Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

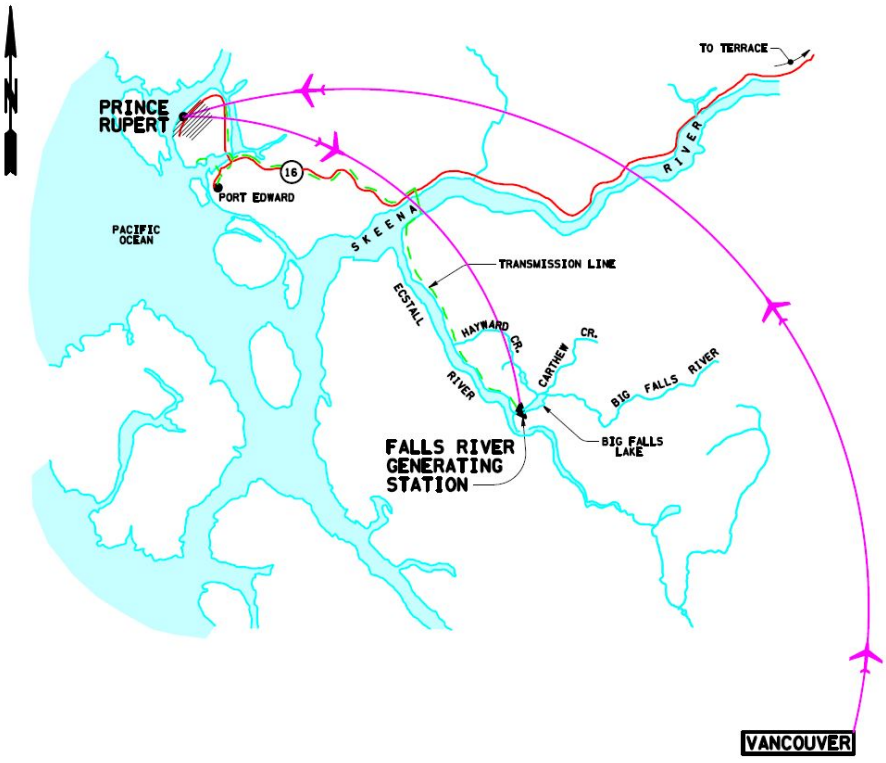
Executive Summary

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 October 1, 2017 to December 31, 2017, 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 have been no substantive changes in risk this quarter, however the risk index has been adjusted to correct for a previous error in the calculated vulnerability of the Cheakamus spillway gate piers.

Quarterly Featured Damsite – Falls River Dam

Falls River Dam is a Significant consequence dam located on the Big Falls River near its confluence with the Ecstall River, about 50 kilometres southeast of Prince Rupert. Accessibility is difficult in poor weather conditions since the only way to access the site is via air or sea, and if travelling by sea, access is available only at high tide. Since there are no homes or businesses in the inundation zone below Falls River Dam, there is no permanent population at risk. However, transient populations, including BC Hydro workers in the powerhouse, would be at risk in a dam or penstock failure due to the very short response time that would be available to get out of the inundation zone.



The Falls River facility consists of a dam and spillway at the top of a 52 metre high natural waterfall; two 1.83 metre diameter penstocks; and a two-unit, 7 megawatt powerhouse located at the base of the falls on the right bank of the river.

The dam was completed in 1930 and is approximately 12 metres high and 154 metres long. The reservoir covers roughly 340 hectares and the reservoir retaining structures consist of the right bulkhead, the intake structure, the two-bay gated sluiceway, the free overflow spillway, and the left bulkhead. The sluiceway consists of two bays each with a 6 metre wide by 6 metre high vertical lift fixed wheel sluice gate. The free overflow spillway is 75 metres wide.

Falls River Facility

The facility intake structure consists of four intakes and a gated undersluice. The undersluice can only be operated by local manual control and is not currently used for normal operation. The penstocks are connected to intakes No. 1 and No. 2 while intakes No. 3 and No. 4 remain unused and are blocked with timber stoplogs.

Two 233 metre long steel penstocks convey water from the intake to the two-unit powerhouse. The powerhouse accommodates two vertical shaft Francis turbine-generators each rated for 3.5 megawatts. Unit 1 was commissioned with the dam in 1930 while unit 2 was installed and commissioned in 1960. The original units were replaced in 1992. The combined maximum discharge capacity of the units is approximately 14 cubic metres per second.

Discussion/Information

Falls River Dam looking downstream

A "fitness-for-service assessment" of the two facility penstocks was conducted in F2015. Although several tested sections had measured wall thickness loss which resulted in calculated safety factors below those recommended in guidance documents, both penstocks were deemed fit for continued service for three years with certain provisions such as annual inspections, repairs to the worst area and a complete internal inspection of the penstocks. Repairs have been made to mitigate one of the identified areas with the highest level of corrosion and deterioration, however these repairs are deemed unlikely to have restored the design factor of safety. An internal inspection was carried out in September 2016 as recommended. The inspection included non-destructive testing to measure the thickness of the steel penstock. This testing confirmed that the thickness is less than recommended in guidance documents and supports the recommendation that another fitness-for-service assessment be completed in 2018. While in operation, there is a risk that a transient event could rupture the penstock resulting in an uncontrolled release of the reservoir flooding the powerhouse and causing a significant environmental impact downstream. Since the site crew is typically only at site once a month and their time in the inundation area is minimized, the loss of life associated with failure of the penstocks is considered to be very low.

Penstock assessment frequency has been recommended to occur every 3 years so that any change in condition can be monitored to inform the risk mitigation strategy.

Falls River Dam looking across towards the left abutment

High inflows at Falls River are managed with the two spillway gates and the free overflow spillway. The vulnerability of the Falls River spillway gates has been given a very high rating in the Dam Safety Database due their age, poor condition, and lack of reliability. There is also a vulnerability associated with these gates due to their potential inability to open when the reservoir level is above the crest of the free overflow spillway. For this reason, although the facility was designed to have flashboards installed along the free overflow spillway to store additional water in the reservoir, these are no longer used, so that a crew must be dispatched to site if the reservoir exceeds a certain elevation. The existing flood discharge gate system requires comprehensive review but this is not planned to be done prior to redevelopment as there is large capacity provided by the overflow spillway.

The gated sluiceway at Falls River.

Numerous components of the Falls River Facility are at or near their end of life. In addition to the penstocks and the sluiceway, the dam concrete itself is deteriorating. The current Facility Asset Plan for Falls River proposes to make modest life extension investments to major assets in order to continue operations for the next 10-15 years. Investments will be of a more reactive nature and will be assessed through the established asset management framework. If future operating investments are required that are larger than those allowed under the established framework, then one or both units may remain out of service until facility re-development, expected outside of the 10-year capital planning window.

Update on Other Major Dams

Mica Dam

There are currently two ongoing dam safety projects:

Special Investigations Project

The work on Mica under the special investigations project for large embankment dams was initiated in 2015. 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. It is anticipated that a full review will take 3-5 years to complete.

Work completed since 2015 include compilation of the background information, plotting of the instrumentation data, the start of the development of a 3-D CAD/GIS model, and the first meeting of the Expert Engineering Panel (August 2016). In the opinion of the Expert Engineering Panel, Mica Dam is designed and constructed in such a way that it safely controls all current seepage flows; however, there is a potential issue in a post-seismic situation at the very top of the dam.

Current work is following the key recommendations of the Expert Engineering Panel Report No. 1. Following the field identification of potential borrow sources for the core and shell materials for future laboratory testing in Q2, work continued this quarter on:

- Development of 3D CAD and GIS models, and
- Characterization of dam fill and foundation materials,

Rehabilitate Vertical Movement Gauges

During construction of the dam, six vertical movement gauges were installed in the core of the dam. The gauges are no longer used to measure settlement or deformation and have since been monitored as quasi-standpipe piezometers, making use of their “leaky” behaviour at casing couplings. Periodic sudden water level drops have been observed in the gauge casings, as well as an accumulation of fine material in the bottom of the casings, suggesting a lack or degradation of sealing at some or all casing couplings and a hydraulic connection through the dam core. This could potentially induce hydraulic fracturing or exacerbate internal erosion within the dam core. These gauges, and the associated issues, are similar to the gauges in the WAC Bennett Dam that were remediated in the past few years.

In Q3, a site investigations program was completed and conceptual design work began for sealing the vertical movement gauges. The project is expected to add new scope to address vertical movement

gauges at Revelstoke Dam which was originally planned as a separate project to be released in F2019. This will allow project and construction efficiencies to help reduce the overall cost of the work.

Revelstoke Dam

There are currently two ongoing dam safety projects, and one study (initiated in F2018) which are described in the following sections.

Left Bank – Slope Stabilization

The Left Bank Slope Stabilization Project was initiated in F2017, with the objective to address the risk posed by the '731A Nose' rock slope area on the safety and operation of the powerhouse and the new Penstocks 5 and 6. In addition, further upgrades are required to ensure the safe performance of the 731 Block, which was previously anchored just after construction of the dam and powerhouse. Ongoing rock falls have damaged the anchors heads and seepage ingress into the heads of the restressable anchors has corroded the strands of the anchors. Engineering has now started working on the combined conceptual and feasibility design stages.

Replace Downie Slide Instrumentation

Downie Slide is a 1.5 billion cubic metre slowly moving rock slide located on the west slope of the Revelstoke Reservoir 65 km upstream of the Revelstoke Dam. Eighteen inclinometers were installed between 1965 and 1993, of which five are still operational. It is forecasted that these five inclinometers will have been disrupted by the slide activity by 2020. To proactively measure slide displacement, an instrument replacement strategy is required to define the degree/level of monitoring. Incorporated in this strategy is a requirement to evaluate alternative displacement monitoring capabilities that could address the high cost of conventional techniques, both from an installation and operation perspective. This project was initiated in Q2; and funding is anticipated early in Q4.

Spillway Chute Condition Assessment

Small movements of the Marble Shear Block have produced cracking of the spillway concrete slab, and although unrated, this deficiency has been monitored for some time. The cracking has become more pronounced with time, and together with the observation that one of the underdrains is now flowing during spillway use, prompted a review of the design, and the rating of the deficiency. There will be a study initiated to determine at what point the long-term movement of the Marble Shear Block endangers the proper functioning of the Revelstoke spillway, so that remedial works can be prioritized and executed within the capital plan. A screening level assessment of the Revelstoke spillway chute was completed in Q3 and concluded that generally, the spillway design at Revelstoke appears to be consistent with modern spillway design practices, considered satisfactory, and no immediate concerns were identified. The screening level assessment recommended that maintenance and repairs continue as currently planned. The chute condition and Marble Shear Block drainage will continue to be closely monitored.

WAC Bennett Dam

There are seven ongoing dam safety projects as follows:

Spillway gate reliability

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

Long-term performance of the dam core

A special investigations project for large embankment dams was initiated in 2011, starting with the WAC Bennett Dam. The overall objective of this project is to develop tools and methodologies for performance monitoring of BC Hydro dams. As part of this project, the objective has been to better understand the current condition and behaviour of the dam. This has been a multiple year project, and the progress has been reported previously.

In Q3, work on understanding the dam core performance continues, as well as the work on the 3D CAD model continued.

Embankment Instrumentation Upgrade

Following from the findings of the special investigations performance assessment work, an evaluation of the failure modes, and a review of the existing instrumentation, sufficient characterization of the dam has been completed to determine future dam instrumentation requirements. A capital upgrade project to install new dam instrumentation was initiated in 2017.

The current phase of the work will undertake a systematic process to identify the gaps in the instrumentation network and to identify both conventional and potentially new, non-intrusive type methods of dam monitoring. As per plan, the first of a series of workshops was organized in order to share background information and to refine the scope of work for the project. In Q3, the third interactive workshop was organized to assess the usefulness of the existing instrumentation and to identify deficiencies, using failure modes and key performance indicators as the basis for evaluation. A draft user requirements document was prepared. Also in Q3, a seepage modelling of the dam by an external consultant was started.

Core Casing Upgrades

This project was initiated to address the leaky open casings in the core, while retaining their usefulness where applicable, and successfully completed most of the work in F2016 and F2017. In Q3 of F2018, the field work to grout up the remaining selected open casings in the dam core was successfully completed, and the work was put in-service. The construction and project completion report will be completed and issued in Q4. There will be no further reporting on this project.

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

Year 1 of the riprap placement was successfully completed by May 2017. Production of riprap and bedding materials for the second year started in Q2 and was completed in Q3. The placement of the riprap is scheduled to start in Q4, with reservoir forecasts favourable to the project.

Seal Low Level Outlets

A long term strategy document was previously developed to assess the options for the future role of the low level outlets at the WAC Bennett Dam. This document was forwarded to, and accepted by, the

Regulator earlier this year. An introductory start-up meeting with dam safety, site, operations, environmental and engineering staff was held in Q2 to present the findings and conclusions of the options study.In Q3, a design plan for the conceptual design stage was finalized, and the team is currently preparing funding request for the conceptual design stage.

Recommission/Seal Sluice Gates

As part of original construction, the WAC Bennett Dam included nine sluiceways and slide gates (sluice gate) located under the radial gate spillway ogee block, on the right abutment. The last known operation of any of the sluice gates was in 1987, when some problems were noted. Subsequent inspections have revealed further deterioration of components of the sluice gates.

Due to the potential risk of uncontrolled release of water if the gates are left in place, this project was initiated to develop a long term strategy for the future role of the sluice gates, Also, included in this project is to determine the future need for and possible upgrades to the leaky spillway stoplogs.

The Project is in the conceptual stage and is progressing as planned. Initial site inspections were carried out in late Q2 including visual and ROV inspection of the sluice gates. A site investigations program was completed in Q3. The conceptual options for both sluice gates and stoplogs and functional requirements for stoplogs will continue in Q4.

Ruskin Dam

By December 2017, four of the five new gates were placed in-service. Construction of the fifth gate is completed. Restoring the shotcrete face on the spillway at bays 3, 4 and 5 is outstanding; this work could not be carried out at this time as gates 3 and 4 are required for spilling. This work will be scheduled for a later date.

Terzaghi Dam-Spillway Chute

The Terzaghi Dam and spillway were constructed in the late 1950's. The last significant use of the spillway was 26 years ago; since that time, it has been possible to pass all excess flows down the Bridge River via the Low Level Outlet facilities, which provide better flow control for downstream fish flows. The spillway chute has not been inspected for at least 15 years due to the rockfall hazard from the adjacent rock slope. Stabilization of the rock slope at Terzaghi Dam has been previously deferred in capital plans due to higher priority work on the assumption that the current observable condition of the spillway chute and a generally robust design (as per a 1994 design review) made the residual risk acceptable.

A screening level assessment of the Terzaghi spillway chute was completed in Q3 and concluded that the spillway at Terzaghi Dam does not satisfy current design standards nor does it comply with the design criteria and practices followed on more recent spillway projects at BC Hydro. There are a number of key design characteristics that resemble those associated with the recent spillway failure at Oroville Dam, however, these characteristics appear to be more robust at Terzaghi Dam due to better foundation material, better foundation preparation, continuous reinforcement at construction joints though not at contraction joints, and a favorable shear key design. This deficiency has now been rated and is deemed a high priority. A work plan has been developed, which will start by addressing the rockfall hazard, followed by a detailed in-chute inspection, drain maintenance and concrete joint repairs, and likely upgrades to preclude water injection under the concrete slab.

Campbell River System

The high-level strategy for long-term risk management for the Campbell River System was described in a previous Executive Summary (Q3 of the F2014 report), and an overall update was provided in Q3 of the F2017 report. There are currently three ongoing dam safety projects, one per site. Recent and ongoing work is as follows:

Strathcona Dam-Upgrade Discharge

The conceptual phase on the design of the Low Level Outlet was completed in Q1 of F2018. The leading alternative has been identified as a short channel located on the right abutment and connecting to the existing spillway channel. A decision was made in F2017 to combine the discharge function with a combined low level outlet for operational discharges and the spillway for higher reservoir conditions, thus allowing for an option to convert the existing gated spillway into an overflow spillway. The spillway upgrade scope (originally released as a separate project in F2016) was combined with this project in F2017.

In Q3, work continued with:

- Completion of all site investigation activities, including geotechnical drilling along the proposed LLO alignment and in the reservoir,
- Development of the Low Level Outlet design, including evaluation of the types of gates; and
- Development of conceptual overflow spillway upgrade options.

Ladore Dam

The conceptual design report for the spillway seismic upgrades was finalized in F2017. The alternative to be assessed in the next phase includes new gates, new hoist towers, and new mechanical/electrical equipment. In Q1, work included preparation and submitting funding approval for the feasibility stage. Funding has now been approved. Work continued in Q2 and Q3 on feasibility-level design work, including carrying out reliability analyses and preparation for field investigations.

John Hart Dam

In Q2, the third Advisory Board meeting was organized in early September 2017, and the team presented the current feasibility stage designs. No major issues that would require a change of direction for the project were identified by the Board, and the project team is considering the specific comments and recommendations of the report. In Q3, the project was progressing through feasibility design, including scoping out a site investigations program as per the Advisory Board's recommendation. Assessment of the technical feasibility of potential water quality mitigation options is underway, with preliminary findings expected in early 2018.

Overall coordination of the Campbell River System

As the three projects progress, additional coordination work will be undertaken by Dam Safety, Project Delivery, Procurement, Regulatory, Environmental, Indigenous Relations, and Generation Operations, and others, as required, to ensure that the designs, construction, Supply Chain strategies, etc. will be strategically optimized and coordinated.

Salmon River Diversion

The dam removal/river restoration was largely completed in Q2, and remaining construction work was completed in Q3. Major items to complete post-decommissioning include finalization with the Regulator regarding a Certificate of Compliance and Land Tenure for assets remaining in place; these are expected to complete in F2019.

GATE MAINTENANCE AND TESTING

During the period of October to December 2017, 58 scheduled gate tests at 23 sites were carried out. No gate system failed to operate on demand during testing. In five other cases, gates operated on demand; however certain equipment malfunctioned or was found to be in unacceptable condition.

Operational restrictions are in place on two out of 109 flood discharge gates due to known deficiencies (no change from the previous quarter). Fifteen gates were intentionally not moved due to potential equipment issues associated with cold weather.

A total of 40 corrective maintenance issues were identified through ongoing testing and maintenance from October to December 2017. A total of 22 new and previous issues were addressed in the same period, for an increase of 18 overall in this reporting period. There were 93 corrective maintenance issues outstanding at the end of December 2017, which is 21 more than one year ago. The increase is primarily due to diligence in reporting rather than a deterioration in equipment condition or level of care.

CIVIL MAINTENANCE

As of the end of the third quarter, 38 of 47 planned projects are substantially complete and 10 others underway. Total spend for the first 3 quarters is $3.589 million. Two projects have been deferred.

Among the projects completed are spillway inspections and repairs, instrumentation access road repairs, tunnel baseline mapping, canal repairs, trashrack debris clearing, and a variety of other civil maintenance work.

Work continues on the sustainable civil preventative maintenance program. The Revelstoke Pilot is substantially complete with a variety of lessons learned to be rolled out to the fleet in February. The first set of civil asset maintenance standards and instructions have been issued with fleet wide rollout commencing in F2019. The second set of maintenance standards and instructions will be ready for a soft rollout in F2019 and full fleet wide rollout in F2020.

EMERGENCY PREPAREDNESS AND PUBLIC SAFETY

Emergency Preparedness is managed by the Strategic Emergency Management team. Dam Safety reports on 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 reports on Public Safety activities related to dams during the Dam Safety Reviews.

Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

Please refer to other reports for quarterly updates on Emergency Preparedness and Public Safety around dams.

COMPLIANCE WITH PROCESSES AND REGULATION

A schedule for updating OMS Manuals in 2018 was provided to the Regulator in Q3 and the schedule accepted. A request for approval to drill and test dewatering wells and install piezometers in John Hart Middle Earthfill Dam was submitted in late December and approved.

Inspections

A total of 425 of 431 (98.6%) scheduled inspections were completed during Q3. Three separate inspections were missed at Wahleach and Terzaghi due to weather-related road closures, and two inspections were missed at Terzaghi and Elko due to lack of manpower. One inspection was missed at Revelstoke as a result of a miscommunication.

Dam Safety Reviews

Dam Safety Reviews are a regulatory requirement carried out at minimum intervals of every five to ten years at high, very high and extreme consequence dams. Nine Dam Safety Reviews are currently in progress. Final Reports for Cheakamus and John Hart were received in late Q3. Final reports for Comox and Stave Falls are being printed. The draft report for Clayton Falls was received in December. Draft reports for Alouette, Duncan, Seven Mile and Revelstoke are expected in January.

VULNERABILITY INDEX: UPDATE

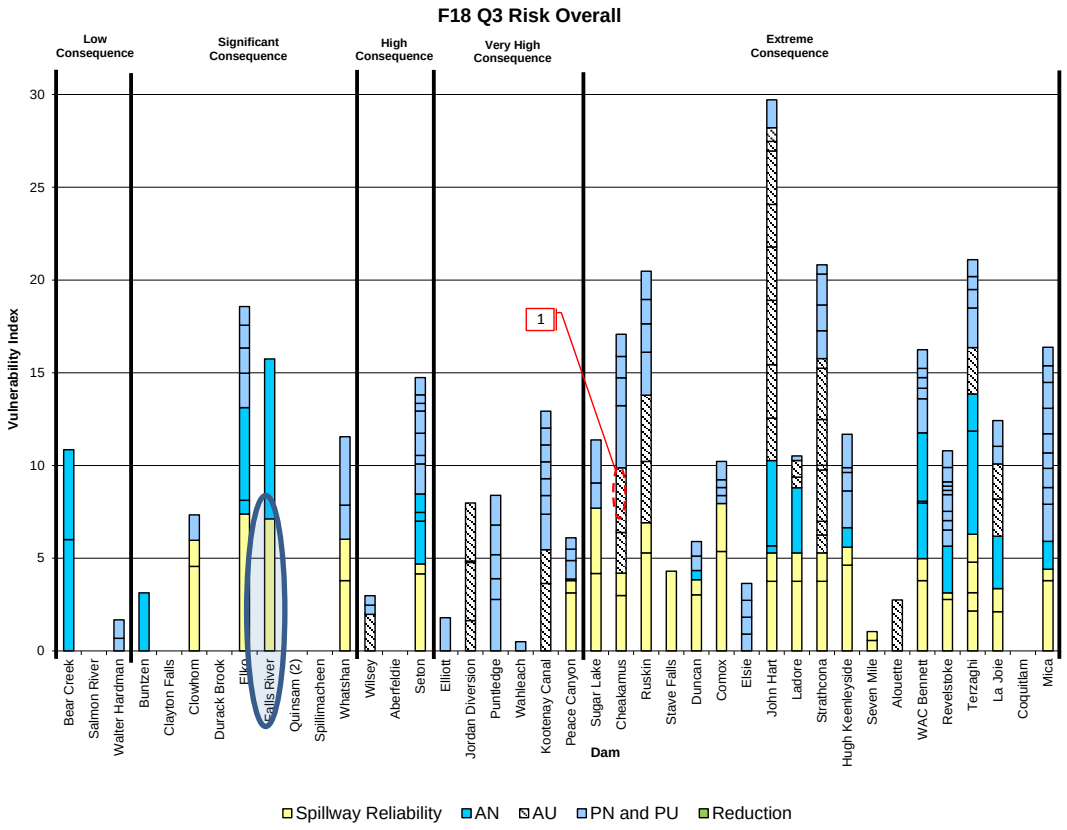
Changes in Vulnerability Index for actual and potential deficiencies, as outlined in Figure 1, are tracked on a quarterly basis and shown on Figures 2 and 3. This is an indication of the changes in the understanding of the dam safety risk profile. In Figure 3, the total index is shown (sum of actual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

Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

Figure 1 - Dam Safety: Overall Risk Profile



Legend and Summary of Changes

Increase in Risk

Cheakamus Dam *– correction of an error in calculated vulnerability of the spillway gate piers.*

Reduction Risk

None this quarter

Quarterly Featured Dam

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.
- 33 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

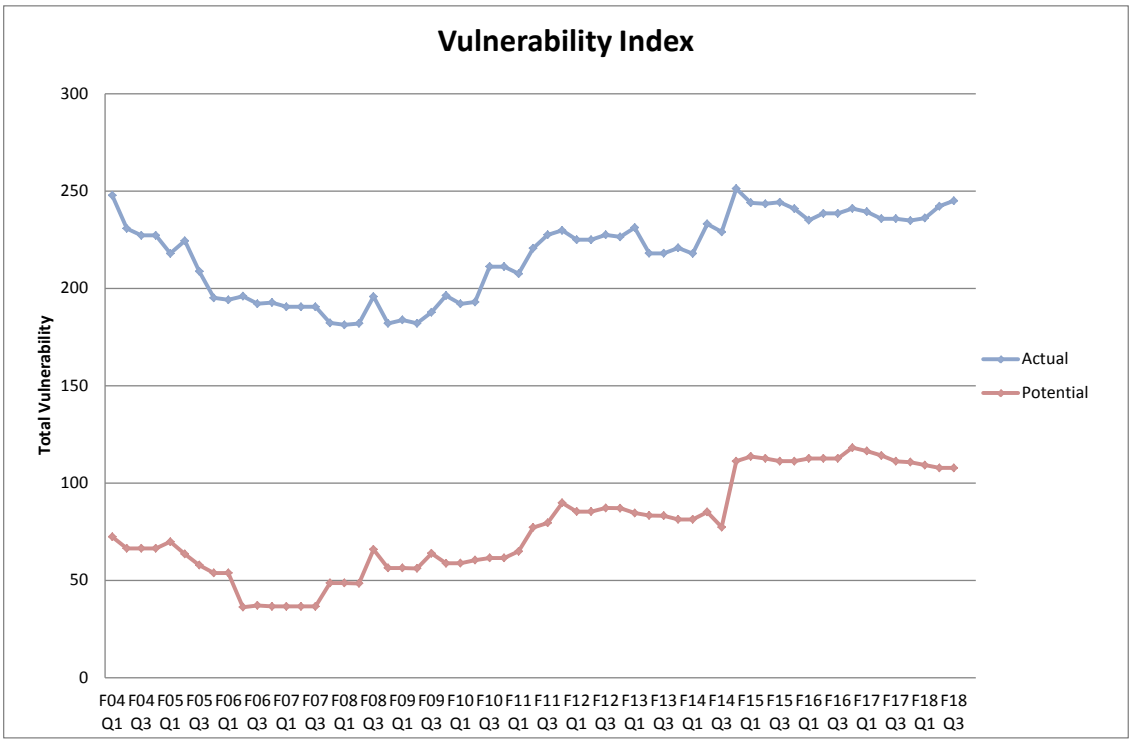


Figure 3 – Change in Total Vulnerability Index Components