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# Board briefing – DAM SAFETY QUARTERLY REPORT

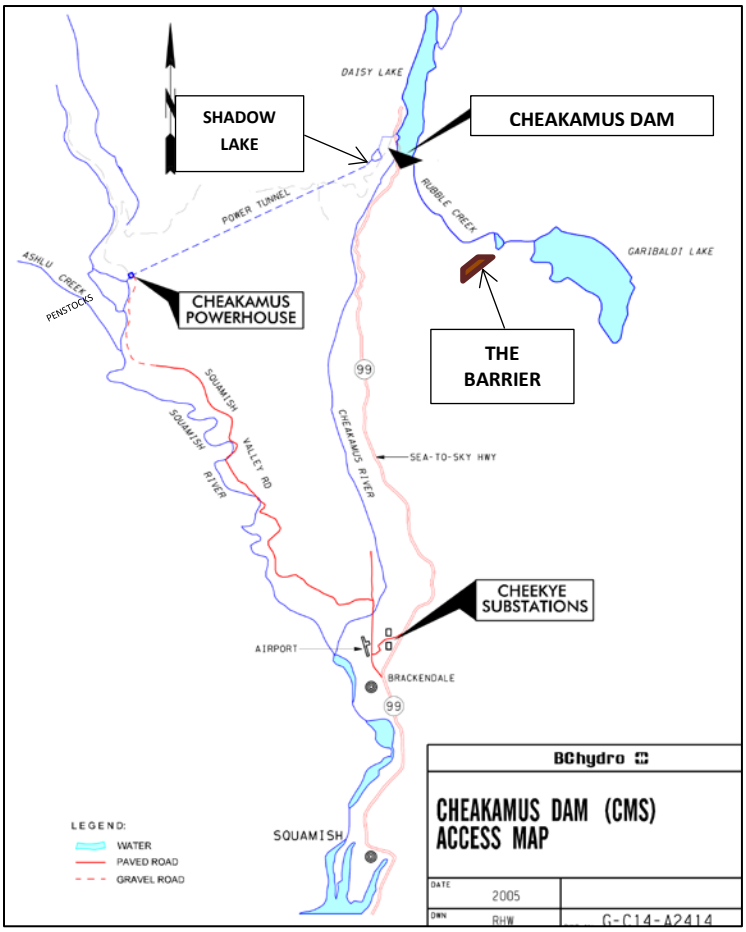
## Executive summary

The purpose of this report is to update the Capital Projects Committee of the Board of Directors on key dam risk management activities during the period from October 1, 2015 to December 31, 2015, and to provide reasonable assurance that the safety of dams operated by BC Hydro continues to be managed to the established guidelines and criteria of the Dam Safety program.

The Dam Safety Program has been carried out consistent with its stated objectives throughout the reporting period. The overall Dam Safety risk profile is shown in Figure 1. There has been no change to the risk profile this quarter.

## Quarterly Featured Damsite – CHEAKAMUS PROJECT

The Cheakamus project is located on the Cheakamus River about 35 kilometres north of Squamish, B.C. Six dams were constructed between 1954 and 1957 to impound Cheakamus River and form Daisy Lake Reservoir and Shadow Lake. These dams provide storage for power generation at Cheakamus Generating Station. Water is diverted from the Daisy Lake reservoir by a canal to Shadow Lake and then via a tunnel and penstocks to a powerhouse located on the left bank of the Squamish River.

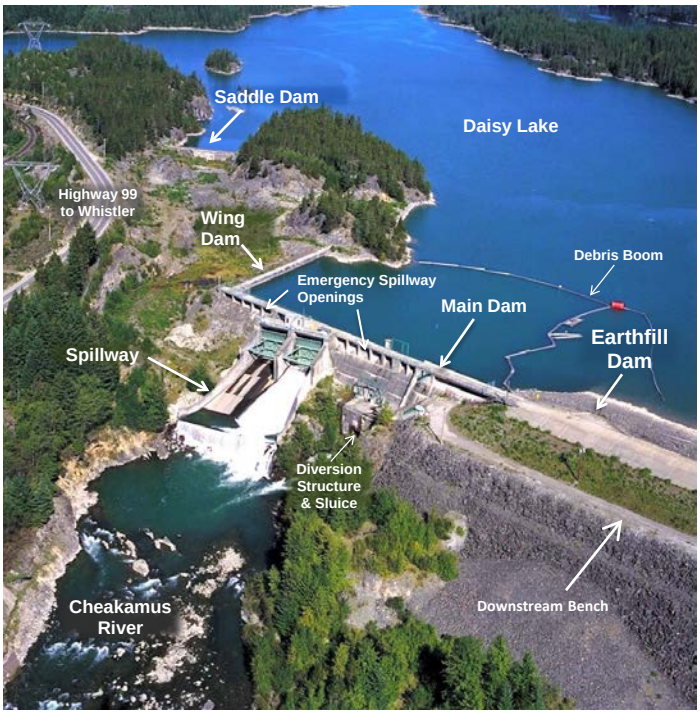



*Cheakamus location*

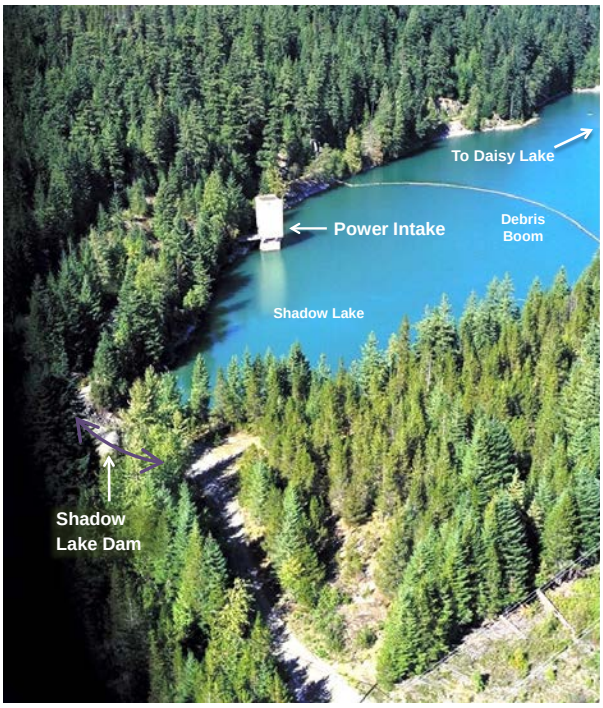
The Daisy Lake reservoir is retained by four dams, three of which make up the Cheakamus dam component: the Main Concrete Dam (140 metres long, 27 metres maximum height), the Earthfill Dam (435 metres long, 29 metres maximum height) adjoining the left side of the Main Dam, and the Wing Dam (86 metres long, 15 metres maximum height) adjoining the right side of the Main Dam. There are also two concrete gravity saddle dams located on Daisy Lake. The larger of the Cheakamus dams are classified as Extreme consequence dams.

Water is diverted from Daisy Lake by a canal to Shadow Lake where the earthfill Shadow Lake Dam and power intake structure are located. A partially lined tunnel and two steel penstocks convey water from the Shadow Lake intake through Cloudburst Mountain to the two unit, 150 MegaWatt powerhouse located on Squamish River.

The discharge facilities at the Cheakamus Dam comprise two radial spillway gates, a vertical lift sluice gate and several overflow ports located in the Main Dam. Free overflow spillways are located over the Wing Dam and Saddle Dam 1 which discharge to the Cheakamus River via an overflow channel.




*Cheakamus Dam*




*Intake on Shadow Lake*

The Cheakamus earthfill dam is constructed on and of Rubble Creek slide debris. The slide debris material originated from The Barrier, a precipitous cliff located nearby at the head of Rubble Creek. The slide debris was deposited in 1855 as a result of a very large (~40 million cubic metres) landslide from The Barrier which flowed down the Rubble Creek channel and spread out into the Cheakamus Valley. It underlies the earthfill dam on the left bank and forms a terrace downstream of the right side of the dam.

## Structural Upgrades

Between 1981 and 1988, the Cheakamus Dam was rehabilitated to withstand a maximum credible earthquake (0.2g at the time), pass the Probable Maximum Flood, and withstand overtopping by a slide generated wave originating from The Barrier. The worst case Barrier slide scenario, studied in 1978, concluded that the estimated slide mass would travel about 300 metres into Daisy Lake and create a wave approximately 15 metres high with a 14 second duration. The report concluded that overturning of some concrete dam sections and significant erosion of the embankment dam could occur as a result. This led to the remedial measures to strengthen the dams and reduce the erosion potential of the earthfill section.

Between 2009 and 2011, a project to upgrade and replace the spillway and sluice gates and their lifting equipment and controls was carried out. The project also replaced spillway bridge deck which had deteriorated due to Alkali-Aggregate Reaction.

## Major Meteorological Event

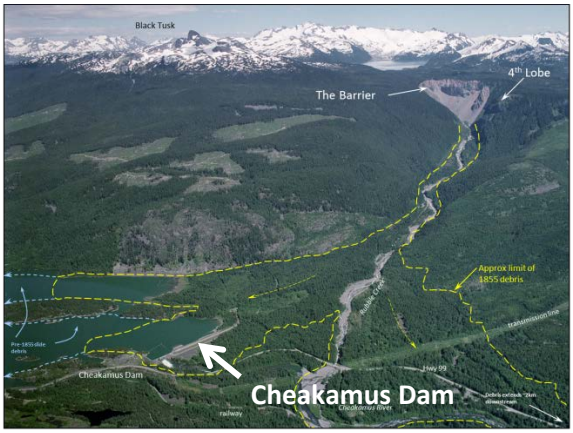
Daisy Lake Reservoir experienced very high reservoir levels during a storm in October 2003. High inflow from the Cheakamus River (1,185 $m^3/s$) led to extreme spilling (up to 850 $m^3/s$) at the dam and resulted in downstream debris build-up and flooding. A Red Alert was issued to evacuate residents on the downstream flood plain. A special inspection of The Barrier, initiated as a result of turbidity observed in Rubble Creek, reported that the stability of the Barrier had not deteriorated during the event. This was estimated to be in the order of 1:50 to 1:100 year event


*Spilling in October 2003 from Cheakamus Dam*

## The Barrier

The Barrier has a recurring trend of large rockslides. An investigation in 2010 suggested the frequency of a large rapid rockslide entering the reservoir is about 1/1,500 based on the geological record. BC Hydro personnel visually inspect the Barrier annually. The installation of instrumentation to monitor the landslide has been proposed and is under consideration.

*The Barrier*




*Extent of 1855 Slide Debris*

## Seismic Issues

The Probabilistic Seismic Hazard Assessment, completed in 2012, calculated the Maximum Design Earthquake to be 0.46g with an annual exceedance frequency of 1/10,000. There are actual and potential deficiencies with respect to the seismic withstand of the Cheakamus and Shadow Lake dams, with damages expected for loads of 0.2g (1/1,350 – 1/1,500 return period). A decision to proceed with further rehabilitation of the dams will require consideration of the hazard posed by The Barrier.

## Normal Operations

The earthfill dam was constructed with a downstream filter to prevent internal erosion. However, the filter was only placed to the top of the downstream bench, not to the crest of the dam. The dam has a history of seepage when the reservoir is high, on the downstream face above the bench. It is believed that potential construction horizons have led to preferential seepage paths through the dam. In 2010, the seepage reached unacceptable levels and, as an interim risk measure, a reservoir restriction was implemented to maintain the reservoir normal maximum elevation below the level at which seepage is observed.

# Update on Other Major Dams

## Mica Dam

Final piezometer upgrades were completed in Q1, addressing the deficiency in regard to the under-instrumentation of this extreme consequence dam. All new instruments are commissioned and in-service. The 2014 construction report was issued in Q3. Project completion is targeted for Q4.

## Revelstoke Dam

Updating of the Marble Shear Block rock slope geologic model was carried out in Q2. The new geologic model and piezometric information were used for a stability re-assessment. The final stability re-assessment report is targeted for completion in Q4.

The instrumentation installation project for the Left Bank slopes, initiated in F2015, is in progress. The field work, including the drilling and instrumentation installation, was successfully completed in Q2. Project documentation is underway and is targeted for completion in Q4.

## La Joie Dam

Progress continues to be made to improve the functionality of the water passages. A few small outstanding items remain and will be addressed during the next available outage window in Q4. Project documentation continued in Q3.

## Terzaghi Dam

Work is in progress to determine the performance of the dam for the updated seismic hazard. The first phase analyses and reporting has been completed. The second phase of the study started in Q2 and continued in Q3.

## WAC Bennett Dam

There are five ongoing dam safety projects:

### *Condition of the spillway (deterioration of the spillway chute concrete surface)*

As previously noted, the second year of construction has been deferred to year 2016 due to reservoir conditions.

### *Spillway gate reliability*

The project will upgrade selected electrical and mechanical components of the three spillway gates as the first of a multiple stage program to improve the reliability of gate operations. The project is currently in Definition Phase. Issues with some of the gears have been identified, and an interim risk management plan has been put in place.

### *Long-term performance of the dam core*

The work plan for F2016 was approved in Q1. Work continued in Q3 on: the failure modes assessment, the review of the seismic geophysical data, and the performance assessment of the dam. The Expert Engineering Panel Meeting was held in Q3 and a draft report received. Report finalization is expected in Q4.

### *Casing Upgrades*

This project was initiated to address the leaky open casings in the core, while retaining their usefulness where applicable. This project will be implemented in phases, and the first part includes the grouting of observation wells and selected drill holes, completed in Q2.

In Q3, further work continued to assess the requirements to address the remaining drill holes and other instrumentation in the dam core.

*Condition of the riprap layer protecting the upstream face of the dam*

In Q3, the Request for Proposal (for construction) was issued. In addition, the BCUC application was submitted with the first round of questions submitted to BC Hydro in December 2015. Work will continue in Q4 to address the BCUC questions.

**Ruskin Dam**

In Q3, work at the new Piers 1, 2 and 3 and the new Gates 1 and 2 was completed with the new gates commissioned in December. Some backup power and hydraulics work remains outstanding. The construction bulkhead was successfully moved to start the next phase of construction (work at piers 4, 5 and 6 and replacing old gates 4, 5, and 6 with new gates 3 and 4). The bulkhead will be moved again later in the schedule in order to construct the remaining pier and new gate 5.

Also in Q3, the Ruskin Advisory Board was held and their draft report was issued. Report finalization is expected in Q4.

**Campbell River System**

Recent and ongoing work at the three sites is as follows:

*Strathcona Dam*

The project to construct a new Low Level Outlet is in a preliminary 'needs' phase to identify project requirements. In Q3, a high level potential failure modes assessment of the dam was completed. Work also continued on the assessment of options for the Low Level Outlet.

*Ladore Dam*

A first draft of the summary report on investigations to assess the seismic performance of the dam has been prepared and reviewed. Preliminary results show that some remedial work will be required. The second draft of the summary report has been reviewed. The report is being finalized.

*John Hart Dam*

This project was initiated in F2011 to address the seismic deficiencies associated with the dams. The draft Advisory Board report issued in Q2, was used, and additional analyses on options were reviewed by the team.

## NEW ISSUES

**La Joie Dam**

An Interim Dam Safety Risk Management Plan was issued in January 2015 with a requirement to operate the Downton Reservoir to a lowered reservoir elevation of 734.0 m. It was expected that this could be achieved without exceeding the Bridge Water Use Plan target hydrographs for Terzaghi and Seton. However, 2015 had significant forced outages and high inflows. We are starting 2016 with very high reservoir levels and it is not possible to achieve 734.0 m without exceeding Water Use Plan target hydrographs. Consultations with First Nations are scheduled for January 2016.

## GATE MAINTENANCE AND TESTING

During the period of September to end of December 2015, 77 scheduled gate tests at 23 sites were carried out. One gate system failed to operate on demand during testing but was promptly repaired to route a series of storms the following week. In another case, gates operated on demand however certain equipment malfunctioned or was found to be in near-fail condition.

As of the end of December 2015, operational restrictions were in place on 5 out of 111 flood discharge gates due to known deficiencies (no change from the previous quarter). A total of 6 gates were intentionally not moved due to potential equipment issues associated with cold weather. No flood discharge gates were locked out for construction and operational reasons (reduced from 8 in the last quarter). Three gates at Ruskin Dam were permanently decommissioned this Quarter as previously noted.

A total of 33 corrective maintenance issues were identified through ongoing testing and maintenance between September and December 2015. A total of 42 new and previous issues were addressed in the same period, for a decrease of 9 issues overall in this reporting period. There has been a progressive decrease in the issue count, which is down from a peak of 78 at the end of May. There are now 57 corrective maintenance issues outstanding at the end of December 2015, compared to 64 as of one year ago.

## CIVIL MAINTENANCE

To date 25 of 35 projects are substantially complete. There have been five projects deferred or cancelled. Two of these were due to First Nations issues/concerns (Seton Forebay repairs and Wilsey dam dredging), one due to a chance of spilling (WAC Bennett Dam Spillway repairs) and two due to other groups completing the work (Fall River Penstock expansion joint repair and Cheakamus concrete arch repair). Also as per the Q2 update, two projects have been capitalized and an additional $100,000 project was capitalized this quarter (Seton Canal preparation and assessment). This leads to a program underspend of $1,300,000. These dollars were transferred back to Generation Operations. Current spend for the program is $2,150,000 and the remaining budget is $2,700,000.

Completed projects are: Bridge River 1 Penstock inspections; Bridge River 1 tunnel concrete repairs; Bridge River Penstock and tunnel inspections; Seton Canal assessment and preparation; La Joie debris boom repair, La Joie dam face joint repairs; Cheakamus tunnel and surge tower inspection; Cheakamus concrete arch repair; Mica Unit 4 penstock and draft tube inspection; Mica Outlet works inspection; Revelstoke Unit 2 penstock and draft tube inspection; Revelstoke 731 block scaling, walkway repairs and access improvements; Downie helicopter pad repairs; Checkerboard creek road repair; Fall River underwater inspection of the dam face; Mica Dutchman and Little Chief road repairs; Bridge Inspections; Coquitlam tunnel inspection; Wahleach helicopter pad inspection; Revelstoke Downie road repairs; Falls River penstock saddle repairs; Spillimacheen Scaling; and the Seven Mile Penstock Inspection.

## EMERGENCY PREPAREDNESS AND PUBLIC SAFETY

### Emergency Preparedness[1]

Emergency Preparedness Plans are required to be updated annually for all Significant, High, Very High and Extreme consequence dams. The emergency plans are undergoing significant revision and are therefore have not been updated as required annually. A plan for getting back into compliance with the Dam Safety Regulation has just recently been submitted for approval.

*Columbia Operations*

The regional Columbia Operations emergency response plan and local facility Emergency Action Plans for Mica and Revelstoke were completed.

- An internal regional exercise was held to validate and test the completed plans on November 30, 2015.
- The Columbia Basin Emergency Planning Guide is in the final stages of completion.
- Internal training on the Mica Emergency Action Plan is scheduled for February 18, 2016.

*Peace region (includes WAC Bennett / Peace Canyon / Site C)*

- First draft of the regional Peace region emergency response plan is under review.
- First draft of the Peace region Emergency Planning Guide is under review.
- GMS and Peace Canyon Emergency Actions Plans are scheduled to commence Q4 (January 2016).
- Site C Emergency Action Plan is scheduled for review in Q4 (February 2016)

### Public Safety[2]

Starting in F2016, all Public Safety Management Plans are being reviewed on a three yearly basis. The plan in F2016 to complete 9 plans has been achieved; three were completed in Q1 and Q2 and six were completed in Q3. High risk items identified from the reviews for remediation will be forwarded to Generation Asset Management for consideration and scheduling. The strobe and siren standard is complete and is now being used for design of the new siren/strobe installations at Clowhom, Elko and Puntledge. These installations are for public awareness of flow releases under normal operating conditions. There is no further work planned for F2016. Work will resume on Generation priorities in Q1 of F2017.

## COMPLIANCE WITH PROCESSES AND REGULATION

Approval was requested and granted for the John Hart investigative work in Q3.

One Operation, Maintenance and Surveillance Manual (Stave Falls) was submitted in Q3. In order to remain within compliance of the regulation, updates to the Mica, La Joie and Terzaghi manuals were required in 2015. These are all in progress and a revised schedule for these updates has been

[1] Emergency Preparedness is managed by the Strategic Emergency Management team. Dam Safety audits the updating of emergency plans for compliance with the BC Dam Safety Regulation.

[2] Public Safety is managed by the Public Safety team in Safety Engineering. Dam Safety audits Public Safety activities related to dams.

submitted to the Comptroller of Water Rights for approval. Additional resources from Engineering are being provided in Q4 to assist with meeting this schedule.

The BC Dam Safety Regulation is being revised in conjunction with the new Water Act. BC Hydro was provided with an opportunity to review a draft version of the new regulation with provincial dam safety staff. Finalization of the regulation is expected in early 2016 and implications to the dam safety program will be assessed at that time.

### Inspections

Overall regulatory expectations were met in Q3 for weekly and monthly dam safety inspections. Three of 431 scheduled inspections for Q3 were not completed. Two of these were at Kootenay Canal due to staffing conflicts with generating unit overhauls and one at Bear Creek Dam due to access issues. No two sequential inspections were missed.

### Dam Safety Reviews

Dam Safety Reviews are a regulatory requirement carried out at minimum intervals of every five to 10 years at high, very high and extreme consequence dams.

Five external Dam Safety Reviews are in progress for F2016 for Buntzen, Falls River, Elsie, Spillimacheen and Salmon River Diversion Dams. Draft reports have been reviewed for Falls River, Spillimacheen and Buntzen. Draft reports are being prepared for Salmon River and Elsie. All findings for the F2015 Dam Safety Reviews will be reviewed and entered into the dam safety issues database by the end of Q4.

## VULNERABILITY INDEX: UPDATE

Changes in Vulnerability Index for actual and potential deficiencies, as outlined in Figure 1, are tracked on a quarterly basis and shown on Figures 2 and 3. This is an indication of the changes in the understanding of the dam safety risk profile.

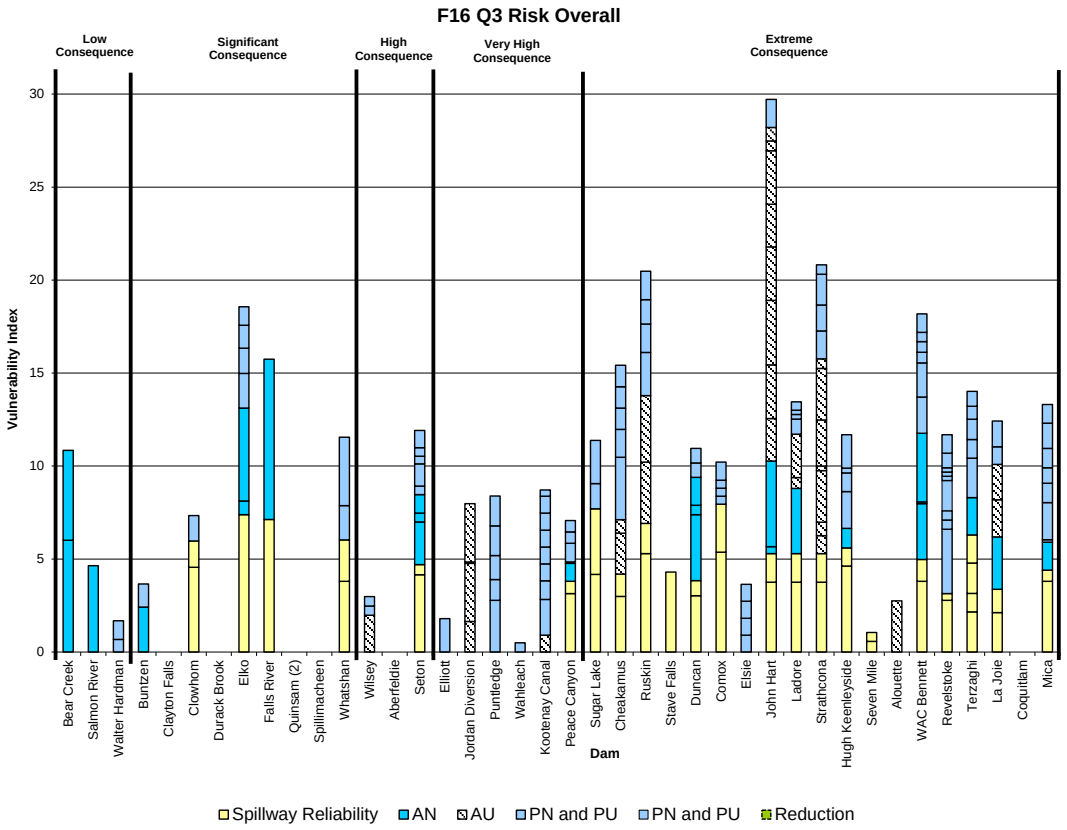
In Figure 3, the total index is shown (sum of actual and potential deficiencies), as well as separate plots for decreases and increases in the total index. Decreases are due to remediation projects as per the Capital Plan and resolution of issues via Performance Investigations. Increases in the index are due to the recognition of new issues. Existing issues are re-examined on a regular basis, and re-rated as required.

Vulnerability Index values have been calculated for trending purposes since 2003. There was a general decreasing trend in the value of the index from that time up to 2008, as major risk reduction projects were completed, such as the construction of the new Coquitlam Dam and the decommissioning of Coursier Dam. As noted in previous Quarterly reports, there has been a fairly steady rise in total Vulnerability Index since the minimum value was reached in Fiscal 2008. This rising trend has been mainly due to more complete definition of existing risks, by consideration of more system components, and by better hazard characterization, such as the Seismic Hazard study. For the report this Quarter, the increasing and decreasing components of the total Vulnerability Index have been plotted back to a baseline of Fiscal 2008 to allow closer examination of the changes in Vulnerability Index since the start of the rising trend.

**Discussion/Information**

# Board briefing – DAM SAFETY QUARTERLY REPORT

## Figure 1 - Dam Safety: Overall Risk Profile




### Legend and Summary of Changes

| | |
|---|---|
| Increase in Risk | ***None*** |
| Reduction Risk | ***None.*** |

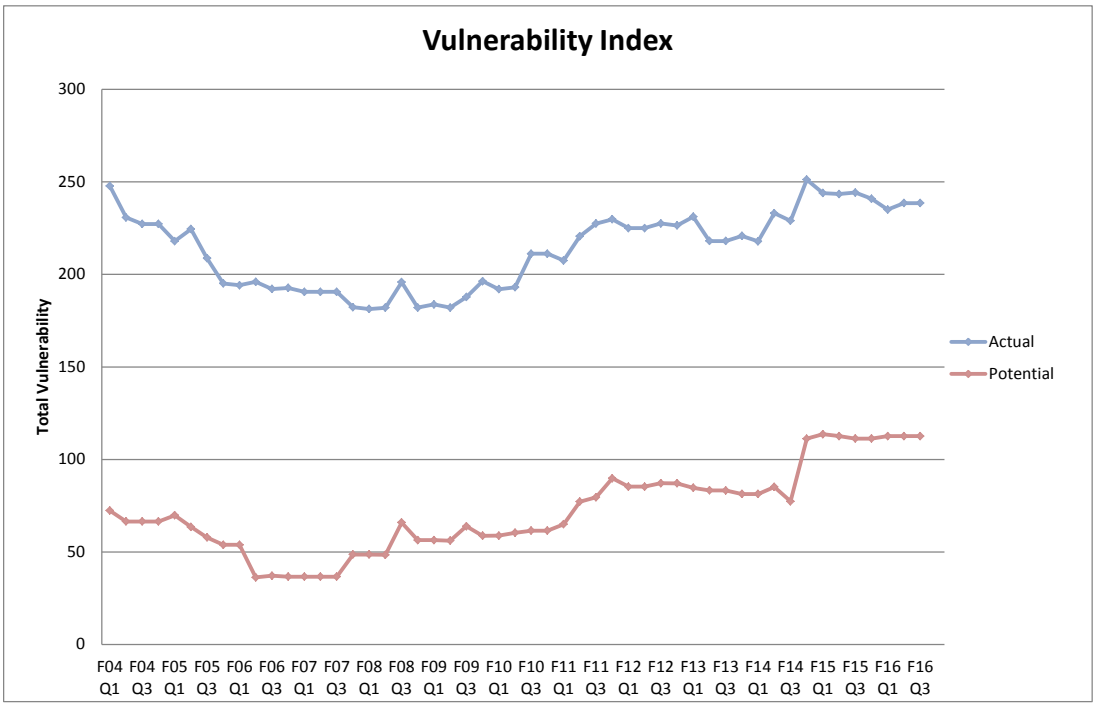
A – Actual deficiencies have been shown to exist.
P – Potential deficiencies require further investigation.
N – Normal Load conditions; associated with daily or short-term operations.
U – Unusual Load conditions: associated with flood and earthquakes

Consequence classifications reflect current BC Dam Safety Regulations.
Dam order reflects generally increasing downstream consequences

**NOTES:**

- Vulnerability Index (Rating) is a qualitative assessment of future dam performance from all causes – the higher the rating the higher the likelihood of poor performance.
- 34 dam sites as identified have reportable risk at present
- This Risk Profile represents only currently known and rated issues. Changes do not necessarily indicate a physical change to BC Hydro assets that increase or decrease risk; rather they often represent a change in knowledge and understanding of the risk. Additionally, many known deficiencies (those without a direct impact on potential dam failure) have yet to be rated.

## Figure 2 – Change in Actual and Potential Vulnerability Indices




## Figure 3 – Change in Total Vulnerability Index Components