/NZS 1, 2004):

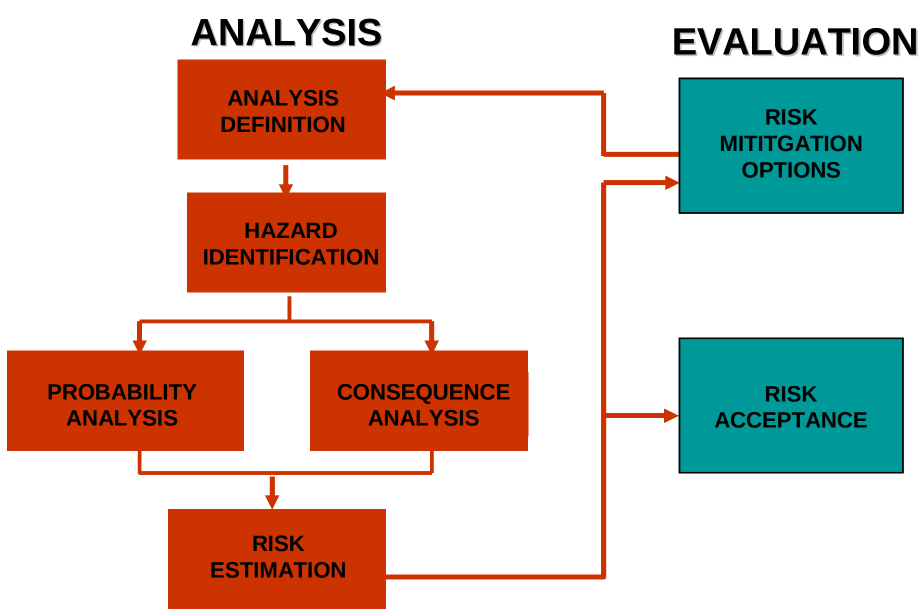
- Communication (all stakeholders, two-way, complete process, individual steps)
- Context, Initiation (external, internal, risk management scope, risk criteria)
- Hazard Identification (what can happen –hazards and incidents, when, where, how, why)
- Risk Analysis (methodology, existing controls, likelihood, consequence magnitude)
- Risk Evaluation (compare risk estimate with criteria, rank, prioritize actions)
- Risk Treatment, Control (options for risk mitigation, cost effectiveness)
- Monitoring (effectiveness of all steps, continuous improvement)

This process is applicable for managing risks including those associated with mine reclamation and closure plans. Many methods have been developed for the risk assessment elements and selection of a specific method depends on objectives and available resources. Results from risk assessment provide improved information for decision-making but do not substitute for decision-making. It is therefore important to match the objectives (and context) for the risk assessment to the method selected for effective management. In addition, it is understood that risk assessment results are not the only information used for decisions. Other information such as technology limitations, stakeholder values and other evidence may also factor into risk management decisions. Documentation is required for each element of the process to promote understanding among stakeholders and improved decision-making.

2.3 Risk Assessment

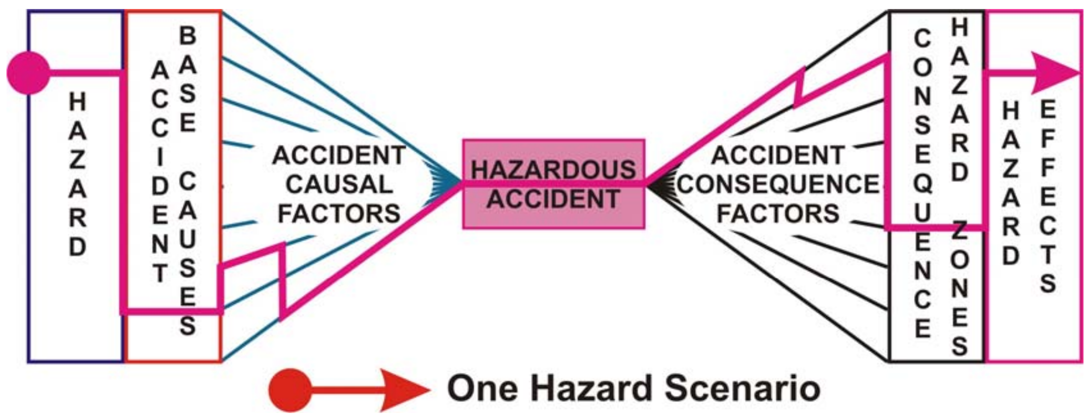
Risk assessment includes both the analysis and evaluation of risks as previously shown in Figure 2.1. The objective of risk analysis is to understand the risk and its nature and then measure it. Risk evaluation will help determine priorities for risk mitigation and assess risk mitigation options. As previously described, the terminology of risk assessment varies in different applications and the more detailed steps in the risk assessment process used for this study are shown in Figure 2.2.

Figure 2.2
Risk Assessment Process



Following definition of the objectives and scope, the hazard identification step is used to identify both the hazards and the hazard scenarios. This is a critical step because those risks not identified are therefore not assessed and unknown risks may result in poor risk management. In order to illustrate the components of a hazard scenario, a schematic is presented in Figure 2.3.

Figure 2.3
Anatomy of a Hazard Scenario

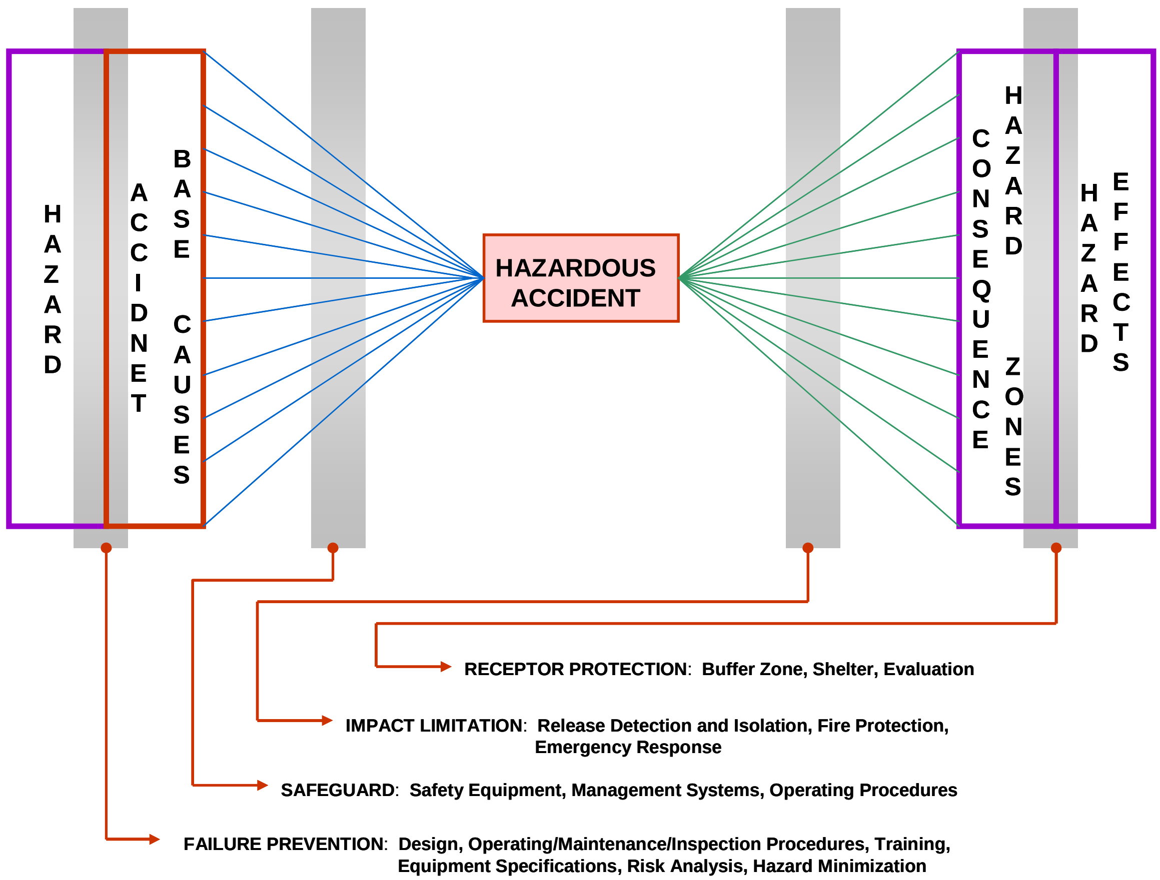


The hazard scenario in this figure begins on the left with a source of risk or hazard (source of potential harm). A series of causes lead to an event or accident occurring (such as an accidental release of tailings). Current practice may also address the following non-accident events that do not achieve performance objectives:

- Events during normal operations (e.g. emissions); and
- Unplanned activities (e.g. new regulations).

Following an event, there may be a number of consequence factors that determine the effects and the magnitude of those effects being analyzed. Effects generally include impacts to people (i.e. public safety, worker health, social expectations), the environment (i.e. damage, adverse effects to eco-receptors, loss of habitat) and finances (i.e. reputation, loss of assets). The temporal and spatial aspects of the consequences (when and where) may also define the hazard scenario risk. Usually, there are a number of controls in place such as detection systems, security systems or emergency response plans that may prevent the development or limit the consequence severity of the hazard scenario. Such controls or risk mitigation measures also need to be identified in order to proceed in the risk analysis. A schematic of various classes of risk mitigation measures and where they are applied is shown in the hazard scenario format in Figure 2.4.

Figure 2.4
Typical Risk Mitigation Measures for a Hazard Scenario



Each class of risk mitigation provides an additional layer of protection to prevent a hazard scenario progressing to a risk. The first two classes can prevent an accident while the last two can mitigate the severity of consequences from an accident. Any number of measures may exist for a given hazard scenario and should the associated risk levels be deemed too high, then additional measures may be recommended.

The hazard identification step is completed when principal hazard scenarios are identified that represent the risk in sufficient detail to achieve the analysis objectives.

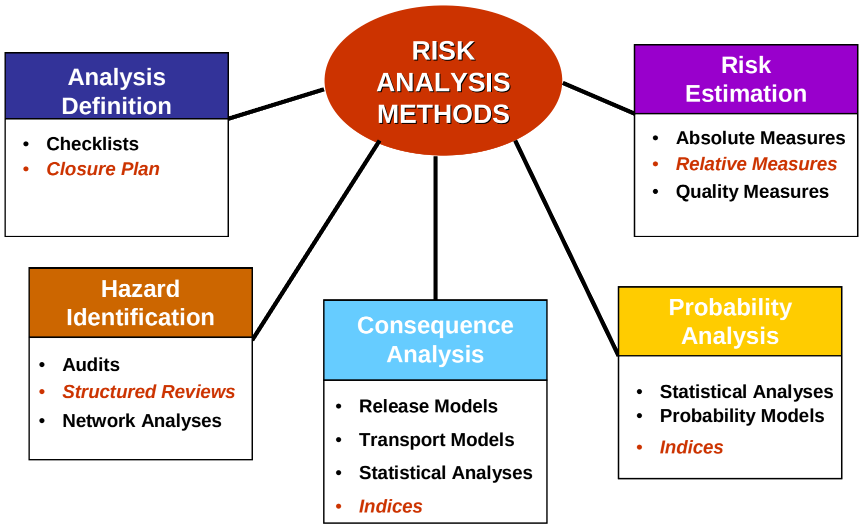
Following hazard identification, the next step in risk analysis is the estimation of risk for each identified hazard scenario in terms of consequence severity and likelihood. Generally, risk analysis may involve qualitative, semi-quantitative or quantitative analyses that involve different levels of analytical detail. The selected risk analysis method should match the risk management objectives and scope. Methods are further described in the following Sub-Section 2.4. Uncertainty is inherent in risk analysis and therefore needs to be evaluated and communicated with the results as it can affect decision-making. Finally, sensitivity analyses may be carried out to test the effect of uncertainty in assumptions or data and the effect of alternative risk mitigation measures.

Following the risk analysis steps, the risk evaluation steps include risk acceptance and where appropriate, risk mitigation options. The estimated risks are first compared to criteria established in the risk management process. These criteria provide a basis for ranking risks and prioritizing the requirement for risk mitigation action. Where risks do not meet criteria, potential risk mitigation options are developed and cost effective solutions are analyzed to mitigate risks to the necessary criteria level (or possibly eliminate them). Another iteration of the risk analysis may be appropriate to confirm the estimated risk benefit for implementing the selected control option.

2.4 Risk Analysis Methods

A large variety of risk analysis methods have been developed and adapted within many industries, economic sectors and organizations. Different methods may address one or more of the risk analysis steps described previously in Sub-Section 2.3. An overview of these methods organized according to the risk analysis steps is illustrated in Figure 2.5.

Figure 2.5
Overview of Risk Analysis Methods



A description of methods may be classified in many ways. Some methods are specific to a risk analysis process step but many address more than one-step and are applied in varying levels of detail and effort. In general, risk analyses are site or project specific and therefore there is no generic risk analysis applicable to all similar activities. The common classification used here and referenced in (AS/NZS 1, 2004) is based on qualitative, semi-quantitative or quantitative analyses. This classification follows the requirements from a general understanding of risk to the most detailed understanding of risk. One class or method is not superior to another but the appropriate method should be selected for the objectives.

Qualitative methods involve descriptive assessments of risk and include multi-disciplinary group evaluation, expert judgments, interviews, questionnaires, what-if analysis and checklists. Semi-quantitative methods involve numerical index descriptions of risk and may include Failure Modes and Effects Analysis, HAZard OPerability Analysis and Dow or Mond Index Analysis. Quantitative methods involve more rigorous numerical descriptions of risk and include actuarial analysis of historical data, consequence and probability modeling, fault and event tree analysis, and toxicity effects analysis. Detailed descriptions of risk analysis methods may be found in references such as CSChE 1992 (technological risk), BC Environment 1993 and HWC 1994 (human health risk) and U.S. EPA 1998-1999 (ecological risk).

The focus of the present study is the Systems Failure Modes and Effects Criticality Analysis (FMECA) method that is described in the following Section 3. Supplemental methods are also described where they may provide additional value for the YTG in evaluating reclamation and closure plans.

3. SYSTEMS FMECA

3.1 Systems Failure Modes Effects Criticality Analysis

The focus of the present study is the Systems Failure Modes Effects Criticality Analysis (FMECA). This risk assessment method is being considered by the YTG to assist in their evaluation of mine reclamation and closure plans. It is a method proven through many years of use and is established (along with other risk analysis methods) for applications in the mining industry. The Systems FMECA can also be used as a screening tool to identify risks that may require more detailed analysis through supplemental risk methods.

Following a description of the Systems FMECA method, the advantages and disadvantages of the method, and the possible requirement for supplemental risk analysis methods are described in this section.

3.1.1 Description of Method

The Systems FMECA is an adaptation of the FMEA method originally developed to assess the detailed risk associated with parts and components of equipment. These adaptations include the study of large systems rather than small components, the identification of existing risk mitigation measures and the estimation and ranking of risk. The method covers all of the risk assessment steps described previously in Sub-Section 2.3.

As with all risk assessments, the first step involves defining the objectives and context for the assessment. Objectives will focus the assessment on specific impacts that may include any number of risks to people, the environment or financial parameters. The scope of the analysis will define the system that can be divided into principal facilities or units to be analysed separately (and then as a complete system).

The Systems FMECA method is based on a team of experienced personnel led by a risk facilitator assessing risks in a systematic workshop process. A team may include operations, engineering, environmental and management personnel led by an experienced risk facilitator. The experience of team members provides the knowledge base and the workshop format provides a method to build synergies among the different types of experience. Other stakeholders such as representatives from the public or government may also participate in one or more workshops. Including stakeholders promotes communication and understanding in a transparent process. In addition to team knowledge, background information is collated before workshop including the site or operation history, hazardous materials and inventories, principal activities (on and off-site), and the process description during normal and upset conditions. Specific background information requirements depend on the objectives and scope of the risk assessment.

Significant failure modes and their associated consequences are first identified using an assessment protocol and the knowledge base of the risk assessment team. Existing controls to mitigate risk are also identified. Then the safety, environmental and/or financial risk (as defined in the objectives), is estimated for each failure mode and associated consequence using a risk matrix approach.

A Systems FMECA is a comprehensive process designed to identify potential significant "failure modes" associated with the system being assessed (e.g. mine closure plan). The "failure mode" describes how a system may fail and includes all possible causes ranging from natural events such as earthquakes to equipment failures, operator errors and management system deficiencies. Potential safety, environmental and/or financial "effects" as defined in the study objectives are also identified for each failure mode. For example, environmental "effects" may be measured in monetary terms for clean up response, fines, remediation and follow up actions with public and government stakeholders. A series of events usually needs to occur before a "failure mode" results in an "effect" and therefore the complete series of events is assessed. Following the identification of this series of events, the risk or "criticality" is estimated using a Risk Matrix approach described in the following sub-section.

An example protocol of prompts that may be used to identify failure modes for each unit in the system is summarised as follows:

- hazards inherent in the unit such as mechanical or gravity stored energy;
- inputs to the unit such as utilities, operation communications etc.;
- outputs from the unit such as products, wastes etc.;
- environmental effects such as storms, earthquakes, dust, etc.;

- operation modes such as normal and shutdown conditions, maintenance, etc.;
- protection safeguards such as controls, emergency plans, etc.;
- facility condition such as fit for use, etc.;
- facility design such as capacity, technology, etc.; and
- management systems such as procedures, training, inspections, monitoring, etc.

Checklists with detailed prompts to assist with hazard identification are often developed for specific types of operations with similar risks. The protocol is used systematically with all units in a system and then for the complete system of units.

In addition to addressing potential failure modes for unplanned events, normal or planned operations should also be evaluated to identify potential risks. For example, chronic dust emissions or site clearing for a new facility may have environmental effects that are not meeting criteria.

The final step in the risk identification process is to identify the existing principal control measures, contingency plans and recovery procedures that will mitigate risk. The objective of the analysis is to estimate the residual risks of the system as planned. When the risk assessment is complete, the residual risks may require reduction.

3.1.2 Risk Matrix

For each of the significant failure modes and associated consequences (hazard scenarios) identified in the Systems FMECA, a measure of the associated risk is estimated using risk matrix methodology. A risk matrix is comprised of one index representing the measure of frequency and another index representing the measure of consequence severity. When a failure mode and consequence scenario is identified, the associated risk is estimated by locating it within the risk matrix.

A number of attributes of the risk matrix are illustrated in the format presented in Figure 3.1.

Figure 3.1
Risk Matrix Format

LIKELIHOOD		CATEGORY	CONSEQUENCE SEVERITY				
			A) Very Low	B) Low	C) Moderate	D) High	E) Very High
		I Health & Safety					
		II Community					
		III Environment					
		IV Operation					
		V Cost					
Index	**Events/Year**						
5) Probable	**>1**						
4) Likely	**1 - 1/10**						
3) Possible	**1/10 - 1/100**						
2) Unlikely	**1/100 - 1/1,000**						
1) Rare	**1/1,000 - 1/10,000**						

Increasing Risk

As shown in Figure 3.1, the frequency index on the left of the matrix ranges from a “rare event” to a “probable” event and is more formally defined in terms of frequency with an events/year value. The example index is divided into orders of magnitude with the expectation that the knowledge base of the team will be sufficient to estimate the level of risk to this accuracy.

In this example, five categories of consequences are being assessed:

- people impacts measured according to I) Health & Safety and II) Community concerns;
- environmental impacts measured according to III) Magnitude of impacts on biological or physical environment; and
- financial impacts measured according to IV) Operational downtime and V) Total costs.

The severity of effects for each category of consequence is defined by an index ranging from "Very Low" to "Very High." Although these indices are blank in the figure, they would be defined as appropriate for the risk management program. In total there are five separate risk matrices shown in Figure 3.1 (one for each consequence category) and each hazard scenario would be located in 1 or more of these five matrices as appropriate.

For example, an "Environmental" risk estimate of 4D translates to Frequency Level 4 or "Likely" quantified as a frequency between 1 event in 1 year and 1 event in 10 years. The Consequence Severity Level D or "High" would be quantified further in the consequence index. This same hazard scenario may also have an "Operational" risk estimate of, for example, 2E. In order to assess the respective consequence severities, the hazard scenarios must be evaluated in terms of the exposed people or surrounding biological, physical and social components of the environment. Further analysis may be required following the Systems FMECA to refine either the frequency or consequence severity estimates.

The five levels of Frequency and five levels of Consequence Severity shown in Figure 3.1 may be changed into any number of levels depending on the risk management program. In addition, the common frequency index for all consequences categories is common practice but not required. All the consequence categories are described in this example according to the same consequence severity index. Therefore, there is an implied equivalence between each consequence category (i.e. a Level C (Moderate) consequence level for, say Health & Safety is equivalent to a Level C (Moderate) consequence level for other categories, say Environment).

Following the identification and measurement of risks, they must be evaluated and then managed appropriately. The evaluation of risk requires determining the acceptability of risk as defined through the different locations (or risk values) within the risk matrix developed for the risk assessment.

The criteria for evaluating risks are developed for the risk management program and are useful for comparing risks among different operations. The risk matrix shown in Figure 3.1 was divided into four groups representing the criteria for managing risks. These groups are color coded from lower risk Green to Yellow to Orange to highest risk Red. These different locations in this risk matrix have been categorised into corresponding levels of action requirements (or next steps) for managing the risks. Common practice is to combine the risk matrices into between three to five levels of risk and retain the same criteria for all risk matrices used in the risk assessment (in the Figure 3.1 example, five risk matrices).

The high priority risk level (color-coded red) may be associated with a management action to "Reduce Risk." Action steps may involve more detailed study to improve the risk estimate and determine if it is actually lower than estimated. In some cases, all mitigation options may prove to be uneconomic and management may decide to accept the risk but continue to manage it actively.

The intermediate risk levels (color coded orange and yellow) may be associated with various management actions to "Reduce Risk as Appropriate" and involve balancing the cost of mitigating risk with the benefits received. Action steps may again involve further study to improve the risk estimate. They may also include prioritising the application of resources according to the identified risks and implementing measures to decrease risk either by decreasing frequency, consequences or a combination of the two. The risk matrix illustrates this concept of reducing risk. Different cost implications are often associated with the choice of decreasing frequency, consequences or a combination of the two.

The lowest risk level (color-coded green) may be associated with the management action to "Monitor and Control Risk" and involve accepting the risk as long as it is both monitored and controlled to ensure it does not creep up to the next level.

3.1.3 Risk Register

Results from the Systems FEMCA are documented in a risk register that is normally a table format that includes the following information:

- system, unit description;
- failure mode;
- causes;
- consequences (one or more for each failure mode);
- existing controls (safeguards);

- residual risk estimate according to frequency and consequence location is each risk matrix; and
- notes

A schematic of the Risk Register layout is presented in Figure 3.2.

Figure 3.2
Risk Register Format

Risk Element	Problem Issue Failure	Causes	Consequences	Exisitng Safeguards	Frequency	Severity					Comments Uncertainty
						H&S	Environment	Community	Operation	Cost	
1.3 Dam	A) Seepage	Design limit	Tailings released to the environment.		3	A	C	C	D	A	High water level required in wet year. Community concerns.

The risk register can also provide the basis for recording management actions such as the implementation of risk mitigation measures and monitoring, reviewing and communicating throughout the risk management process.

3.2 Advantages and Disadvantages

Advantages of the Systems FMECA method may be summarized in a few sentences. The method first is a complete process to both analyse and evaluate risks that has wide application and is proven in the mining industry (among many other industries). It is a cost effective screening type of risk assessment that provides a semi-quantitative profile of risk useful for effective management actions. The following advantages are specific to the potential application being evaluated by the YTG:

- Many mining companies (and regulators) are familiar with the method and use it.
- It provides a balance between qualitative and detailed quantitative methods.
- The knowledge base of existing personnel is effectively incorporated.
- The framework is adaptable to the objectives at hand.
- The process is defined for consistent application.

- Risks are prioritized in a cost effective process so more detailed analyses (with greater resource requirements) are focussed only on higher risks.
- It may be applied to different types of risks (public health and safety, environment and financial).
- The process is transparent with documented results.
- Risk acceptance and tolerance criteria are defined.
- Results are readily useful for management actions.
- Results are easily understood and promote effective communication among stakeholders.

Disadvantages of the Systems FMECA method involve the objectives and requirements for a particular risk assessment. The method may not be suitable for some requirements, for example a requirement for the probability distribution of dam failures from earthquakes. In general, application of the method by different people may lead to differences depending on the detail of the procedures used for implementation. The results can be more subjective depending on the procedures used. The following disadvantages are specific to the potential application being evaluated by the YTG:

- It requires more resources than more simple qualitative methods (costs may dictate less frequent FMECA analyses).
- Risk estimates may be considered order of magnitude (may require more detail to improve management decisions).

4. SUPPLEMENTAL RISK ASSESSMENT METHODS

As described in Section 2.4, there are a large number of risk assessment methods that have been developed for different objectives. The Systems FMECA method provides screening results that may require further analysis using more detailed methods. This approach provides cost effective deployment of limited resources so the level of assessment detail is dependent on level of risk.

Example applications are described where supplemental risk assessment methods may be appropriate. Environmental health risk assessment is described followed by three example applications for health and engineering probability and consequence assessments.

4.1 Environmental Health Risk Assessment

Fundamental Concepts of Environmental Health Risk

Environmental health risk assessment is a generic term that collectively captures ecological risk assessment (ERA) and human health risk assessment (HHRA), which differ from the approach of FMECA discussed previously. The following concepts derive from a risk assessment guidance document for mining that was co-developed by Golder for the Province of BC (Golder 2003).

Environmental health risk assessment is one tool and not the only consideration in the process leading to an action or decision for risk reduction. The complexities and scope of various types of risk assessments that might be contemplated at mine sites will vary, and may employ different analytical methods. Risk assessments, however, are not the only inputs for decision making. For example, decision analysis, professional judgment, best available technology, regulatory and stakeholder considerations may be the more influential factors underlying a risk management decision.

HHRA and ERA do not focus on the probability of a failure event, but rather target some form of health effect as the risk outcome. Effectively it is the assessment of the severity of the "health consequence" that an FMECA approach may identify during analysis of a potential failure event. Typically it is used to assess health risk from environmental contamination, and the core concept is that the inherent toxicity of a chemical combined with the amount of receptor exposure allows an estimate of the potential for adverse impacts (i.e., risk).

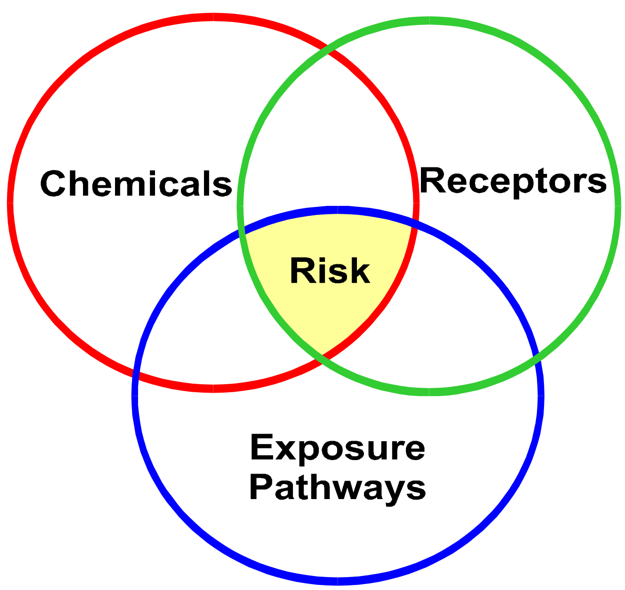
Environmental health risk assessments may express "risk" in various ways. By definition, risk is the probability of an adverse event (i.e. a bad outcome). The probability addresses the likelihood of the event to be realized, and the adverse event is the undesired effect or outcome causing concern (e.g. reduced reproduction in fish, or toxic effects to the liver or nervous system, etc.).

Three components must be present for health risks to arise from environmental contamination (Figure 4.1):

i. There must be contaminant(s) present at hazardous concentrations;
ii. There must be receptor(s) present; and
iii. There must be exposure pathway(s) by which the receptor(s) come into contact with the environmental contaminant.

Figure 4.1
Three Elements of Environmental Health Risk

(From Health Canada, unpublished, 1994)



By convention, environmental health risk assessors express risk numerically, since a numerical approach lends itself to expressing the probabilistic component of risk as well as the magnitude (significance) of the adverse event. For risk associated with environmental contaminants, the magnitude of the adverse event/outcome has, by convention, been expressed as the "hazard quotient" or "exposure ratio"; the ratio of the observed contaminant exposure rate versus the safe exposure rate (also known as a toxicity reference value or exposure limit).

Magnitude of Adverse Effect = Exposure Ratio

or

ER = estimated exposure/safe exposure

An exposure ratio of 1.0 infers that the observed exposure rate matches the safe exposure rate; values greater than one would therefore suggest concern since the safe exposure rate is exceeded, and values less than one would suggest low concern. This approach to expressing the magnitude of the adverse effect is often used for both human health as well as ecological risk assessment. For stressors other than contaminants (e.g., hunting, fishing, habitat loss), the adverse event/outcome may also take a numerical form (e.g., population growth rate index), depending on the effect and measurement.

Objectives of Environmental Health Risk Assessment at a Contaminated Mine Site

Risk assessments are carried out to evaluate potential health concerns for human and/or ecological receptors and to prioritize issues of greatest concern for subsequent risk management. The results of the risk assessment can be used to identify cost-effective and protective remedial measures. Examples of the types of general questions typically addressed within an environmental health risk assessment are:

- Who/what are the relevant human and ecological receptors?
- Are there contaminants present at levels that pose potential human health and/or ecological concerns (e.g., levels above applicable regulatory criteria based on health or environmental health risk considerations)?
- How might human or ecological receptors be exposed to the contaminants?
- What types of adverse effects might result from exposure to the contaminants?
- Based on a quantitative analysis of contaminant exposure and toxicity, what is the magnitude of health risks to human and ecological receptors on the site?
- How do current and proposed mine activities and future land use influence the predicted risks?

- What are the potential environmental and/or human health risks of contaminant migration off-site?
- Is the risk likely to remain stable, increase, or decrease with time in the absence of any remediation?

Answering the above questions provides a basis for addressing the need to implement risk reduction measures. If such a need exists, then the following additional questions should be incorporated into the risk management process:

- Where, and in what conceptual manner should risk reduction measures be implemented?
- What would be acceptable risk-based clean up criteria for the site and contaminants in question?
- What methods should be used to ensure that the risk reduction measures are effective (e.g., monitoring program)?

Risk Assessment Process

The approach to environmental health risk assessment typically involves four main components: problem formulation (which identifies contaminants of potential concern, receptors and exposure pathways), exposure assessment and toxicity assessment (the numerical analysis phase), and risk characterization (the process of deriving and interpreting risk estimates). Figures 4.2 and 4.3 summarize the common framework to HHRA and ERA, respectively.

Figure 4.2
Human Health Risk Assessment Framework

(From Health Canada, unpublished, 1995)

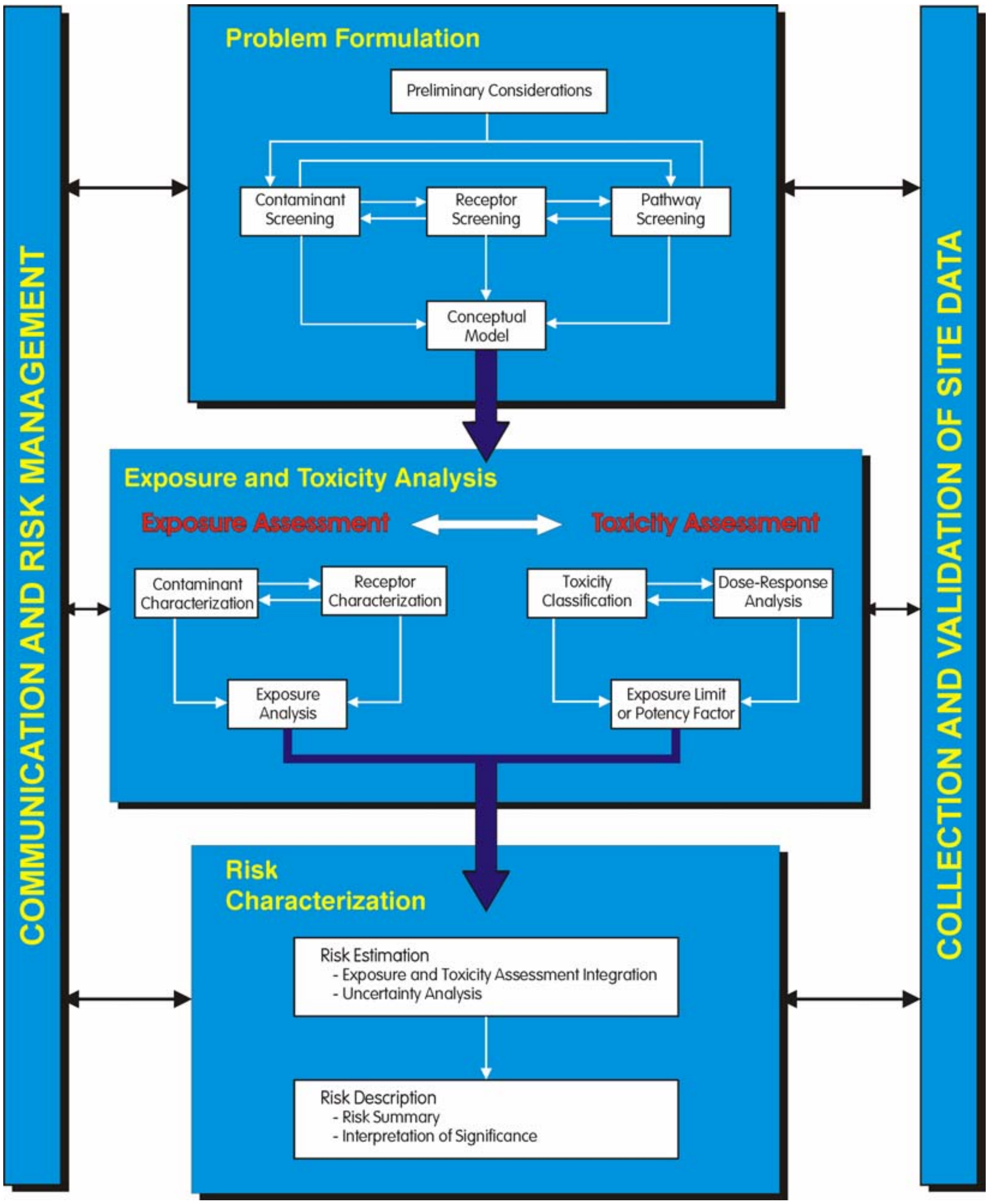
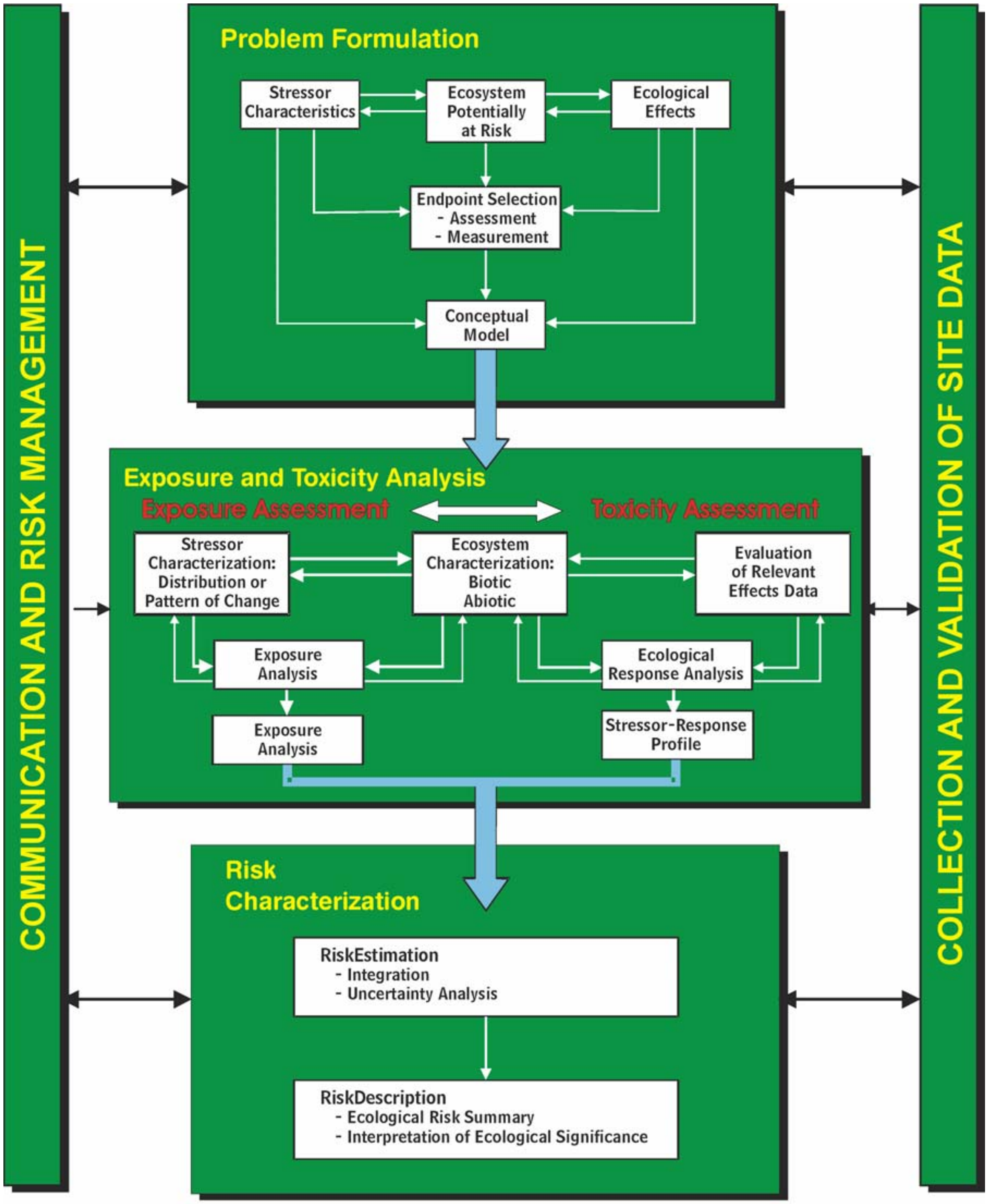


Figure 4.3
Ecological Risk Assessment Framework (USEPA 1992)



Note that although approaches are very similar, ecological risk assessment includes additional steps in the analysis to address characterization of the ecosystem. Unlike human health risk assessment, ecological risk assessment may include ecosystems features (e.g., a wetland) as a receptor, in addition to individual species or populations.

Problem Formulation is the first and perhaps the most important stage of environmental health risk assessment. The objective is to screen contaminant sources, receptors and pathways to focus subsequent investigation and remediation steps. Recognizing that both time and monetary resources are limited, these screening steps are designed to determine key exposure pathways and chemicals. Objectives of the risk management and therefore the risk assessment are also articulated at this early stage to promote proper design of the risk assessment. The result is a *Conceptual Exposure Model* which focuses the resources on those contaminants, receptors and pathways which are relevant to the risk management issue.

Exposure Assessment is the estimation of the dose rate or concentration to which a human and ecological receptor is subjected. For virtually all animals (including humans) the primary routes of contaminant exposure are through inhalation, ingestion, and dermal (or trans-dermal) absorption. For fish, exposure is primarily via gill uptake, but ingestion may be important for chemicals which bio-magnify through the food chain. The relative importance of each of these exposure routes will vary depending on the receptors selected. Various mathematical equations, models or direct measurements are used to predict the dosage rates and exposure concentrations.

Toxicity Assessment for human health risks involves classifying the contaminants in accordance with their potential toxic effects, and estimating the acceptable dose or concentration that can be received by a person without experiencing measurable adverse health effects (i.e. exposure limit or toxicity reference value). The basic principles applied in human health toxicity assessments also apply to ecological toxicity assessments, however, carcinogenicity is rarely considered. In the case of ecological receptors, the selection of appropriate toxicity reference values relates to the desired level of protection that is to be given to ecological receptors at the mine site.

Risk Characterization involves numerical estimation of the magnitude and probability of health risks, and a descriptive interpretation of the estimated risks associated with exposure to contaminants of concern. Health risks are estimated by comparing the predicted exposure(s) to the acceptable toxicity reference values. For threshold-acting contaminants, the human and non-human risk estimate is expressed as a Hazard Quotient (HQ). For human exposure to non-threshold-acting chemicals (some carcinogens), a numerical cancer risk estimate is calculated. The same mathematical principles used generate the risk estimate can be used to derive what is sometimes called a “risk-based criterion” that defines a contaminant concentration (e.g., in soil) that would yield acceptable health risk to the receptor; this is particularly useful for risk reduction planning.

In the case of a mine, an environmental health risk assessment is invariably supported by existing relevant data (e.g. derived from site monitoring, environmental effects monitoring, soil geochemistry of the area etc.) as well as supplemental data collected as part of a site-specific investigation. Virtually all historic data that is collected through the mine life cycle and compliance monitoring programs should be scrutinized for their value towards use in the risk assessment. However, it is not uncommon that supplemental data may be needed to meet the specific goals of the risk assessment and risk management decisions.

The common approach to risk assessment is to make overly conservative exposure and toxicity assumptions in order to ensure that risks are not underestimated. This screening level type of assessment is typically carried out using a "deterministic" approach, in which single, conservative values are used as input parameters to the quantitative analysis. If the screening level assessment indicates that risks are below levels deemed acceptable by regulatory authorities and other stakeholders, then a more detailed analysis is not necessary. If the screening level assessment indicates a potential problem, then the risk assessor can conduct additional iterations of the analysis with more realistic assumptions about exposure and toxicity to determine if the refined calculations support the original findings.

Linkage with FMECA Approach

The fundamental applications of ERA and HHRA are to assess specific scenarios for their inherent health risks, primarily arising from environmental contamination. The premise is: “given the existing environmental quality or given the future (predicted) environmental quality…what are the health risks?” Thus the environmental health risk assessment framework is less engaged in predicting an adverse event or occurrence of the conditions, but rather in estimating the health risk (probability and effect) given the environmental conditions currently exist or could exist in the future. This is key difference from FMECA method.

Thus, environmental health risk assessment practitioners are generally unlikely to apply FMECA methods in their analyses because it engages a different expertise, and in many cases it may not be warranted. For example, if an environmental health risk assessment is very focused on a particular issue of a mine, an FMECA may not be needed. Similarly, if the conditions already exist at a mine, then the event (failure to preserve environmental quality) has in effect already occurred, and the follow-up to ascertain the health risk is now of interest. If however, the environmental health risk assessment for the mine is holistic in nature (i.e. addresses the whole site and various "what if" scenarios) then FMECA and the associated risk register may provide a useful screening step to flag scenarios or events that ERA or HHRA may then provide added insight.

4.2 Engineering Probability and Consequence Assessments

4.2.1 Pit Lake

Many hard rock mines are developed as open-pits rather than adits or underground workings. Upon completion of mine-related work, many of these pits are left in place and generally fill with water due to intrusion into the groundwater zone or through meteoric sources. Leaching of metals from the pit walls may result in elevated concentrations in the water column or developing sediments. If concentrations get sufficiently high, they may pose a risk to fish or other aquatic life that colonize the pit lakes, or to wildlife that feed on the aquatic food chain or use the lakes as a source of drinking water.

Using the principles of risk assessment, one can see that the risk scenario involves i) a *contaminant source* (i.e., leached metals entering from groundwater seepage and possibly dissolution from the pit walls; ii) potential *receptors* such as aquatic organisms and wildlife that may, over time, use the pit lake if suitable habitat permits; and iii) *exposure pathways* such as water ingestion or absorption across the skin or gills.

Analysis of risks associated with these scenarios could involve several elements. Recognizing and characterizing these elements over significant time scales is the first basis to designing mitigative options either *a priori* (preferably), or a *posteriori* as described below:

- prediction of long-term hydrogeological response to cessation of dewatering;
- prediction of contaminant flux into the pit lake from groundwater transport;
- geochemical modelling of contaminant dissolution from pit walls;
- geochemical modelling of predicted aqueous metals equilibrium and bioavailability;
- evaluation of aquatic and terrestrial habitat and accessibility to aquatic environment; and
- contaminant exposure modelling of relevant receptors and risk prediction

Over the past 6 to 8 years, regulatory concern has grown about the potential for such risks to occur and what type of management practices should be put in place at the time of mine closure to mitigate against such risk. Pit lake risk assessments now are routinely required for approval of permits for pit development or expansion in the southwestern U.S. Two examples of such risk assessments conducted in Nevada illustrate that the potential exists for significant risk to wildlife, and that risk reduction can be achieved through appropriate pit design and other site-relevant management controls. Pits with steep sides where the topmost bench is many feet below the predicted water surface will have significantly reduced risk overall. This is because development of a sustainable aquatic life community depends upon the establishment of some type of primary production, either by growth of algae and bacteria or rooted aquatic plants. If the bench is far enough below surface, light penetration will not be sufficient to allow the plant community to establish, which will then significantly reduce the potential for colonization by other aquatic life. Unstable slopes above the water surface will discourage wildlife or livestock from using the pits as a water source, and lack of fish or invertebrate larvae will reduce risk to wildlife that feed on such organisms. Other institutional controls such as fencing, signage and removal of roads also have been suggested as risk mitigation measures, particularly for human use concerns.

None of the proposed mitigation measures for pit lakes deals directly with the contaminant source of the risk, (i.e., leaching of metals from soils); rather they focus on reducing or preventing either the presence of receptors or their interaction with the contaminant source. Therefore, a residual risk will remain, and there are no "walk away" solutions. Continued monitoring and management will be required to ensure that pit wall failures do not occur and result in shallow embayments, or that water levels decrease such that deep shelves become more shallow. Nevertheless, with appropriate monitoring and maintenance, it is likely that pit lakes can be maintained in a state of low residual risk.

4.2.2 Water Cover on Tailings

In light of potential for tailings mineralization of metals through oxidation process and its exacerbation by acidification from sulphide deposits, a water cover may be considered in some instances to insulate effectively the exposed tailings from atmospheric oxygen. In some cases this may be planned and implemented as a final engineered water cover, and in rare cases permission may be granted to utilize an existing water body for the submerged and long-term storage of tailings. If the latter approach is permitted, it is likely predicated on the forfeiture of the water body as a habitat resource and a long-term management plan is then considered to minimize risks to local receptors or adjacent resources. It is important however to include analysis of potential risks that might arise from:

- contaminated surface water transport;
- contaminated groundwater transport; and
- wildlife access to and use of the affected water body.

Where an engineered water cover is implemented, the same objective exists which is to design a system that will be stable with minimal management needs (e.g., energy, water management etc.) and results in low dissolved oxygen systems to minimize metals release into the overlying water. While the above list of risk analysis elements will again factor in, additional elements that warrant attention include:

- propensity for water cover to be disturbed and result in re-suspension of tailings and consequent metals release to the more oxygenated water column;
- propensity for wave generation, sediment transport, beach formation and consequent oxidation and metals release;
- risk of exceeding water storage capacity and forced release of non-compliant water to local watershed;

- assessment of reservoir/dam integrity for long-term physical stability;
- assessment of potential for groundwater and associated receptors to become affected by water cover seepage.
- geochemical analysis of metals equilibrium in sediment, porewater and water column; and
- potential for colonization of the water cover and associated health risk to such receptors as well as the risk of such organisms causing bioturbation and upset the planned stability of the system.

Again, the use of risk principles would guide one to associate the above elements into the categories of contaminant source/release, receptor or exposure mechanisms, as previously discussed. Where an unacceptable risk becomes apparent through such analyses, risk management measures would need to be considered to reduce or eliminate the causative factor(s) (e.g., beach prevention through design for wave suppression, contingency plan for increased and temporary water storage, increased freeboard on dam, etc).

4.2.3 Soil Cover on Waste (Acid-generating) Rock Dump

In this scenario, waste rock material is covered using a soil material to reduce the potential for dissolution caused by contact with atmospheric precipitation. The potential however, exists for surface water from precipitation or snowmelt, to percolate into the soil and facilitate mineralization. Ultimately metals may leach into the groundwater and subsequently be transport to surface water where various receptors may become exposed.

Assuming the soil cover is acceptably clean, such a situation would likely warrant the risk assessor to again focus on numerical predictions of:

- characterization of geochemical mechanisms governing dissolution of metals in subsurface soils (e.g., acid base accounting);
- groundwater contaminant transport mechanisms;
- contaminant concentration at, flux to, and dispersion within nearby surface water;
- use of affected groundwater and surface water by various receptors;

- thickness of soil cover and accessibility of subsurface material to burrowing animals and tree roots; and
- exposure and risk characterization from the combined effects of all of the above factors.

If the estimated residual risks from this management option were unacceptably high, an additional mitigative option might then be warranted to suppress the dissolution:

- by reducing permeability of the cover;
- by hydraulic control of groundwater flow;
- by placement of interception wall or leachate control systems to capture and treat leachate; or
- by additional treatment technology (e.g., passive reactive wall).

In any of these cases, the risk assessor would need to re-visit the analysis and determine the risk reduction to be achieved by the supplemental management actions.

5. EVALUATING MINE RECLAMATION AND CLOSURE PLANS

5.1 Guidelines on Potential Hazards

There are a number of common potential hazards associated with mine closure activities and some of these are summarized in this section as a check for the hazard identification step in the risk assessment process. This summary is not intended to be comprehensive, but rather to provide a generic list of considerations to trigger and stimulate ideas for the workshop participants as they identify site-specific hazard scenarios.

The Mining Association of Canada has developed a series of check lists that are part of A Guide to the Management of Tailings Facilities (MAC 1998) to manage mine waste facilities and in particular tailings facilities. The checklist for Decommissioning and Closing a Tailings Facility from (MAC 1998) is shown for reference in Appendix I. As shown in this checklist, management actions are listed from policy and commitment through planning, implementation and review. For each action there are columns to describe the responsible person(s), the performance measure, the schedule, technical considerations and references.

The tailings management guide covers the various stages of the mine life from the site selection of a tailings disposal site, to the operation to the facility, to the decommissioning and closure of the tailings facility. This guide provides a check list of events or activities that should be covered in a closure planning effort, from the role of management / owner to the staff on site to the events that could and should be considered by the closure plan. It includes planning for the closure and proposed long-term end land uses, managing the risks that are associated with the facility up to and at closure, working on the elements on the mine site that allow progressive closure of the mine and the associated tailings and mine facilities.

The guide also presents the events that should be assessed as a minimum in closure planning. These include:

- flood routing of major and design storm events through and around the closed tailings facility;
- management of acid drainage and metal leaching, if these are issues at the mine;

- long term stability of the tailings dams – static and seismic;
- the need to maintain a flooded cover on the tailings pond, if required;
- the need for a spillway to satisfy long term dam safety criteria;
- long term water treatment issues and costs;
- long term monitoring of dams and related infrastructure;
- surface water and groundwater at and downstream of the mine site;
- management of dust;
- cost of the long term care and maintenance issues; and
- documentation of the all of the closure and long term maintenance activities.

The risk process would identify the hazards associated with each event, the frequency and the consequences either to the environment or the long term care concerns (bonding to cover contingent liability issues). All the above issues will not be relevant for all mines, but the topics should be considered in a risk assessment for closure planning.

5.2 Criteria for Risk Assessment

The context for developing a risk based approach to evaluate mine reclamation and closure plans was previously illustrated in the schematic presented in Figure 1.1. As shown in Figure 1.1, the criteria for closure provide the basis for developing a plan. These criteria address issues such as implementing the most current engineering practises (minimizing environmental risks), defining post-closure land use (and addressing community expectations) and achieving long term environmental standards for air and water quality. An implicit criterion is acceptable environmental risk and this will now be addressed explicitly for use in a risk assessment.

The objectives for the closure plan are to achieve the above criteria as defined for a particular mine site. A Systems FMECA will define the risks for events with the potential to cause an exceedance of these criteria. An example could be failure of a treatment plant to achieve water quality standards. Should the closure plan not be able to address specified criteria (water quality due to background effects, for example), a more detailed health risk assessment may be required as described previously in Section 4.

Mine closure planning begins with a definition of the long-term management goals for water and air quality and the end land uses. These issues and closure criteria will define the closure process and development of a successful closure plan. The establishment of agreed to "measures of success or completion" will assist with setting out the anticipated expectations of stakeholders and the anticipated end point for the project. Thus, the closure plan should address the specific closure target criteria for water and air quality and, if needed, site-specific risk-based standards. The definition of the goals and final criteria for closure will make the closure planning more effective and expectations for stakeholders can be addressed, if success is not achieved or only partly achieved.

5.3 Yukon Territorial Government Risk Matrix

A general description of the risk matrix tool and its use in the Systems FMECA method was previously presented in Section 3.1.1. A risk matrix is comprised of one index representing the measure of frequency and another index representing the measure of consequence severity. When a hazard scenario (failure mode and consequence) is identified, the associated risk is estimated by locating it within the risk matrix. The adaptation of this tool to achieve the YTG study objectives is described in this section.

5.3.1 Objectives for the YTG Risk Matrix

The objective for the YTG risk matrix is to provide a tool for measuring environmental risks associated with mine reclamation and closure plans. Environmental risks have been divided into the following categories:

- public health and safety;
- community concerns;
- environmental impacts; and
- total costs.

These categories were selected to address the potential public issues with mine closures and both the mine and YTG cost management issues. The first two categories deal with the public stakeholders. The third category deals with the possible geographic extent and severity of environmental damage (provides a descriptive perspective). The final category deals with the cost impacts from the first three environmental categories. These costs may include response activities (access, limiting effects, dealing with media and stakeholders), repair and reclamation activities, implementation of improved risk mitigation measures, etc.

5.3.2 Consequence Category Indices

Indices were developed for each of the four environmental risk categories described in Sub-section 5.3.1. Each index was developed based on experience from applications of the Systems FMECA method for mining and other industries. Five levels of severity, from very low to very high, were selected and are quantified for each consequence category index in Table 5.1.

As shown in Table 5.1, the severity levels are descriptive for the three public and environment categories but still are quantified through specific definitions. The final total cost is quantified by order of magnitude dollar estimates. There is an implied equivalency between all four consequence categories for each consequence severity level when they are lined up as shown in Table 5.1. This is common practice for many risk matrices.

Table 5.1
Risk Matrix Consequence Category Indices

Consequence Category	Consequence Severity Index				
	A) Very Low	**B) Low**	**C) Moderate**	**D) High**	**E) Very High**
I Public Health & Safety (over short and long term)	Medical treatment not required.	Reversible disability or injury requiring hospitalization.	Irreversible moderate (<30%) disability to 1 or more people.	Single fatality. Single irreversible severe (>30%) disability.	Multiple fatalities. Multiple irreversible severe health effects.
II Community Concerns	Minor short-term (weeks) local community impacts. Minor repairable damage to local community assets or items of cultural significance.	Minor medium-term (months) local community impacts. Major repairable damage to local community assets or items of cultural significance.	Major long-term local community impacts. Permanent damage to local community assets or items of cultural significance.	Serious on-going local community impacts. Significant damage to local community assets or items of cultural significance.	Very serious and regional community impacts. Significant damage to highly valued community assets or items of cultural significance.
III Environment Impacts	Minor short-term on-site effects on physical or biological environment.	Minor medium-term effects on physical or biological environment limited to small area.	Moderate medium-term effects on physical or biological environment.	Serious medium-term effects on physical or biological environment impairing ecosystem functions.	Very serious long-term wide-spread effects on significant physical or biological environment imparing ecosystem functions.
IV Total Costs	< $100 thousand	$100 thousand - $1 million	$1 million - $10 million	$10 million - $100 million	> $100 million

5.3.3 Frequency Index

A common frequency index was developed for the risk matrices for all four consequence categories described in Sub-section 5.3.2. Five levels of frequency were selected according to order of magnitude values based on the YTG requirements and experience from applications of the Systems FMECA method for mining and other industries. These frequency levels range from rare to probable as defined though events/year in Table 5.2.

Table 5.2
Risk Matrix Frequency Index

Likelihood	
Index Descriptor	**Events/Year**
5) Probable	>1
4) Likely	1-1/10
3) Possible	1/10-1/100
2) Unlikely	1/100-1/1,000
1) Rare	1,1000-1/10,000

As shown in Table 5.2, the frequency levels vary from a rare event occurring once every 10,000 years (a possible design criteria for engineered systems) to a probable event occurring more than once per year.

5.3.4 Risk Matrix

The study risk matrix is a combination of four matrices defined by the four consequence category indices defined in Section 5.3.2 and the common frequency index defined in Section 5.3.3. This study risk matrix is presented in Figure 5.1.

Figure 5.1
Study Risk Matrix

		CONSEQUENCE SEVERITY				
	CATEGORY	A) Very Low	B) Low	C) Moderate	D) High	E) Very High
	I Health & Safety					
	II Community					
	III Environment					
	IV Cost					
LIKELIHOOD						
Index	**Events/Year**					
5) Probable	**>1**					
4) Likely	**1 - 1/10**					
3) Possible	**1/10 - 1/100**					
2) Unlikely	**1/100 - 1/1,000**					
1) Rare	**1/1,000 - 1/10,000**					

Increasing Risk

5.3.5 Risk Ranking

Following the identification and measurement of risks, they are evaluated and ranked to assist with risk management decisions. The evaluation of risk requires determining the acceptability of risk as defined through the different locations (or risk values) within the risk matrix.

The risk matrix shown in Figure 5.1 was divided into four groups representing different ranking levels of risk. These are the same groups as shown previously in the generic example presented in Figure 3.1. The groups are color coded from lower risk Green to Yellow to Orange to highest risk Red. These risk-ranking levels correspond to the YTG expectations for the mine company to manage environmental risk associated with their closure plans. A summary of suggested YTG expectations is presented in Table 5.3.

Table 5.3
Risk Ranking and Management Actions

Risk Level		Management Action
(red)	Highest	Action required. More detailed risk analysis may be required. YTG and mine company agreement required to accept risk if not mitigated. For total costs category, potential impacts for financial assurance funding will be assessed.
(orange)	High	Assess risk mitigation options and reduce risk before closure, where practical. Prioritize resources to manage these risks before Moderate or Low ranked risks. More detailed risk analysis may be required
(yellow)	Moderate	Assess risk mitigation options and reduce risk before closure, where practical.
(green)	Low	Monitor risk to ensure it does not creep up during mine life.

6. IMPLEMENTING A RISK ASSESSMENT PROGRAM AT THE YTG

6.1 Program Objectives

As described in Section 1.2, a risk-based approach to evaluating mine reclamation and closure plans is being considered by the YTG in order to implement a systematic and documented process that achieves the following objectives:

- identification of site-specific risks;
- estimation of risks in terms of their likelihoods and consequence severities;
- identification of uncertainties; and
- consideration of risk management measures where appropriate.

A Systems FMECA method for carrying out the closure plan evaluation was described in this report. The overall objective of the YTG risk assessment program is to implement this standardized Systems FMECA in evaluating mine reclamation and closure plans.

6.2 Program Outline

The following program elements are proposed in a phased approach to implement an effective risk management program at the YTG:

- YTG review of this report describing the Systems FMECA approach;
- Golder presentation of the report to key YTG personnel including feedback and discussion of the process, the standardized risk matrix and the implementation program.

  This presentation could include an overview summary for senior personnel followed by a detailed presentation for those interested in:
  - Golder facilitation of a demonstration workshop for the YTG. YTG would select case studies that represent a range of applications such as:
    - operating mine near closure;
    - abandoned mine with no owner; and
    - closed mine.

- YTG selection of a risk program manager(s) and potentially a risk consultant to provide implementation support. YTG decision on the appropriate method for carrying out risk assessments of closure plans (mining company, YTG consultant, YTG staff, other arrangement);
- incorporation of the risk assessment basis into the Technical Guidelines of the Yukon Mine Reclamation and Closure Policy;
- YTG role out of the Technical Guidelines (with the risk assessment basis) to stakeholders (public and industry);
- review of stakeholder feedback;
- evaluation of a mine reclamation and closure plan(s) using the new Technical Guidelines; and
- regular management review (and update) of the YTG risk assessment program.

A schedule to implement the above program elements would depend on YTG priorities however, a possible timeline for the first three elements could be as follows:

1. YTG review	2 weeks following receipt of final Golder report
2. Golder presentation	1 week following authorization, ½-1 day in Whitehorse
3. Demonstration workshop	2 weeks following authorization (allowing for preparation), can be combined with the Golder presentation, 1-2 days for workshop depending on most effective format for the YTG.

6.3 Cost Estimate

Preliminary costs in terms of manpower for both the YTG and a support consultant were estimated for implementing the above proposed elements of a YTG risk assessment program. These manpower estimates are listed in Table 6.1.

Table 6.1
Manpower Estimate for Implementing a Risk Management Program

Risk Program Element	Consultant Manpower	YTG Manpower
1. YTG Review		2-4 hours per person
2. Presentation	*Preparation* Senior consultant -2 days Support -2 days *Presentation* Senior consultant 2 days	*Presentation* Senior personnel -½ day each Risk personnel -1 day each
3. Workshop	*Preparation* Senior consultant -5 days Support -2 days *Session* Senior consultants (2) -2 days (travel expenses)	*Preparation* Risk personnel -5 days Support -1 day *Session* Risk personnel -1 day each Stakeholders -to be determined
4. YTG Manager		YTG action
5. Guidelines	*Review* Senior Consultant -4 days	*Reporting* YTG action
6. Program Roll Out	*Support as needed*	*Communication Plan* YTG action
7. Feedback	*Support as needed*	YTG action
8. Closure Evaluation	To be determined	To be determined
9. Management	*Support as needed*	YTG action

6.4 Recommendations

The following recommendations for implementing a risk assessment program at the YTG were developed based on experience of the study authors:

- Many different people operating in different functions at the YTG are involved in mine closure review and a common understanding of the risk management approach for the YTG Closure Policy is essential. An internal communications plan is recommended to address the varying expectations and understandings.
- A presentation and internal discussion of the Systems FMECA risk assessment method is recommended to kick-off the internal communication plan.
- A hands-on workshop for YTG personnel who may be involved in any aspect of reviewing mine closure plans is recommended. A workshop format provides an

effective demonstration of how the Systems FMECA is applied and the value of results for managing risk.

- A stakeholder communication plan for the Closure Policy (and Technical Guidelines) is recommended to engage those affected by the policy. A transparent process with an on-going communication strategy will facilitate an effective implementation.
- Use of visual presentation material is recommended for describing the Systems FMECA process in the Technical Guidelines. Risk and its management are usually expressed differently by most everyone and therefore a common language that is easy to understand is essential to the success of the program.
- A dedicated risk program manager in the YTG is recommended with responsibilities for assuring program quality, implementing the communication plan (internal and external) and managing continuous improvements. The process for carrying out risk assessments needs to be drafted based on YTG policies. This process would define who should facilitate the Systems FMECA and suggest how to involve public, industry and government stakeholders.
- Although technical personnel may carry out the initial risk assessment, it is recommended to have a process to involve representation from all stakeholders.
- A phased approach for using risk assessment in the evaluation of closure plans is recommended to allow all stakeholders to participate and understand the benefits. For example, a parallel process may be used for the first evaluation or some other adaptation to phase in the new with the known approach.

7. REPORT AUTHORS

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8. REFERENCES

Australian/NewZealand Standard. 2004. Risk Management. Standards Australia International Ltd. and Standards New Zealand.

BC Environment. 1993. Human Health Risk Assessment Guidance for Contaminated Sites. Phase 1 – Review of Risk Assessment Methods. Industrial Wastes and Hazardous Contaminants Branch. Prepared by Golder Associates Ltd..

Canadian Standards Association. Oct. 1997. Risk Management: Guideline for Decision-Makers.

Center for Chemical Process Safety of the American Institute of Chemical Engineers. Guidelines for Hazard Evaluation Procedures, 2nd Edition, New York, NY: 1992.

Companion to AS/NZS 4360:2004. 2004. Risk Management Guidelines. Standards Australia International Ltd. and Standards New Zealand.

Golder Associates Ltd. Rational and Key Steps for Conducting Human Health and Ecological Risk Assessments in the Mining Sector for British Columbia. Dec. 2003.

Health Canada. Human Health Risk Assessment Framework. Unpublished,1994

HWC (Health and Welfare Canada). 1994. Human Health Risk Assessment of Chemicals from Contaminated Sites Volume 1 Risk Assessment Guidance Manual. Draft prepared on January 31, 1994. Prepared for Health and Welfare Canada. Prepared by Cantox Inc. and Golder Associates Ltd.

ISO. IEC. Guide 73. 2002. Risk Management – Vocabulary – Guidelines for use in standards.

The Mining Association of Canada. Sep. 1998. A Guide to the Management of Tailings Facilities.

USEPA. 1992. Ecological Risk Assessment Framework.

U.S. EOA. 1998-1999. Risk Assessment Guidance for Superfund. Volume I. Human Health Evaluation Manual. Parts A to D. Interim Final. Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. EPA/540/1-89/002. (Including Supplemental Guidance).

APPENDIX I

CHECKLIST FOR DECOMMISSIONING AND CLOSING A TAILINGS FACILITY

Checklist for Decommissioning and Closing a Tailings Facility

(A Guide to the Management of Tailings Facilities, The Mining Association of Canada, 1998.)

Management Action	Responsibility	Performance Measure	Schedule	Technical Considerations	References
POLICY AND COMMITMENT					
Decommission and close the tailings facility in such a manner that all remaining dams and associated structures are safe and stable. All solids and water will be managed within the area designated in the closure plan, and in compliance with company standards, the MAC Environmental Policy, the MAC tailings management framework, legislative requirements and commitments to stakeholders.					
Consult external stakeholders on the tailings facility closure and decommissioning plan, and incorporate where feasible stakeholder views/ expectations.					
Establish an ongoing program of review and continual improvement.					
PLANNING ***Roles And Responsibilities***					
Identify prime responsibility for implementing this component of the tailings management framework.					
Assign a project manager responsible for the overall decommissioning and closure of the tailings facility.					
The project manager will ensure responsibilities are assigned for:					
▪ completion of development of the tailings facility closure plan and cost estimate;					
▪ obtaining approvals;					
▪ tailings facility decommissioning and closure;					
▪ emergency preparedness;					
▪ construction;					
▪ long-term maintenance;					
▪ ongoing support for monitoring, geotechnics, hydrology, hydrogeology, chemistry, impact assessment and revegetation;					
▪ financial assurance; and					
▪ communications and stakeholder consultations.					
Objectives					
Close the tailings facility in conformance with design, and to:					
▪ meet legal requirements, operating licences, legislation, policies, codes of practice and commitments to stakeholders;					
▪ effectively enable surrender of the land or transfer to non-mining use consistent with regional land-use					

Management Action	Responsibility	Performance Measure	Schedule	Technical Considerations	References
objectives or approved uses, or provide for long-term care and maintenance;					
▪ ensure long-term stability of dams and related tailings facilities;					
▪ protect public health and safety;					
▪ minimize adverse environmental impact; and					
▪ achieve the specified technical performance and decommissioning financial requirements.					
Establish an appropriate process of external stakeholder consultation for land-use and public accessibility issues.					
Planning For Closure					
Prepare detailed plans for implementation of closure:					
▪ revisit the approved design;					
▪ identify “new” environmental concerns that have become apparent through operations since the design was approved;					
▪ identify potential environmental impacts that may be caused by the implementation of closure;					
▪ review alternative technology for closure;					
▪ review performance of progressive reclamation to date;					
▪ develop a detailed monitoring and surveillance plan to verify that closure meets objectives;					
▪ detail items to be documented and reported; and					
▪ outline the long-term care and maintenance requirements, including maintenance requirements for dams, hydraulic structures and appurtenances, revegetation, erosion control and treatment systems					
Obtain all permits, licences and approvals required.					
Establish required financial assurance.					
Establish responsibility for long-term care and maintenance.					
Provide rehabilitation work schedule for facilities no longer required.					
Develop a plan to control contaminant release.					

Management Action	Responsibility	Performance Measure	Schedule	Technical Considerations	References
Ensure that final land-use issues are determined (e.g. restoration for recreation, agriculture, forestry and wildlife habitat, commercial / industrial use or residential) in consultation with stakeholders.					
Ensure that inherent dangers and hazards are identified and mitigative measures developed.					
Managing Risk					
Conduct a comprehensive risk assessment for decommissioning and closure to:					
▪ evaluate the risks associated with possible failure modes;					
▪ identify possible impacts on the environment, health and safety;					
▪ determine parameters critical to these failure modes and possible impacts; and					
▪ develop control strategies to manage the identified risks.					
Develop, test and maintain detection, emergency preparedness and response plans.					
Managing Change					
Prepare procedures to identify and document changes made to approved plans and procedures for decommissioning and closing the tailings facility.					
Resources And Scheduling					
Determine required resources and schedule for decommissioning and closure of the tailings facility, or alternately for long-term care.					
Develop detailed closure budget estimates and schedule for:					
▪ decommissioning/ rehabilitation/ closure by activity; and					
▪ monitoring the closure.					
Assess the adequacy of the closure financial assurance.					
IMPLEMENTING THE PLAN ***Closure Control***					
Decommission and close the tailings facility as per detailed closure design and plans.					
Obtain approvals and permits.					
Implement management control to:					

Management Action	Responsibility	Performance Measure	Schedule	Technical Considerations	References
▪ review the progress of the work;					
▪ ensure that work meets design and plan specifications;					
▪ identify deviations from the plans, schedule and budget; and					
▪ approve modifications to the design and plans.					
Implement a preventive maintenance schedule and reporting system.					
Assign responsibility for long-term care and maintenance, including emergency response and communications plans.					
Financial Control					
Implement financial control measures and project cost schedule for tailings facility decommissioning and closure.					
Documentation					
Implement a documentation management procedure to ensure that all appropriate documents are prepared, maintained and kept accessible, including:					
▪ submissions to regulatory agencies;					
▪ training records;					
▪ Quality Assurance / Quality Control reports, construction reports, photos, videos, etc.;					
▪ monitoring results;					
▪ unusual or special conditions; and					
▪ as-built drawings for closure.					
All deviations from the closure plan requirements should be recorded.					
Prepare reports and reviews on the progress of the closure as required.					
Prepare and retain final as-built drawings and construction reports.					
Competency					
Assign qualified personnel to decommission and close the tailings facility, or alternately for long-term care.					
Review competency and identify trainings needs.					
Provide appropriate training, including health, safety and environmental aspects.					
Implement a program for monitoring physical and environmental stability during and after the closure period.					

Management Action	Responsibility	Performance Measure	Schedule	Technical Considerations	References
Monitoring					
Perform routine inspections to ensure conformance of implementation with the closure plan.					
Communications					
Establish and maintain reporting procedures on implementing the closure plan, and effectiveness of the closure plan.					
Establish and maintain communications within the organization.					
Establish and maintain communications with external stakeholders.					
CHECKING AND CORRECTIVE ACTION ***Checking***					
Perform a comprehensive inspection and review to measure effectiveness of the closure against designed performance measures.					
Corrective Action					
Develop action plans, and implement and record corrective action to address non-conformance items identified through routine and/or periodic inspections and reviews.					
MANAGEMENT REVIEW FOR CONTINUAL IMPROVEMENT					
Conduct regular reviews of the management framework for closure.					
Assess the adequacy of the management framework for long-term care.					