April 24, 2014

Middle and Lower Chase River Dams
Dam Safety Analysis

Golder Associates
Dam Safety Analysis Framework

- CDA Guidelines:
- “Safety Management is ultimately concerned with management of risk and should provide answers to the following questions,
  - What can go wrong?
  - What is the likelihood (probability) of it happening?
  - If it occurs, what are the possible consequences?”
- Two approaches considered
  - Risk-Informed Approach
  - Traditional Standards-Based Approach
Dam Safety Analysis Framework

- Risk Informed Approach
  - CDA Guidelines: “In view of the large uncertainties involved, a risk-informed approach is encouraged. Such an approach includes traditional deterministic standards-based analysis as one of many considerations, as shown in Figure 6-1”.
  - Such an approach has been adopted in the dam safety analysis for Colliery Dams – e.g. seismic analysis (numerical (FLAC) modelling), H and H analyses.
  - The deterministic analyses have been supported by extensive additional site information
- Established, performance-based criteria
  - This approach, with the performance based criteria, forms the basis for determination of dam safety conformance.
Dam Safety Analysis Framework

- Traditional Standards-based Approach
  - Means of comparative assessment – to determine how dam safety performs relative to traditional Approach – a means of “bench-marking”.
  - Demonstrate justification for variation from the Traditional Standards-based Criteria, if Risk-Informed performance targets are met.
Middle Dam  Ref – Schedule 1, BC Dam Safety Regulation

- Considers Middle Dam consequences, separate from failure of Lower Dam (ie route release hydrograph through Lower Dam).

- Affected areas
  - 1) Area between MD and Lower Dam, and Lower Dam reservoir
  - 2) Area below Lower Dam
Middle Dam Breach Inundation Map

- Middle Dam fast breach (10-min)
- Maximum velocities in meters/sec
- Maximum depths in meters
  - Above normal pool
  - Average at banks
- Assumes Lower Dam labyrinth spillway

Source: ESRI, DigitalGlobe, NearEyes, LiDARs, USGS, USGS,keley, ESRI, USGS, and the GIS User Community
Consequence Classification

Middle Dam  Ref – Schedule 1, BC Dam Safety Regulation

- Population at Risk.
  - Permanent (populated area downstream of Lower Dam)
- Environmental and Cultural
  - Significant loss of important wildlife habitat (*not critical*) downstream
  - Important (*not critical*) fish habitat for salmon in the lower Chase River.
  - Restoration or compensation is highly possible.
- Unique landscapes or sites of cultural significance?
- Consequences – Loss of Life; Infrastructure and Economic
  - Two scenarios – hydrology (this governs over seismic)
    - Base case - SC19 – PMF plus MD breach (60 minutes)
    - Sensitivity case – SC3 – PMF plus MD breach (10 minutes)
Middle Dam  Sensitivity case – SC3 – PMF plus MD breach (10 minutes)
Middle Dam SC8 – PMF, no MD breach
Consequence Classification

Middle Dam SC1 – Seismic MD breach (10 min)
Consequence Classification

**Middle Dam**  Ref – Schedule 1, BC Dam Safety Regulation

- Consequences – Loss of Life; Infrastructure and Economic
  - Two scenarios – hydrology (this governs over seismic)
    - Base case - SC19 – PMF plus MD breach (60 minutes)
    - Sensitivity case – SC3 – PMF plus MD breach (10 minutes)

<table>
<thead>
<tr>
<th>Scen ID</th>
<th>Building Damage</th>
<th>Contents Damage</th>
<th>Total Damage</th>
<th>Number Fatalities</th>
<th>Max Ind Ann P[F]</th>
<th>Incremental Consequences</th>
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<tr>
<td>SC19</td>
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<td>$3.9</td>
<td>$10.1</td>
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<td>$12.1</td>
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<td>1.9E-01</td>
<td>$5.3</td>
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</table>
## Consequence Classification – Middle Dam

<table>
<thead>
<tr>
<th>Dam failure consequences classification</th>
<th>Population at risk</th>
<th>Loss of life</th>
<th>Environment and cultural values</th>
<th>Infrastructure and economics</th>
</tr>
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<tbody>
<tr>
<td>Significant</td>
<td>Temporary only²</td>
<td>Low potential for multiple loss of life.</td>
<td>No significant loss or deterioration of (a) important fisheries habitat or important wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is highly possible.</td>
<td>Low economic losses affecting limited infrastructure and residential buildings, public transportation or services or commercial facilities, or some destruction of or damage to locations used occasionally and irregularly for temporary purposes.</td>
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<tr>
<td>High</td>
<td>Permanent³</td>
<td>10 or fewer</td>
<td>Significant loss or deterioration of (a) important fisheries habitat or important wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is highly possible.</td>
<td>High economic losses affecting important infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to scattered residential buildings.</td>
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<tr>
<td>Very high</td>
<td>Permanent³</td>
<td>100 or fewer</td>
<td>Significant loss or deterioration of (a) critical fisheries habitat or critical wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is possible but impractical.</td>
<td>Very high economic losses affecting important infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas.</td>
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</tbody>
</table>
Consequence Classification

Lower Dam
- Assumes cascading failure of Middle Dam to Lower Dam
- Affected areas
  - Area downstream of Lower Dam
- Population at Risk.
  - Permanent (populated area below Lower Dam)
- Environmental and Cultural
  - Significant loss of important wildlife habitat (not critical) downstream important (not critical) fish habitat for salmon in the lower Chase River.
  - Restoration or compensation is highly possible.
  - Unique landscapes or sites of cultural significance?
Consequence Classification

Lower Dam

- Consequences – Loss of Life; Infrastructure and Economic
  - Two scenarios
    - Base case - SC13 – PMF plus MD breach (60 minutes), LD breach (120 min)
    - Sensitivity case – SC14 – PMF plus MD breach (10 minutes), LD breach (10 min)
Consequence Classification

**Lower Dam** Base case - SC13 – PMF plus MD breach (60 min.), LD breach (120 min)
Consequence Classification

Lower Dam Sensitivity case – SC14 – PMF plus MD breach (10 min), LD breach (10 min)
Consequence Classification

**Lower Dam**  Ref – Schedule 1, BC Dam Safety Regulation

- Consequences – Loss of Life; Infrastructure and Economic
  - Two scenarios
    - Base case - SC13 – PMF plus MD breach (60 minutes), LD breach (120 min)
    - Sensitivity case – SC14 – PMF plus MD breach (10 minutes), LD breach (10 min)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Building Damage</th>
<th>Contents Damage</th>
<th>Total Damage</th>
<th>Number Fatalities</th>
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<th>Incremental Consequences</th>
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<td>SC14</td>
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<td>$5.5</td>
<td>$15.0</td>
<td>1.12E+01</td>
<td>6.40E-01</td>
<td>$8.2 $1.1E+01 $6.3E-01</td>
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## Consequence Classification – Lower Dam

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<td>(b) rare or endangered species, or</td>
<td></td>
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<td></td>
<td></td>
<td>(c) unique landscapes or sites of cultural significance, and</td>
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<td></td>
<td>restoration or compensation in kind is possible but impractical.</td>
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</table>
- Apply risk assessment to each remediation option under consideration.
- Demonstrate justification for variation from the Traditional Standards-based Criteria, if Risk-Informed performance targets are met.
Middle Dam.

- Traditional Standards-Based Requirements - HIGH
  - Flood (design for capacity $1000 \text{ year} + \frac{1}{3}(\text{PMF-1000}\text{year})) \sim 125\text{m}^3/\text{sec}$ requirement,
    - current cap $62\text{ m}^3/\text{sec}$
  - Earthquake (design for 2475 period event)
    - Current - est $70\%$ failure likelihood in 975 EQ, $30\%$ likelihood in 475 EQ

- Options Under Consideration
  - As-is, (w/ LD spillway improvement)
  - Spillway upgrade (w/ LD spillway improvement)
  - Seismic buttress (w/ LD spillway improvement)
Middle Dam.

Options Under Consideration

- As-is, (w/ LD spillway improvement)
- Spillway upgrade (w/ LD spillway improvement)
- Seismic buttress (w/ LD spillway improvement)
## Dam Remediation Approach

### Middle Dam.

- Incremental Consequences (Risk Assessment)
- As-is

### For Labyrinth Lower Dam and no Middle Dam Change

<table>
<thead>
<tr>
<th>Storm</th>
<th>Breach</th>
<th>P[Middle Dam]</th>
<th>P[Low</th>
<th>Mid]</th>
<th>P[Scenario]</th>
<th>Rep Scenario(s)</th>
<th>Damage</th>
<th>Fatalities</th>
<th>Ind Risk</th>
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</thead>
<tbody>
<tr>
<td>PMF</td>
<td>Middle Dam only</td>
<td>1.90E-05</td>
<td>1.90E-05</td>
<td>0.95</td>
<td>1.81E-05</td>
<td>SC19</td>
<td>$ 3.4</td>
<td>3.8E-01</td>
<td>5.0E-02</td>
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<tr>
<td></td>
<td>Middle Dam &amp; Lower Dam</td>
<td>0.05</td>
<td>9.50E-07</td>
<td>1.00</td>
<td>7.31E-04</td>
<td>SC13</td>
<td>$ 2.5</td>
<td>1.0E+00</td>
<td>1.0E-01</td>
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<tr>
<td>1000 yr</td>
<td>Middle Dam only</td>
<td>7.50E-04</td>
<td>7.31E-04</td>
<td>1.00</td>
<td>7.31E-04</td>
<td>SC11</td>
<td>$ 0.9</td>
<td>8.8E-02</td>
<td>8.3E-03</td>
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<tr>
<td></td>
<td>Middle Dam &amp; Lower Dam</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>1.00</td>
<td>0.00E+00</td>
<td>SC12</td>
<td>$ 2.7</td>
<td>2.3E-01</td>
<td>3.3E-02</td>
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<tr>
<td>100 yr</td>
<td>Middle Dam only</td>
<td>3.50E-03</td>
<td>2.75E-03</td>
<td>1.00</td>
<td>2.75E-03</td>
<td>SC18 (35% of SC17)</td>
<td>35%</td>
<td>$ 1.7</td>
<td>2.5E-02</td>
</tr>
<tr>
<td></td>
<td>Middle Dam &amp; Lower Dam</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>1.00</td>
<td>0.00E+00</td>
<td>SC17</td>
<td>$ 4.9</td>
<td>7.0E-02</td>
<td>1.0E-02</td>
</tr>
<tr>
<td>Seismic</td>
<td>Middle Dam only</td>
<td>4.50E-03</td>
<td>0.53</td>
<td>2.40E-03</td>
<td>2.40E-03</td>
<td>SC16 (10% of SC1)+LowR</td>
<td>10%</td>
<td>$ -</td>
<td>8.2E-03</td>
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<tr>
<td></td>
<td>Middle Dam &amp; Lower Dam</td>
<td>0.47</td>
<td>2.10E-03</td>
<td>30%</td>
<td>2.10E-03</td>
<td>SC15 (30% of SC17)+Low</td>
<td>30%</td>
<td>$ 1.5</td>
<td>2.2E-02</td>
</tr>
</tbody>
</table>

### Conditional Incr Conseq

<table>
<thead>
<tr>
<th>Damage</th>
<th>Fatalities</th>
<th>Ind Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ 0.01</td>
<td>2.1E-04</td>
<td>2.4E-05</td>
</tr>
</tbody>
</table>

April 29, 2014
# Dam Remediation Approach

## Middle Dam.

- **Incremental Consequences (Risk Assessment)**
- **Spillway upgrade**

## For Labyrinth Lower Dam and Middle Dam spillway

| Storm  | Breach                 | P[Middle Dam] | P[Low|Mid] | P[Scenario] | Rep Scenario(s) | Damage  | Fatalities | Ind Risk |
|--------|------------------------|---------------|----------|-------------|-----------------|----------|------------|----------|
| PMF    | Middle Dam only        | 6.00E-06      | 0.83     | 4.98E-06    | SC19            | $ 3.4    | 3.8E-01    | 5.0E-02  |
|        | Middle Dam & Lower Dam | 0.17          | 1.02E-06 | SC13        |                 | $ 2.5    | 1.0E+00    | 1.0E-01  |
| 1000 yr| Middle Dam only        | 0.00E+00      | 1.00     | 0.00E+00    | SC11            | $ 0.9    | 8.8E-02    | 8.3E-03  |
|        | Middle Dam & Lower Dam | 0.00E+00      | 0.00E+00 | SC12        |                 | $ 2.7    | 2.3E-01    | 3.3E-02  |
| 100 yr | Middle Dam only        | 0.00E+00      | 1.00     | 0.00E+00    | SC18 (35% of SC17) | 35% | $ 1.7       | 2.5E-02  | 3.6E-03  |
|        | Middle Dam & Lower Dam | 0.00E+00      | 0.00E+00 | SC17        |                 | $ 4.9    | 7.0E-02    | 1.0E-02  |
| Seismic| Middle Dam only        | 4.50E-03      | 0.53     | 2.40E-03    | SC16 (10% of SC1)+LowR | 10% | $ -         | 8.2E-03  | 4.0E-05  |
|        | Middle Dam & Lower Dam | 0.47          | 2.10E-03 | SC15 (30% of SC17)+LowR | 30% | $ 1.5       | 2.2E-02  | 3.1E-03  |
|        |                        |               |          |             |                 | $ 0.00   | 6.9E-05    | 6.9E-06  |

*Conditional Incr Conseq*
## Dam Remediation Approach

**Middle Dam.**
- Incremental Consequences (Risk Assessment)
- Seismic buttress

### For Labyrinth Lower Dam and Middle Dam buttress

<table>
<thead>
<tr>
<th>Storm</th>
<th>Breach</th>
<th>P[PMF Middle Dam]</th>
<th>P[Low</th>
<th>Mid]</th>
<th>P[Scenario]</th>
<th>Rep Scenario(s)</th>
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<td>0.95</td>
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<td>SC19</td>
<td></td>
<td>$3.4</td>
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<tr>
<td></td>
<td>Middle Dam &amp; Lower Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$2.5</td>
<td>1.0E+00</td>
<td>1.0E-01</td>
</tr>
<tr>
<td>1000 yr</td>
<td>Middle Dam only</td>
<td>7.50E-04</td>
<td>1.00</td>
<td>7.31E-04</td>
<td>SC11</td>
<td></td>
<td>$0.9</td>
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<td></td>
<td>Middle Dam &amp; Lower Dam</td>
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<td>100 yr</td>
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<td>1.00</td>
<td>2.75E-03</td>
<td>SC18 (35% of SC17)</td>
<td>35%</td>
<td>$1.7</td>
<td>2.5E-02</td>
<td>3.6E-03</td>
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<td>SC17</td>
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<td>$4.9</td>
<td>7.0E-02</td>
<td>1.0E-02</td>
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<tr>
<td>Seismic</td>
<td>Middle Dam only</td>
<td>2.80E-03</td>
<td>0.00</td>
<td>0.00E+00</td>
<td>SC16 (10% of SC1)+LowR</td>
<td>10%</td>
<td>-</td>
<td>8.2E-03</td>
<td>4.0E-05</td>
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<td>$0.01</td>
<td>2.0E-04</td>
<td>2.6E-05</td>
</tr>
</tbody>
</table>
Dam Remediation Approach

Middle Dam. – Seismic (fast breach)
Middle Dam.

- Proposed remediation
  - Select option, based on
    - Preliminary results indicate that ALARP Principle applies (i.e., above Acceptable condition)
    - Which option (Spillway, Buttress or nothing), gives greatest risk reduction.
      - Life safety
      - Economic
      - Environmental and cultural
  - Other considerations
    - Cost
    - Environmental – during construction and permanent
    - Aesthetic, Park use, etc
Dam Remediation Approach

- **Lower Dam.**
- **Traditional Standards-Based Requirements**
  - **Flood** - design for capacity
    - 1000 year + \( \frac{1}{3}(PMF-1000\text{year}) \) ~ 125m³/sec requirement, (HIGH);
    - 1000 year + \( \frac{2}{3}(PMF-1000\text{year}) \) ~ 143m³/sec requirement, Very High
    - current cap 35 m³/sec
  - **Earthquake**
    - design for 2475 period event) – HIGH;
    - \( \frac{1}{2} \) between 2475 and MCE (Very High)
    - Current seismic resistance – under analysis
Dam Remediation Approach

- Lower Dam.
- Options Under Consideration
  - Spillway upgrade (135 and 175 m³/sec capacity)
  - LD hardening
Dam Remediation Approach

- **Lower Dam.**
- **Proposed remediation**
  - Flood capacity requirement, select option based on (TC requirements)
    - Cost
    - Environmental – during construction and permanent
    - Aesthetic, Park use, etc
    - Additional capacity needed for future requirements, additional risk reduction?
  - **Seismic**
    - Complete analyses (FLAC and structural)
    - Determine incremental consequences for dam in as-is condition (risk assessment).
    - Assume dam is damaged by EDGM, and would require removal/reconstruction after event
- **Other – make use of other mitigation measures**
  - E.g. instrumentation and rapid drawdown capabilities
  - Early warning system
Next Steps

- Complete seismic assessment of Lower Dam
  - Determine consequences
- Complete risk assessment
- Confirm dam remediation requirements
- Lower Dam – preliminary design and costing of options – May 8
- Middle Dam – conceptual design and costing of options – May 8 (target)