newfoundland labrador
hydro
a nalcor energy company

Hydro Place. 500 Columbus Drive.
P.O. Box 12400. St. John's. NL
Canada A1B 4K7
t. 709.737.1400 f. 709.737.1800
www.nlh.nl.ca

March 29, 2019

Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL A1A 5B2

Attention: Ms. Cheryl Blundon
Director of Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: An Application by Newfoundland and Labrador Hydro ("Hydro") for approval of capital expenditures to complete a Level 2 condition assessment on Penstocks 1 and 2, and a report on Penstocks 1, 2, and 3 at the Bay d'Espoir Hydroelectric Generating Station – Bay d'Espoir Condition Assessment and Refurbishment Options for Penstocks No. 1, 2, and 3, Report 2 of 3.

Following significant refurbishment works on Bay d'Espoir Penstocks 1 and 2 during 2016 and 2017, Hydro launched a comprehensive review of Bay d'Espoir Penstocks 1, 2, and 3. The objective of this review was to provide a thorough assessment of the current condition of all three penstocks, validate the condition of the penstocks for current operations, and review the need and options for life extension works for the penstocks.

This review is being completed through three separate reports produced by an external engineering consultant, Hatch Ltd. ("Hatch"), in conjunction with Hydro:

1. Report 1: "Bay d'Espoir Level II Condition Assessment of Penstocks No. 1, 2, and 3," was filed with the Board of Commissioners of Public Utilities (the "Board") on December 17, 2018. It provided a summary of the preliminary findings of the Level II Condition Assessments of Bay d'Espoir Penstocks during 2018, an assessment of the refurbishment work completed in 2016 and 2017, results of the testing and analysis to date, and addressed the readiness of the penstocks for the 2019 operating season;

2. Report 2: "Bay d'Espoir Condition Assessment and Refurbishment Options for Penstocks No. 1, 2, and 3," is attached to this letter. This report provides the final comprehensive condition assessment of Bay d'Espoir Penstocks 1, 2, and 3, including the details of all testing, data collection, and the plan to use a stress multiplier model using data currently being collected. Results of this analysis will be reported separately. The report confirms that major failures or ruptures are unlikely in the next five years. Finally, the

report documents the eight alternatives for life extension of the penstocks, including capital cost estimates with an accuracy of ±50%; and

3. Report 3: "Penstocks No. 1, 2, and 3 Life Extension Options," is planned for completion in the second quarter of 2019. The life extension alternatives reviewed in Report 3 will be the three most viable options selected by Hydro from the alternatives presented in Report 2. Each conceptual review will be accompanied by a capital cost estimate with an accuracy of ±20%. Information regarding recommended maintenance activities will be provided and can be used by Hydro to determine total life cycle costs for each alternative.

The major findings contained in Report 2 are as follows:

- Inspections completed on all three penstocks in 2018 confirmed the refurbishment work completed in 2016 and 2017 is verified as effective with no defects identified in the refurbished welds;
- The current condition of the penstocks is suitable for operation;
- The penstocks are aging assets and show signs of deterioration. Critical life extension work is recommended to commence within the next three to five years; and
- Life extension options vary by capital cost, ranging from a combined total of $44.8 million for the minimum recommended life extension work to a combined total of $144.3 million for substantial penstock replacement.

During 2017 and 2018 the engineering consultant made a number of recommendations for the future of the Bay d'Espoir penstocks, namely:

- A thorough condition assessment should be performed on Penstocks 1, 2, and 3 in 2018;
- Critical life extension work is recommended to commence within the next three to five years; and
- Annual internal inspections should be performed on the penstocks to monitor for any change in the penstock condition until such time as the life extension work is completed.

Hydro has acted upon these recommendations as follows:

- A thorough condition assessment was performed on Penstocks 1, 2, and 3 in 2018;

- With the capital cost and maintenance information provided in Report 3, Hydro will develop total life cycle costs for the three alternatives to determine the preferred approach for ensuring the continued delivery of least cost, reliable power from the Bay d'Espoir plant. These life extension works for the penstocks will be incorporated into Hydro's five-year or 20-year capital plan, as necessary; and

- Annual penstock inspections are scheduled in Hydro's 2019 work plan and will be included in future work plans until the life extension work is complete. The timing is incorporated in its annual planned generation outage schedule.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

SWalsh

Shirley A. Walsh
Senior Legal Counsel, Regulatory
SAW/sk

Encl.

cc: Gerard Hayes, Newfoundland Power
Paul Coxworthy, Stewart McKelvey
Sheryl Nisenbaum, Praxair Canada Inc.
Dennis Browne, Q.C., Browne Fitzgerald Morgan & Avis
Denis Fleming, Cox & Palmer

ecc: Larry Bartlett, Teck Resources Limited
Dean Porter, Poole Althouse

HATCH

Newfoundland and Labrador Hydro

Final Report

For

Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3

H357395-00000-240-066-0002
Rev. 0
March 28, 2019

Newfoundland and Labrador Hydro

Final Report

For

Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3

H357395-00000-240-066-0002
Rev. 0
March 28, 2019

HATCH

Newfoundland and Labrador Hydro
Bay d'Espoir Penstock Condition Assessment 1, 2 and 3
H357395

Engineering Report
Mechanical Engineering
Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3

Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3

H357395-00000-240-066-0002

PROVINCE OF NEWFOUNDLAND
PEG Newfoundland and Labrador PROFESSIONAL ENGINEERS AND GEOSCIENTISTS
PERMIT HOLDER
CLASS "A"
This Permit Allows
MIRC: 01626 HATCH LTD.
To practice Professional Engineering in Newfoundland and Labrador
Permit No. as issued by PEG-NL D0090
which is valid for the year 2019

REGISTERED PROFESSIONAL ENGINEER
PEG Newfoundland and Labrador PROFESSIONAL ENGINEERS AND GEOSCIENTISTS
GREG SAUNDERS
SIGNATURE
Mar. 28, 2019
DATE
NEWFOUNDLAND & LABRADOR

2019-03-28	0	Final	M. Pyne	Z. Kenneally	G. Saunders
DATE	REV.	STATUS	PREPARED BY	CHECKED BY	APPROVED BY

Disclaimer

This document has been prepared for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authorization of Hatch being obtained. Hatch accepts no responsibility or liability for the consequence of this document being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on the document for such other purpose agrees and will by such use or reliance be taken to confirm their agreement to indemnify Hatch for all loss or damage resulting therefrom. Hatch accepts no responsibility or liability for this document to any party other than the person by whom it was commissioned.

To the extent that this report is based on information supplied by other parties, Hatch accepts no liability for any loss or damage suffered by the client, whether through contract or tort, stemming from any conclusions based on data supplied by parties other than Hatch and used by Hatch in preparing this report.

Table of Contents

List of Tables

List of Figures

List of Appendices

Executive Summary

Newfoundland and Labrador Hydro (NL Hydro) engaged Hatch to conduct a condition assessment of Penstocks No. 1, 2, and 3 at the Bay d'Espoir Hydroelectric Generating Facility during the 2018 operating season. Due to the nature of the 2018 outage schedule and NL Hydro's reporting requirements for items such as winter readiness and capital budget applications, the Condition Assessment report will be developed in three phases, as shown below.

- Report 1 – Bay d'Espoir Level II Condition Assessment of Penstocks No. 1, 2 and 3.
- Report 2 – Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3.
- Report 3 – Penstocks No. 1, 2 and 3 Life Extension Options.

All three penstocks were inspected as part of a Level II Condition Assessment. Inspections and data collection included: detailed weld inspection, material testing, 3D scanning and water pressure monitoring.

The weld inspections consisted of, at a minimum, pressure washing, buffing, visually inspecting and magnetic particle inspecting the longitudinal welds at a frequency of 1 in every 10 cans for the total penstock length. The overview of the inspections consists of the following:

- Penstock No. 1 was inspected from August 13 to 24, 2018. Refurbished welds completed in 2016 and 2017 show no sign of additional degradation.
- Penstock No. 2 was inspected from September 17 to 28, 2018. Refurbished welds completed in 2017 show no sign of degradation.
- Penstock No. 3 was inspected from May 14 to June 21, 2018. This was the first detailed inspection carried out and extensive weld metal corrosion and cracking was discovered, similar to what was found during the first inspections of Penstocks No. 1 and No. 2 in 2016 and 2017. Approximately 1027 m (3369 feet) of internal weld refurbishment was completed on Penstock No. 3.

Material samples were removed from Penstock No. 3 to determine the grade of steel and compare with samples removed from Penstock No. 1

Laser scans were completed to create a more accurate 3D model of the penstock geometry. The data showed similar peaking in all three penstocks consequently the FEA model results for Penstock No. 1 can be extrapolated to the similarly constructed Penstock No. 2 and No. 3. This geometric data is also valuable for future use should NL Hydro wish to review the penstocks for geometric changes, such as settlement.

In conjunction with the laser scans, pressure transducers were installed at key locations on all three penstocks and connected to a data logging device to assess any internal pressure transients. Data collection is currently on-going, and this data will be analyzed and compared to data obtained in 2017 on Penstock No. 1. To provide meaningful analysis data collection needs to take place over a longer period of time so trends can be observed. This data collection should continue until a life extension option is implemented for Penstocks No. 1, 2, and 3. Hatch will provide a preliminary commentary based on a three-month data collection. This data and analysis will be presented in a standalone document at a later date, however, this information is not expected to impact any of the findings or recommendations contained in this report.

The penstocks have been in service for approximately 50 years. These are aging assets and as such require regular inspection and maintenance. To ensure the long-term operation of these assets, refurbishment is required. This report outlines various refurbishment options of which a select few will be chosen by Hydro for further analysis by Hatch. This work will be completed in the second quarter of 2019.

Several life extension options were reviewed in this report for the purposes of comparison. However, preliminary estimates suggest full weld refurbishment and application of a corrosion resistant coating would be the best option for the rehabilitation of the penstocks. The preliminary estimates for refurbishment are approximately $14,000,000 to $16,000,000 per penstock.

Based on the current operational history, refurbishments and current operating procedures, it is Hatch's opinion the penstock's current condition will provide uninterrupted service through the 2019 winter season. Hatch recommends annual inspection of the penstocks should continue until a life extension strategy is implemented within the next 3-5 years.

1. Introduction

NL Hydro engaged Hatch to conduct a Level II Condition Assessment of Penstocks No. 1, 2, and 3 at the Bay d'Espoir Hydroelectric Generating Facility during the 2018 operating season. The findings from the condition assessment will ensure the penstocks are in reliable operating condition for the 2019 production season and will assist in verifying potential penstock life extension refurbishments.

The contents of this report build on the initial assessment of the inspections, testing and refurbishments completed to date. Due to the time intensive nature of inspection, data collection, analysis and refurbishment option evaluations this work will be completed in three phases each of which will have a report issued upon its completion. This second Report completes the second phase of the work and provides further detail on each penstock condition in addition to refurbishment options. The following are the three report titles.

- Report 1 – Bay d'Espoir Level II Condition Assessment of Penstocks No. 1, 2 and 3.
- Report 2 – Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3.
- Report 3 – Penstocks No. 1, 2 and 3 Life Extension Options.

The Bay d'Espoir Hydroelectric Generating Facility is comprised of four buried penstocks, three of which are connected to the main powerhouse containing six generating units. Each penstock bifurcates near the powerhouse to feed each unit through separate spherical valves. Units No.1 and No. 2 along with Penstock No. 1 were built in 1967. Units No. 3 and No. 4 along with Penstock No. 2 were built shortly after in 1968. The final addition to Powerhouse No.1 was completed in 1969 and consisted of the installation of generation Units No. 5 and No. 6 as well as Penstock No. 3. The penstocks run approximately 1,200 m (3,900 feet) in length and are constructed from a series of carbon steel cans[1] that vary in length, diameter and thickness.

Penstock No. 1 experienced multiple ruptures during 2016 and 2017 in longitudinal seams in an area upstream of the surge tank. A detailed description of these ruptures can be found in Hatch's "Repair and Failure Investigation" report dated May 17, 2017. These ruptures resulted in multiple inspections in 2016 and 2017 that discovered approximately 950 m (3116 feet) of longitudinal weld seams that had deteriorated primarily due to corrosion and required refurbishment. As Penstock No. 1 and No. 2 are very similar and of the same age Hatch recommended that Penstock No. 2 undergo similar inspections where similar deterioration was discovered resulting in 500 m (1640 feet) of seam refurbishment. As a result, NL Hydro engaged Hatch to complete a failure investigation.

[1] Lengths of penstock that are approximately 2.74 m (9 feet) long and constructed of two hemispheres of rolled plates longitudinally welded together to form a circumference.

Recommendations from the final “Repair and Failure Investigation” report May 17, 2018 for the November 2017 rupture of Penstock No. 1 included further assessment of Penstock No. 1 during the summer of 2018, along with further assessment of Penstock No. 2 and 3 during the next available outage. NL Hydro initiated the 2018 assessments of all three penstocks based upon these recommendations. The purpose of this report is to provide a thorough assessment of the current condition of all three penstocks, provide a preliminary review of various life extension options and to collect data to assist in recommendations for Report 3 “Penstocks No. 1, 2 and 3 Life Extension” to be issued late in the second quarter of 2019.

All three penstocks were inspected as part of a Level II Condition Assessment during the summer of 2018. Penstock No. 1 was inspected from August 13 to 24, 2018, and showed no sign of degradation of previously refurbished weld seams or reinforcing plate fillet welds. However, weld refurbishment was required on a single seam that was not previously inspected. Penstock No. 2 was inspected from September 17 to 28, 2018, and showed no sign of degradation of previously refurbished weld seams. However, there were two weld refurbishments required on seams that were not previously inspected. Penstock No. 3 had not undergone the same inspection regime as Penstock No. 1 and Penstock No. 2. The first detailed inspection of Penstock No. 3 took place from May 14 to June 21, 2018, and similar problems with the longitudinal weld seams, as encountered in Penstock No. 1 and Penstock No. 2, were also found in this penstock. As a result, Penstock No. 3 underwent significant refurbishment prior to return to service in late June 2018.

2. Condition Assessment Methodology

Previous inspections of the penstocks utilized a can numbering based on manhole locations which varied by penstock. As this numbering system was not consistent for all three penstocks, it was not utilized for the Level II condition assessments carried out in 2018. The new numbering system refers to the first can at the intake as Can No. 1 for all penstocks and progresses numerically from the intake structure towards the surge tanks (approximately Can No. 250 to No. 260 depending on penstock) and finally to the powerhouse (Can No. 400).

Due to the length of the penstocks, the number of weld seams and the time available during shutdowns, an inspection methodology was employed that would quickly identify problem areas and provide a comprehensive overview of the overall condition of all three penstocks. All three penstocks were inspected as part of a Level II Condition Assessment. Inspections included: detailed weld inspection, material testing and water pressure monitoring.

The general scope of the inspection was to pressure wash, buff, magnetic particle and visually inspect the longitudinal welds at a frequency of 1 can in every 10 cans for the total length of the penstock. If welds that warranted refurbishment were discovered during inspection, a further 5 cans upstream and 5 cans downstream of this area would be subject to the same level of inspection. This method allows for an overview of the total penstock condition and an increased inspection frequency in areas that showed signs of damage. The weld inspection and subsequent refurbishments, completed on each penstock, were evaluated following inspection by NDE techniques. The inspection techniques used for the longitudinal and circumferential weld seams of Penstock No. 1, 2, and 3 were visual inspection (VT) and Magnetic Particle Inspection (MT) carried out by Canadian Government Standards Board (CGSB) certified NDE Technicians.

All three of the penstocks have sections that are prone to general deformation/sagging and peaking of weld seams. This is particularly true in sections where the penstock diameter (D) is more than 400 times larger than the penstock wall thickness (t) ($D/t > 400$). Due to previous out of round concerns, the high D/t ratio, and high residual stresses observed in previously tested welds, it was decided that further review of the overall shape of the penstock was required. To assess these concerns and obtain information pertaining to the shape of the penstock, a 3D laser scan was completed to measure the roundness and weld seam peaking for each penstock.

Also, in a similar matter to mechanical tests that were carried out on Penstock No. 1 and No. 2, a plate coupon from Penstock No. 3 was also sent to a testing laboratory. The penstock plate material sample test results were used to determine the metallurgical properties of the weld and base metal and to compare them to the steel specifications listed on the drawings. In addition to the mechanical testing, chemical analysis of the welds and parent metal were completed along with a macro and microscopic examination of the weld cross sections. These tests were completed to determine if there were any anomalies that could have contributed to the accelerated corrosion and subsequent cracking of the seams.

During the major refurbishment of Penstock No. 2 in 2017, rolled angle rings were discovered on the exterior of the penstock. These rings were not found on Penstock No. 1 but excavations on Penstock No. 3 in 2018 indicated rings similar in cross section to the ones found on Penstock No. 2. These rings were not of sufficient depth/thickness and/or frequency to provide additional support to Penstocks No. 2 and No. 3 while under pressure. In our opinion, these rings were more likely used to assist in field erection and weld fit up of the half can sections and adjacent circumferential seams. During internal inspections of Penstock No. 1, there was frequent evidence of poor alignment which required localized mechanical deformation of the penstock shell to achieve a fit up that would allow welding of the seams during original construction more than 50 years ago. It is believed that the fabricator installed these rings on Penstock No. 2 and No. 3 to reduce the fit up and installation issues encountered on the previously constructed Penstock No.1.

Following the data collection of Penstock No. 1 in November 2017, which included collection of pressure and strain data, Hatch recommended similar data collection for Penstocks No. 2 and 3. As a result of this recommendation, NL Hydro installed pressure transducers on Penstocks No. 2 and 3 along with additional ones on Penstock No. 1 and connected them to a data logger. Data collection is currently on-going, and Hatch recommends Hydro collect data over the next few years to generate historical data that can be used to analyze and interpret the long-term operational trends of the penstocks.

3. Penstock Inspections and Refurbishments

3.1 Previous Inspections and Major Refurbishments

To compare the refurbishments and overall condition of the penstocks, it is important to compare the initial inspection findings.

The initial inspections and major refurbishments of all three penstocks did not occur within the same year. Penstock No. 1 (2016), Penstock No. 2 (2017) and Penstock No. 3 (2018) found cracking in the form of linear indications along the top and bottom edge of the weld seams. In addition to the linear weld cracking, the weld seams had noticeable deterioration of the weld cap in the form of general corrosion (weld metal loss), localized pitting corrosion of varying degrees throughout the sections of penstocks, and preferential corrosion of the heat affected zone (HAZ) resulting in areas of low material thickness, edges and therefore high stress concentrations or "notches" in the upper and bottom portion of the weld edge. All three penstocks exhibited cracking and linear indications of weld seams. These indications were predominantly located in the longitudinal seams.

Figure 3-1: Sample of Deteriorated Longitudinal Weld Seam

The previous repairs consisted of:

1. Penstock No. 1 required refurbishment from Can No. 1 through Can No. 173, which resulted in a total refurbished weld seam length of approximately 950 m (3116 feet) (a total of 346 seams at 2.74 m (9 feet) per seam).
2. Penstock No. 2 required refurbishment from Can No. 1 through Can No. 91, which resulted in a total refurbished length of approximately 500 m (1640 feet) (a total of 182 seams at 2.74 m (9 feet) per seam).
3. Penstock No. 3 required refurbishment from Can No. 1 through Can No. 132, excluding a single seam at Can No. 65. After Can No.132 refurbishments were intermittent from Can No. 132 through Can No. 175, Can No. 205 through Can No. 225 and Can No. 302 through Can No. 342. The total length of this refurbishment was approximately 1030 m (3378 feet).

An overview of the refurbishments can be seen in Figure 3-2. For a detailed breakdown of inspections, repairs and general locations per penstock refer to P1 CA Tracker, P2 CA Tracker and P3 CA Tracker provided in Appendix C.

Where refurbishment was required, the indications identified by MT inspection were removed by gouging the full profile of the weld seam and HAZ with care not to remove the full thickness of the weld metal. Following the completion of gouging and subsequent grinding for cleanup of the seam, the seams were inspected visually and by MT to ensure no cracks or indications remained and sound weld metal was present prior to the start of refurbishment. The seams were then welded and after a hold time of 48 hours they were inspected by VT and MT methods to verify weld quality.

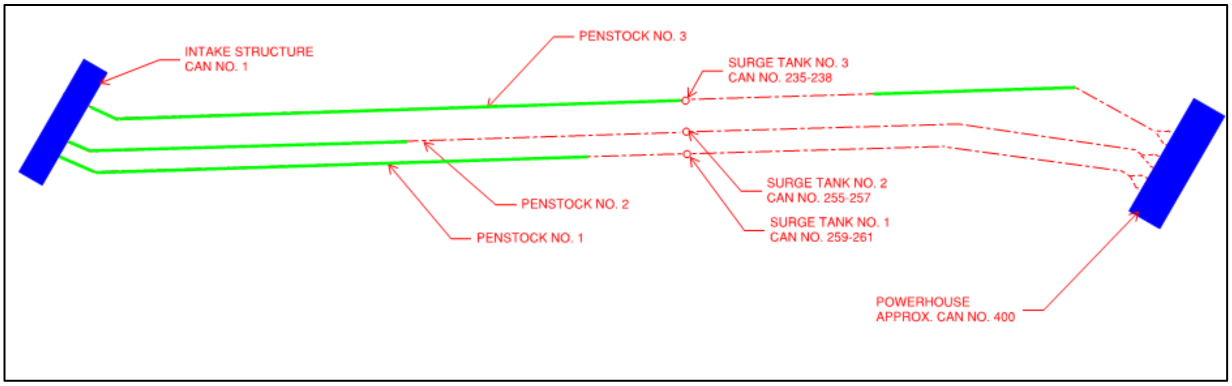

Figure 3-2: Concept Sketch of Penstock Refurbishment Overview (Green Indicates Refurbished Areas)

3.2 Level II Condition Assessment 2018

The inspections and refurbishments of Penstocks No. 1, 2, and 3 were quantified during each penstock shutdown using inspection and refurbishment spreadsheets called trackers. These were used as progress aids as they identified can/seam locations. The data from these trackers was later used for statistical analysis welds, findings on weld quality, and refurbishment lengths.

3.2.1 Penstock No. 1

Penstock No. 1 was inspected from August 13 to 24, 2018. The inspection started adjacent to the intake and progressed through the penstock towards the powerhouse. The inspection followed a 1 can in every 10 cans frequency. Additionally, all cans in the 2016 rupture area from Can No. 91 through Can No. 102 were inspected to assess the effectiveness of the refurbishment.

The inspection encompassed the full-length penstock and included 102 weld seams. Of the 102 weld seams inspected, 56 were previously refurbished weld seams and/or reinforcing plate locations. The inspection verified that the welds remain intact and show no signs of degradation. Additionally, the inspection included 46 weld seams that were not repaired previously. Out of the 46 weld seams inspected, only the south seam on Can No. 215 had a defect requiring refurbishment, resulting in a total longitudinal weld seam refurbishment length of approximately 2.74 m (9 feet). Since the first inspections conducted in 2016 approximately 61% of longitudinal weld seams have been inspected.

The surge tank transition in Penstock No.1 showed evidence of cracking as water was visible leaking through the weld seams. As this is not a structural connection and due to the schedule, the transition was not refurbished at that time. Hatch addressed this issue in "Project Completion Memorandum" H352666-00000-240-030-0002 for Penstock No. 1. While not a structural issue, there is no critical time line for this refurbishment, however, Hatch recommends these cracks be refurbished during the next planned refurbishment of this penstock.

During the inspection, three new instrument trees were installed on Penstock No. 1 similar to those utilized previously during 2017/2018. The pressure transducers were installed on Penstock No. 1 to determine if there are any pressure transients occurring within the penstock.

3.2.2 Penstock No. 2

Penstock No. 2 was inspected from September 17 to 28, 2018. The inspection started at the intake and progressed downstream, with a one can in ten frequency.

The inspection encompassed the entire penstock and included 120 weld seams of which 18 were previously refurbished. The inspection verified that the welds remain intact and show no signs of degradation. Additionally, the inspection included 102 weld seams that were not repaired previously. Out of the 102 weld seams inspected, only the north seams on Can No. 230 and Can No. 270 required refurbishment resulting in a total longitudinal weld seam refurbishment length of approximately 5.49 m (18 feet). Since the first inspections conducted in 2017 approximately 40% of longitudinal weld seams have been inspected.

Penstock No. 2 surge tank transition cracked seams were re-welded in 2017 and visually appeared intact during the 2018 inspection. While there were no evident signs of leakage, detailed testing was not completed as this is not a structural concern. During the next shut down, it is recommended to perform spot MT to determine if the re-welded sections remain in good condition and are crack free.

Penstock No. 2 was noted to have "stiffener" rings present on the upstream sections; an excavated stiffener ring can be seen in Figure 3-3. The stiffener rings were fabricated by rolling a 5"x3"x3/8" angle spaced roughly every 3.66 m (12 feet). These rings are not of sufficient size or spacing to act as pressure retaining elements. As previously discussed, in Section 2 of this report, these rings were likely used to assist in field erection and weld fit up.

It should be noted that the quality of the penstock fit up was noted to be superior to that of Penstock No. 1, likely due to the use of external rings during assembly.

Figure 3-3: Excavated Stiffener Ring – Penstock No. 2

The Bay d'Espoir Operations group had scheduled the application of two coating samples to determine how they would respond over time to exposure to the penstock's interior environment. The two samples to be tested were originally intended to consist of a Galvatech 2000 Primer/MC Tar and a Mio Zinc Primer/MC Tar. The samples were to utilize two different primers as noted above and be applied on a tee section (capturing the intersection of a longitudinal and circumferential weld). During the assessment, the required curing time and application environmental conditions (humidity, dry bulb and wet bulb temperatures) for the Galvatech 2000 primer were not met, and this primer was not applied. Based on this issue, instead two locations were selected for application of the Mio Zinc primer coat and two top coats of MC Tar. The coating preparation and MC Tar finish coat can be seen in Figure 3-4.

Figure 3-4: Coating Prep (Left) Final MC Tar (Right) – Penstock No. 2

During the inspection, three new instrument trees were installed on Penstock No. 2. Each instrument tree consisted of a pressure transducer connection, a drain, and a high point vent. The pressure transducers were installed on Penstock No. 2. to determine if there are any pressure transients occurring within the penstock and to provide data to be used for further analysis provided in a later document. A typical pressure transducer tree is shown in Figure 3-5.

Figure 3-5: Pressure Transducer Instrument Tree – Penstock No. 2

3.2.3 Penstock No. 3

The Penstock No. 3 condition assessment and refurbishment took place from May 14 to June 21, 2018. During the shutdown, 561 longitudinal weld seams were inspected, and 390 longitudinal weld seams were refurbished, resulting in a total longitudinal weld seam refurbishment length of approximately 1030 m (3378 feet).

The inspection began with entry through a manhole at Can No. 118. Planned inspection frequency was 1 can every 10; however, initial findings showed the upstream section of Penstock No. 3 required major refurbishment similar to that of Penstock No. 1 and No. 2. Further inspection downstream indicated refurbishment in this section was also required. The 5.18 m (1717 feet) diameter section (excluding Can No. 65) was refurbished, Can No. 132 to Can No. 175; Can No. 205 to Can No. 225; and Can No. 302 to Can No. 342 sections were also refurbished intermittently. The areas between these sections had a minimum inspection frequency of 1 can every 10. The end of the refurbishment areas was determined when 5 cans passed inspection both upstream and downstream of the refurbished can. Since the inspection conducted in 2018 approximately 67% of longitudinal weld seams have been inspected.

The inspection identified seams in the downstream portion of the penstock, Can No. 240 to Can No. 295 and downstream of Can No. 345, that indicated the beginning stages of preferential corrosion of the heat affected zone. No refurbishment was performed in this area as the noted corrosion was deemed minimal and low risk, therefore does not pose an immediate threat to operability. Refer to Hatch project memo H357358-00000-240-030-0001 “Minor Weld Indications in Penstock 3” for further discussion.

A coupon was removed from Can No. 222 and sent for mechanical testing and chemical analysis. The testing determined the plate was of similar composition and strength as the plates tested for the other two penstocks. Findings are discussed later in this report.

Similar to Penstock No. 1 and No. 2, the surge tank transition on Penstock No. 3 displayed cracking as well as visible water leakage through weld seams. As this is not a structural connection, and due to the schedule, the transition was not refurbished at this time. Hatch addressed this issue in “Project Completion Memorandum” H352666-00000-240-030-0002 for Penstock No. 1. Hatch recommends this be completed during the next planned refurbishment of Penstock No. 3.

Penstock No. 3 was discovered to have rings present on the upstream sections similar to those found on Penstock No. 2. These are believed to be fabrication aids similar to Penstock No. 2.

During the inspection, four new instrument trees were installed on Penstock No. 3 similar to those utilized on Penstock No. 2. The pressure transducers were installed on Penstock No. 3 to determine if there are any pressure transients occurring in the penstock and to provide data.

3.3 Testing

An extensive array of examination and mechanical testing was completed on coupons removed from various locations along the length of the penstocks. The coupon locations from Penstock No. 1 (2016) included one coupon from Section 8, one coupon from Section 16, and one coupon from Section 17. Penstock No. 3 (2018) had one coupon removed from Can No. 222. The coupons consisted of plate sections containing both base and weld metal. These samples underwent mechanical and chemical testing to determine if there were metallurgical abnormalities that could cause or contribute to failures of the penstock pressure boundary such as low tensile strength and high hardness. Test results indicated that there does not appear to be any metallurgical strength anomalies in the base metal or weld metal for any of the penstock material coupons tested. In all instances, the tested tensile strengths exceeded the minimum requirements of the specified steels from the design drawings.

The chemical analysis of the weld metal and base metals measured levels of sulphur, in all of the samples, that was higher than currently found in today’s welding consumables and structural steels.

High amounts of sulphur can produce porosity in the weld metal and heat affected zones, primarily at the surface which can contribute to accelerated pitting corrosion. It is our opinion the higher sulphur content could be a contributing factor in the accelerated corrosion and pitting of the welds and HAZ.

Refer to Appendix A.1 for a detailed summary of the mechanical testing completed on Penstock No. 1, 2 and 3.

The specifications and previous inspection reports indicate Penstock No. 1 and No. 2 had an interior coating of coal tar epoxy. There does not appear to be any information regarding the interior coating of Penstock No. 3 and based on communications with NL Hydro operations, regarding previous inspections it is our understanding no internal coating was utilized on Penstock No. 3. It is our opinion this is the main reason for the extent of the pitting corrosion of this penstock.

In order to confirm this for the assessment of Penstock No. 3 in 2018, samples were taken from two areas to confirm if an internal coating is present. Internal samples were retrieved from a section near the surge tank and can section 345-350 of the penstock. The samples were sent to Cambridge Testing and Materials in Mississauga, Ontario, and are awaiting results for further analysis in the second quarter of 2019.

3.4 Data Collection

3.4.1 2017 Data Collection

In November 2017, during the shutdown for the third rupture of Penstock No. 1, strain gauges and pressure transducers were installed for data collection. The data collected was analyzed and results and conclusions based on the analysis were presented in Hatch’s “Repair and Failure Investigation” report dated May 17, 2017.

The strain gauges provided stress magnitude data and displayed any transients for various operating zones and conditions (e.g., speed no load, unit ramp up and load rejection).

NL Hydro also provided data from their Supervisory Control and Data Acquisition System (SCADA) system which aided with interpretation of the collected strain and pressure data.

The data collected from 2017 will be used in conjunction with data collected from 2018 and 2019 for analysis in Report 3 “Penstocks No. 1, 2 and 3 Life Extension Options” to be issued in the second quarter of 2019.

3.4.2 2018 Data Collection

During each of the shutdowns for Penstocks No. 1, 2, and 3, instrumentation trees were welded on the external (top) of each penstock for installation of pressure transducers.

With the data logger, the pressure transducers will measure and collect operational data. With this data, Hatch will analyze the pressure transients for anomalies and compare the results with the 2017 recorded pressure and stress/strain data.

3.4.3 2018/2019 Data Analysis

Hatch was supplied with approximately 3 months of operational pressure data for Penstocks No. 1, 2, and 3 from October 02, 2018 to January 22, 2019. In addition to the pressure data, NL Hydro also provided operational power generation (MW) readings for Units 1 to 6 for the same 3-month period. The data is high level data sampled once every minute.

Analysis of the penstock pressure data determined that modification to the data collection system is required. As such the pressure data will be issued separately as an appendix to this report once the recommended three months of data have been collected. While the pressure data provides valuable information regarding the penstock operating environment, this information does not impact the findings of this report as the observed peaking is more gradual than that analyzed in the previous stress analysis model, therefore the as-built geometry would have reduced residual and operational stresses.

Laser Scan and Inverts

In 2018, Allnorth (an external survey company) completed 3D Laser Scan Inspections on Penstock No. 1, 2 and 3 during each of the three shutdowns. All three inspections utilized Leica C10 3D Laser Scanner – ACLLS-007 technology and the inspections for both Penstock No. 2 and 3 started at the intake gate and proceeded downstream to just upstream of the bifurcation. The laser inspection of most of Penstock No. 1 was completed by a different contractor, EPCO, thus only the areas not surveyed previously were completed by All North.

Refer to Appendix A for the tables showing the maximum, minimum, and average out of roundness for the laser scans completed on Penstocks No. 1, 2, and 3. This information can be compared with out of roundness tolerances used by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) Sec. VIII division 1 which stated the difference between the maximum and minimum inside diameters at any cross-section shall not exceed 1% of the nominal diameter at the cross section under consideration.

The penstock has three different diameters over its length. Based on the diameter, the following are the maximum acceptable out of round tolerances.

- 5.18 m (17 feet) I.D. section: 52 mm (2.04 in.)
- 4.57 m (15 feet) I.D. section: 46 mm (1.83 in.)
- 4.11 m (13.5 feet) I.D. section: 41 mm (1.62 in.)

For this analysis, the penstocks were put into 7 sections and compared (3 sections for the 17' I.D., 2 for the 15' I.D. and 2 for the 13.5' I.D.). To be conservative, the maximum and minimum values were compared across multiple scanned cross sections in each of the 7 sections. The Table 3-1 summarizes the maximum out of roundness.

Table 3-1: Penstocks Out of Roundness

Penstock Diameter	Maximum Out of Roundness Measured by Laser Scan	Maximum Permissible Out of Roundness from ASME VIII
5.18 m (17' I.D.)	124 mm (4.88 in.)	51.8 mm (2.04 in.)
4.57 m (15' I.D.)	138 mm (5.43 in.)	45.7 mm (1.80 in.)
4.11 m (13.5' I.D.)	127 mm (5 in.)	41.1 mm (1.62 in.)

The scanned sections were also analyzed for the longitudinal weld seam peaking as shown in Table 3-2 below.

Table 3-2: Weld Seam Maximum Peaking

Penstock Diameter	Maximum Measured Peak	Maximum Permissible Out of Roundness from ASME VIII
5.18 m (17' I.D.)	60 mm (2.36 in.)	51.8 mm (2.04 in.)
4.57 m (15' I.D.)	28 mm (1.10 in.)	45.7 mm (1.80 in.)
4.11 m (13.5' I.D.)	35 mm (1.38 in.)	41.1 mm (1.62 in.)

The results show the penstock shell is very flexible and does not meet the generally accepted tolerances for out of roundness in the unpressured condition. Also, the peaking at the longitudinal joints does not meet the acceptable tolerance with respect to weld seam fit up for pressure vessels.

This condition has existed since installation, and in our opinion, does not present an immediate concern for refurbished welds.

4. Finite Element and Fatigue Analysis

Further analysis and comparison were completed on the laser scan data and out of roundness measurements recorded. Originally, this data was intended to be used for FEA analysis, however given the extent of out of roundness and similarity to previously scanned and measured data; Hatch has deemed the best approach is to forgo a new FEA analysis and use the stress multiplier model that was created from past FEA models during the analysis of Penstock No. 1 in 2017/2018. This model is accurate provided Penstocks No. 2 and 3 have comparable pressures to the FEA model used to produce the stress multiplier model. Data collection is currently on-going and more historical data is needed to extrapolate and ensure an accurate model is produced to represent the long-term operational trend of the penstocks. Hatch will analyze this data and determine if it validates the existing FEA model. This will be included in a standalone document to be issued at a later date.

5. Current Condition and Life Expectancy Estimation

All three penstocks have had similar repairs completed due to longitudinal weld deterioration and cracking. The completed refurbishments have focused on stabilization of the penstocks. Based on the condition of the penstocks the likelihood of continued operation without failures is unlikely without intervention. It is Hatch's belief that major failures/ruptures are unlikely in the next 5 years. However, due to the deteriorated state, lack of corrosion protection, water chemistry and accumulated damage, it is likely that pin hole leaks and micro crack leaks could occur in the coming years.

In general, the refurbishments to date have been completed on longitudinal seams due to the amount of risk associated with major failures. Refurbishments were completed on welds that exhibited significant weld material loss, notching, and/or cracks. However, it should be noted that the penstocks have not been refurbished to a new condition and there are still many locations of welds with material loss, notching, and surface indications. As the penstocks have no current means of corrosion resistance, deterioration will continue, and these areas will eventually be considered high risk if no action is taken.

6. Refurbishment or Replacement Options

Refurbishment or replacement options were investigated for each penstock. The options selected are as follows:

1. Refurbishment of deteriorated weld seams, both longitudinally and circumferentially, and re-coating the interior of the penstock.
2. Replacement options for each penstock

    A Full penstock replacement

    B Replacement of penstock 17’ ID section
3. Refurbishment of deteriorated weld seams and installation of a fiber-reinforced plastic (FRP) liner.
4. Refurbishment of deteriorated weld seams and installation of reinforcing plates over all longitudinal and circumferential weld seams.
5. Installation of a steel liner inside the existing penstock with grout injection to fill void space to existing penstock.
6. Encasement of the existing penstock in a concrete ring approximately 2 feet thick.

The following options present varying degrees of life extension. Referencing published material from the American Society of Civil Engineers (ASCE), the design life of a steel penstock is normally in the range of 40-80 years with proper maintenance (ASCE, Guidelines for Evaluating Aging Penstocks). As corrosion has been a major contributing factor relating to metal loss and in particular the welds, maintenance of a coating system is extremely important to the longevity.

Refurbishment options include replacement of the internal coating but not the external coating. Inspection of the external coating on Penstocks No. 1, 2, and 3 from the brief sections that have been excavated during the penstock refurbishments and condition assessment have shown the coating is still intact. Additionally, wall thickness measurements were taken along the length of the penstock and showed no signs of metal loss due to external corrosion.

With adequate maintenance of the coating systems, full replacement and installation of a new penstock will have an estimated design life of approximately 80 years. Hatch estimates the refurbishment options that include replacement of the interior coating will provide an additional life extension of at least 40 years provided there is no breakdown of the internal or external coating system.

6.1 Refurbishment of Existing Penstocks

The first refurbishment option investigated for life extension of the penstocks includes completion of the weld refurbishment that started in 2015. This will include full inspection of all seams, both longitudinal and circumferential, and refurbishment of all deteriorated seams (Note: all options with refurbishment consider 50% refurbishment rate of unrefurbished longitudinal and circumferential seams). Following the completion of weld refurbishment, the penstock internals will have abrasive blasting to bare metal and a new internal coating installed. The current coating option priced is for three coat paint system by the Wasser Corporation.

Table 6-1: Proposed Coating System

Coat Number	Product	DFT
First	MC-Zinc 100	3.0 to 5.0 mils DFT
Second	MC-Tar 100	5.0 to 7.0 mils DFT
Third	MC-Tar 100	5.0 to 7.0 mils DFT
Total	**N/A**	**13.0 to 19.0 mils DFT**

The first coat would consist of MC-Zinc primer and be followed by two coats of MC-Tar moisture cure urethane that has similar performance to the coal tar epoxy that was originally installed, having a life span of approximately 15-20 years (recoating should be planned for every 15 years). The benefit of using the moisture cure product is that there will be significantly less environmental control and equipment required in the penstock during application. Other products can be assessed for this service however a large emphasis should be placed on the environmental application requirements (i.e. the internal penstock temperature, humidity, dew point, etc.). Hatch considers this important as Hydro and other companies like Newfoundland Transshipment Limited have experienced difficulties in the past with trying to apply other coatings in high humidity environmental.

Refurbishment of the welds is required to ensure that the newly applied coating is not compromised from existing cracking. If cracks are present it will lead to premature coating failure in those areas. This can be completed via grinding if the defect is removed within 2.0 mm. If the excavation is beyond 2.0 mm it would require the deposition of addition weld metal.

The penstocks should have regular interior inspections. Hatch would recommend doing an internal inspection after the first year of operation after coating is applied to assess if any installation issues caused delamination of the coating and repair as required. After the initial warranty inspection, the frequency would be reduced to one interior inspection every 6 years. The interior inspection would be largely focused on coating condition and would include visual inspection and adhesion testing.

Table 6-2: Refurbishment of Existing Penstock Cost

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Mob/Demob (10%)	$1,056,000	$1,101,000	$1,044,000
Backfill Manipulation	$20,000	$20,000	$20,000
Longitudinal Weld Refurbishment	$1,350,000	$1,800,000	$1,300,000
Circumferential Weld Refurbishment	$6,000,000	$6,000,000	$6,000,000
Doorsheet Removal and Re-installation	$60,000.00	$60,000.00	$60,000.00
Blasting/Coating	$3,000,000	$3,000,000	$3,000,000
Rescue / Safety	$130,000	$130,000	$60,000
EPCM(10%)	$1,056,000	$1,101,000	$1,044,000
Contingency (20%)	$2,112,000	$2,202,000	$2,088,000
Total	**$14,784,000**	**$15,414,000**	**$14,616,000**

6.2 Penstock Replacement

6.2.1 Replacement (A)

The second option investigated for the penstock’s life extension includes full replacement or replacement of specific sections. Full replacement includes newly constructed cans from the intake imbedded thimble to the surge tank tee and from the surge tank tee to the section beneath the switchyard. Plate thickness should be increased in some areas, in particular the upper 17ft. diameter section, and a corrosion allowance added. The design would meet current standards. The full replacement option guarantees the longest life extension but comes at the greatest cost. A replacement penstock could be constructed in parallel to the existing to minimize penstock downtime, but this would require excavation and rock blasting to create a trench which comes at a higher risk to the adjacent penstocks and at an additional cost. The options estimated for this report did not include any cost for trench excavation.

Complete replacement poses considerable challenges as some of the existing sections are virtually irreplaceable or replaceable at great cost. These locations include the intake thimble, surge tank tee, sections under the substation, and sections under the powerhouse. Due to the challenges associated with complete replacement it was determined that the replacement option would not include these sections. It is Hatch’s opinion a partial penstock replacement represented a more viable approach.

The remaining sections would be considered field tie points where the new penstock sections would be connected to the existing. The irreplaceable sections would then be internally inspected, refurbished as required and coated. Internal and external coating would need to be applied to newly constructed sections as well (cost estimates include costing for the recommended coating system).

Table 6-3: Full Replacement Cost Estimate Per Penstock

Construction Activity	Cost
Mob/Demob (10% of Site Work)	$3,436,750
Backfill Manipulation	$500,000
Replacement Steel (Material/Shipping/Fab)	$21,600,000
Reinforcing Steel	$1,187,500
Demo of Existing Penstock Sections	$1,000,000
Blasting/Coating	$5,000,000
Site Labour and Cranes	$5,000,000
Rescue / Safety	$80,000
EPCM (10%)	$3,436,750
Contingency (20%)	$6,873,500
Total	**$48,114,500**

6.2.2 *Replacement (B)*

Based on the recent refurbishment history and the results of the stress analysis the section of the penstock that has had the most problems would be the 17-foot section located upstream of the Surge Tank. This estimate considers only replacing this section with material and design to current standards and fully refurbishing and re-coating the remaining penstock sections.

Table 6-4: Partial Replacement and Refurb Cost Estimate Per Penstock

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Mob/Demob (10%)	$1,614,250	$1,624,250	$1,609,250
Backfill Manipulation	$100,000	$100,000	$100,000
Longitudinal Weld Refurbishment	$1,350,000	$1,450,000	$1,300,000
Circumferential Weld Refurbishment	$4,000,000	$4,000,000	$4,000,000
Demo of Existing 17' ID Section	$300,000	$300,000	$300,000
Replacement Steel for 17' ID	$5,320,000	$5,320,000	$5,320,000
Blasting/Coating	$3,210,000	$3,210,000	$3,210,000
Site Labour and Cranes	$1,762,500	$1,762,500	$1,762,500
Rescue / Safety	$100,000	$100,000	$100,000
EPCM (10%)	$1,614,250	$1,624,250	$1,609,250
Contingency (20%)	$3,228,500	$3,248,500	$3,218,500
Total	**$22,599,500**	**$22,739,500**	**$22,529,500**

6.3 Weld Refurbishment and FRP Liner

Similar to Option 1, this option includes completion of weld refurbishment for all weld seams and substitutes a paint coating system with the installation of an FRP liner. An FRP liner would have a longer lifespan compared to a coal tar epoxy. Preliminary estimates indicate the FRP liner is multiple times the cost of a MC-Tar epoxy but has a much longer lifespan, ranging from 25-50 years with proper resin selection and adequate maintenance. Due to the high velocity flow and turbulence in some area's penstocks, maintenance may be required in areas such as the intake thimble, elbows, tees, reducers, and the bifurcation.

The FRP liner materials currently under review require the penstock internal to be abrasively blasted to a "white metal" SSPC-SP-5 finish. Additionally, current review of FRP liner materials indicates considerable work would be required to ensure the surface is sufficiently uniform for proper installation and adhesion. This would be required at areas of pitting/crevices in excess of 1.5 mm. This resurfacing could be completed by weld buildup and grinding or by the use of poly filler compounds. The cost of resurfacing was not included in the estimate. Preliminary research indicates this as a feasible but high cost option, however further research must be conducted as material selection could present liner cracking concerns with penstock shape changes during water up (pressurization) and dewatering (depressurization).

Table 6-5: Weld Refurbishment and FRP Liner Cost Estimate

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Mob/Demob (10%)	$2,417,725	$2,462,725	$2,412,725
Backfill Manipulation	$20,000	$20,000	$20,000
Longitudinal Weld Refurbishment	$1,350,000	$1,800,000	$1,300,000
Circumferential Weld Refurbishment	$6,000,000	$6,000,000	$6,000,000
Doorsheet Removal and Re-installation	$60,000	$60,000	$60,000
Blasting / FRP Liner	$16,687,250	$16,687,250	$16,687,250
Rescue / Safety	$60,000	$60,000	$60,000
EPCM (10%)	$2,417,725	$2,462,725	$2,412,725
Contingency (20%)	$4,835,450	$4,925,450	$4,825,450
Total	**$33,848,150**	**$34,478,150**	**$33,778,150**

6.4 Refurbishment with Reinforcing Plates

Building on the requirements of Option 1, reinforcing plates could be installed internally over all existing weld seams. Following the weld refurbishment, reinforcing plates similar to that installed in Penstock No. 1 (Nov. 2017) would be installed to stiffen the existing penstock and provide additional protection to the weld seams. Abrasive blasting to bare metal and installation of a coating system would still be required for penstock longevity.

Table 6-6: Refurbishment and Reinforcing Plates Cost Estimate

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Mob/Demob (10%)	$2,161,250	$2,206,250	$2,156,250
Backfill Manipulation	$20,000	$20,000	$20,000
Longitudinal Weld Refurbishment	$1,350,000	$1,800,000	$1,300,000
Circumferential Weld Refurbishment	$6,000,000	$6,000,000	$6,000,000
Conduct Roundness Correction	$3,600,000	$3,600,000	$3,600,000
Installation of Reinforcing Plates	$7,080,000	$7,080,000	$7,080,000
Doorsheet Removal and Re-installation	$60,000	$60,000	$60,000
Blasting/Coating	$3,000,000	$3,000,000	$3,000,000
Rescue / Safety	$60,000	$60,000	$60,000
Site Labour For Repad Installations	$442,500	$442,500	$442,500
EPCM (10%)	$2,161,250	$2,206,250	$2,156,250
Contingency (20%)	$4,322,500	$4,412,500	$4,312,500
Total	**$30,257,500**	**$30,887,500**	**$30,187,500**

6.5 Internal Steel Liner

This option investigated the installation of a steel liner inside the existing penstock. The liner would be designed to be fully pressure retaining providing a new smaller diameter penstock inside the existing. Grout would need to be injected to fill the void between the 2 steel structures, providing support and load transfer to the exterior shell and exterior soil. The new steel sections would be sized for ½" (12.7mm) plate throughout the length of the penstock and would require an internal coating. For the grouting, couplings or structural connections would be welded into the gap between the new liner and existing penstock to support construction prior to grout injection. Installation of steel liner without grouting was reviewed but based on the existing deformation insuring the new shell is in continuous contact would be difficult and require installation of the new shell in many segments. Additionally, the amount of welding required could cause damage to the exterior coating of the existing penstock and the direct contact of the new internal liner to existing shell could create a galvanic cell.

Table 6-7: Internal Steel Liner Cost Estimate (A)

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Mob/Demob (10%)	$2,836,450	$2,881,450	$2,831,450
Backfill Manipulation	$60,000	$60,000	$60,000
Longitudinal Weld Refurbishment	$1,350,000	$1,800,000	$1,300,000
Circumferential Weld Refurbishment	$6,000,000	$6,000,000	$6,000,000
Liner Steel	$17,100,000	$17,100,000	$17,100,000
HSS Reinforcing	$280,000	$280,000	$280,000
Cranes	$200,000	$200,000	$200,000
Jacking & Steel Placement	$600,000	$600,000	$600,000
Blasting/Coating	$2,374,500	$2,374,500	$2,374,500
Rescue/Safety	$400,000	$400,000	$400,000
EPCM (10%)	$2,836,450	$2,881,450	$2,831,450
Contingency (20%)	$5,672,900	$5,762,900	$5,662,900
Total	**$39,710,300**	**$40,340,300**	**$39,640,300**

Table 6-8: Internal Steel Liner Grouted Cost Estimate (B)

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Mob/Demob (10%)	$2,883,075	$2,928,075	$2,878,075
Backfill Manipulation	$20,000	$20,000	$20,000
Longitudinal Weld Refurbishment	$1,350,000	$1,800,000	$1,300,000
Circumferential Weld Refurbishment	$6,000,000	$6,000,000	$6,000,000
Liner Steel	$17,100,000	$17,100,000	$17,100,000
HSS Reinforcing	$280,000	$280,000	$280,000
Cranes	$200,000	$200,000	$200,000
Jacking & Steel Placement	$600,000	$600,000	$600,000
Grouting	$506,250	$506,250	$506,250
Blasting/Coating	$2,374,500	$2,374,500	$2,374,500
Rescue/Safety	$400,000	$400,000	$400,000
EPCM (10%)	$2,883,075	$2,928,075	$2,878,075
Contingency (20%)	$5,766,150	$5,856,150	$5,756,150
Total	**$40,363,050**	**$40,993,050**	**$40,293,050**

6.6 Concrete Ring Encasement

This option investigates the installation of a external steel reinforced concrete ring with a thickness of approximately 2 feet. The penstocks would first have all weld refurbishments completed and a coating system applied (similar to that described in Section 6.1). Excavation operations would commence once sections of the penstock were refurbished, and then concrete placement would begin. Support steel would be required and total support of the penstock during forming and concrete placement would be challenging. Similar to the replacement options, some sections would not be accessible for encasement, although some of these areas are already encased in concrete. Once again, these specific sections will have internal reinforcement to ensure life expectancy is similar throughout the entire penstock.

Table 6-9: Concrete Ring Encasement Cost Estimate

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Mob/Demob (10%)	$2,939,700	$2,984,700	$2,934,700
Backfill Manipulation	$3,200,000	$3,200,000	$3,200,000
Longitudinal Weld Refurbishment	$1,350,000	$1,800,000	$1,300,000
Circumferential Weld Refurbishment	$6,000,000	$6,000,000	$6,000,000
Reinforcing Steel	$1,187,500	$1,187,500	$1,187,500
Doorsheet Removal and Re-installation	$60,000	$60,000	$60,000
Concrete	$14,625,000	$14,625,000	$14,625,000
Cranes	$200,000	$200,000	$200,000
Blasting/Coating	$2,374,500	$2,374,500	$2,374,500
Rescue/Safety	$400,000	$400,000	$400,000
EPCM (10%)	$2,939,700	$2,984,700	$2,934,700
Contingency (20%)	$5,879,400	$5,969,400	$5,869,400
Total	**$41,155,800**	**$41,785,800**	**$41,085,800**

7. Option Comparison

Due to the complexity of the various options it was decided to include a brief comparison matrix ranking the options based on five key factors, see Table 7-2. The factors used for the comparison were reliability, cost, schedule/phasing and risk.

Reliability- Considers the long-term reliable operation of the penstocks unimpeded by outages.

The majority of the options scored high on reliability excluding FRP lining. Due to the strict application processes and the elastic deformation (change in shape when pressurizing or depressurizing) of the penstock there is a possibility of localized failures or cracks in the liner occurring. Similar reliability issues could occur with a new steel liner installation due to galvanic reactions between the existing and new steel if water leaks into the interstitial space between the two steel shells.

Cost – Based on the estimated capital cost of the various options. Costing was provided in the previous sections.

The estimates were based on industry norms for estimating and do not consider inflation and cost adders associated with phasing the project over multiple outages. Additional cost savings would be possible if Hydro was purchasing equipment or materials in advance and free issue these items to contractors

Schedule/Phasing – Some of the options allow for application in a phased manner.

This decreases down time and allows for more cash flow flexibility. Option 2 would be the most difficult to phase due to existing irreplaceable infrastructure. It could be phased by section to make it more attractive however the outages would be substantial.

Risk – Risk during operation and construction were considered.

Risk scores are similar based on the majority of the options being largely interior work. However, replacement would be subject to weather delays, risk to bedding wash out, and would require lifting and other construction related issues around and over operational penstocks.

Prior to completing the ranking matrix, the life extension options were first analyzed with listed advantages and disadvantages as shown in Table 7-1. This table complements the ranking matrix and lists some of the reasoning for decided weighting for the ranking matrix.

Table 7-1: Option Comparison Table

Item Number	Description	Advantages	Disadvantages
1	Refurbish circumferential and unrefurbished longitudinal welds of penstock followed by water blasting to bare metal and re-coating of penstock internal	1. Lower risk of failure 2. Lower cost 3. Work is internal and weather delays would be minimal 4. Reduction in surface roughness via new coating system. 5. Smaller labor force required and can be staged over multiple outages. 6. No large civil works required, minimal risk to existing infrastructure. 7. Minimal lifts over operational penstocks.	1. Multiple outages required. 2. Flexible 17' diameter section remains. 3. Poor fabrication alignment issues remain. 4. Interior is repaired but exterior coating from original construction remains. Life extension is limited by external coating condition. 5. No inclusion of corrosion allowance on existing wall thickness. Therefore, coating needs to remain intact over the lifespan of the penstock. Essentially the coating system should be budgeted for replacement every 15-20 years. 6. Existing bedding and drainage system cannot be upgraded. Bedding remains in contact with the penstock in areas checked. However, some sections of the bedding were saturated during inspection.
2A/B	Replace sections of penstock	1. Low risk of failure 2. New sections can be constructed to meet current standards 3. Reduction of Surface roughness via application of new coating. 4. Existing flexible 17' diameter section is removed. 5. Inclusion of corrosion allowance would be included in wall thickness. Reduces risk of corrosion effect on the penstock shell. This would allow initial recoating interval to be greater (approximately 25-30 years). After the first recoating the interval would revert back to 15-20 years. 6. Life extension up to 80 years depending on maintenance schedule. 7. Bedding and drainage could be upgraded during replacements.	1. High cost for total replacement. 2. Long outage required. 3. High likelihood of weather delays. 4. Lifts over operational penstocks. 5. Heavy civil works required that could cause damage to existing infrastructure. 6. Demo of existing penstock sections would leave bedding system exposed to elements which could lead to compromised bedding and/or washouts. 7. Road transport of steel will require special permits for transport due to size and most likely be shipped in sections. This requires at least 2 longitudinal joints in the field per can. 8. Barge transport could be expensive due to the volume of steel cans. 9. Supply of required steel would have to be ordered one year in advance and free issued to contractors.
3	Install fiberglass liner	1. Construction can be phased 2. Work is all internal and weather delays would be minimal 3. Decreased roughness due to new fibreglass liner 4. Composite liner allows for increased strength when combined with existing steel. 5. Failure of fiberglass coating is easily identified by discoloration at delamination sites. 6. Highly resistant to corrosive environments	1. High cost 2. Multiple outages required 3. Work is confined space and additional ventilation will be required. 4. Extensive refurbishment required to smooth entire penstock internal surface due to application limitations. 5. Fiberglass delamination is could occur during watering up due to excessive peaking at longitudinal seams and general flexibility of the 17' diameter sections. 6. If leakage occurs, determining extent is impossible without removal of fiberglass liner. This could lead to corrosion of steel penstock behind fiberglass liner. Fiberglass liner has insufficient thickness to retain entire pressure, consequently steel integrity is still required. 7. Environmental requirements are difficult to attain inside of the penstock.
4	Install internal reinforcing	1. Lower risk of failure 2. Construction can be phased 3. Work is all internal and weather delays would be minimal 4. Increased reinforcement over welded areas	1. High cost 2. Multiple outages required 3. Possible flow disturbances caused by plates protruding into flow contributing to head loss 4. Reduced flow through penstock do to repetitive pressure disturbances. 5. Refurbishment of existing welds is required prior to installation and with refurbishment there is no advantage to additional plate reinforcement.
5A/B	Install steel liner inside penstocks and pump epoxy grout into interstitial space.	1. Composite structure consisting of existing steel, new grout layer and new steel liner would be considerably stronger than current arrangement. 2. Construction can be phased. 3. Majority of work is internal and not subject to weather delays. 4. Increased rigidity due to increased thickness and reduced diameter.	1. High cost 2. Multiple outages required, or increased outage length required. 3. Installation of caps required at terminations if phased to ensure grout is not saturated. 4. Lack of access for full penetration welds. Could require backing rings. 5. Higher head loss due to reduced cross-section. 6. Risk of galvanic corrosion between new liner and existing steel due to minimal grout layer. This is often encountered in double bottom bulk storage tanks. Typically, these would require large separations between new and existing steel (6" and up) along with some type of cathodic protection. 7. Existing peaked sections could lead to failure of the grout section after repeated watering and dewatering cycles. 8. Due to deformation of existing penstock ensuring complete contact of internal liner without grout poses considerable challenges. Not considered technically viable at this time.

Item Number	Description	Advantages	Disadvantages
6	Install concrete ring that externally encases the existing	1. Lower risk of failure. 2. Construction can be phased. 3. Increased rigidity and reinforcing on penstock shell. 4. External repairs would be simpler on exposed concrete sections.	1. High cost 2. Extensive excavation works 3. Supporting penstock during construction (forming/placing concrete) will be challenging 4. Multiple outages will be required. 5. Lifting and placing concrete over operational penstocks 6. Increased rigidity may cause increased reactions as there is no longer any flex in the system. 7. Repairs to interior lining would be difficult in the event of failure. 8. Could cause failure of buried storm culverts due to the increase in weight. 9. Concrete has poor performance in tension. Not considered a technically viable option at this time.

Table 7-2: Refurbishment Option Matrix

Item Number	Option	Reliability	Cost	Schedule/Phasing	Risk	Total
1	Refurbish and Coat	4	5	5	4	90%
2A	Replace Existing	5	1	1	2	45%
2B	Replace Existing + Refurbishment	5	4	3	3	75%
3	Install FRP Liner	2	2	5	2	55%
4	Install Internal Reinforcement	4	3	5	3	75%
5	Install Steel Liner	2	2	5	2	55%
6	Encase Penstock in Concrete Ring	5	2	1	2	50%

8. Conclusions

Following the 2018 shutdowns of Penstocks No. 1, 2, and 3, each of the three penstocks have undergone a large-scale inspection and refurbishment of the sections upstream of the surge tank and for Penstock No. 3 the section downstream of the surge tank.

The three penstocks required refurbishment of the longitudinal seams due to significant weld metal loss from general corrosion, localized pitting corrosion, and preferential pitting corrosion of the HAZ. The weld metal loss has resulted in the formation of linear indications (i.e., cracking) along both edges of the weld. The 2018 inspection and refurbishment of Penstock No. 3 found the penstock in similar condition to that of Penstock No. 1 and No. 2 but with more refurbishment required downstream of the surge tank than the other two penstocks.

Based on the current condition of the penstocks and the lack of corrosion protection, Hatch cannot guarantee no further leakages or micro cracks (if not already present) will occur for each of the three penstocks. Hatch believes the probability of a major rupture or failure is low within the next 5 years however, a pin hole leak or micro crack could eventually lead to a rupture or failure.

The reviewed pressure data showed events of interest and additional data is required for these events. Three months is an insufficient period to analyze data to determine, provide commentary on trends and compare this with previously recorded data. Several years of data collection and monitoring is more appropriate for this type of installation and Hatch recommends continual data collection until a life extension option is implemented. Hatch will utilize results over the next 3 months to provide preliminary commentary in a later document.

The 2018 inspection of Penstocks No. 1 and 2 indicates the refurbishments completed in 2016 and 2017 show no deterioration since the previous shutdown. Approximately 8.4% of the Penstock No. 1 refurbished welds showed deterioration when re-inspected in 2017 but since the reinforcement and additional refurbishment carried out in 2017, no new indications were found in these areas during the 2018 inspection.

Mechanical testing was completed on Penstock No.1, 2 and 3 and shows the materials used for fabrication meet or exceed the design specifications. Metallurgically the material does not appear to have any characteristics that would have caused a failure. There are high readings of sulphur within the base and weld metals tested. It is Hatch’s belief this makes the penstock welds sensitized to corrosion when compared to typical steels when left unprotected.

The surveys completed indicate the penstocks are not within specified tolerances of the ASME BPVC. The excess peaking will cause higher stresses than typical code calculated stresses and will need to be evaluated in conjunction with the operational pressure data once available. However, it appears that weld repairs completed to date have sufficient ductility to allow for this deformation during water up. Stress analysis based on the collected survey and pressure data will be completed for the final report “Penstocks No. 1, 2 and 3 Life Extension” in the second quarter of 2019.

Penstocks No. 1 and No. 2 have reached 50 years in service. The internal coating of Penstocks No. 1 and No. 2 have failed in numerous locations and there is a possibility that Penstock No. 3 was never internally coated.

The unrefurbished sections of the three penstocks, including circumferential seams, are showing signs of weld metal loss and preferential pitting corrosion of the HAZ and in the future will need to be protected by application of a coating to avoid further deterioration.

Based on completed inspections, refurbishments and current operating procedures as recommended by Hatch in previous reports, there have been no ruptures or recurring indications in the longitudinal seams. As a result, Hatch believes the refurbishment methodology has been successful in stabilizing the penstocks and the penstock’s current condition will provide uninterrupted service through the 2019 winter season. Hatch recommends annual inspection of the penstocks should continue until a life extension strategy is implemented within the next 3-5 years. Hatch also believes that the refurbishment of backfill around Penstock No. 1, as outlined in Report H356043-00000-240-230-0003, may be deferred until the execution of the selected life extension work is completed.

Considering the welded joints in the refurbished areas have remained crack free, this would indicate that full strength defect free welds are able to undergo this deformation without crack propagation and complete removal and reinstatement of correctly rolled flush patches is not required. When welded seams are left unprotected and subject to continued corrosion this stress intensification factor becomes too much for the steel to handle. Survey data was checked for comparison against the FEA stress multiplier model’s maximum peaking values and both maximums were comparable. The rate of change of the penstock inside radius on either side of the peaked seam for the stress multiplier model is much more gradual, therefore the actual stresses based on this geometry would be less than that of the current FEA model.

Preliminary cost estimates for six options have been presented as part of Report 2. Based on our analysis only one of the five options, Option 1, is feasible. After carefully reviewing the data collected, the yearly inspection of the completed refurbishments, and cost estimates it is Hatch’s belief that at this time refurbishment of the penstocks, Option 1, is the most desirable solution. With refurbishment of the remaining seams (removal of surface cracks, deposition of new weld metal where required) and the application of a new protective coating, the life of the penstocks could be extended for an additional 20 years. Further life extension could be accomplished depending on maintenance of the new coating, maintenance of existing backfill and maintaining the current reduction in rough zone operation.

Table 8-1: Penstock Cost Estimate Comparison

	Penstock No. 1	Penstock No. 2	Penstock No. 3	Total
1. Refurbish and Coat	$14,784,000	$15,414,000	$14,616,000	**$44,814,000**
2A. Replace Existing	$48,114,500	$48,114,500	$48,114,500	**$144,343,500**
2B. Replace Existing + Refurb	$22,599,500	$22,739,500	$22,529,500	**$67,868,500**
3. Install FRP Liner	$33,848,150	$34,478,150	$33,778,150	**$102,104,450**
4. Install Internal Reinforcement	$30,257,500	$30,887,500	$30,187,500	**$91,332,500**
5. Install Steel Liner	$39,710,300	$40,340,300	$39,640,300	**$119,690,900**
6. Encase Penstock in Concrete Ring	$41,155,800	$41,785,800	$41,085,800	**$124,027,400**

Construction methodologies, estimates and schedules associated with shortlisted options selected by Hydro will be examined in much greater detailed and presented in Report 3.

Appendix A
Testing Results Summary

A.1 Penstock No. 1 – 2016 Testing Summary

A.1.1 2016 Testing Results

Penstock No. 1 had three coupons removed and the following testing was completed on each sample:

- Radiographic Examination
- Macroetch Evaluation
- Microstructural Examination
- Vickers Hardness Traverse
- Transverse Weld Tensile Testing
- Weld Metal Chemical Analysis
- Base Metal Chemical Analysis

Penstock No. 1 had an analysis completed on internal samples that were coating the penstock (existing coating and organics) to determine the coating system used and for testing of organics. The following tests were performed for organics:

- Low Nutrient Bacteria (LNB)
- Iron-Related Bacteria (IRB)
- Anaerobic Bacteria (ANA)
- Acid-Producing Bacteria (APB)
- Sulfate-Reducing Bacteria (SRB)

A galvanic analysis was completed on the three coupons from Penstock No. 1.

A water analysis was completed in 2016 as part of the Penstock No. 1 testing.

A.1.2 ASTM A285 Gr. C Sample – Penstock No. 1 (Section 16)

As part of the root cause analysis performed in 2016-2017 for the assessment of Penstock No. 1, a 460 mm x 460 mm (18” x 18”) coupon was removed from Penstock No. 1 and sent for analysis. The test results are as follows.

Radiographic Examination

The radiographic examination showed no rejectable defects. Porosity was detected but was in the range of acceptable limits.

Macroetch Evaluation

A Photomacroetch of the weld was prepared from two different sections of the coupon etched in 2% Nital. A stereo microscope was then used to examine the samples for general comments on weld imperfections.

- Both sections showed a profile consistent with “Preferential Heat Affected Zone Corrosion”.
- Both sections exhibited cracks propagating from the toes of the weld.
- One section exhibited porosity on the face of the weld.

Microstructural Examination

The two sections used in the previous Vickers hardness traverse were re-prepared according to ASTM E3-11 for microstructural examination. The specimens were etched in 2% Nital and examined using an optical microscope at various magnifications. The examination was performed at and near the fusion line locations on either side of the weld, where cracks were observed in the macroexamination.

- Microstructure examination showed ferrite and pearlite in both specimens.
- Both specimens displayed a relatively coarse grain HAZ on either side of the FL locations.
- Both specimens displayed a more refined structured HAZ consisting of fairly uniform mixture of pearlite and ferrite on the FL+1mm locations.
- Viewing at a higher magnification, cavities can be seen at both weld toes. Both cavities were filled with corrosion product.
- Transgranular cracking was present within the corrosion cavities. Both cracks were propagating through the HAZ.

Vickers Hardness Traverse

Both macroetch sections were re-polished according to ASTM E3-11 and subjected to a Vickers Hardness Traverse. The Vickers Hardness readings were performed according to ASTM E92-16 using a 10kgf test force and indentations were measured at 100x magnification.

- Hardness values for the weld metal ranged from 169 to 198
- Hardness values for the HAZ ranged from 143 to 173
- Hardness values for the Base material ranged from 139 to 151

Hardness values are within the range of normal expected values for this type of material and E4918 (E7018) welding consumables.

Transverse Weld Tensile

- Ultimate Tensile Strength (UTS) of base metal = 69.5 ksi (480 MPa)

The tensile specimen fractured in the base metal indicating the UTS of the weld metal meets the requirements of being higher than the UTS of the base metal.

Weld Metal Chemical Analysis

The chemistry indicated on the attached report is consistent with an E4918 (E7018) electrode.

The sulphur content is below the maximum allowable of 0.035% (CSA W48, Table 1); however, according to Lincoln and Air Liquide specification sheets, the normal level of sulphur in the deposited weld metal for standard SMAW electrodes is 0.008% to 0.013% with E4918 (E7018) normally around 0.011%. Thus, even though the sulphur content is below the maximum allowable, it is 2X the normal percentage.

Base Metal Chemical Analysis

The base metal chemistry is consistent with ASTM A285 Gr C material.

Coating System Asbestos and Quantitation Test

Coating system was identified as a Coal Tar Epoxy.

No presence of asbestos was detected in the coating system.

A.1.3 CSA G40.8 Gr. B Sample – Penstock No. 1 (Section 17)

A 460 mm x 460 mm (18” x 18”) coupon of CSA G40.8B was removed from Penstock 1 (Section 17) for testing and incorporated a portion of one of the circumferential weld seams.

Radiographic Examination

The radiographic examination showed no rejectable defects. Porosity was detected but was in the range of acceptable limits.

Macroetch Evaluation

A Photomacroetch of the weld was prepared from two different sections of the coupon etched in 2% Nital. A stereo microscope was then used to examine the samples for general comments on weld imperfections.

- Both sections showed the weld had pitting along the inside diameter surface within the HAZ (at the weld toes).

- No cracks or inclusions were exhibited in either of the sections.
- Both sections showed there was complete penetration and complete fusion was observed throughout the weld.

Vickers Hardness Traverse

Both macroetch sections were re-polished according to ASTM E3-11 and subjected to a Vickers Hardness Traverse. The Vickers Hardness readings were performed according to ASTM E92-16 using a 10kgf test force and indentations were measured at 100x magnification.

- Hardness values for the weld metal ranged from 170 to 214
- Hardness values for the HAZ ranged from 168 to 214
- Hardness values for the Base material ranged from 174 to 185

Hardness values are within the range of normal expected values for this type of material and E4918 (E7018) welding consumables.

Microstructural Examination

The two sections used in the previous Vickers hardness traverse were re-prepared according to ASTM E3-11 for microstructural examination. The specimens were etched in 2% Nital and examined using an optical microscope at various magnifications. The examination was performed at and near the fusion line on either side of the weld and labeled “FL” and “FL+1mm” as instructed by the customer.

- Microstructure examination showed ferrite and pearlite in both specimens.
- Both specimens displayed a relatively coarse grain HAZ on either side of the FL locations.
- Both specimens displayed a more refined structured HAZ consisting of fairly uniform mixture of pearlite and ferrite on the FL+1 mm location.
- Some sulphide inclusions were found dispersed throughout the material at higher magnification.

Transverse Weld Tensile

- Ultimate Tensile Strength (UTS) of weld metal = 84.5 ksi (582.6 MPa)

The tensile specimen fractured in the weld zone in a ductile manner. Even though this test failed in the weld metal, the UTS of the weld metal is significantly higher than the normal UTS of the base metal.

Weld Metal Chemical Analysis

The chemistry indicated on the attached report is consistent with an E4918 (E7018) electrode.

The sulphur content is below the maximum allowable of 0.035% (CSA W48, Table 1); however, according to Lincoln and Air Liquide specification sheets, the normal level of sulphur in the deposited weld metal for standard SMAW electrodes is 0.008% to 0.013% with E4918 (E7018) normally around 0.011%. Thus, even though the sulphur content is below the maximum allowable at 0.018%, it is still above normal levels.

Total carbon, manganese, phosphorus, sulphur, and silicon values are all within specifications.

Base Metal Chemical Analysis

The base metal chemistry is consistent with CSA 40.8 Gr B material.

Total carbon, manganese, phosphorus, sulphur, and silicon values are all within composition specifications for UNS grade G15240 (1524) steel.

A.1.4 ASTM A285 Gr. C – Penstock No. 1 (Section 8)

A second coupon of ASTM A285 Gr. C was removed from Penstock No. 1 (Section 8). This coupon incorporated a portion of one of the circumferential weld seams.

Radiographic Examination

The radiographic examination showed no rejectable defects.

Macroetch Evaluation

A Photomacroetch of the weld was prepared from two different sections of the coupon etched in 2% Nital. A stereo microscope was then used to examine the samples for general comments on weld imperfections.

- Both sections showed the weld had pitting along the inside diameter surface within the HAZ (at the weld toes).
- No cracks or inclusions were exhibited in either of the sections.
- Both sections showed there was complete penetration and complete fusion was observed throughout the weld.

Vickers Hardness Traverse

Both macroetch sections were re-polished according to ASTM E3-11 and subjected to a Vickers Hardness Traverse. The Vickers Hardness readings were performed according to

ASTM E92-16 using a 10kgf test force and indentations were measured at 100x magnification.

- Hardness values for the weld metal ranged from 153 to 181
- Hardness values for the HAZ ranged from 121 to 158
- Hardness values for the Base material ranged from 130 to 158

Hardness values are within the range of normal expected values for this type of material and E4918 (E7018) welding consumables.

Microstructural Examination

The two sections used in the previous Vickers hardness traverse were re-prepared according to ASTM E3-11 for microstructural examination. The specimens were etched in 2% Nital and examined using an optical microscope at various magnifications. The examination was performed at and near the fusion line on either side of the weld, arbitrarily named “Side A” and “Side B” for CMTL identification purposes. These locations were labeled “FL” and “FL+1 mm” as instructed by the customer.

- Microstructure examination showed ferrite and pearlite in both specimens.
- Both specimens displayed a relatively coarse grain HAZ on either side of the FL locations; with “Side A” having more ferrite observed and “Side B” having more pearlite with a more distinct coarse grain HAZ.
- Both specimens displayed a more refined structured HAZ consisting of fairly uniform mixture of pearlite and ferrite on the FL+1mm locations.
- Some sulphide inclusions were found dispersed throughout the material at higher magnification.

Transverse Weld Tensile

- Ultimate Tensile Strength (UTS) of weld metal = 63.5 ksi (437.8 MPa)

The tensile specimen fractured in the weld zone in a ductile manner. Even though this test failed in the weld metal, the UTS of the weld metal is significantly higher than the normal UTS of the base metal.

Weld Metal Chemical Analysis

The chemistry indicated on the attached report is consistent with an E4918 (E7018) electrode.

The sulphur content is below the maximum allowable of 0.035% (CSA W48, Table 1); however, according to Lincoln and Air Liquide specification sheets, the normal level of sulphur in the deposited weld metal for standard SMAW electrodes is 0.008% to 0.013% with

E4918 (E7018) normally around 0.011%. Thus, even though the sulphur content is below the maximum allowable at 0.023%, it is still above normal levels.

Total Carbon, Manganese, Phosphorus, Sulphur, and Silicon values are all within specifications.

Base Metal Chemical Analysis

Chemical Analysis is similar to the chemical composition limits of ASTM A285 Grade C steel, with the exception of sulphur.

A.1.5 Organic Samples – Penstock No. 1

For the assessment conducted on Penstock No. 1 in 2016-2017, organic samples were taken and tested. The following organic tests were performed by Acuren (Mississauga, Ontario).

- Low Nutrient Bacteria (LNB)
- Iron-Related Bacteria (IRB)
- Anaerobic Bacteria (ANA)
- Acid-Producing Bacteria (APB)
- Sulfate-Reducing Bacteria (SRB)

Final readings of testing indicate the following:

- Negative readings for IRB and SRB
- Weak positive reading for LNB, ANA, and APB

A.1.6 Galvanic Testing

Potential difference measurements were taken on the three coupons removed from Penstock No. 1. They generally indicate that a galvanic cell between the weld metal and base metal is present and the weld metal, in particular the heat affected zone, was more susceptible to pitting corrosion than the base metal.

A.1.7 Water Analysis – Penstock No. 1

Water testing data was collected from 1965, 1980, 1988, 1992, 1993, 1994, 1995, 1996 and 2016. Testing between 1965 and 2016 yielded similar Langelier saturation index (LSI) results. However, the most recent water test indicates a change in water chemistry. We recommend additional testing to confirm these results.

The available data from 1965-2016 was used to compute the LSI, which is used to quantify the corrosive behavior of a specific water source. This calculation takes the pH, alkalinity, Total Dissolved Solids (TDS), temperature and calcium all into account rather than strictly depending on the pH value.

The LSI ranks water corrosion potential on a scale typically between -5 to 4, with -5 being highly corrosive and 4 having a high likely hood of scale buildup. When applying the LSI to the Bay d’Espoir water samples the following values were obtained:

Table A-1: LSI vs Water Sample Year

Year	LSI	Year	LSI
1965	-4.77	1994	-5.72
1980	-6.57	1995	-5.69
1988	-5.02	1996	-4.75
1992	-5.71	-	-
1993	-5.65	2016	-3.9

In several instances the LSI ratings calculated were outside of the typical range, indicating the water is more corrosive than typical water bodies. These values would indicate that the water flowing through the penstock would be considered highly corrosive.

A.2 2018 Testing Summary

A.2.1 Mechanical Testing - Penstock No. 3

Macro Examination

The photomacrograph in Figure A-1 below shows the appearance. The macro shows a clean weld exhibiting columnar weld grains with good fusion, no cracking or weld defects.

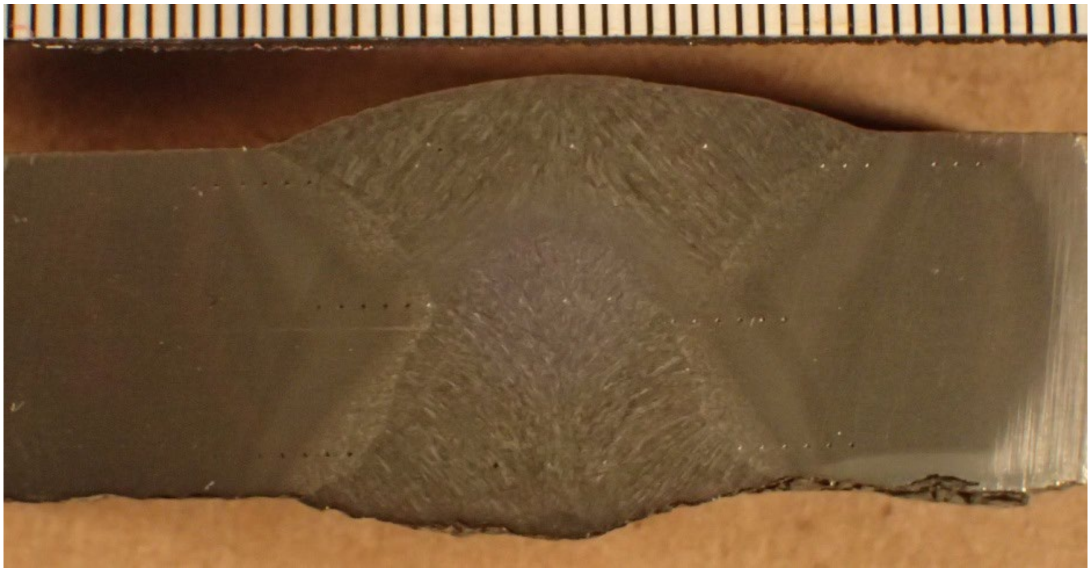

Figure A-1: Weld Macro Examination – Penstock 3

Microstructural Evaluation

A cross section of the weld was cut and prepared for a micro examination, polishing the cut to a 1µm finish and etched with a 5% Nital solution according to ASTM E3-11 standards. The micro examination revealed a fine grain, low carbon steel with few inclusions, typical of a structural quality steel.

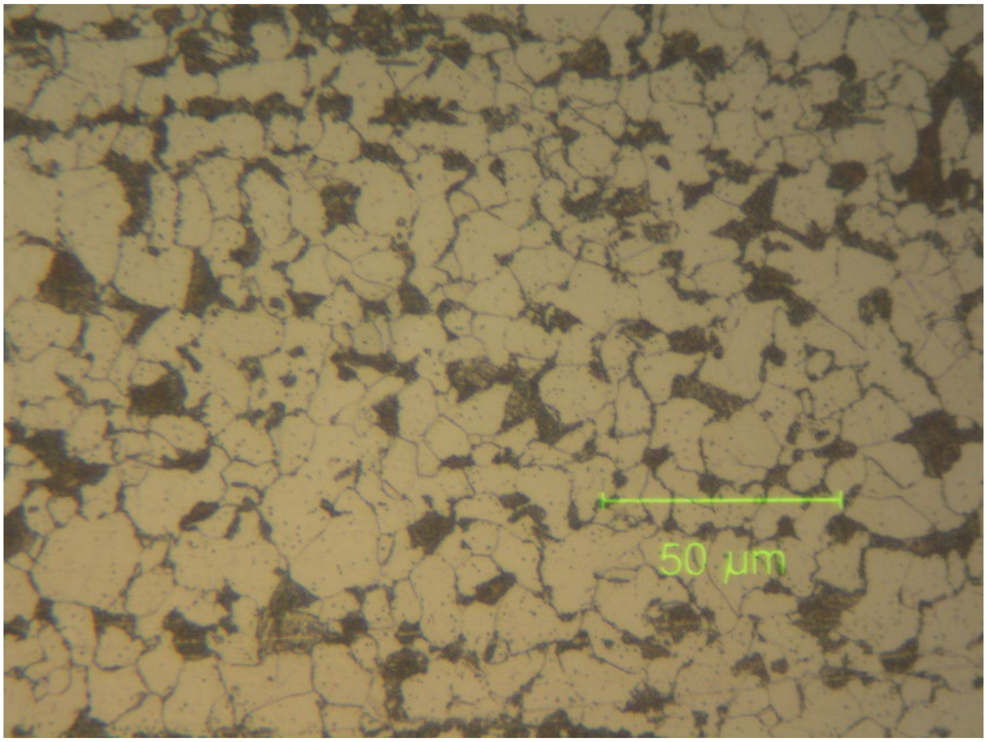

Figure A-2: Weld Micro Examination - Penstock 3

Vickers Hardness

Vickers hardness testing (HV10) using a 10-kg test load according to ASTM E3-11, was completed on the specimen. Three rows were tested according to ASTM E92-16 standards. Hardness values in these regions are stated below:

- Base Metal: 160 to 182 HV10
- HAZ: 183 to 223 HV10
- Weld: 183 to 201 HV10

Weld Tensile Results

Two specimens were sectioned and removed transverse to the weld in the sample using ASTM A370 specifications. The specimens were tested on a calibrated instron 8800 tensile machine with both resulting in a ductile fracture in the parent material. The numerical results are noted in the table below.

Table A-2: Tensile Tests Results - Penstock 3 Coupon

Sample	Area (in^2)	Load (lbs)	UTS (ksi)	Type of Fracture	Location
T1	0.429	31 880	74.3	Ductile	Parent
T2	0.422	34 510	81.8	Ductile	Parent

Weld / Base Metal Chemical Analysis

A sample from both the plate and weld metal were analyzed using a conventional ICP instrument following ASTM D1976 Standard to determine the metal's chemistry. The material was found to be plain carbon steel with no significant amounts of nickel, chromium or molybdenum. The table summarizes both plate and weld metal chemistry in comparison with ASTM A612 and A285 standards.

Table A-3: Penstock No. 3 Coupon Chemical Analysis

Elements	Chemical Composition (%wt.)			
	Plate Metal	Weld Metal	ASTM A612	ASTM A285
Carbon	0.15	0.1	0.25 Max	0.28 Max
Nickel	0.02	0.02	Trace	-
Sulphur	0.023	0.021	0.05 Max	0.035 Max
Chromium	0.02	0.02	Trace	-
Aluminum	Trace	Trace	Trace	-
Copper	0.03	0.06	0.35 Max	-
Manganese	1.41	1.49	1.00-1.50	0.98 Max
Molybdenum	Trace	0.01	Trace	-
Silicon	0.44	0.40	0.15-0.50	-
Phosphorus	0.021	0.024	0.04 Max	0.035 Max

The plate sample is not consistent with the chemical requirements of ASTM A285. The manganese content found exceeds the max %wt, and the levels of silicon exceed that of

A285 as well. Based on the report, the chemical composition indicates it is more suited towards the ASTM A612 standard.

Charpy Impact Testing

Twelve charpy specimens were machined from the welded plate to meet dimensional requirements of ASTM A370. The specimens were cut transversely to the weld with notch for testing perpendicular to the top and bottom surfaces of the plate. The specimens were chilled in a bath for at least 10 minutes to obtain a test temperature of -20°C. The bath was monitored and calibrated with a digital thermometer along with the charpy impact machine verified as per ASTM E23. The testing was completed on full size charpy impact specimens (10mm x 10mm), which can be seen in the table below.

Table A-4: Penstock No. 3 Coupon – Charpy Impact Testing Results

RPC ID	Notch Location	Test Temperature (°C)	Energy Absorbed		Average Energy Absorbed Ft-lbs (Joules)
			Ft - lbs	Joules	
2315	WC	-20	12	16.2	11.6 ft-lbs (15.8 J)
2316	WC	-20	11	14.9	
2317	WC	-20	12	16.2	
2318	FL	-20	13	17.6	12.1 ft-lbs (16.5 J)
2319	FL	-20	10	13.6	
2320	FL	-20	13.5	18.3	
2321	FL +2	-20	75	101.7	60.5 ft-lbs (82 J)
2322	FL +2	-20	71	96.2	
2323	FL +2	-20	35.5	48.1	
2324	FL +5	-20	71.5	96.9	68.8 ft-lbs (93.4 J)
2325	FL +5	-20	67	90.8	
2326	FL +5	-20	68	92.2	

Where:

- WC = Weld Center
- FL = Fusion Line of Weld
- FL+2 = Fusion Line +2 mm FL+5 = Fusion Line +5 mm

A standard consumable used for welding of steels for Penstocks No. 1, 2, and 3 during the timeframe of construction would be that of the SMAW E6010/6011 or E7018. A typical impact energy value of ASTM A285 Grade C and a E6010/6011 or E7018 would produce a minimum average impact energy of 27 J at -20°C. Given that the base metal sample is suspected to be of a higher grade of steel, the impact energies for the FL+2 and FL+5 appear to be reasonable. However, the weld metal and HAZ samples produced below average impact energies.

A.2.2 Penstock No. 1 and No. 3 Mechanical Testing Comparison

RPC indicates the coupon analyzed from Penstock No. 3 to be most consistent with ASTM A612. Of the three coupons taken from Penstock No. 1, the CSA G40.8B coupon is most mechanically similar to the ASTM A612. The report conducted by RPC compared the Penstock No. 3 sample to the ASTM A285 standard whereas the results and drawings align with the CSA G40.8 Gr. B standard. The mechanical testing for 2016 was conducted by Cambridge Materials (Mississauga, Ontario). For more accurate and comparable results, it would be beneficial to conduct all mechanical testing at the same facility (reduce lab error), have the same format of testing completed on all samples.

Microstructural

Samples were prepared for microstructural examination and the Penstock No. 1 coupon was etched using a 2% Nital solution whereas Penstock No. 3 used a 5% Nital solution. The micrograph of the Penstock No. 3 coupon was completed on the base metal and shows a fine grain low carbon steel with few inclusions. The Penstock No. 1 coupon micrograph was completed on the fusion line (FL) and FL+1mm locations noting some sulphide inclusions present dispersed throughout the material and a HAZ with a refined and relatively coarse grain structure.

Vickers Hardness

The table below compares the hardness values obtained from the two separate samples in Penstock No. 1 along with the recent RPC test results for Penstock No. 3.

Table A-5: Vickers Hardness Results

Vickers Number	Penstock 1 Sample – ASTM A285			Penstock 3 Sample			Penstock 1 Sample – CSA G40.8 Gr B		
	Base Metal	HAZ	Weld Metal	Base Metal	HAZ	Weld Metal	Base Metal	HAZ	Weld Metal
Low	130	121	153	160	183	183	174	168	170
High	158	158	181	182	223	201	185	214	214

It can be noted that the Penstock No. 3 hardness test results correlate best with the Penstock No. 1 CSA G40.8B hardness numbers (right section of table).

Weld Tensile

The tensile test results below show a comparative summary between the 2016 samples for penstock 1 and 2018 samples for penstock 3.

Table A-6: Tensile Test Results

Sample	UTS (ksi)	Type of Fracture	Location	Standard Range (ksi)
Penstock 3 T1 (A612)	74.3	Ductile	Parent	81-101
Penstock 3 T2 (A612)	81.8	Ductile	Parent	81-101
Penstock 1 CSA G40.8 Gr B	84.5	Ductile	Parent	65-85
Penstock 1 ASTM A285	63.5	Ductile	Parent	55-75

RPC indicated the chemical analysis for the Penstock No. 3 coupon is most consistent with ASTM A612. Comparing the tensile test results with the A612 standard, the tensiles are slightly lower than standard.

A.2.3 Laser Scan and Inverts

The laser surveys of the interior of the penstocks was used to determine the interior shape of the penstock and confirm the level of peaking present. The results for each of the penstocks, was used to compare the level of deviation in ovality as shown in Table A-7. Table A-8 compares the level of peaking found at the welds as an average for all three Penstocks. Through analysis of the data, the location of the maximum and minimum weld deviation around the penstock for each section was noted and can be seen in Tables A-9 to A-11. Zero degrees was taken at the top of the penstock and continued clockwise around the penstock. Since the laser scan inspection completed by All North was only taken from the surge tank downward, Penstock 1 was only compared using this section.

Table A-7: Deviation in Penstock Ovality Comparison

	Location (m)	Length of Section (m)	# of Chainages in Section	Overall Average Deviations (mm)	Average Min. Deviation (mm)	Average Max. Deviation (mm)
Section 1	0.00-101.4 0.00-119.47	101.4 119.47	6 10	-3.96	-29.83	23.03
Section 2	101.4-200.49 119.47-244.53	99.09 125.06	3 8	-2.67	-25	35.04
Section 3	200.49-341.15 244.53-382.31	140.66 137.78	5 7	-2.18	-48.2	36.09
Section 4	341.15-433.65 382.31-492.46	92.5 110.15	3 5	-3.49	-60.33	30.68
Section 5	433.65-629.8 492.46-692.41	196.15 200.01	8 7	-4.43	-41.63	16.57
Section 6	692.41-953.37 628.8-889.64 692.41-953.37	260.96 260.84 260.96	12 9 9	-1.37	-16.79	17.11
Section 7	953.37-1163.48 889.64-1128.00 953.37-1163.48	210.11 238.36 210.11	11 10 6	-1.09	-35.32	20.40

Penstock 1
Penstock 2
Penstock 3

Table A-8: Peaking at Welds Comparison Across Penstocks No. 1, 2, and 3

	North Welds			South Welds		
	Average Peaking(mm)	Max. peak (mm)	Min. peak (mm)	Average Peaking (mm)	Max. peak (mm)	Min. peak (mm)
Section 1	5.1	60	-17	5.4	41	-23
Section 2	13.0	36	-6	16.8	56	-19
Section 3	6.8	29	-23	3.2	31	-30
Section 4	-2.4	28	-67	-4.8	17	-46
Section 5	1.7	24	-31	-2.1	18	-28
Section 6	3.7	35	-15	5.2	20	-12
Section 7	9.3	35	-21	7.6	27	-7

Table A-9: Penstock 1: Location of Max. and Min. Weld Deviation

	Penstock 1					
	Approximate Location of Max. Deviation (deg.)	Chainage that had Max. Deviation	Max. Deviation (mm)	Approximate Location of Min. Deviation (deg.)	Chainage that had Min. Deviation	Min. Deviation (mm)
Section 1						
Section 2						
Section 3						
Section 4						
Section 5						
Section 6	99	HZ Chainage 54.96	27.07	186.75	HZ Chainage 54.96	-30
Section 7	274.5	HZ Chainage 264.18	34.94		HZ Chainage 416.74	-86.78

Table A-10: Penstock 2: Location of Max. and Min. Weld Deviation

	Penstock 2					
	Approximate Location of Max. Deviation (deg.)	Chainage that had Max. Deviation	Max. Deviation (mm)	Approximate Location of Min. Deviation (deg.)	Chainage that had Min. Deviation	Min. Deviation (mm)
Section 1	261	HZ Chainage 43.17	60	165.5	HZ Chainage 73.46	-33
Section 2	60	HZ Chainage 180.70	26	201	HZ Chainage 180.70	-40
Section 3	69	HZ Chainage 233.35	53	349	HZ Chainage 208.53	-71
Section 4	278.5	HZ Chainage 346.11	50	177	HZ Chainage 346.11	-88
Section 5	293	HZ Chainage 629.68	27	161.5	HZ Chainage 469.96	-83
Section 6	78	HZ Chainage 705.21	21	178	HZ Chainage 867.23	-32
Section 7	288	HZ Chainage 1087.76	45	180	HZ Chainage 1087.76	-62

Table A-11: Penstock 3: Location of Max. and Min. Weld Deviation

	Penstock 3					
	Approximate Location of Max. Deviation (deg.)	Chainage that had Max. Deviation	Max. Deviation (mm)	Approximate Location of Min. Deviation (deg.)	Chainage that had Min. Deviation	Min. Deviation (mm)
Section 1	66	HZ Chainage 77.08	41.22	202.5	HZ Chainage 92.01	-48.86
Section 2	90	HZ Chainage 167.06	55.88	187	HZ Chainage 181.71	-51.04
Section 3	259	HZ Chainage 247.77	51.64	337.5	HZ Chainage 247.77	-47.8
Section 4	255	HZ Chainage 428.21	27.93	183	HZ Chainage 401.94	-51.97
Section 5	100.5	HZ Chainage 550.90	26.62	180	HZ Chainage 591.11	-48.82
Section 6	254	HZ Chainage 889.95	25.25	171.5	HZ Chainage 889.95	-61.75
Section 7	288.5	HZ Chainage 1066.55	32.7	181.5	HZ Chainage 1066.55	-94.63

Appendix B
Penstock Refurbishment Statistics

B.1 Weld Statistics

Table B-1: Longitudinal Weld Statistics - Penstock 1

Item	Description	Number	Units
1	2016 Total Seams Repaired/Refurbished	346	Count
2	2016 South Seams Repaired/Refurbished	173	Count
3	2016 North Seams Repaired/Refurbished	173	Count
4	2017 Longitudinal Seams Repaired/Refurbished	31	Count
5	Repaired/Refurbished 2016 – Inspected 2017 Internal Longitudinal Seams with Defects	29	Count
6	2017 Welds Showing Defects from Original Construction	2	Count
7	2017 South Internal Seams Repaired/Refurbished	10	Count
8	2017 North Internal Seams Repaired/Refurbished	21	Count
9	2018 Internal Seams Not Inspected	678	Count
10	2018 Total Seams Repaired/Refurbished	1	Count
11	2018 Inspection Passed on Refurbished Welds	46	Count
12	2018 Inspection Passed on Original Welds	28	Count
13	Seam Total (Intake to Powerhouse)	870	Count
14	Approximate Visual (VT) and Magnetic Particle (MT) Length 2018	1098	ft
15	Approximate Seam Repair/Refurbishment Length 2017	279	ft
16	Approximate Seam Repair/Refurbishment Length 2016	3114	ft
17	Approximate 2016 Repair/Refurbishment Vs Total Penstock	39.77	%
18	Approximate 2017 Repair/Refurbishment Vs Total Penstock	3.56	%
19	2017 Defects on 2016 Welds	8.38	%
20	2018 defects on 2017 Welds	0.00	%
21	2018 defects on Original Weld	1.52	%

Table B-2: Longitudinal Weld Statistics - Penstock 2

Item	Description	Number	Units
1	2017 Longitudinal Seams Repaired/Refurbished	182	Count
2	2017 Welds Showing Defects from Original Construction	182	Count
3	2017 South Internal Seams Repaired/Refurbished	91	Count
4	2017 North Internal Seams Repaired/Refurbished	91	Count
5	2018 Internal Seams Not Inspected	384	Count
6	2018 Total Seams Repaired/Refurbished	2	Count
7	2018 Total North Seams Repaired/Refurbished	2	Count
8	2018 Total South Seams Repaired/Refurbished	0	Count
9	2018 Inspection Passed on Refurbished Welds	18	Count
10	2018 Inspection Passed on Original Welds	98	Count
11	Seam Total (Intake to Powerhouse)	870	Count
12	Approximate Visual (VT) and Magnetic Particle (MT) Length 2018	702	ft
13	Approximate Seam Repair/Refurbishment Length 2017	2492	ft
14	2017 defects on Original Welds	21	%
15	2018 defects on 2017 Welds	0.00	%
16	2018 defects on Original Weld	2.30	%

Table B-3: Longitudinal Weld Statistics - Penstock 3

Item	Description	Number	Units
1	2018 Internal Seams Not Inspected	347	Count
2	2018 Total Seams Repaired/Refurbished	390	Count
3	2018 Total South Seams Repaired/Refurbished	192	Count
4	2018 Total North Seams Repaired/Refurbished	198	Count
5	2018 Inspection Passed on Refurbished Welds	0	Count
6	2018 Inspection Passed on Original Welds	171	Count
7	Seam Total (Intake to Powerhouse)	870	Count
8	Approximate Seam Repair/Refurbishment Length 2018	3369	ft
9	2018 defects on Original Weld	48.75	%

Appendix C
Penstock Condition Assessment Trackers

Date: July 16th 7:30

PENSTOCK 1 WELD PROGRESS TRACKER

North		NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	
SECTION #		1																			2		3		4	5	6	7	8																																	
CAN#	INTAKE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	A
Other																											RW										RW			MH							RW									RW						
South		NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	

North		NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	FP	FP	NI	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	
SECTION #		9	10	11	12																									13	15	16																							
CAN#	A	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	B
Other								RW	MH							RW													DP	RW		RW	RW	RW	DP	IP	IP	RW	RW	RW	RW	RW	RW										RW		
South		NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	FP	FP	NI	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	

North		NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	
SECTION #		17																										18	70	72	74	20	21																	117												
CAN #	B	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	C
Other											RW						MH					RW								RW											RW										RW										RW	
South		NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	

ADDITIONAL SCOPE (cans 210–220)

North		NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	
CAN #	C	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	D
Other											OW										OW												OW					OW	OW	OW	OW	OW	OW	OW	OW	OW	OW	OW														
South		NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	FP	FP	FP	FP	FP	WR	FP	FP	FP	FP	FP	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	

North		NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	
CAN #	D	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	E
Other																	IT?										ST	ST										IT?										IT?														
South		NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	

North		NI	FP	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	
CAN #	E	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	F
Other																																																														
South		NI	FP	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	

North		NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	
CAN #	F	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	PH
Other																																																	
South		NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	

Legend		
NI	=	NOT INSPECTED
PW	=	PRESSURE WASHED
P	=	Weld Preperation Complete
FP	=	Final Inspection Passed
FF	=	Final Inspection Failed
WR	=	Weld Repair
FIP	=	Final Inspection Passed
IT?		Possible Intstrument Tee Location
ST	=	SURGE TANK
RW	=	REFUBISHED WELD
OW	=	ORIGINAL WELD
MH	=	MAN HOLE

Date: 3/28/2019
Rev: E

PENSTOCK 2 WELD PROGRESS TRACKER

North		NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	
SECTION #		1																			2		3		4	5	6	7	8																																	
CAN#	INTAKE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	A
Other																					RW										RW									MH	RW								RW							RW					RW	
South		NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	

North		NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	
SECTION #		9	10	11	12																									13	15	16																							
CAN#	A	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	B
Other									MH			RW									RW								RW													OW						SPI		NPI	OW				
South		NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	FP	NI	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	

North		EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	
SECTION #		17																			17							18	70	72	74	20	21																	117													
CAN #	B	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	C
Other								OW					NPI				MH			SPI								OW		NPI																																
South		EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	

North		EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EFP	EFP	EFP	EFP	EFP	WR	EFP	EFP	EFP	
CAN #	C	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	D
Other														SPI	NPI	SPI	NPI	OW	NPI		NPI							OW										OW										OW														
South		EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EFP	EFP	EFP	EFP	EFP	FP	EFP	EFP	EFP	

North		EFP	EFP	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EFP	EFP	EFP	EFP	EFP	WR	EFP	EFP	EFP	EFP	EFP	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	
CAN #	D	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	E
Other													SPI	NPI		SPI	NPI			NPI	NPI		ST	ST	ST			SPI	NPI	NPI	NPI	SPI																NPI	NPI	NPI	NPI	SPI	NPI				SPI	SPI	SPI			
South		EFP	EFP	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	EPW	FP	EPW	EPW	EPW	EPW	EFP	EFP	EFP	EFP	EFP	FP	EFP	EFP	EFP	EFP	EFP	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	

North		NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	
CAN #	E	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	F
Other			SPI																																																	NPI	NPI				NPI	NPI	NPI	SPI	SPI	
South		NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	

North		NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	
CAN #	F	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	PH
Other		SPI	SPI	SPI																																													
South		NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	FP	

Legend		
NI	=	NOT INSPECTED
PW	=	PRESSURE WASHED
P	=	Weld Preperation Complete
FP	=	Final Inspection Passed
FF	=	Final Inspection Failed
WR	=	Weld Repair
FIP	=	Final Inspection Passed
EPW	=	PRESSURE WASHED
EP	=	Weld Preperation Complete
EFP	=	Final Inspection Passed
EFF	=	Final Inspection Failed
EWR	=	Weld Repair
EFIP	=	Final Inspection Passed
SPI	=	SOUTH INSPECTED 2017
NPI	=	NORTH INSPECTED 2017
ST	=	SURGE TANK
RW	=	REFUBISHED WELD
OW	=	ORIGINAL WELD
MH	=	MAN HOLE

Date: June 24, 2018

PENSTOCK 3 WELD PROGRESS TRACKER

Intake

CAN#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
North	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP
South	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP

Doorsheet #1 Location (CAN 63)

Doorsheet #2 Location (CAN 89)

Tested Seams (94–100) · Tested Seams (105–111) · Tested Seams (114–120)

Appr

CAN#	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
North	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP
South	FP	FP	FP	FP	NI	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP

Tested Seams (125–130)

Doorsheet #3 Location (CAN 175)

CAN #	121	122	123	124	125	126	127	128	129	130	131	132	132b	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
North	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	NI	FP	FP	FP	FP	FP	FP	FP	NI	NI	FP	FP	NI	NI	FP	NI	FP	NI	FP	NI	FP	NI	FP	FP	FP	NI	FP	FP	FP	NI	FP	FP	FP	NI	NI	NI	NI	NI	FP	NI	NI	FP	FP	NI	NI	NI	NI	NI
South	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	NI	FP	FP	FP	FP	FP	NI	NI	NI	FP	NI	NI	NI	FP	NI	NI	NI	NI	NI	FP	FP	NI	FP	FP	NI	NI	NI	NI	NI	FP	FP	FP	NI	FP	NI	FP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI

Approx. Manway #2 Location (CAN 232)

Surge Tank (CAN 235)

CAN #	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240
North	NI	NI	NI	NI	NI															NI	NI	NI	NI	NI	FP	NI	NI	NI	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	FP	NI	FP	FP	NI	NI	NI	NI	NI	NI	NI	NI				NI	NI				CH	
South																NI				NI	NI	NI	NI	NI	FP	FP	NI	FP	FP	FP	FP	FP	NI	FP	FP	NI	FP	NI	FP	FP	NI	FP	FP	FP	FP	NI	NI	NI	NI	NI	NI	NI								

CAN#	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
North							NI								NI													NI	NI							NI					NI					NI					NI		NI	NI	NI	NI	NI	NI	NI	NI
South						NI										NI									NI	NI									NI																				CH	NI	NI	NI	NI	NI

CAN#	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360
North	NI		FP	FP	FP	FP	NI	NI	NI	FP	NI	FP	FP	FP	FP	FP	FP	NI	FP	FP	FP	NI	FP	NI	NI	FP	FP	NI	FP	FP	FP	FP	FP	NI	FP	NI	NI	FP	NI	FP	NI	FP		NI		NI	NI	NI	NI	NI		NI	NI			NI		NI		
South	NI	FP		NI	NI	NI	FP	FP	FP	FP	NI	NI	FP	FP	FP	FP	FP	FP	FP	FP	FP	NI	NI	NI	NI	FP	FP	FP	FP	FP	NI	FP	NI	FP	FP	FP	FP	NI	NI	FP	NI	FP		NI		NI	NI	NI	NI	NI										

CAN#	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420
North		CH										NI																	NI										NI																					
South						NI														NI																																								

Legend		
NI	=	No Indications
CH	=	Chipped
G	=	Gouged
P	=	Weld Preperation Complete
1P	=	First Inspection Passed
W	=	Welded
PIP	=	Preliminary Inspection Pass
FP	=	Final Inspection Passed
FF	=	Final Inspection Failed

newfoundland labrador
hydro
a nalcor energy company

BAY D'ESPOIR
PENSTOCK 3 INSPECTION TRACKER

Date: June 21, 2018

North				I, F	I, F	I, F	I, F	I, F	I, F	I, F								I, F	I, F	I, F		I, F		I, F		NI				I, F	I, F	I, F	I, F		I, F				I, F		I, F				I, F	I, F	I, F	I, F	I, F		I, F
CAN #	INTAKE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
South							I, F	I, F	I, F		I, F	I, F	I, F	I, F	I, F	I, F							I, F				I, F	I, F						I, F		I, F			I, F		I, F										I, F
		ASTM A285 11mm Plate																																																	

Doorsheet #1 Location (north)

Doorsheet #2 Location (north)

North									I, F	I, P					I, F					I, F					I, F					I, P				I, F											I, F	I, F	I, F	I, F	I, F	I, F	I, F		
CAN #	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
South					I, F					I, F		I, F	I, F	I, F	NI	I, F	I, P	I, F	I, F	I, P	I, F	I, F	I, F	I, F	I, F	I, F	I, F		I, F	I, P	I, F	I, P	I, F	I, F	I, F	I, F	I, F	I, F	I, F	I, F	I, F	I, P	NI	NI	I, P	I, F	I, P	I, F	I, F	I, F	NI	NI	I, F
	ASTM A285 11mm Plate																																												G40.8B 11mm Plate								

Approx. Manway #1 Location

Elbow #3C

North			I, F	I, F	I, F	I, P	I, F	I, F					I, F	I, F	I, P	I, P	I, F						I, F	I, F	I, F	NI	I, F	NI	I, F	I, F	NI	NI	I, P	I, P	I, F	I, F	I, F	I, F	NI	NI	I, F	I, P	NI	NI	I, P	NI	I, P	NI	I, P	NI	I, P	NI	I, F
CAN #	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132A	132B	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155
South	I, F	I, F	I, F	I, F	I, P	I, P	I, F	I, P	I, P	I, F	I, F	NI	I, F	NI	NI	I, P	NI	NI	I, P	NI	I, P	I, P	I, F	I, P	I, P	I, P	I, F	NI	NI	I, F	NI	NI	NI	I, P	NI	NI	I, F	I, P	NI	NI	NI	I, P	NI	NI	NI	I, P	NI	NI	NI	NI	NI	I, P	I, P
	G40.8B 11mm Plate																												G40.8B, 14.3mm THK				G40.8B, Can 136/137=11mm THK, 138 to 156=14.3mm THK																				

Elbow #4C

Doorsheet #3 Location (south)

North	I, P	I, P	NI	I, P	I, P	I, F	NI	I, F	I, F	I, F	NI	NI	NI	NI	NI	I, F	NI	NI	I, P	I, P	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI							NI								NI	NI	NI	NI	NI	I, P	NI	NI	NI
CAN #	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208
South	NI	I, P	I, P	NI	NI	NI	NI	NI	NI	I, P	I, P	NI	I, F	NI	I, F	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI												NI				NI				NI	NI	NI	NI	NI	I, F	I, F	NI	I, F
	G40.8B, 14.3mm THK									G40.8B, 19.05mm THK				G40.8B, 15.875mm THK																									G40.8B, 15.875mm to 17.4625mm THK												OX522-D		

Coupon taken (north)

Approx. Manway #2 Location

Reducer

North	I, F	I, F	I, F	I, F	I, F	I, F	I, F	I, F	I, F	I, F	I, F	NI	I, F	I, F	NI	NI	NI	NI	NI	NI	NI	NI				NI		NI			NI	I, P	NI							NI								NI				
CAN #	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	SURGE TANK	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259
South	I, P	I, P	I, P	I, P	NI	I, F	I, F	NI	I, F	NI	I, F	I, P	NI	I, F	I, P	I, F	I, P	NI	NI	NI	NI	NI	NI	NI							NI								NI										NI			
	OX522-D, 15.875mm to 16.59mm THK																G40.8B, 19.05mm THK																																				

Doorsheet #4 Location (north)

Elbow #7C

North						NI				NI							NI					NI					NI					NI		NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	I, F	I, F	I, F	I, F	NI	NI	NI	I, P	NI	I, F
CAN #	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312
South							NI									NI											NI									NI		NI	NI	NI	NI	NI	I, P	NI	NI	NI	NI	I, P	I, F	I, P	I, P	NI	NI

Approx. Manway #3 Location

Coupon taken (north)

North	I, F	I, F	I, F	I, F	I, F	NI	I, F	I, F	I, F	NI	I, F	NI	NI	I, F	I, P	NI	I, P	I, P	I, F	I, P	I, P	NI	I, F	NI	NI	I, P	NI	I, F	NI	I, F	NI	NI	NI	NI	NI	NI	NI	NI		NI	NI			NI		NI				I, P			
CAN #	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365
South	I, F	I, F	I, F	I, F	I, F	I, F	I, P	I, F	I, F	NI	NI	NI	NI	I, F	I, P	I, P	I, P	I, F	NI	I, P	NI	I, P	I, P	I, P	I, P	NI	NI	I, P	NI	I, P	NI	NI	NI	NI	NI	NI	NI	NI									NI						

Elbow #9C

Elbow #8C

North							NI																	NI										NI	
CAN #	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
South	NI														NI																				

Elbow #10C

LEGEND	
No Indications (of Inspected)	NI
Indications - Partial Seam	I, P
Indications - Full Seam	I, F

Appendix D
Cost Tables

Estimate - Refurbishment BDE
Price Per 3 Penstocks

No.		Description	Quantity	Unit	$/Unit	Hours	$/Hour	Material Cost	Labour Cost	Cost	Comments
1	**Excavation**										
1.1		Excavation and backfill re-instatement of buried Penstock	3000	m3	$20					$60,000	
2	**Welding / Labour**										
2.1		Welding repair of longitudinal weld seams - Penstock No. 1	675	m	$2,000					$1,350,000	All in Rates from previous penstock repair
2.2		Welding repair of longitudinal weld seams - Penstock No. 2	900	m	$2,000					$1,800,000	All in Rates from previous penstock repair
2.3		Welding repair of longitudinal weld seams - Penstock No. 3	650	m	$2,000					$1,300,000	All in Rates from previous penstock repair
2.4		Welding repair of circumferential weld seams - Penstock No. 1	3000	m	$2,000					$6,000,000	All in Rates from previous penstock repair
2.5		Welding repair of circumferential weld seams - Penstock No. 2	3000	m	$2,000					$6,000,000	All in Rates from previous penstock repair
2.6		Welding repair of circumferential weld seams - Penstock No. 3	3000	m	$2,000					$6,000,000	All in Rates from previous penstock repair
2.7		Removal of doorsheets for entry (6 each)	18			10	$100		4	$72,000	
2.8		Re-installation of removed doorsheets (6 each)	18			10	$150		4	$108,000	
2.9		Safety personnel / rescue attendants - Penstock 1								$130,000	
2.10		Safety personnel / rescue attendants - Penstock 2								$130,000	
2.11		Safety personnel / rescue attendants - Penstock 3								$60,000	
3	**Blast / Recoat**										
3.1		Blast to bare metal and recoat penstock interior		3	$3,000,000					$9,000,000	
3.2											
4	**Mobilization**										
4.1		Mobilization / Demobilization was estimated at 10% of the total.								$3,201,000	
5	**EPCM**										
5.1		EPCM costs were estimated at 10% of the total.								$3,201,000	
6	**Contingency**										
6.1		Contingency was estimated at 20% of the total.								$6,402,000	
7	**Total**									**$44,814,000**	

Estimate - Replacement BDE

Price per 1 Penstock

No.		Description	Quantity	Unit	$/Unit	Hours	$/Hour	Material Cost	Labour Cost	Cost	Comments
1	**Excavation**										
1.1		Excavation and backfill re-instatement of buried Penstock	25000	m3	$20					$500,000	
2	**Welding / Labour**										
2.1		Replacement steel for each Penstock (fab and shipping)	2700	tonnes	$8,000					$21,600,000	
2.2		Safety personnel and rescue attendants	40	days		10	$100		2	$80,000	
2.3		Cranes	200	days	$2,500					$500,000	
2.4		Site Labour	200	days		10	$150		15	$4,500,000	
2.5		Reinforcing Steel	125	tonnes	$8,000					$1,000,000	
2.6		Install reinforcing steel								$187,500	
2.7		Demo of existing Penstock								$1,000,000	
4	**Blast / Recoat**										
4.1		Coating Penstock Internal and External	1							$5,000,000	
5	**Mobilization**										
5.1		Mobilization / Demobilization was estimated at 10% of the total.								$3,436,750.00	
6	**EPCM**										
6.1		EPCM costs were estimated at 10% of the total.								$3,436,750.00	
7	**Contingency**										
7.1		Contingency was estimated at 20% of the total.								$6,873,500.00	
8	**Total**									$48,114,500	

Estimate - Replacement BDE - Replace 17' ID and Refurb the rest

Price per 3 Penstock

No.		Description	Quantity	Unit	$/Unit	Hours	$/Hour	Material Cost	Labour Cost	Cost	Comments
1	**Excavation**										
1.1		Excavation and backfill re-instatement of buried Penstock	5000	m3	$20					$300,000	
2	**Welding / Labour**										
2.1		Welding repair of longitudinal weld seams - Penstock No. 1	675	m	$2,000					$1,350,000	All in Rates from previous penstock repair
2.2		Welding repair of longitudinal weld seams - Penstock No. 2	725	m	$2,000					$1,450,000	All in Rates from previous penstock repair
2.3		Welding repair of longitudinal weld seams - Penstock No. 3	650	m	$2,000					$1,300,000	All in Rates from previous penstock repair
2.4		Welding repair of circumferential weld seams - Penstock No. 1	2000	m	$2,000					$4,000,000	All in Rates from previous penstock repair
2.5		Welding repair of circumferential weld seams - Penstock No. 2	2000	m	$2,000					$4,000,000	All in Rates from previous penstock repair
2.6		Welding repair of circumferential weld seams - Penstock No. 3	2000	m	$2,000					$4,000,000	All in Rates from previous penstock repair
2.7											
2.8		Replacement steel for each Penstock (all in cost) - 17' ID	665	tonnes	$8,000				3	$15,960,000	
2.9		Safety personnel and rescue attendants	50	days		10	$100		2	$300,000	
2.10		Cranes	75	days	$1,000					$225,000	
2.11		Site Labour	75	days		10	$150		15	$5,062,500	
2.12		Demo of existing Penstock (135 cans)							3	$900,000	
3	**Blast / Recoat**										
3.1		Coating Penstock Internal and External (17') + internal for remainder	3							$9,630,000	
4	**Mobilization**										
4.1		Mobilization / Demobilization was estimated at 10% of the total.								$4,847,750.00	
5	**EPCM**										
5.1		EPCM costs were estimated at 10% of the total.								$4,847,750.00	
6	**Contingency**										
6.1		Contingency was estimated at 20% of the total.								$9,695,500.00	
7	**Total**									**$67,868,500**	

Estimate - FRP BDE
Price per 3 Penstocks

No.		Description	Quantity	Unit	$/Unit	Hours	$/Hour	Material Cost	Labour Cost	Cost	Comments
1	**Excavation**										
1.1		Excavation and backfill re-instatement of buried Penstock	3000	m3	$20					$60,000	
1.2											
2	**Welding**										
2.1		Welding repair of longitudinal weld seams - Penstock No. 1	675	m	$2,000					$1,350,000	
2.2		Welding repair of longitudinal weld seams - Penstock No. 2	900	m	$2,000					$1,800,000	
2.3		Welding repair of longitudinal weld seams - Penstock No. 3	650	m	$2,000					$1,300,000	
2.4		Welding repair of circumferential weld seams - Penstock No. 1	3000	m	$2,000					$6,000,000	
2.5		Welding repair of circumferential weld seams - Penstock No. 2	3000	m	$2,000					$6,000,000	
2.6		Welding repair of circumferential weld seams - Penstock No. 3	3000	m	$2,000					$6,000,000	
2.7		Removal of doorsheets for entry (6 each)	18			10	$100		4	$72,000	
2.8		Re-installation of removed doorsheets (6 each)	18			10	$150		4	$108,000	
2.9		Safety personnel and rescue attendants [x3 Penstocks]	30	days		10	$100		2	$180,000	
3	**Blast / Recoat**										
3.1		Water blasting to bare metal	15830	m2	$25				3	$3,561,750	
3.2		FRP Liner		1					3	$46,500,000	
4	**Mobilization**										
4.1		Mobilization / Demobilization was estimated at 10% of the total.								$7,293,175.00	
5	**EPCM**										
5.1		EPCM costs were estimated at 10% of the total.								$7,293,175.00	
6	**Contingency**										
6.1		Contingency was estimated at 20% of the total.								$14,586,350	
7	**Total**									**$102,104,450**	

Estimate - Reinforce BDE
Price per 3 Penstock

No.		Description	Quantity	Unit	$/Unit	Hours	$/Hour	Material Cost	Labour Cost	Cost	Comments
1	**Excavation**										
1.1		Excavation and backfill re-instatement of buried Penstock	3000	m3	$20					$60,000	
2	**Labour**										
2.1		Welding repair of longitudinal weld seams - Penstock No. 1	675	m	$2,000					$1,350,000	
2.2		Welding repair of longitudinal weld seams - Penstock No. 2	900	m	$2,000					$1,800,000	
2.3		Welding repair of longitudinal weld seams - Penstock No. 3	650	m	$2,000					$1,300,000	
2.4		Welding repair of circumferential weld seams - Penstock No. 1	3000	m	$2,000					$6,000,000	
2.5		Welding repair of circumferential weld seams - Penstock No. 2	3000	m	$2,000					$6,000,000	
2.6		Welding repair of circumferential weld seams - Penstock No. 3	3000	m	$2,000					$6,000,000	
2.7		Removal of doorsheets for entry (6 each)	18			10	$100		4	$72,000	
2.8		Re-installation of removed doorsheets (6 each)	18			10	$150		4	$108,000	
2.9		Install interior reinforcing								$1,327,500	
2.10		Conduct roundness correction on Penstock	1200	can		10	$100		3	$10,800,000	
2.11		Safety personnel and rescue attendants [x3 Penstocks]	30	days		10	$100		2	$180,000	
3	**Material**										
3.1		Installation of steel reinforcing plates (x3 Penstocks)	885	tonnes	$8,000				3	$21,240,000	
4	**Blast / Recoat**										
4.1		Blast to bare metal and recoat penstock interior	1						3	$9,000,000	
5	**Mobilization**										
5.1		Mobilization / Demobilization was estimated at 10% of the total.								$6,523,750.00	
6	**EPCM**										
6.1		EPCM costs were estimated at 10% of the total.								$6,523,750.00	
7	**Contingency**										
7.1		Contingency was estimated at 20% of the total.								$13,047,500	
9	**Total**									**$91,332,500**	

Estimate - Steel Liner BDE
Price per 3 Penstock

No.		Description	Quantity	Unit	$/Unit	Hours	$/Hour	Material Cost	Labour Cost	Cost	Comments
1	**Excavation**										
1.1		Excavation and backfill re-instatement of buried Penstock	9000	m3	$20					$180,000	
2	**Labour / Materials**										
2.1		Welding repair of longitudinal weld seams - Penstock No. 1	675	m	$2,000					$1,350,000	
2.2		Welding repair of longitudinal weld seams - Penstock No. 2	900	m	$2,000					$1,800,000	
2.3		Welding repair of longitudinal weld seams - Penstock No. 3	650	m	$2,000					$1,300,000	
2.4		Welding repair of circumferential weld seams - Penstock No. 1	3000	m	$2,000					$6,000,000	
2.5		Welding repair of circumferential weld seams - Penstock No. 2	3000	m	$2,000					$6,000,000	
2.6		Welding repair of circumferential weld seams - Penstock No. 3	3000	m	$2,000					$6,000,000	
2.7		Cranes	200	days	$1,000				3	$600,000	
2.8		Liner steel (all in cost)	1800	tonnes	$8,000	10	$150			$51,300,000	
2.9		HSS reinforcing (all in cost)	35	tonnes	$8,000				3	$840,000	
2.10		Jacking / Steel Placement Cost	200	days		10	$100		3	$1,800,000	
2.11		Rescue/Safety	200	months		10	$100		2	$1,200,000	
3	**Water Blast / Recoat**										
3.1		Coating steel liner internal	15830	m2	$150				3	$7,123,500	
4	**Mobilization**										
4.1		Mobilization / Demobilization was estimated at 10% of the total.								$8,549,350.00	
5	**EPCM**										
5.1		EPCM costs were estimated at 10% of the total.								$8,549,350.00	
6	**Contingency**										
6.1		Contingency was estimated at 20% of the total.								$17,098,700	
7	**Total**									**$119,690,900**	

Estimate - Steel Liner + Grouting BDE
Price per 3 Penstock

No.		Description	Quantity	Unit	$/Unit	Hours	$/Hour	Material Cost	Labour Cost	Cost	Comments
1	**Excavation**										
1.1		Excavation and backfill re-instatement of buried Penstock	3000	m3	$20					$60,000	
2	**Labour / Materials**										
2.1		Welding repair of longitudinal weld seams - Penstock No. 1	675	m	$2,000					$1,350,000	
2.2		Welding repair of longitudinal weld seams - Penstock No. 2	900	m	$2,000					$1,800,000	
2.3		Welding repair of longitudinal weld seams - Penstock No. 3	650	m	$2,000					$1,300,000	
2.4		Welding repair of circumferential weld seams - Penstock No. 1	3000	m	$2,000					$6,000,000	
2.5		Welding repair of circumferential weld seams - Penstock No. 2	3000	m	$2,000					$6,000,000	
2.6		Welding repair of circumferential weld seams - Penstock No. 3	3000	m	$2,000					$6,000,000	
2.7		Cranes	600	days	$1,000					$600,000	
2.8		Liner steel (all in cost)	1800	tonnes	$8,000	10	$150			$51,300,000	
2.9		HSS reinforcing (all in cost)	105	tonnes	$8,000					$840,000	
2.10		Concrete Cost	225	m3	$2,250					$1,518,750	
2.11		Jacking / Steel Placement Cost	200	days		10	$100		3	$1,800,000	
2.12		Rescue/Safety	200	months		10	$100		2	$1,200,000	
3	**Water Blast / Recoat**										
3.1		Coating steel liner internal	47490	m2	$150					$7,123,500	
4	**Mobilization**										
4.1		Mobilization / Demobilization was estimated at 10% of the total.								$8,689,225.04	
5	**EPCM**										
5.1		EPCM costs were estimated at 10% of the total.								$8,689,225.04	
6	**Contingency**										
6.1		Contingency was estimated at 20% of the total.								$17,378,450	
7	**Total**									**$121,649,150**	

Estimate - ConcreteEncasement
Price per 3 Penstock

No.		Description	Quantity	Unit	$/Unit	Hours	$/Hour	Material Cost	Labour Cost	Cost	Comments
1	**Excavation**										
1.1		Excavation and backfill re-instatement of buried Penstock	480000	m3	$20					$9,600,000	
2	**Labour / Materials**										
2.1		Welding repair of longitudinal weld seams - Penstock No. 1	675	m	$2,000					$1,350,000	
2.2		Welding repair of longitudinal weld seams - Penstock No. 2	900	m	$2,000					$1,800,000	
2.3		Welding repair of longitudinal weld seams - Penstock No. 3	650	m	$2,000					$1,300,000	
2.4		Welding repair of circumferential weld seams - Penstock No. 1	3000	m	$2,000					$6,000,000	
2.5		Welding repair of circumferential weld seams - Penstock No. 2	3000	m	$2,000					$6,000,000	
2.6		Welding repair of circumferential weld seams - Penstock No. 3	3000	m	$2,000					$6,000,000	
2.7		Removal of doorsheets for entry (6 each)	18			10	$100		4	$72,000	
2.8		Re-installation of removed doorsheets (6 each)	18			10	$150		4	$108,000	
2.9		Cranes	200	days	$1,000					$600,000	
2.10		Concrete (all in cost)	6500	m3	$2,250					$43,875,000	
2.11		Reinforcing Steel	125	tonnes	$8,000					$3,000,000	
2.12		Install reinforcing steel								$562,500	
2.13		Rescue/Safety	200	months		10	$100		2	$1,200,000	
3	**Water Blast / Recoat**										
3.1		Coating steel liner internal	15830	m2	$150				3	$7,123,500	
4	**Mobilization**										
4.1		Mobilization / Demobilization was estimated at 10% of the total.								$8,859,100.00	
5	**EPCM**										
5.1		EPCM costs were estimated at 10% of the total.								$8,859,100.00	
6	**Contingency**										
6.1		Contingency was estimated at 20% of the total.								$17,718,200	
7	**Total**									**$124,027,400**	

80 Hebron Way, Suite 100
St. John's, Newfoundland, Canada A1A 0L9
Tel: +1 (709) 754 6933

HATCH

80 Hebron Way, Suite 100
St. John's, Newfoundland, Canada A1A 0L9
Tel: +1 (709) 754 6933