BC Hydro
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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, 2018 to December 31, 2018, 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 executed in a manner that is 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 risk this quarter with the decommissioning of the John Hart wood stave penstocks. There have been small increases in risk related to the Terzaghi spillway not having sufficient capacity to pass 100 per cent of the Probable Maximum Flood.

Members of the Capital Projects Committee will notice a number of changes in this quarter's report. This is the first step in transitioning the Quarterly Report to widen the breadth of reporting; expanding the focus from a concentration on physical deficiencies and remediation projects to a more comprehensive view of the Dam Safety Program, including surveillance, maintenance, and regulatory compliance. Additional metrics are also being introduced to provide objective measures of performance and progress within the Program. More changes will follow in subsequent quarters as we work to provide the Committee with a more streamlined, more comprehensive and more broadly informative report.

Risk Profile of BC Hydro's Dam

Dam Safety contribution to Enterprise Risk

Dam Safety is assigned a high "risk priority" within BC Hydro's Enterprise Risk report, as depicted below. This high rating is arrived at by recognizing that: (1) there can be extremely severe consequences from the failure of a dam; (2) a dam failure can progress quickly without leaving adequate time to take effective actions to reverse the failure; and (3) our ability to mitigate this risk is considered to be "moderate" given that upgrades to existing dams are typically expensive, time and resource intensive and frequently technically challenging. The nature of dam safety risk is that it can only be realistically managed by minimizing to the extent practicable the probability of occurrence through a well-constructed and well-executed Dam Safety Program.

Risk	Severity	Likelihood	Speed of Onset	Ability to Mitigate	F19 Q3 Risk Priority	Change from Last Quarter
Dam Safety *Risk of a dam safety incident*	**H**	**L**	**Fast**	**M**	**H**	• For F19 Q3 the overall Dam Safety risk is stable.

Given the nature described above, this Dam Safety component of the Enterprise Risk is not expected to change from quarter to quarter. Neither is it expected to diminish over time in response to dam upgrade projects delivered within the Capital Plan, such projects being intended to adequately manage this aspect of BC Hydro's risk rather than eliminate it.

Vulnerability Index update

Significant dam safety issues, *i.e.*, those having direct impact on potential dam failure, are rated for severity by way of the Vulnerability Index. The Vulnerability Index is a qualitative assessment of future dam performance from all causes; the higher the rating, the higher the likelihood of poor performance.

The Vulnerability Index for each currently identified issue at each dam site is shown in Figure 1. Dams are sequenced from left to right in order of increasing downstream consequences, per the BC Dam Safety Regulation. The nature of each issue is characterized as one of the following types:

AN **Actual** deficiency (demonstrated to exist) under **normal** load conditions (associated with daily or short-term operations)

AU **Actual** deficiency (demonstrated to exist) under **unusual** load conditions (associated with flood and earthquake loading)

PN & PU **Potential** deficiency (requiring further investigation to demonstrate existence) under either normal or unusual conditions

Spillway Reliability Actual or potential deficiency related to reliability of the dam's spillway and/or other flood discharge systems

Notable changes in Vulnerability Index in F2019 Q3 are described below and identified on Figure 1.

1. A Vulnerability Index ***addition*** of 0.47 (AU deficiency) at Terzaghi Dam due to capacity to pass only approximately 80% of the updated Probable Maximum Flood, but with an estimated probability of overtopping the dam of less than 1.7×10^{-6}.

2. A Vulnerability Index ***addition*** of 0.43 (AU deficiency) at Terzaghi Dam due to the possibility of the spillway chute walls being overtopped when passing extreme floods. The spillway was originally designed to have a capacity of about 1,275 cubic metres per second but the current Probable Maximum Flood requires discharge through the spillway greater than this.

3. A Vulnerability Index ***reduction*** of 4.6 at John Hart Dam due to the permanent dewatering of the wood stave penstocks, eliminating the risk related to the penstocks failing under seismic loading.

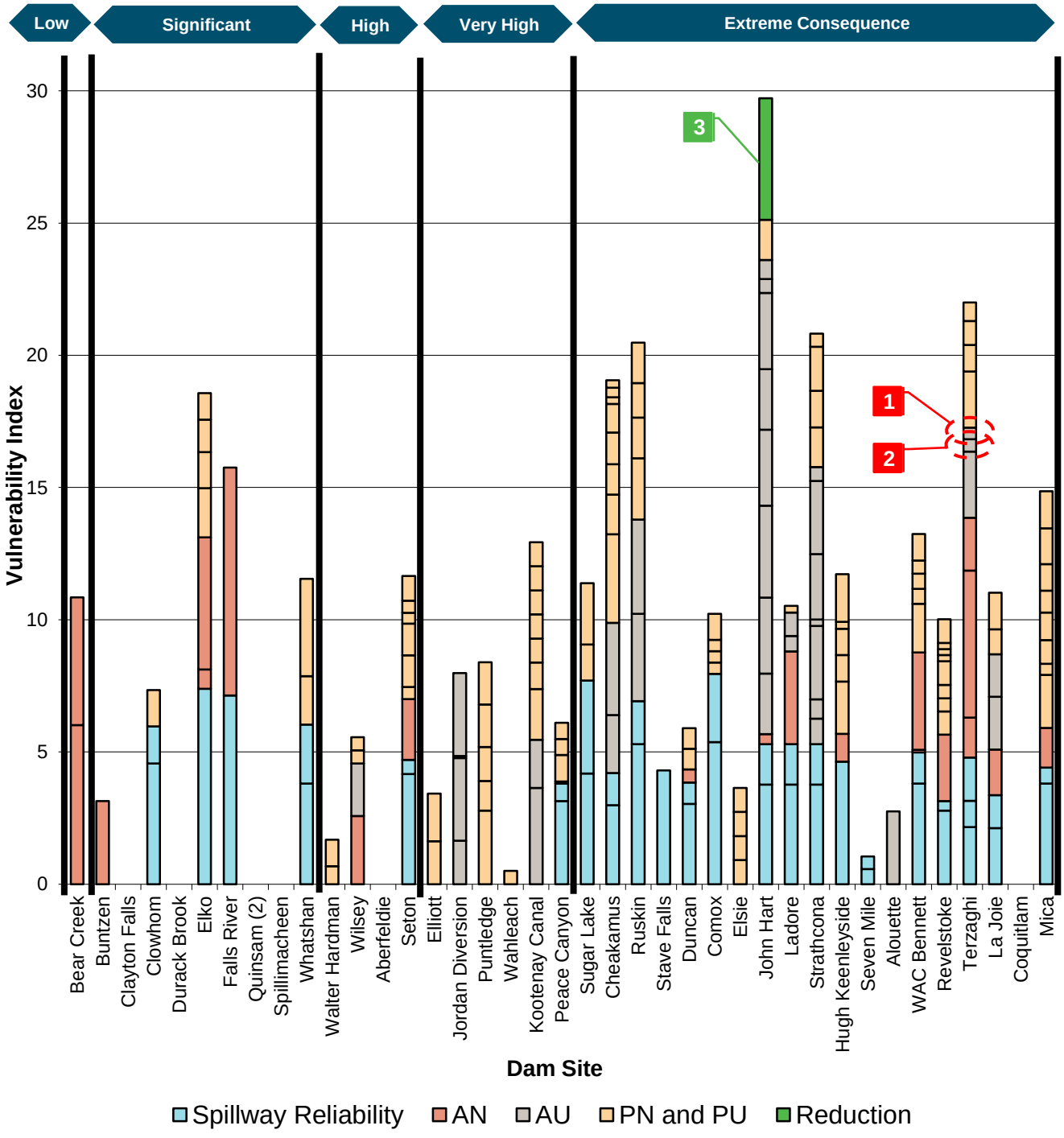

Figure 1 Dam Safety overall risk profile at the end of F2019 Q3, as represented by the Vulnerability Index. Notable changes are identified.

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Changes in Vulnerability Index for actual and potential deficiencies, aggregated across the entire fleet of dams, are tracked on a quarterly basis and shown in Figure 2. This is an indication of the changes in the understanding of BC Hydro's dam safety risk profile. Additions are due to the development or recognition of new issues. Reductions are due to risk remediation projects delivered through the Capital Plan, completed repairs and corrective maintenance, and resolution of issues via Dam Safety Investigations. Existing issues are re-examined on a regular basis and re-rated as required. These changes—additions and reductions—have been tracked since the end of Fiscal Year F2011.

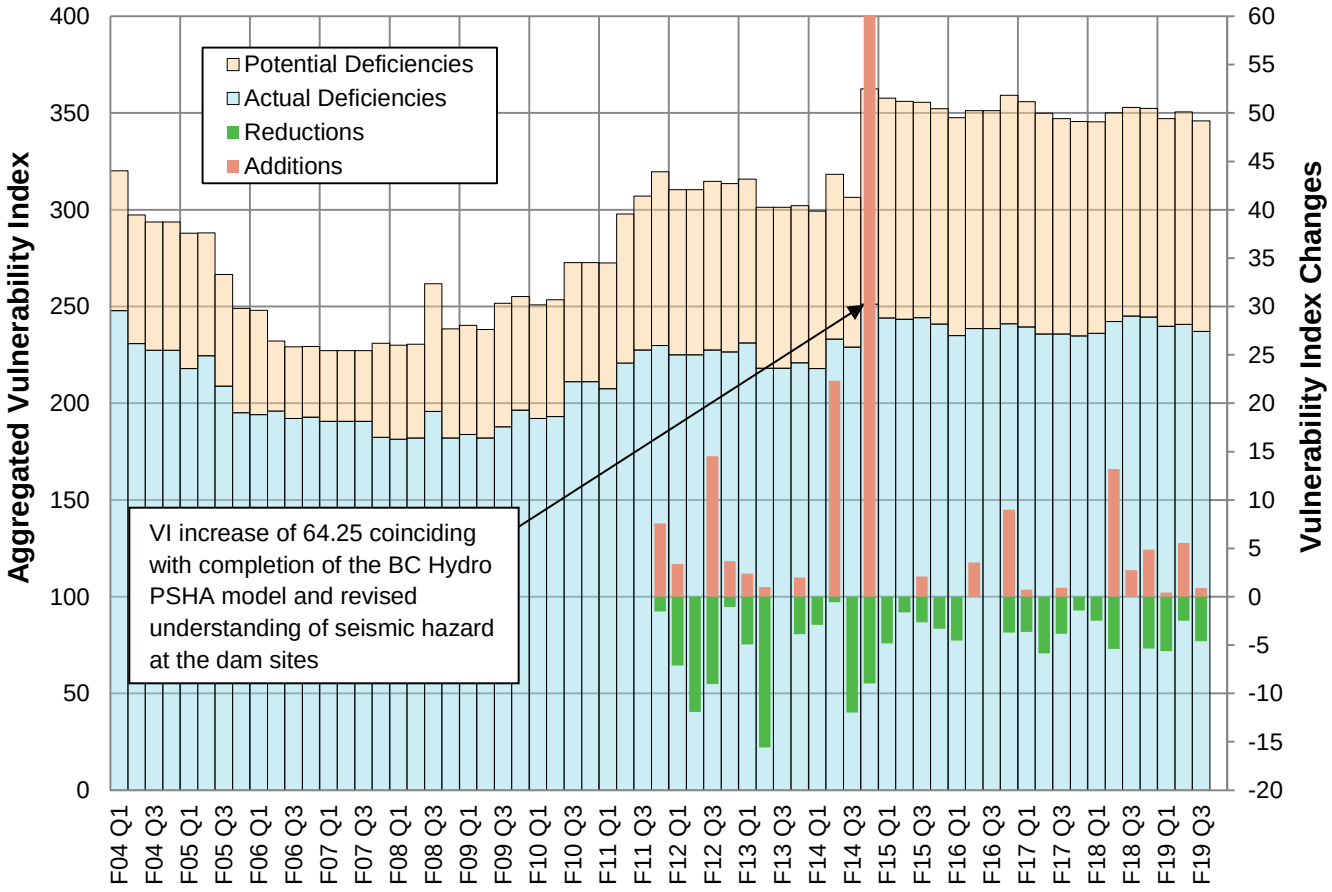

Figure 2 Changes and trends in the Vulnerability Index aggregated across the BC Hydro system. Note: the bars are "stacked" such that total aggregated VI is given by the top of the Potential Deficiencies bar.

Quarterly Featured Dam Site

The Comox Dam is being featured in this quarterly report. A two page summary of the dam has been prepared containing key data, photos and short descriptions of the dam and current issues. Similar summaries for all BC Hydro dams are in preparation. These summaries will be available via links in future quarterly reports and this "Featured Dam Site" section will be discontinued.

Comox Dam

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Technical Details	
Date of original construction	1912, 1957 (modified), 1982 (current configuration)
Purpose	Provides flow regulation for the downstream Puntledge Project
Location	14 km upstream from the City of Courtenay on Puntledge River, 300 m downstream from the outlet of Comox Lake.

Reservoir	Comox Lake
Surface Area	30 km^2
Total Storage	117.63 x 10^6 m^3
Top of Dam Elevation	137.46 m
Full Supply Level	135.33 m
Normal Maximum Operating Elevation	135.33 m (1 Oct – 31 March) 134.42 m (1 Apr – 30 Sept)
Minimum Operating Elevation	128.93 m
Drainage Basin Area	464 km^2

Dam	Comox Dam
Type	Concrete Gravity
Height above lowest foundation	10.7 m
Crest Length	142 m
Foundation	Bedrock (metamorphic volcanic breccia)

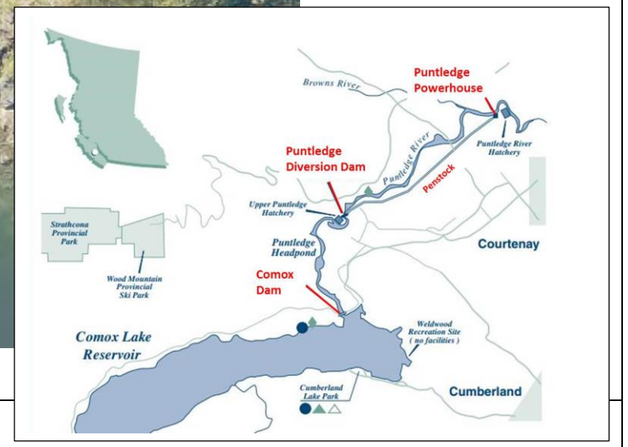
Water Passages

Spillway	
Location	Immediately downstream of the buttressed undersluice section of the original dam
Type	Free-Crest Overflow
Material	Concrete
Capacity	90 m^3/s (El. 137.46 m)

Sluiceway	
Location	Right abutment
Number and Type	Two-bay, gated
Capacity	360 m^3/s (El. 137.46 m)

Power facilities	See Puntledge Dam

Hazard consequence	
Consequence Category	Extreme
Maximum Design Earthquake	0.821 g (1/10,000 Annual Exceedance Frequency)
Inflow Design Flood	Probable Maximum Flood (Peak 6-hour inflow average 2,079 m^3/s)



Dam Description

The Comox Dam is located on the Puntledge River approximately 14 kilometres upstream from the City of Courtenay and about 300 metres downstream of the east end of Comox Lake Reservoir. The Comox Dam is 142 metres in length with a maximum height of 10.7 metres. The reservoir covers 3000 hectares and services a drainage basin area of 460 square kilometres. The dam is currently classified as Extreme consequence.

There are no power generation facilities at Comox Dam. The purpose of the dam is to regulate flow in the Puntledge River for power generation downstream. The dam is also used to provide minimum flow, provide recreational opportunities and for flood management for the City of Courtenay. Water conveyance at Comox Dam is through a two vertical sluice gates and over a free overflow spillway. There is also a fish ladder present, but its discharge capacity is small and is not considered from a dam safety perspective at Comox Dam.

The original dam was constructed in 1912 comprising a concrete buttress dam with undersluices in the centre of the river channel. The dam was purchased by the BC Power Commission in 1953 and in 1957 the dam underwent significant modifications including the replacement of the old fishway, construction of the sluiceway at the right abutment and construction of the overflow spillway in the centre of the river channel.

The current general arrangement of Comox Dam was completed in 1982 when the dam was modified to allow safe passage of the then predicted Probable Maximum Flood with allowance of 2.4 metres dam overtopping. These modifications comprised of the construction of the left gravity section, free-crest ogee profile overflow spillway, raising and strengthening portions of the central section, and the construction of the right abutment cut-off wall. The sluiceway, constructed in 1957, was left unchanged. In 1989, the dam was anchored to improve stability. All of the anchors installed in the Comox Dam in 1989 were fully grouted and cannot be tested.

Current Dam Safety Issues

Both the Comox Dam and the downstream Puntledge Diversion Dam have potential seismic deficiencies which are being managed in the interim through public education. Initial high level assessments indicate that the Comox seismic withstand is below expectations and a more detailed review will be carried out. There are a number of flood-related issues in the system related to the reliability of the gates and the potential for overtopping the abutment at Comox Dam. Initial high level assessments also indicate there may be stability concerns for floods greater than a 1/1,000 Annual Exceedance Frequency. Flood related deficiencies associated with the Comox-Puntledge system are considered a lower priority since recreational users are not expected to be using the river during large floods.

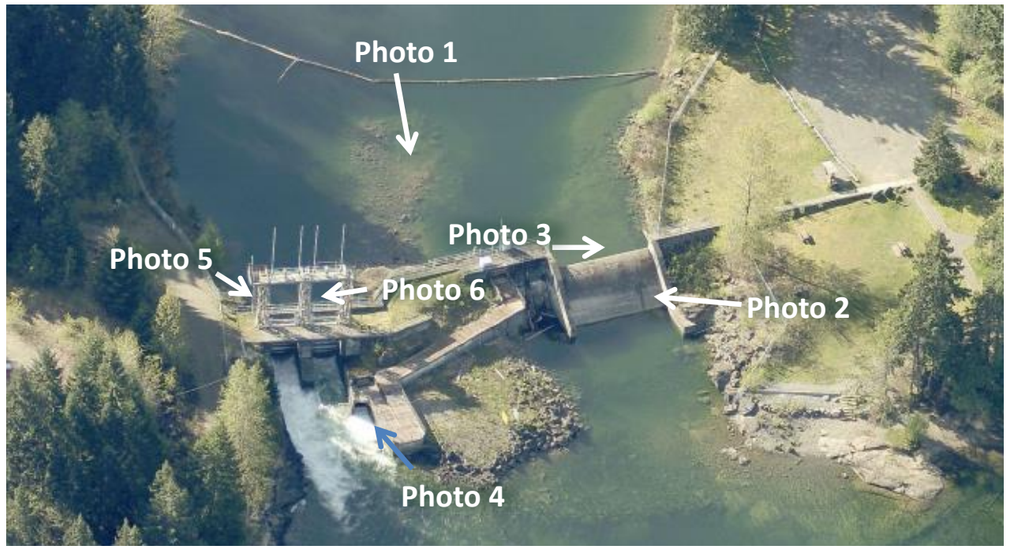


Photo 1 – Upstream face of Comox Dam

Photo 2 – Free Overflow Spillway with Fishway in background

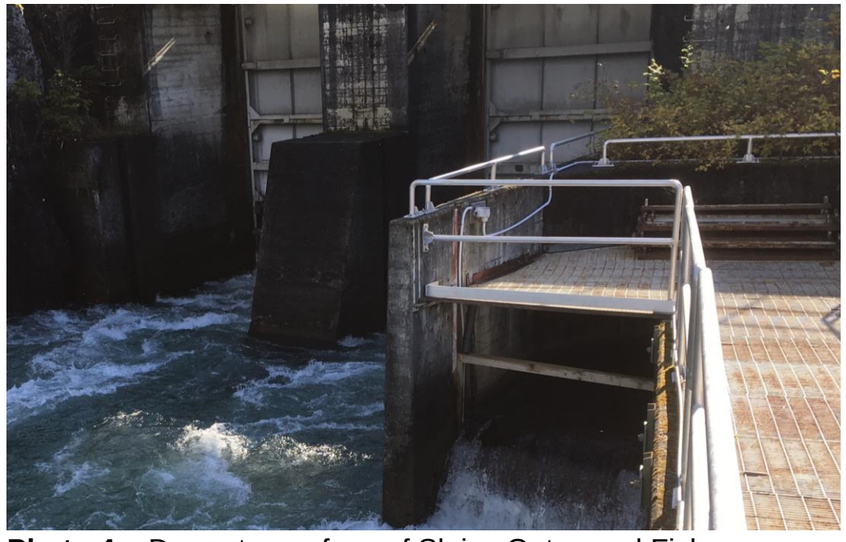


Photo 4 – Downstream face of Sluice Gates and Fishway

Photo 6 – Passing flows with Sluiceway gates fully open

Photo 3 – Spilling over the Free Overflow Spillway

Photo 5 – The upstream side of the Sluiceway at low flow

New Issues

Earthquake near Site C Dam

A felt seismic event occurred on 29 November 2018 with magnitude M_W 4.5 approximately 16 km from Fort St. John. The event has been tied to hydraulic fracturing operations by Canadian Natural Resources Ltd. The BC Oil and Gas Commission shut down all hydraulic fracturing operations for 30 days in the Kiskatinaw Seismic Monitoring and Mitigation Area, which includes the area around the Site C Project, while they investigated the event. The recorded ground motion data from the event has been provided to BC Hydro to assess structures at Site C. A large number of instruments have been installed at Site C to monitor displacements during construction. None of these instruments recorded a displacement response to the November 2018 event. No instrumentation at BC Hydro's other Peace River dams, WAC Bennett and Peace Canyon, recorded any response either.

Update on Major Dams

This update section has not yet been modified to the new template, and for this quarter remains a comprehensive update. In future reports, this section will be streamlined to include only salient new issues or developments, and links to ongoing project descriptions and updates will be available for the Committee members' discretionary review.

Alouette Dam

There are three projects (two capital and one investigation) currently underway to address the seismic deficiencies associated with Alouette Dam and Spillway.

Intake Structures Seismic Upgrade

This capital project was initiated in 2016 to address concerns related to the spillway structure's inadequate resistance to earthquake loading by assuring an alternative means of conveying water out of the Alouette Lake Reservoir after a major earthquake. The spillway is expected to suffer damage and not to be functional after a major earthquake. Use of the spillway in such a damaged state could lead to an eventual failure of the dam. Rather than upgrade the spillway to better resist an earthquake, which is both technically challenging and most likely costly, a decision was made to upgrade the power/ tunnel such that it can be relied on to pass the Alouette Lake inflows to Stave Lake following the Maximum Design Earthquake. This will remove the post-earthquake need to pass flows over a damaged spillway, providing time to remediate the spillway.

The field investigations planned as part of feasibility-level design were successfully completed in Q2. Documentation of the field work is progressing. During review of the ROV inspection report, it was discovered that a construction adit that enters the tunnel between the trash rack and the intake gate on the Alouette Lake Reservoir may not have been plugged as originally thought, and may present a second connection to the reservoir that would have to be blocked prior to construction. The project is working on a plan to investigate further and conclusively determine whether or not the adit was plugged. Work was also started to initiate reliability-based assessment into the project scope. Feasibility-level design is targeted for completion in October 2019.

Spillway Seismic Assessment Dam Safety Investigation

A Dam Safety Review for Alouette Dam, completed in 2017, identified that upgrades to address the seismic deficiencies in the dam and/or spillway—as described above—have not yet been completed and that interim measures to manage the risks posed by those deficiencies have not, to date, been put into place. The Dam Safety Review identified this lack of an Interim Dam Safety Risk Management Plan to be a "serious omission" and recommended that one be put in place without undue delay, with consideration given to modifying reservoir operation so as to minimize containment against the spillway in other than flood operation.

This Dam Safety Investigation (DI) was initiated early in Q2 and is now essentially complete with a final report having been submitted. First, the study reviewed the current spillway design features, reviewed the previous stability analyses and predicted deformations, carried out additional seepage modelling, investigated additional inflow routing scenarios, and identified the failure modes and qualitatively assessed their likelihoods. This work concluded that, although loss of reservoir containment was not likely due to the spillway design and expected stability and deformations, damage to the concrete structure and slabs in a major earthquake is expected. Therefore, the importance of reducing the likelihood of post-earthquake use of the spillway and the effectiveness of the capital project in addressing this risk was confirmed.

The DI also assessed the benefit of reservoir operational changes as a risk reduction measure in reducing the probability of overtopping the spillway weir and resultant flows over a damaged spillway. Several risk reduction measures were identified, and a draft Interim Dam Safety Risk Management Plan (IDSRMP) has been prepared. Consultation on the draft plan with the Comptroller of Water Rights, First Nations, local authorities, and public stakeholder groups is planned prior to implementation of the IDSRMP.

Environmental Flow Discharge Upgrade and Low Level Outlet Sealing

The original hydraulic fill dam was replaced in 1983 by the current 22 m high zoned-earthfill dam constructed immediately downstream. Portions of the original hydraulic fill on the upstream side together with the low level outlet (LLO) intake tower and conduit were left in place, and the downstream end of the LLO was extended through the new dam to the downstream toe to continue to provide environmental flow releases.

This pressurized conduit poses an ongoing risk to the safety of the earthfill dam. If, through age and deterioration of the intake tower, gates and conduit, or through damage induced by moderate earthquake shaking, water starts leaking out of the conduit, a piping/internal erosion process would be initiated. This process could ultimately lead to dam failure. The objective of this project is to eliminate this risk to the dam by closing off this conduit and providing a new means of passing environmental flows past the dam. Post-earthquake drawdown of the reservoir for dam safety requirements is not required through this LLO, but rather will be provided by the seismically upgraded power tunnel, as described above.

This project was initiated in Q3 and is currently in Needs stage. Work in Q4 will continue to identify the most appropriate alternatives to be assessed in the Conceptual Design Stage for meeting the current environmental flow requirements.

Mica Dam

There are two capital upgrade projects and one investigations project underway for Mica Dam.

Special Investigations Project

The work on Mica Dam under the special investigations project for large embankment dams was initiated in 2015. The overall objectives of this project are to carry out comprehensive performance assessments and develop better understanding of the performance of the subject dams, to develop tools and methodologies for performance monitoring, and to develop future risk management strategies. It is anticipated that a full review of Mica Dam will take several more years to complete.

Work in Q3, continuing from Q2, included:

- Continuing development of the 3D CAD and GIS models; and
- Partnering with Powertech Labs in planning and designing a soil testing laboratory that will be capable of performing the specialized testing required to characterize the key properties of the fill materials in BC Hydro's large embankment dams in general and Mica Dam in particular.

To supplement the External Engineering Panel (EEP) already in place for this project, a decision was made to retain a 3-person Independent Expert Panel (IEP) on Laboratory Testing and Interpretation who will be more closely advising BC Hydro on the details and results of the specialized laboratory tests.

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 but have since been used to monitor water levels in the casings, 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.

The Mica Dam project was initiated in F2018, with early work to evaluate the various sealing and instrumentation options. A site investigation to assess the condition and alignment of the casings was completed. Also, in F2018, the project to address the Revelstoke movement gauges was released and combined with the Mica project, for project design and construction efficiencies.

The field work completed at both Mica and Revelstoke in Q2 confirmed that the preferred option of installing both a fibre optic cable and piezometer is feasible. A draft report has been prepared.

Discharge Facilities Seismic and Reliability Upgrades

The objective of this project is to upgrade the discharge facilities to retain the reservoir and safely pass flows for operational, flood and post-earthquake conditions, including the ability to drawdown the reservoir post-earthquake if required. This project was released in Q3, and initial planning work has just started.

Revelstoke Dam

There are currently three Dam Safety capital projects and one investigation under way, which are described in the following sections. Note that the project to seal/rehabilitate the vertical movement gauges in Revelstoke Dam was described in the preceding section for Mica Dam.

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 some of the strands of the anchors.

In F2018, conceptual designs of works to stabilize the 731A Nose and the slopes above and to protect the 731 anchor heads from rockfall were completed. The options include scaling/bolting of the 731A Nose, excavation of the slopes above and scaling/bolting/meshing and/or shotcreting, and the construction of anchor protection sheds at the 731 Block.

In Q3, with the feasibility design of the upgrade options completed, planning work for the Definition Phase commenced.

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 kilometres upstream of the Revelstoke Dam. Between 1965 and 1993, eighteen inclinometers were installed during four separate field programs for the purpose of characterizing the slide, measuring displacements and replacing failed instruments. Historically, at any one time, there have been between five and eleven inclinometers measuring the displacement of the slide. There are currently five inclinometers that are still operational at the slide. It is forecasted that these inclinometers will have been disrupted by the slide activity within the next five years. 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 and funding for the Conceptual Design Stage was approved in F2018.

In F2019, conceptual design for the project was completed in Q2. The recommended additional instrumentation includes 8 new inclinometers, additional piezometers and surface monuments (i.e.

ground-based GPS) mounted on towers (to allow for winter readings). Funding of the Feasibility Design Stage was approved in Q3. A field trial of the ground-based GPS, started in Q2, continues in Q3.

Spillway Chute Condition Assessment

Small movements of the Marble Shear Block have produced cracking of the spillway concrete slab. The cracking has become more pronounced with time and, together with the observation that one of the underdrains is now flowing during spillway use, has prompted a review of the design and the rating of the deficiency. A screening level assessment in F2018 concluded that, generally, the spillway design at Revelstoke appears to be consistent with modern spillway design practices and is considered to be satisfactory. No immediate concerns were identified. Nevertheless, the chute condition and Marble Shear Block drainage will continue to be closely monitored.

To further gain more knowledge of the spillway performance, work to develop a computational fluid dynamic (CFD) model of the spillway was initiated in Q3. The intent is to use the outcome of this work for input into the 3D CAD/GIS model of the Revelstoke Dam spillway.

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. Construction is expected to start in February 2019 and be completed by October 2019.

Special Investigations Project, 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 objectives of this project are to carry out comprehensive performance assessments and develop better understanding of the performance of the subject dams, to develop tools and methodologies for performance monitoring, and to develop future risk management strategies. This has been a multiple year project, and the progress has been reported previously.

Work continued on the development of the 3D CAD model, specifically to include the earthfill wrap-around section and its contact with the concrete portion of the spillway, which has proved to be challenging to implement in CAD.

Finally, anticipating the need for large volumes of dam fill materials in preparation for the specialized laboratory testing (see description under Mica Dam), a permit was obtained to collect large samples from the original borrow area for the WAC Bennett Dam. The soil samples were collected in Q3.

Embankment Dam 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 F2018. The objective of this project is to identify and install/upgrade dam instruments to ensure that, coupled with the existing monitoring network, the dam is and will continue to be adequately monitored. A plan was developed to systematically identify the gaps in the instrumentation network and to identify both conventional and potentially new, non-intrusive type methods of dam monitoring.

In F2018, four workshops were organized in order to share background information, identify monitoring deficiencies using failure modes and key performance indicators as the basis for evaluation, and to refine the scope of work for the project. A user requirements document was prepared to guide the assessment, and development of a 3D seepage model of the dam was started.

In Q3 of F2019, the 3-D seepage model of the dam was completed by the consultant and is being used to better understand the flow regime in the canyon section, as input to the design for the weir upgrades. Other alternative instrumentation methods are under evaluation.

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

After a 20-year Dam Safety initiative and after 8 years of this project, the bedding and riprap construction on the dam face was successfully completed in late F2018.

This project was awarded “Major Project of the Year” for 2019. Project documentation is continuing and project closure is planned in F2020.

Seal Low Level Outlets

A long term strategy was previously developed—as part of a separate study—to assess the best alternative for the future of WAC Bennett Dam’s Low Level Outlets, constructed in the original diversion tunnels and left in place since construction. The following alternatives were considered: maintaining the status quo, refurbishment for additional discharge capability, re-purposing for additional generation, and decommissioning, either permanently or with the alternative to re-open the LLOs at some time in the future. Based on this study, the recommended alternative was to permanently decommission the Low Level Outlets, which was forwarded to and accepted by the Comptroller of Water Rights. The ensuing capital project was started in F2018.

Work has progressed, including site inspection in early F2019. Conceptual-level options to seal the LLOs by installing a reinforced concrete plug have now been developed and presented in Q3. The options include variations in installation techniques and locations. Evaluation of the technical merits and construction risks, amongst other factors, 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, 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 in an unaltered, unmaintained and continuously deteriorating state, this project was initiated in F2018 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. Work completed in F2018 included site inspections (including visual and remotely operated underwater vehicle inspection of the sluice gates and visual inspections of the stoplogs), decision framework meetings to assess the functional requirements of the sluice gates and the stop logs, and to develop options.

In Q2, the leading alternative of sealing the sluices from the downstream end was selected, to be carried into the Feasibility Design. To carry out this construction work, the need for competent stoplogs is not required as the existing sluice gates can provide the necessary function. A recommendation will be made to upgrade the stoplogs, possibly by initiating a separate project with its own business case and released in priority order. In Q3, the conceptual design report was finalized. Work is underway to plan for the Feasibility Design Stage.

Spillway Concrete Upgrade (New Project)

The Spillway Chute Upgrade Project (GY0109) was closed in 2017, with in-chute construction work completed in October 2016 (previously reported). That project successfully remediated the most severely damaged sections of the steeply sloping part of the chute.

Additional work to repair damaged concrete in the flatter portions of the chute and less severely damaged portions of the steep section was anticipated to be performed on an ongoing, annual basis within the Civil Maintenance program. Planning to implement repairs to the next priority chute areas (station 30+00 to 31+00 located on the upper sloping part of the chute) in the spring and summer of 2019 stalled when, due to the difficult access of the work area and the extent of the proposed upgrades, the bids received for the work exceeded the available budget. Moreover, in June of 2018, as part of the scheduled Dam Safety Surveillance inspection, the condition of the concrete chute just below the newly resurfaced section and just above the flip bucket was observed by photo inspection to have deteriorated significantly since the previous inspection in 2016. An in-chute inspection was subsequently performed by the Civil Maintenance team in September and confirmed the degree of the damage.

In response, an ex-plan capital project was released at the end of Q3 to address both of these high priority items. The project team has been assembled and initial planning work is underway.

Ruskin Dam

After a 20 year Dam Safety initiative, and 11 years of this project, the reconstructed upper portions of Ruskin Dam—including new spillway piers and gates—was put in service in F2018. The project remains active in correcting a number of deficiencies, however, including the replacement of portable hydraulic power units that have not met project objectives with a new diesel generator for back-up power supply for gate operation. The project team also remains engaged in completing the construction record drawings and the construction report.

In Q3, work to re-assess the stability of the dam using the comprehensive 3-D finite element model neared completion. The reference case—using expected values for the various foundation and structural material properties—was completed for crustal and subduction earthquake scenarios.

Sensitivity analyses that considered a reasonable worst-case combination of properties were completed for crustal earthquake scenarios. Remaining sensitivity analyses for subduction earthquake scenarios will be completed in January 2019, as will a draft report. The work and its results will be presented to the Ruskin project's Advisory Board in February 2019. While the important sensitivity analyses of the subduction scenarios are not yet complete, all indications to date suggest that additional anchoring of the dam structure will not have to be prioritized, if required at all.

La Joie Dam – Seismic Upgrade

The La Joie Dam was constructed of sluiced, dumped rockfill in 1951 to a height of 70m and then raised to its present height of 87 m in 1955. The original embankment dam design called for an upstream reinforced concrete face to control seepage through the dam. However, a temporary timber face was constructed and it was later replaced by a relatively thin unreinforced shotcrete face. This shotcrete face is now considered to be at or near the end of its serviceable life as routine repairs must now be considered, and generally implemented, on an annual basis to keep seepage through the dam to safe levels. The embankment Dam is considered seismically deficient as the increased seepage through the dam in the anticipated post-earthquake condition of the upstream shotcrete face is expected to exceed the dam's flow-through stability. An upstream intake tower controls flow to two steel conduits installed within two concrete lined rock tunnels located beneath the dam. Both the north and the south conduits are relied upon for reservoir drawdown. The intake tower and gates are also seismically deficient. An interim measure has been implemented since 2013 to manage the seepage by keeping the Downton Reservoir below El. 734 m. The objective of this project is to seismically upgrade the embankment Dam and other seismically deficient appurtenant structures to ensure post-seismic safety and reservoir control and to address/meet the environmental and First Nations concerns and requirements. This project is currently in Needs Stage.

Terzaghi Dam

Spillway Chute Investigations

Deficiencies associated with the Terzaghi spillway chute were documented in the F2018, Q3 report, which concluded that the issues were a high priority. In F2018, a plan was prepared to gain partial access to the chute in order to carry out a limited inspection in June of 2019.

Access to the upstream end of the spillway—that portion between the headworks structure and the spillway bridge only—was enabled by rock scaling of the slope above, which sufficiently reduced the risk of rockfall to allow entry into the chute by BC Hydro personnel for cleanout and inspection. This portion of the spillway, and specifically an area on the left-hand side of the spillway adjacent to the dam's core, was targeted for first inspection due to concerns that a lower rock surface elevation might present a seepage path into and through the dam's core in the event of localized chute failure at that location.

This rock scaling and associated inspection by BC Hydro Engineering provided beneficial information to the recently initiated project to provide permanent safe access into the spillway and has provided confidence to the view that—in the upstream portion of the rock face, at least—there is a relatively straightforward rock meshing solution available. Design concepts for the downstream portions are still being developed.

Activities included in the inspection of the upstream portion of the spillway chute were: visual observations and photographs; basic dimensional checks of the spillway and measurements; mapping of damaged areas; Schmidt Hammer testing; core drilling for concrete and bedrock samples in the spillway chute; local reinforcement scans; drain cleanout inspection and drain flushing.

Engineering's sealed site investigation reports have been submitted. The inspected portions of the chute indicate good materials and construction, meeting or exceeding design specifications, and fair to good condition considering the spillway's age. Drains were observed to be free-flowing. The rock under the spillway's concrete slab is competent: strong, not weathered, only slightly fractured near the surface consistent with the original excavation processes. There was very good observed contact and bond between the rock and the concrete slab, to the point where separating the rock and concrete for testing required breaking of the concrete rather than the interface. These conditions were found at all cored locations, including the targeted point adjacent to where the exposed rock elevation is lowest. No immediate risk to the structural integrity of the spillway's upstream portion was observed.

As a result of these findings, the concerns initially communicated in the F2018 Q3 report have been substantially allayed. There is no longer a heightened concern that deficiencies in the spillway's design could lead to a failure of the dam in the event of a spill. Recognizing that only the upstream portion of the spillway has been inspected and that there are verifiable deficiencies in the spillway's design relative to modern practices, however, there does remain some potential for significant damage to the spillway and associated financial loss resulting from a spill. Plans for future site investigations and drain maintenance on the lower spillway and analytical investigations of the impacts of the design deficiencies remain to be developed. Until such time as the aforementioned investigations are complete and/or all identified concerns have been dispelled, spillway operation will be accompanied by enhanced surveillance.

Spillway Chute Access Improvement

In Q2, a new capital project (Spillway Chute Access Improvement) was initiated. The objective of this project is to provide a sufficient combination of stabilization and/or protection measures to allow long term safe access for workers into the chute. This access is essential for necessary inspection and maintenance of the spillway. A funding request for the Conceptual Design Stage was submitted and was approved in Q3. Work on the conceptual design will start in Q4.

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 three ongoing dam safety projects:

Strathcona Dam – Upgrade Discharge

This project was initiated in 2015. The Identification Phase of this project determined the feasible alternatives for the new Low Level Outlet, including the sizing of the new discharge and options for safe discharge downstream through the Campbell River system. The spillway upgrade project (originally released as a separate project in F2016) was combined with the Low Level Outlet project in F2017. Work completed to date includes:

- Selection of the preferred alignment of the new Low Level Outlet on the right abutment;
- A decision to combine the spillway and low level outlet functionality, which provides dam safety risk reduction with improved reliability at the lowest cost; and
- Key design decisions relating to the Low Level Outlets, including selection of the number (two) and type of gates (vertical lift gates), the type of hoists (wire rope), and the selection of an open channel over the tunnel option.

In Q1 of F2019, Conceptual Design of the conversion of the existing gated spillway to a free overflow spillway neared completion. A key decision input to the design was the decision of whether to raise the dam crest in order to accommodate routing of the dam's Probable Maximum Flood. It was determined that by maintain the current dam height by either replacing or repairing the existing lock block and membrane flood wall, the new configuration of spillway and Low Level Outlet could safely route floods having return periods of significantly greater than 10,000 years, meeting the "risk-informed" performance targets in the CDA Guidelines. Due to the costs and marginal flood benefits associated with a dam raise, the project is moving forward on the basis that there will be no change to the current dam height, and this design decision has been presented in person and in a detailed letter to the Comptroller of Water Rights.

In Q2, work continued on the feasibility design of the new low level outlet and spillway. The first Strathcona Dam Advisory Board meeting was held in August, and their draft report has been issued. In general, the Advisory Board agrees with the approach taken in this project and has made some recommendations on the design options, which are currently being assessed by the project team. In addition, the terms of reference for the reliability assessment work were prepared, and a consultant has been contracted to carry out this work.

In Q3, work on the feasibility-level designs continued and planning for the project's Definition Phase commenced. The project team also provided updates to the Campbell River Liaison Committee (comprised of representatives from various government offices, agencies and public stakeholder groups) on project status, plans for moving the Strathcona Campground and the environmental baseline studies that have been performed.

Ladore Dam

The project has completed Conceptual Design, with the decision made to replace the existing gates, hoists, tower and deck. The project is currently in Feasibility Design, with design of the new vertical lift gates, the new hoist towers, deck and new control building on the right abutment continuing. In Q1, the site investigations program, including the drilling of three holes into the concrete and underlying rock foundation, was completed.

The first Ladore Dam Advisory Board meeting was held in August 2018, and their draft report has been issued. In general, the Advisory Board is in agreement with the proposed work of upgrading the gate systems, but has made some recommendations on analyses and designs. The project is currently reviewing these comments and recommendations and their impacts on the work going forward.

John Hart Dam

The project is currently in the Feasibility Design Stage. Work to date has identified preferred alternatives for the North Earthfill Dam, the Main Concrete Dam, the Middle Earthfill Dam and the existing Intake Dam. Designs are also continuing on converting the non-overflow section of the Concrete Dam into an overflow spillway.

In F2019, in-reservoir drilling was completed, with early findings presented to the Advisory Board in mid-August. This work addressed one of the Advisory Board's key recommendations from the previous meeting, which was to obtain site-specific geotechnical information from the reservoir to confirm the upstream berm design details before proceeding to Preliminary Design. Drinking water quality issues associated with the planned reservoir drawdown during construction will need to be managed by the project. An engineering study has evaluated potential water quality mitigation options and has concluded that a temporary treatment facility is technically feasible but costly.

In Q3, the team completed evaluation of findings of the in-reservoir investigations. A constructability workshop, with input from specialized contractors, was held in October to assess the impacts of these findings on construction activities. Findings from this workshop included an assessment that the Middle Earthfill Dam upstream berm can be constructed without relying on a reservoir drawdown, significantly mitigating concerns over drinking water quality issues.

A physical hydraulic model was constructed to test the hydraulic performance of the existing spillway and the proposed overflow spillway and to obtain hydraulic information for design purposes. Model testing was completed in December and generally confirmed previous numerical modelling, though some refinements to the design were identified.

Preparation of the feasibility design cost estimate is underway and is expected to be completed in Q4.

Overall coordination of the Campbell River System

As the three projects progress, additional coordination work will be undertaken by Dam Safety, Project Delivery, Engineering, Supply Chain, Regulatory, Environmental, Indigenous Relations, Operations and others, as required, to ensure that the designs, construction, Supply Chain strategies, etc., will be strategically optimized and coordinated. The John Hart Dam Advisory Board’s terms of reference has been expanded to include the Strathcona and Ladore Dam Safety Projects to further ensure coordination. The Advisory Board will now be referred to as the Campbell River Advisory Board and the first combined meeting was held in Q2.

Salmon River Diversion

The dam removal/river restoration was completed in F2018 and work continued in F2019 on post-decommissioning documentation and procurement of a Certificate of Compliance and Land Tenure.

Compliance with Processes and Regulations

Regulatory Communications

The 2017 Compliance Reports were submitted in October 2018 and approval to alter the John Hart Intake Dam was received in October 2018.

Dam Status Forms are required to be completed annually for all high, very high and extreme consequence dams and are due by 1 March 2019. These are in progress.

BC Hydro also submits Compliance Reports annually which contain more information than the Dam Status Forms and have the Semi-Annual, Annual and Reservoir Slope Inspections attached as well as a list of identified dam safety concerns. These are due to be drafted by 31 March 2019.

The annual meeting with the Comptroller of Water Rights is scheduled to take place in Burnaby on February 4-5, 2019.

Operation, Maintenance and Surveillance Manuals

BC Hydro is currently updating the Operations, Maintenance and Surveillance (OMS) Manuals for its dam sites. Each dam has an Operation, Maintenance and Surveillance (OMS) Manual for Dam Safety. The OMS Manuals are a requirement under the Dam Safety Regulation and must be updated every seven to ten years. The manuals identify responsibilities and expectations within BC Hydro for maintaining the safety of the dam.

The updates under preparation are substantial in nature, bringing much more detailed and comprehensive information into the manuals, and represent a step change in our practices. As a consequence, this round of OMS Manual updates has taken more time to complete than previous rounds and has caused BC Hydro to fall somewhat behind in the update schedule. The Comptroller of Water Rights is aware of these schedule difficulties and, recognizing the substantial improvements to practice these updates represent, has agreed to a revised schedule for the updates and is kept apprised of their status. BC Hydro will have caught up to this regulatory schedule by the end of F2020.

To date in F2019, three manuals have been updated, the most recent being that for Walter Hardman Dam in Q3. Completion is lagging somewhat behind schedule, due primarily to changed responsibilities for maintenance and asset ownership arising from the corporate reorganization that needed to be resolved and properly reflected in the manuals. The necessary changes have now been made, and updating the remaining seven manuals has resumed, but three of those manuals are now forecast to be completed in the early part of F2020 as a consequence of the delay.

	Year-To-Date			Year-End	
	Actual	Target	Indicator	Forecast	Target
OMS Manual updates completed	3	4	✘	7	10
Completion of F19 work plan	67%	83%	✘		

Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

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.

The final report for Revelstoke Dam was received in Q3. Staff interviews were held in Q3 for the Hugh Keenleyside and Kootenay Canal Dam Safety Reviews. Draft reports for the WAC Bennett and Peace Canyon Dam Safety Reviews are due in the first half of Q4. All eight Dam Safety Reviews targeted for completion in F2019 are forecast to be completed. The Walter Hardman Dam Safety Review start has been postponed to Q4 with the majority of work planned to take place in F2020, which accounts for the overall work plan tracking behind schedule (77% vs. 88% planned).

	Year-To-Date			Year-End	
	Actual	Target	Indicator	Forecast	Target
Dam Safety Reviews completed	7	7	✓	8	8
Completion of F19 work plan	77%	88%	✗		

Surveillance

Inspections

Routine weekly, monthly inspections are a regulatory requirement. These visual inspections are carried out by trained inspectors within Dam Safety or Field Operations using checklists prepared by the Dam Safety Engineer. The purpose of these inspections is to identify changing conditions at a dam, reservoir or appurtenant structure that could threaten the safety of the dam. During the third quarter of this year all 435 (100%) scheduled inspections were completed.

Semi-Annual and Annual inspections comprise comprehensive visual inspections of the facility combined with detailed assessments of the monitoring data from associated instrumentation. These inspections are a regulatory requirement and are completed by the Dam Safety Engineers within the Dam Safety Surveillance department. The end of third quarter coincides with the end of the calendar year. All 67 Semi-Annual and Annual Inspections were completed in the 2018 calendar year.

An iPhone app is presently being developed that will allow both inspections and monitoring data to be completed and reported directly through the iPhone. The beta version of the app was completed late in Q3 and will undergo testing in Q4 of this year. Full implementation of the app is expected to occur in the first half of F2020. Once fully implemented, use of the app will result in several efficiencies, including more timely review of routine inspection checklists, streamlined compliance reporting and a reduction in transcription errors.

Instrumentation and Monitoring

An initiative for F2019 has been for the Regional Dam Safety Technologists to perform three checks/reviews per week of their instrumentation data plots to identify any unusual trends and to ensure continued accuracy of the data being collected. Through the first two quarters of the year, 369 of the

targeted 390 reviews were performed. In the third quarter of the year 231 reviews were completed exceeding the target of 210.

The readings collected by the Automated Data Acquisition System (ADAS) must be manually verified on a regular basis to ensure the system is collecting accurate data. Such verifications were completed at Strathcona Dam and WAC Bennett Dam in the third quarter and are partially completed at four other dams. In addition, ADAS verifications were completed at the following four reservoir landslide locations: Checkerboard Creek, Dutchman's Slide, Downie Slide and Little Chief Slide. As of the end of Q3, the annual target of verifying the ADAS readings at 5 sites per year has been exceeded.

Reservoir Slopes

In F2019, thirteen (13) general reservoir slope inspections were planned. These are 5 and 10 year frequency inspections intended to identify development of new landslide activity around BC Hydro reservoirs, and/or to report on previously identified landslides that are not presently considered to pose a significant hazard to the safe operation of the dams and reservoirs. All 13 inspections were completed as planned, and have been documented as of the end of Q3. No new landslide activity was identified as part of these 5 and 10 year inspections.

Also in F2019, twelve (12) specific landslides areas were inspected, as part of the planned Dam Safety landslides program. These specific landslides are inspected annually, as they represent identified hazards to the dams and reservoirs. No significant changes to the landslide activity at these areas were identified in F2019. Documentation of these inspections will be completed in Q4.

Unusual Events or Observations

The Dam Safety On Call Person (DSOP) responded to 86 calls in the third quarter. The calls included instrumentation alarms, operational inquiries, operations notifications during floods and earthquake notifications. Significant events from the third quarter include the following.

- Between October 21 and 22 a series of earthquakes ranging from magnitude 4.6 to 6.8 occurred off the coast of Vancouver Island, about 300 km west-southwest of Campbell River. These earthquakes did not impact any of the dams.

- A magnitude 4.5 earthquake was triggered by oil and gas activities about 16 km from Fort St. John on November 29. The earthquake did not trigger any instrument alarms or result in any damage at Site C (10km), Peace Canyon Dam (70km) or WAC Bennett Dam (80 km).

- Significant rainfall events in late December resulted in higher than normal reservoir levels at several dams in the Lower Mainland and Vancouver Island Areas, requiring an increased frequency of inspections. The rainfall events also triggered a number of instrument alarms.

Staffing

Two staff left the surveillance group in the third quarter. Rick Enegren, a Specialist Dam Safety Engineer with over 35 years' experience, retired and Eric Allarie, a Dam Safety Technologist, left the company to pursue other opportunities. This brings the total vacancies within the Surveillance group to three. All three vacancies are in active recruitment and are expected to be filled in Q4.

Maintenance

Civil Maintenance

As of the end of Q3, 30 of 33 planned civil maintenance projects were substantially complete. The total spend on the projects to the end of Q3 was approximately $3.6M.

The following projects were completed in Q3:

- BR2 concrete lined tunnel, intake tower, and surge shaft inspections
- ALU spillway joint repairs
- SPN dam undermine underwater inspection
- WIL downstream sediment monitoring
- SEV spillway repairs.
- REV visitor center access road repairs, clearing, and scaling
- REV PH roof access bridge repairs
- REV spillway bridge repairs
- WHN weir diversion dam repairs
- WHN penstock inspection
- PCN drain cleaning investigation

Work continues on the Civil Preventative Maintenance (PM) Program development. The “Package 1” assets, which include booms and non-water-to-wire tunnels, are in implementation across the fleet.

A Passport audit of the Civil PM Package 1 implementation was completed in Q2 and some gaps were identified. The Civil PM team is planning to complete a detailed audit of Package 1 before the end of F19 to determine the effectiveness of the package 1 release. The audit findings will be reviewed with Station Field Operations, Maintenance Engineers, and Dam Safety.

Development of the maintenance standards and maintenance instructions for Packages 2 and 3, which includes penstocks, draft tubes, tailraces, spillways, canals, foundation pressure relief drains, and rock retention systems is ongoing. The scheduled release of Packages 2 and 3 is at the beginning of F20.

The Civil Maintenance team is working with Dam Safety on an initiative to develop a proposal for vegetation management at generation sites, which would include assets such as dams, penstocks, and canals.

Gate Maintenance and Testing

In F2019 Q3, 56 scheduled gate tests at 23 sites were carried out. Two gate systems failed to operate on demand during testing. In five other cases, while gates did operate on demand, certain individual components of the gate system malfunctioned or were found to be in unacceptable condition.

As of the end of December 2018, operational restrictions were in place on two out of 109 flood discharge gates due to known deficiencies (reduced from nine at the end of Q2).

A total of 31 corrective maintenance issues were identified through ongoing testing and maintenance from October to December 2018. A total of 22 new and previous issues were addressed in the same period, for an increase of 9 overall in this reporting period. There were 121 corrective maintenance issues outstanding at the end of December 2018; 9 more than in December 2017.

Since 2006, when improved reliability of flood discharge (spillway) gates was identified as a priority in and the Dam Safety Program was adjusted to provide better stewardship of our spillway gates systems through regular maintenance and testing and capital upgrades, there has been a notable improvement in the rates of failure to operate on demand during scheduled tests. As illustrated in Figure 3, rates of failure have decreased by nearly a full order of magnitude.

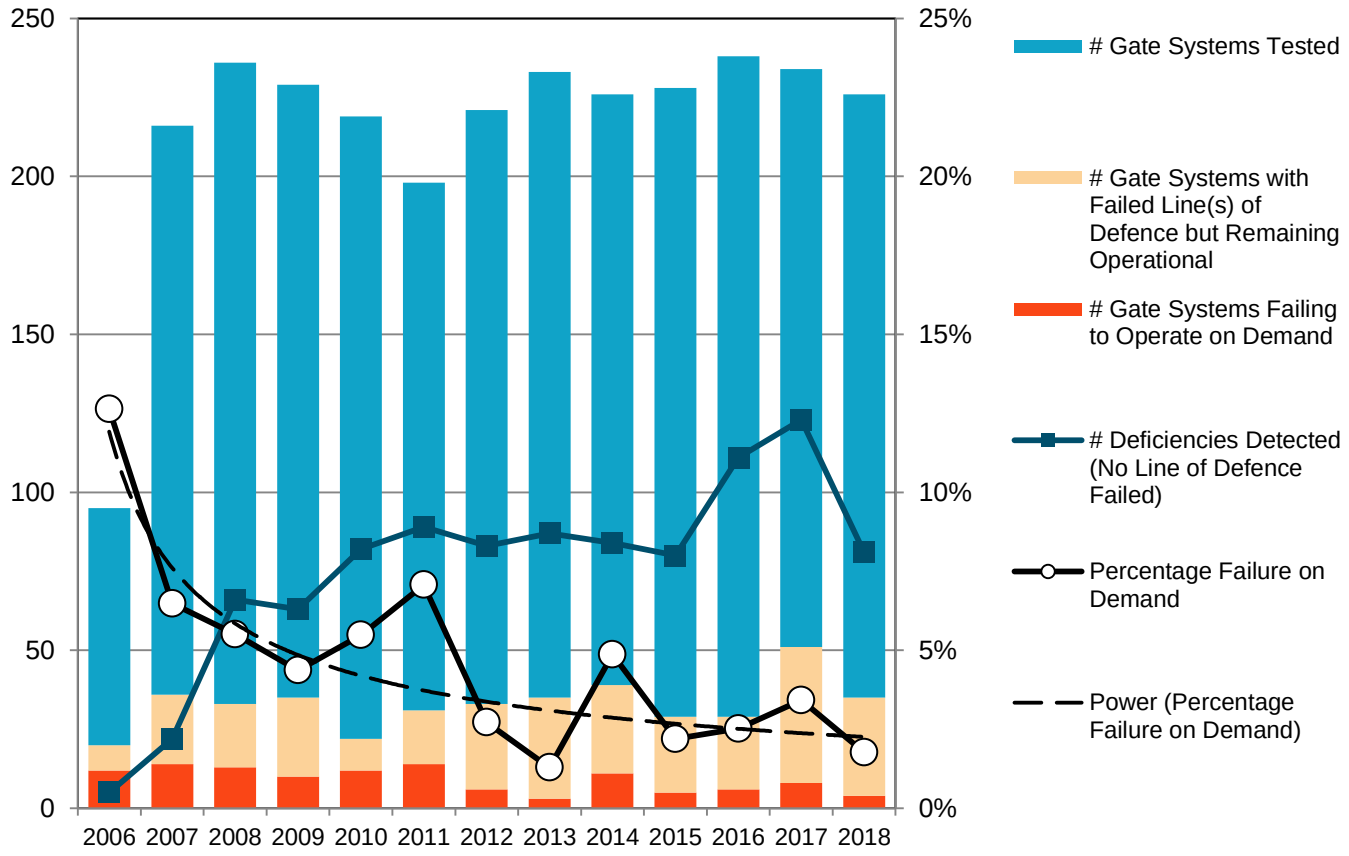


Figure 3 Deficiencies detected and rates of failure to operate on demand during flood discharge gate testing.

Figure 3 additionally shows that the number of deficiencies identified each year through testing is not diminishing. It is not yet clear that the detection of deficiencies has settled into a reasonably steady state that would be commensurate with a well-established maintenance program. Dam Safety is presently evaluating maintenance records and developing metrics to assess the status and adequacy of maintenance of flood discharge gate systems. These metrics will be included in and become a regular part of future reports.

Emergency Preparedness and Public Safety

Emergency Preparedness is managed by the Security & Emergency Management. 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 near dams and reservoirs is managed by the Public Safety team in Safety Engineering & Work Methods. 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.

The Great BC Shakeout Exercise – October 18, 2018

On October 18, 2018, Dam Safety participated in a BC Hydro emergency response exercise in conjunction with the Great BC ShakeOut drill. Dam Safety staff contributed to the planning of the exercise, provided the scenario earthquake and participated in the drill.

Starting with the mock earthquake notification at 10:18 am, Dam Safety staff responded to the event in real time following the Dam Safety emergency response plan. Steps taken by our personnel were:

1. Personnel ensured their own safety and checked on the safety of their coworkers and families.

2. Personnel then called in to Dam Safety's conference number and began to collect and distribute information, prioritize tasks and organize resources to be dispatched to the affected Vancouver Island and Lower Mainland sites.

3. Director, Dam Safety simulated instructions to PSOSE to issue a Dam Safety Alert for the following facilities: John Hart, Ladore, Strathcona, Comox and Puntledge Dams. (No actual communications were effected at the request of Security & Emergency Management.)

4. Dam Safety Engineers and Technologists followed the emergency helicopter booking procedures and contacted suppliers. Suppliers were informed that BC Hydro was performing an exercise and asked, in the event that a real emergency was in progress, to respond with the availability and ETAs for arrival of suitable helicopters at pick-up points for our personnel. Five helicopters were "secured" in this manner.

5. Using the real-time helicopter availability, plans were developed to begin mobilizing staff to the affected areas as early as 1:00 pm that day. An action plan was developed for the remainder of the day and for the start of the next day.

6. Dam Safety continued to participate through completion of the drill by providing situation reports to the BC Hydro Emergency Coordination Centre based on the expected conditions at the facilities and through discussing the actions that would be required during a real event.

Within the parameters of the exercise, the plan was found to be workable and effective. The plan documents were found to contain out-of-date information, and have since been updated.

Closure

As previously stated, changes in this Quarterly Report will be followed up by additional changes in following quarters' reports. The reporting on projects will be significantly streamlined—albeit with links to the required details provided—and reporting on other issues such as identified non-conformances relating to surveillance, maintenance and processes within the Dam Safety Program will be added. Supporting metrics are being developed and will be included. We trust that this will better inform the Capital Projects Committee of the breadth and quality of BC Hydro's Dam Safety Program and will meet with the Committee's approval.