BC Hydro
Power smart

Discussion/Information

Board briefing – DAM SAFETY QUARTERLY REPORT

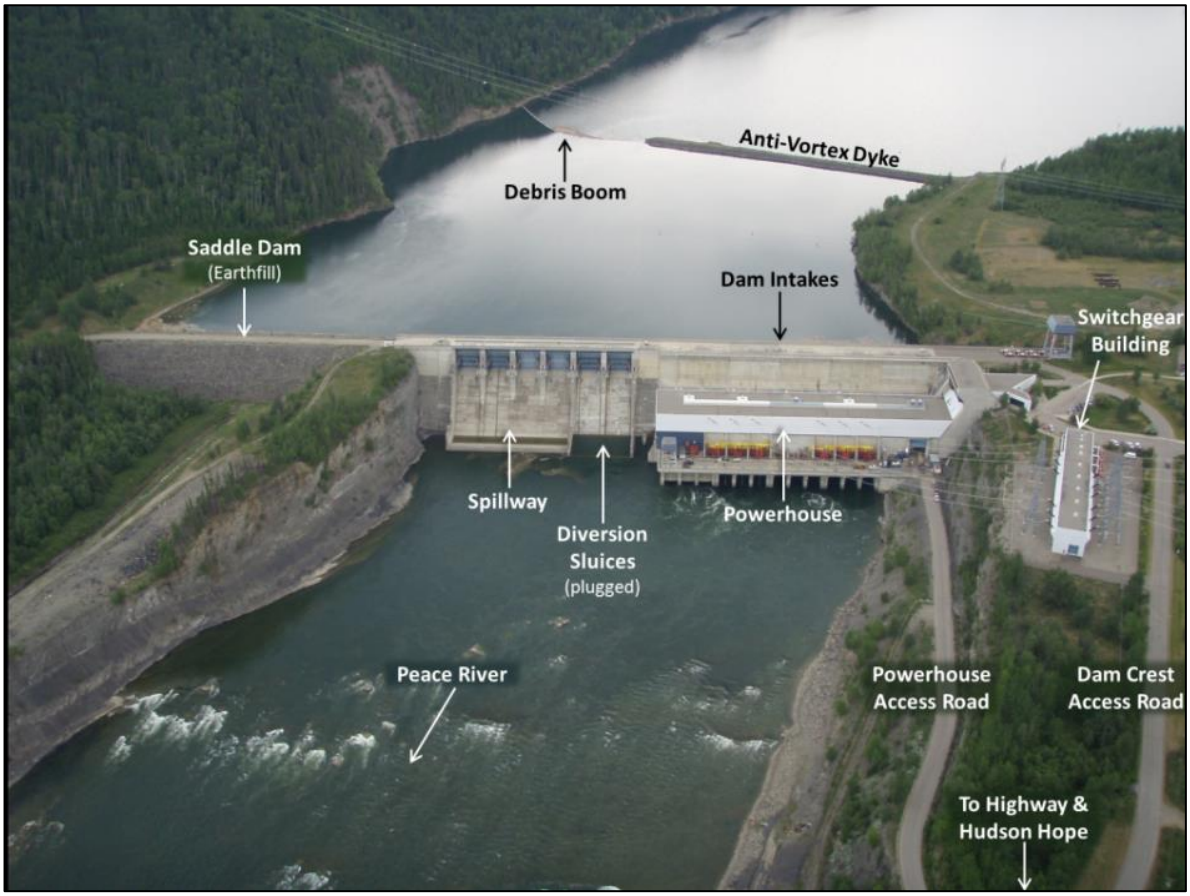
Executive Summary

The purpose of this report is to update the Capital Projects Committee of the Board of Directors on key dam risk management activities during the period from October 1, 2016 to December 30, 2016, 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 the risk profile this quarter due to completion of the WAC Bennett spillway chute upgrades and a reassessment of seismic deficiencies at Terzaghi Dam.

Quarterly Featured Damsite – Peace Canyon Dam

The Peace Canyon project was completed in 1980 and consists of a four-unit 700MW power plant located directly downstream of a concrete gravity dam. The dam consists of an intake section on the left and a spillway with six radial gated bays and flip buckets on the right. An embankment saddle dam is located on the right abutment.



The dam is located on the Peace River 6 kilometres upstream of Hudson's Hope, BC, and 22 kilometres downstream of W.A.C. Bennett Dam. The Peace Canyon Reservoir (Dinosaur Lake) extends to the tailrace of the G.M. Shrum powerhouse at the WAC Bennett Dam.

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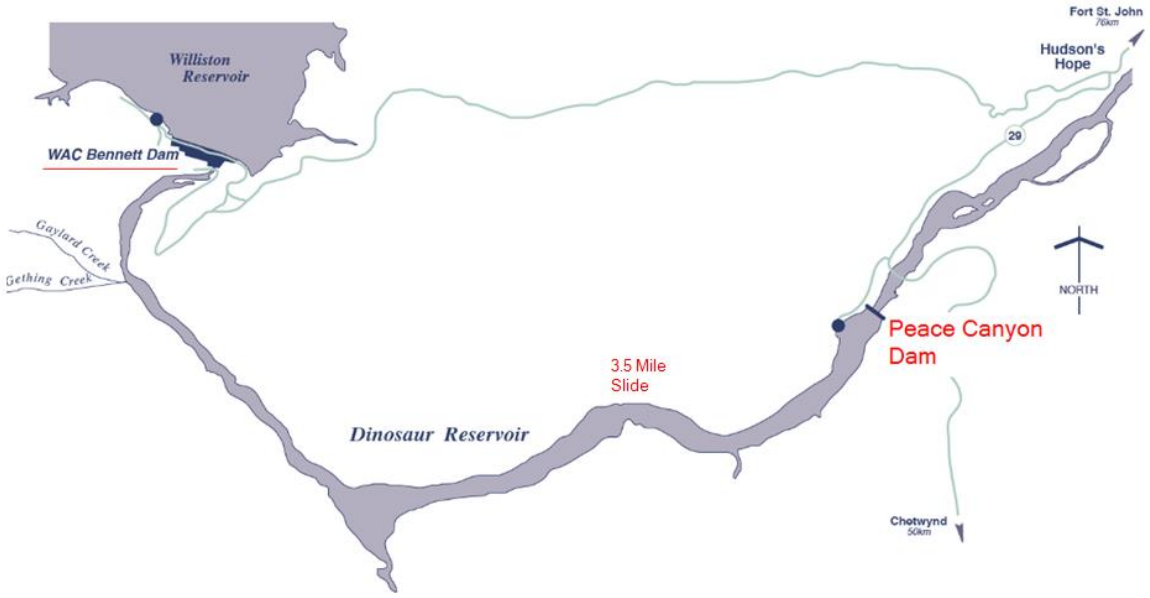

Vulnerabilities

Static Stability

The Peace Canyon Dam is founded on bedrock containing relatively weak bedding planes, which govern the stability of the gravity structures. The presence of weak bedding planes at foundation level was not recognized until during construction, and resulted in a number of design changes. However the dam stability under normal loading remains less than the industry norm and relies on active pumping foundation drainage to reach a Factor of Safety against sliding of 1.5. The Factor of Safety reduces to 1.0 with drains at about 50% efficiency. As such, the drainage gallery pumping system is documented as dam safety critical equipment.

Seismic Stability

The dam was designed for a peak ground acceleration of 0.1 g, which relates to a 1/4,200 year annual exceedance probability under the 2012 updated seismic hazard. Based on the current Very High Consequence Classification of the Peace Canyon Dam, the expected Maximum Design Earthquake ground motion would have an annual exceedance probability of 1/10,000, in accordance with the CDA Guidelines. Such an event has a peak horizontal ground acceleration of 0.17 g. Once Site C Dam is constructed, the consequence classification of the Peace Canyon Dam will likely be reduced from Very High to High, with a corresponding reduction in expected seismic withstand.

The 2015 Spillway Investigation Report concluded that the post-earthquake stability of the spillway is deficient with respect to Canadian Dam Association expectations due mainly to the assumed post-earthquake drain efficiency. A sliding factor of safety of between 0.7 and 0.8 is calculated, whereas a minimum of 1.1 is expected under guidelines. This deficiency will be considered in view of the likely future reclassification of the dam, and the risk profile will be updated accordingly.

Spillway Toe Scour

Weak rock foundation bedding planes are widespread and continuous in the spillway area of the Peace Canyon Dam. During design, hydraulic studies had indicated that scour hole development could be expected to extend about 30 metres deep. A 1985 Investigation concluded that, should this theoretical depth of scour develop, no remedial measures involving strengthening were required for the sliding safety of the spillway, provided a high drain efficiency was maintained. However, as noted above, survey of the plunge pool to check on the development of scour is required after spilling, based on duration and flow.

Flow Imbalance

The inflow at Peace Canyon Dam is regulated by the WAC Bennett Dam with limited short-term storage provided by Dinosaur Lake reservoir and is essentially operated as a run-or-river facility. As a result of the limited storage, the facility is vulnerable to flow imbalance situations (inflows much greater than outflows) which could lead to overtopping of the spillway gates and overtopping and breach of the earthfill saddle dam. This situation will never occur as long as the autospill function of the spillway gate system operates as intended. However if the autospill function fails, the spillway gates could be overtopped in 30 minutes (rendering them likely inoperable) followed by the overtopping and breach of the earthfill saddle dam 4.5 hours later. The autospill system will be upgraded in a future project. A protocol has been added to Generation Operating Orders, whereby all GM Shrum generating units will be shut down if Dinosaur Lake Reservoir has increased to autospill actuation level but no direct evidence of autospill actuation has been received.

3.5 Mile Slide

The 3.5 Mile Slide is an overburden and bedrock slide located on the left bank of Dinosaur Lake about 6 kilometres upstream of the dam. The surface of the slide mass exhibits many signs of current movement such as cracks, scarps, ridges and tilted and fallen trees. The area of the slope currently moving is approximately 250 metres along the reservoir and extending approximately 200 metres up the reservoir slope, with a surface area of about 50,000 square metres. The wave that would be produced by a slide represents a hazard to the public and also to the spillway equipment, although the dam itself would not be overtopped. The slide is being monitored on a regular basis.

Update on Other Major Dams

Mica Dam

A 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. The work will provide a good understanding of the current condition of the dam as well as a set of monitoring and response systems that can be utilized for dam safety management decisions and activities.

Work continued in Q3 on development of a comprehensive three-dimensional computer model of the foundation. This is the first step in a complete design review to be undertaken over the next 3-5 years. The draft report by the Expert Engineering Panel covering their first meeting (held in Q2) has been internally reviewed and sent back for some further clarifications. In particular, the scope and extent of the recommended laboratory testing remains in question.

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Revelstoke Dam

The final remaining project work addressing the Marble Shear Block is nearing completion. The installation of two new in-place inclinometers in the Marble Shear Block was completed in Q3. The LiDAR survey will be carried out in Q4.

The Project construction report for the Left Bank instrumentation was completed in Q3, and project completion documentation is targeted for completion by Q4, pending resource availability.

WAC Bennett Dam

There are five ongoing dam safety projects:

Condition of the spillway (deterioration of the spillway chute concrete surface)

The construction work on the sloping part of the spillway chute has been successfully completed. In addition, remaining minor repairs to the flat part of the chute were also completed. With the completion of the construction work, the spillway chute was returned to service. Work will continue into Q4 to finalize the construction report, including the record drawings.

Spillway gate reliability

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

Long-term performance of the dam core

The overall project objective is to better understand the current condition and behaviour of the dam and to provide improved monitoring and response systems. Work in Q3 continued with:

- Incorporating the comments received from the Expert Engineering Panel into the WAC Bennett Dam performance assessment report,
- Continuing with the development for the 3 Dimensional CAD Model of the earthfill dam and
- Developing high level plans for the next 3 years for funding approval.

Casing Upgrades

This project was initiated to address the leaky open casings in the core, while retaining their usefulness where applicable. In Q3, the contractor was successful in unplugging the cross-arm casing by over-reaming the seismic hammer which then fell to the bottom of the casing. The plan is to grout up the bottom of the casing in 2017 and retain the use of the cross-arm casing for future geophysical testing, pending the development of a seismic hammer small enough for use.

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

The contractor mobilized to site in Q2. Work progressed in Q3 with upgrades of the access road to the quarry site and the production of rock at the quarry. Some issues are being encountered with lower than expected yields during cold-weather blasting, and work is underway to address these.

Ruskin Dam

Work continued In Q3 on development of a two dimensional finite element model of the dam and its verification, for use in the assessment of additional anchors that may be required to stabilize the structure during an extreme seismic event.

In Q3, new Gates 3 and 4 were completed and are undergoing testing/commissioning. Plans are underway to subsequently move the bulkhead in preparation for the next phase of construction.

The Advisory Board meeting was held in Q3, and the Board members were updated on the finite element analysis results and on the planned/completed upgrades. A draft report was received from the Advisory Board, and this is currently under internal review.

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 is given in a Board Briefing document attached to this report. Recent and ongoing work at the three sites is as follows:

Strathcona Dam

Work continued in the conceptual phase on the design of the Low Level Outlet. A leading alternative has been identified on the right abutment, and includes combining spillway and low level outlet functionality, which will make it possible to significantly reduce the level of effort in upgrading the current spillway for post-seismic operability.

Ladore Dam

A second draft of the conceptual design report for the spillway seismic upgrades was submitted for review. Preparation of the feasibility design plan is in progress.

John Hart Dam

A field investigations program was initiated in Q3 to obtain additional soils information required to improve stability models, as was suggested by the Advisory Board. This information is required to develop the upstream remediation options at the Middle Earthfill Dam.

Salmon River Diversion

The Salmon Diversion Dam and Canal divert water, when available and/or required, from the Salmon River Headpond into the Lower Campbell Lake Reservoir. The Diversion Dam is a Low Consequence rockfill timber crib dam. The dam has deteriorated over the last several years, and it is now considered to be in Fair to Poor condition. Operation of the diversion canal is limited in capacity because of the poor condition of the concrete lining. Both upstream and downstream fish passage facilities perform poorly, and BC Hydro has previously committed to improving fish passage at this site. A project was initiated to address the fish passage and other issues at this site, but by the end of Definition phase, the alternative of refurbishing the facility was deemed not viable on the basis of marginal economic benefit and impact of maintaining an ongoing environmental footprint. Thus, a new project has been initiated to decommission the dam and reinstate natural flow and fish passage. Application to the BCUC is scheduled for February 2017 and dependent on approvals, Implementation is scheduled for this coming summer.

GATE MAINTENANCE AND TESTING

As of the end of November 2016, 61 scheduled gate tests at 23 sites were carried out during the Quarter. One gate system failed to operate on demand during testing. In seven other cases, gates

operated on demand; however certain equipment malfunctioned or was found to be in unacceptable condition.

Operational restrictions are in place on six out of 111 flood discharge gates due to known deficiencies (increased from five from the previous quarter). Six flood discharge gates are locked out for operational reasons due to the onset of winter conditions (changed from zero from the last quarter). Ruskin continues to operate with two new gates and one original gate.

A total of 29 corrective maintenance issues were identified through ongoing testing and maintenance from September to November 2016. A total of 26 new and previous issues were addressed in the same period, for an increase of three issues overall in this reporting period. There are now 73 corrective maintenance issues outstanding at the end of November 2016, compared to 62 as of one year ago.

CIVIL MAINTENANCE

To date, twenty-one projects are substantially complete. These include penstock inspections and support repairs, La Joie Dam upstream dam face shotcreting and intake inspections, various concrete and joint repairs, vegetation removal, tunnel inspections, a rock trap cleanout and underwater surveys, road repairs and head pond dredging at Wilsey Dam. Six other projects are on track for completion this year, as per the annual plan. Civil maintenance development continues together with Generation Operations.

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. The Dam Safety Plan for Emergency Response following a major earthquake was revised and issued in Q3 following a test of the plan in June.

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

Authorization was requested and received to replace the rip rap on the upstream face of the WAC Bennett Dam. The final design and construction report for the Duncan Dam cut-off wall was also provided in Q3.

How BC Hydro will interpret and apply the revised Dam Safety Regulation has been incorporated into the draft Dam Safety Governance Manual. This has now been finalized, and BC Hydro will submit this portion of the Governance Manual for formal acceptance by the Comptroller of Water Rights in Q4.

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Inspections

As previously noted, road access into Bear Creek Dam is not possible due to rotten wooden bridges and an uncleared landslide. Plans were put in place to access the site by helicopter until further notice. In Q3, two of the four monthly inspections were missed, and Dam Safety is following up with Operations to better the situation going forward.

One weekly inspection was missed this past quarter at four other dams (Seton, Aberfeldie, Keenleyside, and Kootenay Canal) due to lack of staff availability. No two consecutive inspections were missed.

Dam Safety Reviews

Dam Safety Reviews are a regulatory requirement carried out at minimum intervals of every five to 10 years at high, very high and extreme consequence dams. Four Dam Safety Reviews are currently in progress for 2017: Cheakamus, Comox, John Hart and Stave Falls. Site visits took place in Q3.

VULNERABILITY INDEX: UPDATE

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

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

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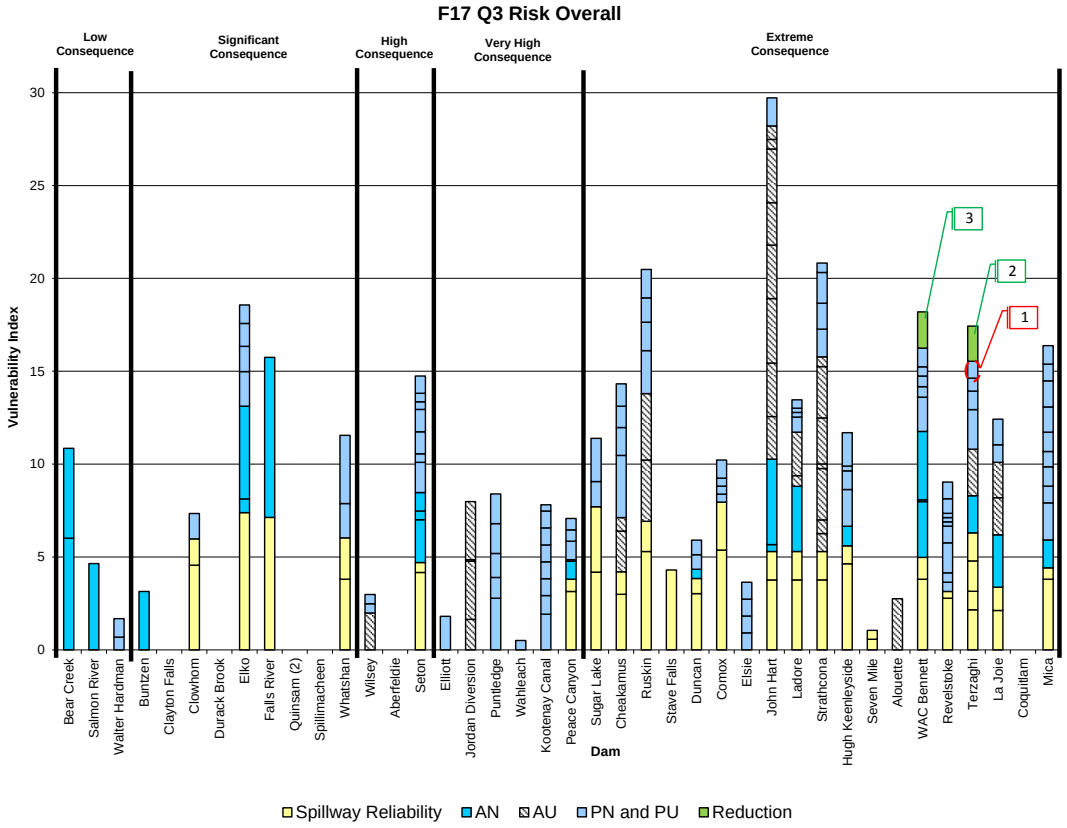
Figure 1 - Dam Safety: Overall Risk Profile



Legend and Summary of Change

Increase in Risk

Reduction Risk

1. ***Terzaghi Dam –*** *The low level outlet may not be operable after seismic events greater than the 1/2,475 event.*
2. ***Terzaghi Dam –*** *The withstand of the earthfill dam under the 1/10,000 event has been reassessed and found to be acceptable.*
3. ***WAC Bennett Dam –*** *The spillway chute repairs have been completed*

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.
- 34 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

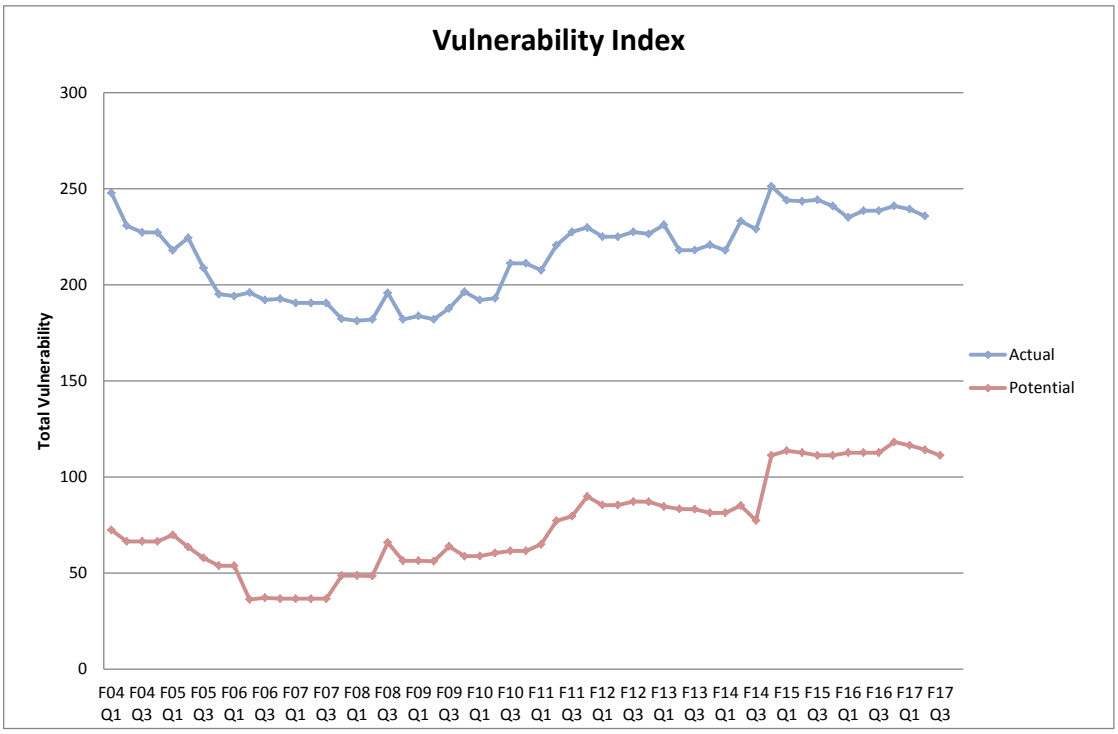


Figure 3 – Change in Total Vulnerability Index Components