Risk Management Analyses (RMA)

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ABSTRACT: Risk Management Analysis (RMA) for a mine tailing facilities is a valuable tool to identify risks and to assist in developing and implementing risk management plans. Risk assessment methodologies include quantitative (probabilistic) and qualitative (deterministic). RMA is built upon the Failure Modes Effects Analysis (FMEA), which is a recognized qualitative method that has been used since the Bhopal disaster in India. This paper presents the RMA methodology which includes the following elements: risk assessment team, stakeholder incorporation, component selection, determination of failure modes, assessment of likelihood of failure, and ranking of the consequence of failure for water quality, biophysical and socio-economic impacts. Standard procedures for screening risks and developing risk reduction plans are presented. Contingency plans are then developed for any residual risks. A case example, using the New World gold project, near Yellowstone National Park, (Montana, United States) is presented.

RÉSUMÉ : L'analyse de gestion des risques pour une usine de résidus miniers est un outil précieux pour identifier les risques et contribuer au développement et à la mise en œuvre de plans de gestion des risques. Les méthodes d'évaluation des risques comprennent l'évaluation quantitative (probabiliste) et l'évaluation qualitative (déterministe). L'analyse de gestion des risques est fondée sur l'analyse des modes de défaillance et de leurs conséquences, une méthode qualitative reconnue utilisée depuis le désastre de Bhopal en Inde. L'actuel document présente une méthodologie d'analyse de gestion des risques qui comprend les éléments suivants : équipe d'évaluation des risques, incorporation des parties intéressées, sélection des composantes, détermination des modes de défaillance, évaluation de la probabilité de défaillance et hiérarchisation des conséquences d'une défaillance par rapport à la qualité de l'eau et aux impacts biophysiques et socio-économiques. Des procédures standard de tri des risques et d'élaboration de plans de réduction des risques sont présentées. Des plans d'urgence sont ensuite élaborés pour les risques résiduels. Un exemple de cas est présenté, celui du projet de la mine d'or New World, près du parc national de Yellowstone.

1 INTRODUCTION

As engineers and members of the community we have a responsibility to design and build structures which optimize cost and risk. Throughout the 1990’s there have been a number of examples of failures of tailing dams, and associated facilities, which illustrate that, despite significant advances in the engineering aspects of such structures, there is still a risk of failure. There is a requirement for an “easy to understand” risk assessment methodology that systematically identifies the main risks that require management and mitigation. The Risk Management Analysis (RMA) is a structured qualitative risk assessment that is built upon the Failure Modes Effects Analysis (FMEA). RMA incorporates the key stakeholders in the process and develops a risk assessment plan, a risk management plan and risk contingency plan. RMA becomes a risk management tool for Engineering design optimization and for Corporate and Regulatory assurance. This paper presents the RMA methodology and a case example using the New World Gold project in the United States.

2 RMA SUMMARY

Risk is the product of likelihood times the consequence. The RMA process starts with identification of potential failure modes or problems and moves on to quantifying the consequences. Risk assessment, risk management, and risk contingency plans are then developed. The RMA process is shown in Figure 1 and comprises the following key steps.

2.1 Design Basis

RMA can be carried out at any stage of the project, from conceptual design to closure. For the analysis it is necessary to have a clear understanding of the main project components and sub-components. All of the project elements that could contribute to the risk are subdivided into components. Each component is treated as a “free body” unit which is “tested” for everything that could go wrong. An identity number is assigned for each component and sub-component. For example, a mine
A typical component summary sheet for the main dam is presented in Figure 2.

### 2.2 Stakeholder Involvement

Part of the success of RMA is the incorporation of key stakeholders into the process. This has the advantage of developing “buy in” for the risk assessment and the risk management plans that come out of the assessment. Stakeholders could include some or all of the following groups: owner, designers, regulatory agencies, NGO’s, community and environmental groups, etc. The stakeholders are encouraged to contribute concerns and ideas regarding the main project components and these are incorporated into RMA. For projects with a high degree of controversy, we recommend that an independent review panel, consisting of at least three experts, be set up to review work being carried out by the RMA team.

### 2.3 RMA Workshop

The RMA workshop is based on the failure modes effects analysis (FMEA). FMEA is a structured qualitative risk assessment methodology that was developed in response to the Bhopal and Challenger disasters. The methodology has been used in a wide variety of applications and is described in numerous papers. The Canadian Standards Association also has a published standard for FMEA. The standard FMEA has been modified for RMA to reflect the concerns for mine tailing dams and to provide a clearer framework for risk management. The assessment is carried out in a workshop environment. Attendees at the workshop typically include the following:

- Owner or Client
- Designers
- Contractors or Operators
- Risk assessment team
- Representatives of regulatory agencies or Non Government Organizations, (NGO’s)
- Risk Review Board (optional)

The workshop typically takes two to three days to complete and may be reiterated in two or three additional workshops to allow additional feedback from participants and the other parties. During the workshop, each component of the facility is discussed, and a brainstorm session of “what can go wrong” is carried out. The failure mode and the effect of failure is assessed. Each failure mode is then assessed with respect to likelihood, consequences, etc. The following sections discuss each of the main components of RMA and a sample table is shown in Figure 3.

<table>
<thead>
<tr>
<th>ID</th>
<th>COMPONENT</th>
<th>SUB-COMPONENT</th>
<th>PROJECT STAGE</th>
<th>FUNCTION</th>
<th>DESCRIPTION</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>Main Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>121</td>
<td>Dam fill</td>
<td>C,O,P</td>
<td>Store 500 Mt of tailings with potential to expand to 1,000 Mt. Provide for 1,000 year flood, with 5 m freeboard.</td>
<td>Compacted cycloned sand with less than 15% fines and estimated permeability of 10^-4 cm/s</td>
<td>Conceptual design only.</td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>Impervious Upstream Zone</td>
<td>C,O,P</td>
<td>Minimize seepage loss through dam during pond filling and mill startup.</td>
<td>HDPE geomebrane on upstream tailings face.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>Cutoff zone</td>
<td>C,O,P</td>
<td>Minimize seepage loss through the dam foundation.</td>
<td>Excavation into the abutment as the dam is raised. Possible grouting.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>124</td>
<td>Filters &amp; Drains</td>
<td>C,O,P</td>
<td>Reduction of pore water pressure and safe transport of seepage water.</td>
<td>500 mm wide drain zone (1/2 inch material) underlying the 500 mm thick filter zone (5% fines) over the entire downstream face of the starter dam. Two @ 1m x 1m rock drains with a 300mm dia. Drain pipe, surrounded with geotextile, in the main valley section. System of 0.5 m x 1 m rock drains, with a 300 mm dia. drain pipe, surrounded with geotextile, under the dam.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>Foundation</td>
<td>C,O,P</td>
<td>Foundation for the dam</td>
<td>Estimated 12 m of alluvial soils overlying weathered intrusives and volcanics, overlying competent rock. Shallow colluvium on the dam abutments.</td>
<td>Site investigations have not been carried out.</td>
<td></td>
</tr>
</tbody>
</table>

**Project Stage:** C = Construction; O = Operation; P = Post Closure

Figure 2. Typical Component Summary Sheet for a Dam.
<table>
<thead>
<tr>
<th>COMPONENT/SUB-COMPONENT</th>
<th>I.D. No.</th>
<th>FAILURE MODE/POTENTIAL PROBLEM</th>
<th>EFFECTS</th>
<th>PROJECT STAGE</th>
<th>WATER QUALITY</th>
<th>BIODIVERSITY</th>
<th>ECONOMIC</th>
<th>EVICTION</th>
<th>COMPENSATING FACTORS</th>
<th>LEVEL OF CONFIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane or impervious zone</td>
<td>122</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>122.1 Liner/impervious zone 'failure'</td>
<td></td>
<td>Higher seepage</td>
<td>O</td>
<td>M</td>
<td>N</td>
<td>N</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>122.2 Climate conditions</td>
<td></td>
<td>Membrane rupture</td>
<td>O</td>
<td>M</td>
<td>N</td>
<td>N</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>122.3 Installation deficiencies</td>
<td></td>
<td>Membrane displacement</td>
<td>O</td>
<td>M</td>
<td>N</td>
<td>N</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grout curtain</td>
<td>123</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>123.1 Very pervious materials in cutoff zone/poor cutoff</td>
<td></td>
<td>Piping of tailings</td>
<td>O</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filters / Drains</td>
<td>124</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>124.1 Drains plug due to inadequate design</td>
<td></td>
<td>Reduce stability</td>
<td>O.P</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>124.2 Drains plug due to seismic deformation</td>
<td></td>
<td>Reduce stability</td>
<td>O.P</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>124.3 Drains plug due to ARD precipitates</td>
<td></td>
<td>Reduce stability</td>
<td>O.P</td>
<td>N</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>124.4 Drains plug due to poor construction</td>
<td></td>
<td>Reduce stability</td>
<td>O.P</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>124.5 Drains plug due to geotextile degradation</td>
<td></td>
<td>Reduce stability</td>
<td>P</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>125.1 Weak foundation material - instability</td>
<td></td>
<td>Dam failure</td>
<td>O.P</td>
<td>M</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>125.2 Loose materials - high settlements</td>
<td></td>
<td>Dam deformations</td>
<td>O.P</td>
<td>M</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>125.3 Piping through open fractures in soils or rock</td>
<td></td>
<td>Release of tailings</td>
<td>O.P</td>
<td>I</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>125.4 Piping through open fractures in soils or rock</td>
<td></td>
<td>Dam failure</td>
<td>O.P</td>
<td>M</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>125.5 Presence of active seismic zones</td>
<td></td>
<td>High seismic acceleration, low dam stability, drain discontinuity</td>
<td>O.P</td>
<td>M</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>L</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Project Stage:** C = Construction; O = Operation; P = Closure

**Figure 3. Typical RMA Worksheet.**

### 2.4 Identity Number and Component

An identity number is used, as described previously, and each failure mode is assigned a number (e.g. dam failure modes would be 110.1, 110.2, etc.).

### 2.5 Failure Modes and Effects

All potential problems and failure modes are identified in a neutral environment that encourages “creativity” in identifying unusual modes and “brainstorming” to generate a “long” list of all potential issues. For this it can be advantageous to have a mix of technical and non-technical members in the workshop. The process also acts as a “due diligence” to illustrate that all aspects have been considered.

### 2.6 Project Stage

The stage of the project is noted for each failure mode. The duration of the risk exposure is important in comparing risks between different project stages. The main project stages are summarized as follows ( actual time frames vary from those shown and need to be adjusted on a project basis).

- **Construction (C)**: 1 to 3 years
- **Operation (O)**: 10 to 30 years
- **Decommissioning (D)**: 10 years
- **Post-mining land use (P)**: 1,000 years

The selection of an appropriate time frame for the post mining land use period can be controversial. Some groups will argue that it has to be forever, e.g. > 1 million years, others will argue that they can only be expected to be able to plan for, at the most, the next few hundred years. The 1,000 year time frame, however, is proposed as a reasonable estimate of what we would like to achieve,
without being unduly conservative. The time period also recognizes man’s ingenuity and capacity to solve some of our current problems over that time frame.

2.7 Likelihood of Failure:

The likelihood or probability of failure is ranked on a five level scale which is based on the annual probability of failure. Table 1 summarizes the five levels and gives typical corresponding examples. It is necessary that workshop participants are consistent in applying the likelihood of the failure mode occurring.

<table>
<thead>
<tr>
<th>Level</th>
<th>Annual Probability</th>
<th>Return Period (y)</th>
<th>Typical Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible (N)</td>
<td>$&lt;10^{-8}$</td>
<td>&gt; 1 million</td>
<td>Doubt it could happen.</td>
</tr>
<tr>
<td>Very Low (VL)</td>
<td>$10^{-4}$ to $10^{-2}$</td>
<td>10,000 to 1 million</td>
<td>Unlikely to happen, lightning death, probable maximum flood, maximum credible earthquake.</td>
</tr>
<tr>
<td>Low (L)</td>
<td>$10^{-2}$ to $10^{-1}$</td>
<td>100 to 10,000</td>
<td>Could happen: cancer, suicide, intermediate earthquakes &amp; floods.</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>$10^{-1}$ to $10^{0}$</td>
<td>10 to 100</td>
<td>Has or will happen: open pit slope failures, concrete degradation, death in a vehicle accident.</td>
</tr>
<tr>
<td>High (H)</td>
<td>$&gt;10^{1}$</td>
<td>&gt; 10</td>
<td>Happens regularly: pump shutdown, pipeline breakage, vehicle accidents, QA/QC excursions.</td>
</tr>
</tbody>
</table>

2.8 Consequence of Failure

The consequences of failure could be quantified with a wide variety of parameters, however, it is advantageous to limit the number of consequences to allow workshop participants to focus on key issues. A proposal for a standard set of consequences is presented herein, along with preliminary criteria for each level of consequence. The consequences are ranked on a five level scale and need to be reviewed and developed on a project by project basis. The level of detail will vary depending on the complexity of the project, the level of studies and the potential impacts. It is, however, necessary that the workshop participants use the criteria consistently to allow comparison of risks. The three main areas of risk are the water environment, the bio-physical environment and the socioeconomic environment. The proposed consequence criteria is shown in Table 2. Several “consequences” are included for most of the levels. In general, it is only necessary to meet one of the consequences to be included in the respective level.

The water environment criteria includes the following:

- Terrestrial biology (flora and fauna);
- Surficial geology and lacustrine, fluvial and marine sediments; and
- Soil quality.

The socioeconomic environment includes the following:

- Public image and community relations;
- Economic costs;
- Land use and relocation impacts;
- Archaeology;

- Number of people affected; and
- Number of deaths.

| Table 2. Summary of Consequence Criteria
<table>
<thead>
<tr>
<th>Category</th>
<th>Consequence - Water Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible (N)</td>
<td>No detectable changes relative to &quot;background&quot; conditions.</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Minor changes, occasional exceedance of water quality standards. Minimal impacts on aquatic life, less than 20% mortality. All groundwater degradation is “onsite” conditions.</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Exceedance of water quality standards on a regular basis; sediment load between twice and 5 times baseline. Localized, short term, reversible impact on aquatic life with 20% to 50% mortality. Sulphate concentrations between 500 mg/L and 1,000 mg/L. Potential for groundwater degradation in offsite wells to reach drinking water standards.</td>
</tr>
<tr>
<td>High (H)</td>
<td>Up to 10 times water quality standards. Widespread, long term impact on aquatic life with 50% to 90% mortality. Sediment load between 5 and 100 times baseline. Sulphate concentrations between 1,000 mg/L and 10,000 mg/L. Potential for groundwater degradation in offsite wells to exceed drinking water standards.</td>
</tr>
<tr>
<td>Extreme (E)</td>
<td>Over 100 times water quality standards. Severe, potentially irreversible impact on aquatic life with over 90% mortality. Sediment loads greater than 100 times baseline. Sulphate concentrations between 1,000 mg/L and 10,000 mg/L, with sustained depressed pH and elevated metals present. Groundwater degradation in offsite wells to exceed 100x drinking water standards.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Consequence - Biophysical</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>No measurable impact</td>
</tr>
<tr>
<td>L</td>
<td>Minor impact on the habitat, release of up to 10,000 t tailings/waters.</td>
</tr>
<tr>
<td>M</td>
<td>Significant, reversible impact on habitat, release of 10,000 to 100,000 Mt of tailings/water.</td>
</tr>
<tr>
<td>H</td>
<td>Significant irreversible habitat impact, release of 100,000 to 1 Mt of tailings/water.</td>
</tr>
<tr>
<td>E</td>
<td>Catastrophic impact, release of &gt; 1 Mt of tailings/water.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Consequence - Socio-Economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>No measurable changes</td>
</tr>
<tr>
<td>L</td>
<td>Less than $1 million in costs, affects &gt; 10 people, local public image concern.</td>
</tr>
<tr>
<td>M</td>
<td>$1 to 10 million in costs, affects 10 to 100 people, Provincial public image concern. 1 to 10 lives lost.</td>
</tr>
<tr>
<td>H</td>
<td>$10 to 50 million in costs, affects 100 to 1,000 people, National public image concern. 10 to 50 lives lost.</td>
</tr>
<tr>
<td>E</td>
<td>&gt;$50 million in costs, affects &gt; 1,000 people, International public image concern. &gt; 50 lives lost.</td>
</tr>
</tbody>
</table>

Table 2 Notes:
1. Water quality as defined by permit limits or World Bank guidelines for receiving water quality.
2. Impact on aquatic is quantified by bioassay tests to determine the mortality rate.
3. Drinking water standards as defined by permit limits or World Bank guidelines.
4. Sulphate concentrations are used as an indicator of acid rock drainage.
2.9 **Confidence Level**

The level of confidence in the likelihood and/or consequences is illustrated on a three level scale as follows:

- **Low (L)**: Do not have confidence in the estimates, potential for high variability.
- **Moderate (M)**: Have some confidence in the estimates and moderate variability.
- **High (H)**: Have confidence in the estimates and low variability.

2.10 **Compensating Factors**

For each failure mode and effect there may be compensating factors that could be introduced to reduce the risk. The compensating factors could include some of the following general components:

- Specific QA/QC programs to ensure compliance with design.
- Additional engineering or scientific studies to increase level of confidence.
- Operational monitoring.
- Civil works to increase factor of safety.
- Community liaison and community development programs to reduce public perception and reduce risks by incorporating “local” knowledge.

2.11 **Post Compensation Risks**

After compensating factors are applied the level of risk should be reduced. The failure mode is then assigned a revised likelihood, assuming the same consequence. The confidence level that the compensating factor is appropriate, technically feasible, and cost effective, is assessed to reflect the level of certainty that the compensating factors will be applied and will be effective.

3 **RISK ASSESSMENT**

Risk assessment involves a “binning” (screening) process to identify the higher risk items. The criteria for binning considers the likelihood and consequence of failure, as well as the time exposure of the annual probability. The resulting risks are plotted on a “Risk Review Chart”, an example of which is shown in Figure 4. The chart can also be used to illustrate which risks could be considered to be the responsibility of Corporate, Engineering, Supervisory or Labour staff. The criteria for binning is summarized as follows and involves a number of risk levels:

- **Level 1**: Risks with high likelihood and extreme consequences (H-E) are classified as “fatal flaws”. These risks are unacceptable and mean that a new design has to be evolved or the project should not go ahead.
- **Level 2**: Risks with high likelihood and high consequences (H-H); and risks with moderate likelihood and extreme consequences (M-E). These risks are of concern to senior management, shareholders and the potentially affected public. They require a high level of scrutiny and detailed risk management and contingency plans.
- **Level 3**: Risks with high likelihood and moderate consequences (H-M); risks with moderate likelihood and high consequences (M-H); and risks with low likelihood and extreme consequences (L-E). These risks are of the concern of Senior management, engineering design and operating staff. They require a risk management plan and contingency plan.
- **Level 4**: Risks with high likelihood and low consequences (H-L), risks with moderate likelihood and moderate consequences (M-M) and risks with low likelihood and high consequences (L-H). These risks are of concern to the Engineering design and operations staff and require operating procedures and risk management plans to manage the risks.

In addition, the time exposure of the risk and the confidence factor will trigger a binning to the next highest likelihood category in consideration of the following:

- Risks with a low level of confidence will be “binned” out as equivalent to the next highest likelihood category; and
- Post closure land use risks, because of their long exposure time, will bin out as equivalent to the next highest likelihood category.

4 **RISK MANAGEMENT PLAN**

The objective of the risk management plan is to apply compensating factors to reduce the level of risk. The plan is specifically directed towards the levels 1, 2, 3 & 4 risks. Other risks, however, should be assessed and managed on a “day by day” basis with the appropriate design and operations staff. Compensating factors that are identified in the risk assessment workshop need to be considered in a cost/risk reduction benefit assessment, with a goal to economically reduce the level of risk. Low cost/high risk reduction compensating measures are easily adopted and high cost/low risk reduction compensating factors require detailed analysis to justify their use. The risk management plan describes the compensating factors for each of the risks that bin out in the risk assessment process. The Owner, designers and other key stakeholders need to assess and decide on which compensating factors are to be implemented. After application of the risk management plan the resulting risks are binned out and plotted on the Risk Review Chart.
### LIKELIHOOD OF FAILURE

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Negligible</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/E</td>
<td>121.1</td>
<td>Low compaction with drainage failure &amp; liquefaction</td>
<td>O,P</td>
<td>121.2</td>
<td>Low compaction and liquefaction (seismic)</td>
</tr>
<tr>
<td></td>
<td>121.11</td>
<td>Land slides over the dam</td>
<td>O,P</td>
<td>121.13</td>
<td>Under estimation of the density and potential liquefaction failure</td>
</tr>
<tr>
<td></td>
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**EXTREME**

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**NEGLECTIBLE**

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**Figure 4. Typical Risk Review Chart.**

### 5 RISK CONTINGENCY PLAN

The risks remaining on the Risk Review Chart, after the compensating factors and risk management plan is applied, are classified as residual risks, and represent the expected risks associated with the project. These risks are the inherent result of the project. Contingency plans are required to address the required action and to mitigate the consequences if the event occurs. Contingency plans need to address issues of responsibility, notification, emergency response, technical monitoring and technical response, and other issues.

### 6 CASE EXAMPLE

The RMA was applied to the New World Gold Project in Montana, USA at the request of the United States Forest Service (US Department of Agriculture). The New World project involved a proposed 1500 ton per day underground gold mine located 5 km north of Yellowstone National Park. Yellowstone National Park is the first park declared in the United States and the project came under intense environmental and regulatory review. The main risk items were associated with the tailings facility, the potential for acid rock drainage, and the potential for any impacts on Yellowstone National Park. An independent Risk Review Board was established to review the work of the risk.
assessments team. The risk assessment team assessed ten
alternatives for tailings disposal and developed an
additional dewatered tailings alternative (No. 11). Input
from all stakeholders, which included numerous
regulatory agencies and environmental coalitions were
incorporated. Up to 1,000 failure modes and effects were
identified (about 100 for each alternative) and assessed.
The RMA identified the low risk alternative (which was
significantly different than that proposed) and concluded
that the mine could be developed with a low level of risk.
The recommended alternative was a dewatered tailings
pile for storage of low sulfide tailings and the sulfide
tailings were placed underground and in a separate surface
containment area. Examples of the Risk Review Chart for
the proposed tailings facility, the proposed tailings facility
with compensating factors applied, and a recommended
alternative facility, are shown in Figures 5, 6 and 7,
respectively.

The RMA showed that the facility, as proposed, had a
high level of risk. However, a number of compensating
factors could be applied to significantly reduce the level of
risk to be compatible with other civil engineering
structures. In addition, a dewatered tailing facility was
proposed to further reduce the risk to a low level. The
project, however, had a major environmental lobby, and,
just prior to the release of the Risk Assessment Report, the
President of the United States withdrew the proposed
mine area from its mining tenure and declared it a
protected area.

7 SUMMARY

The risk of a tailing dam failure, or a failure of the
associated facilities, is a significant potential liability to
the mining industry. Tailing dams are increasingly
becoming more significant structures, whose height and
importance rival some of the largest water supply and
hydroelectric dams in the world. The consequences of
tailings dam failure can be greater than for water supply
dams, in that the mudflow resulting from the tailings
outflow can also result in catastrophic environmental
damage associated with the sulfides and residual
chemistry. This paper presents a Risk Management
Analysis (RMA) that has been used to quantify the risks
associated with a numerous tailings facilities around the
world and forms the basis for development of risk
management and risk contingency plans. The proposed
guidelines in this paper, if adopted, will assist in
comparing risks between projects and in working towards
acceptable international standards for risk acceptance for
mine tailing facilities.
**Figure 5. Risk Review Chart - New World Project Proposed Tailings Facility.**
### Figure 6. Risk Review Chart - New World Project - Proposed Tailings Facility AFTER COMPENSATING FACTORS APPLIED

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<th>HIGH</th>
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**CONSEQUENCE**

- 2.3.03 Damage to filter fabric causes piping (P)
- 4.1.05 Side-cutting at main diversion inlet (O, D)
- 2.2.05 Animal/plants damage liner (P)
- 3.2.05 Heavy loads rupture liner (O, D, P)
- 3.4.01 Early mine shutdown (D, P)
- 3.4.03 Differential settlement of closure cap (D, P)
- 3.4.05 Liquefaction of tailings (D, P)
- 4.1.03 Large flood on main diversion (O, D, P)
- 2.1.01 Erosion of dam (P)
- 3.2.01 Uplift of liner between branch drains (O)
- 3.2.02 Impoundment liner defects (O)
- 3.4.02 Final tailings configuration (D, P)
- 3.5.01 Debris in closure spillway (D, P)
- 4.1.02 Sedimentation on main diversion (P)
- 4.1.07 Snow on main diversion (O, D, P)
- 4.1.09 Ice-jamming of main diversion (O, D, P)
- 4.1.10 Tree/organic debris on main channel (P)
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Figure 7. Risk Review Chart - Alternative Dewatered Option