

## Confidential - Discussion/Information

### Board briefing – DAM SAFETY QUARTERLY REPORT

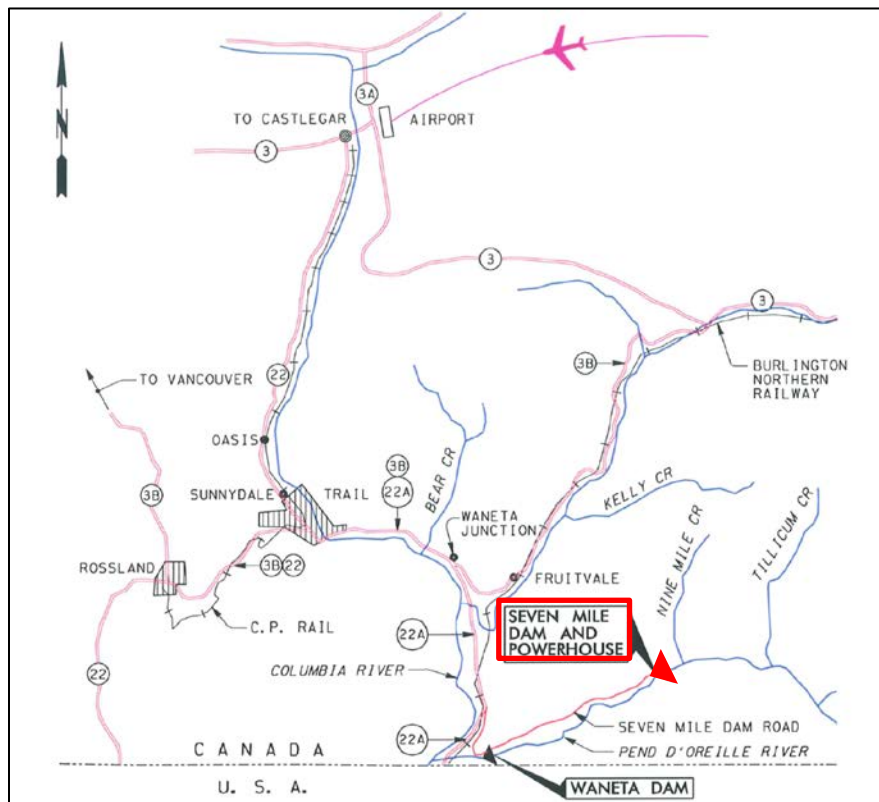
#### Executive summary

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 January 1, 2016 to March 31, 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 a slight increase in the risk profile this quarter due to estimates of the vulnerability of Mica, Seton and Cheakamus Dams to overtopping waves from landslides, as well as the vulnerability associated with the lack of a means to cutoff flow from the Bridge River 1 penstocks in the event of a penstock breach.

#### Quarterly Featured Damsite – SEVEN MILE DAM

Seven Mile Dam is located on the Pend d'Oreille River in South-Eastern B.C., approximately 15 kilometres southeast of Trail. It is one of eight hydroelectric projects along the Pend d'Oreille River, which originates in the United States, located about 18 kilometres downstream of the Boundary Dam, and about 9 kilometres upstream from Waneta Dam. Seven Mile dam was constructed from 1975 – 1980 with the addition of Unit 4 in 2003. Seven Mile is an Extreme consequence dam.



Seven Mile Dam location

A 15 kilometre long reservoir is retained by Seven Mile concrete gravity dam. The dam consists of the concrete gravity dam (347 metres long, 80 metres high) with the north gravity section (106metres wide), power intakes (102metres wide), spillway (98metres wide) and south gravity sections (39.6

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metres wide). The power intakes provide flow to four penstocks which lead to the four unit Generating Station (814 MW total). The discharge facility consists of a five-gated spillway located on the left side of the dam, with a total design flow capacity of 13, 290 cubic metres per second.



Seven Mile project

Communication with the upstream Boundary Dam (owned and operated by Seattle City Light) and the downstream Waneta Dam (70% Teck Cominco and 30% BC Hydro ownership; operated by FortisBC) is required to safely route upstream flood discharges and emergency releases. Upstream reservoirs in the United States, including Boundary Dam immediately upstream of Seven Mile Dam, provide a high degree of flow regulation.

### Dam Safety Improvements Project

Between 2000 and 2005, the Seven Mile Dam underwent strengthening and rehabilitation to meet modern design and safety expectations. This involved improvements to dam stability, the spillway and other systems. Modifications to the spillway included replacement of the concrete gate towers and hoist house structure with steel towers and five hoist housings. In effect, the site was upgraded to a reliability level similar to that now being achieved under the current Spillway Upgrade Program. The current spillway hoist facilities are likely the most reliable in the BC Hydro system, in terms of operation following a major earthquake.

Other systems were upgraded with new and modified power supply and gate controls, and improvements to dam drainage and reservoir level indication, monitoring and communications.

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Concrete gate towers and hoist house structure (left) were replaced with steel towers and five hoist housings at deck level in 2005 (right)

Dam stability was considerably improved with the installation of 57 post-tensioned, large capacity foundation anchors, carried out in 2 phases between 2002 and 2003. The anchors are post-tensioned 92 strand, fully corrosion protected, load testable and restressable. The anchors are oriented vertically and located near the upstream face of the gravity dam in four spillway blocks, four power intake blocks and seven gravity blocks. The two abutment blocks did not require anchoring. At the time of installation, the anchors had the largest capacity of any such anchors in the world. All 57 anchors were retested between 2003 and 2011 to determine if they were maintaining load capacity. All anchors achieved at least 2% above design loads.



Anchor Installation 2002-2003



Anchor Testing

The Seven Mile Dam anchors provide a reference for BC Hydro to undertake an overall evaluation of all its anchored sites, due to the extensive documentation outlining testing summaries, photos and follow-

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ups. We have recently developed an extensive database which documents all passive and post-tensioned rock anchors in the BC Hydro system, detailing anchor components, maintenance and testing procedures, information references and other details. Through an industry group known as CEATI, we have initiated a collaborative effort with other dam owners to share information and to address the varied and changing philosophies in regard to the long-term maintenance of such large anchors. Our overall approach will be developed following this ongoing worldwide collaboration with other owners.

#### 2012 Reservoir Slide Instrumentation Improvement Project

Multiple landslides or sloughs have been identified along the reservoir slopes upstream of Seven Mile Dam. In 2012, a project to improve monitoring of the landslides was carried out. Construction included new instrumentation and Automatic Data Acquisition System installations, standpipe piezometer installations and road access upgrades. Immediately downstream from the dam, a particular area known as Schiavon Slough presents a hazard in that it could completely block the tailrace, and back-flood the powerhouse with very little warning. Recent work to monitor slope movements included the installation of three laser stations, three reflector stations, associated Automatic Data Acquisition System equipment and a survey monument. Alarms are monitored by Dam Safety to provide early warning capability.

#### Update on Other Major Dams

##### Mica Dam

Piezometer upgrades were completed in Q1, addressing the deficiency in regard to the under-instrumentation of this extreme consequence dam. All new instruments are now commissioned and in-service. The 2014 construction report was issued in Q3. Project completion is targeted for Q1 of F2017.

Little Chief Slide is a landslide located upstream of Mica Dam. The possibility of an overtopping wave caused by failure of the Little Chief Slide was identified and accounted for in the original dam design. The issues associated with the long-term stability of the Little Chief Slide has always been noted in the dam safety issues database, but without a numerical rating. The vulnerability of Mica Dam to this hazard was rated in Q4 as part of an annual reservoir slopes review meeting, following comments from the recent external dam safety review. Similar ratings were also developed for landslides at Seton and Cheakamus Dams. These vulnerability ratings have been added to overall risk profile (Figure 1), for comparison with other rated vulnerabilities at these sites.

##### 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 Q1.

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 Q1 of F2017.

Two of the many piezometers installed in the foundation of the Revelstoke concrete gravity dam to measure uplift pressures under the dam have been recording pressures that are well above the design limits. Based on

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a performance review and the history of problems associated with these instruments, it was determined that the high pressures are more likely to be a reflection of bad data rather than representing actual high uplifts. The rating associated with this vulnerability was therefore reduced in Q4. Replacement instrumentation will be considered in future work prioritizations.

#### **Bridge River**

Analyses undertaken as part of the Bridge 1 Penstock Leak Detection project have noted that the surge tanks will overflow upon a full load plant rejection. Consequences of an overflow would be considerable damage to the Bridge 1 powerhouse, and potential life loss. This new vulnerability has been added to the Risk Index, and will be addressed by way of civil mitigation works to be prioritized for a future project.

#### **Terzaghi Dam**

Work to determine the performance of the dam for the updated seismic hazard has been completed. The first phase analyses and reporting was completed in FY15. The second phase of the study started in Q2 and was completed in Q4. The investigation concluded that the dam will be damaged in the Maximum Design Earthquake, however a release of the reservoir is not expected to occur. This is a significant conclusion, as rather than requiring a major upgrade project, some relatively simple upgrades are being developed on the basis of this study, and these will be undertaken in a project to be entered in the 10-year capital plan.

#### **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 was deferred in F2016 due to the high risk of spilling during construction because of higher than normal reservoir conditions in 2015. After assessing the reservoir conditions and operations, a decision was made in late Q4 to proceed with the second year of work in 2016, and this will begin shortly.

##### *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*

In Q4, the Expert Engineering Panel Report was finalized. The report states that the work undertaken by BC Hydro over the past three years confirms their 2012 conclusions on the satisfactory condition of the dam, and that the filtering system at the WAC Bennett Dam would prevent erosion in normal seepage flows. The Panel agrees that the overall dam will remain stable under extreme seismic loads, but that the very upper part of the dam may be vulnerable to deformations and cracking. However, this situation would only be a concern after an extreme seismic event in combination with a series of conditions that the Panel considers highly unlikely. BC Hydro intends to prioritize the additional studies and laboratory tests suggested by the Panel, and carry these out in future studies.

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Work also continued on the Performance Assessment Report, incorporating comments from the Expert Engineering Panel. The geophysics consultant continued work in assessing the cross-hole data. In preparation for F2017, a draft work plan was developed, in conjunction with the Mica performance assessment work.

#### *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. The first part included the grouting of observation wells and selected drill holes and completed in Q2.

In Q4, work continued on the evaluation of options for the remaining drill hole casings in the dam core. In addition, a request for proposal was issued to propose methods to extract the stuck downhole hammer from the Cross arm device without damaging the dam core. New and/or innovative methods may be required, as previous attempts using traditional methods have not been successful.

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

In Q3, the BCUC application was submitted with the first round of questions submitted to BC Hydro in December 2015. In Q4, first round of questions were answered, and the second round of questions were received. BC Hydro's responses will be submitted to BCUC in early Q1 of F2017. Also in Q4, the construction contract was awarded and the open book discussions are underway. The recent Expert Engineering Panel report notes that that project is "in hand".

#### Ruskin Dam

The Ruskin Advisory Board final report was issued in Q4. The Board provided some useful advice on how to manage the dam safety risks during the bulkhead move (from the Stage 1 position to Stage 2) and the commissioning of the New Gates 1 and 2. The Board also provided advice and recommendations regarding the sequencing of the left abutment berm construction to meet proper compaction requirements and on the dam seismic stability assessment using the complex models, to determine if additional anchors may be required.

Design work for anchoring of the spillway structure continued. 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. 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.

#### 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 Q4, work continued to determine the Low Level Outlet requirements including the establishing optimal invert levels and tunnel diameter.

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#### *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. In Q4, the Advisory Board Report #1 was finalized. The Board agreed with BC Hydro that, based on the improved understanding of the performance of the Middle Earthfill Dam, a seismic upgrade was required to meet safety expectations. The Board however did note some technical and constructability issues regarding the proposed options for the Middle Earthfill Dam and identified other options for BC Hydro to consider. The Board also provided comments regarding the options for the Concrete Dam, the Intake Dam and the North Earthfill Dam, to optimize these options. Advisory Board Meeting #2 is planned for Q2 of F2017, once these options are further developed.

Work by BC Hydro and their partners continued on the development of options for the Middle Earthfill Dam and the conceptual options for the spillway gate systems.

#### GATE MAINTENANCE AND TESTING

During the period of January to end of March 2016, 55 scheduled gate tests at 23 sites were carried out. No gate systems failed to operate on demand during testing. In four cases, gates operated on demand however certain equipment malfunctioned or was found to be in near-fail condition.

As of the end of March 2016, operational restrictions were in place on five out of 111 flood discharge gates due to known deficiencies (no change from the previous quarter). A total of six 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 (same as the last quarter).

A total of 25 corrective maintenance issues were identified through ongoing testing and maintenance between January to end of March 2016. A total of 18 new and previous issues were addressed in the same period, for an increase of seven issues overall in this reporting period. There are now 66 corrective maintenance issues outstanding at the end of March 2016, compared to 62 as of one year ago.

#### CIVIL MAINTENANCE

At the end of F2016, 29 of 35 projects are complete, with four projects being 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 one due to reservoir elevation changes (Mica Trashrack Cleaning). Final Fiscal 2016 spend for the program is approximately \$2,700,000, not including five projects that were transferred to, and are underway or were completed by, other groups.

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

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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; Revelstoke diversion tunnel inspection; Downie helicopter pad repairs; Downie Road repairs; Checkerboard creek road repair; Falls River underwater inspection of the dam face; Mica Dutchman and Little Chief road repairs; Bridge Inspections; Coquitlam tunnel inspection; Wahleach helicopter pad inspection; Falls River penstock saddle repairs; Spillimacheen Scaling; Seven Mile penstock inspection; Seven Mile road assessment and design; Seven Mile cut slope meshing design; Ladore penstock inspection; and Puntledge penstock de-mossing trial.

The budget for F2017 is \$4 Million and there are 30 projects currently being planned.

## EMERGENCY PREPAREDNESS AND PUBLIC SAFETY

### Emergency Preparedness<sup>1</sup>

Emergency Plans are required to be updated annually for all Significant, High, Very High and Extreme consequence dams. Emergency plans were completed in Q4 for the Peace Region, the Peace Canyon site and Site C. Finalization of the emergency plans for WAC Bennett, and the Small Generation Sites were delayed due to the need to produce emergency plans for Site C sooner than anticipated. The Provincial Dam Safety Officer has been apprised of these delays (expected to be two Quarters at most), and no concern has been expressed.

Internal training on the Mica Emergency Plan was completed in February 2016.

Emergency Planning Guides are more concise documents produced for distribution to external emergency responding agencies. The Columbia Operations Emergency Planning Guide was updated in Q4 and the Peace Region Emergency Planning Guide is nearing completion.

### Public Safety<sup>2</sup>

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. The plan in F2017 is to complete 11 plans. The schedule to complete the plans will be determined during the first half of April.

## COMPLIANCE WITH PROCESSES AND REGULATION

Dam Safety Status Report Forms were submitted for all High, Very High and Extreme consequence dams in early January, 2016. Annual Compliance Reports for all dams have been finalized and will be

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<sup>1</sup> 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.

<sup>2</sup> Public Safety is managed by the Public Safety team in Safety Engineering. Dam Safety audits Public Safety activities related to dams.



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submitted in April, 2016. Approval was requested and granted for Duncan Dam investigative work in Q1 in order to finalize the design of the core raising. Two Dam Safety Reviews were submitted for acceptance in Q4: Buntzen Dam and Falls River Dam.

The annual meeting between the Comptroller of Water Rights and the Director of Dam Safety took place in Victoria on February 9 and 10, 2016.

The revised BC Dam Safety Regulation was passed on February 29, 2016. Dam Safety is in the process of determining the implications to the dam safety program and documenting how BC Hydro intends to meet the new regulation.

#### Inspections

Overall regulatory expectations were met in Q4 for weekly and monthly dam safety inspections. Four of the 375 scheduled inspections for Q4 were not completed for various reasons. 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.

Two of the five external Dam Safety Reviews for F2016 have been completed and final reports received. The remaining three: Elsie, Spillimacheen and Salmon River Diversion Dams, are nearing completion. All findings for the F2015 Dam Safety Reviews were reviewed in Q4 and have now been entered into the dam safety issues database. Any required changes in Vulnerability Index will be noted in these Quarterly reports as these issues are re-rated over time. .

Four Dam Safety Reviews are scheduled for F2017: Cheakamus, Comox, John Hart and Stave Falls.

#### 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.

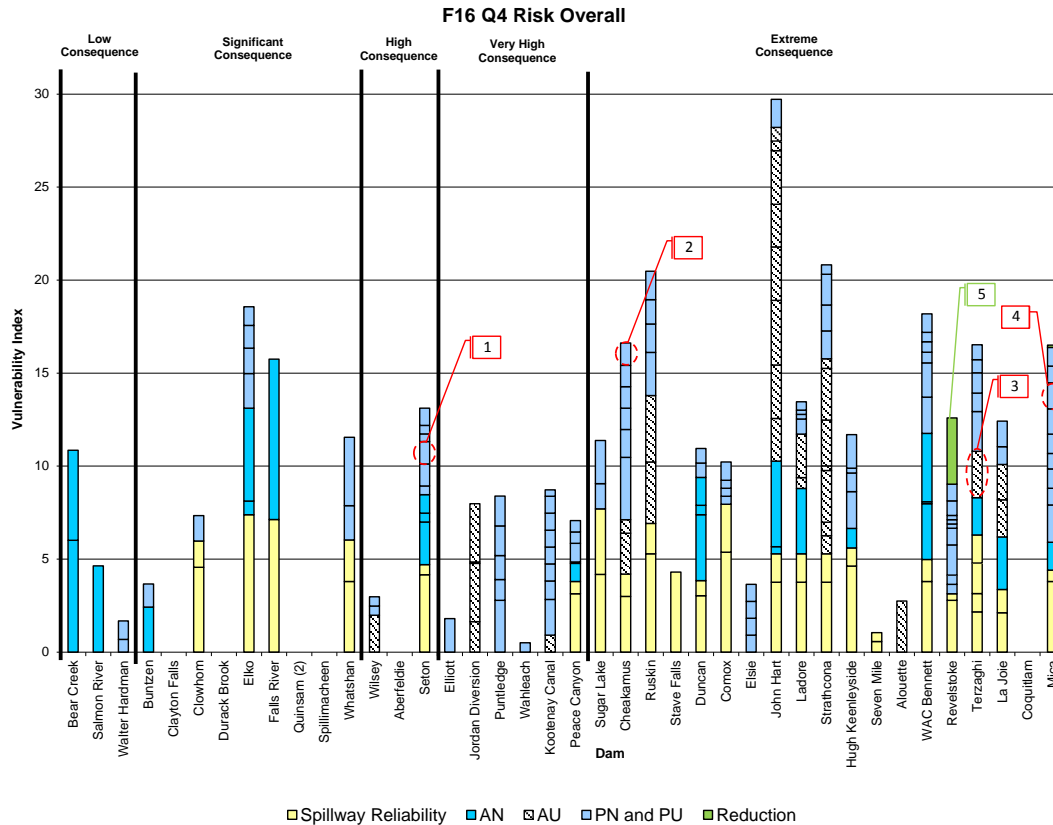
In Figure 3, the total index is shown (sum of actual and potential deficiencies), as well as separate plots for decreases and increases in the total index. Decreases are due to remediation projects as per the Capital Plan and resolution of issues via Performance Investigations. Increases in the index 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

1. **Seton Dam** – The known vulnerability of Seton Dam to an overtopping wave caused by failure of the Santa Clause Mountain slope has been entered into the profile.
2. **Cheakamus Dam** - The known vulnerability of Cheakamus Dam to an overtopping wave caused by failure of The Barrier has been entered into the profile.
3. **Bridge River 1** – The penstock inlet valves do not provide the penstocks with reliable rupture protection
4. **Mica Dam** - The known vulnerability of Mica Dam to an overtopping wave caused by failure of Little Chief Slide has been entered into the profile.

Reduction Risk

5. **Revelstoke Dam** – High uplift pressure measured under the concrete dam is believed to be instrument failure rather than actual high pressures.

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

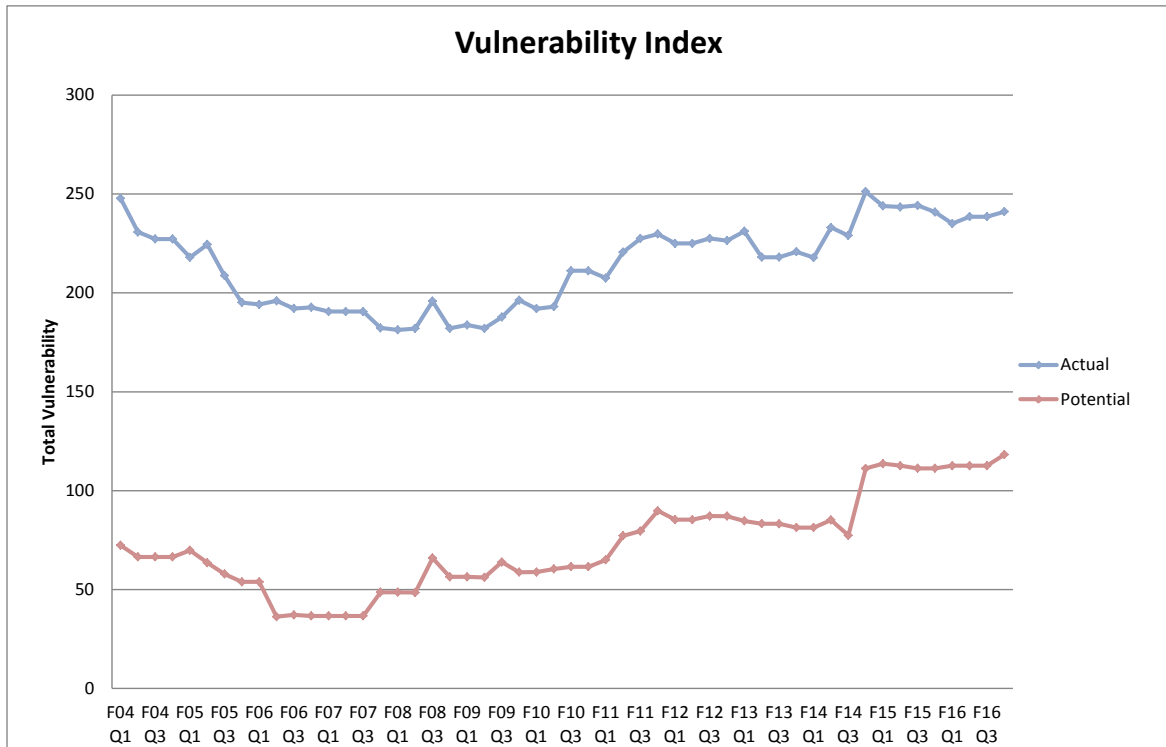


Figure 3 – Change in Total Vulnerability Index Components

