Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

Executive Summary

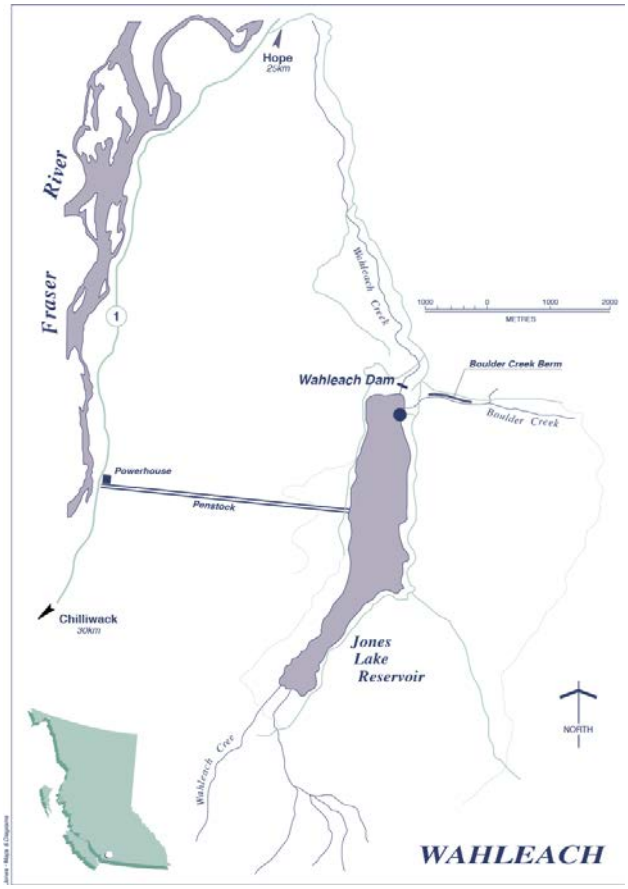
The purpose of this report is to update the Capital Projects Committee of the Board of Directors on key dam risk management activities during the period from July 1, 2016 to September 30, 2016, and to provide reasonable assurance that the safety of dams operated by BC Hydro continues to be managed to 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 an overall decrease in the risk profile this quarter due to completion of the cut-off wall in Duncan Dam and a reassessment of seismic deficiencies at Cheakamus Dam.

Quarterly Featured Damsite – Wahleach Dam

The Wahleach Project comprises four principal assets:

- the Wahleach Dam, which impounds Jones Lake creating the Wahleach Reservoir;
- the Boulder Creek Diversion Dike, which directs flow from Boulder Creek into the Wahleach Reservoir;
- the Wahleach Power Tunnel, running 4.2 kilometres through Four Brothers Mountain; and
- the Wahleach Powerhouse (one unit, 60 MW), located adjacent to the Trans-Canada Highway on the east side of the Fraser River, 2 kilometres west of the Wahleach Dam. The maximum normal reservoir level is 641.6 metres and the center line of the generating unit is at 21.3 metres; providing up to 620.3 metres of operational head.



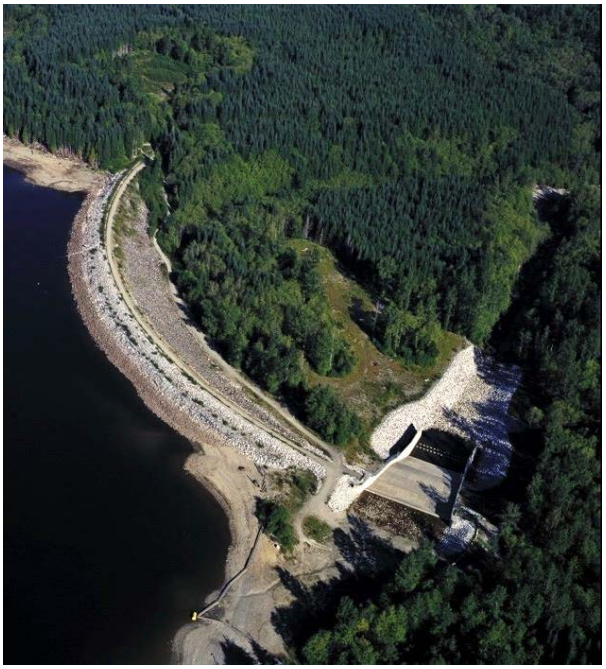
The Wahleach Dam, constructed in 1951-52, is located approximately 150 kilometres east of Vancouver. The consequence category of the dam is “Very High,” as there are up to 120 people in the community of Laidlaw at risk should failure of the dam occur. Downstream impacts from dam failure are expected to be extensive. A failure of the dam would result in peak water levels up to 3 metres deep and maximum velocities of up to 2 metres per second in the Laidlaw area within one hour.

The Wahleach Dam is a zoned earthfill structure, 22 metres high with a top length of approximately 418 metres. The dam is founded on overburden consisting of glacial deposits and the impervious core is keyed into the till foundation. A free overflow spillway, located on the right abutment of the dam, discharges into an excavated channel which carries water about 400 metres downstream of the dam. A fishwater release siphon has been installed over the top of the

dam near the left abutment. The siphon discharges into Wahleach Creek immediately downstream of the dam.

The Maximum Design Earthquake for the Wahleach Dam was established in the 2012 Probabilistic Seismic Hazard Assessment as a Peak Horizontal Ground Acceleration of 0.35g with an annual exceedance probability of 1/10,000. The seismic withstand of the dam has not yet been formally assessed, but is believed to be in the order of 0.40g.

Jones Lake and Wahleach Spillway



Wahleach Dam and Spillway

Wahleach Slope Movement

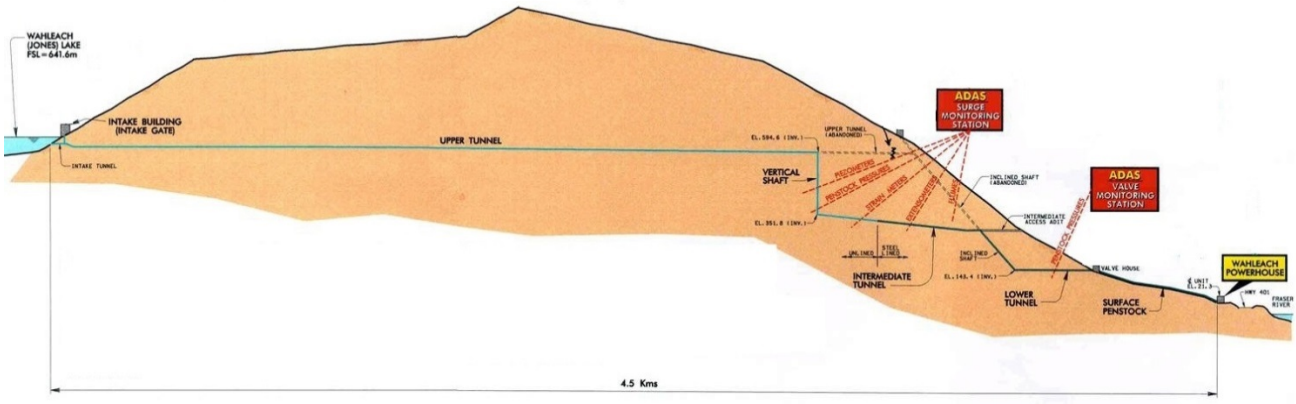
The Wahleach Slope, located above the Wahleach Powerhouse, is a rock mass undergoing slow continual downslope creep. The movement of the Wahleach Slope has been of concern for many years because there are numerous utility corridors at the base of the slope including a gas pipeline, railroad tracks, the Trans-Canada Highway, the Fraser River, telephone lines, fibre optic cables, and B.C. Hydro's Wahleach Powerhouse, switchyard, and transmission line.

In January 1989, abnormally high leakage was discovered in the Wahleach Tunnel. The leakage was caused by slow movement in Four Brothers Mountain deforming and rupturing the steel lining on the horizontal portion of the upper tunnel. In addition to the rupture of the upper tunnel steel lining, the initial inspection found seven buckled zones in the inclined part of the power tunnel and one in the 3.2 metre diameter surge shaft. This incident initiated a major slope investigation and instrumentation program, which led to the portion of the Wahleach Tunnel located within the slow moving rock mass to be replaced by a 243 metre unlined vertical rock shaft constructed in sound rock below the zone of distressed slow moving rock. The replacement power conduit was filled and operated for the first time in June 1992.

Since January 1989, the rate of lining break deformation on the horizontal portion of the upper

tunnel has decreased approximately logarithmically from an initial rate in the order of 250 mm / year, immediately following the lining break, to the current 1-2 mm / year. Short-term accelerated movements of about 2-3 mm occur when the tunnel is unwatered, due to changes in hydrostatic pressures within the rock mass.

On February 24, 2011, the Wahleach Intake Operating Gate closed unintentionally, causing the 243 metre high vertical unlined rock shaft to dewater in less than ten minutes and the generating unit power to drop. The rapid de-watering resulted in a quick depressurization of the rock shaft, dislodging significant rock fall in the process, filling the rock-trap, as well as causing an increase in movement in the slow moving rock mass above the tunnel. The rock trap has been subsequently cleaned out, but the shaft has not yet been inspected following this event due to challenging safety issues associated with the inspection. A future project is being planned to carry out the inspection.



Wahleach Tunnel Cross Section

Current real-time monitoring to provide warning of increased slope movements consists of one strainmeter and three extensometers. The functionality of the extensometers has been plagued with problems over the last several years. Efforts to rehabilitate the extensometers were carried out in 2007 and 2011 with limited success, and, as of 2013 the extensometers have been unable to provide the necessary resolution of movements in the disturbed rock mass. To improve real-time slope monitoring, a project is underway to provide additional monitoring instruments.

In addition to the real-time monitoring of the slope movement, slope stability data is obtained from annual visual inspections, surface and underground piezometers, ground surveys, GPS surveys, Power Tunnel pressure sensors, buckle zone strainmeters, tunnel flow measurements, and borehole inclinometers.

Flood Passage

The inflow design flood was updated in 1985 and the probable maximum flood was calculated. In 1990, dam safety investigations identified that the Wahleach Spillway was unable to pass the probable maximum flood, which could result in overtopping and failure of the dam. Between 1993 and 1994, the spillway was entirely reconstructed and the dam was raised by 1.6 metres to enable safe passage of the probable maximum flood. There remains some concern regarding the potential for scouring of the downstream channel during an extreme flood to undermine the

spillway structure.

Powerhouse Flooding

On March 11, 2007, the Wahleach powerhouse was flooded by a debris torrent originating from nearby Ted Creek, which normally passes under the Trans-Canada highway to the east of the powerhouse through a large culvert. The trashrack on the culvert plugged with debris, diverting the flow along the ditch on the south side of the highway. The water and debris forced open the door on the north side of the second floor of the powerhouse. The first floor was completely submerged and the second floor was submerged to within four feet of the ceiling. Significant efforts were needed to clean the powerhouse, inspect the turbine bearings, inspect the governor system and restore station service.

Wahleach Powerhouse and the Trans-Canada Highway

Tailrace Tunnel Leakage

In April 2013, the Wahleach Tailrace Tunnel — an 85 metre long tunnel between the powerhouse and the Fraser River — was inspected and leakage into the tunnel was observed. The tunnel is lined with corrugated steel and the lining is deteriorating. Temporary concrete crack repairs were completed to fix poor construction joints and eliminate leakage. Since a section of the Trans-Canada Highway and the CN rail line are located above the tunnel, it is important to maintain the overall water tightness of the tunnel to prevent leakage which could cause a sinkhole. A project is underway to upgrade the lining in the tailrace tunnel.

Update on Other Major Dams

Mica Dam

A special investigations project for large embankment dams was initiated in F2014. The overall objective of this project is to develop tools and methodologies for performance monitoring of BC Hydro dams. At Mica, the objectives are to carry out a detailed performance assessment of the dam by developing, testing and verifying numerical analyses of the dam behaviour. The work will

provide a good understanding of the current condition of the dam as well as a set of monitoring and response systems that can be utilized for dam safety management decisions and activities.

Work continued in Q2 on development of a comprehensive three-dimensional computer model of the foundation. The Expert Engineering Panel meeting was carried out in Q2 which included a visit by the team to the Mica Dam. The project scope of work, Mica Dam project chronology, and construction history were compiled and presented to the panel. A draft report was received from the panel and is currently under review by BC Hydro. This is the first step in a complete design review to be undertaken over the next few years.

Revelstoke Dam

New thresholds to assess the stability of the Marble Shear Block were established based on the updated geological model and piezometer data in Q1 and project documentation of this work was completed in Q2. The project scope has been extended to include installation of two new in-place inclinometers in the Marble Shear Block and to carry out a baseline LiDAR survey. The work for installation of the new in-place inclinometers began in Q2 and will be completed in Q3. The LiDAR survey will be carried out in Q3.

The instrumentation installation project for the Left Bank slopes was completed in F2016. Project documentation is underway and is targeted for completion in Q3.

WAC Bennett Dam

There are five ongoing dam safety projects:

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

The Contractor mobilized to site in April 2016, and the second year of construction work is underway on the chute. Construction works for the planned upgrades continued in Q2 and is on track for completion this season with the last major concrete pour completed in late September. In addition to major resurfacing in the lower part of the chute, localized repairs planned for this year were also completed in the flat portion of the chute.

Spillway gate reliability

The project will upgrade selected electrical and mechanical components of the three spillway gates. The project is currently in Definition Phase, and engineering work is continuing.

Long-term performance of the dam core

The overall project objective is to better understand the current condition and behaviour of the dam and to provide improved monitoring and response systems. Work in Q2 continued with:

- Incorporating the comments received from the Expert Engineering Panel into the WAC Bennett Dam performance assessment report,
- Completing the documentation for the 3 Dimensional CAD Model of the earthfill dam and
- Processing of the transition materials for laboratory testing to confirm whether or not a crack could hold open in a post-seismic scenario.

Casing Upgrades

This project was initiated to address the leaky open casings in the core, while retaining their usefulness where applicable. In F2016, all six observation wells and four open casings were successfully grouted. In Q1 of F2017, the contractors started the work by developing the

conceptual design options for removing the stuck probe in the Cross-Arm casing. Further open casings have been selected for grouting in a later stage of this project.

Work in Q2 continued with:

- The completion of the definition phase and approval of the implementation phase for the grouting and instrumenting of the nine open casings, and for removal of the stuck probe in the Cross-Arm casing in the dam core and
- The award of the contract for removal of the stuck probe in the Cross-Arm casing (work is scheduled to start at site by mid-October).

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

The contractor mobilized to site in Q2 and construction works started at the quarry, and at the stockpile area close to the dam. Upgrading of the access roads also started in Q2. Blasting at the quarry will start in early Q3.

Ruskin Dam

Anchors were installed in the upper portion of the structure as an interim risk reduction measure in 2007. Some additional anchors will likely be required to stabilize the structure during an extreme seismic event. Any anchoring will be undertaken as a separate work activity nearing the end of, or following the current redevelopment project. Additional analyses are being undertaken to check the stability of the main body of the spillway against the updated seismic hazard results, as modified for actual hard rock site conditions. In Q2, the seismic parameters needed for dynamic analyses were determined and the dynamic analyses of the structure will continue in Q3.

In Q2, the construction of the new spillway piers # 4 and # 5 was completed and work continued on new spillway gates # 3 and # 4. Excavation and fill placement of the left abutment between elevations 20 m and 30 m was also completed in Q2.

Campbell River System

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

Strathcona Dam

The high-level strategy for long-term risk management was described in a previous Executive Summary (Q3 of the F2014 report). A full update will be presented in the next Quarterly Report.

The project to construct a new Low Level Outlet is in a preliminary 'needs' phase to identify project requirements. Work in Q2 continued and included:

- Development of high level layouts for the new Low Level Outlet and new powerhouse,
- Investigation into the use of the Low Level Outlet as a replacement for the spillway, and
- Consultation with the First Nations with regard to the project alternatives.

Work in Q3 will consist of the development and selection of the more favourable layout options.

Ladore Dam

The summary report on investigations to assess the seismic performance of the dam has been finalized. Results show that upgrades are required for the spillway. The project to design and construct these upgrades is underway and a draft conceptual design report was prepared and

reviewed. Preparation of the feasibility design plan is in progress.

John Hart Dam
This project was initiated in F2011 to address the seismic deficiencies associated with the dams.

Work by BC Hydro and our partners continued on the development of options for the Middle Earthfill Dam and the conceptual options for the spillway gate systems. Advisory Board Meeting #2 was carried out in Q2. The project team presented the studies and analyses completed to date, including the developed upgrade options for the Middle and North Earthfill Dams, concrete dam and spillway gates system, to the Advisory Board. An upstream remediation scheme has been confirmed as being preferable to downstream options.

GATE MAINTENANCE AND TESTING

During the period of July to end of August 2016, 41 scheduled gate tests at 23 sites were carried out. One gate system failed to operate on demand during testing. In two other cases, gates operated on demand; however certain equipment malfunctioned or was found to be in unacceptable condition.

As of the end of August 2016, operational restrictions were in place on five out of 111 flood discharge gates due to known deficiencies (no change from the previous quarter). No flood discharge gates were locked out for construction and operational reasons (same as the last quarter). Ruskin continues to operate with two new gates and one original gate.

A total of 29 corrective maintenance issues were identified through ongoing testing and maintenance from July to the end of August 2016. A total of 20 new and previous issues were addressed in the same period, for an increase of 9 issues overall in this reporting period. There are now 73 corrective maintenance issues outstanding at the end of August 2016, compared to 69 as of one year ago.

CIVIL MAINTENANCE

To date, nineteen projects are substantially complete. The nineteen substantially completed projects include penstock inspections and support repairs, La Joie Dam upstream dam face shotcreting and intake inspections, various concrete and joint repairs, vegetation removal, tunnel inspections and underwater surveys, road repairs and head pond dredging at Wilsey Dam. Eleven other projects are on track for completion this year, as per the annual plan. Civil maintenance development continues together with Generation Operations.

EMERGENCY PREPAREDNESS AND PUBLIC SAFETY

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 as part of annual compliance reporting to the Comptroller of Water Rights.

Public Safety is managed by the Public Safety team in Safety Engineering. Dam Safety audits Public Safety activities related to dams during the Dam Safety Reviews.

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There are no specific updates this quarter pertaining to dam safety. Please refer to other reports for quarterly updates on Emergency Preparedness and Public Safety around dams.

COMPLIANCE WITH PROCESSES AND REGULATION

The Annual Dam Safety Program Report was provided to the Comptroller of Water Rights in July, 2016. Approval was requested and granted for geotechnical investigations near two of the John Hart Dams and was granted for upcoming instrumentation work at Walter Hardman Dam. Approval to have an external review of the performance of WAC Bennett Dam carried out every five years instead of every three years was also provided through a revised Order, based on the last review by the Expert Engineering Panel.

A meeting was held with the head of the Provincial Dam Safety section of the Comptroller's office to discuss how BC Hydro will interpret and meet the revised BC Dam Safety Regulation. On the basis of this meeting, our approach is being tabulated and incorporated into the draft Dam Safety Governance Manual. Once finalized, BC Hydro will submit this portion of the Governance Manual for formal acceptance by the Comptroller of Water Rights.

Inspections

In Q2, one monthly inspection was missed at Bear Creek due to impassible road conditions. These conditions, which cannot be simply repaired, will continue until the site can replace the rotten wooden bridges and work around a landslide. Plans are to access the site by helicopter until further notice.

One weekly inspection was missed this past quarter at four dams (Cheakamus, Lajoie, Seton and Clayton Falls) due to lack of staff availability. No two inspections in a row were missed.

Last quarter, it was noted that some inspections were missed due to the retirement of the inspector for Sugar Lake and Wilsey Dams. This inspector has now been replaced, and no further inspections have been 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. Four Dam Safety Reviews are currently in progress for F2017: Cheakamus, Comox, John Hart and Stave Falls. Site visits are planned to take place in Q3.

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.

The baseline for the separate plots of decreases and increases to the VI has been set at the time of the development of the first 10 year capital plan.

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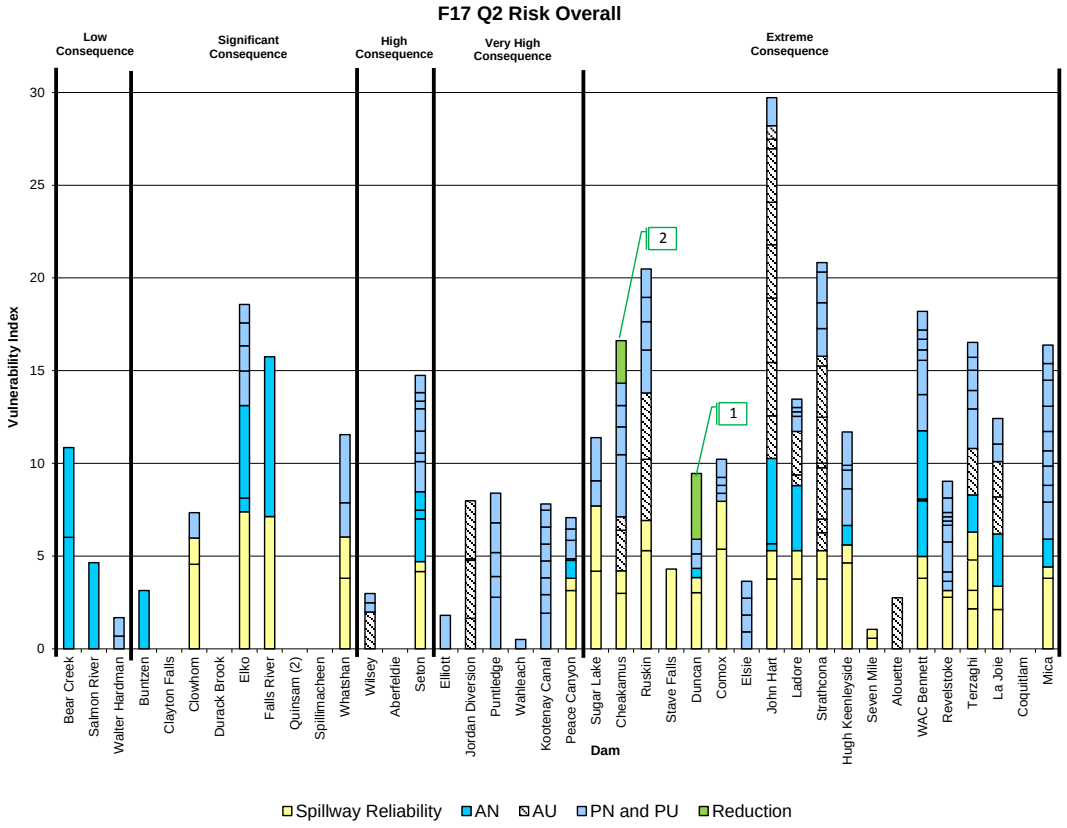
Figure 1 - Dam Safety: Overall Risk Profile



Legend and Summary of Change

Increase in Risk — ***None this quarter***

Reduction Risk

1. ***Duncan Dam –*** *The construction of a cut-off wall was completed.*
2. ***Cheakamus Dam –*** *The seismic withstand of two components of the Cheakamus facility are better than previously reported.*

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

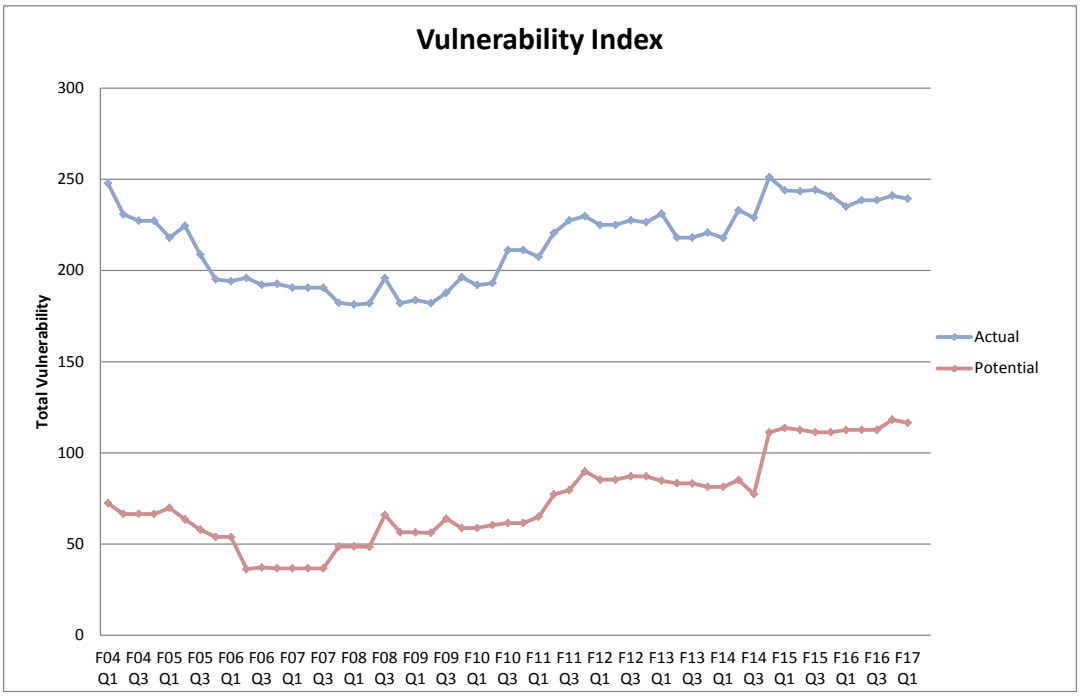


Figure 3 – Change in Total Vulnerability Index Components