Confidential - Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

Executive Summary

The purpose of this report is to update the Capital Projects Committee of the Board of Directors on key dam risk management activities during the period from January 1, 2019 to March 31, 2019, 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 a slight overall increase in assessed risk this quarter with the re-evaluation and reclassification of pre-existing issues at La Joie and Wilsey Dams.

Members of the Capital Projects Committee will again notice a number of changes in this quarter's report. With a general reorganization, updates of ongoing projects and investigations have been greatly reduced to only report on significant developments that took place within the quarter. Additionally, metrics are being introduced to report on Program non-conformances. 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 Q4 Risk Priority	Change from Last Quarter
Dam Safety *Risk of a dam safety incident*	**H**	**L**	**Fast**	**M**	**H**	• For F19 Q4 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.

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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. Notable changes in Vulnerability Index in F2019 Q4 are described below and identified on Figure 1.

1. A Vulnerability Index ***addition*** of 0.31 (AN deficiency) at Wilsey Dam related to continued deterioration of the overall condition and structural integrity of the dam due to concrete spalling, cracking of concrete and seepage through joints.

2. A Vulnerability Index ***addition*** of 2.00 (AN deficiency) at La Joie Dam due to corrosion of the penstock in the south tunnel. This is a reclassification of an existing Non-conformance Maintenance.

3. A Vulnerability Index ***reduction*** of 0.95 at La Joie Dam due to a reassessment of the seismic withstand of the south conduit penstock. This issue remains in the database as a Non-conformance Information, as it is not currently known whether corrosion of the penstock is sufficient to negatively impact the seismic withstand.

Changes in Vulnerability Index for actual and potential deficiencies—including those related to spillway reliability—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.

The height of the stacked blue and sand-coloured bars has remained essentially constant since the end of Fiscal Year F2014—when the risk to BC Hydro's dams from seismic hazard was reassessed—which indicates that the corporation's intent to not allow an overall increase in the dam safety risk profile has been realized over this period.

The red and green bars—additions and reductions in Vulnerability Index, respectively—indicate that in any given quarter there has been activity within the Program to identify new issues, update our understanding of these issues, and actively mitigate or eliminate them. This is one indicator of a healthy Dam Safety Program.

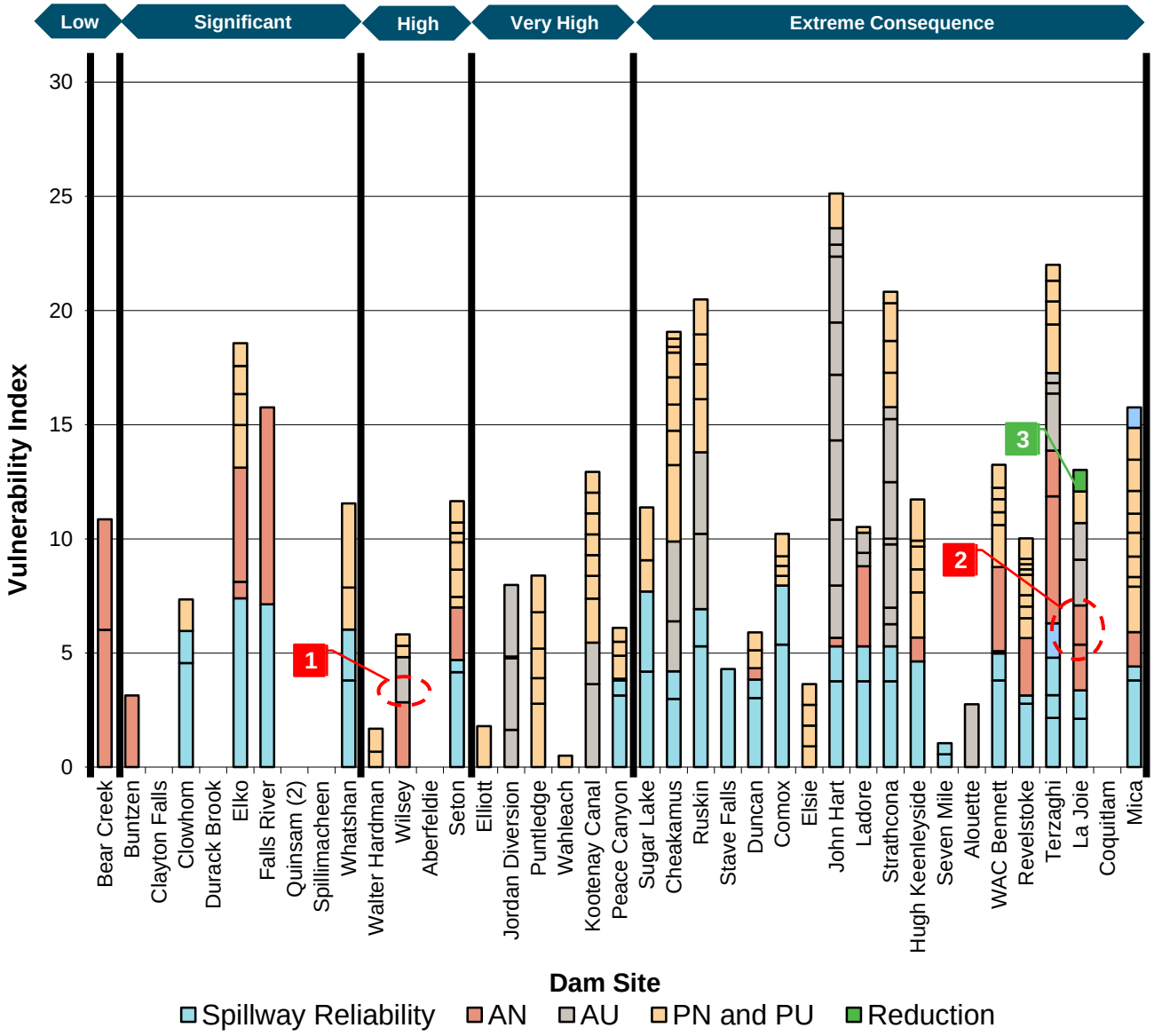

Figure 1 Dam Safety overall risk profile at the end of F2019 Q4, as represented by the Vulnerability Index. Notable changes are identified.

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 and 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

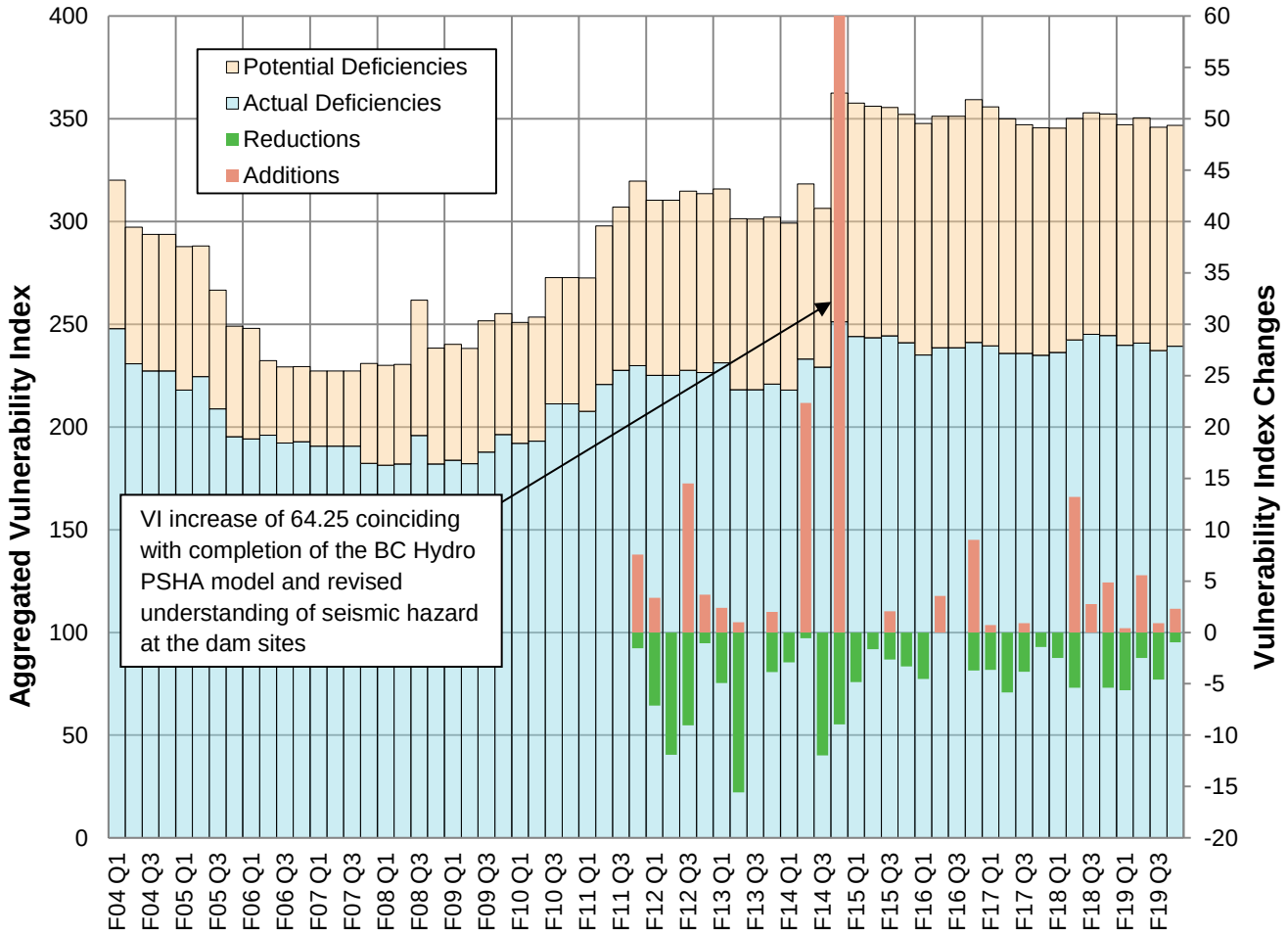

Figure 2 Changes and trends in the Vulnerability Index aggregated across the BC Hydro system. Note: the bars are "stacked" such that total aggregated Vulnerability Index is given by the top of the Potential Deficiencies bar.

Non-Conformances in the Dam Safety Program

The risk profile of BC Hydro's dams—and our understanding of it—is very much dependent upon the effectiveness of the operational, maintenance and surveillance procedures in place and being utilized within the Dam Safety Program. Effective and rigorously followed procedures are required to collect and interpret the observations and measurements necessary to verify the adequacy of the physical performance of the dams.

The most recent corporate audit of the Dam Safety Program, performed in Q1 of Fiscal Year F2019, found that the Capital Projects Committee of the Board was not receiving an inclusive overview of the issues in the database. Specifically, the status of routine risk controls and processes have not been a focus in these reports. The subject matter experts retained for the audit recommended that issues related to non-conformances in the operation, maintenance and surveillance of BC Hydro's dams also be reported as these also impact the risk profile.

Although non-conformances are identified through a number of activities within the Program, Dam Safety Reviews performed by external consultants serve as the Dam Safety Program's independent review and a significant portion of the non-conformances are identified by these means.

Non-conformances are categorized as follows:

NCI **Non-conformance Information:** a deficiency in information required to determine if an actual or potential performance deficiency exists.

NCM **Non-conformance Maintenance:** missing or uncompleted maintenance activities required to assure dam performance under normal and unusual loading conditions.

NCO **Non-conformance Operation:** a deficiency in the operation of the dam or inadequacies in the operation procedures under normal or unusual loading conditions.

NCS **Non-conformance Surveillance:** surveillance, inspection and data interpretation activities are not being performed in accordance with established procedures or there are inadequacies in the procedures in comparison with best practices.

NCP **Non-conformance Procedure:** a deficiency in the implementation of the management system or inadequacy of policies and procedures for activities required for normal and unusual load conditions.

OMS **Non-conformance OMS Manual:** information in the Operations, Maintenance and Surveillance Manual or Operating Orders is insufficient, incorrect or out of date.

Once identified, the relative importance and priority for correction of the non-conformance is rated as "High", "Moderate" or "Low". High priority non-conformances might be the absence of a documented analysis of the stability of a structure (NCI) or the significantly deteriorated condition (NCM) of another. Low priority non-conformances might be an analysis or data that is somewhat overdue for an update (NCI) or the slightly deteriorated condition of an asset (NCM).

A question that had arisen within Dam Safety is how well these non-conformances have been managed and whether significant additional effort needs to be expended in their correction. We have begun to track and analyze performance in this regard. Figure 3 shows the number of non-conformances in the Dam Safety Database at the end of each calendar year from 2011 onward. The tan, light green, blue and grey bars break them down into High, Moderate, Low and unrated issues, respectively. These are stacked so as to indicate the total number, which is seen to have varied from just under 500 to just under 600 issues at the end of any given year. Roughly 100 of these issues have been considered to be of High priority in any given year. Figure 3 also shows the numbers of non-conformances added and completed (resolved)—in red and green bars, respectively—through the course of each year.

Since the end of 2015, there has been a slightly downward annual trend in the overall number of non-conformances, with a net decrease of just over 100 issues, or 18%, over that period. There has also been substantial activity in identifying and addressing issues, with 25 to 50 added and 40 to 85 completed in each of those years. With specific regard to High priority non-conformances, since the end of 2015 there have in total been 24 new issues added and 39 issues closed. These figures are indicative of a reasonably healthy level of activity in reviewing the Program and, at least to the extent that overall numbers have been contained, in addressing these non-conformances.

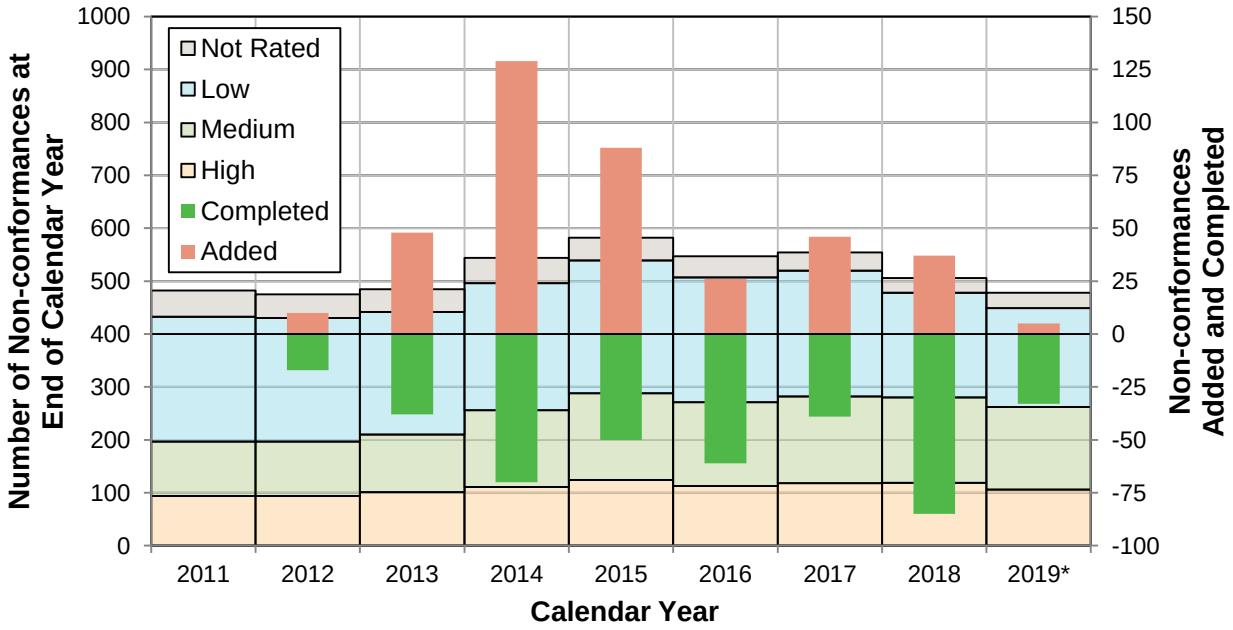

Figure 3 Changes and trends in the total number of non-conformances within the Dam Safety Program. This data is plotted by *calendar* year. (*2019 reflects only the first three months—January through March—of the year.)

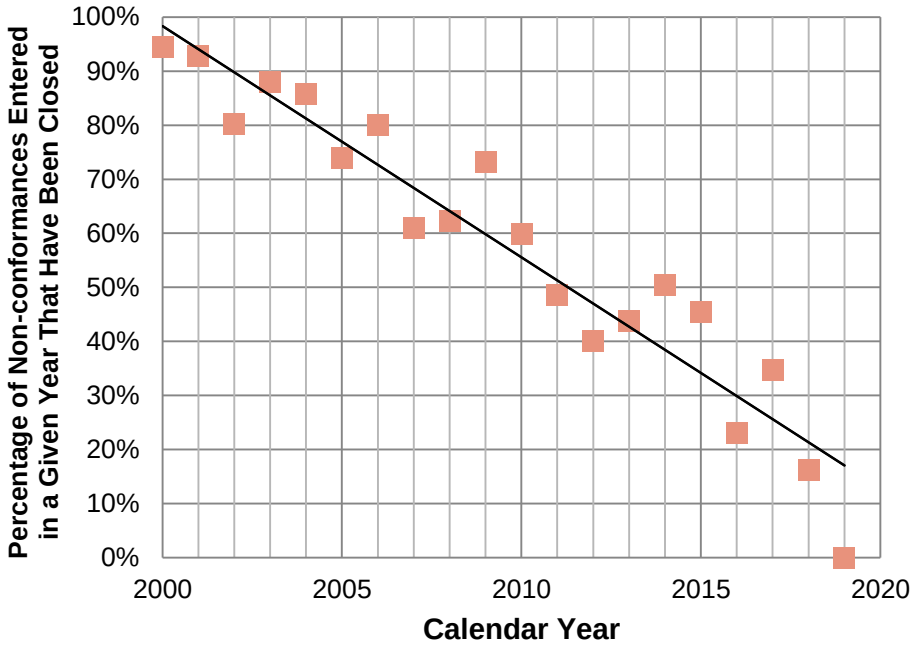

Figure 4 Percentage of non-conformances entered into the Dam Safety Database in any given year that have since been resolved and completed.

Dam Safety is endeavouring to more closely track non-conformances and to understand and, if warranted, improve their rate of closure. This work is just beginning, but early results are available. Figure 4 plots the percentage of non-conformances that have been closed against the year in which they were first entered into the database. The trend line indicates that about five percent of all the non-conformances that are entered into the system in any one year are resolved and completed in any successive year, *i.e.*, that it's taking approximately 20 years to fully close out all the non-conformances that arise in any one year. We have not yet broken this closure rate out into High, Moderate and Low non-conformances, and will do so as a part of our coming round of assessment.

This data indicates that, while they are not being set aside indefinitely, many non-conformance issues are taking a substantial period of time to close. In some instances there may be valid reasons; doing so may require the completion of a complex investigation or a capital project. A number of the outstanding non-conformances fall into this category. In other instances, it may simply be that non-conformances that are deemed to be of Low priority are not assigned the resources needed for closure for several years, waiting for higher priority work to be completed; with some perhaps so low in priority that they may never be addressed. While we perform a deeper dive into these matters, however, non-conformances are being reviewed as a component of all dam data and issues reviews with an aim to resolving as many as practicable.

Dam Safety is using this information to develop a corrective action plan to more expediently address outstanding non-conformances, which is due at the end of August. Regularly scheduled reviews of non-conformances, prioritization for their closure and tracking of progress will be among the components of this plan. This is one of the priorities identified in Dam Safety's F2020 Business Plan. Non-conformances and progress in addressing them will be reported regularly to the Capital Project Committee in future quarterly reports.

New Issues

Dam Safety Incident, Spillimacheen – Ruptured Penstock Inlet Valve

The Spillimacheen Dam and Generating Station are located on the Spillimacheen River about 50 km northwest of Invermere and about 4 km upstream of the confluence of the Spillimacheen and Columbia Rivers. The small, concrete gravity dam diverts water through an intake structure into a 1.1 km long power tunnel that emerges uphill from the powerhouse at a small structure that houses two penstock inlet valves and supports a surge tower. From there, water flows through the two penstock inlet valves and the penstocks down to the three generating units (1 × 2.2 MW and 2 × 0.9 MW) in the powerhouse. The general configurations of the dam, water conduits and powerhouse are shown in Figure 5, below.

The consequence category for failure of Spillimacheen Dam is "Significant", with no homes or businesses along the river valley downstream and no permanent population at risk.

In the very early hours of March 15, 2019, while Spillimacheen was offline for maintenance, Stations Field Operations personnel from Invermere were dispatched to respond to an alarm signalling an overflow condition in the powerhouse sump. Upon arrival, the crew observed the powerhouse to be flooded and water cascading down the penstock slope. The crew determined the source of the leak was Penstock 01/02, near the Penstock Inlet Valve PIV01/02, located as shown in the right hand photo of Figure 5. Photos showing the water leakage later that morning (in daylight) are in Figure 6.

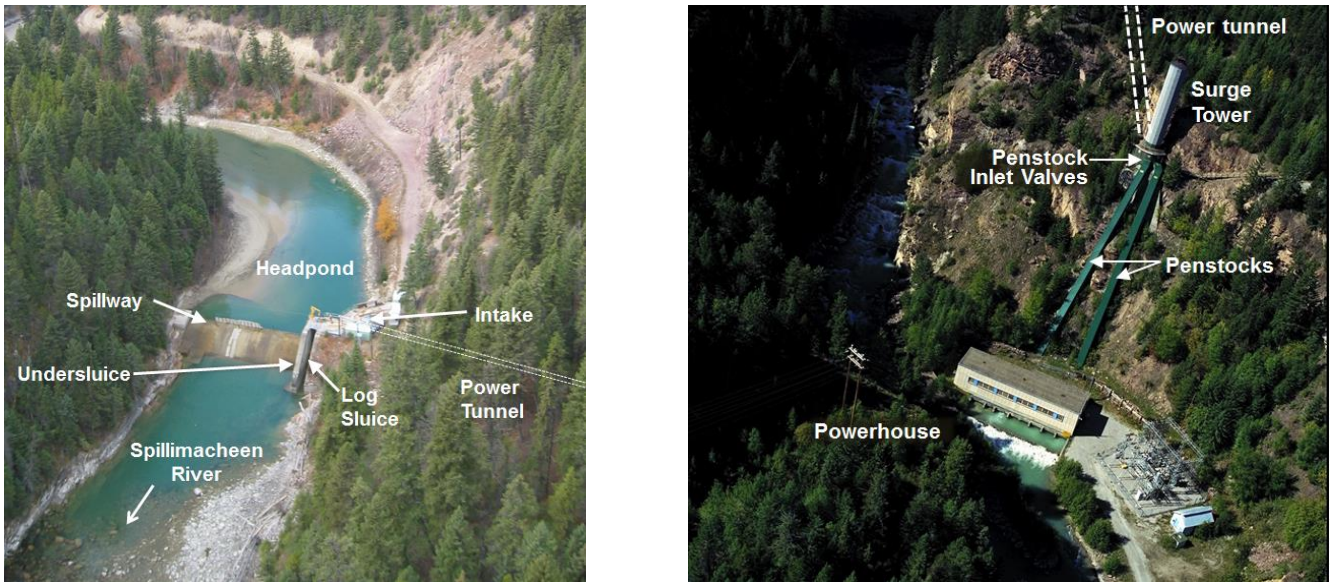

Figure 5 Spillimacheen Dam (left) and Spillimacheen Generating Station (right).

Figure 6 Water cascading down the slope adjacent to Penstock 01/02 along a channel eroded through the soil overburden.

During the subsequent conference call, Dam Safety highlighted the increased potential for a landslide or debris flow damaging the site's remaining penstock, which was full at the time. To reduce the risk of a much larger breach, Penstock 03 was drained. At the conclusion of the call, a Dam Safety Incident was declared and the Dam Safety Engineer and two Dam Safety Technologists were mobilized to site to provide 24/7 surveillance and assist in the incident response.

Stopping this flow required isolating and then dewatering the tunnel. These actions were complicated and prolonged by several factors. The intake is not equipped with a gate but rather requires the time consuming placement of stoplogs. Moreover, the stoplogs slot was completely filled with a 2'-3' thick layer of ice. Before the stoplogs could be installed, the ice had to be removed. A powerful heater arrived the evening of March 15 and, augmented by a steam truck that arrived the next day, had the ice largely broken up by the March 16. Then debris at the bottom of the slot covering the sill had to be removed. The normal method of using divers was considered to be unsafe due to the risk that the failure and leak could suddenly worsen and the ensuing flows at the intake could pin the divers underwater. Instead, on March 17, the log sluice (Figure 5) was fully opened to lower the forebay. Workers in a man basket were lowered into the inlet and, using hand tools, pushed the debris away. Strong eddy currents from the open log sluice aided this process. By late afternoon on March 17, the stoplogs were installed; thus isolating the tunnel, and the leak further downstream, from the forebay.

Uncontrolled discharge continued as the tunnel slowly drained through the PIV01/02 leak. On March 19, tunnel drainage was hastened by opening the PIV03 bypass valve. By the morning of March 20, the flow of water down the slope had ceased completely, bringing the incident to an end.

Throughout the course of the incident, Dam Safety Engineers and Technologists maintained 24/7 surveillance on the site to provide warning of any worsening condition.

Figure 7 A large fracture was discovered in the body of Penstock Inlet Valve PIV01/02. This was the source of the leak and the uncontrolled flows down the penstock slope that created the Dam Safety Incident.

After regaining control of the flows, the failure was inspected and found to be a large fracture located in the penstock inlet valve. This is shown in Figure 7. The potential for such a fracture does not appear to have been identified in any previous inspections or documented in Equipment Health Rating reports. The conclusions from a root cause analysis of the failure are not yet known to Dam Safety.

The Spillimacheen facility remains secured in this state, with the stoplogs isolating the tunnel from the forebay and the generating station out of service. A root cause analysis of the failure is being conducted and the results will be documented in a Forced Outage Report.

Seton – Forebay Drain Pipe Leak

On March 5, 2019, during a planned unwatering of the Seton Forebay, the forebay drain pipe developed a leak upstream of the shutoff valve with significant flows resulting. The leakage continued to flow down the penstock slope until the forebay was drained. The leak was later determined to have been from a previous sleeve repair from 2017 that lost water-tightness. The sleeve is being welded on to the pipe before the forebay is watered up in early May. This repair should prevent future leakage from this location.

Update on Existing Issues

Alouette Dam Interim Dam Safety Risk Management Plan

A Dam Safety Review for Alouette Dam, completed in 2017, identified that upgrades to address seismic deficiencies in the dam and/or spillway 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 recommended that an Interim Dam Safety Risk Management Plan be put in place without undue delay.

In response, a Dam Safety Investigation was initiated early in Q2 and completed at the end of Q3. This investigation 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. From this investigation, a preferred set of risk reduction measures was identified, principally composed of modified operations that meet the reservoir elevation requirements throughout the year (including recreational levels) but result in periods of diversion of water through the tunnel that the licenses only allow for the routing of high inflows to prevent downstream flooding. Based on these measures, a draft Interim Dam Safety Risk Management Plan (IDSRMP) was prepared.

In Q4, BC Hydro engaged with First Nations and various community stakeholder groups regarding various issues relating to Alouette Dam, including this one. Dam Safety further met with Comptroller of Water Rights to inform that office of our plans to modify reservoir operations and impacts to our ability to operate within the terms of our water licenses. Through the course of these meetings, the draft Interim Dam Safety Risk Management Plan was refined and brought to a near-final state.

The Interim Dam Safety Risk Management Plan will be issued to the Comptroller of Water Rights in Q1 of Fiscal Year F2020. Operations outside of the terms of our water licenses will be authorized on the basis of dam safety requirements.

Compliance with Processes and Regulations

Regulatory Communications

The annual meeting with the Comptroller of Water Rights took place in Burnaby on February 4-5, 2019. During this meeting, BC Hydro provided a general update on all activities and developments within the Dam Safety Program. Other communications and submissions in Q4 included:

- Notification of the Dam Safety Incident at Spillimacheen (see New Issues);
- Dam Status Forms (submitted annually) for all High, Very High and Extreme consequence dams; and
- A schedule for updating OMS Manuals in 2019 which was accepted by the Comptroller's office;

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.

Five of the ten planned updates were completed in F2019, the two most recent being Seven Mile Dam and Duncan Dam which are in the process of being printed. Significant progress has been made on the other five manuals and these will be issued in Q1 and Q2.

One factor that has contributed in some part to not meeting the OMS Manual production targets for F2019 was the need to completely revise the roles and responsibilities for all aspects of maintenance to reflect the changes made to the organization last year. These revisions were completed in the fall and are now being incorporated into all the manuals currently being updated.

	Year-To-Date			Year-End	
	Actual	Target	Indicator	Forecast	Target
OMS Manual updates completed	5	10	✘	5	10
Completion of F19 work plan	76%	100%	✘		

As has been pointed out in previous quarterly reports, the OMS Manual updates currently under way are substantial in nature, bringing much more detailed and comprehensive information into the manuals, making them far more valuable a resource and representing 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 is working hard to catch up to the regulatory schedule by the end of calendar year 2020.

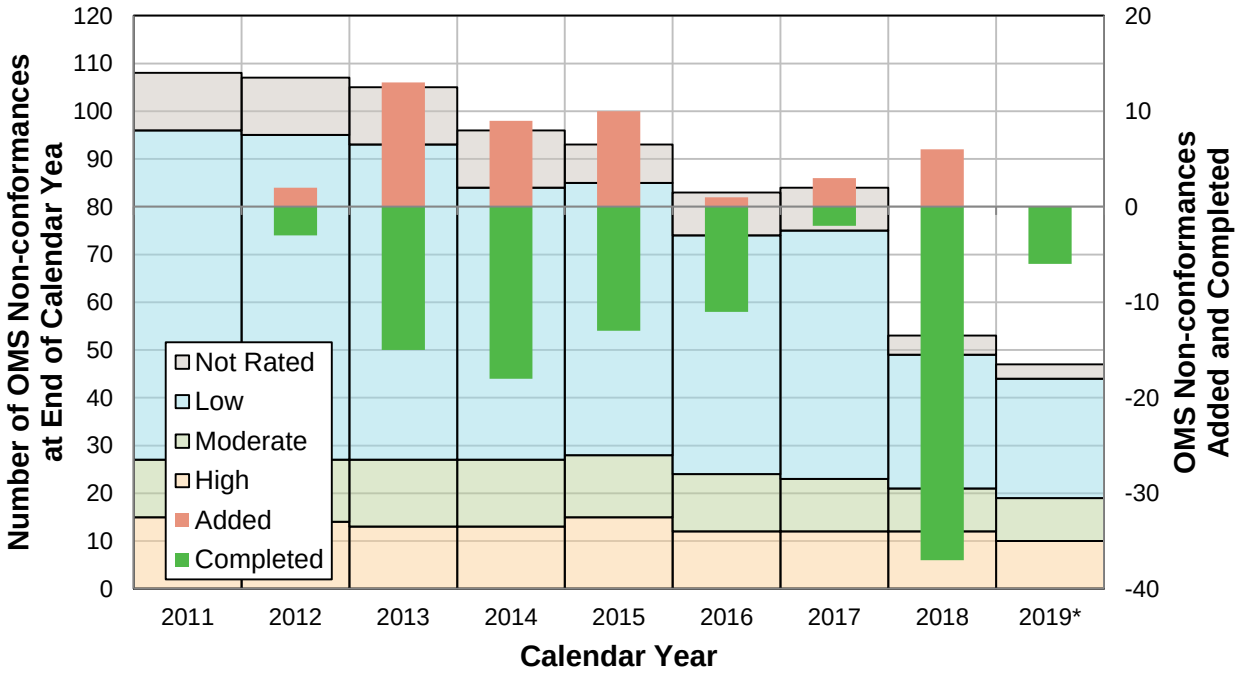

Figure 8 Changes and trends in the number of OMS non-conformances. This data is plotted by *calendar* year. (*2019 reflects only the first three months of the year.)

The significance of the updates to the OMS Manuals is illustrated in Figure 8, which shows the number of OMS non-conformances in the Dam Safety Database at the end of each calendar year from 2011 onward. This figure is similar to Figure 3 which was discussed in some detail earlier in the report. What is notable in Figure 8 is the very great reduction in OMS non-conformances that has been achieved over the past few years. Although the number of updates that were fully completed lagged behind the plan, it can be seen that much progress was made, nevertheless. Through the remainder of 2019 and 2020, the planned OMS Manual updates will close approximately one-half of the remaining non-conformances and 5 of the 10 issues rated as High, at which point the number of OMS non-conformances will be structural. *i.e.*, the number that must naturally arise in accordance with regular reassessments and the regulated and manageable schedule for OMS Manual updates.

Dam Safety Reviews

Dam Safety Reviews are a regulatory requirement carried out at minimum intervals of every five to ten years for High, Very High and Extreme consequence dams.

Seven of F2019's eight targeted Dam Safety Reviews were completed. The Peace Canyon Dam draft report was late being submitted by the consultant and BC Hydro's review of this draft could not be completed in time for the report to be finalized in F2019. The final Peace Canyon Dam Safety Review report is expected be issued in Q1 of F2020 along with that for WAC Bennett Dam. Draft reports for Hugh Keenleyside Dam and Kootenay Canal Dam are due in the in early F2020 and are on schedule.

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	Year-To-Date			Year-End	
	Actual	Target	Indicator	Forecast	Target
Dam Safety Reviews completed	7	8	✘	7	8
Completion of F19 work plan	87%	100%	✘		

Surveillance

Inspections

Routine weekly, monthly inspections are a regulatory requirement. These visual inspections are carried out by trained inspectors within Dam Safety or Stations 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 fourth quarter of this year all 381 (100%) scheduled inspections were completed.

There has been a positive trend in completion of inspections by Stations Field Operations over the past two years, and this year that group missed only two out of more than 1500 inspections for which they were responsible. This speaks to the high priority that has been assigned to this task by that group and its leadership, and a letter of thanks for their performance has been sent from Dam Safety.

Routine Inspections	F19		F18	F17	F16	F15
	Q4	Total				
Completed	381	1638	1595	1583	1594	1603
Missed	0	2	16	29	24	8

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 app will result in several efficiencies, including more timely review of routine inspection checklists, streamlined compliance reporting and a reduction in transcription errors. Roll out of the app will start on Vancouver Island in early May and will be rolled out to the other regions shortly thereafter.

Instrumentation and Monitoring

An initiative for F2019 was to drive consistent, regular checking of instrumentation data plots at all dams to identify any unusual trends and to ensure continued accuracy of the data being collected. The Regional Dam Safety Technologists were each tasked to perform three such checks per week. Over the course of F2019, 812 checks were completed, exceeding the target of 780. This requirement will be kept in place and tracked through F2020.

Unusual Events or Observations

The Dam Safety On Call Person (DSOP) responded to 84 calls in the fourth quarter. The calls included instrumentation alarms, operational inquiries, operations notifications during floods and earthquake notifications. Significant events from the third quarter include:

- Significant rainfall events in early January resulted in higher than normal reservoir levels at several dams on Vancouver Island, requiring an increased frequency of inspections. The rainfall events also triggered a number of instrument alarms.

Staffing

The Surveillance group has three vacancies to fill. Interviews for the Dam Safety Technologist and the Dam Safety Engineer have been completed and the positions should be filled shortly. The interviews for the Specialist Dam Safety Engineer position are scheduled for early May. Additionally, the Team Lead for the Dam Safety Technologists has accepted an offer to take on the role of Field Manager at Peace Canyon Dam in Stations Field Operations, which will create another vacancy in Q1 of F2020.

Maintenance

Civil Maintenance

In F2019, 29 of 31 planned civil maintenance projects were completed with a total spend of $4.034 million on a plan of $4.000 million. Some of the key projects were:

- Spillway inspections and repairs at Aberfeldie, Alouette, Revelstoke, Seven Mile and WAC Bennett Dams;
- Terzaghi Dam spillway access planning;
- Spillway bridge repairs at Blind Slough and Revelstoke Dams;
- La Joie Dam upstream shotcrete face repairs;
- Underwater inspections at the toes of Hugh Keenleyside and Spillimacheen Dams;
- Repairs to the expansion coupling on penstock G3 at Kootenay Canal Dam;
- Repairs to canals at Quinsam Diversion and Seton Canal; and
- Peace Canyon Dam drain cleaning

The project to scale the rock slope above the wood stave penstock at Shuswap Generating Station was cancelled as that conduit is no longer kept watered up and foundation drain cleaning at WAC Bennett Dam was deferred.

Spillway Gate Maintenance and Testing

Over the entire course of F2019, a total of 187 gate testing operations were conducted at 23 facilities during the reporting period. The 23 facilities included 22 sites with flood discharge gate systems, plus the Kootenay Canal headworks gate system which is also included in the test program.

In Q4 alone, 60 scheduled gate tests at 23 sites were carried out. Four gate systems failed to operate on demand during testing. In six 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 March 2019, operational restrictions were in place on two out of 109 flood discharge gates due to known deficiencies (no change from the end of Q3).

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 9, rates of failure have decreased by nearly a full order of magnitude.

A total of 26 corrective maintenance issues were identified through ongoing testing and maintenance from January to March 2019. A total of 28 new and previous issues were addressed in the same period, for a reduction of 2 overall in this reporting period. There were 118 corrective maintenance issues outstanding at the end of March 2019, seven more than in March 2018.

Dam Safety has been monitoring the identification and resolution of these issues. Figure 10 shows the overall number of outstanding maintenance issues related to flood discharge gate systems from 2009 to 2019. It is clear from this figure that there has been a significant increase in the number of outstanding issues since 2016.

As of March 2019 the outstanding issues comprise: 58 issues identified in 2018-19 (49% of the total); 37 issues identified in 2016-17 (31% of the total); 15 issues (13%) identified in since 2014-15; and 9 issues (8%) identified before 2014. This suggests that about 50% of the issues take more than 2 years to address. About 10% of the issues have been outstanding for more than 5 years.

Dam Safety is working to assess this data in more detail—including breaking down the nature of the outstanding issues—in order to determine what if any risks this situation poses and any necessary corrective actions. Generating Stations Maintenance Planning has set up a system to identify any maintenance needs resulting from the monthly and annual gate tests, has risk assessed all of the outstanding work orders and entered them into BC Hydro's PassPort system for prioritization within the maintenance program. With this assistance, tracking and reporting on outstanding maintenance items related to spillway gates will be significantly improved. It is further anticipated that these efforts will allow us to determine the time and resources that will be required to clear this backlog of issues and to develop the plan to do so.

Outstanding spillway gate maintenance issues and progress in closing them will be reported regularly to the Capital Project Committee in future quarterly reports.

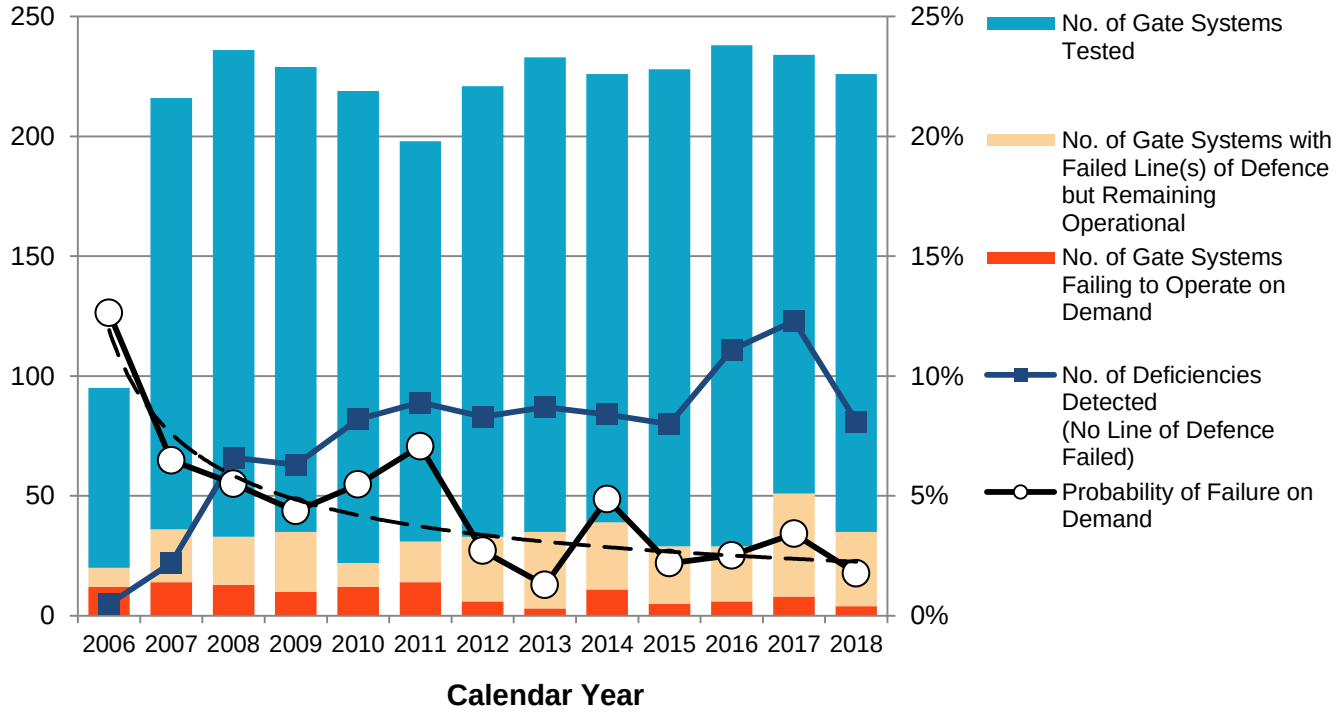

Figure 9 Deficiencies detected and rates of failure to operate on demand during flood discharge gate testing.

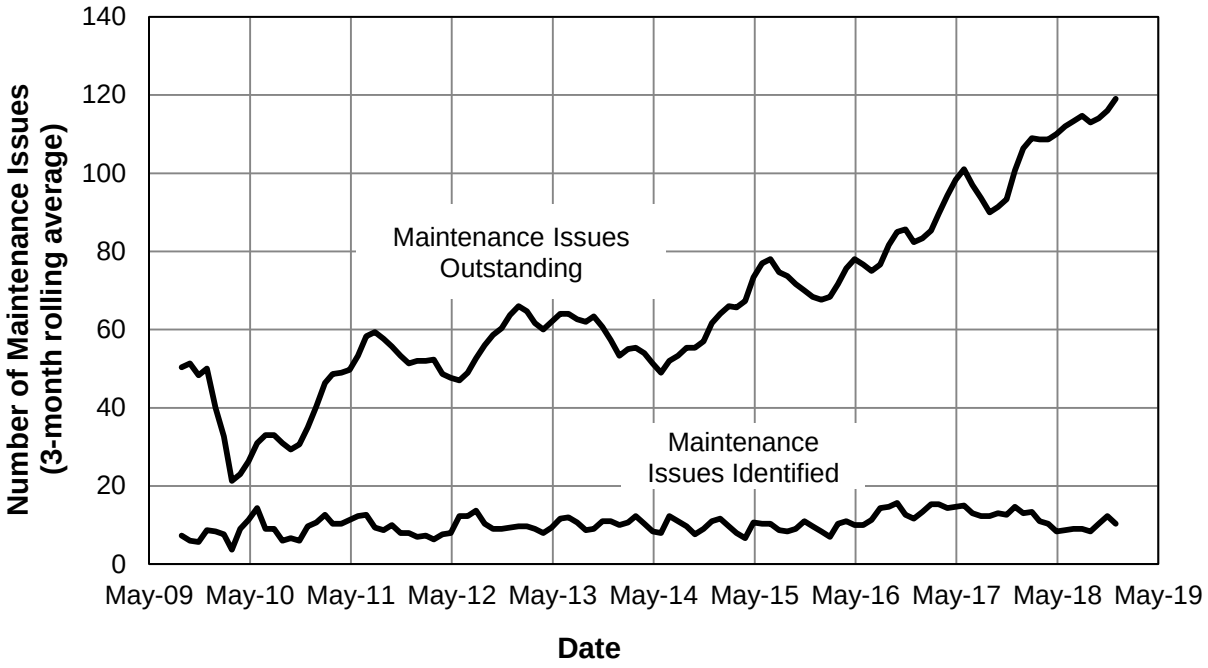

Figure 10 Number of identified and outstanding spillway gate maintenance issues identified and retained on a monthly basis.

Emergency Preparedness and Public Safety

Emergency Preparedness is managed by 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.

Table Top Exercise

In February, Dam Safety's team in the Upper Columbia region conducted their own table top exercise. The objectives of the exercise were to provide training for the newer staff and to assess the readiness of the team to respond to such an emergency. The team discussed how they would respond to a regional flood that resulted in an escalating situation. Initially the simulated flood impacted the smaller facilities, but as the scenario progressed the larger facilities were also impacted. As an outcome of the exercise, the team is putting together "go bags" with surveillance tools, food and water, and reference materials (*e.g.*, OMS Manuals, Operating Orders) so they can respond more efficiently.

Capital Projects

With this quarter's report, Dam Safety capital project reporting will be condensed to include those just launched, those where significant developments occur or those where milestones are achieved. A list of all Dam Safety capital projects underway is attached as Appendix B. Although not yet functional, in future reports the table will include hyperlinks to detailed descriptions of all the projects for the Committee's discretionary review.

John Hart Dam Seismic Upgrade

In Q4, the project completed Feasibility Design and developed plans for Definition and Partial Implementation Phase work. The project team will be coming before the Committee in June to seek approval of the preferred alternative, which includes extensive seismic upgrades to all five dams on site, complete replacement of the spillway gates system, and conversion of several concrete gravity blocks to a passive overflow spillway, and to further seek approval of the funding request for Definition and Partial Implementation work.

Ruskin Dam and Powerhouse Seismic Upgrade

The 13th and final Advisory Board Meeting for the Ruskin Dam and Powerhouse Seismic Upgrade Project was held on February 19 through 22, 2019.

The Advisory Board has concluded that the overall project, now essentially completed:

- Has met the overall project objectives of withstanding the Maximum Design Earthquake (1:10,000 Annual Exceedance Frequency) without uncontrolled release and assurance of rapid post-earthquake drawdown capability with at least two of five spillway gates operable;

- Has addressed the long-term seepage and seismic performance objectives on the left and right abutments; and

- Has adequately considered and addressed the comments and recommendations made by the Advisory Board in previous meetings.

With specific reference to the stability analyses performed to investigate the potential need for additional anchoring of the so-called "crest block" and the dam overall, the Board concurred with the analysts' conclusion that no additional anchors for the concrete gravity monoliths are required. On this point, the Advisor Board commented:

> "The 3D LS-Dyna model and corresponding analyses comprise the most comprehensive modeling program the Board has seen being used for any seismic evaluation of a concrete gravity dam. The Board commends BC Hydro on developing this important in-house capability. The capability is recognized in North America as being the most advanced in the dam safety community."

In the closure of its report, the Advisory Board had this to say:

> "As this project draws to a close, the Board commends BC Hydro for significantly improving the safety of Ruskin Dam, in some cases through the inclusion of appropriation application of innovation to address challenging issues. The jet grouting applications, the flexible asphalt connection, the yielding beams in the gates, and the industry-leading 3D LS-Dyna model are all innovations of which BC Hydro should be justifiably proud. The Board was pleased to hear that early contractor involvement, which BC Hydro used for the first time on this project, has become a common practice for the organization's dam safety projects."

With work on the Ruskin Dam and Powerhouse Seismic Upgrade Project now essentially complete, the project's design team is preparing Engineering Design Conformance Records to provide their professional assurances that the works were designed in conformance with the project's objectives and that they were built in conformance with the design intent. Dam Safety relies on these assurances as the basis for closing relevant outstanding issues in the Dam Safety Database. Since the project is addressing all of the issues for which Vulnerability Index values have been assigned to Ruskin Dam, it is expected that the bar in Figure 1 for Ruskin Dam will be reduced to or very near to zero by the end of Fiscal Year F2020 Quarter 1.

Dam Safety Investigations

With this quarter's report, Dam Safety Investigations reporting will be condensed to include those just launched, those where significant developments occur or those where milestones are achieved. A list of all Dam Safety Investigations and System-Wide Initiatives that are underway is attached as Appendix C. Although not yet functional, in future reports the table will include hyperlinks to detailed descriptions of all the investigations for the Committee's discretionary review.

Revelstoke Dam – Computational Fluid Dynamics Modelling (CFD) of Revelstoke Spillway

This investigation was initiated in Q3 to develop a better understanding of the Revelstoke Dam's spillway performance, particularly in light of the observed deformations of the Marble Shear on which it's situated. This will be accomplished by developing a computational fluid dynamic (CFD) model of the discharge through the spillway that will allow detailed hydraulics assessment of:

- approach flow conditions
- discharge rating curve checks
- water surface profiles through the spillway headworks and downstream chute (for example to assess the potential for wall overtopping)
- pressure distributions (for example to assess the potential for cavitation)
- flow patterns associated with asymmetrical gate operation
- tailrace flow patterns

Work in Q3 and continuing through Q4 included review and compilation of the available hydrotechnical information on the dam and the history of the spillway operations. It also included the development of a three-dimensional computer model of the spillway, dam, approaches and tailrace that will be incorporated into the CFD model.

Work will now transition into development of the CFD model and subsequent analyses. This investigation is expected to be completed in the latter half of Fiscal Year F2020.

Wilsey Dam – Static and Seismic Performance Assessments

Wilsey Dam is a high consequence dam based on the potential environmental impacts of the sediment release (deposited against the upstream face of the arch dam) if the dam were to fail. The surficial condition of the concrete comprising the main arch dam and the plug dam at the base has deteriorated with time. Seepage through the dam's lift joints and existing structural cracking has been noted. Furthermore, sediments have been accumulating against the upstream face of the dam. The current sediment level measured against the upstream face of the arch dam exceeds the critical elevation as computed by the 1992 stability analyses. Given the current condition of the dam, a stability review of the dam is being carried out to assess the level of concern.

As Wilsey Dam's condition is deteriorating, so too is the adjoining Shuswap Generating Station and a long-term strategy for the facility is being updated to reflect these and other developments, including demands for fish passage around the dam. Amongst the alternatives being considered for both the dam and the generating station is decommissioning. The objective of this Dam Safety Investigation is to provide a clear and complete understanding of the dam's deficiencies and the scope and high-level costs for any required repairs and upgrades. The results from this investigation will be fed into the facility's overall strategy.

This investigation was initiated in late Q4, and will be phased. The first phase is to update the stability assessment, using current concrete conditions, to better evaluate the level of concern. Depending on the results, the next steps can be better scoped. As part of a separate project, the clean-up of the downstream face and the dredging of the upstream silts will be carried out in summer/fall 2019. Following the clean-up, a site inspection and possible investigations as part of this study will be carried out.

System-wide – Flood Dashboard

The project objective is to compile available information on Inflow Design Floods (IDF) and other flood measures for dams across BC Hydro's fleet into one platform, and to apply stress tests (*e.g.,* spillway gate outages and increases in flood magnitudes) to demonstrate the sensitivity of flood capacity at each of the dams. This will help in prioritizing the next phase of IDF and stochastic flood studies, as well as to provide more ready identification of dams that are vulnerable to faults and climate change. Although measures for gate outages have already been assessed for many projects, there is currently no compilation of such flood information for all dams. This initiative will help to fill that gap.

Closure

As previously stated, this Quarterly Report continues from last quarter's changes in report format, with a goal of streamlining the report while also reporting on a larger breadth of the Dam Safety Program. Additional metrics have been incorporated to aid in assessing the effectiveness of the Program and its initiatives, and additional metrics and forecasts will be reported in the future as they become available and provide relevant insights.

Our goal for next quarter's report is to have fully put into place hyperlinks in the appended tables that will direct the reader to summaries of each of BC Hydro's dams and ongoing projects and investigations for convenient reference while reading the report.

Appendix A – BC Hydro's Dams

With this report, the Quarterly Featured Dam Site segment has been discontinued. In future reports, summary information regarding each of BC Hydro's dams will be accessible via hyperlinks in the following table. This feature is not available in this quarter's report, however.

Dam Site	Consequence [1]	Dam Type [2]	# of Dams	Year [3]	Height (m)	Generating Station	Reservoir / Headpond
Aberfeldie	H	PG	1	1953	32	Aberfeldie	Aberfeldie Headpond
Alouette	EX	TE	1	1926 / 1983	21	Alouette	Alouette Lake Reservoir
Bear Creek	L	TE	1	1958	19	Jordan River	Bear Creek Reservoir
Buntzen	S	PG	1	1903	16.5	Buntzen 1 & 2	Buntzen Lake Reservoir
Cheakamus	EX	TE/PG	5	1957	29	Cheakamus	Daisy Lake Reservoir
Clayton Falls	S	PG	1	1961	7	Clayton Falls	Clayton Falls Headpond
Clowhom	S	PG	2	1958	22	Clowhom	Clowhom Lake Reservoir
Comox	EX	PG	1	1912	10.7	Puntledge	Comox Lake Reservoir
Coquitlam	EX	TE	1	1914 / 2008	30	-	Coquitlam Reservoir
Duncan	EX	TE	1	1967	38.7	-	Duncan Reservoir
Durack Brook	S	TE	1	1963	4.5	-	Durack Brook Reservoir
Elko	S	PG	1	1924	16	Elko	Elko Headpond
Elliott	VH	PG	1	1971	27.4	Jordan River	Elliott Headpond
Elsie	EX	TE	6	1958 / 2001	31	Ash River	Elsie Lake Reservoir
Falls River	S	PG	1	1930	13	Falls River	Bigs Falls Headpond
Hugh Keenleyside	EX	TE/PG	2	1968	58	-	Arrow Lakes Reservoir
John Hart	EX	TE/PG	4	1947	34	John Hart	John Hart Reservoir
Jordan Diversion	VH	CB	1	1913	39.9	Jordan River	Jordan Diversion Reservoir
Kootenay Canal	VH	PG/ER	8	1975	38	Kootenay Canal	Kootenay Canal Headpond
La Joie	EX	ER	1	1948	87	La Joie	Downton Reservoir
Ladore	EX	PG	3	1949	37.5	Ladore	Lower Campbell Lake Reservoir
Mica	EX	TE	1	1972	244	Mica	Kinbasket Reservoir
Peace Canyon	VH	PG	2	1979	61	Peace Canyon	Dinosaur Reservoir
Puntledge Diversion	VH	PG	1	1912	5.5	Puntledge	Puntledge Headpond
Quinsam Diversion	S	PG	1	1957	15	Ladore	Quinsam Diversion

Dam Site	Consequence [1]	Dam Type [2]	# of Dams	Year [3]	Height (m)	Generating Station	Reservoir / Headpond
							Headpond
Quinsam Storage	S	PG	1	1957	9	Ladore	Upper Quinsam Lake Reservoir
Revelstoke	EX	TE/PG	4	1984	175	Revelstoke	Revelstoke Reservoir
Ruskin	EX	PG	1	1930	59.4	Ruskin	Hayward Lake Reservoir
Seton	H	PG	3	1956	13.7	Seton	Seton Lake Reservoir
Seven Mile	EX	PG	1	1980	80	Seven Mile	Seven Mile Reservoir
Spillimacheen	S	PG	2	1955	14.5	Spillimacheen	Spillimacheen Headpond
Stave Falls	EX	PG	2	1911	26	Stave Falls	Stave Lake Reservoir
Strathcona	EX	TE	2	1958	53	Strathcona	Upper Campbell Lake, Buttle Lake Reservoir
Sugar Lake	EX	CB	1	1942	13.4	Shuswap Falls	Sugar Lake Reservoir
Terzaghi	EX	TE	1	1960	60	Bridge River 1 & 2	Carpenter Reservoir
W.A.C. Bennett	EX	TE	1	1968	183	GM Shrum	Williston Reservoir
Wahleach	VH	TE	1	1953	21	Wahleach	Jones Lake Reservoir
Walter Hardman	S	TE	6	1960	12	Walter Hardman	Walter Hardman Headpond
Whatshan	S	PG	2	1951	12	Whatshan	Whatshan Lake Reservoir
Wilsey	H	VA	2	1929	30	Shuswap Falls	Wilsey Headpond

[1] Consequence Categories: EX extreme, VH very high, H high, S significant, L low

[2] Main dam at site: PG concrete gravity, CB concrete buttress, VA concrete arch, TE earthfill, ER rockfill, ER/T rockfill timber crib.

[3] Where two years are indicated, the dam has been substantially or completely rebuilt; the first is the year of original construction and the second is the year of the rebuild.

Appendix B – Dam Safety Capital Projects

All Dam Safety capital projects that are currently underway are listed in the following table. In coming quarterly reports, each project listing will contain a hyperlink that will direct the reader to a detailed project description and status summary. This feature is not available in this quarter's report, however.

Dam / Facility	Project Description	Current Phase	Forecasted Completion Date for current phase	Update Available
Alouette Dam	Headworks and Surge Tower Seismic Upgrade	Identification – Feasibility	October 2019	*This column not yet functional*
Alouette Dam	Environmental Flow Discharge Upgrade and LLO Sealing	Needs	TBD	
Bridge River 1	Slope Drainage Improvements	Identification	December 2021	
Bridge River 1	Mitigate Surge Spill Hazard	Identification – Feasibility	August 2019	
Bugaboo Diversion Dam	Decommissioning	Definition	October 2019	
Clowhom Dam	Gate Control Improvement	Identification	January 2020	
Comox – Puntledge	Flow Control Improvements	Identification – Feasibility	TBD	
Duncan Dam	Spillway Gates Replacement	Needs	April 2019	
Hugh Keenleyside and Revelstoke	Debris Boom Replacement	Definition & Implementation (Combined)	June 2019	
John Hart Dam	Seismic Upgrade	Identification - Feasibility	July 2019	
Kootenay Canal	Power Intake Piezometers Installation	Identification	February 2019	
Kootenay Canal	Replace Silt Slope Piezometers Project	Identification	April 2019	
Kootenay Canal	Reservoir Boom Replacement	Implementation	June 2019	
Ladore Dam	Spillway Seismic Upgrade	Identification – Feasibility	September 2019	
La Joie Dam	Dam Improvements	Needs	April 2019	
Mica Dam	Discharge Facilities Seismic and Reliability Upgrades	Needs	August 2019	
Mica and Revelstoke	Rehabilitate Vertical Movement Gauges	Identification	March 2019	

Dam / Facility	Project Description	Current Phase	Forecasted Completion Date for current phase	Update Available
Peace Canyon Dam	Instrumentation Upgrades	Identification-Conceptual	August 2019	*This column not yet functional*
Revelstoke Dam	731 Block Stability Improvements	Identification – Feasibility	February 2019	
Revelstoke Dam	Replace Downie Slide Instrumentation	Identification – Feasibility	September 2019	
Ruskin Dam	Seismic Upgrade	Implementation	January 2018 – in service	
Salmon River Diversion	Decommissioning	Implementation – Project Completion	August 2020	
Seven Mile Dam	Reservoir Boom Replacement	Feasibility	May 2019	
Sugar Lake Dam	Gate Reliability	Needs	May 2019	
Strathcona	Upgrade Discharge	Identification – Feasibility	August 2019	
Terzaghi Dam	Spillway Chute Access Upgrade	Identification – Conceptual	November 2019	
WAC Bennett Dam	Riprap upgrade	Implementation – Project Completion	August 2019	
WAC Bennett Dam	Spillway Concrete Upgrade	Needs	TBD	
WAC Bennett Dam	Spillway Gate Reliability	Implementation	5 May 2020	
WAC Bennett Dam	Instrumentation Embankment Dam	Identification – Conceptual	March 2019	
WAC Bennett Dam	Seal Low Level Outlets	Identification – Conceptual	5 April 2019	
WAC Bennett Dam	Recommission/Seal Sluice Gates	Identification – Conceptual	30 January 2019	
Wahleach Dam	Tailrace Upgrade	Implementation	September 2022	
Wahleach Dam	Replace Intake Over-Velocity System	Implementation	March 2021	
Walter Hardman Dam	Improve Orifice Control Structure	Definition	August 2019	

Appendix C – Dam Safety Investigations

All Dam Safety Investigations and system-wide initiatives that are currently underway are listed in the following tables. In coming quarterly reports, each Investigation listing will contain a hyperlink that will direct the reader to a detailed description and status summary. This feature is not available in this quarter's report, however.

Investigations:

Dam / Facility	Description	Update Available
Alouette Dam	Seismic Assessment of Spillway	*This column not yet functional*
Coquitlam Dam	Data Compilation, 3-D stability model	
Hugh Keenleyside Dam	Low Level Outlets – Operations Concerns	
Mica Dam	Performance Assessment of the Earthfill Dam	
Revelstoke Dam	Computational Fluid Dynamic Modelling of Spillway	
Strathcona Dam	Seismic Performance Assessment	
WAC Bennett Dam	Embankment Dam Project; Long-term Performance	
WAC Bennett Dam	Spillway Seismic Performance Assessment	
Walter Hardman Dam	Performance Assessment Investigations	
Wilsey Dam	Static and Seismic Performance Assessment	

System-wide Initiatives:

Description	Update Available
Constitutive Model to Analyse Internal Erosion in Embankment Dams	*This column not yet functional*
Dam Safety Information System development	
Flood Dashboard- Inflow Design Floods Information Compilation	
FloodSiMM-Hydraulic Models Update	
Hydrofracturing Hazard	
Remote Sensing, LiDAR Surveys and InSAR Analysis and Information Database for Landslides	
Stochastic Modelling of Extreme Floods-Columbia River System	
Systems Engineering Analysis of Dam and Reservoir Systems	
Tolerability of Risk	