Selection of Remediation Measures for Abandoned Mine Sites

Michael Nahir, Daryl Hockley

Public Works & Government Services Canada

NATO, CCMS, Non-Ferrous Mining Sector, Baja Mare, Romania 2003
Outline

• Uniqueness of mine closure
• Mine closure evaluation approaches
• “Top Down” approach
• Case studies
Why are mines different?

- Large volumes of relatively uniform waste
  - Waste rock
    - Millions of tonnes
    - Somewhat uniform composition
  - Tailings
    - Millions of tonnes
    - Highly uniform composition
  - Other
    - Processing wastes (e.g. arsenic trioxide dust)
    - Hydrocarbons
    - Other hazardous wastes
Why are mines different?

- Delayed reactivity
  - Acid rock drainage
    - $\text{Metal Sulphide minerals} \rightarrow O_2 \rightarrow H_2O \rightarrow \text{Metals & Sulphuric Acid}$
  - Cyanide $\rightarrow$ SCN $\rightarrow$ NH$_3$
    - Cyanide toxic to fish, birds and animals
    - Thiocyanate not very toxic
    - Ammonia toxic to fish only
Why are mines different?

• Contaminated water streams
  – Mine water
  – Tailings ponds
  – Waste rock drainage
Why are mines different?

- Physical hazards
  - Mine openings
  - Water-retaining structures
    - Large dams
  - Water-conveyance structures
    - Ditches, pipelines and pumps
  - Buildings
Canadian Mine Closure Management

• “Contaminated Sites” methods
• “Risk Management” approach
• “Bottom up” or “Guideline” methods
• “Top Down” approach
Contaminated Sites Approach

- Commonly used for contaminated properties outside of mining industry
- Clearly defined phases designed to identify and delineate contaminants
- CCME Guidance Documents
  - Phase I - Identify possible contaminants
  - Phase II - Locate contaminants
  - Phase III - Delineate contaminants
  - Phase IV+ - Select remediation methods
Contaminated Sites Approach

- Direct usefulness is limited to hydrocarbons and building wastes
  - About 10% of liabilities on most mine sites
- About 90% of liabilities are associated with waste rock, tailings and minewater management
- Why put 100% of the planning through a process that is only set up for 10% of the liability?
Risk Management Approach

• Commonly used in industry for environmental management

• Semi-quantitative methods:
  – Define site elements and hazards
  – Select consequence severity definitions
  – Select probability definitions
  – Locate all site elements on a risk ranking table

• Fully quantitative methods
  – Very complex analyses and data needs
## Risk Management Approach

<table>
<thead>
<tr>
<th><strong>Probability</strong></th>
<th><strong>Consequence Severity</strong></th>
<th><strong>Low</strong></th>
<th><strong>Minor</strong></th>
<th><strong>Moderate</strong></th>
<th><strong>Major</strong></th>
<th><strong>Critical</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost Certain</td>
<td></td>
<td>High</td>
<td>High</td>
<td>Extreme</td>
<td>Extreme</td>
<td>Extreme</td>
</tr>
<tr>
<td>Likely</td>
<td></td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>Extreme</td>
<td>Extreme</td>
</tr>
<tr>
<td>Possible</td>
<td></td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Extreme</td>
<td>Extreme</td>
</tr>
<tr>
<td>Unlikely</td>
<td></td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Extreme</td>
</tr>
<tr>
<td>Very Unlikely</td>
<td></td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
## Risk Management Approach

<table>
<thead>
<tr>
<th>Probability</th>
<th>Consequence Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Almost Certain</td>
<td>Orange</td>
</tr>
<tr>
<td>Likely</td>
<td>Yellow</td>
</tr>
<tr>
<td>Possible</td>
<td>Waste Rock Slope Failure</td>
</tr>
<tr>
<td>Unlikely</td>
<td>Green</td>
</tr>
<tr>
<td>Very Unlikely</td>
<td>Green</td>
</tr>
</tbody>
</table>
Risk Management Approach

• Most useful in management of ongoing liabilities
  – Creates inventory of risks and identifies priorities
• Some use in mine closure planning
  – Can help to determine “what” needs to be done
  – Does not lead directly to a decision about “how” to do it
• Therefore not suitable as overall framework for mine closure planning
Bottom Up Approach

• “Bottom up” and “top down” come from software development

• Bottom up approach in a nutshell:
  – Start doing numerous scientific and engineering studies
  – Hope they will add up to a clear decision
    • Often leads to “further study required”, ie. Don’t stop until every question answered
Bottom Up Approach

• Literal interpretation of regulatory guidelines
  – Follow the Table of Contents
  – Prescriptive
• Loss of focus on objectives of the planning process
Bottom Up Approach

• Inefficient use of investigation dollars
• Difficult to control schedule
• Driven by specialist’s opinion of what is enough, rather than by need to make a particular decision
Top Down Approach

• Elements of method selected from good mine closure projects

• Successfully applied in mine closure projects of different complexity:
  – Survey of abandoned Yukon mines
  – Arctic Gold & Silver tailings (Yukon)
  – Colomac Project (NWT)
  – Giant Mine (NWT)
Top Down Approach

- Define alternatives
- Define evaluation factors
- Create initial evaluation matrix using available information
- Make decisions where results are clear
- Initiate investigations where not clear
- Continue investigations only until decision is clear
Case 1 - Arctic Gold & Silver

Small size and moderate complexity

A number of alternatives to be considered

Phases of investigation, analysis and selection
Case 1 - Arctic Gold & Silver

1968-69 operation

Mill + tailings (300,000 m³)

Tailings contain several % arsenic

Paste pH 1.8 - 3.0
Case 1 - Arctic Gold & Silver

Tailings contain several % arsenic

Paste pH 1.8 - 3.0
Case 1 - Arctic Gold & Silver
Case 1 - Arctic Gold & Silver
Case 1 - Arctic Gold & Silver

Arsenic in seepage up to 28 mg/L

Tailings plume in lake
Case 2 - Arctic Gold & Silver

Mill structures
Health and safety issue
Case 1 - Arctic Gold & Silver

Physical stability concerns
### Case 1 - Define Alternatives and Evaluation Factors

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Evaluation Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Physical Stability</td>
</tr>
<tr>
<td>Do nothing</td>
<td>no</td>
</tr>
<tr>
<td>Control access</td>
<td>no</td>
</tr>
<tr>
<td>Cover tailings</td>
<td>yes</td>
</tr>
<tr>
<td>Consolidate sources</td>
<td>no</td>
</tr>
<tr>
<td>Reduce contact w water</td>
<td>no</td>
</tr>
<tr>
<td>Chemical amendment</td>
<td>no</td>
</tr>
<tr>
<td>Reprocessing</td>
<td>yes</td>
</tr>
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</table>
## Case 1 – Design Investigations

<table>
<thead>
<tr>
<th>Studies</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographic survey</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>Surface water quality survey</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>Tailings characterization</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>Delineation of other arsenic sources</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>Groundwater investigation</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>Delineation of in-lake tailings</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>Metallurgical properties</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>Borrow sources</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>Cost estimate</td>
<td>y</td>
<td>y</td>
</tr>
</tbody>
</table>
# Case 1 - Investigate & Re-evaluate

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographic survey</td>
<td>y</td>
<td></td>
</tr>
<tr>
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<td>y</td>
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</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Groundwater investigation</td>
<td>y</td>
<td></td>
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<tr>
<td>Delineation of in-lake tailings</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>Metallurgical properties</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>Borrow source delineation</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>Cost estimate</td>
<td>y</td>
<td>y</td>
</tr>
</tbody>
</table>
Case 1 - Select Alternative

• Investigations showed that best alternatives were:
  – Consolidate and cover tailings
  – Reprocess tailings

• Stakeholder working group selected consolidate and cover because:
  – No need for multi-year funding
  – No risk of changing gold price
Case 1 - Implementation

- Covers constructed in 1999
- Monitoring shows good results
The third case is an example of a very large and very complex mine closure. The Giant Mine near Yellowknife NWT operated from 1948 to 1999. The gold ore at Giant was associated with the mineral arsenopyrite. To liberate the gold, the ore was roasted at high temperature. The roasting resulted in the production of arsenic gases, which were captured in an electrostatic precipitator. The resulting arsenic trioxide dust was then stored underground.
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Case 2 – Evaluation Factors

- Environmental protection
- Human health and safety
- Local Aboriginal acceptance
- Other public acceptance
- Cost
- Long-term effectiveness
- Technical certainty
- Corporate (Can.Gov.) objectives
Case 2 – Water Management
Alternatives & Investigations

• Literature review paper
• Expert and stakeholder workshop to brainstorm options – select studies
• Lab study selection of treatment methods
• Second workshop to select short list:
  – Enhanced natural removal
  – Active treatment of water
  – Complete relocation of tailings to Pit
Case 2 – Phase 2 Investigations

- Detailed water balance – schedule, inputs
- Field test of enhanced natural removal
- Pilot testing of best water treatment methods
- Predictive modeling
- Diversions / Pits
- Engineering / Costs
Case 2 – Alternatives Evaluation

• Enhanced Natural Removal ($8 - $20 Million)
  – Good field evidence
  – Some questions, but many mitigation options

• Rapid Treatment ($38 - $50 Million)
  – Good pilot plant performance data
  – Proven technology

• Tailings Relocation ($30 - $100 Million)
  – Not been done in the north
  – Many questions and uncertainties
Case 2 – Alternative Selection

- Preparation of simple graphics to present alternatives to stakeholders

- Rating of alternatives in stakeholder meetings

Ammonia prediction

Additional water management measures

- No Change 2006 - 2007
- New Ditches 2008 - 2009
- Full Pit & New Ditches 2009 - 2010
- Ring Road 2025
- Polishing or Treatment
Case 2 – Alternative Selection

• Federal government and Aboriginal community agree that enhanced natural removal plus water management is the preferred alternative
• Project Description in preparation
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Case 3 – Giant Mine

Dust now stored in 14 underground chambers and stopes.
Case 3 – Giant Mine

- Dust is very soluble
  4000 mg/L arsenic
- Also contains gold
  ~ 0.5 oz/ton
Case 3 – Evaluation Factors

From public workshops

– Risks
  • Risk of arsenic releases during implementation
  • Risk of arsenic releases over long term
  • Worker health and safety

– Net Cost
  • Capital and operating costs
  • Revenue from sale of gold or arsenic
  • Cost uncertainties

Evaluation criteria for assessing the four alternatives were selected at a series of public workshops held in 1999 and 2000. They included the different types of risk associated with each process, and costs.
To address this complex problem, we put together a group of engineers and scientists and started by listing all of the potentially applicable management or remediation methods. That list included over 90 methods. We then put together groups of methods and selected “representative alternatives” to represent each group. The next steps were all done on the four representative alternatives you see listed here.
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Case 3 – Detailed Investigations

For each alternative:
  Engineering designs
  Risk assessments
  Cost estimates

The investigations to fill in the blue area of the matrix took about six months. We started by developing pre-feasibility level engineering designs for each alternative. The engineering designs were then used as a basis for risk assessments and cost estimates.
# Case 3 – Alternative Selection

<table>
<thead>
<tr>
<th>“Leave it Underground” Alternatives</th>
<th>Overall Risk</th>
<th>Dominant Risk Category</th>
<th>Net Cost Range (Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1. Water Treatment &amp; Minimum Control</td>
<td>High</td>
<td>Long term</td>
<td>30-70</td>
</tr>
<tr>
<td>A2. Water Treatment &amp; Drawdown</td>
<td>Moderate</td>
<td>Long term</td>
<td>80-110</td>
</tr>
<tr>
<td>A3. Water Treatment &amp; Seepage Control</td>
<td>Moderate</td>
<td>Long term</td>
<td>80-120</td>
</tr>
<tr>
<td>B2. Frozen Shell</td>
<td>Low</td>
<td>Long term</td>
<td>90-110</td>
</tr>
<tr>
<td>B3. Frozen Block</td>
<td>Low</td>
<td>Long term</td>
<td>90-120</td>
</tr>
<tr>
<td>C. Deep Disposal</td>
<td>Moderate</td>
<td>Worker H&amp;S</td>
<td>190-230</td>
</tr>
</tbody>
</table>
## Case 3 – Alternative Selection

<table>
<thead>
<tr>
<th>“Take it Out” Alternatives</th>
<th>Overall Risk</th>
<th>Dominant Risk Category</th>
<th>Net Cost Range ($Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. Removal &amp; Surface Disposal</td>
<td>High</td>
<td>Short term</td>
<td>600-1000</td>
</tr>
<tr>
<td>F. Removal, Gold Recovery &amp; Arsenic Stabilization</td>
<td>Moderate</td>
<td>Worker H&amp;S</td>
<td>400-500</td>
</tr>
<tr>
<td>G1. Removal &amp; Cement Stabilization</td>
<td>Moderate</td>
<td>Worker H&amp;S</td>
<td>230-280</td>
</tr>
</tbody>
</table>
Case 3 – Alternative Selection

Current status
- Public consultation on two alternatives recommended by technical team
- Decision and detailed Project Description next year

The investigations to fill in the blue area of the matrix took about six months. We started by developing pre-feasibility level engineering designs for each alternative. The engineering designs were then used as a basis for risk assessments and cost estimates.
I would now like to pull together the three case histories and suggest a “unified top down approach” to this type of work.
1. Define Alternatives

<table>
<thead>
<tr>
<th>Project Cost</th>
<th>Definition of Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>$100,000</td>
<td>Standard list</td>
</tr>
<tr>
<td>$1,000,000</td>
<td>Site specific list after initial investigation</td>
</tr>
<tr>
<td>$10,000,000</td>
<td>Use of creativity methods and representative alternatives</td>
</tr>
</tbody>
</table>

“Start with the end in mind”

The first step in all cases is to start with the end in mind, i.e. define complete alternatives. The process of doing that will depend on the scale of the project. For small sites and simple projects, a standardized list of alternatives might be applicable. For medium-sized projects, a site specific list will be needed. For the very large projects, a lot of work is required to define all possible methods and select representative alternatives for further assessment.
The next step is to define the evaluation criteria and the level of detail required to assess each alternative with respect to each criteria. Again, the level of effort needs to vary depending on the complexity of the project. Looking at the cost column for example, simple unit cost approaches might be adequate for small projects, but multi-phased investigations with lab, bench, and pilot scale studies may be needed for very large projects. The point is to let the top down process direct investigation efforts to key uncertainties.
3. Analyze & Select

<table>
<thead>
<tr>
<th>Project Cost</th>
<th>Investigations and Evaluation Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>$100,000</td>
<td>Screening investigation Matrix</td>
</tr>
<tr>
<td>$1,000,000</td>
<td>Screening investigation Alternatives definition Follow-up investigation Limited consultation</td>
</tr>
<tr>
<td>$10,000,000</td>
<td>Initial studies Confirmatory investigations Feasibility level design Project Description Public review</td>
</tr>
</tbody>
</table>

Finally, the process of selecting alternatives can be a single step in small projects, but will probably be iterative and involve significant public interaction in the larger projects.
End

Questions?
# Risk Management Process

## Consequence Severity Definitions

<table>
<thead>
<tr>
<th>Categories</th>
<th>Very Low</th>
<th>Minor</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury and Disease</td>
<td>Low-level designate subjective symptoms. No measurable physical effect. No medical treatment.</td>
<td>Objective but reversible disability/disability or impairment and/or medical treatment injuries requiring hospitalization.</td>
<td>Moderate irreversible disability or impairment to one or more persons.</td>
<td>Single fatality and/or severe irreversible disability or impairment to one or more persons.</td>
<td>Short or long term health effects leading to multiple fatalities. Catastrophic event leading to multiple fatalities.</td>
</tr>
<tr>
<td>Environmental Impacts</td>
<td>No lasting effect. Low-level impact on biological or physical environment.</td>
<td>Minor effects on biological or physical environment.</td>
<td>Moderate effects on biological or physical environment but not affecting ecosystem function. Medium term widespread impacts.</td>
<td>Serious environmental effects/some impairment of ecosystem function. Widespread medium-long term impacts.</td>
<td>Very serious environmental effects with impairment of ecosystem function. Long-term effects on the environment.</td>
</tr>
<tr>
<td>First Nations Impacts</td>
<td>No impact to traditional lands.</td>
<td>Minor or perceived impact to traditional lands.</td>
<td>Some non-reversible impact to traditional lands or lifestyle.</td>
<td>Significant impact to traditional lands. Short-term amount to harvest rights.</td>
<td>Irreparable (permanent) damage to traditional lands. Long-term impact to harvest rights.</td>
</tr>
<tr>
<td>Mitigation Costs</td>
<td>$150,000</td>
<td>$100,000 - $300,000</td>
<td>$500,000 - 2.5 Million</td>
<td>$2.5-10 Million</td>
<td>$5-10 Million</td>
</tr>
</tbody>
</table>
Risk Management Process

**Likelihood Definitions**

<table>
<thead>
<tr>
<th>Assigned Likelihood</th>
<th>Description</th>
<th>Frequency</th>
<th>Human Health</th>
<th>Safety, Environment and Community</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost Certain</td>
<td>…expected to occur in most circumstances</td>
<td>1 case / 100 person-year</td>
<td>High frequency of occurrence – occurs more than once per year</td>
<td></td>
</tr>
<tr>
<td>Likely</td>
<td>…will probably occur in most circumstances</td>
<td>1 case / 1000 person-year</td>
<td>Event does occur, has a history, occurs once every 1 – 10 years</td>
<td></td>
</tr>
<tr>
<td>Possible</td>
<td>…should occur at some time</td>
<td>1 case / 10⁴ person-year</td>
<td>occurs once every 10 – 100 years</td>
<td></td>
</tr>
<tr>
<td>Unlikely</td>
<td>…could occur at some time</td>
<td>1 case / 10⁵ person-year</td>
<td>occurs once every 100 – 1000 years</td>
<td></td>
</tr>
<tr>
<td>Very Unlikely</td>
<td>…may occur under exceptional circumstances</td>
<td>1 case / 10⁶ person-year</td>
<td>occurs once every 1000 – 10 000 years</td>
<td></td>
</tr>
</tbody>
</table>