Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

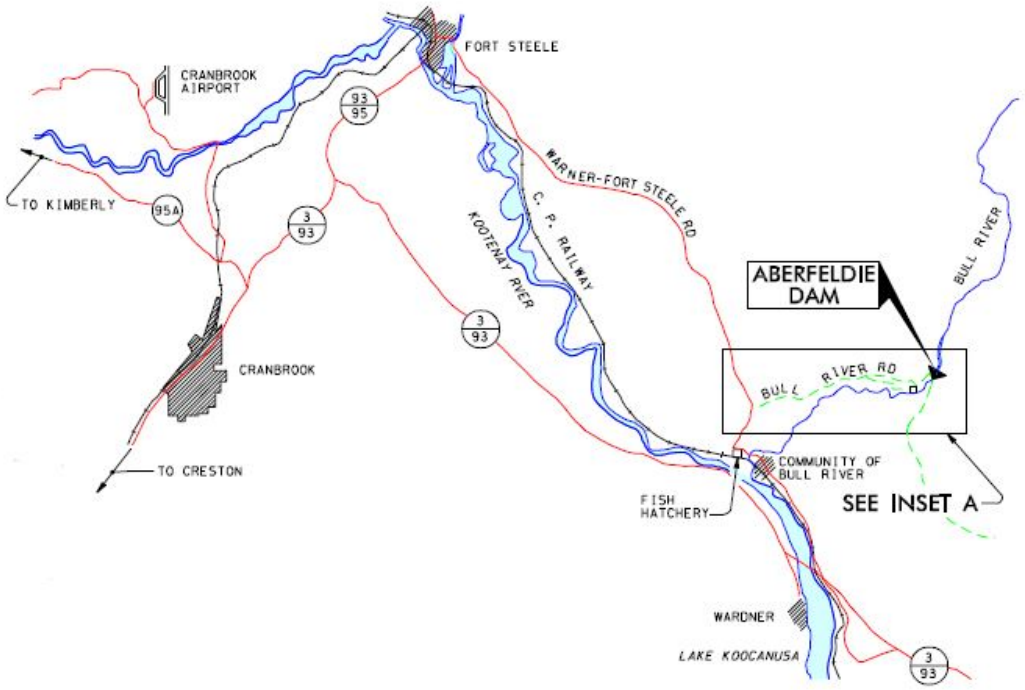
Executive Summary

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, 2017 to September 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 increase in the risk profile this quarter, with new issues related to the design of the Terzaghi spillway, cracking in the Revelstoke spillway chute, and updated information on the Kootenay Canal facilities, including seismic performance of the headworks and stability of the South Gravity Blocks. These increases are partly offset by decreases in risk taken for the decommissioning of Salmon River Diversion Dam and a correction in a vulnerability index calculation for an issue at Revelstoke Dam.

Quarterly Featured Damsite – Aberfeldie Dam

Aberfeldie Dam is a High consequence dam located on the Bull River, approximately 45 kilometres by highway east of Cranbrook in the East Kootenays. The consequence of Aberfeldie Dam is based on the potential inundation of the Community of Bull River, located at the confluence of the Bull River and Kootenay River, if the dam were to fail. The Aberfeldie Project consists of a concrete dam with free overflow spillway, log sluice and power intake; a buried pipeline; section of steel penstock; surge tower; second section of steel penstock leading to the three unit powerhouse located about 1.2 kilometres downstream of the dam. The dam operates as a run-of-river project as there is little storage capacity in the headpond and water routinely flows over the spillway.



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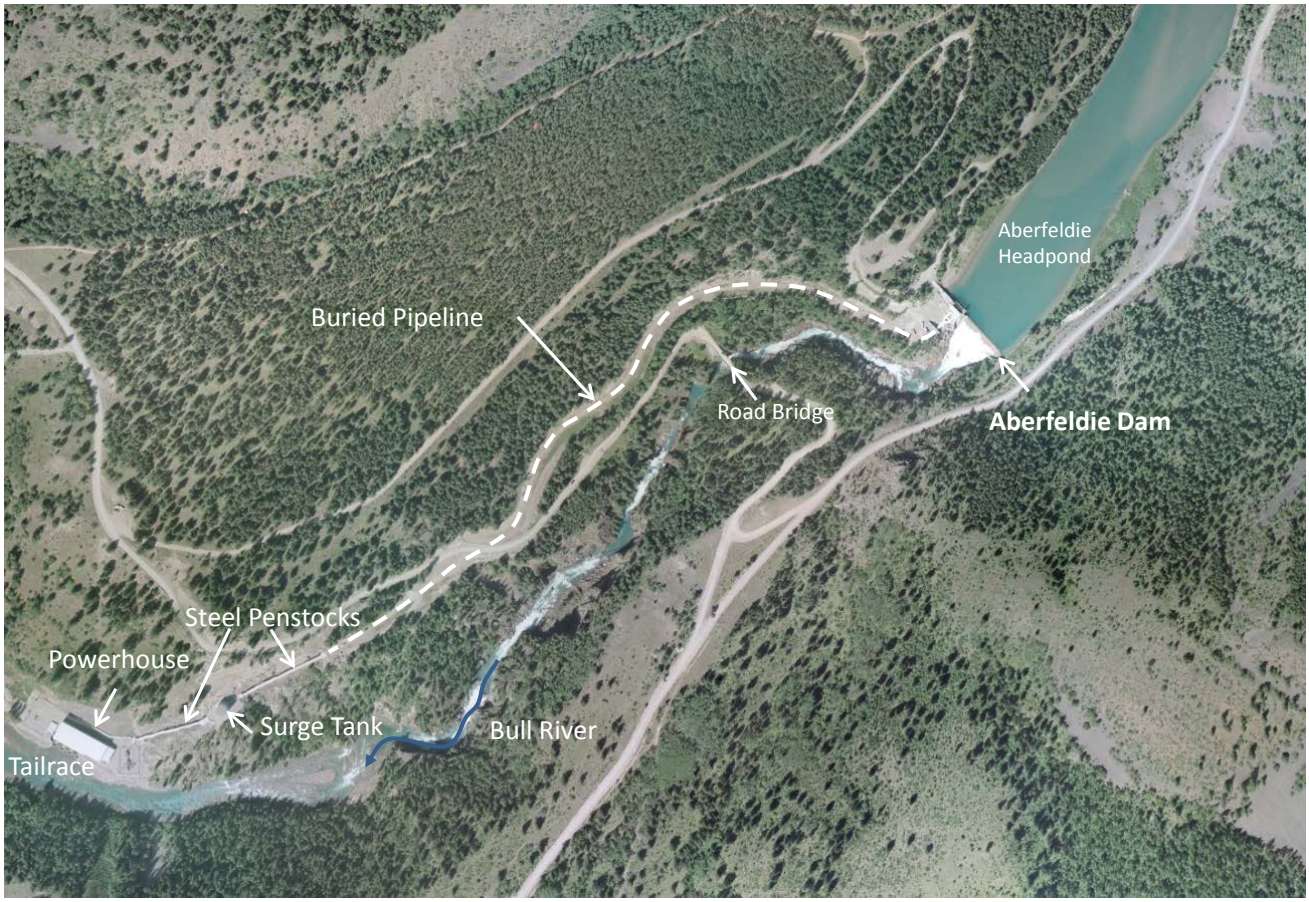
The current Aberfeldie Dam was constructed in 1954 by the Power Corporation of Canada for the East Kootenay Power Company and was subsequently acquired by the B.C. Hydro and Power Authority in 1967.



Aberfeldie Dam

The Aberfeldie Dam is a concrete gravity dam founded on bedrock. The dam is 32 metres high and approximately 135 metres long with the power intake located near the right abutment, a log sluice and a 60 metre wide free overflow spillway. Flashboards were originally installed along the spillway crest to raise the elevation of the headpond after the freshet but these have not been used in decades.

The Bull River carries a high sediment load which is deposited against the concrete dam. In 1999, the stability of the dam was assessed using the most recent surveyed sediment level and it was determined that the dam did not meet stability criteria during flood loading. As the 1999 freshet was expected to be higher than usual, 24/7 surveillance was established at the dam and a manned warning system was installed in the Community of Bull River for the duration of the freshet.

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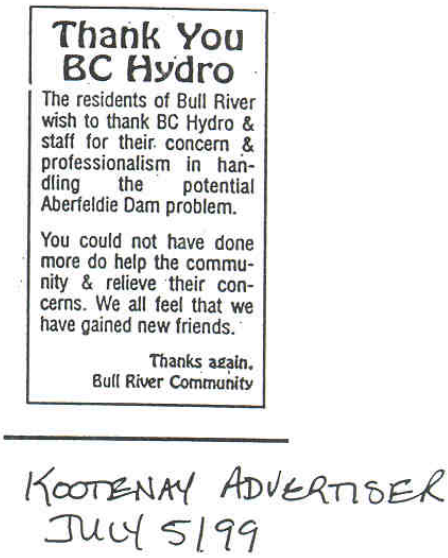
Aberfeldie Dam during the 1999 freshet



Thank You
BC Hydro

The residents of Bull River wish to thank BC Hydro & staff for their concern & professionalism in handling the potential Aberfeldie Dam problem.

You could not have done more do help the community & relieve their concerns. We all feel that we have gained new friends.

Thanks again.
Bull River Community

KOOTENAY ADVERTISER
JULY 5/99

In late 1999, the dam was anchored with 29 fully grouted post-tensioned cable strand anchors to increase the stability of the dam under seismic and flood loading.

Drilling holes for the post-tensioned anchors

Installation of a post-tensioned anchor in the spillway

Between 2006 and 2008, a redevelopment project rebuilt the powerhouse and replaced the original two 2.5 mega-watt units with three 8 mega-watt units. As part of this work, a second intake was utilized at the dam and the woodstave penstock and surge tower were replaced with high density polyethelene pipe and a steel surge tank. The steel penstock from the surge tank to the powerhouse was also replaced. The new plant was put into service in December 2008.

Construction of the new penstock

New steel penstock and surge tower

Repairs to the concrete on the free overflow spillway was carried out in 2016 and ongoing maintenance is required to manage the build-up of sediments in the power intake area at the dam.

There are no identified deficiencies at Aberfeldie Dam. However, flowing water in the range of 1 to 5 liters/minute has been recently noticed adjacent to the buried plastic penstock during a dam safety inspection. As there is no indication of groundwater recharge or any obvious source, the possibility that this flow indicates penstock leakage will be investigated.

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.

Discussion/Information

Following the key recommendations of the Expert Engineering Panel Report No. 1, the plan for the F2018 at Mica Dam work were developed in Q1 and finalized in Q2. Work completed in Q2 included a site reconnaissance of the Mica Dam area where potential borrow sources for the core and shell materials were identified for future laboratory testing.

In preparation for this testing, work will be carried out in the remainder of F2018 to research, seek out and interview geotechnical laboratories with large diameter equipment capable of carrying out the tests. 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.

In Q2, the project plans were approved and funding for the conceptual design phase was approved. In August, a site visit and camera inspections of the casings were completed. Grouting work is just now underway.

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.

A project was initiated in F2014, which enhanced the monitoring of the slope by means of additional instruments and revised acceptability limits based on updated numerical modelling. The last scope to be completed was to carry out a LiDAR survey of the spillway. The LiDAR survey is scheduled for Q3 of F2018, followed by completion of the project documentation to close the project. There will be no further reporting on this project.

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.

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.

The project is in service and final project completion report should be complete by Q4 of F2018. Based on the results, the Slope Stabilization Project (below) was initiated. There will be no further reporting on this project.

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 phase of a project to scale and stabilize the slope. Funding request and approval for a combined conceptual and feasibility stages will be completed in Q3.

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.

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In Q2, a draft project completion report was prepared, which will be finalized in Q3. There will be no further reporting on this project.

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 Q2, work continued with:

- Finalizing the F2018 plan,
- Selecting of the Consultant to undertake the air theory work; work on this task will start in Q3, and
- Continuing development of the 3D CAD/GIS model documentation.

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. In Q2, funding to undertake the identification/conceptual phase design work was approved. 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.

Core 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 Q2, the field trial at the contractor's yard was completed, and all grouting procedures are now confirmed. The plan is to mobilize to site and complete the grouting of the selected remaining casings in Q3.

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. The plan is to complete production and transport the riprap and bedding materials to the main stockpile area by end of December 2017, and to de-mobilize from the quarry. Placement of the riprap on the dam is planned to be completed in Q1 of F2019, subject to availability of reservoir level below the threshold level in spring 2018.

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. Preparation of the design plan for the conceptual design stage is underway.

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 located 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. Funding approval for the conceptual design phase was obtained in Q2, followed by a site visit.

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. In Q2, work also continued on developing the more detailed numerical models of the Ruskin Dam, to assess if further anchors are required. The work has progressed through the 2-D and 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 Q2, work continued with:

- Contract Award for the engineering services for the feasibility stage,
- Contract Award for the geotechnical investigations program, and
- Commencing the work on the conceptual phase of spillways upgrade.

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.

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 Q2 the project progressed as planned through feasibility design stage. The second Advisory Board meeting was organized in early September 2017 and the team presented the current feasibility stage designs to the Advisory Board. The Advisory Board report has now been issued. 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. Site investigations, including drilling in the reservoir are being planned for the spring 2018, which would allow the team to confirm the specific construction methodology for the Middle Earthfill Dam. The Project team is now looking at technical feasibility of potential water quality mitigation options associated with reservoir drawdown, with preliminary findings expected in early 2018.

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

In Q1, all necessary approvals to decommission the diversion dam were received. The construction contract was awarded and the dam removal/river restoration was largely completed in Q2. Remaining construction work is planned for Q3. Major items to complete post-decommissioning include a Certificate of Compliance and Land Tenure for assets remaining in place; these are expected to complete in F2019.

Terzaghi Spillway

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 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. This has been on the basis 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.

The spillway chute design has been recently re-assessed as a check on this risk approach. There are a number of key design characteristics that resemble those associated with the recent spillway failure at Oroville Dam. The design cannot be considered acceptable in view of modern design practices. Further, a critical section was identified, where failure of a single concrete slab could undermine the left training wall and endanger the impervious core of the Terzaghi dam itself. As such, this deficiency has been now been rated, and is deemed high priority. A work plan is being developed in view of the situation, 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.

GATE MAINTENANCE AND TESTING

During the period of June to September 2017, 82 scheduled gate tests at 23 sites were carried out. No gate system failed to operate on demand during testing. In 9 other cases, gates operated on demand; however certain equipment malfunctioned or was found to be in unacceptable condition.

Operational restrictions are in place on 6 out of 109 flood discharge gates due to known deficiencies (no change from the previous quarter).

A total of 45 corrective maintenance issues were identified through ongoing testing and maintenance from June to September 2017. A total of 62 new and previous issues were addressed in the same

period, for a decrease of 17 overall in this reporting period. There are now 70 corrective maintenance issues outstanding at the end of September 2017, which is 13 less than one year ago.

CIVIL MAINTENANCE

As of the end of the second quarter, 25 of 47 planned projects are substantially complete and ten others are underway. Total spend for the first two quarters is $2.539 million. Two projects have been deferred and replaced with two capital-funded projects.

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

Work continues on the pilot at Revelstoke to develop a sustainable civil preventative maintenance program. 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 initial 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.

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

COMPLIANCE WITH PROCESSES AND REGULATION

A letter describing investigative drilling in the abutments of Strathcona Dam was provided to the Regulator in Q2.

Inspections

A total of 399 of 403 (99.0%) scheduled inspections were completed during Q2. Separate inspections were missed at Ruskin and Terzaghi, and two consecutive inspections were missed at Cheakamus, a result of miscommunications regarding lack of available staff. In response, a corrective action plan is under development which will involve automatically-generated alerts following a single missed inspection, so that additional care can be taken to ensure whatever situation that resulted in the first missed inspection is rectified prior to the next scheduled inspection.

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. Nine Dam Safety Reviews are currently in progress. The reports for Cheakamus, Comox, John Hart and Stave Falls are being finalized. Site visits for Alouette, Clayton Falls, Duncan, Seven Mile and Revelstoke were completed in Q2.

Discussion/Information

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VULNERABILITY INDEX: UPDATE

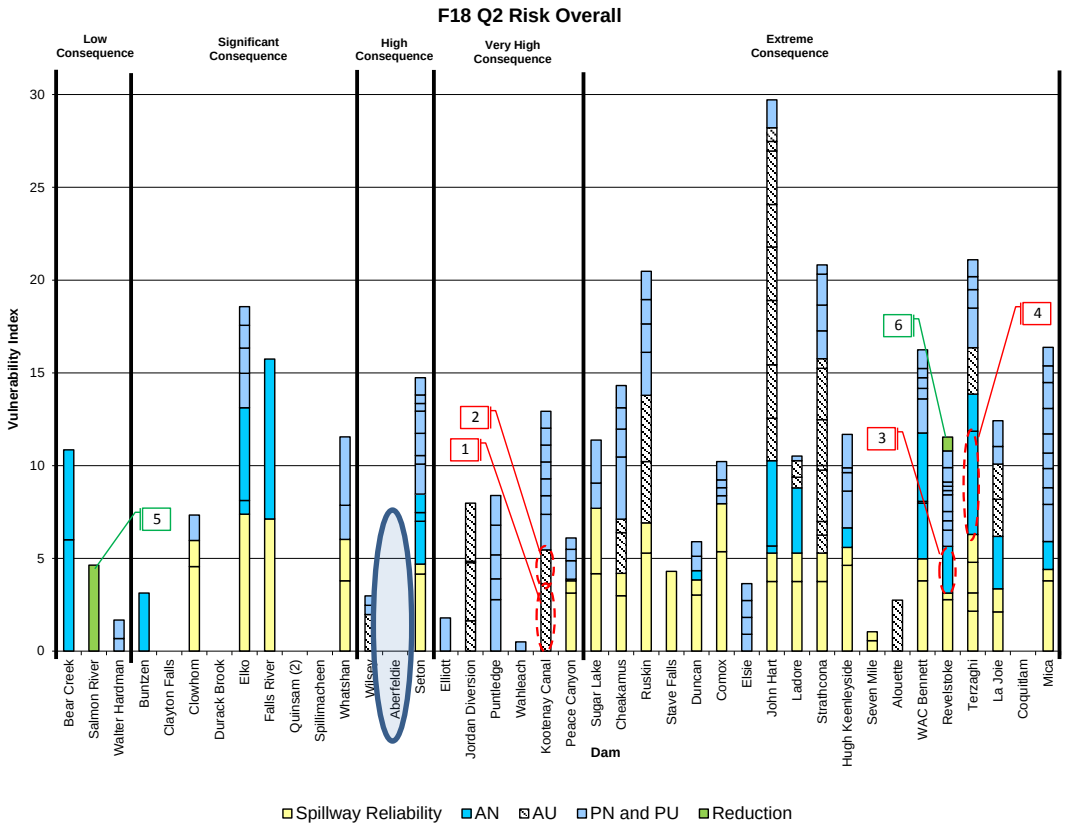
Changes in Vulnerability Index for actual and potential deficiencies, as outlined in Figure 1, are tracked on a quarterly basis and shown on Figures 2 and 3. This is an indication of the changes in the understanding of the dam safety risk profile. In Figure 3, the total index is shown (sum of actual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

Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

Figure 1 - Dam Safety: Overall Risk Profile



Legend and Summary of Changes

Increase in Risk

1. ***Kootenay Canal Dam –****Updated analyses indicate the headworks centre pier is not stable for the design earthquake.*
2. ***Kootenay Canal Dam*** *– Updated analyses indicate the South gravity blocks are not stable for the design earthquake.*
3. ***Revelstoke Dam*** *– Movement of the Marble Shear Block has caused cracking of the spillwaychute concrete.*
4. ***Terzaghi Dam*** *– The design of the Terzaghi spillway does not meet modern design practices and could be susceptible to failure under normal load spills.*

Reduction Risk

5. ***Salmon River Diversion Dam –*** *The dam was decommissioned in Q2.*
6. ***Revelstoke Dam –*** *An error was corrected in a calculation of the vulnerability index for failure of the 731A Nose.*

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

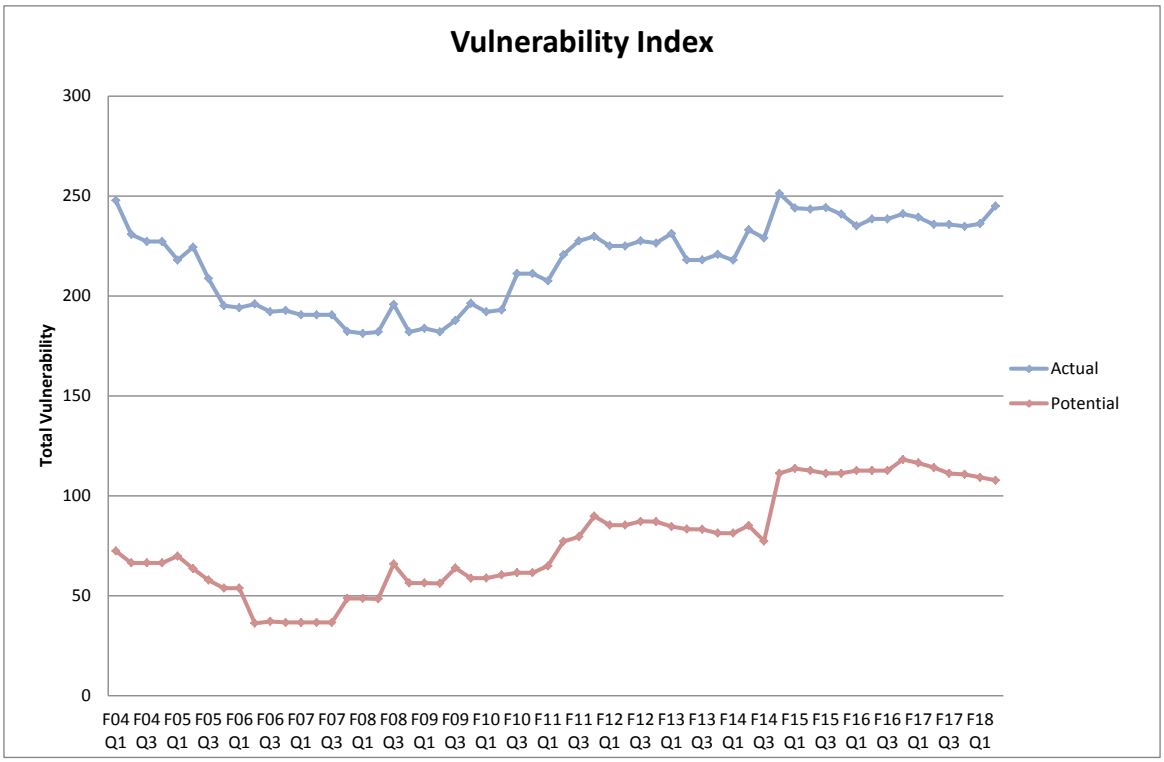


Figure 3 – Change in Total Vulnerability Index Components