Columbia River Project Water Use Plan

Kinbasket and Arrow Reservoirs Revegetation Management Plan

Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works

Implementation Year 7

Reference: CLBMON -11b4

Data Report

Study Period: 2019

Okanagan Nation Alliance, Westbank, BC
and
LGL Limited environmental research associates Sidney, BC

August 31, 2020

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY
CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works




Annual Report
Year 7
2019

Prepared for

BC Hydro

BC Hydro Generation
Water Licence Requirements
6911 Southpoint Drive
Burnaby, BC

Prepared by

Okanagan Nation Alliance

and

LGL Limited environmental research associates

Technical Contact: Virgil C. Hawkes, M.Sc., R.P.Bio.

vhawkes@gl.com; 1.250.656.0127

August 31, 2020

Suggested Citation

Miller, M.T., D. B. Adama, and V.C. Hawkes. 2020. CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Annual Report – 2019. LGL Report EA3414F. Unpublished report by Okanagan Nation Alliance and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 40 pp + Appendix.

Cover photos

From left to right: Site 6A, Eurasian water-milfoil (*Myriophyllum spicatum*) in Cartier Bay, Site 15A, Airport Marsh. Photos © LGL Limited: Virgil Hawkes and Doug Adama.

EXECUTIVE SUMMARY

CLBMON-11B4 (*Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works*) was commissioned by BC Hydro in 2010 under the Columbia Water Use Plan. The mandate of the project is to assess the effectiveness of wildlife physical works (WPW) projects undertaken through CLBWORKS-30A at protecting or enhancing wetland and wildlife habitat in Revelstoke Reach (Arrow Lakes Reservoir). Specifically, CLBMON-11B4 assesses erosion processes and the vegetation and physicochemical characteristics of wetland and riparian habitat following implementation of WPW-6A (Airport Outflow) and WPW-15A (Cartier Bay). The aim of WPW-6A was to stabilize the east arm of an erosion channel that had developed in the floodplain of Revelstoke Reach near the outlet of Airport Marsh, an important wetland and wildlife habitat. WPW-15A was designed to protect the high wetland and wildlife values in Cartier Bay by stabilizing a collapsed box culvert at the wetland's outflow.

Pre-works (baseline) monitoring occurred in 2010, 2011, 2012, and 2013 (for WPW-15A only). A post-works assessment occurred in 2016 at WPW-6A and post-works monitoring was conducted at both sites in 2018 and 2019, with a third year of monitoring scheduled for 2020. Here we report summary results at the two-year mark of post-works monitoring (2019). Fieldwork was carried out in May, in line with the timing of pre-works (2011-2013) monitoring.

Erosion monitoring at WPW-6A followed methods established in 2016 consisting of a visual assessment, survey measurements, Bank Erosion Hazard Index (BEHI) assessment, and air photo imagery assessment of the east and west erosion channels. No sign of erosion or slumping was observed along the perimeter of the riprap, although slumping was observed at the mouth of the east channel where the channel bank remains exposed. BEHI scores were very low for the east channel (and high for the west channel). Differences in BEHI scores were due to higher bank height and steeper bank angles along with lower surface protection in the west channel. BEHI scores for the channels were similar across years (2018 and 2019).

An assessment of aerial images from 2008 to 2016 found that the WPW has to date been successful in arresting channel enlargement in the east channel. The difference in the size of the east erosion channel from 2016 to 2019 was attributed to measurement error due to the differences in image resolution between the 2016 air photos and 2019 drone photogrammetry.

Channel enlargement in the west channel between 2008 and 2019 was 9.3 m^2/year, which is similar to the rate of channel enlargement that occurred in the east channel before the WPW construction in 2013 (10.6 m^2/year). Annual soil loss in the west channel between 2008 and 2019 was estimated at 21.1 m^3/yr and is equivalent to approximately two and a half dump trucks loads (8 m^3 capacity) annually. This falls within the range of values estimated previously (17.2 to 26.4 m^3/yr; Miller *et al*. 2020).

A visual assessment and survey measurements at WPW-15A did not reveal any noticeable or measurable amounts of erosion. Average elevation of the reinforced swale was estimated to be 434.04 m, which compares favourably to value reported by Watson Engineering (434.04 m) following the implementation of WPW in 2016.

Vegetation and physicochemical attributes were monitored at Cartier Bay (Site 15A) only. To characterize conditions in the shallow open water areas, 131 random point intercept

samples of aquatic macrophyte presence and abundance, as well water depth, water turbidity, dissolved oxygen, pH, conductivity, and temperature, were collected. Riparian plant communities adjacent to the shallow open water wetland were characterized using 15 terrestrial 50-m^2 vegetation plots. This shoreline sample was designed to complement the set of terrestrial plots sampled in 2018 at slightly higher elevations within the Cartier Bay floodplain.

At Cartier Bay, measurements of turbidity (Secchi depth), dissolved oxygen (DO), pH, conductivity (µS/cm), and temperature (°C) fell within the range of variation observed during the baseline monitoring period. Consistent with the baseline monitoring period, Eurasian water-milfoil (*Myriophyllum spicatum*), common hornwort (*Ceratophyllum demersum*), the green algae Braun's stonewort (*Chara braunii*), and small pondweed (*Potamogeto pusillus*) were the most frequently encountered aquatic macrophytes in Cartier Bay in 2019; each was present in over a third of point intercept samples. As in previous years, pondweeds (*Potamogeton* spp.) were the most biodiverse group of macrophytes but tended to be relatively less dominant locally (as measured by the sample volume x cover metric, VC).

Eurasian water-milfoil and stonewort showed an ongoing trend of increasing frequency since 2011-12, while common hornwort, small pondweed, and water smartweed showed an ongoing declining trend since the outset of baseline monitoring. Eurasian water-milfoil and stonewort can both form dense mats over the benthic surface, potentially displacing other aquatic plants. The apparent increase in the frequency of these species since 2011, along with a (presumptive) coincidental decline in the frequency of common hornwort and small pondweed, could be an indication that a compositional shift is underway in Cartier Bay (with potential long-term implications for invertebrates and wildlife).

Because the post-works data time series is, as of 2019, limited to two years, it is too early in the monitoring process to test for significance in these trends or to assign them to project-related effects. Such analyses will be deferred until the final summary report (scheduled for 2020). However, since the observed changes appear to have commenced prior to the project implementation, it is quite possible that macrophyte production in Cartier Bay was not directly affected by WPW-15A implementation. As the objective of the WPW was to maintain the status quo with respect to the maximum depth and areal extent of the permanently wetted area, such a finding would be consistent with the expected outcomes.

The sample of 15, low-lying, shoreline vegetation plots yielded a different complement of riparian plant species (and species associations) to those recorded at slightly higher elevations in 2018 (Miller *et al*. 2020). Of note was the observation at this elevation band of a nascent community of perennials including wool-grass (*Scirpus atrocinctus*), water smartweed (*Persicaria amphibia*), and Columbia sedge (*Carex aperta*), together with groundcover-providing annuals such as spring water star-wort (*Callitriche palustris*) and toad rush (*Juncus bufonius*). Wool-grass, Columbia sedge, and Kellogg's sedge have been widely planted elsewhere in Revelstoke Reach as part of the CLBWORKS-2 revegetation program, and thus would be considered highly desirable species from a habitat enhancement standpoint. Under the current hydroregime, these foreshore plants are unlikely to grow sufficiently large to afford much habitat structure, or to flower and set seed, due to the highly truncated growing season. However, their presence gives an indication of the robust riparian community that might develop naturally were reservoir levels to be kept below 434 m ASL (the elevation of the repaired dike) for a sequence of years, or for a longer period of the growing season each year.

The status of CLBMON-11B4 after Year 7 (2019) with respect to the main study management questions (MQs) is summarized in table form below.

We make the following recommendations for the 2020 implementation year:

Erosion Monitoring

1. Continue visual assessments, survey measurements, and aerial image interpretation to monitoring erosion at WPW-6A. Particular attention should be paid to the undercut bank at the mouth of the east erosion channel. We recommend using a drone again to capture higher resolution imagery and DEM at WPW-6A. Drone acquired photogrammetry was a cost-effective approach for monitoring changes in channel size and volume. The higher resolution imagery and DEM acquired by the drone provided more reliable data for delineating channel perimeters and estimating channel area (m^2) than airplane acquired digital orthophotos.
2. We recommend expanding the erosion monitoring to include the main erosion channel at WPW-6A. Survey efforts to date have focused on monitoring and comparing erosion between the east and west channels. The main channel is closer to Machete Island and is immediately threatened by the enlargement of this portion of the erosion channel.
3. We also recommended expanding the erosion monitoring to include the section of the Old Arrowhead Highway between WPW 6A and Airport Marsh. Erosion along this section appears to be increasing. Unabated, this erosion may cause channelling in the adjacent floodplain and affect water levels in Airport Marsh.
4. Given the success of the WPW in arresting erosion in the east channel, we recommend that preliminary scoping of the west and main channels at Site 6 be undertaken in year three of this project (2020/21) to assess the utility of applying a similar approach there.
5. Continue erosion monitoring at WPW 15A, including visual assessments of the riprap and riprap-dyke interface, and survey measurements of the swale for monitoring changes in swale depth.

Vegetation monitoring

1. There is high natural annual variability in macrophyte distribution and abundance; consequently, only very large project-related effects are likely to be detected within the given monitoring time frame. No such large impact has yet been observed, nor is one predicted based on initial observations. Thus, some consideration should be given to whether it is necessary and cost-effective to continue aquatic vegetation and water quality/depth monitoring at Cartier Bay Site 15A for a third year. In making this determination, it should be kept in mind that there may be benefits to maintaining the data time series until the final study year that extend outside the scope of effectiveness monitoring.

Continuing to fill data gaps on invasive species trends could be one such benefit. For example, the non-native Eurasian water-milfoil has exhibited a trend of increasing abundance since the start of baseline monitoring (2011-12). In contrast, the native common hornwort, which occupies a similar ecological niche, has experienced a declining trend over the same time period, possibly in response to increased competition from Eurasian water-milfoil. Another year of monitoring data would assist in determining—as a secondary objective to other, within-scope objectives—if a significant compositional shift is underway in Cartier Bay (with potential long-term implications for invertebrates and wildlife).

2. Wildlife physical works could affect the aerial extent of shallow open water habitat and, by, extension the location, quality, and structure of associated riparian vegetation. Changes in either attribute could in turn alter the area or suitability of wildlife habitat for nesting birds, reptiles, or amphibians. Therefore, it is relevant to know if the permanent (spring) wetland-riparian boundary has shifted substantially since project implantation. Two ways to determine this are:

   - directly, by using available time series of aerial orthoimages to visually compare wetland extents pre- and post-physical works; and
   - indirectly, by estimating the surface elevation (water level) of the wetland prior to inundation in the spring and comparing this estimate to (i) the historical (pre-works) elevation and/or (ii) the target water level established by the WPW objectives.

   We suggest that one or both methods be adopted for the final implementation year (2020).

3. For the final study year, in lieu of undertaking a comprehensive resampling of vegetation at Cartier Bay Site 15-A (as per point 1, above), greater emphasis could be placed on developing recommendations around wildlife physical works methods or techniques that are most likely to be effective at protecting or enhancing the productivity of wetland and associated riparian habitat in the drawdown zone of Revelstoke Reach. To help address this question, results form CLBMON-11B4 would be interpreted in light of results and with data from other relevant studies including some or all of: CLBMON-12, CLBMON-11B3, CLBMON-37, CLBMON-11B2, CLBMON-36, CLBMON-39, and CLBMON-40.

Management Question (MQ)	Summary of Key Results
MQ1. Are the wildlife physical works projects effective at protecting wildlife habitat quality and quantity for nesting and migratory birds and other wildlife?	<u>Summary Findings</u> There is little indication thus far that wildlife physical works have failed to protect wildlife habitat in Revelstoke Reach. In 2019, the second year of post-works monitoring, estimates of physicochemical variables (water depth, turbidity, DO, pH, conductivity, temperature), were comparable to those obtained during the pre-works (baseline) monitoring period (2011-2013). Estimates of aquatic macrophyte frequency and abundance appear to show an increase in certain macrophytes (the non-native Eurasian water-milfoil, and stonewort) over time, and a simultaneous decrease for some native macrophytes (common hornwort, small pondweed, water smartweed). This suggests that a compositional shift may be underway in Cartier Bay (with potential long-term implications for invertebrates and wildlife). However, it appears unlikely at present that these changes are related to the project implementation. Erosion abatement in the east erosion channel at Site 6A appears to have been successful in the short-term. Advance of the east erosion channel in the floodplain ceased following physical works implementation in 2013. Erosion continues unabated in the main and west channel at Site 6A reducing habitat and recreational values of the floodplain. No signs of erosion were evident at Site 15A and the elevation of the swale (434.051 m) was comparable to the construction specification (434.045 m). <u>Sources of Uncertainty/ Limitations</u> Because the post-works data time series is, as of 2019, limited to two years, it is too early in the monitoring process to test for significance in any trends or to attempt direct pre- and post-works comparisons. Such analyses will be deferred until the final summary report (scheduled for 2020). Due to the natural variability of the system (environmental noise), the study may have low power to detect minor changes in habitat attributes within the given time frame. Erosion (bank undercutting and soil movement) was observed at the mouth of the east channel. Continued erosion at this site may result in erosion between the riprap and former channel bank. It is not known if Site 15A has affected dyke porosity, which in turn may affect the water holding capacity of the dyke. <u>Comments</u> There is high natural annual variability in macrophyte distribution and abundance; consequently, only very large project-related effects are likely to be detected within the given monitoring time frame. No such large impact has yet been observed, nor is one predicted based on initial observations. Thus, some consideration should be given to whether it is necessary and cost-effective to continue aquatic vegetation and water quality/depth monitoring at Cartier Bay Site 15A for a third year. That said, there may be benefits to maintaining the data time series until the final study year that extend outside the scope of effectiveness monitoring. This includes filling data gaps around the recently observed shift in macrophyte species composition towards a less native-dominated system. Erosion monitoring should be continued both at Site 6A and 15A to fully address the management question.

Management Question (MQ)	Summary of Key Results
MQ1a. What were the pre-existing conditions at the wildlife physical works Sites 6A and 15A in terms of wetland and associated riparian habitat productivity and habitat suitability for nesting and migratory birds and other wildlife?	<u>Summary Findings</u> Data on pre-existing conditions at Site15A were collected between 2010 and 2013 under CLBMON-11B4 (reported in Miller and Hawkes 2014, and earlier annual reports) as well as through various associated WLR studies involving Revelstoke Reach. Many relevant findings were summarized in detail by Hawkes *et al.* (2015b). <u>Sources of Uncertainty/ Limitations</u> The baseline study phase of CLBMON-11B4 did not closely monitor riparian habitat conditions at Cartier Bay, being primarily focused on characterizing shallow open water habitat conditions. Some data pertaining to Site 15A on riparian habitat productivity and suitability for nesting and migratory birds and other wildlife are available through associated WLR studies involving Revelstoke Reach. Site 6A occurs within a reed canarygrass-dominated floodplain and does not support wetland conditions *per se*. The site was not directly monitored as part of the CLBMON-11B4 baseline study (which instead focused on characterizing conditions in the adjacent Airport Marsh). However, some bird monitoring of the WPW6A site occurred prior to implementation under CLBMON-11, which confirmed that the risk to birds was very low. Other data pertaining to Sites 6A and 15A on habitat productivity and suitability for nesting and migratory birds and other wildlife are available through associated WLR studies and will be reviewed for the final report.
MQ1b. Did the wildlife physical works at Cartier Bay Site 15A affect the function and productivity of adjacent wetland and associated riparian wildlife habitat as indicated by biomass and species richness of macrophytes and abiotic indices of productivity?	<u>Summary Findings</u> The general comments for MQ1, above, also applies to this MQ. Eurasian water-milfoil and stonewort showed an ongoing trend of increasing frequency since 2011-12, while common hornwort, small pondweed, and water smartweed showed an ongoing declining trend since the outset of baseline monitoring. It is presently considered unlikely that these changes are related to the project implementation. <u>Sources of Uncertainty/ Limitations</u> The general comments for MQ1, above, also apply to this MQ.
MQ1c. How did the wildlife physical works projects affect the suitability of wetland and associated riparian habitat for nesting and migratory birds and other wildlife?	<u>Summary Findings</u> The general comment for MQ1, above, also applies to this MQ. <u>Sources of Uncertainty/ Limitations</u> The general comments for MQ1, above, also apply to this MQ. <u>Comments</u> The results of CLBMON-11B4 will be interpreted in light of results and with data from other relevant studies including some or all of: CLBMON-11B3, CLBMON-37, CLBMON-11B2, CLBMON-36, CLBMON-39, and CLBMON-40.

Management Question (MQ)	Summary of Key Results
MQ2. Which wildlife physical works methods or techniques (including those not yet implemented) are likely to be most effective at enhancing or protecting the productivity and suitability of wetland and associated riparian wildlife habitat in the drawdown zone at Revelstoke Reach?	<u>Summary Findings</u> Monitoring of WPW at Site 6A indicates WPW have to date been effective at arresting erosion in the east (treated) channel near Machete Island, and demonstrates the potential of this approach for protecting habitat values in the floodplain and adjacent habitats (e.g., through application of a similar approach to the west and main channels). WPW at Site 15A indicate early success in maintaining water levels in Cartier Bay by reinforcing the integrity of the dyke. Reducing the duration, or delaying the timing, of inundation affecting the Cartier Bay foreshore could facilitate development of the nascent herbaceous riparian plant community at this elevation band, with potential benefits for vegetation productivity and wildlife habitat structure. <u>Sources of Uncertainty/ Limitations</u> Long-term success of the WPW is not known. <u>Comments</u> For the final study year, in lieu of undertaking a comprehensive resampling of vegetation at Cartier Bay Site 15-A (see MQ1 comments, above), greater emphasis could be placed on developing recommendations specific to this MQ. To help address this question, results form CLBMON-11B4 should be interpreted in light of results and with data from other relevant studies including some or all of: CLBMON-12, CLBMON-11B3, CLBMON-37, CLBMON-11B2, CLBMON-36, CLBMON-39, and CLBMON-40.

KEYWORDS: Arrow Lakes Reservoir; wildlife physical works; effectiveness monitoring; wildlife; wetlands; erosion; aquatic macrophytes; riparian habitat; physicochemistry.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the following individuals for their assistance in coordinating and conducting this study. Mark Sherrington administered the project for BC Hydro. Harry van Oort and Alexis Hall (BC Hydro) provided review comments. Dixon Terbasket (ONA) and Addison Fosbery (ONA) assisted in the field. Cassandra Pierre (ONA) assisted with data entry. ONA participation was overseen and coordinated by David DeRosa (ONA). Julio Novoa (LGL Limited) assisted with GIS analysis.

List of contributors

Okanagan Nation Alliance (ONA)

David DeRosa, B.Sc., P.Ag.

Dixon Terbasket

Addison Fosbery, Summer Student

Cassandra Pierre, Summer Student

LGL Limited environmental research associates

Virgil C. Hawkes, M.Sc., R.P.Bio.

Michael T. Miller, Ph.D.

Doug Adama, B.Sc., R.P.Bio.

Julio Novoa, M.Sc.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The Columbia River Water Use Plan (WUP) was developed as part of a multi-stakeholder consultative process to determine how to best operate BC Hydro's Mica, Revelstoke and Keenleyside facilities to balance environmental values, recreation, power generation, cultural/heritage values, navigation and flood control. During the WUP process, the Consultative Committee (CC) supported the implementation of revegetation and wildlife physical works in the Columbia River in lieu of changes to reservoir operations to help mitigate the impacts of Arrow Lakes Reservoir operations on wildlife and wildlife habitat. The CC suggested using an adaptive approach to create habitat for native wildlife, including nesting habitat for birds. In addition, the CC recommended monitoring to assess the effectiveness of these physical works at enhancing or protecting habitat for wildlife (BC Hydro 2005).

Potential Wildlife Physical Works (WPW) projects in Revelstoke Reach were identified and refined through CLBWORKS-29A, a two-year study that evaluated the feasibility of wildlife physical works in the Upper Arrow Reservoir. From an initial list of 44 potential projects, two, WPW-6A (Airport Outflow) and WPW-15A (Cartier Bay), have been implemented to date. The objective of these two WPW projects is to maintain existing shallow wetland habitat at Airport Marsh and Cartier Bay, respectively. Implementation of the projects was carried out under CLBWORKS-30A. Construction of the works at the Airport Outflow WPW-6A was completed in the fall of 2013. Construction of the works at Cartier Bay WPW-15A was completed in October 2016.

CLBMON-11B4 is part of a suite of monitoring programs that together monitor the effectiveness of wildlife physical works at protecting or enhancing wetland and riparian wildlife habitat, and at benefitting the wildlife that utilize it. CLBMON-11B4 specifically assesses erosion processes and the vegetation and physicochemical characteristics of wetland and riparian habitat. Wildlife usage is monitored under CLBMON-11B2 (spring migrant songbirds); CLBMON-36 (nesting birds); CLBMON-37 (reptiles and amphibians); CLBMON-39 (fall migrant songbirds); and CLBMON-40 (water birds and raptors).

CLBMON-11B4 was initiated in 2010. The monitoring involves sampling before-works and after-works characteristics of the affected wetlands. Pre-works monitoring occurred at WPW-15A in 2010, 2011, 2012, and 2013 (Hawkes *et al.* 2011; Fenneman and Hawkes 2012; Miller and Hawkes 2013; 2014). A post-work assessment was conducted at WPW-6A in 2016 (Hawkes and Adama 2020). This was followed by a three-year post-works monitoring program of WPW-6A and 15A beginning in 2018 (Miller *et al.* 2020). The second post-works monitoring session occurred in 2019 and is the subject of this update report. The third and final monitoring session is scheduled for 2020.

Pre-works Monitoring of Wetlands (2010-2013)

During Year 1 (2010), a wetland monitoring protocol was developed, and a pilot study conducted to evaluate the study design and sampling methodology. Reconnaissance-level sampling of biotic and abiotic conditions at Airport Marsh, Montana Slough, and Cartier Bay was also undertaken (Hawkes *et al.* 2011). WPW-6A and WPW-15A were not themselves directly assessed at this time.

Collection of baseline ecological and physical data continued in Years 2 and 3 (2011 and 2012), enabling a description of the diversity and relative abundance/density of aquatic and emergent (and some terrestrial) plant communities at Airport Marsh, Montana Slough, and Cartier Bay, as well as the associated pelagic and benthic invertebrate communities (Fenneman and Hawkes 2012, Miller and Hawkes 2013). As well, in 2012 the study scope was expanded to include reconnaissance-level sampling of two additional, potential enhancement sites in mid and lower Arrow Lakes Reservoir: Beaton Arm Beaver Ponds and Lower Inonoaklin Creek (Miller and Hawkes 2013).

In Year 4 (2013), pre-construction monitoring was continued at Airport Marsh and Cartier Bay, as well as at Beaton Arm Beaver Ponds and Lower Inonoaklin Creek. Montana Slough, which previous years' work had shown to support relatively few aquatic macrophytes and macroinvertebrates, was not resampled in 2013.

Changes to TOR

Initially, all CLBMON-11B modules were conducted under a single Terms of Reference (TOR). During the initial monitoring under CLBMON-11B some indicator species or sampling approaches proposed in the original TOR were found to be ineffective or to lack biological relevance in assessing the effectiveness of revegetation and wildlife physical works. Plans and schedule for wildlife physical works projects have also evolved. Consequently, the TORs for CLBMON-11B drafted in 2009 required updating to reflect improvements to approaches, the addition of modules, and to more correctly identify the differing specifics relevant to each project module.

For example, aquatic macroinvertebrates were formerly sampled at each wetland via two methods: epipelagic sampling with a dip net; and benthic sampling with a hand-held Ponar grab (Miller and Hawkes 2014). Due to low sample sizes, high variability, and high cost of taxonomic sorting, this program will not be implemented for post-works monitoring. Likewise, at Airport Outflow WPW-6A, post-works monitoring will focus primarily on erosion monitoring. Unless erosion continues to a point where the erosion channel interacts with the Airport Marsh hydrology (e.g., cutting through old Arrowhead Highway into the Machete Ponds), post-works monitoring will not include wetland parameters at Airport Marsh.

The 2018 annual report (Miller *et al.* 2020) described the approaches and methods that ONA and LGL Limited used to implement the revised (2018) TOR for CLBMON-11B4, including approaches and methods for addressing the newly revised objectives and management questions specific to the post-works implementation years (2018-2020).

2.0 WILDLIFE PHYSICAL WORKS (WPW) 6A and 15A

WPW-6A (Airport Outflow)

WPW-6A is a small erosion channel (120 m in length) that has developed in the floodplain of the Arrow Lakes Reservoir north of Machete Island (Figure 2-1). The channel begins at the northwest edge of Machete Island and runs northeast towards the Old Arrowhead Highway roadbed before splitting into two side channels (east and west) forming a “Y” like configuration. Erosion occurs in the spring during run-off and in the summer or fall when as the reservoir recedes from elevations above 438 m ASL.

WPW-6A was the first project to be implemented following a two-year consultation process with local stakeholder and agencies (Golder Associates 2009a; Golder Associates 2009b). The aim of the project was to stop erosion along the east channel and protect existing habitat values of the wetland that is upstream. The project was viewed as habitat maintenance as opposed to a specific attempt to enhance wildlife and/or fisheries values. The east erosion channel was selected for treatment because the direction of erosion of this feature was towards the old Arrowhead Highway/CPR rail bed which, if breached, could result in a new drainage route for water from the Airport Marsh and impact water levels presently impounded by the bed of the Arrowhead Highway/CPR rail bed. Airport Marsh is an important wetland area that supports migratory and resident populations of waterfowl, marsh birds, Great Blue Heron (*Ardea herodias*), Osprey (*Pandion haliaetus*), Bald Eagles (*Haliaeetus leucocephalus*), shorebirds, and Western Painted Turtles (*Chrysemys picta*).

A second goal of the WPW-6A project was to “reduce widening of the channel along its length into the relatively high elevation grasslands proximate to Machete Island and north towards the grass plains between the channel and Illecillewaet River” (Golder Associates 2009a). Machete Island provides riparian habitat that is uncommon in Revelstoke Reach, and provides important habitat for migratory songbirds during the fall migration (Golder Associates 2009; CBA 2018). In addition, the floodplain also offers recreational opportunities for hiking, dog walking, nature watching, cycling, and provides access to the river for fishing. Halting erosion in the floodplain would help maintain these recreational values in Revelstoke Reach (Lees + Associates 2008).

A third objective of the project was to provide a learning opportunity for assessing the effectiveness of erosion treatments in Revelstoke Reach. Leaving the west channel unmodified as a control would allow for follow up monitoring to compare rates of erosions between the two channels. Based on the success of the treatment effectiveness, the knowledge gained could be modified and adapted in other areas in Revelstoke Reach and Arrow Lakes Reservoir.

The WPW-6A project was implemented in the fall of 2013 by Landmark Solutions Ltd under BC Hydro’s supervision, and LGL Limited was retained for environmental monitoring during construction. In 2014, Golder Associates (2014) provided recommendations for monitoring WPW-6A. In 2016, LGL Limited undertook a post-construction assessment of the site (Hawkes and Adama 2020). The assessment indicated that the riprap was integrating into the channel bank and that erosion had appeared to be arrested in the east channel (although a potential erosion point at the tip of the east channel was noted). Continued slumping and erosion were reported in the west and main erosion channels.

Figure 2-1: Aerial image of the WPW-6A "Y shaped" erosion channel. Scale 1:500. Inset show the location of the channel south of Revelstoke, BC. Image date May 2016.

WPW-15A (Cartier Bay)

The Cartier Bay wetland consists of an existing slough/shallow open water complex that historically may have been an oxbow of the Columbia River. The main wetland consists of two compartments separated by a gap in an old roadbed (Old Arrowhead Highway) that bisects a large 24.3 ha pond. The outflow of this wetland is through a gap in the old rail grade where a collapsed wooden box culvert exists at the downstream terminus of the wetland (WPW-15A; Figure 2-2). The persistence of water in the pond is a result of this plugged box culvert creating a rudimentary dike.

WPW-15A was designed to protect the high wetland and wildlife values in Cartier Bay by stabilizing the collapsed box culvert. Golder Associates (2009b) recommended replacing the box culvert due to ongoing erosion and the risk of catastrophic failure, which would drain much of the marsh that occupies Cartier Bay. The original project design was revised in 2015 and the new design opted for stabilizing the dyke with the addition of riprap and filter blanket on the downstream side of the dyke at the box culvert. Construction began on October 17 and was completed on October 22, 2016. The dyke elevation, original box culvert and adjacent steel culvert were undisturbed. The lowest point of the dyke was maintained at 434.045 m above sea level (ASL).

To our knowledge, a post-construction inspection has not been completed to assess for site disturbance, erosion, settlement, and spread of invasive plants. Environmental monitoring reports were not provided to identify or assess environmental concerns raised during construction.

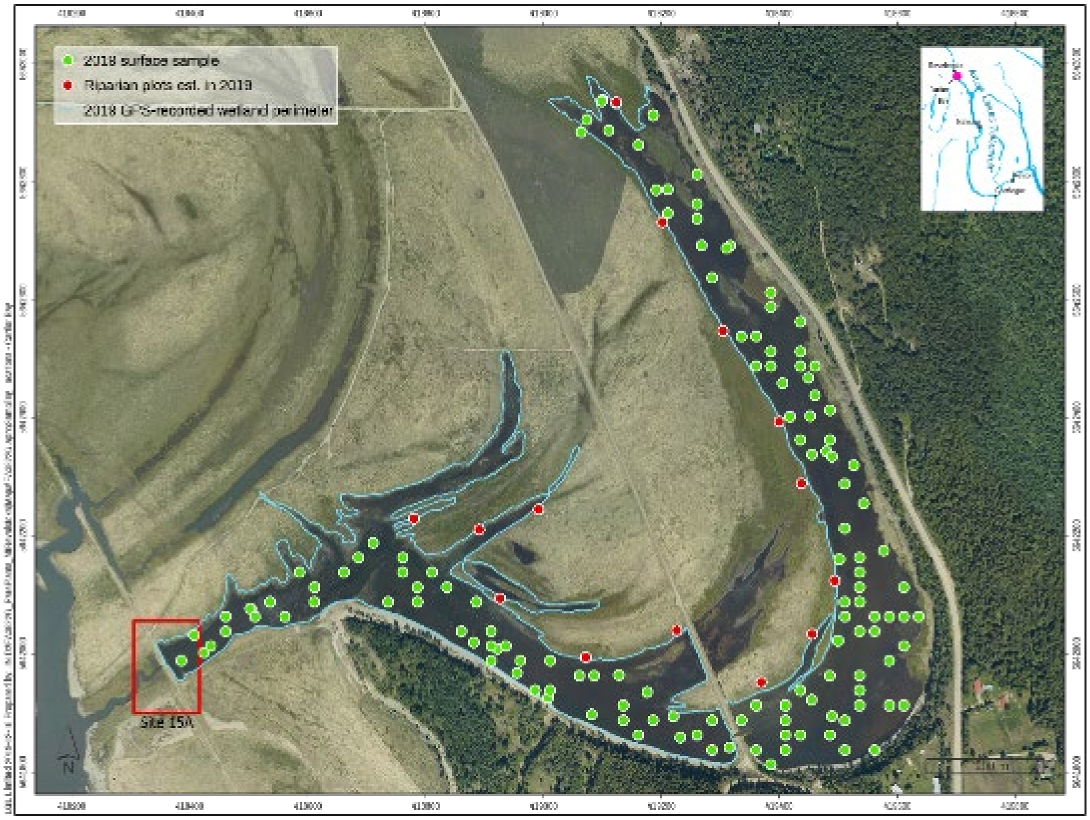

Figure 2-2: **Location of the WPW-15A relative to Cartier Bay.** Sample locations for 2019 are shown as dots. Image date: 30 May 2016. Reservoir elevation: 433.79 m ASL

3.0 MONITORING OBJECTIVES AND MANAGEMENT QUESTIONS

3.1 Monitoring Objectives

The objectives of this study are to:

1. Assess the effectiveness of wildlife physical works projects at protecting and maintaining wetland and associated riparian habitat in the drawdown zone of Revelstoke Reach.
2. Provide recommendations about which wildlife physical works methods or techniques are most likely to be effective at protecting or enhancing the productivity of wetland and associated riparian habitat in the drawdown zone of Revelstoke Reach.
3. Provide information on wetland habitat characteristics at potential wildlife physical works sites to assist in refining works designs, as appropriate (outcomes are reported in Hawkes *et al.* 2015b).

3.2 Management Questions

The revised management questions for CLBMON-11B4 are:

1. Are the wildlife physical works projects effective at protecting wildlife habitat quality and quantity for nesting and migratory birds and other wildlife?
   a. What were the pre-existing conditions at the wildlife physical works Sites 6A and 15A in terms of wetland and associated riparian habitat productivity and habitat suitability for nesting and migratory birds and other wildlife?
   b. Did the wildlife physical works at Cartier Bay Site 15A affect the function and productivity of adjacent wetland and associated riparian wildlife habitat as indicated by biomass and species richness of macrophytes and abiotic indices of productivity?
   c. How did the wildlife physical works projects affect the suitability of wetland and associated riparian habitat for nesting and migratory birds and other wildlife? To address this management question, the results of CLBMON-11B4 will be interpreted in light of results and with data from other relevant studies including some or all of: CLBMON-11B3, CLBMON-37, CLBMON-11B2, CLBMON-36, CLBMON-39, and CLBMON-40.
      i. Did the wildlife physical works at Cartier Bay Site 15A alter the area (m^2) or suitability of wetland and associated riparian wildlife habitat for nesting birds?
      ii. Did the wildlife physical works at Cartier Bay Site 15A alter the area (m^2) or suitability of wetland and associated riparian wildlife habitat for reptiles and amphibians?
      iii. Did the wildlife physical works at Airport Outflow WPW-6A alter the area (m^2) or suitability of wetland and associated riparian wildlife habitat for nesting birds?
      iv. Did the wildlife physical works at Airport Outflow WPW-6A alter the area (m^2) or suitability of wetland and associated riparian wildlife habitat for reptiles and amphibians?
      v. Did the wildlife physical works at Cartier Bay Site 15A affect: erosion; aerial extent of wetland habitat; cover, species richness, and evenness of undesirable macrophyte species; water depth and turbidity?
      vi. Did the wildlife physical works at Airport Outflow WPW-6A affect: physical signs of erosion; aerial extent of wetland habitat?
2. Which wildlife physical works methods or techniques (including those not yet implemented) are likely to be most effective at enhancing or protecting the productivity and suitability of wetland and associated riparian wildlife habitat in the drawdown zone at Revelstoke Reach?

4.0 METHODS

A description of the methods used in 2019, the second year of post-works monitoring, is provided below. For detailed accounts of methods used during pre-works (2010-2013) monitoring, and the outcomes of that monitoring, please refer to earlier annual reports for CLBMON-11B4 (Hawkes *et al.* 2011; Fenneman and Hawkes 2012; Miller and Hawkes 2013; 2014).

4.1 Sampling Approach

Post-works monitoring is designed to assess for impacts accruing to the quality and extent of shallow water habitat and associated vegetation in Revelstoke Reach as a result of wildlife physical works. Specifically, the study entails:

1. Conducting erosion monitoring at WPW-6A and WPW-15A via annual visual checks, standardized annual photo documentation each year, and physical marking (e.g., stakes) to identify how the extent of erosion is changing over time. Drone acquired photogrammetry was obtained of WPW-6A and WPW-15A in lieu of digital orthophotos, which were previously captured biennially from 2008 to 2016.
2. Mapping shallow wetland habitat extent at Cartier Bay upstream of WPW-15A using updated aerial photo-imagery in conjunction with GIS and comparing extent pre- and post-works. Photo-based assessments will be undertaken in 2019 or 2020, once updated imagery is available.
3. Sampling macrophyte (aquatic plant) composition and abundance in the east and west compartments of the main Cartier Bay pond and assessing for changes related to the implementation of WPW.
4. Taking measurements on water chemistry attributes (e.g., DO, conductivity, pH) in the east and west compartments of the main Cartier Bay pond and assessing for changes related to the implementation of WPW.
5. Using updated aerial photo-imagery, in conjunction with ground surveys, to sample riparian (non-aquatic) plant community composition and cover at the edge of Cartier Bay wetland and assessing for changes related to the implementation of WPW. Photo-based assessments will be undertaken in 2019 or 2020, once updated imagery is available.
6. Obtaining depth measurements for the east and west compartments of the main Cartier Bay pond and generating an updated bathymetric map.

4.2 Drone Photogrammetry

A DJI Phantom (model 3-advanced) drone piloted by Scott Waterfield of Osprey Aerial Intelligence Ltd acquired bare ground elevation data and high-resolution imagery of WPW-Sites 6A and 15 on April 26th, 2019 (Figure 4-1). The drone was equipped with a 12.8 MP sensor and GPS/GLONASS satellite navigation systems and was flown at an average altitude of 31 meters along flight lines to attain 70% overlap of adjacent flight lines. Eight Propeller AeroPoint™ ground control points were positioned to allow for post-processing of the georeferenced images. Images were processed using the Propeller software platform, which provided corrected GeoTiffs, 3D DXF files, and digital elevation data stored as LAS files. The area captured during the April 26th drone photogrammetry survey was 10.3 ha at Site 6A and 13.1 ha at Site 15 (Figure 8-1, Figure 8-2).

A second flight planned in the fall of 2019 to resurvey WPW-Sites 6A was cancelled as reservoir levels did not below 434 m ASL.

Figure 4-1: Image showing the safe deployment of a drone by Scott Waterfield (Osprey Aerial Intelligence Ltd) to capture high resolution imagery and elevation data at Cartier Bay on April 26, 2019.

4.3 Erosion Monitoring at WPW-6A (Airport Outflow)

Erosion monitoring included: (1) a visual assessment of the riprap installed in the east channel; (2) measurements of survey pins and stakes established in 2016; (3) a visual assessment of the riprap installed in the east channel; (3) a bank erosion hazard assessment; and (4) an assessment of channel erosion using aerial images obtained in 2008, 2010, 2012, 2014, 2016 and drone photogrammetry acquired in April 2019.

4.3.1 Visual Inspection of Riprap

The interface between the riprap and the channel bank was inspected for signs of erosion such as head-cutting, rilling, and gully erosion. Minor settlement of riprap is expected over time and settlement may contribute to channel formation along the riprap and channel bank interface or to the exposure of the filter blanket. Loss of sidewall material at the interface may cause lateral displacement of riprap into new erosion channels formed at the riprap and channel bank interface. To record our visual assessment, photographs were taken at each survey stake and at various locations along the channel where erosion was observed.

4.3.2 Survey measurements

Reference pins and survey stakes installed along the perimeter of the east and west channel in 2016 were located, inspected, and again georeferenced (Figure 4-2; Figure 4-3). Pins were originally located on the planar surface of the floodplain near the slope break of the channel. Measurements to the nearest centimetre were taken using a tape measure between the survey stakes and reference pins. Distances between the survey stakes and reference pins were compared to the measurements taken in past years to assess for soil movement and slumping along the channel banks. Slumping occurs when the horizontal distance between the pins and the stakes increased as soil slumps down into the channel bank Figure 4-4. Channel depth was measured at the thalweg[1] between pins on the adjacent channel bank (Figure 4-5).

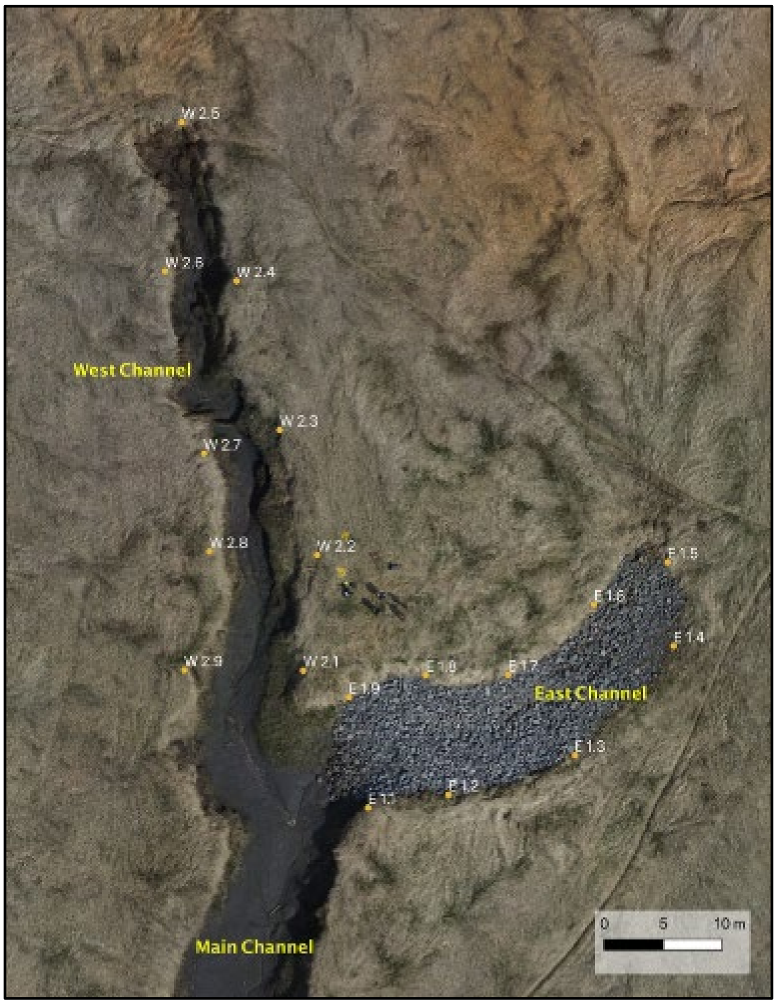

Figure 4-2: Image showing the arrangement of survey pins around the perimeter of the erosion channels. Thalweg measurements were taken between adjacent pins. Image date April 26, 2019

[1] Thalweg is the lowest elevation within a valley or watercourse in a given cross-section between two points (Figure 4-5).

Figure 4-3: **Image showing survey measurements taken at WPW Site 6-A, May 9, 2019.** The erosion pin is located in red circle; behind is the survey originally located 122 cm behind the erosion pin. Environmental technician Addison Fosbery from Okanagan Nation Alliance is holding survey pole.

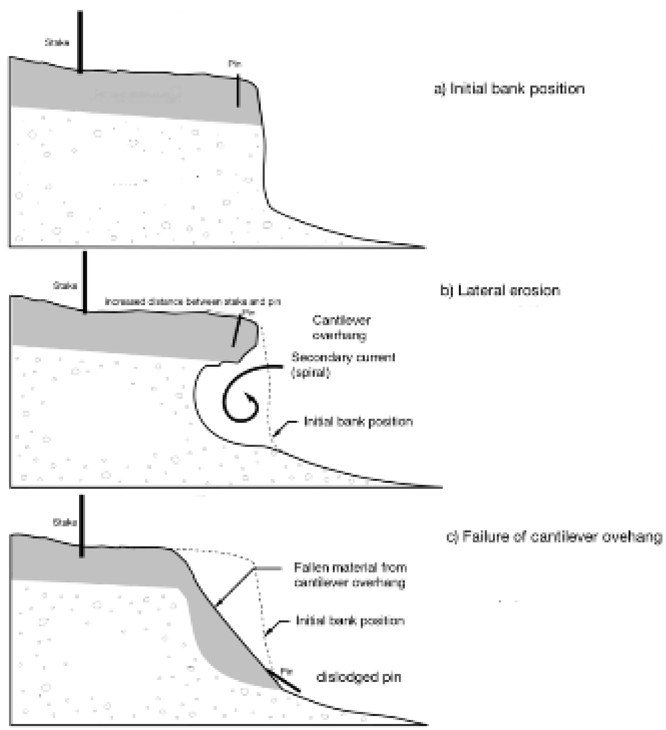

Figure 4-4: Bank undercutting, soil movement, slumping, and mass wasting (adapted from Johnson and Stypula 1993).

Figure 4-5: Image showing thalweg measurement being taken by ONG technician Addison Fosbery between erosion pins in the west erosion channel at WPW Site 6-A on May 9, 2019.

4.4 Bank Erosion Hazard Index (BEHI)

Calculating Bank Erosion Hazard Index (BEHI) is an evaluative process to determine bank susceptibility to erosion using variables that are known to affect bank erosion rates (Rosgen 2001; Rathbun, 2008; Netwon and Drenten 2015). Bank erosion of the east and west erosion channels were assessed and compared using a modified BEHI based on four metrics:

1. Ratio of root depth to bank height (RDH) is the ratio of the average plant root depth to the bank height, expressed as a percentage. Given the uniformity of the site, root depths were assumed to be the same at all pin locations. Root depth was averaged across several measurements made in the west channel.
2. Bank angle is the angle of the bank (as measured with a clinometer) from the base of the bank to the top of the bank. Bank angles greater than 90 degrees occurred on undercut banks.
3. Surface protection (SP) is the percentage of the bank surface covered (and therefore protected) by plant roots, downed logs, branches, rocks, etc.
4. Bank Material (BM). The composition of the bank affects its erodibility and scores are adjusted based on the type of material.

Values for the four metrics were scored against modified Rosgen's BEHI indices (Table 4-1). Bank erosion hazard index (BEHI) values were calculated at each pin location and averaged to provide an overall rating for each channel. The total score was then assigned an overall hazard rating adapted from Rosgen (2001; Table 4-2).

Table 4-1: BEHI metrics and categories scores.

BEHI Category	RDH Ratio (%)	RDH Score	Surface Protection	SP Score	Bank Angle (deg.)	BA Score	Bank Material	BM Score
Very Low	90 - 100	1	80 - 100	1	0 - 20	1	Cobble > 6.5 cm	-10
Low	50 - 89	2.5	55 - 79	2.5	21 - 60	2.5	Clay	1
Moderate	30 - 49	5	30 - 54	5	61 - 80	5	Gravel 0.5 to 6.5 cm	5
High	15 - 29	7.5	15 - 29	7.5	81 - 90	7.5	Sandy Gravel	7.5
Very High	0 – 14	10	0 – 14	10	90+	10	Non-plastic sand and silts	10

Table 4-2: BEHI ratings (adapted from Rosgen 2001).

BEHI Category	Total Score
Very Low	≤ 5
Low	5 – 15
Moderate	15 – 25
High	> 25

4.5 Photogrammetric estimation of erosion.

Annual rates of erosion in the east and west channels were calculated from digital air photos acquired in 2008, 2010, 2012, 2014, and 2016, and from the drone acquired imagery in 2019 (Section 4.2). For each photo set, the perimeter of the erosion channels was delineated manually in GIS and channel lengths and areas were then compared among years. The volume of eroded material between periods and annual volumetric rates of erosion were estimated assuming a channel depth of 2 meters for the east channel and 0.75m in the west channel. The accuracy of these estimates depended upon the resolution of the air photos, which were often very poor.

Volumes of the east and west erosion channels were also calculated from the DEM created from the 2019 drone photogrammetry (Section 4.2). Channel volumes were calculated in QGIS using the Raster Surface Volume tool and verified with the surface volume 3D analyst tool in ArcGIS. These values were compared to values computed from the manual delineation method described above.

4.6 Erosion Monitoring at WPW-15A: Cartier Bay

Our assessment of WPW-15A (May 8th, 2019) included a visual inspection of the installed riprap blanket and dyke, and survey measurement of the swale. Surveys elevations were taken from the top of the dyke and referenced to survey points established previously by Watson Engineering (2016) on a nearby culvert (Table 4-3; Miller *et al.* 2020). Multiple measurements were taken at the deepest point of the swale to determine the depth of the swale. Monitoring the depth of the swale over time will determine if the swale erodes.

Table 4-3: **The location and elevation of survey points established at WPW-15A by Watson Engineering (2016).**

Survey Point	UTM Northing	UTM Easting	Elevation (m ASL)
CN15A	641997.52	418352.03	435.236
CS15A	641995.25	418347.21	435.04

Visual inspection of WPW-15A included the following:

- **Inspection of riprap**. Settlement of placed riprap is expected over time, which may reduce the integrity of the riprap blanket and its ability to stabilize the dyke. Settlement may also contribute to channel formation along riprap and dyke interface.
- **Inspection of riprap interface**. The interface between the riprap and the surrounding material was inspected for signs of erosion such as head-cutting, rill, and gully erosion.

4.7 Wetland and Riparian Habitat Monitoring at WPW-15A (Cartier Bay)

4.7.1 Design

The basic design of the effectiveness monitoring is a before-after physical works comparison, with new random locations sampled each year. There are no control sites. Pre-works monitoring of wetland habitat parameters at Cartier Bay was conducted at WPW-15A in 2010 (pilot study), 2011, 2012 and 2013. Pre-works monitoring specifically focused on aquatic wildlife habitat, and the primary response variables measured were aquatic macrophyte and macroinvertebrate composition and abundance. Point data on water chemistry were also collected. The rationale for the approach and the sampling design is described by Hawkes *et al.* (2011). The design of the study assumes that the same methods will be used to collect data after the works as were used before the works, with minor adjustments where required to maximize the effectiveness of the study.

At the end of monitoring, baseline (pre-works) wetland data from 2011-2013 will be compared with post-works data (2018-2020) to determine if implementation of WPW-15A had a measurable impact on wetland habitat characteristics at Cartier Bay. With respect to macrophyte and water chemistry data, several alternative trend scenarios will be considered for best fit:

1) No trend, prior to or after the project (= no project effect);
2) Linear trend, commencing prior to the project (= no project effect). Modelled using linear regression;
3) Linear trend with breakpoint, with breakpoint coinciding with project implementation (= possible project effect). Modelled using multiple regression;
4) Non-linear monotonic trend, i.e., no or minimal trend prior to the project followed by a stronger trend after project implementation (= possible project effect). Modelled using linear regression with log or other transformations.
5) Step change (i.e., large sudden change), coinciding with project implementation (= project effect). Modelled using *t-test* or *Analysis of Variance*.

The study uses point intercept samples of aquatic vegetation and water physicochemistry collected from a boat, as well as samples of riparian vegetation collected from shoreline (terrestrial) sample plots. Submersed plants are sampled indirectly by deploying a double-headed rake and obtaining benthic grabs of species rooted in the water. The point of intercept in this case is the area of substrate that is combed with the rake—a predefined linear distance of ~1 m. To increase sampling precision, multiple drags (one on each side of the boat) are made. Point source water chemistry data were collected annually at macrophyte sample locations in Cartier Bay during the baseline (2011-2013) sample period, and this sampling procedure will be repeated for the post-works (2018-2020) sample period.

Initial monitoring efforts were focused on aquatic habitats; therefore, pre-works data on riparian habitat characteristics at Cartier Bay were not systematically collected as part of CLBMON-11B4. To assess changes to riparian conditions resulting from implementation of WPW-15A, we will rely on a combination of: (a) prior ground inspection data collected as part of the associated vegetation monitoring programs CLBMON-33; (b) the time series of aerial images of Cartier Bay captured in 2010, 2012, 2014, and 2016 in conjunction with CLBMON-33; and (c) any current (post-works) aerial imagery obtained by BC Hydro, as this becomes available. Prior measurements on vegetation composition and cover, which were obtained under CLBMON-33 for a set of 50-m^2 monitoring plots adjacent to the Cartier Bay wetland, will be used to inform photo interpretation of the associated aerial imagery for the pre-works period. In 2018, these same plots were resampled and the resulting data will be used to inform photo interpretations applied to any newly-obtained, post-works aerial imagery.

In 2020, orthoimagery dating from the pre-WPW period (early 2016 and prior) will be compared to aerial imagery from 2019 to identify possible changes in wetland boundary extent. Photo interpretations will be ground-truthed using a GPS-recorded track of the wetland boundary obtained during the 2019 fieldwork. This GPS track will also serve as a georeferenced baseline for future trend monitoring. Also in 2020, the pre-inundation (May) surface elevation of Cartier Bay wetland will be determined and compared to the top-of-dike elevation, both to assess for leakage and to determine if spring water levels are being maintained at a level that meets the project objectives.

4.7.2 Data Collection

Fieldwork was carried out by a team of two researchers and occurred over six days in May 2019 (May 10-15). Work was timed to occur as late as possible in the growing season but before reservoir inundation occurred, to allow for maximal vegetation development. In contrast to 2018 (Miller *et al.* 2020), the reservoir elevation in 2019 did not surpass 434.045 m (the height of the repaired box culvert and approximate threshold for Cartier Bay inundation) before sampling was completed. This meant that the spring shoreline was fully exposed, enabling us to delimit the current permanent wetland extent by walking the wetted perimeter and recording a GPS track—a procedure that could not be completed in 2018 due to high water levels.

Prior to fieldwork, 100 surface sample points in Cartier Bay were randomly placed using GIS. During the course of field sampling, an additional 31 points were established on the surface along with 15 points on the shoreline resulting in a total of 146 sampled points (Figure 2-2). Water depths of sample points at the time of sampling ranged from < 0.5 m to 2.15 m. The methods implemented at each point are described below under the following subheadings: **Aquatic Macrophyte Sampling** (4.7.2.1); **Riparian Vegetation Sampling** (4.7.2.2); and **Physicochemistry Sampling** (4.7.2.3).

4.7.2.1 Aquatic Macrophyte Sampling

Two benthic rake drags were made, one on each side of the canoe. Following each rake drag, the contents of the rake were examined (Figure 4-6) and the species composition of the macrophyte sample was recorded.

The volume of the vegetation sample was described on a categorical scale from 1 to 3 (Table 4-4), and each macrophyte species in the sample was assigned a relative cover class (Table 4-5). For analysis, local abundance was estimated for each species and sample point using the volume x cover (VC) metric (Miller and Hawkes 2014). To derive this value, we multiplied the total sample volume by the relative cover class of each species to produce a single numeric value (VC) representing the abundance of the species at each sampling point. Volume classes ranged from 1 through 3, and relative abundance classes ranged from 0.1 (for trace) to 1 through 5 (Table 4-4, Table 4-5). For each sample point, the values were averaged across two rake grabs. Thus, the minimum possible volume value was 0.5 and the minimum possible relative cover value was 0.05. The minimum possible (non-zero) value for the volume x cover metric was then 0.5 x 0.05 = 0.025, and the maximum possible value for the volume x cover metric was 3 x 5 = 15.

Per cent frequency was calculated as the number of samples points in which a species was recorded divided by the total number of samples and served as a measure of ubiquity and a proxy for overall cover (Madsen 1999).

Figure 4-6: Rake sample of aquatic macrophytes, Cartier Bay wetland, May 2019.

Table 4-4. Volume classes for macrophyte samples.

Volume Class	Sample Volume	Definition
1	Trace	Sample is restricted to one or very few strands of vegetation
2	Small	Sample fills less than half of the tines of the sampling rake
3	Large	Sample fills half or more of the tines of the sampling rake

Table 4-5. Relative cover classes for macrophyte samples.

Cover Class	Definition
T	Species is present but contributes negligibly (< 1 per cent) to the sample volume
1	Species contributes less than 10 per cent of the sample volume
2	Species contributes 11–20 per cent of the sample volume
3	Species contributes 21–50 per cent of the sample volume
4	Species contributes 51–75 per cent of the sample volume
5	Species contributes 76–100 per cent of the sample volume

Floating-leaved and emergent macrophytes, when present, were sampled using a buoyant 1-m^2 quadrat frame constructed from PVC pipe. Using this frame, one short (2-m x 1-m) belt transect was placed on each side of the boat (total 4-m^2). The per cent cover of the water surface occupied by each floating or emergent macrophyte species was recorded for each of the four quadrats. For analysis, the per cent cover value of each species was averaged among the four quadrats (Miller and Hawkes 2014).

4.7.2.2 Riparian Vegetation Sampling

To assess riparian vegetation conditions at the terrestrial-aquatic interface, vegetation was sampled on the shoreline immediately above the permanently wetted zone within 15 semi-random, 10-m x 5-m (50-m^2) plots (Figure 2-2, Figure 4-7). Substrates at this elevation were characterized by high clay content. This shoreline sample was designed to complement the set of terrestrial plots sampled in 2018 at slightly higher elevations on more loamy soils within the Cartier Bay floodplain (Figure 2-2).

Vegetation within plots was assessed for plant species composition/cover and vegetation community type, or VCT. Community typing followed that used for CLBMON-33 (Miller *et al.* 2020).

Figure 4-7: **Supplemental riparian vegetation plot just above permanently wetted zone, Cartier Bay.** Photographed May 14, 2019. Model: Dixon Terbasket (ONA).

Per cent covers, measured as the percentage of the ground surface covered when the crowns are projected vertically, were visually estimated and rounded as follows: traces = 0.1%; <1% rounded to 0.5%; 1-10% rounded to nearest 1%; 11-30% rounded to nearest 5%; 31-100% rounded to nearest 10%. A VCT category was assigned to the plot following the drawdown zone community classification system as described in Miller *et al.* (2020).

4.7.2.3 Water Chemistry and Depth Sampling

Concurrent with macrophyte sampling, the following point source physicochemical attributes were collected at each surface sampling station:

- Water depth (via weighted tape measure)
- Turbidity (via Secchi disk)
- Dissolved Oxygen (DO; mg/l)
- Conductivity (µS/cm)
- Water Temperature (°C)
- pH

Water temperature, dissolved oxygen, conductivity, and pH were recorded at a depth 30 cm below the water surface using a multi-metric meter.

The set of randomly located depth sound measurements was pooled with similar depth data obtained in previous (2011-2013, 2018) implementation years to produce an updated bathymetric figure for the Cartier Bay wetland compartments. The interpolation method chosen was Simple Kriging, with a Gaussian model and a smoothing weighting factor (*n*: 295; RMSE [cm]: 32.5).

5.0 RESULTS and DISCUSSION

5.1 Erosion Monitoring at WPW-6A (Airport Outflow)

5.1.1 Visual Inspection

As reported previously (Miller *et al.* 2020), the riprap in the east channel continues to become well integrated into the surrounding soils. Fines are accumulating and reed canarygrass is showing ingress along the margin of the riprap (Figure 5-1). Bank erosion and mass wasting continues to be evident on the southwest terminus of the east channel (Figure 5-2; (Hawkes and Adama 2020; Miller *et al.* 2020).

As observed in previous years (Hawkes and Adama, 2020; and Miller *et al.* 2020), extensive slumping and mass wasting was observed in the untreated west and main channels (Figure 5-3; Figure 5-4). While visual inspection and photo documentation are useful for identifying obvious signs of erosion, more quantitative methods were more reliable for assessing erosion in the two channels.

Figure 5-1: Reed canarygrass (in the foreground) ingressing into the riprap along the margin of the WPW-6A east erosion channel. Image Date May 9, 2019.

Figure 5-2: Undercutting of the bank at the mouth of the east channel of WPW-6A. May 9, 2019.

Figure 5-3: Extensive slumping and mass wasting in the WPW-6A west erosion channel. May 9, 2019.

Figure 5-4: ONA field technician Addison Fosberry examining slumping and mass wasting in the main erosion channel at Site 6A. May 9, 2019.

5.1.2 Survey measurements

Survey measurements in 2019 (Table 8-1) indicate, (1) minor slumping along the margin of the east channel, (2) a lower rate of soil movement in the east channel than in the west channel, (3) a higher rate of soil movement in the west channel over the previous period (2016–2018), and (4) an increase in the depth of the west channel (thalweg measurement) in 2019 over 2018. Mean soil movement in the east channel in 2019 was 1.7 cm (SD = 2.5). Although this is twice the rate observed between 2016 and 2018 (0.8 cm/yr, SD = 1.3), and some movement occurred at pins 1-3, 1-8, and 1-9, the difference was mainly caused by a single outlier data point (pin 1-6) and the difference was not statistically significant ($t_{paired\ (df = 1)} = 2.31$, $p = 0.37$). Since localized settlement may be occurring, it will be important to continue to monitor the riprap-soil interface for signs of erosion as extensive erosion at the interface may result in the formation of a sinkhole. At this time, however, the values indicate that the riprap in the east channel continues to settle, albeit slowly.

A comparison of survey measurements along the margin of the west and east channels indicates less soil movement in the east channel than in the west channel ($t_{(df = 15)} = 2.13$, $p = 0.04$). Mean soil movement in the west channel 5.3 cm (SD = 3.9) was over three times greater than the value observed in the east channel (Table 8-1). This result is unremarkable as the riprap placed in the east channel was expected to reduce bank undercutting and slumping.

The rate of slumping in the west channel was higher in 2019 than the rate observed between 2016 and 2018 (Table 8-1; $t_{(df = 7)} = 2.53$, $p = 0.04$). This indicates that the rate of soil movement caused by bank undercutting may have accelerated, likely as a result of lateral erosion below the upper sod layer causing it to cantilever and slump into the channel increasing the distance between the stake and the pin (Figure 4-4; Figure 5-5). Since their placement in 2016, five of the nine pins have moved > 10 cm from their original position from the stake (Table 8-1).

Figure 5-5: Photo of pin 2-4 located in the now overhanging (cantilevered) sod of the undercut bank of the west erosion channel. May 9, 2019.

5.1.3 Bank Erosion Hazard Index

Bank Erosion Hazard Index Scores in 2019 in the two channels were consistent with the score obtained in 2018 (Table 8-2; Table 8-3). BEHI scores were very low for the east channel (mean values for 2018 and 2019 were 4.3 and 5.0, respectively) and high for the west channel (mean values for 2018 and 2019 were 28.7 and 29.5, respectively). Differences in BEHI scores between years were minor and were likely due to measurement error. Differences in BEHI scores between the two channels were due to higher scores in bank height, bank angle, and bank material in the west channel than in the east channel (Table 8-3).

5.1.4 Aerial Imagery Interpretation

Delineation of the east and west erosion channels at Site-6A using aerial orthoimages show the east channel increasing in size at a rate of 9.3 m2/yr from 2008 to 2012 (Table 5-1; Figure 5-6). Similar polygon sizes delineated from 2014 and 2016 imagery indicates that the construction of WPW-6 in 2013 was effective in halting the erosion and channel enlargement. The increase in the size of the east channel (5 %) reported in 2019 (Table 5-1) was due to the improved image resolution and DEM provided by the drone photogrammetry, which allowed for more accurate delineation of the channel perimeters.

Between 2008 and 2019, the footprint of the west channel has increased at rate similar as the east channel prior to WPW (10.6 m^2/yr vs 9.3 m^2/yr; Table 5-1; Figure 5-7). Annual soil loss is estimated to be 21.1 m^2/yr per year. Similar to our previous findings, this is equivalent to approximately 2.6 dump trucks (8 m^3 capacity) of soil per year (Miller *et al.* 2020). Channel volume obtained for the west channel from the drone acquired DEM were 15% lower than the values calculated using area delineated from the imagery (Table 5-1). This is likely due to the slumped soil that remains in the channel following slumping (Figure 5-3). The drone acquired DEM does not differentiate slumped material from the channel floor underestimating the volume of the channel.

Table 5-1: Length and area of the east and west erosion channels at WPW-6A obtained from aerial imagery between 2008 and 2016.

Channel	Image Year	Sample Year*	Channel Length	Annual rate of change (m/yr)	Channel Area (m^2)	Annual rate of change (m^3/yr)	Channel Volume (m2)	Volume of lost soil (m^3/yr) **
East	2008	before 2008	35.6	-	223.0	-	449.7	-
	2010	2008 – 2009	35.8	0.14	232.5	4.0	477.7	17.6
	2012	2010 – 2011	37.7	0.94	259.3	4.8	523.9	23.1
	2014	2012 – 2013	39.6	0.90	299.5	12.6	246.1	-
	2016	2014 – 2015	39.6	0.00	296.3	-0.6	243.4	-
	2019	2016 – 2018	39.6	0.00	311.1	-0.6	242.2	-
West	2008	before 2008	49.5	-	347.8	-	689.2	-
	2010	2008 – 2009	49.5	0	365.3	2.5	723.5	17.2
	2012	2010 – 2011	55.4	2.93	387.3	3.7	776.4	26.4
	2014	2012 – 2013	57.5	1.06	413.0	2.8	820.0	21.8
	2016	2014 – 2015	59.9	1.20	424.2	2.0	849.0	14.5
	2019	2016 – 2018	60.4	0.16	464.0	2.0	923.6 (785.7†)	24.8

* Due to the timing of aerial photography, erosion rates apply to the years preceding the image year. For example, the erosion rate estimated due to differences in area and volume in 2016 image apply to 2014 and 2015 as the image in 2016 was taken before the reservoir was inundated.

** Based on an average channel depth of 2 meters.

†value obtained from drone acquired DEM

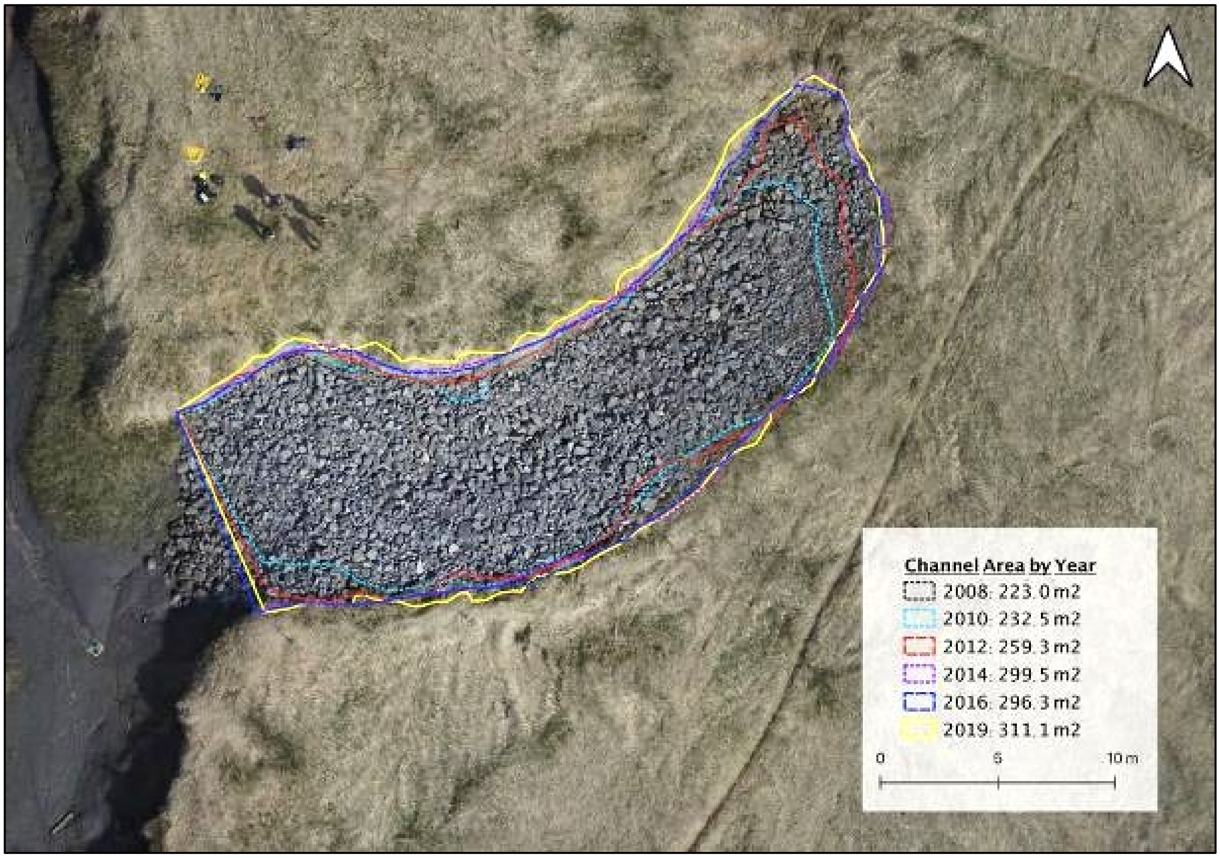

Figure 5-6: **Size of the east erosion channel delineated by image year.** Background image taken April 26, 2019.

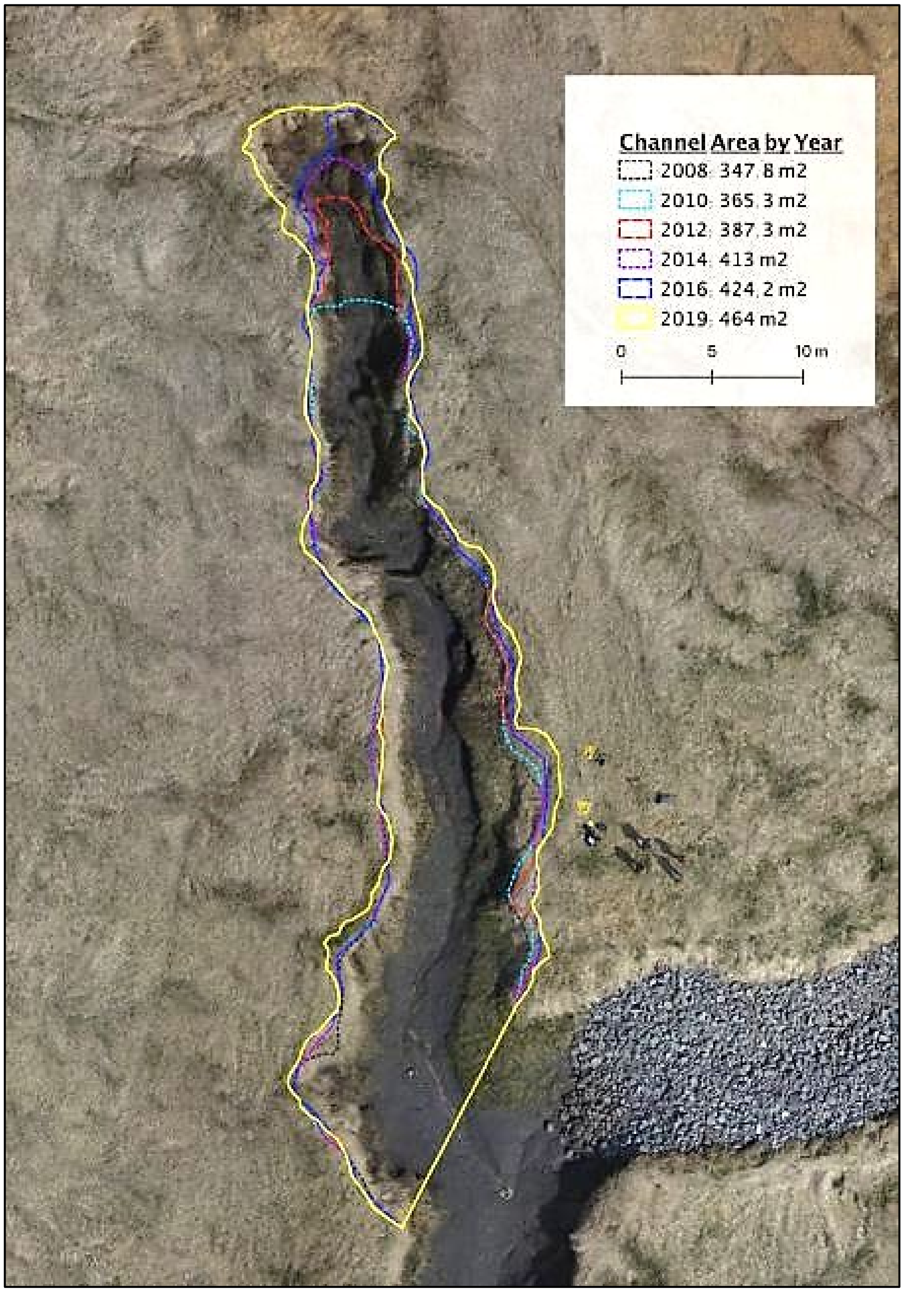

Figure 5-7: **Size of the west erosion channel delineated by image year.** Background image taken April 26, 2019.

5.2 Erosion Monitoring at WPW-15A

No sign of erosion was observed along the margin of the riprap or at the swale invert during our visual assessment of WPW-15A (Figure 5-8). The elevation of the swale invert was similar between years (434.05 m in 2018 and 434.04 m in 2019). These values compare favourably with the values reported by Watson Engineering (2016) of 434.045 m, confirming that no erosion has occurred on the surface of the swale invert since construction.

Figure 5-8: Image of the WPW-15A wildlife physical works at Cartier Bay. May 10, 2019.

5.3 Wetland and Riparian Habitat Monitoring at WPW-15A

5.3.1 Water Depth and Water Chemistry

Average water depth at surface sample points was 0.85 m (Table 5-2). Average measured depths tended to be greater in the west compartment of Cartier Bay (1.33 m) than in the east compartment (0.53 m). Depths in the east compartment ranged from 0.05-1.38 m; those in the west, from 0.17-2.15 m; Figure 5-9).

An updated bathymetric map for Cartier Bay, generated from all depth measurements (*n*=166) collected during surface sampling between 2011 and 2019, shows the distribution of shallow and deep areas within the wetland (Figure 5-10).

Measurements of dissolved oxygen (DO), pH, conductivity (µS/cm), and temperature (°C) recorded in the 2019 point samples fell within the range of variation obtained for the pre-works monitoring period (Table 5-2). In the context of this study, water physicochemical variables are only inherently ecologically significant if they are shown to have changed in response to wildlife physical works, and if these changes can be correlated with a change in aquatic plant abundance and distribution. Therefore, further exploration of physicochemical data will be deferred until 2020 when a more complete time series of post-works conditions has been obtained.

Table 5-2. **Mean (*SD*) water depth, Secchi depth (relative turbidity), dissolved oxygen (DO), pH, conductivity (µS/cm), and water temperature (°C) measured in surface samples taken at Cartier Bay wetland from 2013 to 2018.**

Year (*n*)	Water depth (m)	Secchi depth (cm)	DO (mg/l)	pH	µS/cm	°C
2011 (19)	1.01 (0.56)	n/a	9.32 (1.85)	8.5 (0.37)	203.23 (57.92)	19.54 (1.36)
2012 (13)	1.03 (0.51)	79.62 (15.0)	9.24 (0.32)	n/a	106.42 (13.55)	14.33 (1.24)
2013 (15)	1.43 (0.44)	195 (n/a)	11.82 (1.35)	8.81 (0.38)	114.12 (8.17)	17.25 (1.68)
2018 (104)	0.88 (0.36)	91.81 (17.59)	9.11 (1.03)	8.12 (0.26)	169.7 (20.69)	19.65 (1.83)
2019 (131)	0.85 (0.56)	n/a, visible to bottom	11.47 (1.65)	9.05 (0.22)	205.18 (24.89)	20.51 (2.42)

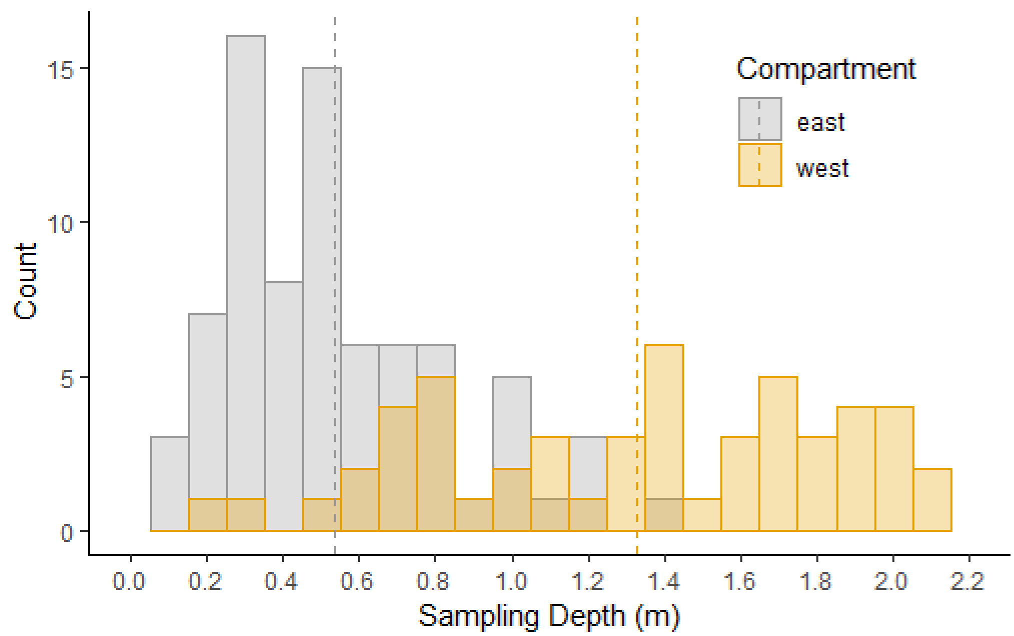

Figure 5-9. **Sampling depth distributions for the east and west compartments of Cartier Bay wetland in 2019.** "East" compartment refers to the area east of the eroded roadbed bisecting the wetland; "west" compartment refers to the area west of the roadbed and east of WPW-6A (Figure 2-2). Dashed lines represent the average sampled depths.

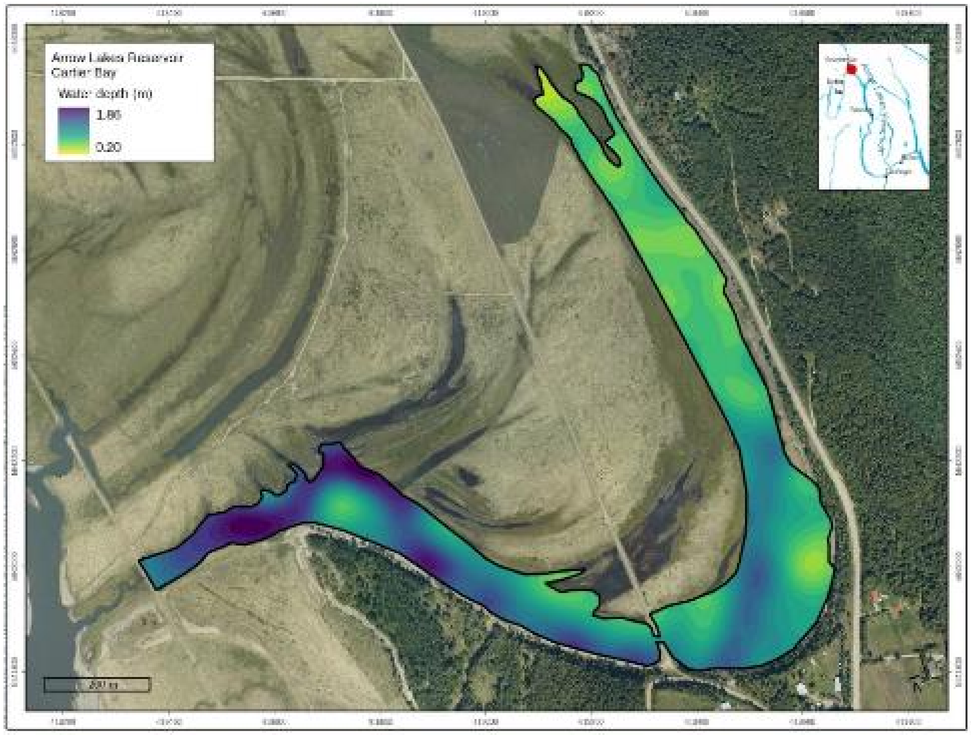

Figure 5-10: Bathymetric map of Cartier Bay wetland, based on depth sound measurements made during surface sampling in 2011, 2012, 2013, 2018, and 2019 (*n*=296).The interpolation method used was Simple Kriging, with a Gaussian model and a smoothing weighting factor. All depth data were back-corrected using historical records of daily reservoir elevations, to correct for overestimates on sample days when the wetland was inundated by the reservoir.

5.3.2 Aquatic Macrophytes

5.3.2.1 Frequency and Abundance

In 2019, the second year of post-works monitoring, per cent frequency of macrophytes at Cartier Bay (Figure 5-11) ranged from nil (for floating-leaved pondweed) to highs of 89, 71, and 42 per cent (for Eurasian water-milfoil, Braun's stonewort, and small pondweed, respectively). Water smartweed, as well as two other pondweeds (Richardson's and eel-grass) were only encountered sporadically. Eurasian water-milfoil and stonewort showed a trend of increasing frequency since 2011-12, while common hornwort, small pondweed, and water smartweed showed a declining trend since the outset of baseline monitoring (Figure 5-11).

Common hornwort, Eurasian water-milfoil, and stonewort (a green algae) tended to have the highest local biomass volume as measured by the VC (sample volume x relative cover) metric. Pondweeds (*Potamogeton* spp.) were the most biodiverse group of macrophytes in Cartier Bay but tended to be relatively less dominant locally (Figure 5-12). VC for common hornwort, a native species, suggests a slight declining trend since 2011, while that of the non-native species Eurasian water-milfoil may have increased somewhat (Figure 5-12). Several of these species provide habitat structure and/or food for wildlife and can be viewed as indicators of habitat condition to some degree (see Appendix 8.1 for a brief review of the ecology of key macrophyte species found in Revelstoke Reach).

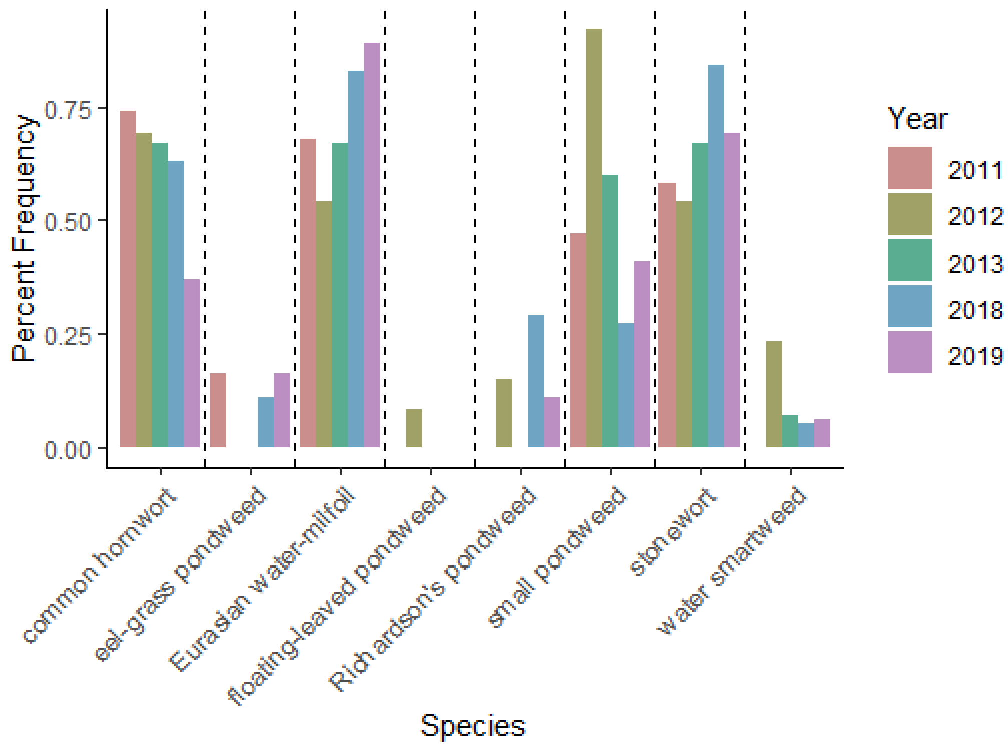

Figure 5-11. Proportion of samples (per cent frequency) in which aquatic macrophyte species were recorded in random surface samples (rake grabs) at Cartier Bay wetland, from 2011 to 2019. *n* = 19, 13, 15, 104, and 131 in 2011, 2012, 2013, 2018, and 2019 respectively. Common hornwort: *Ceratophyllum demersum*; eel-grass pondweed: *Potamogeton zosteriformis*; Eurasian water-milfoil: *Myriophyllum spicatum*; floating-leaved pondweed: *P. natans*; Richardson's pondweed: *P. richardsonii*; small pondweed: *P. pusillus*; stonewort: *Chara braunii*; water smartweed: *Persicaria amphibia.*

Eurasian water-milfoil and stonewort can both form dense mats over the benthic surface, potentially displacing other aquatic plants. The apparent increase in the frequency of these species since 2011, along with a (presumptive) coincidental decline in the frequency of common hornwort and small pondweed, could be an indication that a compositional shift is underway in Cartier Bay (with potential long-term implications for invertebrates and wildlife). Because the post-works data time series is, as of 2019, limited to two years, it is too early in the monitoring process to test for significance in these trends or assign them to project-related effects. Such analyses will be deferred until the final summary report (scheduled for 2020). However, since the observed changes appear to have commenced prior to the project implementation, it is quite possible that macrophyte production in Cartier Bay was not directly affected by WPW-15A implementation.

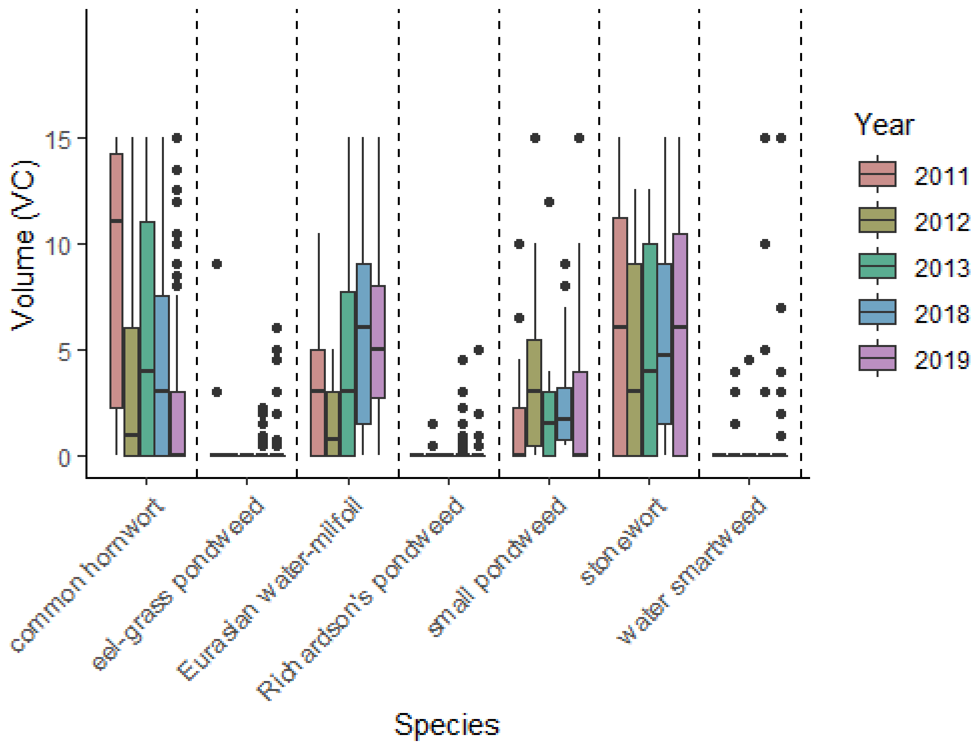

Figure 5-12. **Local abundance, as represented by the VC (sample volume x relative cover) metric, of aquatic macrophytes in random surface samples (rake grabs) at Cartier Bay wetland, from 2011 to 2019.** *n* = 19, 13, 15, 104, and 131 in 2011, 2012, 2013, 2018, and 2019 respectively. Common hornwort: *Ceratophyllum demersum*; eel-grass pondweed: *Potamogeton zosteriformis*; Eurasian water-milfoil: *Myriophyllum spicatum*; Richardson's pondweed: *P. richardsonii*; small pondweed: *P. pusillus*; stonewort: *Chara braunii*; water smartweed: *Persicaria amphibia.*

5.3.2.2 Distribution

Despite the relatively low number of aquatic macrophyte species in Cartier Bay, these species tend to form distinct associations across regions within the two wetland compartments. Macrophyte cover in the western portion of the west compartment (i.e., the area closest to WPW-15A and the river) is primarily composed of stonewort (green algae) and the invasive Eurasian water-milfoil (Figure 5-13). The eastern portion of the west compartment continues to be dominated by those species, but also supports modest covers of common hornwort and three pondweed species, mainly eel-grass pondweed. In the southwest portion of the east compartment (i.e., east of the second roadbed), cover is co-dominated by stonewort, Eurasian water-milfoil, and common hornwort (Figure 5-14), but here small pondweed represents a significant subcomponent as well along with scattered floating beds of water smartweed (an amphibious species that also appears in terrestrial form on the adjacent shoreline). Moving northward along the east compartment, common hornwort and Eurasian milfoil alternately form dense patches, or co-occur in dense patches, while stonewort becomes less common overall and floating beds of water smartweed become more frequent (Figure 5-15). In the northernmost section of the east compartment, small pondweed forms frequent monospecific stands (or mixed stands with Eurasian water-milfoil), particularly in areas of shallower (< 0.5 m) water (Figure 5-14).

Figure 5-13: Rake samples illustrating concentrations of stonewort (left) and Eurasian water-milfoil (right) in the western compartment of Cartier Bay wetland, May 2019.

Figure 5-14: Macrophyte assemblages, east compartment of Cartier Bay wetland, May 2019. Clockwise from top left: rake sample illustrating mixed association of common hornwort, Eurasian water-milfoil, and stonewort; floating bed of water smartweed; submerged bed of small pondweed; and rake sample illustrating dense cover of stonewort.

Figure 5-15: Floating mats of water smartweed, north end of Cartier Bay wetland (east compartment), May 2019.

5.3.3 Riparian Vegetation

The sample of 15, low-lying, shoreline vegetation plots on clayey substrates (Figure 2-2) yielded a different complement of riparian plant species (and species associations) to those recorded on less clayey soils at slightly higher elevations in 2018 (Miller *et al*. 2020). Plant assemblages ranged from variants of the PC-Sedge VCT (characterized by high covers of Kellogg's sedge and/or Columbia sedge) to variants of the PE VCT, consisting of mudflat associations dominated variously by woolgrass, toad rush, the terrestrial form of water smartweed, and mosses (Figure 5-16).

PC-Sedge type habitats were characterized by about 20 per cent cover of Kellogg's sedge, lesser but notable covers of Columbia sedge and wool-grass, and occasionally high moss cover. PE type habitats supported relatively high species richness and relatively high covers of moss, toad rush, water smartweed, and wool-grass (Figure 5-17). Overall, cover was sparse relative to the slightly more upland sites described in Miller *et al.* (2020), likely reflecting differences in early spring conditions. Spring water levels in the main Cartier Bay compartments, temporarily brought higher by snowmelt and runoff, were still in the process of receding at the time of the May survey. This meant that the lower shoreline had been exposed for less time than adjacent sites further up the floodplain, resulting in less time for plant growth. In a "typical" year, re-inundation of the foreshore by the encroaching reservoir commences sometime in mid to late May (for example, in 2018, inundation occurred on 18 May), allowing for a very brief growing season indeed. In that context, the observation at this elevation band of a nascent community of perennial species including wool-grass (*Scirpus atrocinctus*), water smartweed (*Persicaria amphibia*), and Columbia sedge (*Carex aperta*), together with groundcover-providing annuals such as spring water star-wort (*Callitriche palustris*) and toad rush (*Juncus bufonius*), is notable. Wool-grass, Columbia sedge, and Kellogg's sedge have been widely planted elsewhere in Revelstoke Reach as part of the CLBWORKS-2 revegetation program, and thus would be considered highly desirable species from a habitat enhancement standpoint. Under the current hydroregime, they are unlikely to grow sufficiently large to afford much habitat structure, or to flower and set seed (Figure 5-17). However, their presence does give an indication of the robust riparian community that might develop naturally were reservoir levels to be kept below 434 m ASL (the elevation of the repaired dike) for a sequence of years, or for a longer period of the growing season each year.

This sample provides a representative, not a comprehensive, accounting of the plant associations occurring around the perimeter of Cartier Bay wetland. The primary purpose of the 2019 sample was to characterize existing riparian conditions in the immediate post-physical works period, and to provide field verification for any subsequent orthophoto monitoring of riparian changes near the wetland-terrestrial interface in response to the Site 15A WPW.

There is no strong expectation at present that the physical works will have a notable effect on riparian conditions in Cartier Bay. This is because the objective of the works was to maintain the status quo with respect to the maximum depth and areal extent of the permanently wetted area. However, if a change in riparian boundaries or key characteristics is detected by the end of the monitoring period, species covers obtained during the post-works period can be compared against analogous data obtained during the pre-works period (as part of CLBMON-33). A before-after comparison of covers could assist in identifying which plants or vegetation types have contributed substantially to the observed change, and via what mechanism(s).

Figure 5-16: Examples of low-elevation, riparian plant associations recorded at the terrestrial/aquatic interface of Cartier Bay wetland in May 2019, prior to spring reservoir inundation. Clockwise from top left: Kellogg's sedge – Columbia sedge association; spring water-starwort – toad rush association; woolgrass stand (close-up); woolgrass stand (overview); moss cover; water smartweed association.

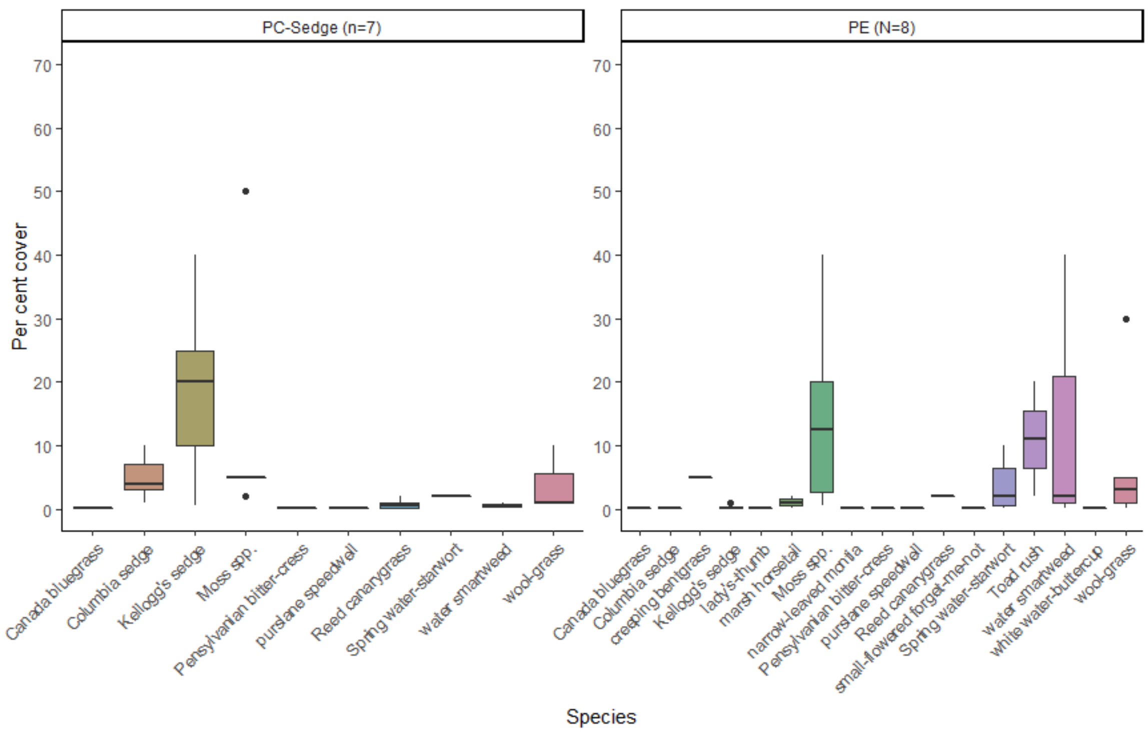

Figure 5-17. **Plant species and covers for different riparian vegetation community types (VCTs) sampled around the perimeter of the Cartier Bay wetland in May 2019**. See Figure 2-2 for sample locations. See Miller *et al.* (2020) for VCT code definitions and descriptions.

6.0 SUMMARY AND RECOMMENDATIONS

This report presents summary results from the second of three years of post-physical works monitoring at Revelstoke Reach (Airport Outflow WPW-6A and Cartier Bay WPW-6A) under the CLBMON-11B4 program. CLBMON-11B4 is part of a suite of monitoring programs that together monitor the effectiveness of wildlife physical works at protecting or enhancing wetland and riparian wildlife habitat, and at benefitting the wildlife that utilize it.

6.1 Erosion Monitoring

The installation of riprap in the east channel at WPW-6A appears to have largely arrested erosion in this channel. There were no apparent signs of erosion or slumping along the perimeter of the riprap; however, as noted in previous years, some erosion and slumping was observed at the channel mouth at the interface between the riprap and the channel bank on the south bank near pin 1.1. The BEHI scores obtained in 2019 were similar to 2018, indicating that little had changed over the two years. The BEHI score obtained for the WPW-6A east channel was very low (BEHI score < 5), further underscoring the success of the WPW.

Analysis of aerial imagery allowed us to estimate and compare rates of erosion in the two channels. Although erosion has mostly ceased in the east channel, we found the rate of erosion in the west channel to be consistent with the rate of erosion in the east channel before WPW (approximately 10 m^2/yr). Unabated, the west channel has been losing about two and a half dump trucks (21.1 m^3/yr) of soil annually since 2008.

In addition to the erosion assessed at Site 6 during our surveys, erosion was also observed along a section of the Old Arrowhead Highway between Site 6 and Airport Marsh. Airport Marsh provides high-value wetland habitat for many species of waterfowl, marsh birds, amphibians, and reptiles, as well as a regionally important population of Western Painted Turtles (*Chrysemys picta bellii*). Changes to water levels in the marsh from the erosion of the Old Arrowhead Highway could be detrimental to the functioning of the wetland and dependant species. Monitoring in future years should include a survey of the erosion occurring along the Old Arrowhead Highway to determine if action should be taken to protect the adjacent habitats.

No signs of erosion were observed at WPW-15A. Survey measurements of the swale obtained in 2019 were consistent with the values obtained in 2016 and 2018.

6.2 Habitat Productivity and Suitability

In terms of wetland and associated riparian habitat productivity and habitat suitability for nesting birds, reptiles, and amphibians at Cartier Bay, the 2019 survey of aquatic and riparian vegetation, and water physicochemical attributes, yielded no immediate indication that the repairs made to the roadbed (WPW-6A) are failing in their objective to protect existing wildlife habitat quality and quantity. Aquatic macrophyte vegetation in the Cartier Bay wetland appears, overall, to be both compositionally and quantitatively like that which existed in the bay prior to implementation of physical works in 2016. Certain native macrophytes such as common hornwort appear to have declined in frequency since 2011, while Eurasian water-milfoil has increased, but the changes do not appear to be linked in time to the physical works implementation. Abiotic water indices (e.g., turbidity, DO, pH, and conductivity) also fell within the general range of variability recorded during the 2011-2013 baseline monitoring period. However, because the post-works data time series is at present limited to two years, it is too early in the monitoring process to test for significance in any trends, or to attempt any direct, statistical pre- and post-works comparisons. These analyses will be deferred until the final summary report (scheduled for 2020).

6.3 Recommendations

We make the following recommendations for the 2020 implementation year:

Erosion Monitoring

1. Continue visual assessments, survey measurements, and aerial image interpretation to monitoring erosion at WPW-6A. Particular attention should be paid to the undercut bank at the mouth of the east erosion channel. We recommend using a drone again to capture higher resolution imagery and DEM at WPW-6A. Drone acquired photogrammetry was a cost-effective approach for monitoring changes in channel size and volume. The higher resolution imagery and DEM acquired by the drone provided more reliable data for delineating channel perimeters and estimating channel area (m^2) than airplane acquired digital orthophotos.

2. We recommend expanding the erosion monitoring to include the main erosion channel at WPW-6A. Survey efforts to date have focused on monitoring and comparing erosion between the east and west channels. The main channel is closer to Machete Island and is immediately threatened by the enlargement of this portion of the erosion channel.
3. We also recommended expanding the erosion monitoring to include the section of the Old Arrowhead Highway between WPW 6A and Airport Marsh. Erosion along this section appears to be increasing. Unabated, this erosion may cause channelling in the adjacent floodplain and affect water levels in Airport Marsh.
4. Given the success of the WPW in arresting erosion in the east channel, we recommend that preliminary scoping of the west and main channels at Site 6 be undertaken in year three of this project (2020/21) to assess the utility of applying a similar approach there.
5. Continue erosion monitoring at WPW 15A, including visual assessments of the riprap and riprap-dyke interface, and survey measurements of the swale for monitoring changes in swale depth.

Vegetation monitoring

1. There is high natural annual variability in macrophyte distribution and abundance; consequently, only very large project-related effects are likely to be detected within the given monitoring time frame. No such large impact has yet been observed, nor is one predicted based on initial observations. Thus, some consideration should be given to whether it is necessary and cost-effective to continue aquatic vegetation and water quality/depth monitoring at Cartier Bay Site 15A for a third year. In making this determination, it should be kept in mind that there may be benefits to maintaining the data time series until the final study year that extend outside the scope of effectiveness monitoring.

   Continuing to fill data gaps on invasive species trends could be one such benefit. For example, the non-native Eurasian water-milfoil has exhibited a trend of increasing abundance since the start of baseline monitoring (2011-12). In contrast, the native common hornwort, which occupies a similar ecological niche, has experienced a declining trend over the same time period, possibly in response to increased competition from Eurasian water-milfoil. Another year of monitoring data would assist in determining—as a secondary objective to other, within-scope objectives—if a significant compositional shift is underway in Cartier Bay (with potential long-term implications for invertebrates and wildlife).
2. Wildlife physical works could affect the aerial extent of shallow open water habitat and, by, extension the location, quality, and structure of associated riparian vegetation. Changes in either attribute could in turn alter the area or suitability of wildlife habitat for nesting birds, reptiles, or amphibians. Therefore, it is relevant to know if the permanent (spring) wetland-riparian boundary has shifted substantially since project implantation. Two ways to determine this are:

a. directly, by using available time series of aerial orthoimages to visually compare wetland extents pre- and post-physical works; and

b. indirectly, by estimating the surface elevation (water level) of the wetland prior to inundation in the spring and comparing this estimate to (i) the historical (pre-works) elevation and/or (ii) the target water level established by the WPW objectives.

We suggest that one or both methods be adopted for the final implementation year (2020).

3. For the final study year, in lieu of undertaking a comprehensive resampling of vegetation at Cartier Bay Site 15-A (as per point 1, above), greater emphasis could be placed on developing recommendations around wildlife physical works methods or techniques that are most likely to be effective at protecting or enhancing the productivity of wetland and associated riparian habitat in the drawdown zone of Revelstoke Reach. To help address this question, results form CLBMON-11B4 would be interpreted in light of results and with data from other relevant studies including some or all of: CLBMON-12, CLBMON-11B3, CLBMON-37, CLBMON-11B2, CLBMON-36, CLBMON-39, and CLBMON-40.

7.0 LITERATURE CITED

Allmanová Z. and J. Matúš. 2016. Is the BEHI Index (Part of the BANCS Model) Good for Prediction Streambank Erosion? *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 64(4): 1107–1114.

BC Hydro. 2005. Consultative Committee report: Columbia River Water Use Plan, Volumes 1 and 2. BC Hydro Power Corporation, Burnaby, BC.

Cooper Beauchesne and Associates Ltd (CBA). 2018. CLBMON 39: Arrow Lakes Reservoir Neotropical Migrant Use of the Drawdown Zone, Year 10 (2017). Unpublished report by Cooper Beauchesne and Associates Ltd., Qualicum Beach, B.C., for BC Hydro Generation, Water Licence Requirements, Burnaby, B.C. 33 pp. + apps.

Enns, K., P. Gibeau, and B. Enns. 2008. CLBMON-33 Arrow Lakes Reservoir inventory of vegetation: 2008 final report. Report prepared by Delphinium Holdings Inc. for BC Hydro, Castlegar, B.C.

Fenneman, J. and V. Hawkes. 2012. CLBMON 11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Annual Report – 2011. LGL Report EA3234. Unpublished report by LGL Limited Environmental Research Associates, Sidney, B.C., for BC Hydro, Water License Requirements, Burnaby, B.C.

Golder Associates and Watson Engineering. 2014. Site 6A - Airport Outflow: As Built Report for Arrow Lakes Wildlife Physical Works 2014. Unpublished report by Golder Associates and Watson Engineering Ltd, for BC Hydro Project delivery, Burnaby, B.C.

Golder Associates. 2009a. CLBWORKS-29A: Arrow Lakes Reservoir Wildlife Physical Works Feasibility Study – Phase I. 49 pp. Unpublished report for BC Hydro, Castlegar, B.C.

Golder Associates. 2009b. Arrow Lakes Reservoir Wildlife Physical Works Feasibility Study, Phase II. Unpublished report for BC Hydro, Castlegar, B.C.

Hawkes, V.C. and D. Adama. 2020. CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works 2016 annual report. LGL Report EA3368D. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., and Okanagan Nation Alliance, Westbank, BC, for BC Hydro Generations, Water License Requirements, Burnaby, B.C. 13 pp. + Appendices.

Hawkes, V.C., K.N. Tuttle, and C.M. Wood. 2015a. CLBMON-37. Kinbasket and Arrow Lakes Reservoirs: Amphibian and Reptile Life History and Habitat Use Assessment. Year 7 Annual Report – 2014. LGL Report EA3533. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Burnaby, BC. 79 pp + Appendices.

Hawkes, V.C., H. van Oort, M. Miller, N. Wright, C. Wood, and A. Peatt. 2015b. CLBWORKS-30 Ecological Impact Assessment – Wildlife Physical Works Project 14 & 15A. Unpublished Report by LGL Limited Environmental Research Associates, Cooper, Beauchesne and Associates, Ecofish Research Ltd. and Okanagan Nation Alliance for BC Hydro Water License Requirements, Burnaby BC.

Hawkes, V.C., M. Miller, J.D. Fenneman, and N. Winchester. 2011. CLBMON-11B4 monitoring wetland and riparian habitat in Revelstoke Reach in response to wildlife physical works. Annual Report – 2010. LGL Report EA3232. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., for BC Hydro Generations, Water Licence Requirements, Burnaby, B.C.

Lees + Associates. 2010. BC Hydro Arrow Reservoir Recreational Demand Study – CLBMON 41: Year 1 Results. Vancouver, BC. Unpublished report by for BC Hydro Water License Requirements, Burnaby, B.C.

Mackenzie, W.H. and J.R. Moran. 2004. Wetlands of British Columbia: A guide to identification. Land Management Handbook No. 52. B.C. Ministry of Forests, Victoria, B.C.

Madsen, J.D. 1999. Aquatic Plant Control Technical Note MI-02: Point intercept and line intercept methods for aquatic plant management. US Army Engineer Waterways Experiment Station. Avail. online: http://el.erdc.usace.army.mil/aqua/pdf/apcmi-02.pdf

Miller, M. and V. Hawkes. 2013. CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Annual Report – 2012. LGL Report EA3413. Unpublished report by Okanagan Nation Alliance and LGL Limited Environmental Research Associates, Sidney, B.C., for BC Hydro, Water License Requirements, Burnaby, B.C.

Miller, M. and V. Hawkes. 2014. CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Annual Report – 2013. LGL Report EA3413. Unpublished report by Okanagan Nation Alliance and LGL Limited Environmental Research Associates, Sidney, B.C., for BC Hydro, Water License Requirements, Burnaby, B.C.

Miller, M.T., D. B. Adama, and V.C. Hawkes. 2020. CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Annual Report – 2018. LGL Report EA3414F. Unpublished report by Okanagan

Nation Alliance and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 37 pp + Appendix.

Miller, M.T., P. Gibeau, and V.C. Hawkes. 2018. CLBMON-33 Arrow Lakes Reservoir Inventory of Vegetation Resources. Final Report–2016. LGL Report EA3545B. Unpublished report by Okanagan Nation Alliance, Westbank, BC, and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generations, Water License Requirements, Castlegar, BC. 84 pp + Appendices.

Newton, S.E., and D. M. Drenten. 2015. Modifying the Bank Erosion Hazard Index (BEHI) Protocol for Rapid Assessment of Streambank Erosion in Northeastern Ohio. J. Vis. Exp. (96), e52330, doi:10.3791/52330 (2015).

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rathbun, J. 2008. Standard operating procedure: assessing bank erosion potential using Rosgen's bank erosion hazard index (BEHI). Michigan Department of Environmental Quality, Water Bureau, Nonpoint Source Division.

Rosgen, D.L. 2001. Proceedings of the 7 th Federal Interagency Sedimentation Conference, Vol. 2, pp. 9-15, March 25, 2001, Reno, NV. Available on the Wildland Hydrology website at: A Practical Method of Computing Streambank Erosion Rate. http://www.wildlandhydrology.com

Warrington, P.D. 1980. Studies on Aquatic Macrophytes, Part XXXIII: Aquatic Plants of British Columbia. Report prepared for the Ministry of Environment, British Columbia. Victoria, BC. 638 pp.

Warrington, P.D. 1983. Selected Control Methods for Aquatic Weeds in British Columbia. Report prepared for Ministry of Environment, British Columbia. Victoria, BC. 102 pp.

Watson Engineering, 2016. Arrow Lakes Reservoir Wildlife Physical Works Site 15A – Cartier Bay Washout Buttressing. Brief Completion Report 2016-11-16. Unpublished Report prepared for BC Hydro Water License Requirements, Burnaby, B.C.

8.0 APPENDIX

8.1 Drone Photogrammetry Coverage

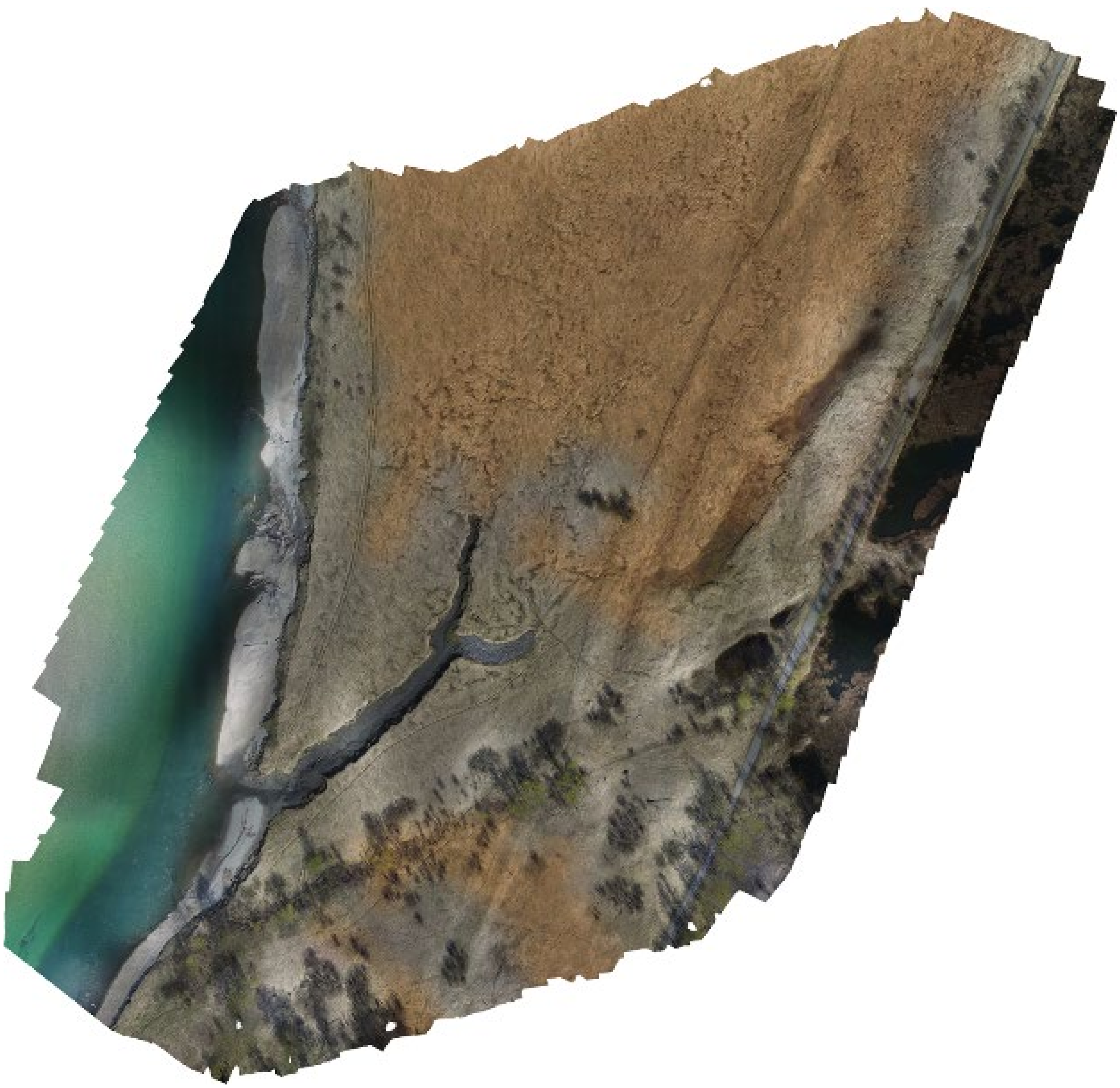

Figure 8-1: Image showing drone photogrammetry-derived coverage of WPW-Site6A acquired on April 26, 2019.

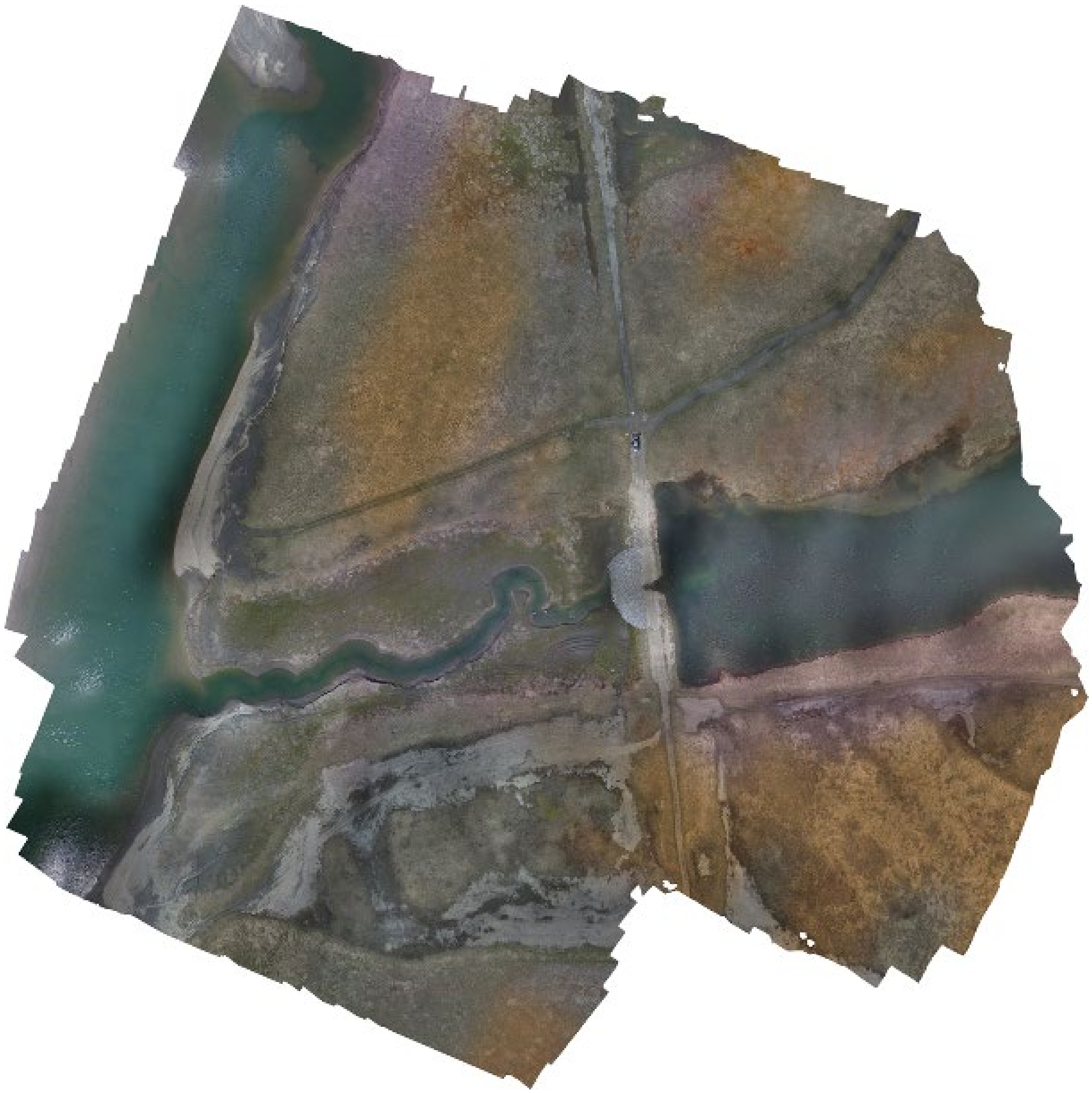

Figure 8-2: Image showing drone photogrammetry-derived coverage of WPW-Site15 acquired on April 26, 2019.

8.2 Erosion Survey Measurements

Table 8-1: Mean and standard deviation of differences of 2016 and 2018 stake to pin measurements along the east and west Channels.

Channel	Stake-Pin Array	2016 Pin to Stake Distance (cm)	2018 Pin to Stake Distance (cm)	2019 Pin to Stake Distance (cm)	Difference between 2018 and 2016 (cm)	Annual rates of soil movement between 2018 and 2019 (cm/yr)	Difference between 2019 and 2018 (cm)
East	1.1	122	129	129.0	7.0	3.5	0.0
	1.2	122	126.5	127.0	4.5	2.3	0.5
	1.3	122	123	125.0	1.0	0.5	2.0
	1.4	122	122	122.0	0.0	0.0	0.0
	1.5	120	120	120.0	0.0	0.0	0.0
	1.6	122	122.5	130.0	0.5	0.3	7.5
	1.7	122	122	121.0	0.0	0.0	0.0
	1.8	120	120	122.0	0.0	0.0	2.0
	1.9	122	122.5	126.0	0.5	0.3	3.5
				Mean	*1.5*	0.8	1.7
				SD	*2.5*	1.3	2.5
West	2.1	122	122	125.0	0.0	0.0	3.0
	2.2	122	122	124.5	0.0	0.0	2.5
	2.3	122	124.5	124.5	2.5	1.3	0.0
	2.4	122	134	144.0	12.0	6.0	10.0
	2.5	122	193	*	71.0		
	2.6	122	135.5	140.5	13.5	6.8	5.0
	2.7	122	137.5	149.0	15.5	7.8	11.5
	2.8	122	125	129.0	3.0	1.5	4.0
	2.9	122	125.5	132.0	3.5	1.8	6.5
				Mean	*13.4*	3.1	5.3
				SD	*22.4*	3.2	3.9

- Pin missing due to bank undercutting and collapse.

Table 8-2: Bank Erosion Hazard Index (BEHI) scores for the east and west erosion channels, 2018.

Channel	Pin	Bank Height	Root Depth	RDH Score	Surface Protection (%)	SP Score	Bank Angle (degree)	BA Score	Bank Material	Total Score
East	1.1	35	45.7	1	90	1	16	1	5	8
East	1.2	15	45.7	1	90	1	12	1	0	3
East	1.3	10	45.7	1	95	1	10	1	0	3
East	1.4	5	45.7	1	100	1	18	1	0	3
East	1.5	5	45.7	1	85	1	7	1	0	3
East	1.6	10	45.7	1	100	1	7	1	0	3
East	1.7	30	45.7	1	80	1	15	1	0	3
East	1.8	40	45.7	1	100	1	25	2.5	0	4.5
East	1.9	50	45.7	1	100	1	14	1	5	8
Mean Values		22.2		1		1		1.2	1.1	4.3
West	2.1	197	45.7	7.5	100	1	45	2.5	10	21
West	2.2	235.5	45.7	7.5	85	1	30	2.5	10	21
West	2.3	259	45.7	7.5	80	1	38	5	10	23.5
West	2.4	257	45.7	7.5	20	7.5	90+	10	10	35
West	2.5	245.5	45.7	7.5	50	5	90+	10	10	32.5
West	2.6	250.5	45.7	7.5	50	5	80	5	10	27.5
West	2.7	254	45.7	7.5	40	5	90+	10	10	32.5
West	2.8	243.5	45.7	7.5	50	5	65	10	10	32.5
West	2.9	189.5	45.7	7.5	30	5	90+	10	10	32.5
Mean Values		236.8		7.5		3.9		7.2		28.7

Table 8-3: Bank Erosion Hazard Index (BEHI) scores for the east and west erosion channels, 2019

Channel	Pin	Bank Height (cm)	Root Depth (cm)	RDH Score	Surface Protection (%)	SP Score	Bank Angle (degree)	BA Score	Bank Material	Total Score
East	1.1	35	45.7	1	90	1	0	1	0	9.5
East	1.2	15	45.7	1	90	1	0	1	0	3
East	1.3	10	45.7	1	95	1	0	1	0	3
East	1.4	5	45.7	1	100	1	0	1	0	3
East	1.5	5	45.7	1	85	1	0	1	0	3
East	1.6	15	45.7	1	100	1	0	1	0	3
East	1.7	30	45.7	1	80	1	0	1	0	3
East	1.8	40	45.7	1	100	1	0	1	0	9.5
East	1.9	50	45.7	1	100	1	25	2.5	0	8
Mean Values		22.8		1		1		1.2	0	5.0
West	2.1	230	45.7	7.5	100	1	45	2.5	10	21
West	2.2	238	45.7	7.5	80	1	30	2.5	10	21
West	2.3	255	45.7	7.5	80	1	38	3	10	28.5
West	2.4	281	45.7	7.5	30	7.5	90+	10	10	32.5
West	2.5	270	45.7	7.5	50	5	90+	10	10	32.5
West	2.6	271	45.7	7.5	40	5	80	7.5	10	32.5
West	2.7	247	45.7	7.5	30	5	90+	10	10	32.5
West	2.8	247	45.7	7.5	50	5	65	5	10	32.5
West	2.9	217	45.7	7.5	40	5	90+	10	10	32.5
Mean Values		250.7		7.5		7.5		6.7		28.3

8.3 Vegetation Indicators of Habitat Condition in Revelstoke Reach Wetlands

Several wetland plants occurring in Cartier Bay and/or Airport Marsh provide positive or negative benefits for wildlife and can be viewed as indicators of habitat condition to some degree. These include **floating-leaved pondweed** (8.3.1), **Richardson's** and **eel-grass pondweeds** (8.3.2), **common hornwort** (8.3.3), **water smartweed** (8.3.4), **Rocky Mountain pond-lily** (8.3.5), **greater bladderwort** (8.3.6), and **Eurasian water-milfoil** (8.3.7).

8.3.1 Floating-leaved Pondweed (*Potamogeton natans*)

Positive or negative indicator. Floating-leaved pondweed communities occur in quiet waters on peat sediment in oligotrophic and mesotrophic lakes and can often be found in deeper waters adjacent to pond-lily communities. This species forms a dense canopy and the understory is frequently sparse. Bladderworts and milfoils are common associates (Mackenzie and Moran 2004). It can be an important component of acidic, organic ponds where few other species grow (Warrington 1983).

Floating-leaved pondweed sometimes forms dense beds of floating leaves and tough stems from a depth of at least 4 m, but it also grows in shallow areas occasionally becomes stranded on wet mud. There is considerable open water under a patch of floating-leaved pondweed that affords shelter to aquatic organisms.

Floating-leaved pondweed is sometimes an important food for ducks, which browse on the rootstocks and, later in the season, on the nutlets. *Potamogeton* species in general are a favourite food of waterfowl, with some eating whole plants and others preferring certain parts of the plant (especially the nutlets/seeds). They are staple food for ducks, which utilize all species. They are also attractive to marsh birds and shorebirds, and are often heavily browsed by muskrats, beaver, deer, and moose. They provide food, shelter, and shade for fish and small animals and are a haven for insects, which in turn provide food for fish populations. Some species have been found to soften the water by removing lime and carbon dioxide and depositing marl (Warrington 1983).

8.3.2 Richardson's and Eel-grass Pondweeds (*Potamogeton richardsonii*, *P. zosteriformis*)

Positive or negative indicator. Unlike floating-leaved pondweed, these species are typically fully submergent, although plants may reach the surface from 4-5 m depth. Richardson's pondweed grows in relatively deep, less nutrient-rich waters, often on mineral sediments with some water movement, whereas eel-grass pondweed tends to occur in shallower and more nutrient-rich water. In places, these species can form the understory to canopies of floating-leaved pondweed (Mackenzie and Moran 2004). Both species provide browse for ducks (Warrington 1983).

8.3.3 Common Hornwort (*Ceratophyllum demersum*)

Positive or negative indicator. The submergent common hornwort thrives in eutrophic conditions, surviving in water up to 5 m deep. An obligate hydrophyte, it cannot survive even brief drying in air, although it tolerates fluctuating water levels and turbidity very well. The plants have no roots and, instead, develop modified leaves with a rootlike appearance to anchor the plant to the bottom or to other objects in the water. Early in the season, plants are mostly erect with the lower part anchored; later most are in floating mats at the surface.

Caddisfly larvae utilize hornwort leaves and waterfowl eat the fruits. The plants provide shelter for young fish, crustaceans, and other small animals, and support insects valuable as fish food. Mostly the seeds, but sometimes the foliage, are an important food for waterfowl and, occasionally, muskrats. Hornwort can sometimes crowd out other plants (Warrington 1983).

8.3.4 Water Smartweed (*Persicaria amphibia*)

Positive or negative indicator. Water Smartweed communities occur in larger lakes in 0.5-1.5 m deep water on sandy substrates where currents limit accumulation of organic matter and fines. Plants can form a dense floating cover associated with scattered floating-leaved pondweed and overtopping submerged species such as Eurasian watermilfoil (Mackenzie and Moran 2004). This species can grow in a truly aquatic fashion in deep water but also has marginal or terrestrial forms. In areas with highly fluctuating water levels, it tends to form floating mats (Warrington 1983).

This and related species produce nutlets, which are the only part commonly eaten; however, these nutlets can be important food for waterfowl, upland game birds, shorebirds, and songbirds. Seed production is copious and waterfowl often congregate in areas where multiple species are found (Warrington 1983).

8.3.5 Rocky Mountain Pond-lily (*Nuphar polysepala*)

Positive or negative indicator. There are several shallow-water wetland types classified with *Nuphar lutea* (a formerly used name for *N. polysepala*) as a dominant component (Mackenzie and Moran 2004). These wetlands occur in a wide variety of aquatic sites, ranging from deep (5 m) lakes with gravel substrates to shallow acidic pools with peat substrates (Mackenzie and Moran 2004). The substrate is often an organic ooze that is anaerobic for at least part of the year; rhizomes survive by utilizing anaerobic respiration and accumulating ethanol until free oxygen again becomes available. Optimum oxygen levels are low (around 2 ppm), with higher levels detrimental to growth. Dense colonies will cover virtually the entire surface of the water and shade out other species. Dense colonies can form and restrict water flow at 1 to 2 m depth, contributing to the oxygen deficit of the sediments and encourage silting in outlet channels of lakes (Warrington 1983). The extensive leaf litter produced by a Rocky Mountain Pond-lily bed contributes to the organic and anaerobic conditions of the sediments (Warrington 1983).

Deer graze on the leaves and petioles in shallow water, ducks eat the seeds (which are produced in generous amounts), and muskrats and beavers browse on the rhizomes. Some larval insects have been found to feed on *Nuphar* leaves but seem to do so only late in the season when the leaves are beginning to die (Warrington 1983).

8.3.6 Greater Bladderwort (*Utricularia macrorhiza*)

Positive or negative indicator. Greater Bladderwort is a widespread and successful species found in many shallow aquatic habitats. It often grows in close association with Rocky Mountain pond-lily; the latter forms an open canopy with greater bladderwort in the understorey. This widespread shallow-water wetland ecosystem type (Mackenzie and Moran 2004) occurs in dystrophic and oligotrophic waters 20-200 cm deep, especially on guano-based and peat sediments. These sites are typically relatively species-poor (Mackenzie and Moran 2004). Within the study area it occurs primarily in Airport Marsh, where it is largely restricted to the protected waters within emergent colonies of cattail and bulrush.

Free-floating mats of greater bladderwort can become entangled in other rooted aquatic plants and impede water flow in irrigation and drainage ditches. The species is carnivorous and utilizes small crustaceans and other minute aquatic animals that it traps in bladders on the leaves. It is not believed to be an important food source for wildlife, although it can provide food and cover for fish and the mats provide breeding areas for mosquitoes (Warrington 1983).

8.3.7 Eurasian Water-milfoil (*Myriophyllum spicatum*)

Negative indicator. The non-native Eurasian water-milfoil generally grows in fresh water but can tolerate salinity up to 10 ppm. It can take on a dwarfed semiterrestrial form when stranded along receding shorelines. The species can reach the surface when rooted as much as 5 m underwater. Birds eat the seeds and, to a limited extent, the vegetation. Snails graze on the plants and caddisfly larvae build cases from the leaves. The plants provide shelter for fish and invertebrates. High population densities can supersaturate the water with oxygen in daylight and deplete the levels to almost zero at night. These fluctuations are detrimental to fish populations. In the fall, large beds can die off and cause significant oxygen deficits that are detrimental to fish and produce large masses of rotting vegetation on shorelines (Warrington 1983).

Given the potential of Eurasian water-milfoil to exert a detrimental effect on wetland health, eradication/control was investigated as a potential component of wetland creation or restoration in Revelstoke Reach. A variety of options for control or eradication of Eurasian water-milfoil have been identified (e.g. Washington State Department of Ecology 2010), but these have variable applicability to the conditions at Cartier Bay. The options range from manual pulling and harvesting to the application of chemical treatments and herbicides (e.g., Fluridone). Manual removal treatments have shown poor success rates elsewhere. Although Fluridone application has shown some success in eliminating Eurasian water-milfoil from lakes in Washington State, its effects on wildlife and other species are either marginally detrimental or unknown. Of particular concern to this study, there are no data on the ability of amphibians, which are notoriously sensitive to water chemistry, to withstand its application. Cartier Bay is one of the most significant breeding sites for Western Toad in Revelstoke Reach (see Hawkes *et al.* 2015a). As Western Toad is a federal species of Special Concern and the driving force behind much of the restoration activities planned for the area, it was deemed inappropriate to administer such an untested chemical due to the potential for catastrophic effects on this population. Indeed, it is possible that the success of the breeding toad population may be related to the abundance of cover provided to the eggs and developing tadpoles by the dense stands of water-milfoil, and their removal may render amphibians more susceptible to predation by fish and birds.

8.4 Field Data Form used for Cartier Bay Site 15A Wetland Monitoring

Below is a sample data form used for post-works (2018) sampling of aquatic conditions at Cartier Bay.

DATE: ______-______-______ **TIME:** ____:____ **SITE:** ______________ **COMMUNITY TYPE:** Submergent ☐ Floating ☐ Emergent ☐ Riparian ☐
dd-mmm-yy

SURVEYORS: ______________ **PLOT NUMBER:** ______________ **UTM:** 11U E ______________ N ______________ **VEGETATION PRESENT?** Y ☐ N ☐

SAMPLING COMPLETED: Rake drag (rel. abundance) ☐ Surface quadrat (cover) ☐ Terrestrial plot (cover) ☐ VCT______________________

WATER DEPTH (cm): ______ **SECCHI DEPTH:** ______ **WATER TEMP:** ______ **DO:** ______ **CONDUCTIVITY:** ______ **PH:** ______ **PHOTOS:** ______________

STRUCTURAL STAGE†: ____________ SLOPE__________ ASPECT__________ SOIL MOISTURE†: ____________ GEN. SURF. TOPOG†: ______________

SURFACE SUBSTRATE (%): ROCK (>7.5 CM) ______ MINERAL (<7.5 CM)______ ORG.______ WOOD______ WATER______

MICROTOPOG†: ______________ROOTING ZONE TEXTURE – COARSE FRAG†: ________ ROOTING ZONE TEXTURE – FINE†: ______________________

PRIM. WATER SOURCE†: ______________________ DISTURBANCE†: ______________________________________ PHOTOS: ______________________

Aquatic Point Samples					Riparian Plots			
Sample #	* Vol.	Species	**Rel. Ab.	%Cover	Species	%Cover	Layer	Notes

*Sample Vol.

1 Trace
2 Small
3 Large

**Relative Abundance in Sample

T Trace
1 <10%
2 10-20%
3 20-50%
4 50-75%
5 75-100%

†Use key in CLBMON-12 (2017) data form for this field