Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

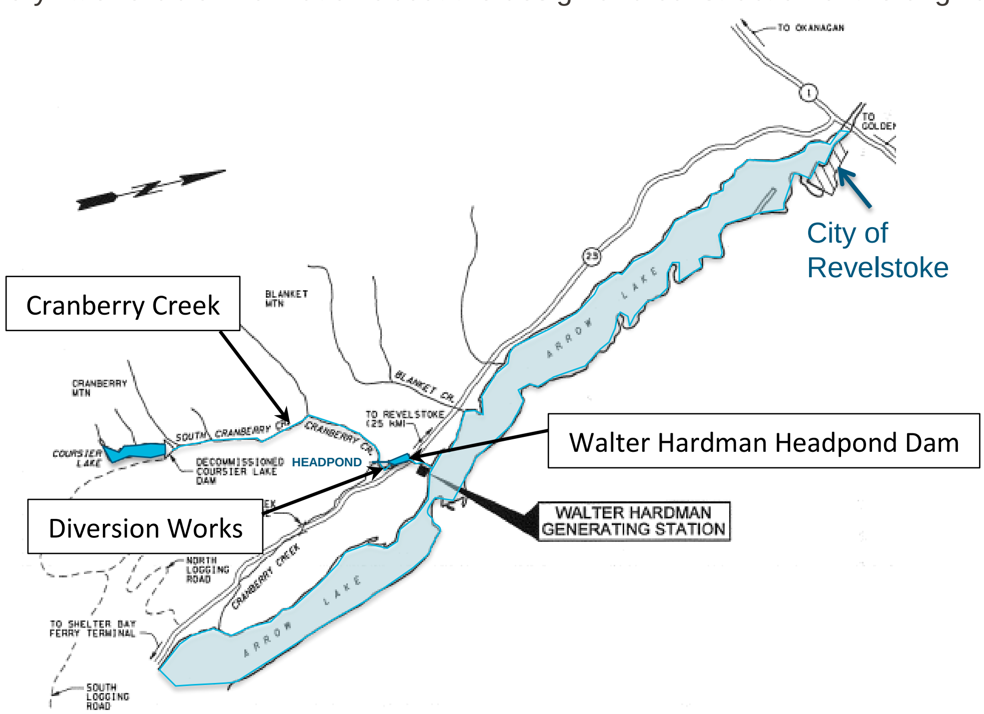
Executive Summary

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, 2018 to March 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 carried out consistent with its stated objectives throughout the reporting period. The overall Dam Safety risk profile is shown in Figure 1. There has been an overall decrease in risk this quarter with the completion of the WAC Bennett Dam Riprap Project, acceptance of the Hugh Keenleyside Spillway Gate Engineering Design Conformance Record and acknowledgement of risk mitigation at La Joie with the lowered reservoir level. These decreases are temporarily offset by a new high priority issue, erosion of the downstream left abutment at Whatshan Dam, which is to be dealt with prior to the 2018 freshet.

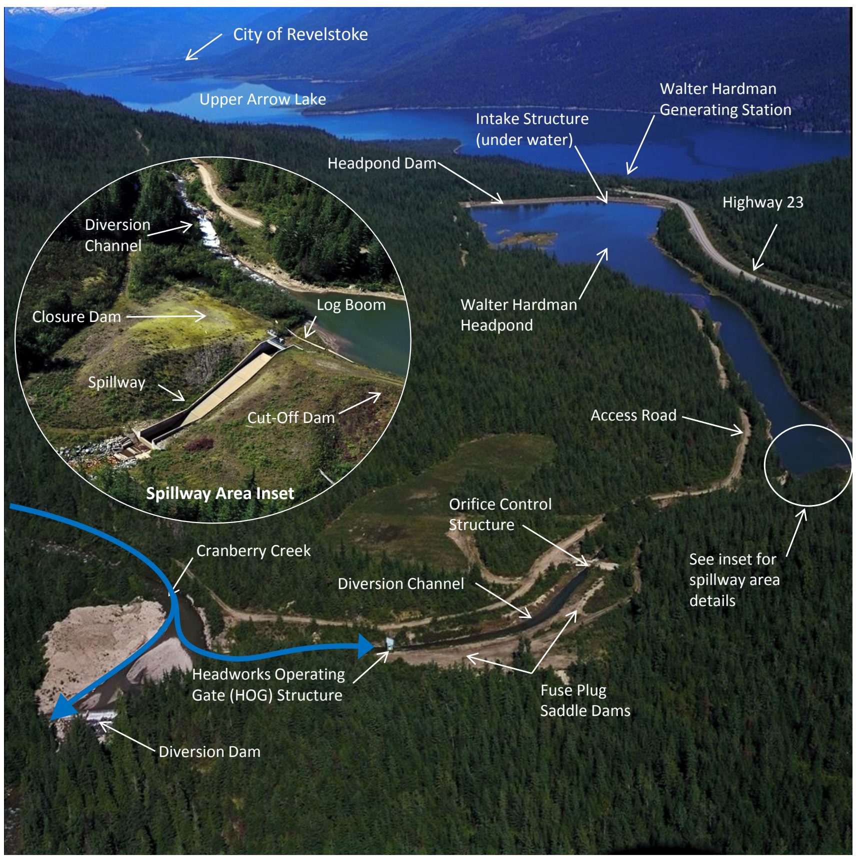
Quarterly Featured Damsite – Walter Hardman Dam

Walter Hardman Dam is a High consequence dam located adjacent to Highway 23, about 27 kilometres South of Revelstoke. The consequence was increased from Significant to High in Q4 based on a recent reassessment of the inundation information. The facility was designed and constructed for the City of Revelstoke between 1959 and 1961 for the purpose of power production and was purchased by BC Hydro in 1972. The Walter Hardman Project consists of the Cranberry Creek diversion works, the Walter Hardman Headpond and a two-unit Powerhouse located on the shore of Arrow Lake. Water is diverted into the headpond from Cranberry Creek by means of a diversion dam across Cranberry Creek then via a diversion channel. The facility was not constructed by BC Hydro, and there is very little reliable information about the design and construction of the original works.



Historically, Coursier Lake Dam and reservoir, located approximately 11 kilometres upstream from the Cranberry Creek diversion works, regulated flow in Cranberry Creek and provided storage for the Walter Hardman Project. Coursier Lake Dam was decommissioned in 2003 for dam safety reasons and Cranberry Creek has returned to its natural flow pattern.

The diversion works, built in 1960 and modified in 1979, consist of the concrete Cranberry Creek Diversion Dam, the Diversion Channel with a gated concrete Headworks Structure near the upstream end and an orifice Control Structure near the downstream end, and two earthfill Saddle Dams that act as fuse plugs if inflow water levels become too high. The Saddle Dams and the Control Structure are critical for limiting the flow into the Headpond as the capacity of the spillway is relatively small compared to the flow in Cranberry Creek.



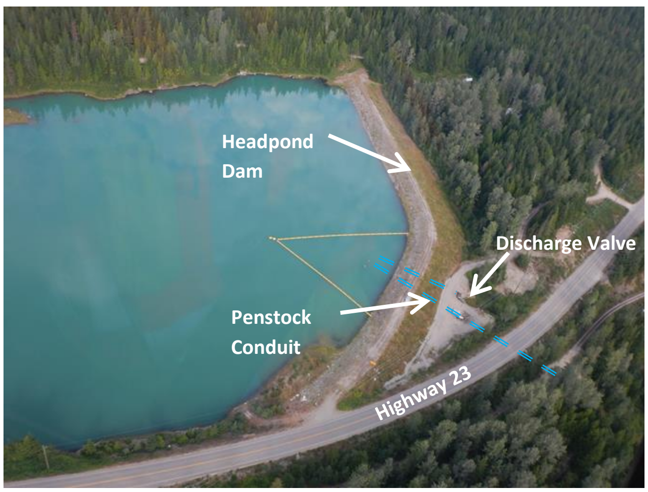
Walter Hardman Facility

The Walter Hardman Headpond is formed by three earthfill dams: the Closure Dam, the Cut-off Dam and the Walter Hardman Headpond Dam (listed from upstream to downstream).

The Closure Dam is located at the south end of the Walter Hardman Headpond and spans a low area between the right side of the Spillway and natural higher ground to the right. The homogeneous earthfill Closure Dam was built in 1979 when the Spillway was relocated from its 1974 location, just south (to the right) of its current location. It is only 2 metres high and approximately 25 metres long.

The Cut-off Dam is also located at the south end of the Walter Hardman Headpond and abuts the left side of the Spillway. Built in 1960 during the original Walter Hardman Project construction, the Cut-off Dam is a 60 metre long zoned earthfill dam with a maximum height of 15 metres. Although record issue drawings show that the dam had riprap placed on the upstream face, there is no evidence of this riprap. However, the upstream face is in good condition and the lack of riprap has been deemed to not be an issue.

The Walter Hardman Headpond Dam was constructed in 1961 and is a 381 metre long earthfill dam with a maximum height of approximately 12 metres. Two through-going conduits encased in concrete (the Discharge and Penstock Conduits) pass through the base of the dam. Drawings indicate that the dam is zoned earthfill constructed of rolled compacted earth fill with a glacial till core, fine gravel transitions on either side of the core, and sand and gravel shells. Original drawings also indicate that the upstream slope was to be protected by 0.9 metres of riprap but this was apparently not completed during construction. Riprap was placed on the upstream face in 1988 to address this omission.



Walter Hardman Headpond Dam

The Walter Hardman Headpond Dam was constructed to a design elevation of 704.1 meters. However, during inspections completed as part of the 1985 CIR, the crest was found to be up to 0.44 metres below the design elevation. This difference is believed to have been a result of construction error rather than excessive settlement. In 1988, rehabilitation work included raising the dam crest to its design elevation of 704.1 metres, although survey data indicates the dam crest was raised higher than this. This is typical of the discrepancies that have been identified between the information provided on the Record Issue drawings and what is observed at site, leading to large uncertainties about what was actually constructed.

The ungated power intake structure is located at the upstream toe of the Headpond Dam. The intake structure leads to a discharge conduit and a penstock conduit located in the base of the dam. The discharge conduit has a hollow cone valve at the downstream end which has not been used since 1986. Flow from the discharge conduit passes under Highway 23 into a steep gully which discharges into Arrow Lake adjacent to the powerhouse. The penstock conduit has a valve house at the downstream end containing a butterfly valve. From the valve house, a steel penstock continues down the hillside to the 8 MW powerhouse.

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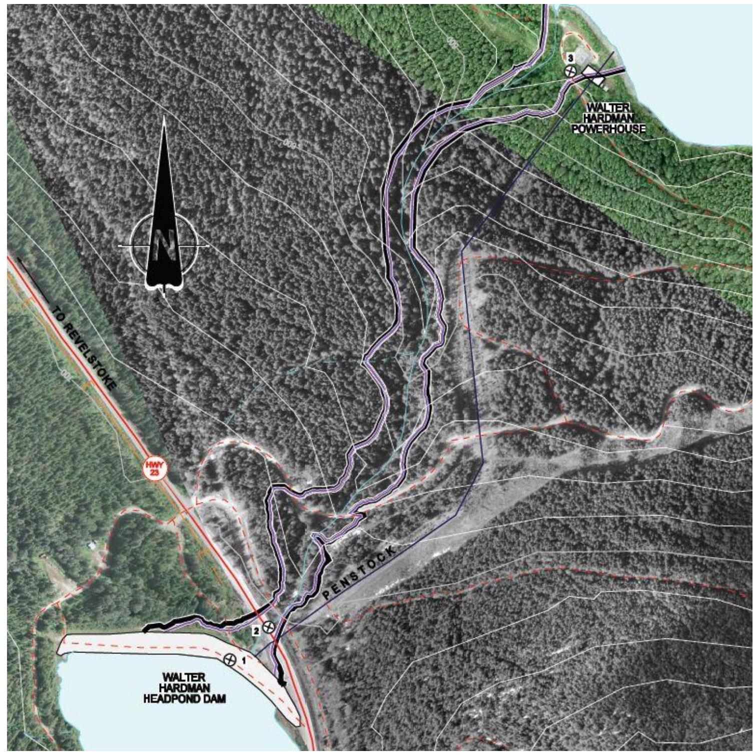
Hollowcone Valve, 1986



Inundation Mapping showing steep slope to Arrow Lake

<u>Spillways</u>

There have been three Spillways built for the Walter Hardman Project. The original Spillway was located on the left abutment of the Walter Hardman Headpond Dam. Scour and erosion problems in the spillway discharge channel were caused during Spillway use. The possibility of high discharges causing channel bank erosion that could encroach on the powerhouse access road and Powerhouse led to the relocation of the Spillway in 1974.

In the fall of 1974, a new Spillway was constructed at the upper end of the Walter Hardman Headpond The second (1974) Spillway was operated in 1975 and 1976 and regular operation caused significant erosion at the downstream end of the channel below the concrete weir. Remedial work was carried out in the fall of 1976 but the downstream spillway channel failed in 1978.

In the fall of 1979, a third Spillway was constructed to replace the failed Spillway. This is the Spillway present at the Walter Hardman Project today. The Spillway is located between the Cut-off Dam and the previous (1974) Spillway. A Closure Dam was constructed in the location of the 1974 Spillway and connects the present Spillway to natural high ground to the south.

Walter Hardman Spillway

Until 1996, the spillway was regularly used for four to five months every year during seasonal high flows from Cranberry Creek. In May 1996, during high water releases, rock-filled gabions and riprap at the toe of the spillway were washed away and erosion in the discharge channel occurred. The erosion caused concern about the environmental impacts of spilling through the discharge channel and as a result, the operating level of the headpond was permanently reduced by 0.9 metres to avoid spilling. The reduced operating level was embedded in the Water Use Plan in 2006.

Recent History

In 2007, improvements were made to drainage along the toe of the Headpond Dam and french drains were installed at the downstream end of both the Discharge Conduit and the Penstock Conduit in order to monitor for seepage along the conduits.

In the spring of 2016, depressions and slumps were observed near the toe of the Headpond Dam, possibly due to excessive seepage through the dam. Upgrades to the toe drain system were carried out in November 2016 to improve drainage and monitoring of flows.

A Dam Safety Review is scheduled to begin in 2018 and in preparation for this review, investigations are planned in September 2018 to gather information about the dams. Drill holes to obtain samples of the earthfill dams will have piezometers installed to enable monitoring of water levels in the dams. The reservoir will be drawn down for the work, enabling the discharge conduit and penstock conduit to be inspected for the first time since 1986.

Update on Other Major Dams

Mica Dam

There are currently two ongoing dam safety projects:

Special Investigations Project

The work on Mica under the special investigations project for large embankment dams was initiated in 2015. The overall objective of this project is to develop tools and methodologies for performance monitoring of BC Hydro dams. At Mica, the objectives are to carry out a detailed performance assessment of the dam by developing, testing and verifying numerical analyses of the dam behaviour. It is anticipated that a full review will take 5 or more years to complete.

Work completed since 2015 includes compilation of the background information, plotting of the instrumentation data, the start of the development of a 3-D CAD/GIS model, and the first meeting of the Expert Engineering Panel (August 2016). In the opinion of the Expert Engineering Panel, Mica Dam is designed and constructed in such a way that it safely controls all current seepage flows; however, there are additional studies required to further develop a better understanding of the dam.

In Q4, work continued with development of the 3D CAD and GIS models and characterization of the dam fills and foundation.

Rehabilitate Vertical Movement Gauges

During construction of the dam, six vertical movement gauges were installed in the core of the dam. The gauges are no longer used to measure settlement or deformation and have since been 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.

In Q3, a site investigations program was completed and conceptual design work began for sealing the vertical movement gauges. Sealing the Revelstoke movement gauges, which was originally planned as a separate project, was added to this project in Q4 as combining the two projects will allow for project and construction efficiencies to help reduce the overall cost of the work. In Q4 work continued with design and estimating, including early constructability reviews.

Revelstoke Dam

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

Left Bank – Slope Stabilization

The Left Bank Slope Stabilization Project was initiated in F2017, with the objective to address the risk posed by the ‘731A Nose’ rock slope area on the safety and operation of the powerhouse and the new Penstocks 5 and 6. In addition, further upgrades are required to ensure the safe performance of the

731 Block, which was previously anchored just after construction of the dam and powerhouse. Ongoing rock falls have damaged the anchors' heads and seepage ingress into the heads of the restressable anchors has corroded the strands of the anchors. In Q4, conceptual designs were developed for the upper slope including rock bolting/meshing and design to better protect the anchor heads from water ingress and corrosion. Further work in feasibility design is planned for F2019.

Replace Downie Slide Instrumentation

Downie Slide is a 1.5 billion cubic metre slowly moving rock slide located on the west slope of the Revelstoke Reservoir 65 km upstream of the Revelstoke Dam. Eighteen inclinometers were installed between 1965 and 1993, of which five are still operational. It is forecasted that these five inclinometers will have been disrupted by the slide activity by 2020. To proactively measure slide displacement, an instrument replacement strategy is required to define the degree/level of monitoring. Incorporated in this strategy is a requirement to evaluate alternative displacement monitoring capabilities that could address the high cost of conventional techniques, both from an installation and operation perspective. This project was initiated in F2018, and funding for the conceptual design stage was approved in Q4.

Spillway Chute Condition Assessment

Small movements of the Marble Shear Block have produced cracking of the spillway concrete slab, and although unrated, this deficiency has been monitored for some time. The cracking has become more pronounced with time and, together with the observation that one of the underdrains is now flowing during spillway use, has prompted a review of the design and the rating of the deficiency. A screening level assessment in Q3 concluded that generally, the spillway design at Revelstoke appears to be consistent with modern spillway design practices, considered satisfactory, and no immediate concerns were identified.

In F2019, studies will commence to determine at what point the long-term movement of the Marble Shear Block endangers the proper functioning of the Revelstoke spillway, so that remedial works can be prioritized within the capital planning process.

The study and its results notwithstanding, the chute condition and Marble Shear Block drainage will continue to be closely monitored.

WAC Bennett Dam

There are seven ongoing dam safety projects as follows:

Spillway gate reliability

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

Long-term performance of the dam core

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

In Q4, work continued with developing the 3D CAD model of the dam, evaluation of the cross-hole seismic data, and planning further work on the large scale soil testing.

Embankment Instrumentation Upgrade

The current phase of the work will undertake a systematic process to identify the gaps in the instrumentation network and to identify both conventional and potentially new, non-intrusive type methods of dam monitoring. As per plan, a series of workshops was organized in order to share background information and to refine the scope of work for the project. In Q3, the third workshop was organized to assess the usefulness of the existing instrumentation and to identify deficiencies, using failure modes and key performance indicators as the basis for evaluation. A draft user requirements document was prepared. In Q4, the fourth workshop was held, to discuss various standard and non-standard instruments to monitor the key failure modes, the User Requirements were finalized, and a 3D seepage model of the dam was started.

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

In Q4, the placement of the remaining bedding and riprap was completed and the rip rap was put in-service. Documentation of the construction is underway. The remaining works, including repaving of dam crest road and reclamation of the quarry, are planned for completion in 2018.

Seal Low Level Outlets

A long term strategy document was previously developed to assess the options for the future role of the low level outlets at the WAC Bennett Dam. This document was forwarded to, and accepted by, the Regulator earlier this year. An introductory start-up meeting with Dam Safety, Operations, Environmental and Engineering staff was held in Q2 to present the findings and conclusions of the options study. In Q3, a design plan for the conceptual design stage was finalized. In Q4, the funding request for the conceptual design stage was submitted, with approval expected in early F2019.

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 and unmaintained state, this project was initiated to develop a long term strategy for the future role of the sluice gates, Also included in this project is to determine the future need for and possible upgrades to the leaky spillway stoplogs.

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

Ruskin Dam

The last spillway gate, SPOG5, was placed in-service in Q4. Additional reliability improvement work is still ongoing, including the procurement, design and installation of a permanent diesel generator and a battery inverter as auxiliary power sourcesWork is also continuing to develop a comprehensive 3-D model of the dam, projected to be fully developed in F19 Q1, producing results in F19 Q2, and fully documented early in F19 Q3.

Terzaghi Dam-Spillway Chute

Deficiencies associated with the Terzaghi spillway chute were documented in last quarter's report, and are deemed to be a high priority. An initial inspection has now been planned for Q1, using temporary rockfall protection measures. Once this inspection is completed, the scope of necessary upgrades can be better assessed.

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

In Q4, work continued on the feasibility design of the Low Level Outlets, including the assessment of the type of gates, the number and the type of hoists, and the selection of an open channel over the tunnel option. Conceptual options continued with the spillway upgrade options, including the options on potentially raising the embankment dam.

Ladore Dam

In Q4, work continued on the feasibility design, including design work on the gates and dam and preparation for a site investigations program, planned for F2019.

John Hart Dam

In Q4, the project initiated a field investigations program in coordination with the John Hart Replacement Project, which resulted in undertaking the land-based drill holes in Q4 and early Q1 of F2019. Reservoir-based drill holes are planned for later in F2019. Drinking water quality issues associated with the drawdown will need to be managed by the project. A recently completed engineering study has evaluated potential water quality mitigation options and has concluded that a temporary treatment facility is technically feasible.

Overall coordination of the Campbell River System

As the three projects progress, additional coordination work will be undertaken by Dam Safety, Project Delivery, 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.

Salmon River Diversion

The dam removal/river restoration was largely completed in Q2, and remaining construction work was completed in Q3. In Q4, work continued on post-decommissioning documentation, i.e., procurement of a Certificate of Compliance and Land Tenure.

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New Issues

Whatshan Dam

Whatshan Dam is a concrete gravity overflow structure with 11 spillway bays controlled by stoplogs and a low level outlet controlled by a vertical slide gate. A short earthfill embankment extends from the main gravity dam to the left abutment, retained by concrete walls on both the upstream and downstream sides. The dam is classified as Significant consequence and is located about 130 kilometres east of Vernon.

The downstream left abutment is steep overburden on rock and has been partially protected by concrete to prevent erosion of material during spills. A slope instability occurred in late May 2017, believed to be the result of seepage from the 2017 freshet combined with years of undermining of the concrete apron. The issue was rated in the Dam Safety Issues Database in January 2018. There is a concern that, if left unrepaired, the abutment will undergo further erosion during the freshet in 2018 with the potential to lose the left abutment of the dam and release the reservoir. A repair has been designed and construction has been awarded, scheduled to occur in May 2018 prior to the freshet.

GATE MAINTENANCE AND TESTING

During the period of January to February 2018, 38 scheduled gate tests at 23 sites were carried out. No gate system failed to operate on demand during testing. In four other cases, gates operated on demand; however certain equipment malfunctioned or was found to be in unacceptable condition.

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

A total of 19 corrective maintenance issues were identified through ongoing testing and maintenance from January to February 2018. A total of 25 new and previous issues were addressed in the same period, for a reduction of 6 overall in this reporting period. There were 102 corrective maintenance issues outstanding at the end of February 2018, which is 13 more than one year ago.

CIVIL MAINTENANCE

As of the end of the fourth quarter, all 47 projects planned for F18 are substantially complete. Total spend for the year is $4.349 million.

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

Work continues on the sustainable civil preventative maintenance program. The Revelstoke Pilot Lessons Learned have beed rolled out to the fleet. The first set of civil asset maintenance standards and instructions have been rolled out. The second set of maintenance standards and instructions are ready for rollout in F2020.

EMERGENCY PREPAREDNESS AND PUBLIC SAFETY

Emergency Preparedness is managed by the Strategic Emergency Management team. Dam Safety reports on the updating of emergency plans for compliance with the BC Dam Safety Regulation as part of annual compliance reporting to the Comptroller of Water Rights. In Q4, the head of the provincial dam safety program confirmed that BC Hydro's Emergency Planning Guides will be accepted as the Dam Emergency Plan required under the Dam Safety Regulation.

Public Safety is managed by the Public Safety team in Safety Engineering. Dam Safety reports on Public Safety activities related to dams during the Dam Safety Reviews.

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

COMPLIANCE WITH PROCESSES AND REGULATION

The Comox OMS Manual was submitted and accepted (with thanks for ongoing improvements which helps to raise the bar for dam safety across BC). Engineering Design Conformance Records were submitted for the Hugh Keenleyside spillway gate work and the WAC Bennett riprap placement. The John Hart Dam Safety Review report was submitted and requests for investigation work at Ladore, Strathcona and John Hart were submitted and approved. The frequency of inspection at Bear Creek was formally reduced from monthly to quarterly, in line with the Dam Safety Regulation, and the consequence classification of Walter Hardman Dam was increased from Significant to High based on a reassessment of the inundation studies.

Inspections

A total of 370 of 374 (98.9%) scheduled inspections were completed during Q4. Inspections were missed at Revelstoke (lack of available Dam Safety staff over Christmas break), La Joie (lack of manpower during an overhaul), Elko and Spillimacheen (Field Services crews assigned to priority substation work). The importance of completing all regulatory inspections has been discussed with responsible staff in these areas.

Additional inspections were carried out at Jordan Diversion and Elliott Dams due to high reservoir levels. The frequency of inspections at Bear Creek Dam was reduced from monthly to quarterly at the end of Q4, in consultation with the Regulator.

Dam Safety Reviews

Dam Safety Reviews are a regulatory requirement carried out at minimum intervals of every five to ten years at high, very high and extreme consequence dams. Nine Dam Safety Reviews are currently in progress. Final Reports for Stave Falls and Alouette were received in Q4. The final report for Comox was received but needs further work before it is accepted. This is in progress. Draft reports for Clayton Falls, Duncan, Seven Mile and Revelstoke were received and are in the process of being finalized.

A Request for Proposals for upcoming Dam Safety Reviews was posted in March and closed in April. Eleven proposals were received and are in the process of being evaluated.

VULNERABILITY INDEX: UPDATE

Changes in Vulnerability Index for actual and potential deficiencies, as outlined in Figure 1, are tracked on a quarterly basis and shown on Figures 2 and 3. This is an indication of the changes in the understanding of the dam safety risk profile. In Figure 3, the total index is shown (sum of actual and potential deficiencies), as well as separate plots for decreases and increases in the total index. Decreases are due to remediation projects as per the Capital Plan and resolution of issues via Performance Investigations. Increases in the index are due to the recognition of new issues. Existing issues are re-examined on a regular basis, and re-rated as required.

The baseline for the separate plots of decreases and increases to the Vulnerability Index has been set at the time of the development of the first 10 year capital plan.

Notable changes in Vulnerability Index in Q4 are:

- The addition of an Actual Normal deficiency at Whatshan Dam, as previously described under “New Issues”, with an assigned Vulnerability Index of 4.85; and
- Reductions in Vulnerability Index of 5.35 due to acceptance of the Hugh Keenleyside Spillway Gate Engineering Design Conformance Record, completion of the WAC Bennett Dam Riprap Project, and acknowledgement of risk mitigation at La Joie with the lowered reservoir level.

The net result is a small decrease in the system-wide Vulnerability Index of 0.5.

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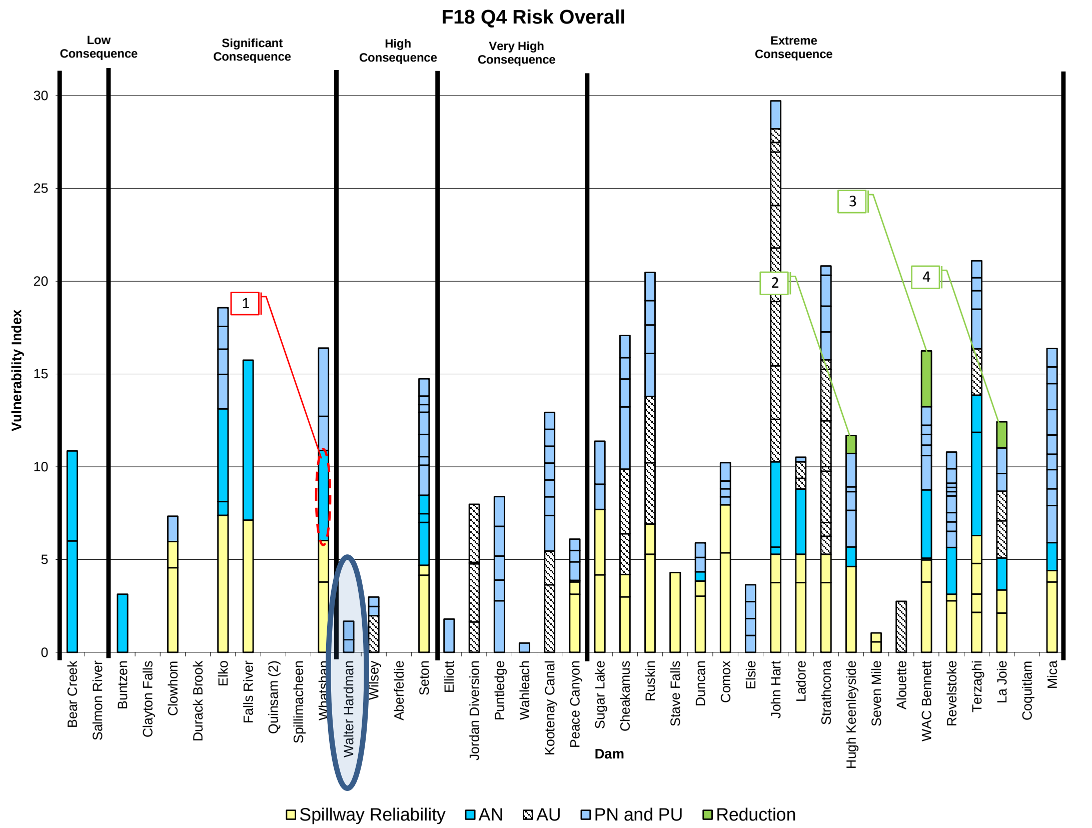
Figure 1 - Dam Safety: Overall Risk Profile



Legend and Summary of Changes

Increase in Risk

Whatshan Dam *– new erosion of downstream left abutment.*

Reduction Risk

Hugh Keenleyside Dam *–Spillway gate reliability project Engineering Design Conformance Record accepted by Dam Safety.*

WAC Bennett Dam *– Riprap placement on the upstream face of the dam completed.*

La Joie Dam – *Reservoir restriction is in place and has been maintained to mitigate risk associated with the seismic withstand of the dam*

Quarterly Featured Dam

A – Actual deficiencies have been shown to exist.
P – Potential deficiencies require further investigation.
N – Normal Load conditions; associated with daily or short-term operations.
U – Unusual Load conditions: associated with flood and earthquakes

Consequence classifications reflect current BC Dam Safety Regulations.
Dam order reflects generally increasing downstream consequences

NOTES:

- Vulnerability Index (Rating) is a qualitative assessment of future dam performance from all causes – the higher the rating the higher the likelihood of poor performance.
- 33 dam sites as identified have reportable risk at present
- This Risk Profile represents only currently known and rated issues. Changes do not necessarily indicate a physical change to BC Hydro assets that increase or decrease risk; rather they often represent a change in knowledge and understanding of the risk. Additionally, many known deficiencies (those without a direct impact on potential dam failure) have yet to be rated.

Figure 2 – Change in Actual and Potential Vulnerability Indices

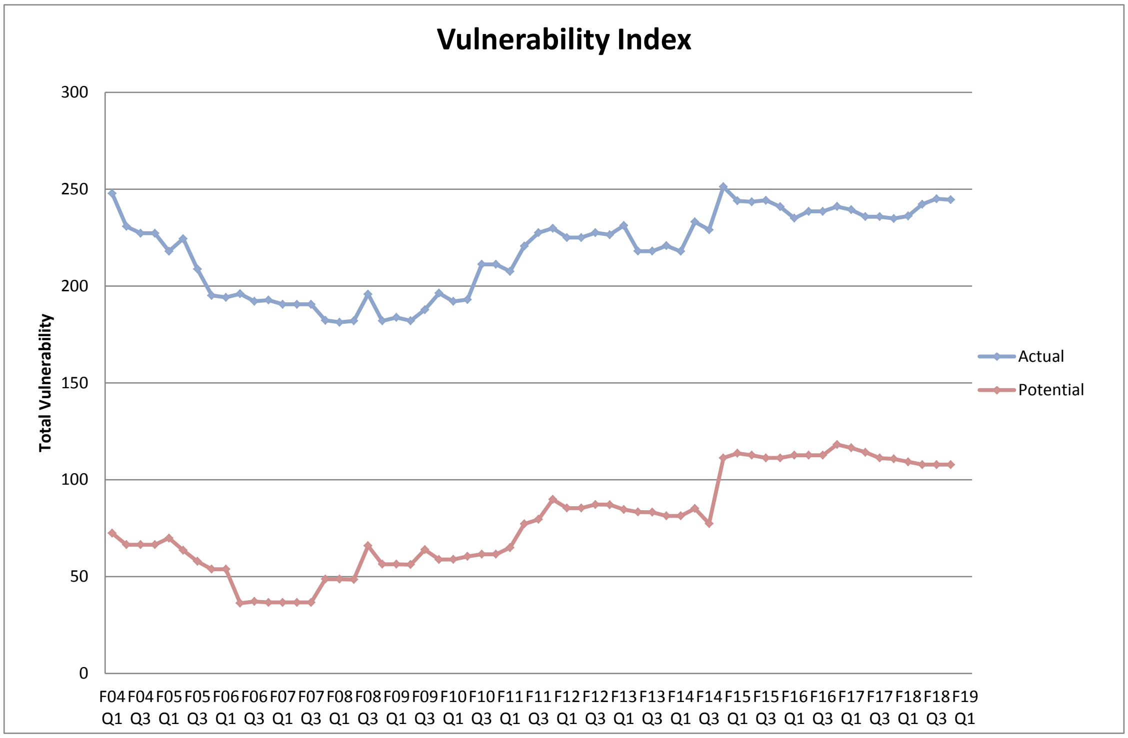


Figure 3 – Change in Total Vulnerability Index Components