Qualitative Environmental Risk Assessment Applied to the Proposed Windy Craggy Project

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Abstract

The concept of risk incorporates two predictive aspects: how frequently might an event be expected to occur and what might be the attendant consequences if it should? Environmental Risk Assessment (ERA) is gaining increasing acceptance as a valuable and systematic method for addressing these questions, as regards matters environmental, and has evolved in response to several compelling issues. Among these are the need to respond to the stringent regulatory framework governing project development and to distill, from the multitude of concerns associated with mine development, the key environmental risks requiring particular consideration. It is the latter function of ERA that is viewed as especially beneficial by both mining companies and government regulators alike. By identifying the elements of project design that pose key risks, due to various uncertainties, recommendations can be made to manage and reduce them as the project is developed, operated and, ultimately, abandoned.

This paper outlines the results of a Qualitative Risk Assessment completed on the Windy Craggy Project proposed for development in northwestern British Columbia. Special attention is afforded to post-closure reclamation considerations.

INTRODUCTION

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. 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 mine development and ultimate closure and reclamation.

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 judgment in completing 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 judgments lacking in foundation. As demonstrated, a well-executed ERA can contribute to a better-designed project with less inherent risk of environmental disruption during operations or abandonment.

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. Risk assessment incorporates two predictive aspects: how frequently might an undesired event be expected to occur and with what attendant consequences? 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, operation and eventual closure 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 project location. Outlined below are some typical risks associated with mine development.
Transportation Corridors

- Accidents resulting in fuel/chemical spills
- Off-loading accidents resulting in toxic reagent spills
- Sediment erosion affecting aquatic resources

Mine Site

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

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 small subset of the potential risks associated with project development. The benefits associated with a systematic review of potential risks (i.e. ERA) to help ensure projects proceed with the least chance of system failure and subsequent environmental disruption, both in the short and long term, are demonstrated herein.

PROCEDURES FOR COMPLETING ENVIRONMENTAL RISK ASSESSMENT

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

Assembling 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.

Setting 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 regulatory requirements governing project development also factor into setting the risk assessment objectives. A fundamental risk associated with new or existing projects, from a regulatory 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.

Inspecting Site and Reviewing 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 on documentation such as environmental impact statements and other reports filed in support of the project.

Choosing Appropriate Risk Assessment Techniques

There are a variety of techniques available to those performing an ERA. Three which have been found to be particularly well suited to mining operations 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 logic approach that requires identifying a potential initiating event, such as a pipe failure, and systematically examining all of the possible sequences which might lead to a more serious undesired event (i.e. complete 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 possible courses 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.
Completing 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 analyze all pertinent project data, including that gathered during the site investigation.

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' judgments 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. This procedure, commonly known as the Delphi technique, has proven particularly effective in multidisciplinary studies.

Preparing 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 focusing both regulators and proponents 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, an ERA might be completed for internal project planning purposes only. In either event, the need for clear communication of the ERA findings cannot be overstated.

Reviewing 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 an ERA on mining projects: FMEA, Event Tree and Fault Tree Analyses.

Failure Modes and Effects Analysis (FMEA)

A Failure Modes and Effects Analysis, sometimes also called Occurrence Modes and Effects Analysis (OMEA), is a structured approach for identifying 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 (i.e. post-closure). 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

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

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

<table>
<thead>
<tr>
<th>Category</th>
<th>Percent Confidence in Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Less than 20%</td>
</tr>
<tr>
<td>Medium</td>
<td>20% to 80%</td>
</tr>
<tr>
<td>High</td>
<td>Greater than 80%</td>
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</tbody>
</table>

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 estimated 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 1-in-10 to 1-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. An event in the "significant" category will be virtually certain to occur within 100 years.

Likelihood Categories Used for Failure Modes and Effects Analysis

<table>
<thead>
<tr>
<th>Category</th>
<th>Expected Likelihood</th>
<th>Annual Chance of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>Less than $10^{-6}$/yr.</td>
<td>1:1,000,000</td>
</tr>
<tr>
<td>Very Low</td>
<td>$10^{-6}$/yr. to $10^{-4}$/yr.</td>
<td>1:1,000,000 to 1:10,000</td>
</tr>
<tr>
<td>Low</td>
<td>$10^{-4}$/yr. to $10^{-2}$/yr.</td>
<td>1:10,000 to 1:100</td>
</tr>
<tr>
<td>Moderate</td>
<td>$10^{-2}$/yr. to $10^{-1}$/yr.</td>
<td>1:100 to 1:10</td>
</tr>
<tr>
<td>Significant</td>
<td>Greater than $10^{-1}$/yr.</td>
<td>Greater than 1:10</td>
</tr>
</tbody>
</table>
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.

**Event Tree Analysis**

Event Tree Analysis can complement FMEA and Fault Tree Analysis as a formal component of an ERA. Event Tree Analysis focuses on potential Initiating Events that might lead to system failure (e.g. extreme flooding causing tailings dam overtopping) and traces through designed operating systems (e.g. spillways) to determine consequences associated with their proper functioning or malfunction. 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 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). These events have particular consequence during long term project closure and decommissioning.
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 an 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.

ELEMENTS OF AN EFFECTIVE ENVIRONMENTAL RISK ASSESSMENT

The combination of techniques chosen to complete an effective ERA will vary with the nature of the 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.

ERA APPLIED TO THE PROPOSED WINDY CRAGGY PROJECT

In July 1992 the Province of British Columbia suspended formal review of the Windy Craggy Project, proposed for development in northwestern B.C. by Geddes Resources Ltd., pending the recommendations of a land and water use process established by the Commission on Resources and Environment (CORE). In September 1992 CORE retained Rescan to complete a qualitative assessment of the risks to the environment should the proposed development be allowed to proceed.

Following the framework for ERA established above, Rescan completed the Windy Craggy Project Qualitative Risk Assessment (Rescan 1992) using a multidisciplinary team of experts. The ERA technique chosen for this particular analysis was an Occurrence Modes and Effects Analysis (OMEA) which is comparable to the FMEA discussed above.

Eight-six different occurrence modes were identified in this analysis. Twelve were considered to have potentially serious consequences with varying occurrence likelihoods and confidence factors. Each were directly related to the potential loss of tailings from the impoundment in the event of a dam breach. It is important to understand that none of the risks identified necessarily represent
fatal flaws to the project. Rather, they represent areas where further analysis and design might be concentrated to reduce the environmental risks associated with project development. The level of risk considered acceptable remains the decision of government.

Although cumulative likelihoods are not assessed, it is noteworthy that for long term occurrences, likelihood increases over time. As some key components of the Windy Craggy Project, such as the tailing dams, must continue to function in perpetuity, it is recognized that some predictions of likelihood must be entirely speculative. For example, the longevity of materials such as concrete is unknown, and biological, climatic, and geological forces may change significantly over long periods of time. It was assumed that monitoring, maintenance and repair would be carried out during project construction and operations and, to the extent possible, for an additional 25-30 year closure period thereafter. These activities were not assumed for the post-closure period beyond 30 years. This has important implications for project closure and abandonment.

CONCLUSION

Environmental Risk Assessment can lead to a better definition of both technical and management-related environmental issues and improve the design, operation and closure 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 judgments 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-designed, thorough 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 focused on key concerns, thus limiting the potential for unforeseen or uncontrolled environmental impacts during project construction, operation and abandonment.
- The mine project review process can be facilitated by focusing on key issues critical to gaining development approval and avoiding costly project delays.
- Decommissioning and reclamation efforts can be focused on reducing risks associated with natural phenomenon (e.g. earthquakes, flooding, etc.) affecting project facilities (e.g. tailings impoundments, waste dumps, etc.) over the long term.

The Windy Craggy Project case study briefly outlined above demonstrates many of the advantages inherent in the completion of an ERA. Most important among these is the fact that, should development proceed, further attention can be afforded to the areas of highest risk (and/or lowest certainty) to help ensure the project is constructed, operated, reclaimed and, ultimately abandoned, with minimal risk to the natural environment. That the areas of greatest risk can be identified and managed, to the satisfaction of both a proponent and regulatory agencies, is considered the principle benefit of Environmental Risk Assessment.