Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

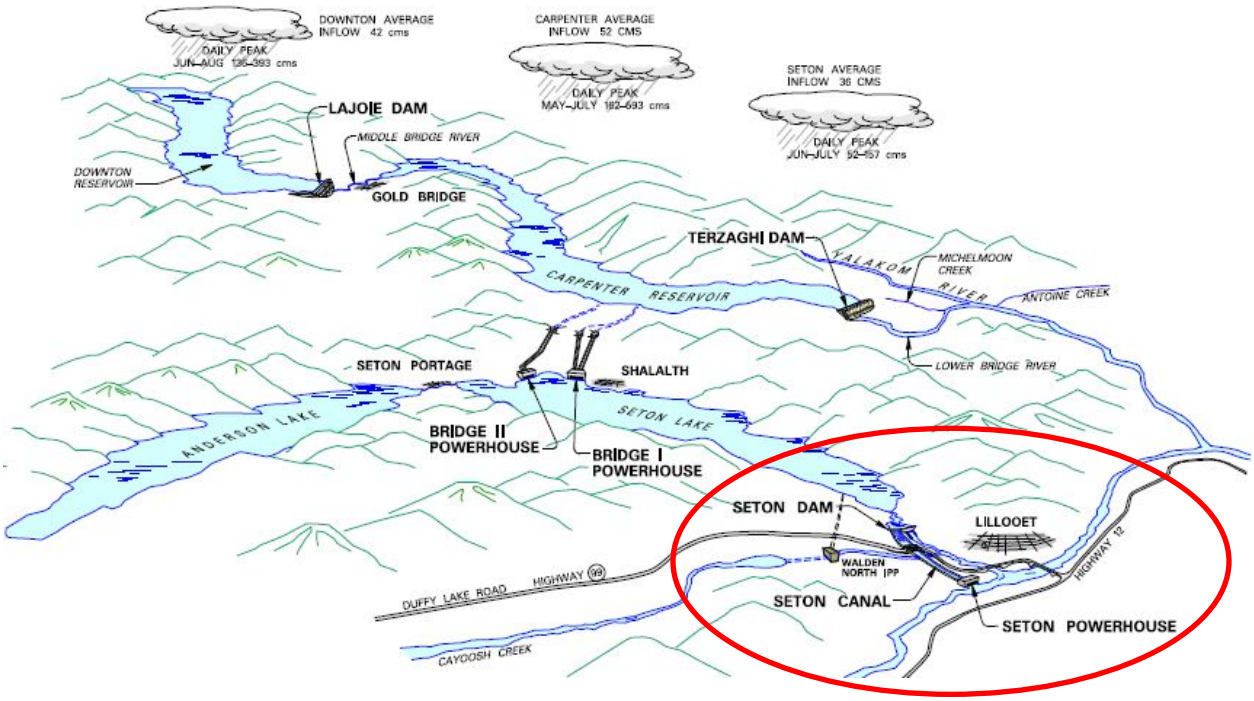
Executive Summary

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 April 1, 2017 to June 30, 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 has been an overall decrease in the risk profile this quarter, as issues additional to those accounted for last quarter, have now been addressed via completion of the Ladore Dam seismic stability assessment.

Quarterly Featured Damsite – Seton Dam

Seton Dam is a High consequence dam located just south of Lillooet and impounds Seton Lake. See Figure 1 on Page 13 for a summary of the Vulnerability Index for this site in relation to the overall BC Hydro dam portfolio. The Seton Project is the furthest downstream in the Bridge River hydroelectric system which also includes La Joie Dam, Terzaghi Dam and the Bridge River Generating Stations. Flow through the Bridge River Generating Stations exits into Seton Lake.



The Seton Project came into service in 1956. The project consists of a concrete dam; power canal; forebay dam; penstock and powerhouse. Flow through the Seton Powerhouse discharges into the Fraser River downstream of Lillooet.

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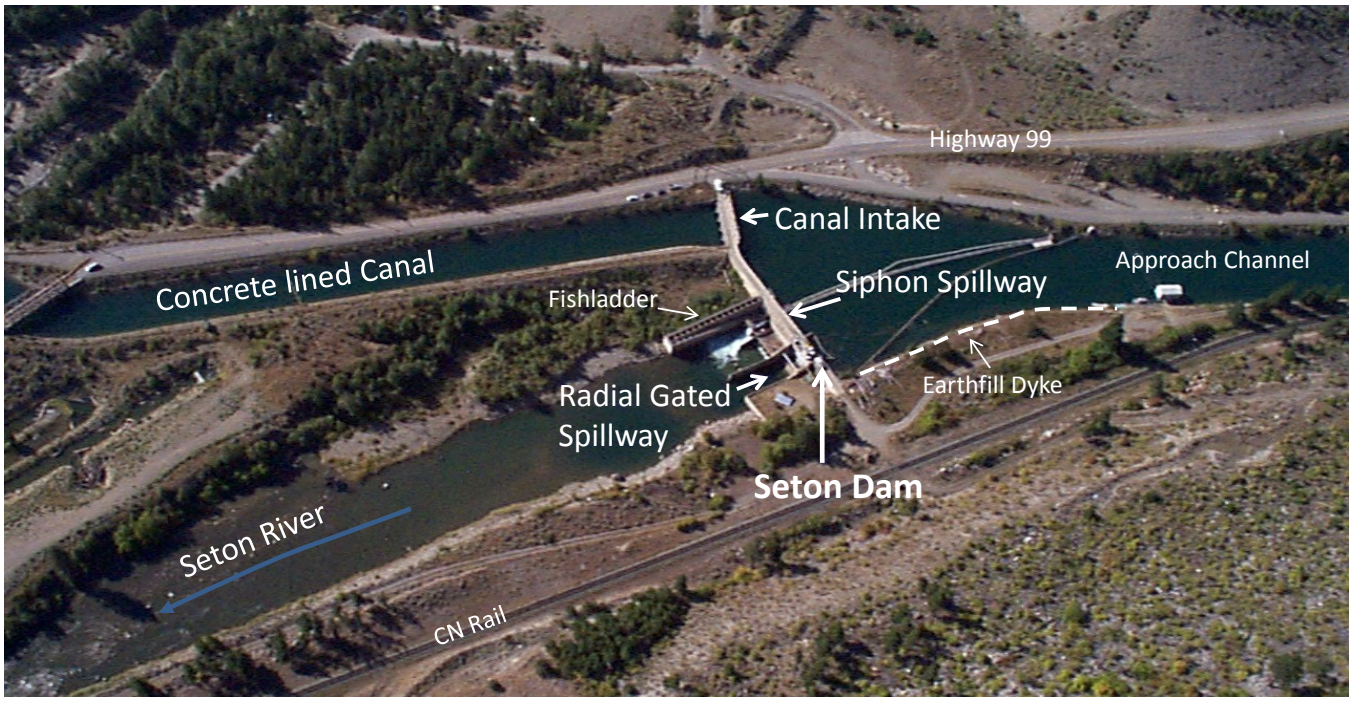

Seton Dam

The Seton Dam and Canal Intake are located at the end of an approach channel at the end of Seton Lake. The main components of the Seton Dam are the earthfill dyke along the left abutment and the concrete gravity dam containing a radial gated spillway, siphon spillway, fishwater release gate and fish ladder. The earthfill dyke is approximately 140 metres long with a maximum height of 6.7 metres where it interfaces with the concrete dam. The dyke is the low point at the dam and would be first to overtop, directing water along the CN Rail right-of-way and back into the river downstream from the dam. The concrete dam has a maximum height of 13.7 metres and is founded on mostly fine gravel with some silt and sand. A sheet pile was installed below the dam in the foundation to control seepage through the foundation. The radial gate and the siphons are used to pass flood flows, and the siphons are also used for fish flows.

From the mid-1990's through to 2011, the radial spillway gate has experienced operating difficulties due to binding of the gate on the concrete on the spillway walls. The aggregate in the concrete that was used to construct the Seton Dam reacts with the cement in a process known as alkali-aggregate reaction and this reaction causes the concrete to expand very slowly over decades. During the Spillway Gate Reliability Project, this issue was temporarily addressed by shaving steel off the sides of the gate and replacing the gate guides. The gate project also replaced the spillway gate hoist and associated electrical system.

View of Seton Dam from the earthfill dyke

Seton Dam fishwater release gate and siphons in operation

Current vulnerabilities at the Seton Dam mainly relate to the need to do an updated assessment of the dam components for the latest seismic hazard. This assessment has been prioritized and is expected to start within the next couple of years.

Power Canal

The canal intake is an open box concrete structure with vertical side walls and four splitter walls for the five intake gates. Control of flow in the canal is provided by the powerhouse, as the canal intake gates can only be operated when there is no flow. Once canal flow has stopped, the gates can be used to isolate the canal for maintenance. From the canal intake, the power canal is 3.7 kilometres long and is fully lined with reinforced concrete. The canal is made up of sections of cut, fill, a combination of cut and fill and has a concrete box section over the Cayoosh Creek known as the Cayoosh Creek Aqueduct. The aqueduct is the low point on the canal and would act as an overflow spillway during extreme floods or surges in the canal. The concrete of the aqueduct is also afflicted with alkali-aggregate reactivity, and has undergone extensive surficial and joint repairs in the past.

The canal embankments are almost 5 metres wide at the crest on the south side and 3 metres wide on the north side. The canal embankments are designed to be free draining and rely on the concrete lining to control seepage. Routine maintenance is required to fix cracks and spalls in the concrete canal lining in order to safely retain the water in the canal. This requires that the canal be dewatered every five to six years, and was most recently completed in April – May 2017.

Cayoosh Creek Aqueduct

2017 Canal lining repairs

View of Seton Canal and spawning channel

View of Seton Canal embankment adjacent to Cayoosh Band

Penstock Forebay

At the downstream end of the canal, water flows into the penstock forebay. The penstock forebay is concrete lined and has a radial gate at the upstream end, an embankment on the left and downstream sides and a power intake structure which leads to a 6.1 metre diameter penstock and 58 megawatt generating station. The forebay embankment is constructed of sandy gravel and also relies on the concrete liner to retain water. The forebay has a history of settlement and cracks and significant repairs were carried out in 2001.

Seton Canal to Powerhouse

Update on Other Major Dams

Mica Dam

There are currently two ongoing dam safety projects:

Special Investigations Project

A special investigations project for large embankment dams was initiated in 2011, starting with the WAC Bennett Dam. The work on Mica started 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. The work will provide a good understanding of the current condition of the dam as well as a developing a set of monitoring and response systems that can be utilized for dam safety management decisions and activities. 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, and the start of the development of a 3-D CAD/GIS model. The first Expert Engineering Panel meeting was held in 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. The Expert Engineering Panel provided a number of recommendations for the scope of the design, construction and performance review that BC Hydro plans to perform.

Plans were developed in Q1 for the F2018 work, following the key recommendations of the Expert Engineering Panel Report No. 1. Key work items planned for F2018 include searching for borrow sources in the Mica Dam area to obtain large quantities of dam fills required for any large scale laboratory testing, which the Expert Engineering Panel recommended. In preparation for any laboratory testing, work will be carried out in F2018 to research, seek out and interview geotechnical laboratories with large diameter equipment capable of carrying out this work. Work will also continue in the development of the 3-D CAD/GIS model.

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 Q1, a project was initiated with the primary objective to permanently seal the gauges in the core of Mica Dam to prevent cross flows and prevent further degradation of the materials surrounding the leaky casing. A secondary objective is to install dam monitoring instruments in the casings, if possible. Plans are currently under development to carry out the conceptual design of the upgrades. This is a similar objective and scope to the one completed at the WAC Bennett Dam.

Revelstoke Dam

There are currently three ongoing dam safety projects, two of which are nearing completion.

Marble Shear Block - Instrumentation

The Marble Shear Block is a large rock mass located on the right bank of the canyon. Extensive stabilization measures were implemented at the time of construction, and no significant movement has occurred in the area of the dam and powerhouse. However, downstream of the powerhouse, the Marble Shear is still considered potentially unstable and water levels must be maintained to reduce the likelihood of slope movement, which could impact the ability to safely operate the discharge facilities.

This project was initiated in F2014, originally to restore or improve the drainage. However, early in the project, the benefits of undertaking a stability review using updated instrumentation readings and a new numerical model was identified, and the work concluded that the stability of the slope was better than previously analyzed. However, it would be beneficial to enhance the monitoring of the slope and additional instruments were recommended.

As part of this project, a total of 5 new piezometers were installed. A stability update was carried out to establish an improved monitoring protocol. The last scope to be completed as part of this project was to install in-place inclinometers in two existing casings (completed in F2017) and to carry out a LiDAR survey of the spillway. This survey has been delayed into F2018, and once completed, this project will be closed.

Left Bank - Instrumentation

A previous investigation had identified seven slopes of interest on the left bank of the Revelstoke Dam that could present a hazard to the powerhouse, penstocks (particularly 5 and 6) and the highway below. The study concluded that further stabilization work is recommended for one slope (referred to as the 731 A Nose). However, for two other slopes, the geology was poorly understood, and that there is insufficient instrumentation to make a definite stability assessment. This project was initiated in F2015 to gain a greater understanding of the stability through the installation of instrumentation.

The Left Bank Instrumentation Project is now essentially completed. The additional instrumentation information combined with a review of the additional geologic information collected has concluded that that slopes located downstream from the 731 A Nose do not require stabilization at this time, and their ongoing performance can be monitored with the new instrumentation.

This project is awaiting final completion documentation, upon which time the project will be closed. Based on the results, the Slope Stabilization Project (below) was initiated.

Left Bank – Slope Stabilization

With the successful completion of the Left Bank Instrumentation Project, the Left Bank Slope Stabilization Project was initiated in F2017, with a much more focussed scope of work. The objective of this project is to address the risk posed by the 731A Nose 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 have corroded the strands of the anchors.

In Q1, plans were developed for the Identification stage, conceptual design of the slope stabilization options, in preparation for funding request and approval in Q2.

WAC Bennett Dam

There are six ongoing dam safety projects, with two new projects soon to be initiated.

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

The second (and final) year of construction work on the sloping part of the spillway chute was completed in F2017. In addition, remaining minor repairs to the flat part of the chute were also completed. With the completion of the construction work, the spillway chute was returned to service.

In Q1, the construction report, including the record drawings, was completed. Preparation of the Project Completion Report is underway. Once completed, this project will be closed.

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. Following a review of redundant power supply options and risk mitigation benefits, the project will proceed with installing a new permanent diesel generator on the right abutment of the spillway, sized for lifting the gates, but not with full power requirements for other items such as heaters, bubbler systems etc.

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 Q1, work continued with:

-Development of the F2018 plan.

-Development of a request for proposal to undertake the air theory work.

-Continued interpretation of the crosshole seismic data, working with an external consultant to develop wave models.

-Continued development of the 3D CAD/GIS model.

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.

In Q1, work was initiated to develop a plan to undertake the Identification phase - conceptual design work. This 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. It is targeted that funding approval will be obtained in Q2.

Casing Upgrades

This project was initiated to address the leaky open casings in the core, while retaining their usefulness where applicable. In F2016, this project was successful in grouting up the observation wells and selected drill hole casings in the dam core while installing piezometers or fibre optic cables in selected holes. In F2017, the contractor was successful in unplugging a casing originally used for a cross-arm device that had been blocked for many years by a seismic hammer. The hammer was freed by over-reaming, and fell to the bottom of the casing.

In F2018, the plan is to grout up the bottom of the cross-arm casing while keeping the remainder of the casing open to retain use for future geophysical testing, pending the development of a new, smaller diameter seismic hammer.

In Q1, work continued with:

- Completion of the final design of the grouting and instrumentation of the remaining nine open casings in the dam core,
- Retaining a Contractor for grouting and instrumentation of the open casings.

The field work is targeted for August/September 2017.

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

Year 1 of the riprap placement was successfully completed by May 2017.

In Q1 of F2018, work continued in documenting the Year 1 of construction, discussing with the contractor in preparation for Year 2 of construction, and completing the freezer testing of the rip rap samples. The current plan is for the Contractor to re-mobilize to site starting with quarry development around August 2017.

Ruskin Dam

In January 2017, new spillway gates 3 and 4 were placed in-service and the temporary bulkhead was successfully re-attached to the dam for the next phase of construction. Restoring the shotcrete face on the spillway is outstanding; this work could not be carried out at this time as the gates 3 and 4 were required for spilling. This work will be scheduled at a later date.

In Q1 work continued on construction of the final spillway gate 5, including demolition of the last pier and construction of the new pier. Work also continued on developing the more detailed numerical model of the Ruskin Dam, to assess if further anchors are required. The work has progressed through the 2-D models and is starting the 3-D modelling.

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. The decision document following from this systems work is currently being updated; no changes to overall strategy are expected, however some specific work items will likely move in risk/cost priority. There are currently three ongoing dam safety projects, one per site. Recent and ongoing work is as follows:

Strathcona Dam

The conceptual phase on the design of the Low Level Outlet was completed in Q1. 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.

In Q1, work included:

- Completion of the conceptual design report; and
- Preparation and submitting funding approval for the feasibility stage, including assessing options for the overflow spillway design. By late Q1, funding was approved.

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. By late Q1, funding was approved.

John Hart Dam

Funding for the feasibility design stage was approved in F2017. A field investigations program was carried out to obtain additional soils information required to improve stability models, as was suggested by the Advisory Board. Further, more detailed design work continued on the North Earthfill Dam, the Intake Dam and the Middle Earthfill Dam. A decision was made in F2017 to replace the existing gates with a new gate system, including new gates, new hoist towers and new mechanical/electrical equipment. Incorporation of reliability principles early in the design work was carried out with the retention of a reliability expert and his inclusion to the design team.

In Q1, work included:

- Evaluation of the buttressing/new plastic concrete cutoff option vs the excavate/replace option for the North Earthfill Dam. A decision to proceed with the buttress/new plastic concrete cutoff option into feasibility design was made.
- Evaluation of the downstream buttress options at the existing Intake Dam was further assessed. The options under consideration include the construction of a downstream dam (with a zones embankment section) and/or extending the plastic concrete cut-off wall to the south abutment. Further work is required before a decision can be made.

- Initial assessments of the impact on the drinking water quality caused by the potential reservoir drawdown were undertaken. Potential mitigation measures were identified and will be further evaluated in F2018.

Overall coordination of the Campbell River System

As the three project progress, additional coordination work will be undertaken by Dam Safety, Project Delivery, Procurement, Regulatory, Environmental, Aboriginal 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 Salmon Diversion Dam and Canal divert water, when available and/or required, from the Salmon River Headpond into the Lower Campbell Lake Reservoir. The Diversion Dam is a Low Consequence rockfill timber crib dam. The dam has deteriorated over the last several years, and it is now considered to be in Fair to Poor condition. Operation of the diversion canal is limited in capacity because of the poor condition of the concrete lining. Both upstream and downstream fish passage facilities perform poorly, and BC Hydro has previously committed to improving fish passage at this site. A project was initiated to address the fish passage and other issues at this site, but by the end of Definition phase, the alternative of refurbishing the facility was deemed not viable on the basis of marginal economic benefit. Thus, a new project has been initiated to decommission the dam and reinstate natural flow and fish passage.

After a number of meetings and discussions, and following BCUC review, both regulatory and Comptroller of Water Rights approvals were obtained in late Q1, thus ensuring that the project could progress to construction in the summer of 2017. Full project funding was approved. The work was awarded to the contractor, who started with some early work items.

GATE MAINTENANCE AND TESTING

During the period of April to May 2017, 40 scheduled gate tests at 23 sites were carried out. Two gate systems failed to operate on demand during testing. In 11 other cases, gates operated on demand; however certain equipment malfunctioned or was found to be in unacceptable condition.

Operational restrictions are in place on 5 out of 109 flood discharge gates due to known deficiencies (decreased from 8 from the previous quarter).

A total of 28 corrective maintenance issues were identified through ongoing testing and maintenance from April to May 2017. A total of 20 new and previous issues were addressed in the same period, for an increase of 8 issues overall in this reporting period. There are now 87 corrective maintenance issues outstanding at the end of May 2017, which is 17 more than one year ago.

CIVIL MAINTENANCE

There are 32 civil maintenance projects planned for F2018 with a budget of $4 Million. To date, seven projects are substantially complete with five more presently underway. The current project spend for the program is approximately $800k.

The seven substantially completed projects include upstream dam face shotcreting, intake, spillway and draft tube joint repairs, vegetation removal from dykes, access road repairs, and penstock and surge tower inspections. The five projects currently underway include penstock repairs, road and intake repairs, rock face scaling and rock anchor greasing, spillway further penstock inspections, and concrete repairs.

Work is ongoing to build a sustainable civil maintenance preventative maintenance program. A pilot program is presently underway at Revelstoke for civil equipment including booms, bridges, roads, powerhouse building, auxiliary buildings and non-water to wire tunnels. Maintenance Standards are being developed for equipment including penstocks, spillways, canals, draft tubes, tailraces and manifolds.

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.

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

COMPLIANCE WITH PROCESSES AND REGULATION

Authorization for the decommissioning of Salmon River Diversion Dam was received in Q1 after the final design report was submitted. A request for investigative drilling in the John Hart Middle Earthfill Dam was also submitted and approval received in Q1.

Inspections

A total of 401 out of 403 (99.5%) scheduled inspections were completed during Q1. No two consecutive inspections were missed at any facility. The missed inspections were the result of either poor access / road conditions (Bear Creek) or a lack of available staff (Seton).

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: Cheakamus, Comox, John Hart and Stave Falls. The draft reports for Stave Falls received in Q1 and comments were returned for the draft Cheakamus report. All four reports are expected to be finalized by the end of Q2. The five Dam Safety Reviews scheduled for F2018 are Alouette, Clayton Falls, Duncan, Seven Mile and Revelstoke. The F2018 reviews were awarded to four consultants in Q1 and site visits will begin in Q2.

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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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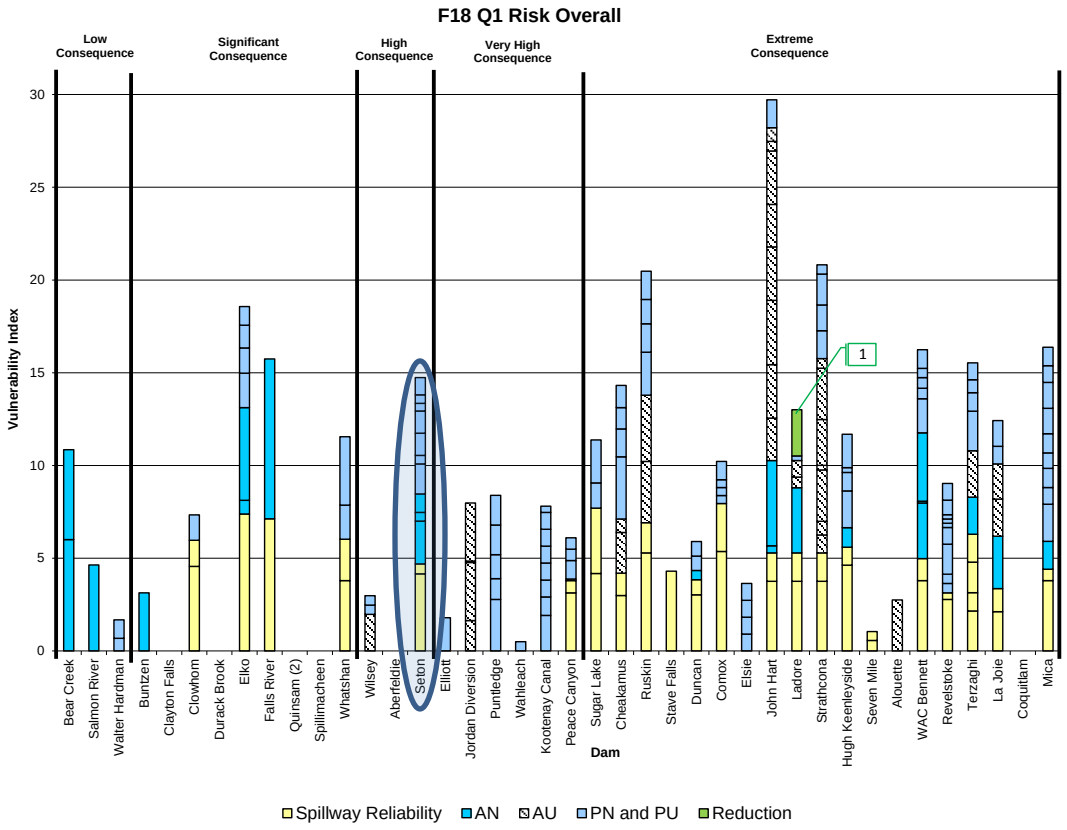
Figure 1 - Dam Safety: Overall Risk Profile



Legend and Summary of Change

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

Reduction Risk

1. ***Ladore Dam –*** *The database was updated to reflect the previously completed stability assessment for seismic loading which determined the dam to be stable for the Maximum Design Earthquake. Further reductions from those reported last quarter were made in Q1 as the issues related to the static stability of the dam, the seismic withstand of the surge tower and the ability to access to the gate controls post-earthquake were closed.*

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.
- 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

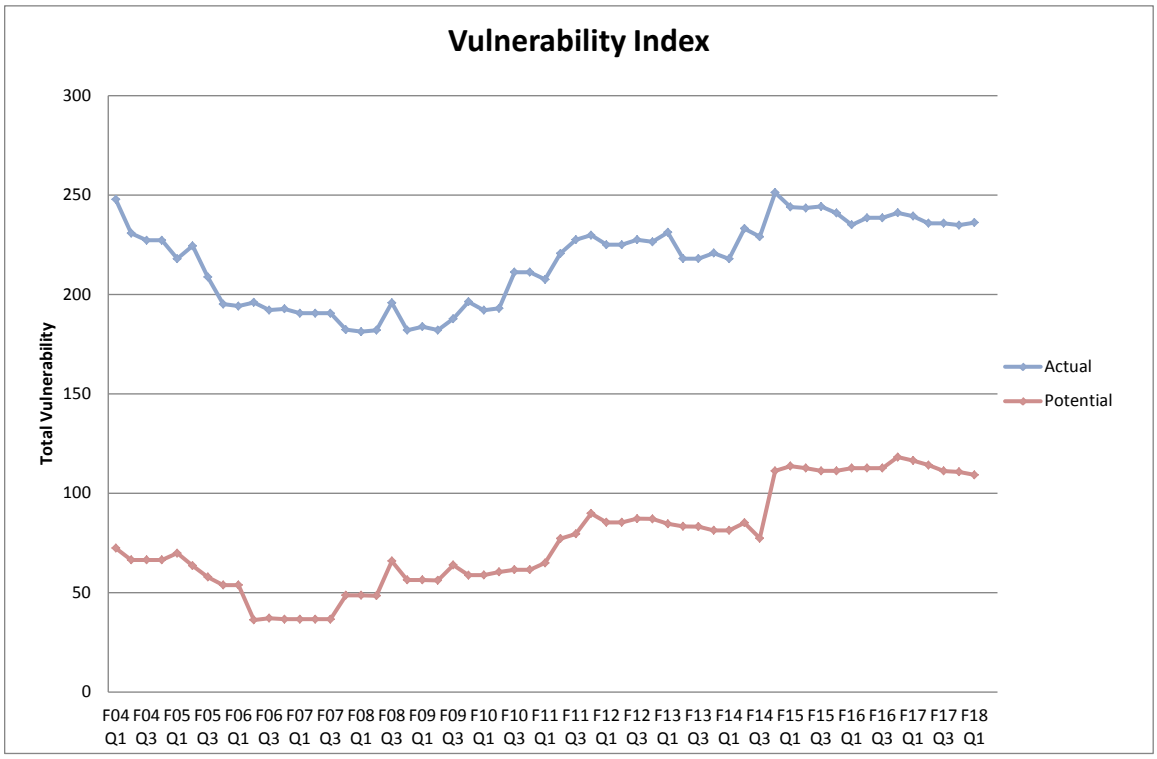


Figure 3 – Change in Total Vulnerability Index Components