January 21, 2014

Middle and Lower Chase River Dams Progress Update
Agenda

- Data Review Findings
  - Review of Historical Information
  - Seismic Hazard Assessment Review
  - Performance of Concrete Dam Core
  - Hydrology Study Review
- Data Gaps and Design Unknowns
- Dam System
- Risk Assessment Update
- Conceptual Design Options
- Next Steps
  - Additional Investigations
  - Geophysics Update
  - Additional Studies
Data Review Findings – Middle Dam

Early years

- 1888: Built by logs to supply water for the city?
- ~1910: Concrete dam constructed by Western Fuel Company/ Wellington Colliery/ Harewood Colliery for coal wash water?
- Former presence of railway line/ spur lines from Harewood Mine to Coal wharves suggests dams built with rock fill <0.6 m dia. from mine. Photos of the rock fill on the upstream and downstream side of the Middle Chase Dam during the 1980 rehabilitation works, indicates the rock fill particle size is generally <0.6 m dia.
- ~1950: Additional fill material added to DS face by end dumping with little/no compaction - Debris (car parts) limited presence.
- Nov 1955: Flooding (heavy rain) problems on Chase River likely occasion that prompted hole made in dam to increase discharge capacity of reservoir.

1976 and 1977 (Dam Inspections)

- Seepage on right abutment contact 3-5 cfs and seepage at DS toe of 2-3 cfs
- Serious piping may be present in the center of the embankment or LLO.
- Underwater inspection – heavy silt conditions. 2” pipe found-old valve stem?
September 1, 1976 Inspection

Seepage along right abutment contact – scap material in embankment

Typical Reinforcing used in dam – car springs, railway rails, drill steel
1978 (Dam Investigation – Golder)
- Test pit (TP) and borehole (BH) investigation (Golder – basis of 1980 work)
- Top soil and bedrock in 2 TPs. Loose gravel, trace sand and silt and loose to compact sand and gravel some clayey silt, cobbles and boulders in 2 TPs.
- Loose to compact sand and gravel, cobbles and boulders (fill) followed by rock fill encountered in BH investigation.
- Till-like material encountered at 12.5 m depth in 1 BH.

1980 (Dam Investigation and Remediation)
- 300mm high concrete addition placed on upstream face concrete wall
- Hole in concrete core (from 1955) patched
- Saturated material was removed and the 3’ thick drainage blanket was placed, shot rock buttress placed ontop
- Digging continued until a intact log crib was exposed. LLO not located.
- Replacement of DS fill in 12-18” lifts. Compacted and verification testing.
- Heavy seepage at DS toe at temporary weir. Drainage trench to intercept seepage.
- New concrete spillway walls and new walkway over spillway.
August 22, 1980 Inspection

Concrete plug from upstream face after stripping

Original log crib exposed – logs were still intact
Data Review Findings – Middle Dam

1981 and 1982 (Dam Inspections)
- Seepage noted at DS toe both years

1983 to 1986 (EBA Assessment of Increase in Seepage 1993)
- City records indicate depth of water over weir 25 to 32 mm. -> 3.7 to 5.1 l/s

1985, 1986 and 1987 (Dam Inspections and Improvements)
- Concrete spillway wall extension to direct flows away from toe and concrete weir replaced temporary weir
- Minor seepage from contact between old and new walls of spillway. Spalling.
- Erosion and undercutting of hillside on left side of spillway. Erosion near toe and along right abutment contact

1992 (Dam Inspection)
- Seepage on right abutment and through right channel wall. Flow through seepage weir (Dec 1) was ~0.3cfs

1993 (Seepage Monitoring and Assessment of Increase in Seepage - EBA)
- Seepage at 2 areas on DS shell near contact with right abutment mid-way up dam. 2 pipes installed to collect water from main seepage and sump installed downhill of pipe discharge to collect material from seepage flow.
Data Review Findings – Middle Dam

1993 (Seepage Monitoring and Assessment of Increase in Seepage - EBA)

- First pipe installed early Sept:
  - Sep 18-Oct 3: flows 0 to 24 l/min, Sept 28- Oct 2: weight of dried sediment 23.1 to 189.5 gms (fine to coarse sand with trace fine gravel)

- Second pipe installed early Oct:
  - Oct 5: flow 1 l/min (first pipe), flow 30 l/min (second pipe)
  - Combined flow both pipes decreased end of Oct from total flow of 50 l/min to 20 l/min. Carried material decreased from 20 gms/day to <10 gms/day

- City records (1992-1993) indicate depth of water over weir 32 to 64 mm. -> 5.1 to 14.4 l/s.

- EBA notes general increase in flow over past 10 years
  - EBA suggests deterioration along bedding planes in bedrock
  - Loss of fines from embankment

- Seepage at 3 locations: near DS end of concrete training wall along right side of spillway - bedding plane 0.2 m below this interface, bedding plane approx. mid-height of the embankment at the right abutment contact, approx. rock fill 1.5 m left of the source at the right abutment contact
Data Review Findings – Middle Dam

1995 (Dam Inspection)
- Extension of concrete spillway wall and installation of wall seepage monitoring weir.

1994, 1995, 1996 (City of Nanaimo)
- Sediment and flow test spillway records

1998 (Dam Inspection)
- Visual seepage observation of 2cfs through notch left side of spillway. No seepage in upper drain pipes. Large seepage flow near toe. Gauge at weir – 4”.

2003 (Dam Inspection)
- Profiling sonar bathymetry – possible LLO and valve detected?

2004 (Dam Inspection)
- Installed concrete chamber over seepage weir and installed telemetry equipment to continuously monitor seepage.
Data Review Findings – Middle Dam

2009 (EBA Seismic Hazard Assessment)
- Diver searched for LLO. Inlet ~20 m from dam face, 9 m from right abutment.
- LLO appears to pass below the patched area in concrete (may have been valve stem)
- LLO appears to be located on left abutment of dam, appears to pass beneath the original fill that was left in place during the 1980 excavation.
- Seepage probably from abandoned LLO
- Diver inspection indicated conditions of exposed wood of LLO at the upstream end were very poor – rotted and partially collapsed. Approx. 1 m from inlet, the LLO was encased in an unknown thickness of concrete. Then buried in sediments.

2013 Anecdotal Information (email from Solomon Hunter, January 5, 2014)
- The LLO pipe at the base was thought to be black cast iron probably 30" or 36". The pipe was not visible from the upstream side but was visible on the downstream face (there was no berm behind the dam).
- The valves to operate the pipe were probably inoperable sometime in the 1950's and eventually removed.
Data Review Findings – Lower Dam

Early Years

- 1887: 5.5 m high built by log cribbing to supply water for the city?
- ~1910: concrete dam constructed by Wester Fuel Company/ Harewood Colliery/ Wakesiah Colliery?
- Former presence of railway line/ spur lines from Harewood Mine to Coal wharves suggests dams built with rock fill <0.6 m dia. from mine. Photos of the rock fill on the upstream and downstream side of the Middle Chase Dam during the 1980 rehabilitation works, indicates the rock fill particle size is generally <0.6 m dia.
- 1918 Railway constructed over the Dam, fill added to permit crossing at orientation not parallel to concrete wall
- ~1918 Slag, cinders, sand and gravel very loose to loose fill end dumped on downstream side

1978 Investigation

- Test pit (TP) and borehole (BH) investigation (Golder – basis of 1980 work)
- Loose cinders, slag, sand and gravel fill 4 TPs and 4 BHs. Rockfill 1 TP and 4 BHs. Till-Like Material in 2 TPS and 1 BH.
1978 Investigation (continued)

- Till-like material encountered at 14.9 m depth in BH9.
- No Bedrock encountered below dam.
- Concrete wall 0.3 m thick to 0.6 m below crest and then increase to 1.2 m thick.
- 3 control valves encountered, two near concrete wall third few meters upstream.
- Coarse rockfill, encountered voids (up to 0.3 m in size)
- Assumed abutments founded on till-like material due to 1 borehole in center and two test pits at edge of right abutment
- No Bedrock encountered below dam, dam on steep sided ravine

1980 (Dam Inspection and Improvement)

- 2 LLO plugged with concrete and all valves chambers filled and capped with concrete
- Poor concrete was removed and replaced on spillway, spillway founded on bedrock
- Spillway walls raised by 300 mm
Data Review Findings – Lower Dam

1980 (Dam Inspection and Improvement continued – Photos below)

- Stabilizing sand and gravel toe berm constructed
- Seepage collection trench installed at toe and backfilled with drain rock
- Crack noted in cinders, slag sand and gravel deposit at crest of filter berm and monitoring commenced

1981 (Dam Inspection)

- Erosion observed on left abutment (no inspection or repair report)

Close up view of crack

Stabilizing berm viewed from left abutment

Drain rock toe drain used to pick up embankment seepage
Data Review Findings – Lower Dam

1983 (Dam Inspection)
- Seepage noted on left side of spillway.
- Noted that sandbagging had been required in recent years at intake to prevent overtopping of spillway walls

2003 (Dam Inspection and Improvement)
- Staff gauge installed to measure reservoir level along with precipitation gauge
- Seepage estimated from flow in seepage collection trench

2009 (reported by EBA)
- Diver visual observation of rockfill at surface of upstream shell

2013 (reported by Klohn)
- GPR – evidence of vertical rebar near the centre of the 1.2 m thick wall at ~760 mm spacing for short distance above water level only
- Coring – evidence of ~16 mm horizontal square twist bars on ~760 mm intervals at center of core
- Minimal reinforcing evidence – general reinforcing or dowels used at cold joints between concrete pours
Section A-A’ – Middle Dam
Section B-B’ – Middle Dam
Section C-C’ – Lower Dam
Section D-D’ – Lower Dam
Seismic Hazard Assessment Review

- Parametric 2D analysis carried out by EBA (April 2010), based on 3 assumed scenarios
  - Best case scenario material properties reasonably assumed
  - Reasonably worst case scenario material properties assumed
  - Most likely case scenario material properties assumed based on available data and engineering judgment

- Friction angle and shear modulus numbers based on SPT “N” values available for Rock Fill, Sand/Gravel and Cinder/Slag.

The dam till-like foundation parameters used for analysis not clear
Safety of the dams are controlled by the concrete walls.

Concrete wall was modelled assuming “elastic and inelastic (moment capacity) beam” behavior for analyses. The effective moment of inertia of the wall was selected as 20% of the value for the cross section and damping ratio was set to 20%.

- No concrete/soil interface taken into account
- Cracking of the concrete core requires further study
  - Does cracking of the concrete core = failure?
- Dynamic analyses performed in time domain using the acceleration response spectrum (earthquake motions) for a design event of 1:3000 per annum for dam sites (similar to design event - Vancouver 1:2475)
  - 1:10,000 event would require another seismology study
- Groundwater level in DS shells assumed to be within 0.5 m above base of dams
- Analyses with concrete wall of plastic moment capacity showed large residual displacements of the wall towards upstream
- The dam may be damaged in an earthquake with lower excitation levels (return-period) that was not investigated by EBA fully
Deformed shape of wall (exaggerated) towards reservoir (Most likely case scenario)

- Illustrates effect of inelastic behavior of concrete walls on deflections. Moment capacities of 150 and 600 KN were used for 0.6 and 1.2 m wide dams, respectively. This is the most critical case.

- Contours of Total displacement, deformed shape of concrete wall and its top deflection (m) for Most Likely case
How does concrete core behave during seismic event

- Toppling, or shearing?
- Cracking, and what is the extent of cracking – effectiveness as a water barrier

Lower Dam.
- Much smaller deformations, thicker concrete section – significant cracking, but maintain containment?

Middle Dam
- Toppling or shearing more likely
  - Loss of containment?
Data Gaps and Design Unknowns – Middle Dam

- Condition of all fills. Some “old” fill left in near spillway (?)
- LLO location still unknown
- Design Criteria for materials in the dam
  - Fill - “new fill” well compacted so should have competent fill properties (can reasonably be estimated)
  - “Old fill” - unknown and questionable, possibly loose (?)
  - Concrete wall – thought to have reinforcement steel (?)
- Performance under earthquakes not established
  - Seismic resistance calculations carried out – need to be verified
- Wall toppling /deformation need to be confirmed. Does Middle core wall topple (?)
  - Seepage from wall if damaged needs to be confirmed
- Performance under floods not established
  - Review of estimated floods needs to be verified
- Capacity of spillway needs to verified
- Fault associated with Chase River Valley
Data Gaps and Design Unknowns – Lower Dam

- Design Criteria for materials in the dam not established
  - Presence and condition of rockfill unknown
  - Presence and condition of ash fill unknown
  - Condition of compacted berm known due to construction records
- Performance under floods not established
  - Review of estimated floods needs to be verified
- Capacity of spillway needs to be verified
Current condition of concrete core
  How effective is the current containment
    Current seepage rates,
    Changes in seepage rates over time?

Thickness of walls

Concrete Reinforcement
  Spacing
  Condition of reinforcement

Concrete condition
  Uniformity – weak spots, weak filler materials, etc
  Cold joints, etc

Dam core will crack under seismic shaking (size of crack (??))

What is seepage through cracks (?)
  With cracks will short term piping cause dam failure (?)
## Hydrology Study Review

<table>
<thead>
<tr>
<th>Item</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Other hydraulic structures</td>
<td>• It appears the influence of other hydraulic structures upstream of the Middle Dam have been ignored. These include two other dams and Hwy 19 (Nanaimo Parkway).</td>
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<tr>
<td>CN = 95</td>
<td>• A very high curve number for such an undeveloped basin.</td>
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<td>• Basin predominately forested.</td>
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<td>• CN&lt;sub&gt;AMCIII&lt;/sub&gt; for forest in good condition ranges from 43 to 89 depending on hydrologic soil group.</td>
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<tr>
<td></td>
<td>• No information about hydrologic soil group(s) provided.</td>
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<tr>
<td>Section 4.2</td>
<td>• Refers to this section for discussion on the high CN.</td>
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Hydrology Study Review

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<td>CN = 95</td>
<td>• This is the explanation referred to in Section 4.1. Does not provide technical justification for the use of the high Curve Number.</td>
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</table>
## Lag = 47 Minutes
- This is a quick lag for a 19 sq-km basin. However, may be valid due to steep topography.

## Baseflow
- 5 cms from 19 sq-km basin.
- 2 cms from 1 sq-km basin.
- Assume that total baseflow to Lower Dam adds to 7 cms.
- Lower dam reported total spillway capacity = 25 cms (baseflow takes up 28% of total capacity?).
- Utilizing weir equation and parameters given in this report for the Middle Dam spillway, 5 cms would flow at a depth of 0.4 meters. Available photos do not suggest this depth of base flow.
Baseflow (Continued)

- How does the recent January 10-11, 2014 storm compare?
- Reported 50mm of rainfall in 9 hours.
- Lower Dam’s spillway peaked at 41 cm of depth.
- The calculated flows from this event are inconsistent with the calculated base flows (2002 report).
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| Weir Equation    | • Weir equation used to develop a rating curve for the Middle Dam spillway.  
• Acceptable, but given the contraction, bridge, pier, and irregular channel, HEC-RAS would be more appropriate to model. |
| HEC-RAS          | • Consultant states that a HEC-RAS model was created and that it predicted similar results as the weir equation.                     |
Hydrology Study Review

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<td><strong>HEC-RAS</strong></td>
<td>• HEC-RAS used to develop rating curve for the Lower Dam Spillway.</td>
</tr>
<tr>
<td>Spillway hydraulic problems</td>
<td>• HEC-RAS model predicts a hydraulic jump for all flows greater than 5 cms on the flat 1% spillway section.</td>
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<td>• What are the potential consequences associated with this flow depth exceeding the wall height?</td>
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<td>• What are some possible remedies to address these consequences?</td>
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<td>• Has this hydraulic jump been observed in the field (assume flows exceeding 5 cms are common).</td>
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<tr>
<td>Powerline Dam</td>
<td>• Powerline dam not included in drainage basin. However, subsequent December 17, 2002 study by the same consultant indicates that it does discharge into the Chase River basin.</td>
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Final Recommendations

Many other studies including preliminary designs, dam breach analyses, etc appear to be based in part on the findings and analysis of this study. If the hydrology and hydraulics (H&H) change, those changes will have ripple effects to those other studies.

Recommend that hydrology be further studied to:
• Account for upstream hydraulic structures/storage.
• Refine Curve Numbers and Lag Times.
• Refine Baseflow values.
• Verify basin delineations (Powerline Dam).

Recommend that spillway hydraulics be further studied to:
• Verify Middle Dam’s rating curve.
• Verify Lower Dam’s rating curve.
• Verify Lower Dam’s hydraulic jump caused by convergence.
• Evaluate consequences of the jump depth exceeding the Lower Dam’s spillway walls and possible ways to remedy.

Recommend a formal incremental damage assessment be performed using updated H&H info and revised breach parameters.
The two dams act as a system.
- Middle Dam fails = Lower Dam may fail
- The mechanism of failure:
  - Seismic event: core toppling and overtopping and failure
  - Flood event: overtopping and failure

Considerations
- Possible Event
- Possible Failure Mode
- Possible Consequence
- Effect Downstream
Design Issues - Summary

- The two dams act as a system.
  - Middle Dam fails = Lower Dam may fail -> dams in EXTREME Category
- The mechanism of failure:
  - Seismic event: core toppling and overtopping and failure
  - Flood event: overtopping and failure
- The control of the consequence designation is the Middle Dam.
- Under present Consequence category, it is necessary to fix the Middle dam for seismic event, check performance of the Lower dam under the new conditions, and provide flood capacity for handling the design floods. With a RISK assessment a different approach is possible.
- If the Middle Dam is fixed for seismic event (no core toppling) then the Lower dam may survive with some damage but still retain water?
- If the Middle Dam fails due to a seismic event and the lower dam is reinforced to withstand a seismic event, will the overtopping flood downstream be acceptable?
- Both dam spillways are undersized for design IDF flood even if the Consequence Category can be downgraded by fixing the Middle Dam for seismic event and ensuring that the cracking of the Lower Dam does not result in uncontrolled dam failure and flooding downstream.
Initial Conceptual Ideas – Increase Flood Routing Capacity

- Allow overtopping of the dam (reinforce downstream face of dam)
  - Roller Compacted Concrete and Soil Cement
  - Conventional/Mass Concrete Slabs
  - Precast Concrete Blocks
  - Gabions
  - Vegetative cover Reinforced and artificial turf
  - Rock fill reinforced rockfill
  - RipRap
  - Geomembranes and Geocells and fabric formed concrete
  - Open stone asphalt (possible)
  - Allu

- Increase spillway capacity
  - Reconfigure (straighten), deepen, (possible Obermeyer weir)
Roller Compacted Concrete and Soil Cement

Figure 2.—Overtopping protection with RCC placed parallel to slope (PCA, 2002).
Roller Compacted Concrete: Concrete compacted by roller compaction, concrete that in its unhardened state will support a roller while being compacted. RCC differs from soil cement (SC) in that it may have coarse aggregate and develops properties similar to conventional placed concrete.

- Generally RCC used instead of (SC) because of less strength and thicker section usually needed to provide the same security as RCC.
- Example where SC has been used is the Alvin Wirtz dam in Austin Texas – 105 ft. high dam.
- Nakusp water front protection -- ~ 30m high slope.
Mass Concrete Slabs

Figure 3.—Defensive design measures for concrete chutes to prevent uplift failure.
Figure 2.—Some common examples of precast revetment systems. (Figure courtesy of HCFC and NRCS manual.)
Precast Concrete Blocks - Continued

- Cable tied
- Interlocking
- Overlapping
- Butt-jointed

Figure 4.—Hydraulic forces on the typical cable-tied ACB system (Courtesy of Armortec, Inc.)

Figure 5.—Typical forces on a wedge-block ACB system (Courtesy of Armortec, Inc.)
Vegetative Cover

- Vegetative protection prevents erosion
- Can be natural or artificial
- Resistant fabrics can be installed in the turf to assist in resistance
- Usually for fairly low velocities and flows.
Rock fill - Reinforced rock fill

- Rock fill sizes can resist erosion
- Reinforcement done by installing rebar
- Also can be reinforced by synthetic geogrid.
Riprap

- Large size rock fragments are sized to resist erosion.
Geomembranes, Geocells and fabric formed concrete

- Synthetic fabrics and cells are frequently used to resist erosion.

Figure 1.—Examples of a perforated and solid geoweb system with various fill materials (a) Geoweb™ (Source: Presto Products Company); (b) TerraCell® (Source: WEBTEC, Inc).

Figure 2.—(a) Filter Point™ fabric form pumped with concrete (Source: Texicon and Hydrotex); (b) Filter Band™ fabric form pumped with concrete (Source: Hydrotex); (c) Uniform Section™ fabric form (Source: Hydrotex).
Geomembranes, Geocells and fabric formed concrete

Figure 4.—Typical cross-section, showing the geomembrane installation procedure along the channel.

Figure 7.—Fabric forms being filled with fine aggregate concrete. (Courtesy of Donnelly Fabricators.)
Open stone asphalt (possible)
Mass Stabilization is a **ground improvement method** for soft soil foundations where the **binder** (cement, lime etc.) is **mixed** to the treated soil. As a result of the treatment, the **strength** and **deformation** properties are **significantly improved** comparing with the original soil.

**The mass stabilization job carried out by:**

Feeding the binder by **ALLU PF** or **PFM** into the soil whilst mixing it with a **ALLU PMX** mounted on an excavator.

The process is controlled by **ALLU DAC** monitoring & control system.
Mass Stabilization - a versatile technology for:
- in-situ improving of soft soils
- remediation of contaminated soils
- improving and utilizing clean and contaminated soft sediments
Mass Stabilization

THE COMPLETE ALLU MASS STABILIZATION SYSTEM

ALLU DAC Control System
ALLU PF Pressure feeder

ALLU PMX Power Mixer
Buttress upstream of Middle Dam to limit deformations
Find and fill low level outlet

Conceptual Upstream Buttress

Middle Dam Cross-Section (EBA, 2010).
Buttress upstream on Lower Dam to limit deformations if needed

Lower Dam Cross-Section (EBA, 2010).
Conceptual Design Options - Dam Stabilization

- Install additional barrier (Middle or Lower Dams) – if needed
  - Liner
    - PVC
    - Coletanche
    - GCL
    - Bitumen

Lower Dam Cross-Section (EBA, 2010).
Next Steps – Additional Information

- Collect and re-evaluate existing information.
- Assess need for any additional geotechnical information
  - Geophysical survey on surface of downstream and cores of both dams
    - Borehole or test pit investigations (mid-February)
      - Collect information on properties of dam fills
      - Collect information on dam foundations
      - Install water level monitoring instruments
      - Determine dam zonation
- This information needed for design
  - Basis for analysis
    - Input to numerical modelling
    - Piping assessment, etc
- This information needed for construction and tendering
- Additional information on concrete core (re-inforcement)?
Next Steps – Additional Information

- Additional information on concrete core
  - Concrete quality
  - Concrete uniformity
  - Reinforcement
    - Spacing, condition
- Proposed program
  - Multiple, fully cored holes through core into foundation
  - Downhole geophysics
    - Information on concrete strength, rebar and concrete thickness
Proposed Boreholes – Lower Dam

- Proposed Borehole (sonic)
- Proposed Corehole (diamond drill)

- SH14-10
- SH14-11
- CH14-13
- CH14-14
- CH14-15
- CH14-16
- CH14-17
- CH14-18
Geophysics Survey Lines-Middle Dam

- Geophysical Survey Coverage consists of **8 GPR profiles**:
  - **Downstream Face (5 profiles) –**
    - 2 profiles from toe to crest
      - Profile nearest the spillway also acquired with the higher-powered/lower frequency GPR system;
    - 3 cross-profiles within lower 20 m of face to focus on LLO;
  - **Crest of Dam (3 profiles) –**
    - one each near the upstream and downstream edges of the crest;
    - one on top of concrete wall.
Geophysics Survey Lines-Lower Dam
Geophysical Survey Coverage consists of 9 GPR profiles & 2 Seismic Profiles:

**Downstream Face (3 GPR profiles, 2 coincident seismic profiles)** –
- 2 profiles from toe to crest near the middle (L-1 & L-2)
  - North Profile (L-1)-Lower Half- also acquired with the higher-powered/lower frequency GPR system
  - L-1 also covered by seismic (MASW and refraction);
- 1 cross-profile (L-3) along “bench” across middle of downstream face – GPR and seismic (MASW and refraction);

**Crest of Dam (7 GPR profiles)** –
- 1 along downstream edge (~1.5 m from fence, 95 m long);
- 3 traversing the peninsula (2 west-east, 1 north-south);
- 3 traversing suspected buried wall (2 are extensions of peninsula profiles);
- 1 crossing width of crest—extending L-1;
- 1 along top of concrete wall
Geophysics Survey - Objectives: To-Date Status

- Profile internal layering of middle and lower dams:
  - GPR profiles show some internal layering within both dams (GPR data still to be processed and interpreted);
  - Radar depth of penetration – To Be Determined;

- Identify “water table,” and other possible variations in water saturation, within middle and lower dams (if conditions allow):
  - To Be Determined;

- Profile underlying foundation (bedrock or till interface):
  - Middle Dam – Appears that GPR profile may track bedrock to ~20-25 m up the face from the toe (outcrop observed at the toe). Depth to be determined (GPR data still to be processed and interpreted). Note—the distanced along face from toe to crest is ~40 m;
  - Lower Dam – Does not appear that GPR reached the base; however, one or both of the seismic refraction lines appear to profile bedrock or till. All data still to be processed and interpreted;
Geophysics Survey - Objectives:

To-Date Status

- Characterize amount of reinforcement (such as rebar) within the concrete wall as discernable from the top of the wall along the dam crest:
  - **Both Dams** – Depths of radar penetration to be determined (possibly to ~2 m). *GPR data yet to be processed and interpreted*;
  - **Middle Dam** – Possibly see 2 or 3 horizons of rebar (shallowest rebar spaced approximately 0.8 m).
    - Possible layering is apparent (possibly 4 interfaces w/in depth range);
    - Anomalously reflective zones – suggest possible variations in moisture content and/or other properties;
  - **Lower Dam** – Rebar not immediately obvious; however a variety of internal structures are apparent—possibly irregularly spaced rebar and nonexistent in some sections.
Geophysics Survey - Objectives: To-Date Status

- **Middle Dam**—Attempt a limited search of the Low-Level-Outlet (LLO) within the lower down-stream face:
  - GPR data yet to be processed and interpreted;
  - Expect that identifying LLO is unlikely, due to variable ground fills and topography that complicate the images.

- **Lower Dam**—Confirm location/existence of buried concrete core-wall through peninsula and obtain information regarding peninsula fill material:
  - GPR data yet to be processed and interpreted (acquired 3 profiles across expected buried wall);
  - Field plots suggest that the wall is visible, however, it is not obvious due to existence of what appear to be adjacent “blocks of material” (poss. including boulders/cobbles) within the fill that produce similar radar signatures.
  - Within peninsula, material appears to be mostly coarse with 1 or 2 distinct layers.
Geophysics Survey - Objectives: To-Date Status

- Lower Dam--Obtain general seismic shear-wave velocity (Vs) versus depth (1-D) profile (from MASW—Multichannel Analysis of Surface Waves):
  - Depth extent of these values to be determined – data yet to be processed and interpreted.

- Lower Dam– Additionally, obtain general seismic refraction (compression-wave) profiles (2-D), coincident with the two MASW profiles, to further explore basal profile of dam:
  - Field records suggest sharp bedrock signal w/in northern half of dam, possibly stepping down deeper w/in southern half of dam – data yet to be processed and interpreted.
Next Steps

- Hydrology and hydraulics
  - Recommend that hydrology be further studied to:
    - Account for upstream hydraulic structures/storage.
    - Refine Curve Numbers and Lag Times.
    - Refine Baseflow values.
    - Verify basin delineations (Powerline Dam).
  - Recommend that spillway hydraulics be further studied to:
    - Verify Middle Dam’s rating curve.
    - Verify Lower Dam’s rating curve.
    - Verify Lower Dam’s hydraulic jump caused by convergence.
    - Evaluate consequences of the jump depth exceeding the Lower Dam’s spillway walls and possible ways to remedy.

- Evaluate dam breach characteristics - Time to failure
  - Breach by overtopping – several scenarios
  - Breach due to seismic shaking – several scenarios
Next Steps

- Seismic analyses
  - Conduct site investigations (concrete core, embankments)
  - Evaluate integrity of core – decision point
  - Evaluate seismic resistance of core
    - FLAC analyses – deformation of dam – several scenarios
    - Evaluate response of concrete core – cracking (Herold Engineering)
    - Resistance (post cracking) – potential for dam breach
- Lower Dam and Middle Dam
  - Middle Dam, with upstream buttress
- Evaluate other Failure modes
  - Piping, static failure
- Updated Inundation Modelling - AE
  - Updated Hydrology, dam breach scenarios
- Updated Damage Assessment – Golder

Based on updated inundation models
Next Steps

- Risk Assessment
  - Develop risk model
  - Develop risk inputs
    - Initial risk workshop – subjective inputs (based on current studies)
    - Subsequent risk inputs – based on analyses outlined above.
  - Risk modelling – use to inform selection of remediation options
    - Remediate both dams, or Lower Dam only
    - Inflow Design Flood (IDF) requirements
    - Requirements for design for seismic resistance
Next Steps

- Develop design (dam remediation) options
  - Spillways
    - Spillway improvement options
    - New spillway options
  - Designs for dam overtopping
  - Buttressing of dams
  - Preliminary cost estimates