Proceedings of the 15th Annual British Columbia Mine Reclamation Symposium in Kamloops, BC, 1991.
The Technical and Research Committee on Reclamation

The Role of Environmental Risk Assessment in the Mining Project Review Process

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Abstract

The practice of assessing risks arising from engineered system failure has evolved over the past several decades in both the nuclear and aerospace industries. It is only relatively recently, however, that similar efforts have been afforded to assessing the potential risks to the environment of resource development projects, including mining. It is argued that this relatively novel application for systematically reviewing the risks of system failure and their associated environmental consequences, or *Environmental Risk Assessment,* has evolved in response to several compelling issues. Among these are the need to respond to the increasingly stringent regulatory framework designed to protect the environment, and to distill from the multitude of concerns associated with resource development the key project-related risks that merit particular consideration in the project review process. One method for applying environmental risk assessment to a proposed mining project, along with the attendant benefits of so doing, is discussed herein.

Key Words Environmental risk assessment, system failure, Failure Modes and Effects Analysis, Event Tree Analysis, Fault Tree Analysis, project review process.

Introduction

Risk assessment incorporates two predictive aspects: how frequently might an undesired event be expected to occur, and how bad might be the expected consequence. In other

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words, it includes a combined assessment of the consequences of undesired events and the probabilities of their outcomes.

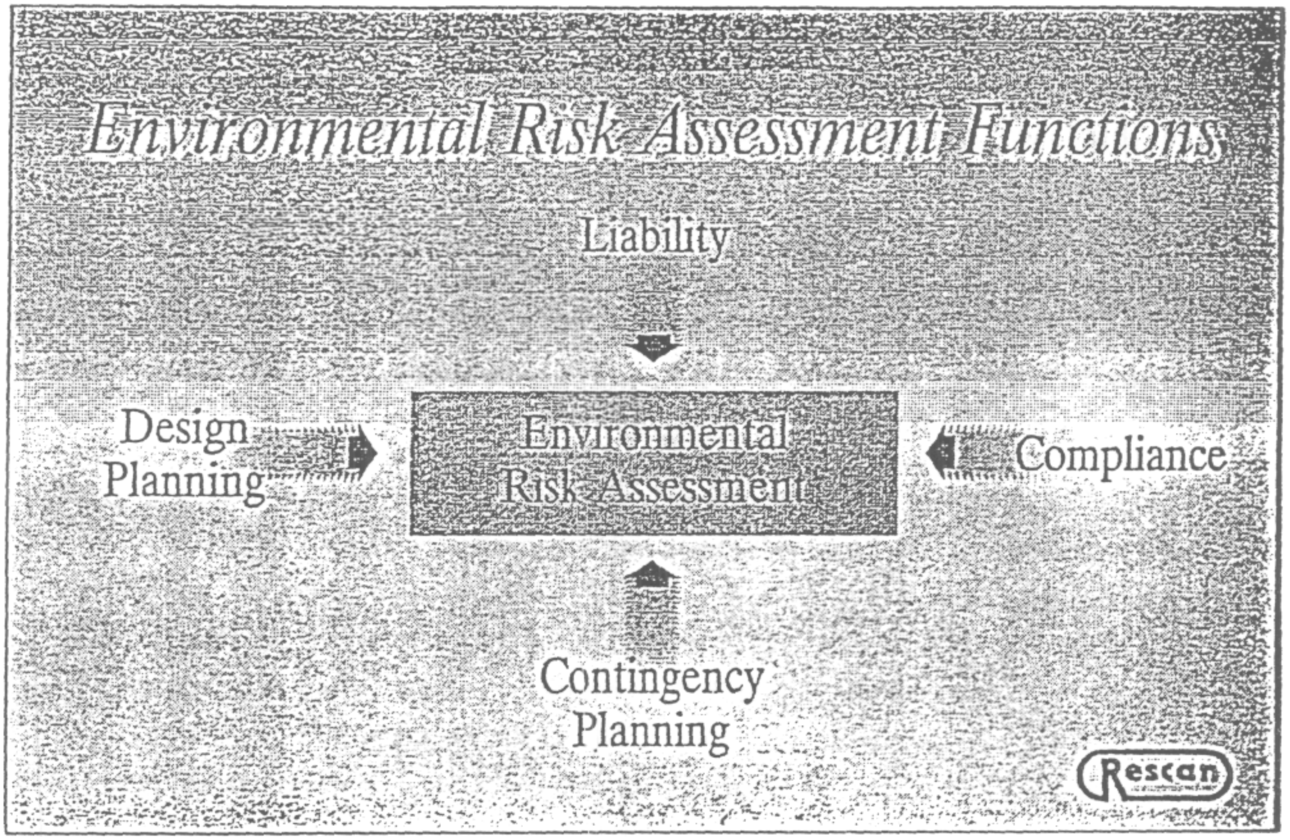
The use of structured environmental risk assessment (ERA) for mine development review is in the early stages of evolution in comparison to its use in such fields as nuclear and aerospace engineering. This is partly due to the heterogeneous nature of the environment potentially affected by resource development projects and partly due to the lack of any established database for failures of components used in mining systems. Yet ERA promises to become increasingly more important in the project review process because it can be used to prioritize the importance of key engineering systems to accompany project development and to estimate the risks to the environment associated with their potential failure.

It should be noted that an ERA can only represent the best professional judgment of the experts assigned to the task. Hence it holds no guarantee that undesired events can be prevented from occurring. Likewise, we note that risk assessment review is not an easy process because it is open to conflicting interpretations by different organizations and individuals. This notwithstanding, ERA provides a unique forum for rigorous, objective, multidisciplinary review of potential project-related risks and is of benefit both to regulators charged with environmental protection and proponents seeking to focus on key issues associated with gaining mine development approval.

The purpose of this paper is to introduce the general principles of ERA and its application to the mining community, and to illustrate some typical results from such an exercise. One of the innovations proposed herein is the emphasis on recognizing the uncertainties associated with using best professional judgement in a risk assessment. By incorporating qualitative confidence factors for the estimates of the consequence of an undesired event and its likelihood, proponents and government regulators are less likely to arrive at poor decisions based on judgements lacking in foundation. As demonstrated, a well-executed ERA can contribute to a better-designed, better-operated project with less inherent risk of environmental disruption.

Environmental Risk Assessment Functions

In essence, the ERA is a systematic review of all project-related risks with respect to potential failure of engineered systems and their associated effects on the natural environment. It thus incorporates such factors as design planning, liabilities associated with system failure, contingency planning and compliance with permitted project requirements.



A principal function of the ERA is to distill the often voluminous amounts of data submitted in support of project development to those risks critical to effective environmental management and ultimate project approval.

Typical Mining Project Risks

Risks associated with the development and operation of a proposed mine will vary greatly from project to project, depending upon such factors as type of operation (e.g. underground vs. open pit), the mineral being extracted, milling process, tailings storage, waste management systems, acid rock drainage potential, transportation corridors and, perhaps most importantly, the natural environment characterizing the proposed project location.

Provided below are some typical risks associated with the proposed development of a large-scale, open pit gold project. They were identified and evaluated during a risk assessment of the proposed operation and are advanced to demonstrate the types of factors considered as part of an ERA, In total over fifty distinct project-related risks were identified during the review. Twelve were considered to have potentially significant consequences combined with relatively high probabilities of occurring.

Typical risks might include the following:

Transportation Corridors

- Accidents resulting in fuel/chemical spills
- Off-loading accidents resulting in toxic reagent spills
- Sediment erosion harming fisheries

Mine Site

- Underestimated or unanticipated acid rock drainage problems
- Water treatment system failure (e.g. sedimentation ponds/water treatment plant)

Mill/Tailings Area

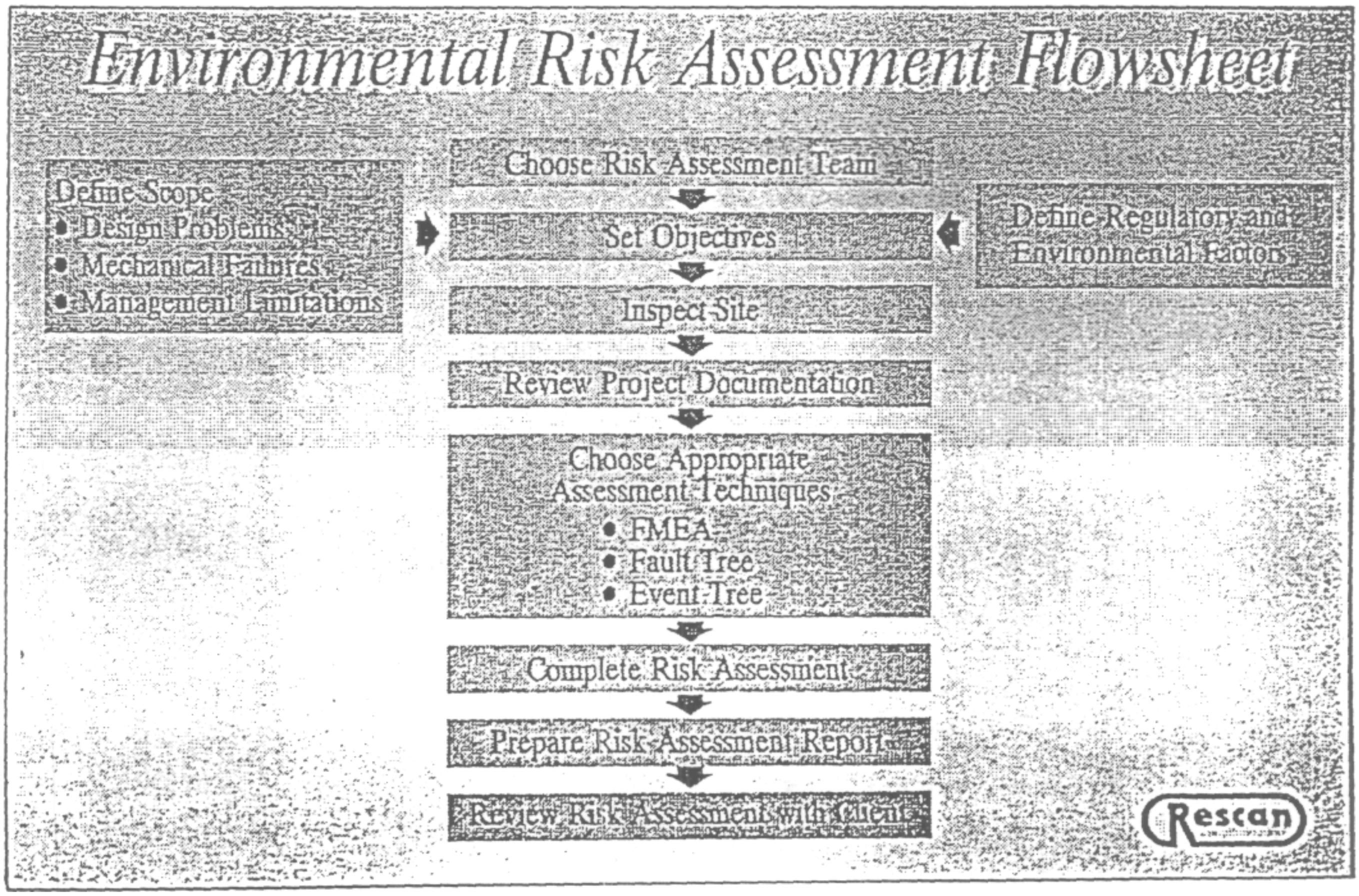
- Waste treatment plant failure
- Reagent/chemical spills
- Tailings line rupture or release
- Tailings impoundment or spillway failure

The above represent only a select subset of the potential risks associated with project development but serve to demonstrate the need for a systematic review of potential risks to help ensure development proceeds with the least chance of system failure and subsequent environmental disruption.

Procedures for Completing Environmental Risk Assessment

A typical mining project ERA will require four to six weeks for completion encompassing all necessary tasks from assembling a qualified ERA team to completing a site investigation and applying formal ERA techniques to submitting the ERA Report.

The elements of an effective ERA, in flowsheet format, are illustrated below.



Choosing Environmental Risk Assessment Team

The selection of a qualified ERA team is fundamental to its success. For most mining projects, the following expertise should be represented: mining and metallurgy, geotechnical engineering, environmental engineering, hydrology/hydrogeology and environmental and biological sciences.

An individual experienced with risk assessment techniques is critical to guide the overall project and ensure the necessary analyses are completed within the risk assessment framework. Depending upon the nature of the project, other specialists (e.g. an acid rock drainage or cyanide disposal expert) may be beneficial to the assessment and can be recruited as required.

Set Environmental Risk Assessment Objectives

In setting objectives for the ERA, both the scope of the study and the regulatory and environmental factors governing project development must be carefully considered. The scope of the risk assessment considers the key factors of the proposed operation including design effectiveness, potential mechanical failures, and management limitations.

A review of design effectiveness requires evaluating the adequacy of project and contingency planning and identifies weaknesses that may lead to system failure. Potential mechanical failures are perhaps the most easily reviewed as mechanical systems are usually illustrated diagrammatically and their reliability can often be based on design specifications and past performance.

Management limitations refer to the overall commitment to ensuring the project is operated in a setting that minimizes the risk of system failure and potential environmental disruption. The regulator}' requirements governing project development also factor into setting the risk assessment objectives. A fundamental risk associated with new or existing projects, from a retaliatory standpoint, is that the operation will experience a system failure that causes it to exceed permit requirements, thereby threatening the integrity of the surrounding natural environment. The importance of understanding key environmental factors associated with the project is thus essential.

Inspect Site and Review Project Documentation

Among the most fundamental steps in the; ERA is the site inspection of the proposed operation and review of critical project documentation. It is this exercise that provides a foundation for understanding the risks associated with project development Failure to witness a parameter of critical environmental concern or potential design flaw while in the field, could be equally detrimental to the ERA as the unavailability of a key document describing the proposed project with respect to design of engineered systems and their intended means of operation. Generally, the site inspection is best attended by a team member well-versed in the technical components of the project along with one familiar with its environmental setting. These members report their findings to the remaining ERA team which then focuses its attention to documentation such as environmental impact statements and! other reports filed in support of the project

Choose Appropriate Risk Assessment Techniques

There are a variety of techniques available to those performing an ERA Three, which have been found to be particularly suited to proposed mining projects include Failure Modes and Effects Analysis, Event Tree Analysis and Fault Tree Analysis.

Briefly, Failure Modes and Effects Analysis (FMEA) provides a structured approach for identifying dominant contributions (failure modes) to an undesired event.

Event Tree Analysis is an inductive lojgic approach that requires identifying a potential initiating event, such as a pipe failure, and systematically examining all of the different possible sequences which might lead to a more serious undesired event (i.e. system failure).

To complete a Fault Tree Analysis one uses a deductive logic approach whereby an undesired event (e.g. system failure) is identified and then, working backward, all of the different possible course that could lead to the event are examined.

The type or combination of ERA techniques best suited to any particular application is largely a function of the type of project data available. Each of the above techniques are described in fuller detail below.

Complete Environmental Risk Assessment

Once the appropriate techniques for completing the assignment are selected the formal ERA can be completed. Depending upon the magnitude and complexity of the operation, and the receiving environment potentially affected, the ERA will normally require four to seven days to completely îinalyze all pertinent project data, including that gathered during the site investigation. For example,- a recently completed ERA for a large-scale, open pit gold project which generated over 2,500 pages of Environmental Impact Assessment data required five days for complete evaluation, not including the site investigation or project reporting.

A workshop method has been found to be the most effective means of completing an ERA It reduces the potential for overlooking critical project-related risks and subjects the participants' judgements to rigorous analysis from a diversity of perspectives. This has the benefit of reducing individual prejudices compared to reviews completed in isolation. During the workshop, participants debate their viewpoints until consensus is reached over each key issue addressed.

Prepare Environmental Risk Assessment Report

Upon completing the ERA, all results !including FMEA, Event Tree and Fault Tree Analyses must be completely documented. The ERA Report is the final compilation of the study findings and will help steer the project approval process by focussing regulators and proponents alike on key items requiring careful attention. It must therefore be well conceived and clearly expressed.

Owing to the possibility that the ERA Report will be subject to public scrutiny, it is often first prepared in draft and is confidential for client review and comment prior to being produced in final form and filed with regulatory agencies. Conversely, we are often commissioned to complete an ERA for internal project planning purposes only and the report is never submitted for government review. In either event, the need for clear communication of the ERA findings cannot be overstated.

Review Environmental Risk Assessment with Client

Whether the ERA is prepared for facilitating the project approval process or for internal design and planning purposes, it is critical that an opportunity be taken to discuss the ERA Report with the consultant to correct any misperceptions and address any unresolved issues.

Environmental Risk Assessment Techniques

Discussed only briefly above, this ,section elaborates on the techniques particularly suited for completing ERA on proposed mining projects: FMEA, Event Tree and Fault Tree Analyses. Of the three, FMEA and Fault Tree Analysis most lend themselves to mining project applications and are thus considered in fuller detail.

Failure Modes and Effects Analysis

A Failure Modes and Effects Analysis (FMEA) is a structured approach for constructing a table that identifies dominant contributions to an undesired event Such an event can be naturally occurring (e.g., an "act of God" such as an earthquake) or it can be initiated by the failure of a system; a system failure can be initiated by one or more failure modes (e.g., a valve fails to properly open or it is plugged, or it fails to properly close or it is ruptured). Since it is virtually impossible to guarantee that every conceivable failure mode can be identified, those failure modes leading to inconceivably low risks should be eliminated.

A FMEA, as a form of preliminary analysis, is a logical first step in identifying environmental concerns, but can only approximately account for possible follow-up actions such as is done during Event Tree Analysis. A FMEA represents a conservative first assessment of potential environmental damage resulting from a project, and does not take full credit for beneficial actions that might be taken to mitigate the consequences. However, if a FMEA *does* not consider positive recovery actions, it also does not include possible detrimental recovery actions, such as human errors that sometime occur during system(s) failure.

This conservative FMEA approach is appropriate because of the possibility that some environmental damage associated with mining projects may never appear until many decades or centuries in the future. It is also conservative since it accounts for situations in which adequate mitigating actions cannot be taken by the proponent for other reasons. Thus, a FMEA represents a worst case scenario for consequences, instead of a less conservative estimate which assumes that the developer can accomplish one or more of the mitigating actions that have been identified or other mitigating actions not expressly identified.

The dominant failure modes of systems and the potential effects on environmental quality caused by the failures are identified. The consequences of those effects can be placed in one of four categories according to severity, as shown below. Potential failure modes with minor consequences and unlikely chances of occurring often are not subjected to detailed analysis.

Consequence Categories Used For Failure Modes and Effects Analysis

Category	Description	Effect on Environment
I	Safe	Negligible effect on environment.
II	Marginal	Failure will degrade environment to some extent, but will not cause major or long term damage.
III	Critical	Failure will degrade environment and, if action is not taken, major or long term damage will occur.
IV	Severe	Failure will produce severe environmental degradation.

The uncertainty in the estimation of a consequence can be given in the form of a consequence confidence factor using *the* categories defined below and represents an intuitive measure of the variance in the magnitude of a consequence.

Confidence Factors Used For Failure Modes and Effects Analysis

CATEGORY	PERCENT CONFIDENCE IN ESTIMATE
Low	Less than 20%
Medium	20% to 80%
High	Greater than 80%

The expected frequency of an event is the second aspect of risk. For mine projects, five categories of likelihood are proposed as defined below. It is essential to assign broad probability ranges to failure likelihood categories in order to ensure consistency in likelihood estimates among the team members conducting an ERA. Corresponding frequency descriptors can be assigned for convenience of discussion by defining "negligible" for the lowest likelihood, "significant" for the highest, and other descriptors within these limits according to how they might be interpreted by a non-technical reviewer. However, such descriptors may convey an unintended bias unless related to their defined probability ranges. For example, an event having a l-in-10 to l-in-100 chance of occurrence may seem by some measures to be far less likely than the term "moderate" might imply. An event in the "moderate" category is one that has good potential (10% to 70% chance) of occurring during a 10-year project lifetime, while an event in the "significant" category can be expected to occur at least once during the active stages of the project (70% chance).

Likelihood Categories Used For
Failure Modes and Effects Analysis

CATEGORY	EXPECTED LIKELIHOOD	ANNUAL CHANCE OF OCCURRENCE
Negligible	Less than 10^{-6}/yr.	1:1,000,000
Very Low	10^{-6}/yr. to 10^{-4}/yr.	1:1,000,000 to 1:10,000
Low	10^{-4}/yr. to 10^{-2}/yr.	1:10,000 to 1:100
Moderate	10^{-2}/yr. to 10^{-1}/yr.	1:100 to 1:10
Significant	Greater than 10^{-1}/yr.	Greater than 1:10

To address the uncertainty associated with estimates of expected frequency, a likelihood confidence factor that represents an intuitive measure of variance in the magnitude of a frequency can be used to estimate the expected failure likelihood, based on the categories defined above.

For each dominant failure mode identified in a FMEA, the risk assessment team should also consider the compensating factors that could influence the final outcome following an undesired event. These include both natural processes and design measures proposed to mitigate either the likelihood or consequences of system failure. In addition, compensating factors include possible mitigative responses to certain accident-initiating events that would be taken according to prudent and responsible operating practice. Such compensating factors involve changes in a project or its operation to mitigate the damage from the event, but could be performed if necessary. Hence, compensating factors informally acknowledge both planned and unplanned backup systems.

A simplified FMEA demonstrating two possible failure modes with respect to a proposed tailings impoundment is illustrated below.

Failure Modes and Effects Analysis

System	Dominant Failure Mode (s)	Effects on Environmental Quality	Consequence (I, II, III, IV)	Consequence Confidence Factor (Low, Medium, High)	Failure Likelihood (Negligible, Very Low, Low, Moderate Significant)	Failure Likelihood Confidence Factor (Low, Medium, High)	Compensating Factors
Tailings Impoundment	Impoundment goes acidic due to improper prediction of waste rock acid generation	Potential acid release to groundwater in Project Creek drainages	II	Medium	Moderate	Medium	Closed system during operation Low tailings permeability would reduce extent of desaturation zone
	Excessive tailings dam seepage produces desaturation of mine waste in impoundment, resulting in AMD	AMD release to Project Creek surface waters	III	High	Low	Medium	Extremely thorough foundation exploration and construction control

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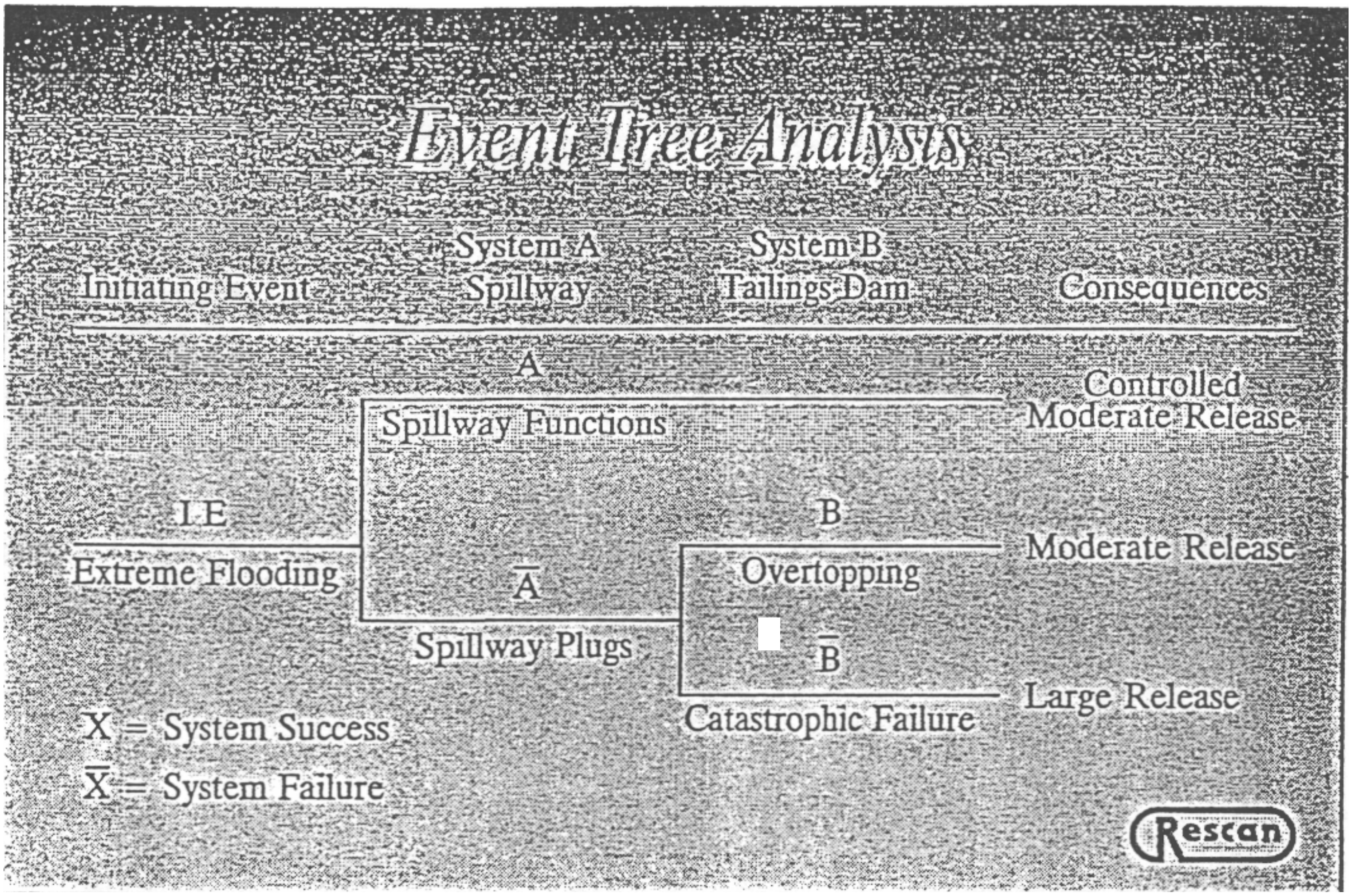
Event Tree Analysis

Event Tree Analysis can complement FMEA and Fault Tree Analyses as a formal component of an ERA. The simple analysis for an extreme flooding event shown below serves as an example. Such an approach is appropriate when considering a more detailed consequence assessment that incorporates the success and failure of actions taken to mitigate the consequences of an initiating event that could potentially result in environmental damage.



Fault Tree Analysis

Fault Tree Analysis is a method that works best on a proposed facility for which piping and line diagrams are complete. In constructing a fault tree, the undesired system failure that is to be studied is labelled the top event. Successive subordinate (i.e. subsystem) failure events that may contribute to the occurrence of the top event are then identified and linked to the top event by Boolean algebraic connective operations (i.e. AND and OR gates). The subordinate events themselves are then broken down to their logical contributions and, in this manner, a failure tree structure is created. The key to constructing a fault tree is to mentally work backward in time by asking the question, "What could have caused this event?"

Typical causes of failure for an operating subsystem might include the following:

- Failure of the device itself, accounted for by each of its appropriate modes of failure;
- Failure of the operator, typically caused by improper operating procedures and errors of omission, commission or maintenance during operation;

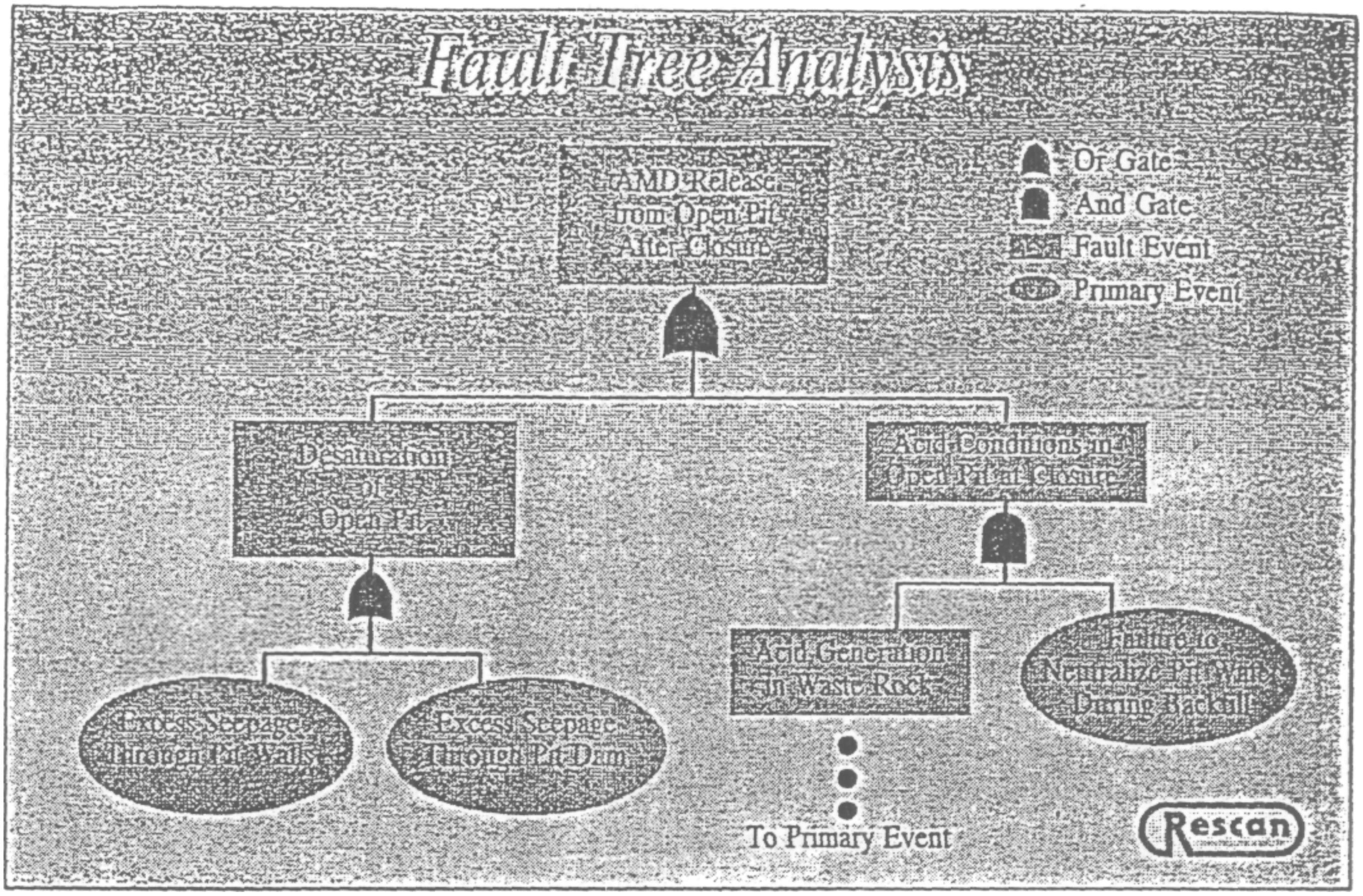
- Failure of an input to the component (e.g. failure of a fluid to flow to a pump or a current to an electrical component); and/or
- Occurrence of an external event that prevents operation of the device, such as a common cause failure (e.g. the possibility of an earthquake is a prime candidate for a common cause failure).

Failures can also arise during testing and maintenance, when a subsystem is "not in operation, and can be included in the tree structure by means of INHIBIT gates.

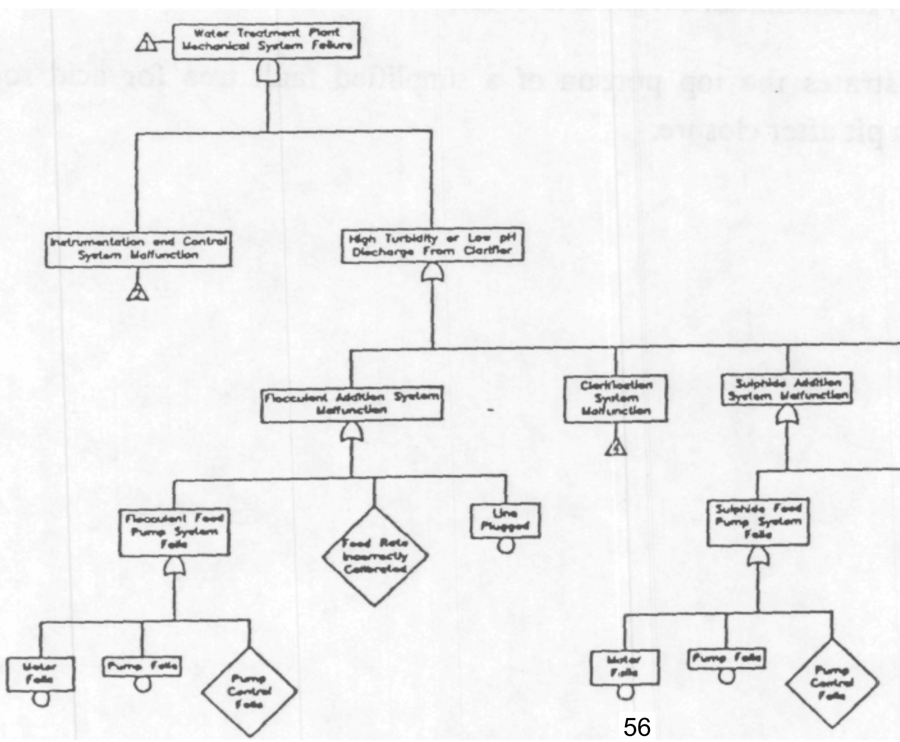
When a contributing failure event can be divided no further, or when it is decided to limit further analysis of a subsystem, the corresponding branch is terminated with a basic event. A basic event is a primary fault event if the subsystem could fail because of a basic mode such as a structural fault, or failure to open or close or to start or stop; a basic event is a secondary fault event if the subsystem is out of tolerance so that it fails because of excessive operational or environmental stress placed on the subsystem.

Once any preliminary fault tree has been constructed, it can be qualitatively evaluated by Boolean algebra to reduce the tree to its logically equivalent form in terms of "minimal cut sets". Each minimal cut set is a combination of specific primary fault events sufficient to cause the undesired top event to occur. The number of primary fault events in a minimal cut set serves as one type indicator of the weak points of the system: the greater the number of fault events required to cause the undesired top event, generally the less likely the minimal cut set is to occur.

The figure below illustrates the top portion of a simplified fault tree for acid rock drainage from an open pit after closure.



For complicated mining operations a fault tree may require tens or even hundreds of gates. In such cases, the tree structure is developed using triangle symbols to indicate that the fault tree is a part of another tree or that one or more additional tress are needed to complete the diagram. An example of the top of a fault tree to analyze mechanical system failures for a mine water treatment plant component is provided below.



Mine Water Treatment Plant Fault Tree: Mechanical System Failure

Elements of an Effective Environmental Risk Assessment

The combination of techniques chosen to complete an effective ERA will vaiy with the nature of project being considered; the elements of an effective ERA will not Regardless of circumstances, an effective ERA will incorporate the following critical elements:

- Multidisciplinary expert participation blending technical and managerial expertise, guided by an experienced risk assessor;
- An objective forum for the ERA team to interact;
- Well defined ERA scope and objectives;
- Management commitment by the proponent to ensure the ERA team is fully informed of project development plans; and
- Thorough, accurate and clear reporting of ERA findings.

Conclusion

An Environmental Risk Assessment and its review can lead to a definition of both technical and management-related issues which can improve the design and operation of a project. This is especially the case if, during the ERA, a workshop is held so that participants are less likely to overlook important risks and are required to defend their judgements during critical review by other ERA participants.

The experience we have gained from participating as external evaluators of risk associated with project development enables us to conclude that the following benefits are likely to result from a well-conceived, thoroughly completed ERA:

- A voluminous amount of project-based data can be distilled to those potential risks fundamental to the effective design and operation of the proposed development.
- Key risks associated with project development can be ranked to provide both proponents and regulators a foundation to focus on potential fatal flaws.
- Project planning efforts can be improved in a proactive fashion, limiting the potential for negative regulator/public scrutiny.

- The mine project review process can be facilitated by focussing on key issues critical to gaining development approval and avoiding costly project delays.

In summary, it is demonstrated that the benefits of a well prepared Environmental Risk Assessment are many. In this era of increased regulatory control, ERA represents perhaps the most cost-effective means of avoiding unnecessary project delays and demonstrating a responsible corporate attitude toward resource development