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# Dam Safety Quarterly Report

## Executive summary


The purpose of this report is to update the Operations, Planning, Information & Technology Committee of the Board of Directors on key dam risk management activities during the period from January 1 to March 31, 2022 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. To keep the Committee as fully abreast of the Dam Safety Program as possible, some notable developments that took place after March 31, 2022 but before the completion of this report have also been included.

The key highlights from F2022 Q4 documented in this report are:

- There was a significant decrease of 46.2 in the aggregated Vulnerability Index in Q4 due to closures of issues at Bear Creek and Falls River Dams and by a change in methodology for calculating Vulnerability Index for spillway gate reliability issues. See page 3 and Appendix A (pp. 19-20).
- Issues Database review meetings were held for seven dam sites in Q4, and Dam Safety Engineers issued 14 sealed memoranda documenting the changes to the Issues Database. As a result, 43 non-conformance issues were completed, and one new issue was identified. See page 6.
- BC Hydro attended a day-long workshop on the John Hart Dam Seismic Upgrade Project in support of its application to the British Columbia Utilities Commission. Dam Safety, Project Delivery, Engineering Design, and Supply Chain gave presentations on the Campbell River System and the project's objectives, design evolution, risks, and contracting strategies. See page 7.
- All planned updates to Operation, Maintenance and Surveillance Manuals for the quarter and fiscal year were completed and submitted to the Comptroller of Water Rights. The reports for two planned Dam Safety Reviews were not issued as scheduled but were instead held in draft for improvements before issuing to the Comptroller of Water Rights. See page 8.
- Surveillance activities were generally completed to plan. A new feature will be added to Dam Safety's Inspection App to notify Dam Safety Engineers of scheduled inspections that have not been completed in sufficient time for corrective action to be taken. See pages 9-10.
- Civil maintenance on Dam Safety and Generation assets was completed fully to plan in F2022. A total of 74 spillway gate maintenance work orders were completed through F2022 resulting in a net decrease of 11 in the outstanding work inventory over the course of the year, continuing the downward trend from F2021. See pages 11-14.
- The Dam Safety Investigation of seismic resistance of the spillway at WAC Bennett Dam was completed. No significant deficiencies were found, and two existing issues in the database regarding potential deficiencies of the spillway following the Maximum Design Earthquake will be reviewed and updated or closed, as appropriate. See page 18.


**Presenter:** Bob Schubak, Director, Dam Safety

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# Dam Safety Quarterly Report

## Dam Safety Program Dashboard

The following dashboard provides an overview of the status of the Dam Safety Program. "Traffic lights" provide a qualitative indication of the status of each of five elements of the Program and trend arrows identify whether the status is improving, deteriorating or unchanged. As referenced, these indicators are supported by more detailed metrics and narratives in the report.

### Risk Profile and Issues Management

- **Vulnerability Index (pp. 3-5):** The aggregated Vulnerability Index was reduced by 46.4 through Q4 and by 60.5 (18 percent) through F2022.
- **Program Non-Conformances (p. 6):** The total number of non-conformances was reduced by 42 through Q4 and by 52 (12 percent) through F2022.
- **New and Current Issues (p. 7):** There were no new issues identified in F2022 Q4. Issues from previous quarters' reports are all under active management or closed.

### Regulatory Compliance

- **Operation, Maintenance and Surveillance Manual Updates (p. 8):** All seven Manual updates scheduled for F2022 were completed.
- **Dam Safety Reviews (p. 8):** Neither of the two planned Dam Safety Review reports were completed. Both reports were held in draft for improvements before issuing to the Comptroller of Water Rights.

### Surveillance

- **Dam Inspections (pp. 9-10):** 409 of 411 scheduled routine dam inspections were completed in Q4. Formal dam inspections and reporting through the fiscal year were completed fully to plan.
- **Reservoir Slopes (p. 10):** Reservoir slopes inspections scheduled for F2022 were completed fully to plan. 16 of 17 reports were completed with one pending completion early in F2023.

### Maintenance and Testing

- **Civil Maintenance (pp. 11-12):** All planned condition-based and preventative maintenance was completed in F2022.
- **Spillway Gates (pp. 12-14):** All 186 scheduled gate tests were completed. Five gates failed to operate on demand. The number of outstanding maintenance work orders decreased by 22 over Q4 and by 11 (7 percent) over the course of the fiscal year.

### Projects and Investigations

- **Capital Projects (pp. 15-17):** Recoating of one penstock at Bridge River 2 is underway and rock debris removal and slope protection work along the four penstocks for Bridge River 1 is due to start in F2023 Q1. A new over-velocity detection system was put into service at Wahleach. A new maintenance / operating gate has been commissioned and put into service on the Coquitlam-Lower Buntzen 1 Tunnel.
- **Deficiency Investigations (p. 18):** The seismic assessment of the spillway at WAC Bennett Dam was completed. No significant deficiencies were found.

**Legend:**

All areas within the Program element are being implemented to a satisfactory level. Minor, isolated issues may exist but are not deemed to be indicative of deteriorating performance.

One or more areas within the Program element exhibit or are at risk of underperformance and are being monitored.

One or more areas within the Program element exhibit unsatisfactory performance and require correction.

Status of the Program element has improved over the quarter.

Status of the Program element was unchanged over the quarter.

Status of the Program element deteriorated over the quarter.

# Dam Safety Quarterly Report

## Risk Profile of BC Hydro's Dams

### Dam Safety Contribution to Enterprise Risk

Dam Safety is assigned a high "risk priority" within BC Hydro's Enterprise Risk report. Please refer to that report for additional details.

### Vulnerability Index Update

Identified physical deficiencies in BC Hydro's dams and the degree of concern that exists with respect to their impact on the integrity and performance of the dam are characterized by the Vulnerability Index. The higher the value of the Vulnerability Index (scale of 0-10), the higher the likelihood of that deficiency leading to poor performance. The Vulnerability Index for each identified issue at each dam site is shown in Figure 1. Vulnerability Indices for the individual deficiencies are aggregated into stacked bars for each dam, and dams are sequenced from left to right in order of increasing downstream consequences per the BC Dam Safety Regulation. 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.

Notable changes in Vulnerability Index in F2022 Q4 are described below and identified in Figure 1.

1. An overall ***reduction*** of 51.16 (Spillway Reliability deficiencies) across the system.
   A new methodology for evaluating the Vulnerability Index for operational reliability of spillway gate systems that makes direct use of monthly gate testing results was piloted at Ruskin Dam in F2022 Q1 and was applied across the remainder of the system in Q4. See "Appendix – Vulnerability Index for Spillway Reliability Deficiencies" for details.

2. ***Additions*** (Spillway Reliability deficiencies) of 5.9 at Terzaghi Dam, 4.4 at Hugh Keenleyside Dam, and 5.9 at Ruskin Dam.
   Individual gates have been taken out of service or subjected to operating restrictions relating to observed physical deficiencies. A prototype approach for evaluating the Vulnerability Index has been applied and is described in "Appendix – Vulnerability Index for Spillway Reliability Deficiencies".

3. An overall ***reduction*** of 0.29 (Potential Unusual deficiency) at **Puntledge Dam**.
   Stability calculations were updated as part of the last Dam Safety Review in 2021. This has resulted in two Potential Unusual deficiencies in the stability of dam components being resolved and the confirmation of three other deficiencies which have been reclassified as Actual Unusual deficiencies.

4. A ***reduction*** of 4.84 (Actual Unusual deficiency) at **Bear Creek Dam**.
   Concerns for erosion at the toe of the dam during high spillway discharges were investigated by Engineering, with findings that significant erosion at the dam toe is not expected and further repair or upgrade to the spillway channel and dam toe is not required.

5. A ***reduction*** of 8.62 (Actual Normal deficiency) at **Falls River Dam**.
   Previous findings that Penstocks 1 and 2 have insufficient structural capacity were revisited. A new structural assessment of the penstocks was performed using industry-appropriate methods and criteria, and both penstocks were assessed to be fit for service.

**6** An ***addition*** of 2.31 (Actual Normal deficiency) at **Lake Buntzen Dam**. The spillway is unable to pass the 1/200 annual exceedance frequency inflow without major damage. This issue has been recharacterized from a previous Non-conformance Information issue.

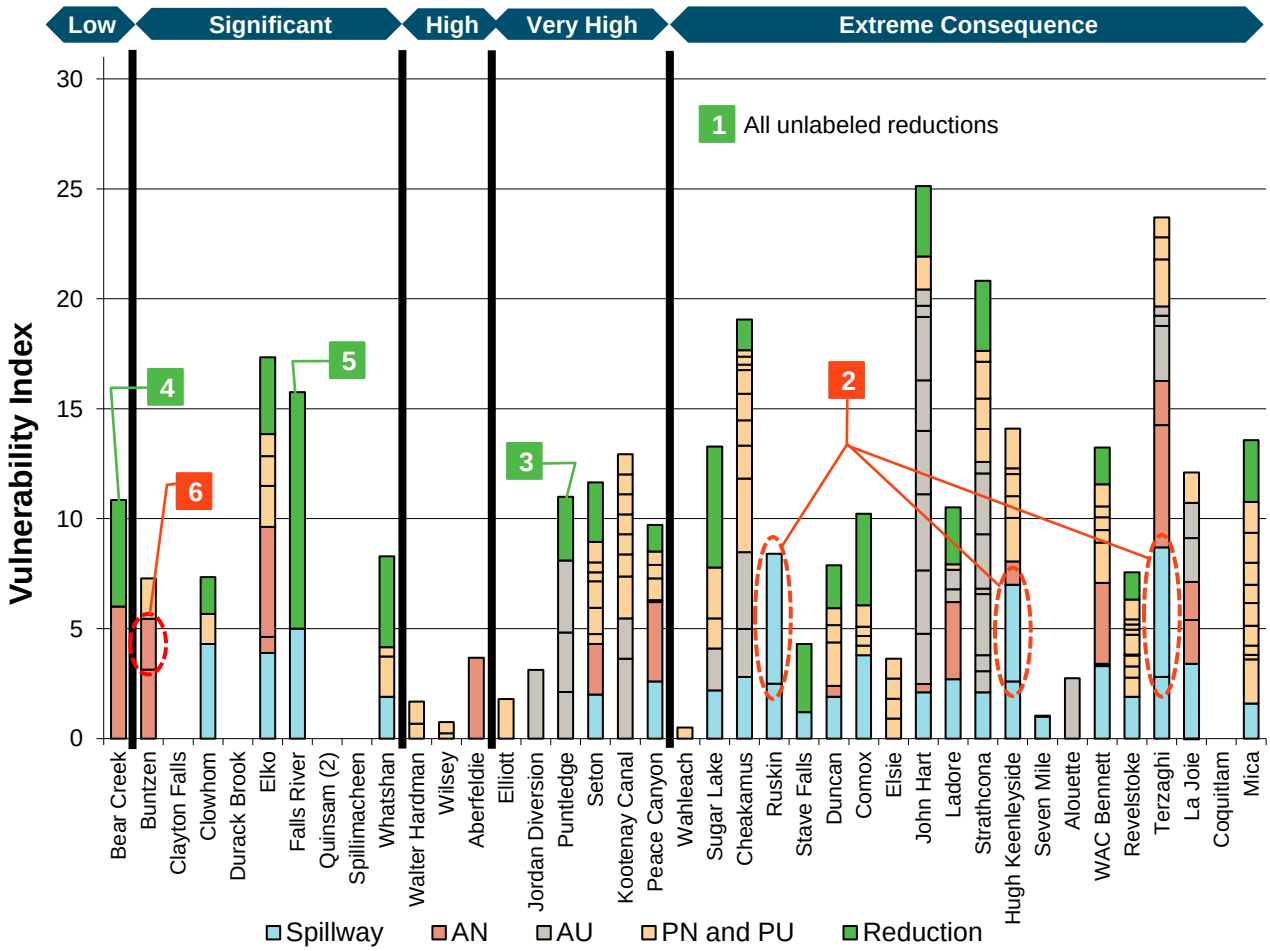


**Figure 1** Dam Safety overall risk profile at the end of F2022 Q4, as represented by the Vulnerability Index. Changes this quarter are indicated by the numbered boxes.

| | |
|---|---|
| **AN** | ***Actual*** deficiency (demonstrated to exist) under ***normal*** load conditions |
| **AU** | ***Actual*** deficiency (demonstrated to exist) under ***unusual*** load conditions |
| **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 operational reliability of the dam's spillway and/or other flood discharge systems |

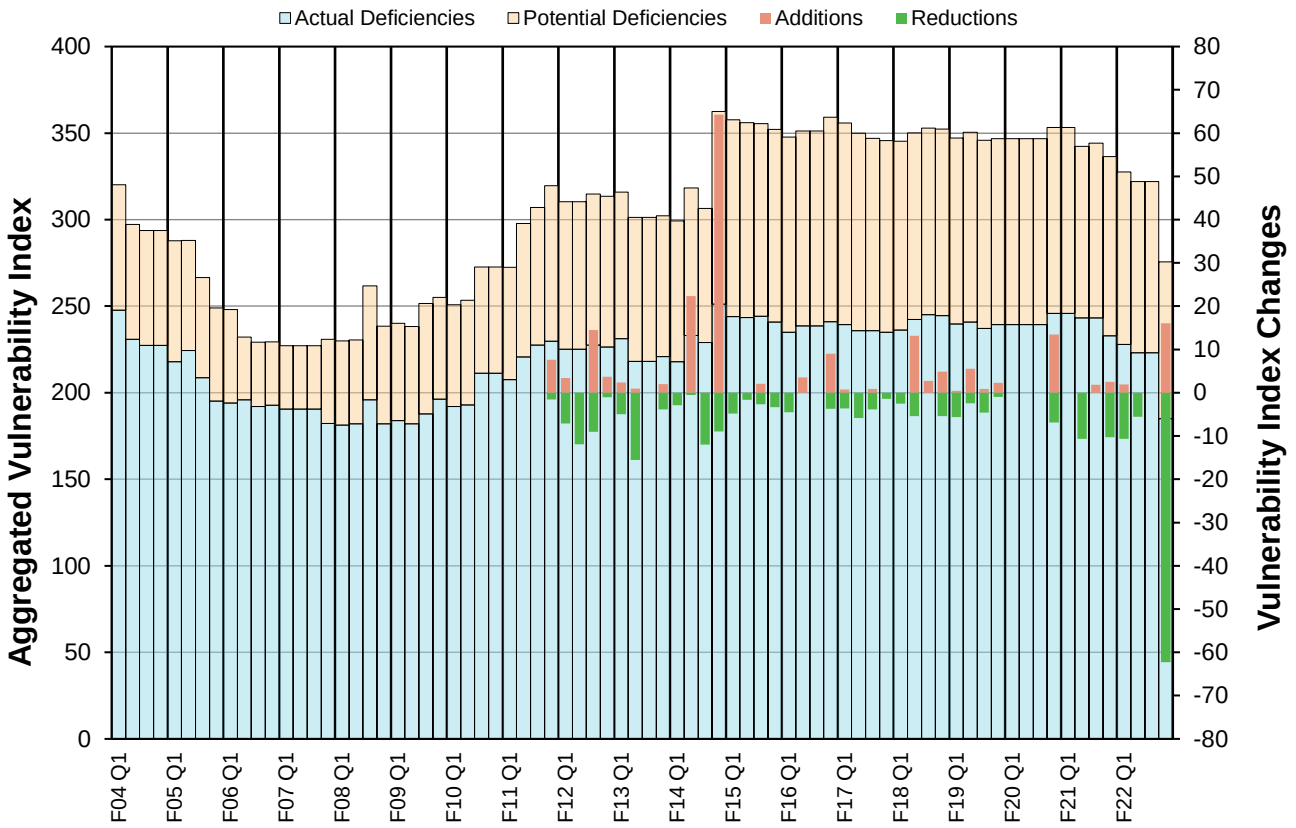


**Figure 2** Historical and forecast changes and trends in the Vulnerability Index aggregated across the BC Hydro system.

Over the last several years, new issues have added to the aggregated Vulnerability Index at a rate of approximately 12 per annum. Therefore, to prevent deterioration of the overall risk position, reductions in Vulnerability Index through resolved issues should occur at the same pace or faster. Table 1 below confirms that this is presently the case and that Vulnerability Index reductions have far exceeded additions. Importantly, this would remain the case even had the methodology for calculating Spillway Reliability deficiencies not been made. Excluding these methodology changes, the Vulnerability Index reductions through F2022 were 27.3 and the additions were only 4.2.

**Table 1** Trends and forecasts for Vulnerability Index changes in F2022.

| | | Actual / Forecast | Target | |
|---|---|---|---|---|
| Dam Safety Vulnerability Index | Reductions - Last 4 quarters | 78.5 | 12 | ✓ |
| | Reductions – Fiscal Year | 78.5 | 12 | ✓ |
| | Additions - Last 4 quarters | 18.0 | | |

## Non-Conformances in the Dam Safety Program

Activities to identity, review, resolve and close non-conformance issues continued in F2022 Q4, with Issues Database review meetings held for 7 dam sites resulting in 36 reviews completed in F2022. This quarter, the Dam Safety Engineers issued a total of 14 sealed memoranda documenting the changes to the Issues Database. As a result, 43 non-conformance issues were completed, and one new issue was identified.

There are currently 383 outstanding non–conformance issues in the database, which is 52 (12 percent) less than at the start of F2022. Since the start of F2019, when resolution of such issues was made a priority within the Dam Safety Program, the number of non-conformance issues has been reduced by approximately 30 percent. Figure 3 shows the continuing progress in reducing the number of non-conformances.

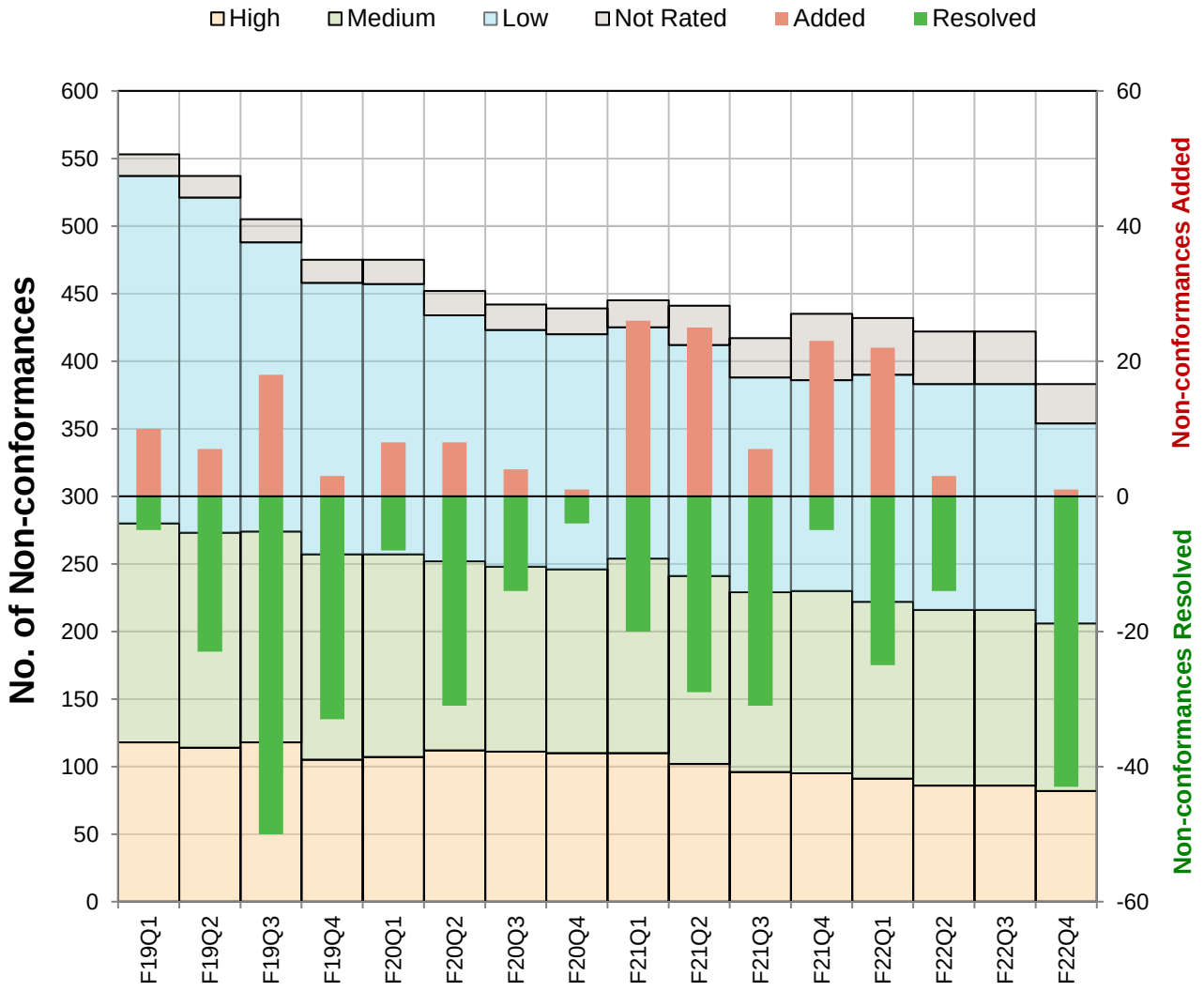


**Figure 3** Changes and trends in the total number of non-conformances (characterized by level of importance) within the Dam Safety Program.

# Dam Safety Quarterly Report

## New Issues

No new dam safety issues were identified in F2022 Q4.

## Update on Existing Issues

### Dam Safety Response to COVID-19

Dam Safety critical work continued through Q4 of F2022 without significant impact. The Dam Safety Engineers and Technologists continued to work and dispatch to dam sites from their homes rather than from their offices to prevent transmission of the virus among Dam Safety personnel. Plans to return to the office on April 11, under the new Flexible Work Model, were developed to facilitate a smooth transition back to the workplace.

## Compliance with Processes and Regulations

### Regulatory Communications – British Columbia Utilities Commission

During Q4, Dam Safety submitted responses to the second rounds of Information Requests for the Fiscal 2023 to Fiscal 2035 Revenue Requirements Application and the Bridge River projects filing.

On March 10, 2022, BC Hydro attended a day-long workshop on the John Hart Dam Seismic Upgrade Project with the Commission's Panel and registered intervenors. BC Hydro and BCUC personnel attended the workshop in person while intervenors attended virtually. Dam Safety, Project Delivery, Engineering Design, and Supply Chain gave presentations on the Campbell River System and the project's objectives, design evolution, risks, and contracting strategies.

As of the date of writing, in F2023 Q1, Round 1 of Information Requests for the John Hart Dam Seismic Upgrade Project had been received and responses submitted on May 13, 2022. In all, there were 585 responses submitted with 168 coordinated through Dam Safety. Dam Safety also responded to a handful of Information Requests (third round) on the Bridge River projects filing.

### Regulatory Communications – Comptroller of Water Rights

The office of the Comptroller of Water Rights and BC Hydro held our annual meeting in Q4. A new format was trialled this year with one session focussed on BC Hydro's dam safety program and two separate sessions focussed on the capital projects requiring regulatory approvals from either the Water Allocation Branch or the Dam Safety Branch. Attendance at the meeting was expanded to include Generation System Operations and Project Delivery. Smaller meetings were also held to discuss the decommissioning approval process to be followed for Wilsey Dam and Durack Brook Dam. The goal of these meetings was to improve communications with the Comptroller of Water Rights office where multiple regulatory approvals are required.

Regulatory Communications with the Provincial Dam Safety Office consisted of the transmission of submittal of two Operation, Maintenance, and Surveillance Manuals, as discussed in the following section. A letter requesting authorization to alter the Site 15A Dam, located at Cartier Bay on Arrow Lake, and also to reclassify the dam as an unregulated dam was submitted in February. An Order authorizing this work was received in March. Approval to carry out invasive investigations at La Joie Dam was requested and granted in February. Authorization to construct a new fish weir at Duncan Dam was also received in February.

# Dam Safety Quarterly Report

## Operation, Maintenance and Surveillance Manuals

Each dam has an Operation, Maintenance and Surveillance Manual ("Manual") for Dam Safety that identifies responsibilities and expectations within BC Hydro for maintaining the safety of the dam. These Manuals are a requirement under the Dam Safety Regulation and must be updated every seven to ten years, depending upon the dam's failure consequences classification.

All seven Manual updates planned for F2022 were completed. The final two Manuals were issued in February (Ladore Dam) and in March (Elsie Dam).

## Dam Safety Reviews

Dam Safety Reviews are independent, systematic reviews and evaluations of all aspects of a dam's physical condition, design, construction, operation, maintenance, processes, and other systems affecting the safety of the dam. Performed by external consultants, they are carried out at minimum intervals of every five to ten years for dams that are classified in accordance with the Dam Safety Regulation as High, Very High, and Extreme consequence dams.

Completion of Dam Safety Reviews is the lone area where the Dam Safety Program did not meet its targets for F2022. Two Dam Safety Review reports were scheduled for completion in F2022. Neither of these reports was issued, however. In both cases, BC Hydro identified that significant revisions to the reports would be required before they would be ready for issuing to the Comptroller. BC Hydro is working with the consultants to get these Dam Safety Reports finalized in the summer of 2022.

We have identified some common themes and encountered some common difficulties in finalizing these and other reports that have been prepared by various consultants. Although we expend much effort in launching the Dam Safety Reviews by providing comprehensive information packages, conducting guided site visits and interviews, and participating in post-visit workshops, there is often a time lag between those intensive, early activities and the receipt of the first draft of the Dam Safety Review report. We have observed that, in some cases, that time lag has led to diminished retention of, and consistency with, the understanding they had developed through those early activities. We are therefore taking steps to increase our level of engagement with the Dam Safety Review engineers during early drafting of their reports and to drive for earlier delivery of the first draft.

**Table 2** Dam Safety Regulation deliverables.

| | Quarter Q4 | | Fiscal Year F2022 | | |
|---|---|---|---|---|---|
| | Actual | Plan | Actual | Plan | |
| Operation, Maintenance and Surveillance Manual Updates | 2 | 2 | 7 | 7 | ✓ |
| Dam Safety Reviews | 0 | 2 | 0 | 2 | ✗ |

## Surveillance

Key activities comprising dam safety surveillance include inspections, monitoring of instrumentation and quality control of data, and characterization of dam performance. Table 3 below provides key metrics regarding these activities, which are described in the following sub-sections of the report.

**Table 3** Dam safety inspections and surveillance activities.

| | | Quarter Q4 | | Fiscal Year F2022 | |
|---|---|---|---|---|---|
| | | Actual | Plan | Actual | Target |
| Routine dam inspections | Completed | 409/411 = 99.5% | 100% | 1635/1644 = 99.5% | 99.5% ✓ |
| | Missed | 2 | | 9 | |
| Formal (annual and semi-annual) dam inspections | Field work completed | 0 | 0 | 71 | 71 ✓ |
| | Reports issued | 36 | 21 | 71 | 71 ✓ |
| Instrumentation data checks | | 195/195 = 100% | 95% | 780/780= 100% | 95% ✓ |
| Reservoir Slopes inspections | Field work completed | 0 | 0 | 17 | 17 ✓ |
| | Reports issued | 12 | 13 | 16 | 17 ✗ |

### Dam Inspections

*Routine Inspections*

Routine weekly and 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.

In Q4, 409 of the 411 scheduled site inspections were completed. The two missed inspections were:

- Terzaghi Dam, week of January 10: The site could not be safely accessed because Mission Mountain and Road 40 were closed due to weather conditions.
- Walter Hardman Dam, week of February 7: The inspector assigned to complete the work was preparing for a larger job that week and simply forgot the inspection was on their work list.

The performance target of 99.5% of scheduled site inspections being completed was just met for F2022. Nevertheless, Dam Safety continues to review the causes of missed inspections (16 misses out of approximately 4900 inspections over the past three years) to identify if there are any common or systemic causes that can be corrected.

Review of the missed inspection at Walter Hardman Dam, for example, is leading to one such improvement. Dam Safety's Data Technology team is adapting the work history function of the Inspection App to generate emails to the Dam Safety Engineers of any dam inspection that have yet

to be completed. The emails will be sent at noon on Thursday of each week in sufficient time for inspectors and their managers to be reminded and to take any necessary corrective actions before the end of the week. The feature will be rolled out for trial in May and, if successful, implemented in June.

*Formal Inspections*

Formal inspections of the dams are regulatory inspections completed by Dam Safety Engineers on a semi-annual or annual frequency, as dictated by each dam's Consequence Classification. These inspections include a comprehensive visual inspection, a review of the monitoring data and an assessment of the condition of the water containment and conveyance structures.

BC Hydro's Dam Safety Engineers issued all 71 inspection reports planned for completion through the course of F2022.

## Instrumentation and Monitoring

Dam Safety Surveillance collects, checks, and assesses about two million data points a month. A vast majority of the data is collected and checked against threshold values automatically by the Automated Data Acquisition System. Even though most of the data is checked automatically it is essential that qualified staff review the data regularly to ensure the systems are functioning as expected. The Dam Safety Technologists in each region regularly check instrumentation data plots for all dams to ensure the Automated Data Acquisition System is functioning as expected, identify any unusual trends, and ensure continued accuracy of the data being for ongoing engineering assessment. They are tasked to perform three such checks per week. All 195 of these checks were completed in Q4 as scheduled.

## Reservoir Slopes

Reservoir Slopes inspections are completed on a frequency ranging from semi-annually to once every 10 years depending on the assessed hazard of the slope. They are typically carried out by the Reservoir Slopes Geologist and the Specialist Dam Safety Engineer for the Upper Columbia Region. The inspections generally consist of a review of all monitoring data and a visual inspection completed from helicopter with boots-on-ground assessment of identified areas of concern.

All 17 reservoir slopes inspections scheduled for F2022 were completed by the end of Q3 despite the challenges of extremely dry conditions on the slopes, active forest fires in the areas to be inspected, and a general lack of helicopter resources throughout the summer. 16 of 17 reservoir slopes inspection reports have been issued in accordance with the plan; the one remaining report will be issued in F2023 Q1. The reservoir slopes inspection reports are not required under the Dam Safety Regulation and the short delay in this one report's completion will have no negative impact on the program or on regulatory compliance.

## Unusual Events or Observations

The Dam Safety On Call Person responded to 89 calls in Q4, which typically includes instrumentation alarms, operational inquiries, operations notifications during high inflows and earthquake notifications. This number of calls and responses is consistent with expectations and past experience. None were sufficiently noteworthy for inclusion in this report.

## Maintenance and Testing

### Civil Maintenance

Civil maintenance on Dam Safety and Generation assets was completed fully to plan in F2022, per Table 4 below. All 31 corrective and condition-based maintenance projects in the plan were completed almost exactly on budget, and 748 of 746 preventative maintenance tasks were completed under budget.

**Table 4** Dam Safety and Generation civil maintenance for F2022.

| | | Quarter Q4 | | Fiscal Year F2022 | |
|---|---|---|---|---|---|
| | | Actual | Target | Actual | Target |
| Corrective and Condition-Based Maintenance | Work Orders Completed | 14 | 9 ✓ | 31/31 = 100% | 90% ✓ |
| | Spend ($k) | 595 | 676 | 3,547 | 3,600 |
| Preventative Maintenance | Tasks Completed | 136/24 = 566% | 90% ✓ | 748/746 = 100% | 90% ✓ |

*Corrective and Condition-Based Maintenance*

The Ladore Dam spillway walkway bridge repair was one of the projects completed in Q4. This project was identified just months earlier in the year when the bridge inspections, performed as part of the civil preventative maintenance program, identified significant damage to the concrete abutment supporting one end of the bridge. The walkway bridge was derated at that time until repairs could occur later in the year. Supporting Program and Contracts Management in delivering the work were Generation Stations Civil Engineering, Construction Services and Stations Field Operations. Figure 4 at right shows the repairs in progress, with damaged concrete removed, additional steel reinforcement installed, and surfaces prepared for placement of new concrete.

**Figure 4** Ladore spillway walkway bridge concrete repair.

Other civil maintenance projects completed in Q4 were: Sugar Lake Dam concrete inspection; Elko intake gate and water passage drainage inspection; Puntledge Dam left abutment tree removal; Ladore Dam low level outlet inspection; Seton Dam forebay weir repairs; Seton Canal embankment toe geotechnical repairs and vegetation removal; Ruskin Dam spillway operating gate bird exclusion

and clean up trial; Alouette Dam public safety boom repair and reinstallation; Cheakamus earthfill dam concrete cap moss removal; Seven Mile Dam foundation drain cleaning; Kootenay Canal upstream bank vegetation removal; and Bridge River 2 intake tower telemetry location change.

*Preventative Maintenance*

In F2022, Stations Field Operations and Engineering Services completed 748 civil preventative maintenance work orders against a plan of 746. Program and Contract Management, Stations Field Operations and Engineering Services achieved strong performance in the final two quarters to meet the targets for civil preventative maintenance work in F2022.

## Spillway Gate Testing and Maintenance

*Spillway Gate Testing*

Table 5 below provides key metrics related to spillway gate testing.

**Table 5** Spillway gate testing results for F2022.

| | | Quarter Q4 | | Fiscal Year F2022 | |
|---|---|---|---|---|---|
| | | Actual | Target | Actual | Target |
| Monthly Tests | Completed | 186/186 = 100% | 100% ✓ | 815/817 = 99.8% | 98% ✓ |
| | Missed | **0** | | **2** | |
| Gates Failing to Operate on Demand during Testing | No. of failures | **5** | | **12** | |
| | Failure rate | 5/186 = 2.7% | | 12/815 = 1.5% | |

During Q4 of F2022, all 186 scheduled gate test operations at 23 sites were completed. In Q4, five gates failed to operate on demand during testing and three gates were removed from service or were subjected to operating restrictions:

- Revelstoke Dam, January 2022 – Spillway Gate Frozen in Place
  One of the two spillway gates failed to operate due to ice binding, which was traced to two failed fuses in the heaters circuit. The fuses were replaced and the gate is now operable. As correction, the maintenance instructions are being updated to include heater checks in the winter months to mitigate the risk of undetected heater failures and future icing events.

- Terzaghi Dam, January 2022 – Low-Level Outlet Gate
  The Low-Level Outlet Gates' Programmable Logic Controllers shut down protectively during cold weather, and Low-Level Outlet Gate 2 lowered, uncommanded, from 14 mm opening to 0.9 mm opening. There were several contributing factors to this uncommanded closure of the gate but more generally the Low-Level Outlet Gates at Terzaghi require upgrades. Low-Level Outlet Gate 1 is unable to open freely, achieving only limited openings from 20 mm to 46 mm, and ***the gate has been put into restricted service***. This deficiency has been entered into the Dam Safety Issues Database (see "Vulnerability Index Update") and is to be remediated in the Terzaghi Low Level Discharge Reliability Improvement that was released in F2022 Q3.

- Hugh Keenleyside, January 2022 – Hoist Rope Kinked
  During annual gate testing, a kink was discovered in the Low Level Outlet Gate 7 hoist rope above water level. This is the third hoist rope with such a problem – the first two were replaced in November 2020 – since they were installed as part of the Keenleyside Dam Gate Reliability Improvement Project approximately ten years ago. ***The gate has been put into restricted service*** and a deficiency has been entered into the Dam Safety Issues Database (see "Vulnerability Index Update") pending hoist rope replacement in the fall of 2022.

- Ruskin Dam, February 2022 – Spillway Gate 3 Hydraulic Oil Leak
  A significant oil leak was discovered and was traced back to one of the two hydraulic cylinders on Spillway Gate 3. The sealing arrangement for a cable leading to a device used to measure gate position had failed, allowing water ingress and hydraulic oil leakage. Unable to sustain sufficient line pressure for operation, ***the gate is out of service*** and a deficiency has been entered into the Dam Safety Issues Database (see "Vulnerability Index Update"). Resolution of this deficiency as a warranty issue is uncertain, and an emergent project is being initiated to correct the deficiency with dispatch while discussions with the equipment supplier continue.

- Peace Canyon, February 2022 – Diesel Generator Room Louver Motor Failure
  Opening of the Diesel Generator louvers is important to prevent overheating of the generator, which has previously led to damage and safety incidents. Following a recent similar incident, a procedure was put in place to have a crew member visually verify the louver opening when the Diesel Generator is locally operated for testing. The louver motor for the Peace Canyon Diesel Generator was found to be malfunctioning and the test was canceled.

### *Spillway Gate Maintenance*

The number of outstanding gate maintenance work orders is shown in the chart in Figure 5. The total number of outstanding work orders decreased from 164 to 142 in F2022 Q4. The number of "high priority" maintenance work orders has increased from 15 to 19. "High priority" maintenance work orders are those where the asset shows moderate to severe signs of deterioration and/or its ability to perform its intended function may be compromised and failure of the asset could lead to loss of reservoir control, albeit with a long intervention time available. The increase of "high priority" maintenance work orders is entirely attributable to Dam Safety's re-assessment of previously identified deficiencies rather than identification of new deficiencies.

24 spillway gate maintenance work orders were completed in Q4 and a total of 74 spillway gate maintenance work orders were completed through F2022. The net result was a decrease of 22 work orders in the outstanding work inventory in Q4 and a decrease of 11 in the outstanding work inventory over the course of Fiscal 2022, continuing the downward trend from F2021.

The Fiscal 2023 annual work plan was finalized and approved in Q4. In coordination with Generation Asset Management a total of $775k was allocated to spillway gate maintenance to further reduce the work inventory during Fiscal 2023. The work plan includes the highest priority work orders, as well as some lower priority work orders at facilities with planned outages to facilitate work planning. In total, 78 work orders were included in the prioritized Fiscal 2023 work plan. An additional 19 work orders are included as in-flight carryover from Fiscal 2022. Programs and Contracts Management has assigned a program manager to oversee this program of work and to work closely with operations to ensure any issues are identified early and that the program as a whole remains on track in Fiscal 2023.

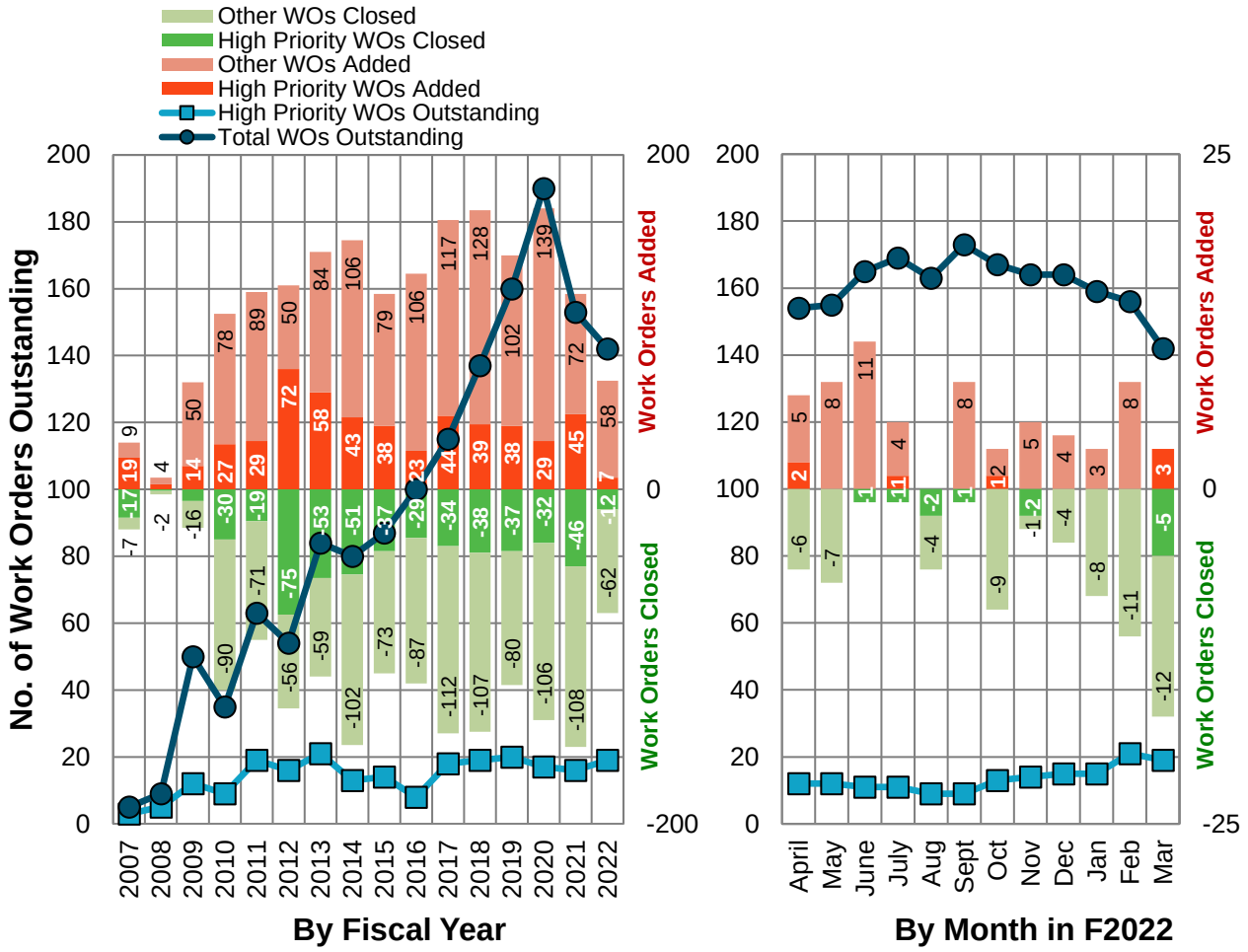


**Figure 5** Number of outstanding corrective and condition-based spillway gate maintenance work orders, new work orders added, and work orders closed as at the end of each previous fiscal year and the end of each month in the current fiscal year.

## 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 Dam Safety Regulation as part of annual 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 the Safety & Emergency Management Quarterly Report, submitted to the Operations, Planning, and Information & Technology Committee, for updates on emergency preparedness and public safety.

## Capital Projects

Summaries of Dam Safety Capital projects are available for reference in the Dam Safety "book" in Diligent. This section of the report describes newly launched projects and provides updates for projects where significant developments occurred or milestones were achieved.

### Bridge River 1 – Penstock Concrete Foundation Refurbishment

During the early stages of the project to recoat the four penstocks at Bridge River 1 it was identified that the visible portions of the penstocks' concrete foundations were damaged by cracking, spalling and other defects, and that the bottoms of the penstocks were covered by rockfall over significant portions of their lengths. See Figure 6 at right. This project was initiated to clear the rock debris, refurbish the penstocks' concrete foundations, and improve rockfall protection measures in advance of the recoating project.

In Q4 the project completed removal of vegetation along the penstocks' alignments in advance of bird nesting. The project has more recently proceeded into Definition / Partial Implementation Phase, within which rock debris removal and slope stabilization is to be undertaken, followed by detailed foundation inspections and preparation of refurbishment designs. This work is scheduled to be completed through 2022 and 2023, and foundation refurbishments are scheduled to occur in 2024.

### Bridge River 2 – Strip and Recoat Penstock 2 Interior

One of two penstocks for Bridge River 2 Generating Station, Penstock 2 conveys water to Generating Units 7 and 8. The exteriors of the Bridge River 2 penstocks were recoated in 2008 through 2011 and the interior of Penstock 1 was recoated in 2019. This project is to recoat the interior of Penstock 2, the adjacent tunnel liner, and the Units 7 and 8 scroll cases. In Q4 the Contractor mobilized to site and the project is on track to complete this recoating by the end of June 2022.

**Figure 6** Bridge River 1 penstocks: (top) accumulated rockfall covering foundations and portions of penstock; (middle and bottom) damaged penstock foundations.

## Coquitlam / Lower Buntzen 1 – Tunnel Gates Refurbishment

The Coquitlam-Buntzen Tunnel conveys water from Coquitlam Lake Reservoir to Buntzen Lake Reservoir for generation at Lower Buntzen 1 Generating Station. The tunnel plays an important role in regulating the discharge of water from the Coquitlam Lake Reservoir and, consequently, the elevation of Coquitlam Lake Reservoir, the flow of water down the Coquitlam River during periods of high inflow, and the flow of water into Buntzen Lake for generation and for protection of the Lower Buntzen 1 Generating Station in event of that station being offline.

The tunnel's inlet at Coquitlam Lake was built in 1903 and modified in 1911. The facility is constructed in natural rock with all gates installed in fixed locations 27 metres underground. The tunnel's single maintenance gate was partially refurbished in 1955. The two operating gates downstream of the maintenance gate are original from 1911 and have a history of mechanical problems resulting in reliability issues, particularly at high reservoir elevations.

This project's scope is to construct a new maintenance gate and gate wall in a new location between the original maintenance gate and the operating gates and to replace the original operating gates in refurbished gate slots with new hoists, controls, and power supplies.

The new maintenance gate was commissioned in Q4 and is now being used temporarily as an operating gate. This operating function was planned to support implementation and was accounted for in the gate's design. The original operating gates were also removed and dismantling of the original guides and hoists was commenced. Installation of the new operating gates is scheduled to be completed this summer.

Following commissioning, the new maintenance gate is considered to be substantially more reliable than the now-dismantled original operating gates. Nevertheless, there is an interim risk arising from there being only one operational gate in place until the two intake operating gates are installed and commissioned. Dam Safety and the Project have instituted an Interim Dam Safety Risk Management Plan, comprising mitigations through various operational measures, to cover this period.

**Figure 7** Downstream side of old intake maintenance gate (left) and upstream side of new intake maintenance gate (right).

# Dam Safety Quarterly Report

## La Joie – Intake Operating Gate and Follower Replacement

The F2021 Q4 quarterly report described the March 23, 2021 failure of the lifting mechanism of Intake Operating Gate 4, one of two intake operating gates on the upstream end of the dam's low level outlet that is referred to as the North Conduit. Subsequent inspections identified that the gate body and the mechanism components called "followers" were in very poor condition or, in the case of some of the followers, a failed state. Since then, the North Conduit has been operated with Gate 4 open (gate dogged at deck level) and Gate 3 closed to prevent a similar failure.

This project was initiated in Q1 to replace the followers on all four gates, to replace North Conduit's Intake Operating Gates 3 and 4 and refurbish the gate guides. This project will ensure that the gates can reliably manage the Downton Reservoir levels for the next 15 years until completion of the La Joie Dam Improvement Project.

During Q4, the Intake Operating Gate 4 followers were delivered to site (see Figure 8 at right) and were successfully installed on April 29, 2022. The original Gate 4 has been returned to service until the new gate can be fabricated and installed.

**Figure 8** Delivery of new Intake Operating Gate 4 followers to intake deck at La Joie Dam.

## Wahleach Dam – Replace Intake Over-Velocity System

The Wahleach over-velocity detection system is an important system in managing safe flows through the power tunnel and into the penstock and generating station. In the event of a rupture of the penstock, the over-velocity detection system would command a closure of the tunnel's intake gate and mitigate the discharge of water from Jones lake onto the slope above Wahleach Generating Station, Highway 1, and the main Canadian National Railway line. Conversely, the system must not spuriously command gate closures that would rapidly dewater the tunnel and penstock and potentially damage them.

The old mechanical system was unreliable and led to spurious intake gate closures and was becoming increasingly difficult to calibrate and maintain. This project was advanced to replace the original mechanical over-velocity system with a system using the Acoustic Scintillation Method technology that was piloted on the Bridge River 1 Penstock Leak Detection System in 2013-2015. In Q4 the new Wahleach over-velocity detection system was successfully placed into service.

**Figure 9** New over velocity detection system at Wahleach on its mounting frame.

# Dam Safety Quarterly Report

## Dam Safety Investigations

Dam Safety Investigation Projects ("Investigations") are generally performed to either refine knowledge regarding potential issues or non-conformances of information recorded in the Dam Safety Issue Database or to perform precursor work for planned capital upgrade projects. This section provides descriptions of newly launched Investigations and updates for those Investigations where significant developments have occurred or where milestones were achieved.

### WAC Bennett Dam – GMS Spillway Seismic Assessment

This Investigation was initiated to assess the seismic performance and post-seismic operability of WAC Bennett Dam's spillway headworks, chute, and flip bucket after a Maximum Design Earthquake and, where required, to provide an initial range of potential retrofit concepts for select components. The work was substantially completed in F2021 Q4 and draft reports were submitted by the engineering consultant performing the assessment to BC Hydro. As was reported in the F2021 Q4 Dam Safety Quarterly Report, the results of the assessment show that the spillway structures meet Canadian Dam Association guidelines for acceptance criteria under usual and extreme load combinations, including earthquake and flood. No significant deficiencies were identified.

In Q4 of F2022, the Investigation was completed with all reports having been finalized, sealed, and issued. With receipt of these final sealed reports now in hand, two existing issues in the database regarding potential deficiencies of the spillway following the Maximum Design Earthquake will be reviewed and updated or closed, as appropriate.

## Appendix – Vulnerability Index for Spillway Reliability Deficiencies

In Q4 of F2022, all spillway reliability deficiencies on BC Hydro dams were sub-characterized as "gate reliability" deficiencies and "gate serviceability" deficiencies, and their Vulnerability Indices re-rated according to two new schemes that are objective, transparent, and repeatable, and are better aligned to the method used to rate other deficiencies. These new characterizations and rating schemes are described below.

### Gate Reliability Deficiencies

Previously, gate reliability deficiencies were subjectively rated based on an assessment of missing or deemed inadequate design features. On completion of the Ruskin Dam spillway gate replacements, a new rating scheme was developed, piloted on assessing the newly commissioned Ruskin gates, and described in the F2022 Q1 Dam Safety Quarterly Report that was submitted to the Capital Projects Committee.

The new methodology for evaluating the Vulnerability Index for operational reliability of spillway gate systems makes direct use of monthly gate testing results. The "Magnitude of the Gap" is the difference between the "Actual Rate of Gate Failure on Demand" and the "Target Rate of Gate Failure on Demand" of 1 failure per 10,000 demands, which is based on BC Hydro's "Reliability Principles for Flood Discharge Gate Systems". If, for example, a gate at a facility fails to operate once in every 50 tests, then the "Magnitude of the Gap" is

$$1/50 – 1/10{,}000 = 0.0200 – 0.0001 = 0.0199$$

and the calculated Vulnerability Index is 2.71.

Where gate systems have yet to record a failed test, such as the newly upgraded and recommissioned gates system at WAC Bennett Dam, the calculation is performed assuming that the next test will result in a failure. Therefore, for WAC Bennett Dam, rather than calculating the Vulnerability Index on the basis of zero failures on 26 recorded tests, the calculation is performed assuming one failure on 27 tests.

This new methodology is simple, repeatable, and reflects the common condition that newly commissioned gate systems are initially less reliable than more mature (well-exercised) systems, often described by the so-called "bathtub curve".

To this last point, the new spillway gates at Ruskin serve as an example. In Q1, the testing statistics led to a calculated Vulnerability Index of 2.0 for those gates; the non-zero value reflecting that the gates were new, not welled "worked in", and potentially subject to failures due to design or workmanship defects as many new systems are. In February 2022, a significant oil leak was discovered and was traced back to one of the two hydraulic cylinders on a spillway gate. Specifically, the sealing arrangement for the linear transducer cable had failed, and the gate had to be removed from service. The consequent test failure resulted in the gate reliability Vulnerability Index being recalculated upward to 2.5, and the gate being out of service has led to a deficiency under the new "gate serviceability" sub-characterization, described below.

### Gate Serviceability Deficiencies

The Dam Safety Issues database must clearly identify and prioritise deficiencies that place spillway gates and other reservoir discharge devices out of service or in restricted service. For such a "gate

serviceability" deficiency, the Vulnerability Index is calculated on the basis of loss in overall discharge capacity. In these prototype calculations, all discharge outlets are assumed to have equal individual discharge capacities. For example, one of five gates out of service therefore leads to a calculated Magnitude of the Gap of 1/5 = 0.2 and a Vulnerability Index of 5.8. The relatively large Vulnerability Indices that arise from this method are deliberate, serving to prioritise the prompt resolution of the deficiency and removal of operational restriction and/or return to service.

Figure A.1, below, shows a comparison of the Vulnerability Indices related to spillway reliability deficiencies before (Q3 – in grey) and after (Q4 – in light blue) these changes in methodology. Aside from the general reduction in Vulnerability Indices related to gate reliability deficiencies, the most noticeable change is the salience of Vulnerability Indices related to gate serviceability deficiencies. The gates that are out of service or operationally restricted at Ruskin, High Keenleyside and Terzaghi stand out, and the new methodology more clearly identifies the priorities to effect repairs to these gates.

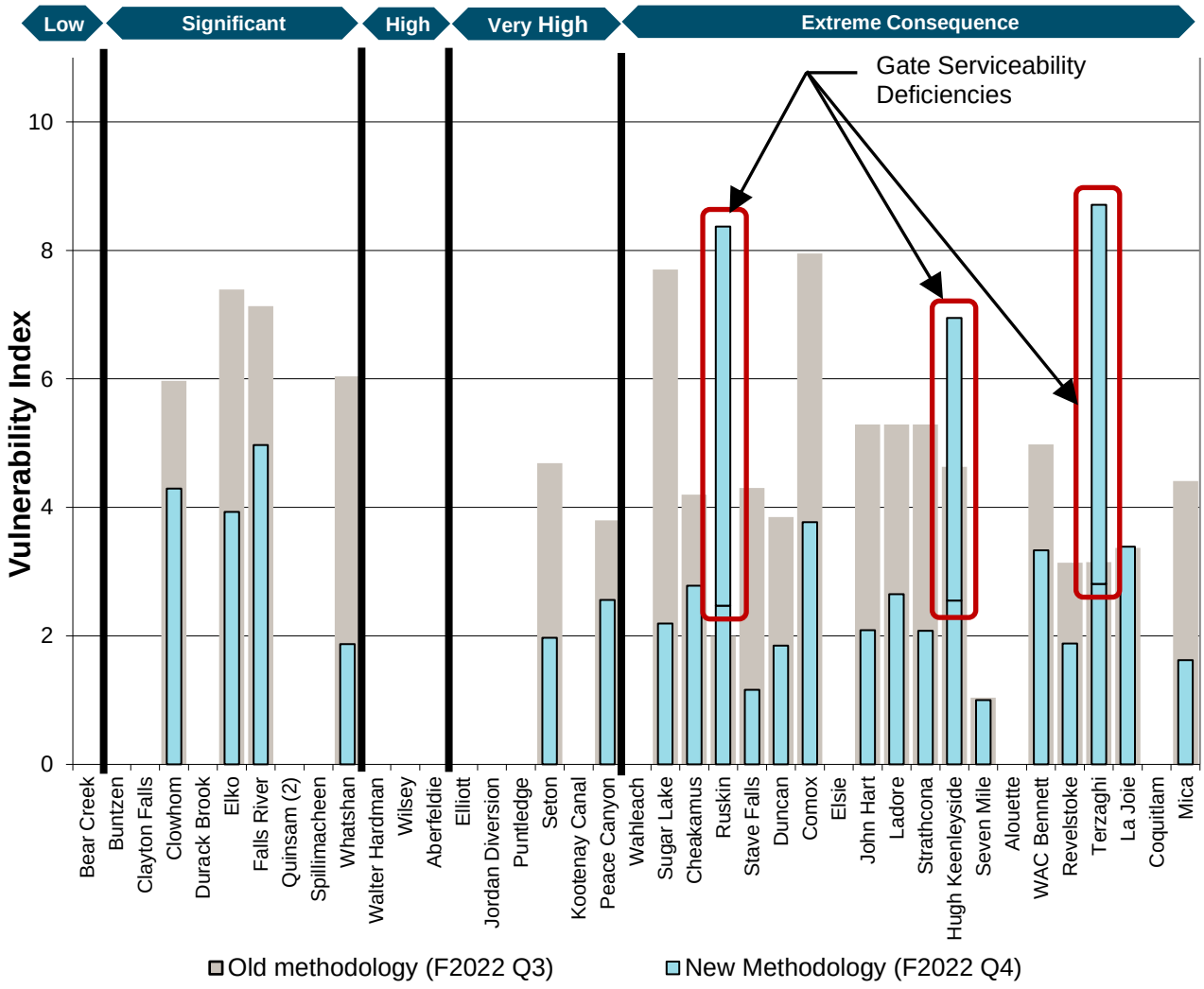


**Figure A.1** Comparison of spillway reliability deficiency Vulnerability Indices before and after the methodology changes.