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 Years 1-8

Reference: CLBMON-11B4

Final Comprehensive Report

Study Period: 2010 - 2020

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

December 17, 2021

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CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works




Final Report
Year 8
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Prepared for

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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 project's mandate is to assess the effectiveness of 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). WPW-6A aimed 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. A second channel (west arm) was left untreated for comparison. 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). Post-works assessments occurred in 2016 at WPW-6A, and post-works monitoring was conducted at both sites in 2018, 2019, and 2020. Interpretation of 2008 to 2020 aerial imagery allowed us to determine erosion rates at WPW-6A before and after implementing physical works. Here we report final results at the three-year mark of post-works monitoring (2020).

Aquatic habitat monitoring at Site 15A followed methods established in 2010 during pre-physical works baseline assessments. Macrophyte frequency and abundance, along with water depths, were sampled at random points along the surface of the two Cartier Bay wetland compartments. Samples were obtained using a double-headed rake (macrophyte grapnel) and depth sounder. Sampling occurred in mid-May, before the annual inundation of the wetland by the reservoir.

Erosion monitoring at WPW-6A consisted of visual assessments, survey measurements, Bank Erosion Hazard Index (BEHI) assessments, and air photo imagery assessments of the east and west erosion channels. The results indicate that physical works at Site -6A successfully halted erosion. During the post-works survey period, no signs of erosion or slumping were observed in the east channel, although slumping was observed at the mouth, where the channel bank remains exposed. Bank undercutting, slumping, channel incision, and head cutting continued in the west erosion channel. As a result, the west channel depth increased by 17.3 cm from 2018 to 2020, while the depth of the east channel did not change.

BEHI scores were low for the east channel and high for the west channel, and BEHI values increased slightly in the west channel but remained relatively constant in the east channel from 2016 to 2019. Differences in BEHI scores between the two channels were due to higher bank height and steeper bank angles, and lower surface protection (due to exposed soils) in the west channel.

Aerial images from 2008 to 2020 provided further evidence that physical works at Site 6A halted erosion in the east channel. The footprint and surface volume of the channel did not change from 2016 to 2020, and minor differences were attributed to measurement error, including differences associated with image resolution.

Prior to project implementation, head cutting advanced the length of the east channel at a rate of 0.53 m/year. After WPW-6A was completed, the length of the east channel lengthened at a rate of 0.02 m/year, which is in the realm of measurement error. In contrast, the length of the west channel advanced by 11.1 m between 2008 and 2020, for an average change of 0.93 m/year.

The volumetric rate of erosion in the east channel was 23.7 m^3/yr prior to project implementation (2008 to 2012) and was negligible afterwards (0.04 m^3/yr; 2016 to 2020) – again within the realm of measurement error. Conversely, the volumetric rate of erosion in the west channel nearly tripled during the before and after implementation periods (22.9 m^3/yr during 2008 to 2012 and 60.3 m^3/yr; 2016 to 2020). This indicates that not only was the west channel continuing to erode but the rate of erosion has increased. This is not unexpected as surface area of exposed soil increases as the depth and length of the channel increases.

These results indicate that WPW-6A successfully arrested erosion and lengthening of the east channel six years after project completion. In contrast, the west channel continued to erode and lengthen. Over time, continued erosion and lengthening of the west channel may threaten Airport Marsh, and a geotechnical assessment is recommended. Further, persistent erosion was also observed in the main channel that connects the Columbia River to the east and west erosion channels and along an section of old Arrowhead Highway adjacent to Airport Marsh. Geotechnical assessments are recommended for these areas as well.

A visual assessment and survey measurements at the WPW-15A water control structure did not reveal any noticeable or measurable amounts of erosion following project completion (e.g., survey elevations of the swale did not change from 2018 to 2020). While there is concern over the long-term success of WPW-15A as-built (see below), thus far wildlife habitat quality and quantity has been well-maintained, consistent with the project's general objective of protecting the status quo. Aquatic macrophyte and other vegetation in the Cartier Bay wetland is, overall, both compositionally and quantitatively like that which existed in the bay prior to implementation of physical works in 2016. While there have been some non-linear changes over time in macrophytes species frequency and abundance, such fluctuations can be expected in a highly dynamic, reservoir-impacted environment such as Cartier Bay. Except possibly for one species of pondweed (small pondweed), which was less common and abundant post-physical works than pre-physical works, there were no obvious step changes in abundance or composition coinciding with project implementation that would indicate a clear project effect. In 2019, the measured May wetland perimeter aligned closely with the wetted perimeter as indicated by aerial imagery captured in May 2016 prior to implementation of physical works, suggesting that the wetland's spatial extent has, until recently, also been maintained.

Nevertheless, the recent appearance (in 2020) of a new erosion channel and head-cut near an unintended outflow point on the north bank of the west compartment of Cartier Bay has raised concerns that the long-term stability of the wetland was affected by WPW-15A. It appears that, as a result of the dike repair and stabilization work at Site 15A, the impoundment may now be retaining slightly more water in the west compartment during spring run-off than before, allowing water to back up and exit from a slightly lower point in the wetland during periods of elevated water. There is a concern that if the erosion channel and head-cut are permitted to advance upstream into the wetland, water levels in the west compartment could be lowered significantly, with possible negative consequences for wildlife habitat. Similarly, increased water depth (from backfilling) could affect utilization of the compartment by shorebirds or migratory birds such as American Pipit, which are known to use the exposed foreshore for foraging. Amphibian breeding habitat could also be impacted. Protection of shoreline habitat features may necessitate a slight (~10 cm) lowering of the repaired sill at Site 15A (back to its previous level of ~433.9 m ASL) to reduce excess water ponding during spring runoff.

Strategic use of riprap placements at wetland outlets or in eroding channels within the reservoir drawdown zone appears to be an effective technique for stemming erosion and strengthening erosion-prone areas in the wetland-reservoir interface. However, as in the case of WPW-15A, monitoring also showed that such measures can produce unintended outcomes, such as the development of new, compensatory erosion channels at other, lower points within the floodplain. The topographical and hydrological characteristics of the local surrounding terrain, especially when the terrain has minimal topographical relief, need to be considered carefully when designing these interventions to ensure that potential risks to non-target areas from altered water storage and other processes are minimized.

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> The methods used to protect wildlife habitat appeared to be effective at both WPW projects. During this monitoring program, wildlife habitat remained intact as planned; however, both WPW-6A and WPW-15A require follow-up modification in order to meet long-term goals. The comparative assessment at WPW-6A indicates that infilling with riprap successfully halted erosion and lengthening in the east channel, whereas erosion and channel lengthening continued unabated in the west channel. This preventative measure effectively protected the high wildlife values for nesting and migratory birds and other wildlife in Airport Marsh from further erosion of the east channel toward Airport Marsh. The WPW-15A water control structure appeared to function well in preventing erosion of the main outlet of the west wetland compartment; however, a slightly deeper pool depth increased flow out a secondary outlet, which began eroding as a result. <u>Sources of Uncertainty/ Limitations</u> The extent to which erosion in the floodplain at Site-6A was caused by seasonal, daily, or hourly reservoir fluctuations from operations or seasonal runoff was not assessed. Understanding the patterns of erosion caused by reservoir operations and seasonal runoff would allow for the development of a predictive model that could inform when erosion may be minor or severe. The pre-and post-works monitoring periods (2011-2013; 2018-2020) at Site 15A were each limited to three years, with an extended (5-year) interval of no monitoring work between periods. Due to the high 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.
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> Site 6A consisted of a deep erosion channel that has formed in fine-textured soils in a floodplain between the Illecillewaet River and Machete Island. The erosion channel has formed a Y shape, with two erosion channels (east and west) branching from a primary channel connected to the Columbia River. The floodplain where the erosion channels occur was dominated by non-native reed canarygrass, with minor amounts of willow occurring on elevated margins. Although the wildlife habitat values of the floodplain dominated by reed canarygrass were relatively minor, the east erosion channel was lengthening towards Airport Marsh. Airport Marsh has highly productive wetland and riparian habitats that support a diversity of mammals (including river otter, beaver, and muskrat), songbirds, marsh birds, waterfowl, amphibians, reptiles, including Bald Eagles, Great Blue Heron and the SARA listed Western Painted Turtle. The concern was that if head-cutting and channel lengthening were allowed to continue, the channel would reach the Old Arrowhead Highway and negatively alter the hydrology of Airport Marsh. Site 15A consisted of an eroding gap in an old rail grade on the western edge Cartier Bay. The rail grade partially impounded Cartier Creek on the upstream side, forming a shallow open water wetland (Cartier Bay wetland). Construction for WPW-15A was limited to the surface of rail grade gap (the sill) and did not directly affect any valued wildlife habitat. The adjacent wetland was devoid of emergent vegetation but supports abundant submergent macrophytes and some floating macrophyte beds. There was a minor amount of riparian woody vegetation (willow) around the elevated margins, while the inner shorelines were vegetated with a low layer of semi-terrestrial sedges (Columbia sedge, Kellogg's sedge, wool-grass), annual herbs, and grasses (primarily reed canarygrass). Although the Cartier Bay wetland did not support a highly diverse plant assemblage, it sustained considerable ecological function and was considered one of the most important wildlife habitat assets remaining within the 433-435 m elevation band of Arrow Lakes Reservoir. It was a frequent stopover site for migrating dabbling and diving ducks; provided foraging habitat for Great Blue Herons, Osprey, and a variety of shorebirds during migration; and provided regionally important breeding habitat for the *SARA*-listed Western Toad.

Management Question (MQ)	Summary of Key Results
	<u>Sources of Uncertainty/ Limitations</u> The effectiveness monitoring program was focused on assessing the effects of physical works on erosion and channel lengthening of the east erosion channel. Erosion and channel lengthening continue in the west channel, and erosion was observed (but not measured) in the main channel and along the roadbed of the old Arrowhead Highway. Assessing the potential risk to wildlife habitat caused by erosion at these additional sites was outside the project's scope and not evaluated. However, there is a risk that continued erosion at these three sites may become problematic in the future and pose a threat to high-value wildlife habitats in the vicinity of the floodplain. 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.
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> With respect to Site 15A, the general comments for MQ1, above, also apply to this MQ. While there have been fluctuations over time in macrophyte species frequency and abundance, such fluctuations can be expected in a highly dynamic, reservoir-impacted environment such as Cartier Bay. Except possibly for one species of pondweed (small pondweed), which was less common and abundant post-physical works than pre-physical works, there were no obvious linear or sudden step changes in density or composition coinciding with project implementation that would indicate a clear project effect. It is possible the riprap installation could have influenced small pondweed performance. However, it is difficult to identify a causal mechanism that would account for this effect. The installation did not impinge directly on small pondweed habitat, although by briefly raising water levels in the pond by a few cm during the spring growing season, the project may have slightly reduced the amount of light available to establishing plants at depth. That said, several other, equally plausible factors could also have contributed to the decrease in small pondweed, such as an increase in competitive pressure from co-occurring macrophytes like stonewort, or changes to the timing, depth, or duration of reservoir inundation. <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> During the course of the monitoring period, the suitability of the wetland and associated riparian habitat remained intact and unaffected by the wildlife physical works projects. See also the summary for MQ1, above. <u>Sources of Uncertainty/ Limitations</u> The general comments for MQ1, above, also apply to this MQ. The erosion was observed in the main channel and along the old Arrowhead highway but was not assessed. The risk that erosion at these sites and the west erosion channel pose to the wildlife habitat in adjacent areas, including Airport Marsh and Machete Island, is unknown but should be assessed by a geotechnical engineer. Prior to physical works implementation, the elevation of the ad hoc dike and wooden box culvert at Site 15A was ~433.96 m ASL. The final elevation of the swale after improvements (addition of riprap and filter blanket) was ~434.04 m ASL. The possibility that the impoundment may now be retaining slightly more water (~10 cm) in the west compartment during spring run-off, resulting in higher back filling of the compartment, raises possible concerns for wildlife habitat. One is that increased water depth could affect utilization of the compartment by waterfowl such as dabbling and diving ducks. Additionally, a higher water level during spring

Management Question (MQ)	Summary of Key Results
	runoff could result in an associated truncation of open foreshore habitat along this stretch of wetland shoreline, which in turn could lead to a loss of available foraging habitat for shorebirds as well as for American Pipit, which are known to heavily select this narrow habitat strip during the spring migration. Any foreshore impacts from slightly higher water levels would likely be limited to the west compartment, since the east compartment (which contains the majority of open foreshore habitat in Cartier Bay) is impounded by the old highway grade (not the outer dike) and sits at a slightly higher elevation in the wetland. <u>Comments</u> The results of CLBMON-11B4 were interpreted in light of results and with data from other relevant studies including: CLBMON-37, CLBMON-11B2, CLBMON-36, CLBMON-39, and CLBMON-40.
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> Strategic use of riprap placements at wetland outlets or in eroding channels within the reservoir drawdown zone appears to be an effective technique for stemming erosion and strengthening potential weak points along the wetland-reservoir interface. However, monitoring also showed that such measures have the potential to produce unintended outcomes, such as, for example, the development of new, compensatory erosion channels at other, lower points within the floodplain. The topographical and hydrological characteristics of the local surrounding terrain, especially when the terrain has minimal topographical relief, thus need to be considered carefully when designing these interventions to ensure that potential risks to non-target areas from altered water storage and other processes are minimized. <u>Sources of Uncertainty/ Limitations</u> The long-term effectiveness of the WPW projects is not yet known.

KEYWORDS: Arrow Lakes Reservoir; wildlife physical works; effectiveness monitoring; wildlife; wetlands; erosion; head-cutting; riprap; aquatic macrophytes; riparian habitat.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Ecological Research Associates

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 was to maintain existing 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 was part of a suite of monitoring programs (CLBMON-11B) that together monitored the effectiveness of revegetation and wildlife physical works throughout Arrow Lakes Reservoir. CLBMON-11B4 specifically monitored the effectiveness of WPW-6A and WPW-15A in curtailing erosion processes and sustaining wetland and riparian habitat. Wildlife usage at the habitats protected by these projects was 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 involved 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. 2020a). The third and final post-works monitoring session occurred in 2020 and is the subject of this final report.

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 identify more correctly 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. 2020a) 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 STUDY AREA

2.1 WPW-6A (Airport Outflow)

Site 6A is an erosion channel (120 m in length) located in the floodplain of the Arrow Lakes Reservoir north of Machete Island (Figure 21). 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. The main objective of WPW-6A was to halt erosion in the east channel from lengthening towards the Airport Marsh. The concern with Site 6A was that the east erosion channel would eventually reach the Airport Marsh and have severe impacts on the hydrology and the wildlife that depend on this wetland. At present, the west erosion channel is eroding out into the floodplain and poses no immediate threat to Airport Marsh. Airport Marsh is an important wetland 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*).

Physical works at Site 6A were envisioned as a learning opportunity to assess how effective the methods applied in the east channel were in reducing erosion by comparing the rates of erosion and channel lengthening in the treated east and untreated west channels (Golder 2010).

Figure 2-1: Aerial image of the WPW-6A "Y shaped" erosion channel. Scale 1:500. Inset shows the location of the channel near Revelstoke, BC. Image date May 2010.

Figure 2-2: Before and after images of the east erosion channel. Image dates April 25, 2013 (above) and May 13, 2020 (below).

The WPW-6A project was implemented in 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. LGL Limited monitored the site in 2016, 2018, 2019, and 2020 (Hawkes and Adama 2020; Miller *et al.* 2020a; b).

2.2 WPW-15A (Cartier Bay)

Within Arrow Lakes Reservoir, Cartier Bay is considered one of the most important ecological assets within the 433 to 435 m elevation band. It is known to be the single most important stopover site for migrating dabbling and diving ducks in Revelstoke Reach and is a key breeding area for the SARA listed Western Toad as well as providing habitat for other amphibians and reptiles (Hawkes *et al.* 2015).

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. Prior to WPW-15A, water retention in the lower pond compartment was improved when a wooden box culvert under the disused rail bed collapsed, causing water to flow over the resulting swale in the rail grade (WPW-15A; Figure 2-4). The persistence of water in the pond was deemed to be uncertain due to considerable erosion occurring on the downstream side of this swale (Figure 2-6, upper photo).

WPW-15A was designed to protect the wetland and wildlife values in Cartier Bay by reinforcing the swale and armouring the downstream face (Figure 2-6, lower photo). After careful consideration (Hawkes *et al.* 2014), the final design opted for stabilization of the swale at its existing elevation. This was accomplished via the addition of riprap and filter blanket on the downstream side of the impoundment at the box culvert. Construction began on October 17 and was completed on October 22, 2016 (Figure 2-6). The swale elevation, original box culvert, and adjacent steel culvert were left essentially unchanged; however, changes to the porosity of the swale could not be assessed, and the swale invert was measured to be raised by ~10-20 cm [pre-works the invert was estimated to be 433.962 m ASL; post-works, it was measured to be 434.045 m ASL (Watson Engineering 2016), and in 2021 it was measured to be 433.92 m ASL (BC Hydro unpublished data)].

Figure 2-3. Cartier Bay wetland, Revelstoke Reach (Arrow Lakes Reservoir).

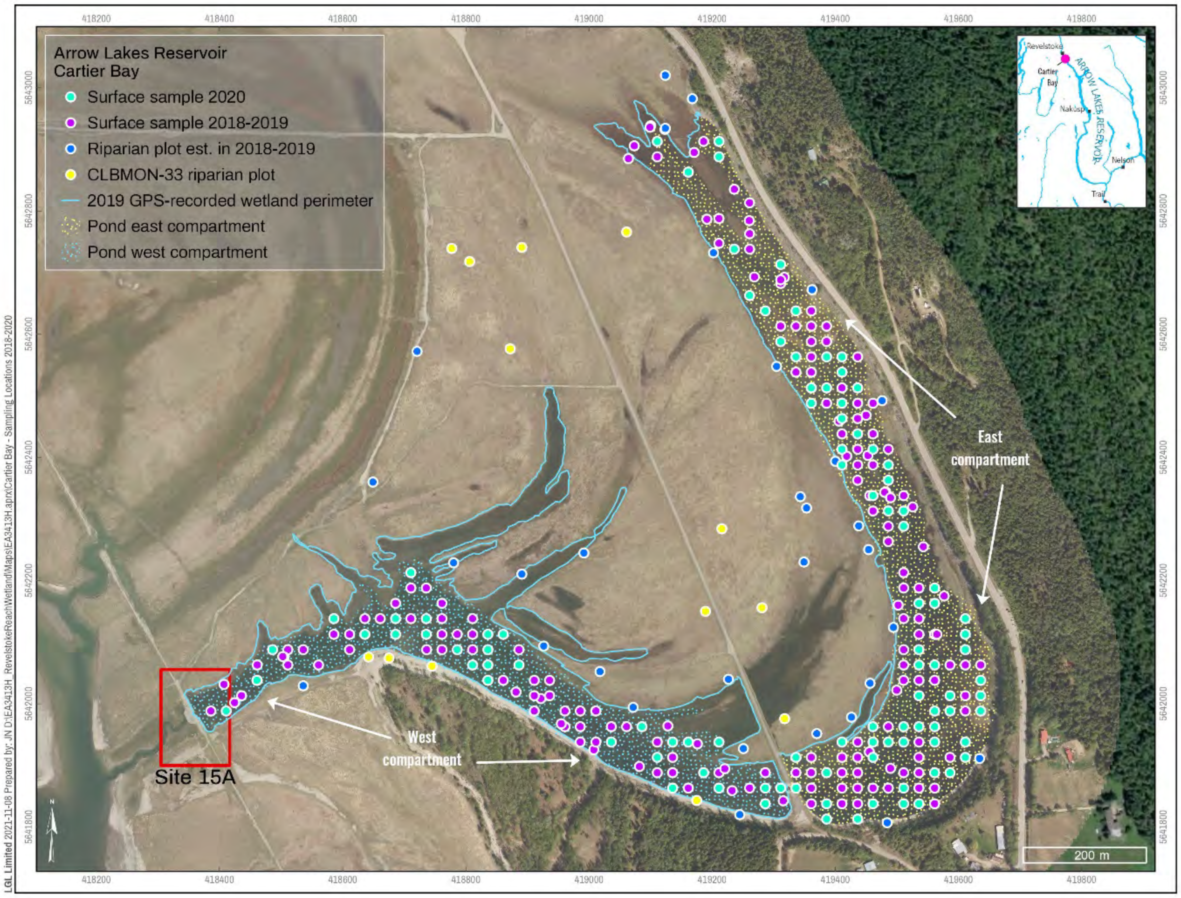

Figure 2-4: **Location of Site 15A relative to Cartier Bay, along with the 2018-2020 sampling locations.** Image date: 30 May 2016. Reservoir elevation: 433.79 m ASL

Figure 2-5. **Eroding Cartier Bay box culvert and swale outlet (September 8, 2014).** Observer: David Polster.

Figure 2-6: Images of the box culvert and swale at WPW 15A before treatment (above, taken in 2009) and after treatment (below, taken in 2020).

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.

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

Descriptions of the methods used in 2020, the third year of post-works monitoring, are provided below. These methods were generally consistent with 2018 and 2019 monitoring methods (Miller *et al.* 2020a and 2020b). 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 was designed to assess for impacts accruing to the quality and extent of shallow water, and riparian habitat and associated vegetation in Revelstoke Reach following physical works. Specifically, monitoring in 2018-2020 entailed:

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 recent (2019) aerial photo-imagery and comparing the extent pre- and post-works.
3. Using boat-based surveys to sample 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. Using ground surveys to sample riparian (non-aquatic) plant community composition and cover at the edge of Cartier Bay wetland and monitoring for changes related to the implementation of WPW.
5. Obtaining depth measurements for the east and west compartments of the main Cartier Bay pond and generating an updated bathymetric maps.

4.2 Drone Photogrammetry

Bare ground elevation data and high-resolution imagery of WPW-Sites 6A and 15A were collected in 2019 and 2020. Drones were equipped with a 1” CMOS 20 MP sensor, GPS/GLONASS satellite navigation systems, and high precision RTK GNSS. The drones were flown along flight lines to attain 70% overlap of adjacent flight lines, capturing 16.8 ha

(Figure 9-1). In 2019, digital elevation data were processed using the Propeller™ platform, and in 2020, the DroneDeploy™ software platform was used. Images and digital elevation models were provided as GeoTiffs, and point data were provided as LAS files.

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

Erosion monitoring at WPW-6A was restricted to the east and west arms of the erosion channel. Annual erosion monitoring included: (1) a visual assessment of the riprap installed in the east channel; (2) measurements of survey pins and stakes surrounding the east and west channels, established in 2016; (3) a visual assessment of the riprap installed in the east channel; (3) a bank erosion hazard assessment of the east and west channels; and (4) mapping the length and width of the east and west erosion channels using aerial images obtained in 2008, 2010, 2012, 2014, 2016 and drone photogrammetry acquired in 2019 and 2020

4.3.1 Visual Inspection of Riprap

The interface between the riprap and the channel bank was inspected annually 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. In addition, the loss of sidewall material may cause lateral displacement of riprap into new erosion channels that form at the riprap and channel bank interface. Finally, erosion at the confluence of the three channels could undermine the riprap at the entrance of the east channel and cause the riprap blanket to fail and tumble into the main channel. 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 and inspected annually (Figure 4-1 and Figure 4-2). Pins were initially located on the planar surface of the floodplain near the slope break of the channel. Survey stakes were located 122 cm behind the pins to aid in relocating the pins and for measuring slope creep. 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 prior years to assess cantilevering, soil movement, and slumping along the channel banks. Cantilevering is caused by bank undercutting, which increases the horizontal distance between the pins as the soil slumps down into the channel bank (Figure 4-3). In the east channel, channel depth was measured at the thalweg[1] between pins on the adjacent channel bank (Figure 4-4). For the west channel, we measured the lowest point of the riprap between pins on the adjacent channel bank.

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

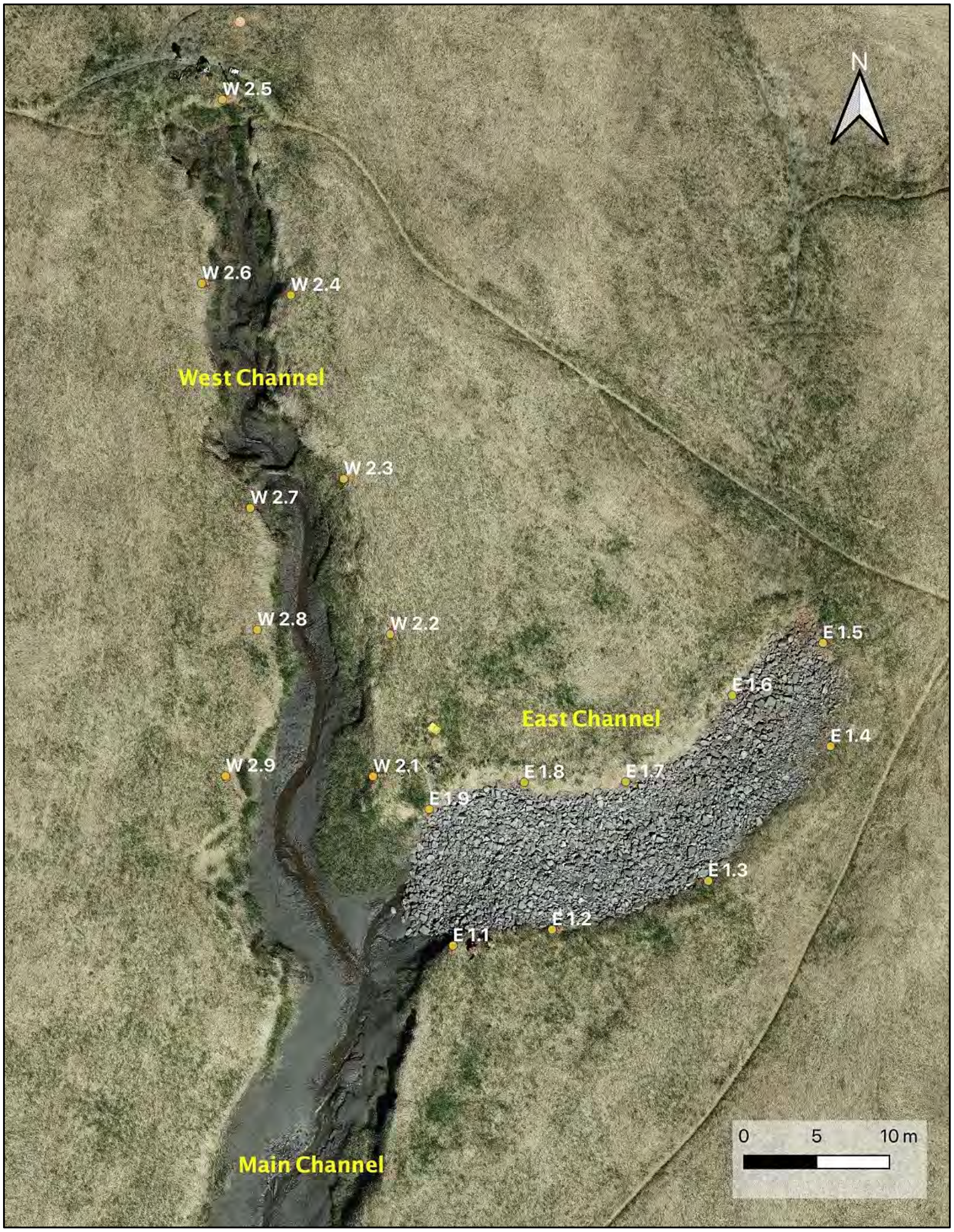

Figure 4-1: **Image showing the arrangement of survey pins around the perimeter of the erosion channels.** Thalweg measurements were taken between adjacent pins. Image date April 26, 2019

Figure 4-2: **Image showing survey measurements taken at WPW Site 6-A.** Environmental technician Addison Fosbery (Okanagan Nation Alliance) is standing above an erosion pin located in the red circle. Behind is the survey stake located 122 cm behind the erosion pin.

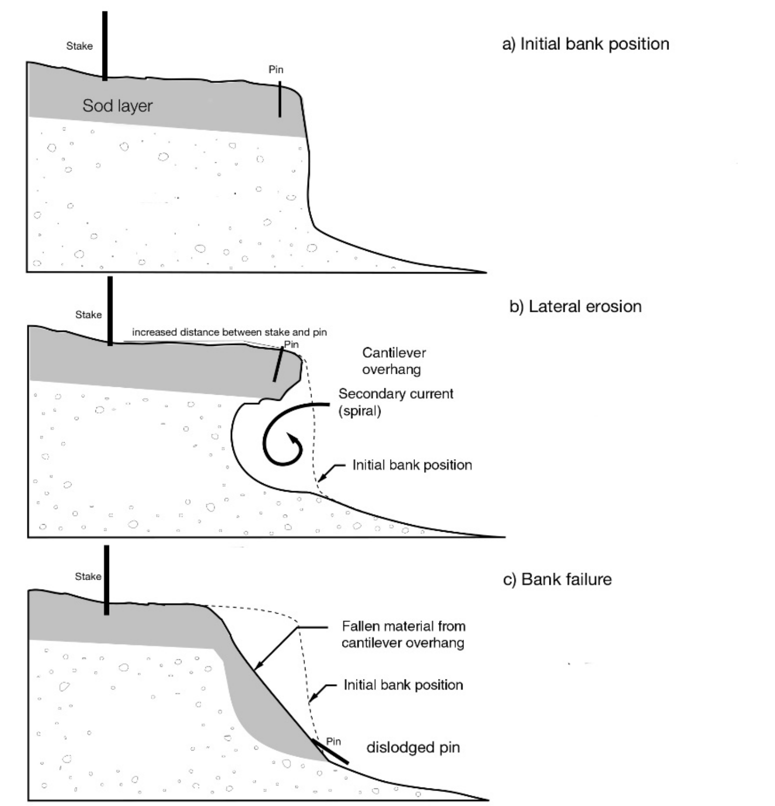

Figure 4-3: **Diagram showing the process of bank undercutting, cantilevering, soil movement, bank failure, and slumping in relation to survey pin measurements.** Adapted from Johnson and Stypula 1993.

Figure 4-4: **Image showing thalweg measurement being taken by Addison Fosbery between erosion pins in the west erosion channel at WPW Site 6-A.** Note the bank failure that has occurred in the foreground (right hand bank).

4.4 Bank Erosion Hazard Index (BEHI) at WPW-6A (Airport Outflow)

Calculating Bank Erosion Hazard Index (BEHI) is an evaluative process to determine bank susceptibility to erosion using variables 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). Scores from all years were reassessed using photo plots to ensure each criterion was scored using the same process.

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 at WPW-6A (Airport Outflow)

Annual erosion rates 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 and 2020. 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 erosion rates was estimated assuming a channel depth of 2 meters for both channels from 2008 to 2014. Average channel depths from survey measurements depths were used from 2016 to 2020. The accuracy of these estimates depended upon the resolution of the air photos, which were often very poor (e.g., 2008 to 2016). Drone imagery provided much higher resolution, and all delineated polygons were reviewed again for this report resulting in some minor adjustments to past values.

Volumes of the east and west erosion channels were also calculated from the DEM created from the 2019 and 2020 drone photogrammetry (Section 4.2). Channel volumes were calculated in QGIS using the Raster Surface Volume tool. These values were compared to values computed from the manual delineation method described above.

4.6 Erosion Monitoring at WPW-15A: Cartier Bay

Annual assessments of WPW-15A included a visual inspection of the installed riprap blanket and dike, and survey measurement of the swale. Survey elevations were taken from the top of the dike and referenced to survey points established previously by Watson Engineering (2016) on a nearby culvert (Table 4-3; Miller *et al.* 2020a). 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 reference points at WPW-15A.** Watson Engineering (2016).

Survey Point	UTM Easting	UTM Northing	Elevation (m ASL)
CN15A	418352.03	641997.52	435.236
CS15A	418347.21	641995.25	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 dike. Settlement may also contribute to channel formation along riprap and dike 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 was a before-after physical works comparison, with new random locations sampled each year. There were no control sites. However, for the final study year (2020), the analysis focused on the west (lower) wetland compartment (the compartment most likely to be affected by the physical works at Site 15A), while the east (upper) wetland compartment was treated as the (non-impacted) ecological reference site (Figure 2-4).

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 adjustments where required to maximize the effectiveness of the study. For example, macroinvertebrates were not sampled following 2013 (for reasons outlined in Section 1.0). Likewise, because no significant works-related effects on wetland parameters had been detected by 2019 (Miller *et al.* 2020b), sampling effort was reduced in the final monitoring year (2020) to include only aquatic vegetation and water depths.

At the end of monitoring, baseline (pre-works) wetland data from 2011-2013 were 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, focusing on the west wetland compartment. With respect to macrophyte abundance and composition, several alternative trend scenarios were 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).
3) Linear trend with breakpoint, with breakpoint coinciding with project implementation (= possible project effect).

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).
5) Step change (i.e., large sudden change), coinciding with project implementation (= project effect).

The study uses a point intercept approach (Madsen 1999) to collect surface samples with the aid of a boat, combined with ground-base sampling of riparian (terrestrial) 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 during the baseline (2011-2013) sample period, as well as in 2018 and 2019 (but not in 2020).

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 vegetation conditions on the Cartier Bay flats resulting from implementation of WPW-15A, we relied on a combination of: (a) prior ground inspection data collected as part of the associated vegetation monitoring programs CLBMON-33; (b) the orthophoto time series of Cartier Bay captured in 2010, 2012, 2014, and 2016 in conjunction with CLBMON-33; and (c) a GPS-recorded track of the wetland boundary obtained during the 2019 fieldwork. Prior measurements on vegetation composition and cover were obtained under CLBMON-33 for a set of 50-m^2 monitoring plots adjacent to the Cartier Bay wetland. These data were used to inform photo interpretation of the associated aerial imagery for the pre-works period (Miller *et al.* 2018a). A subset of these same plots were resampled in 2019 to monitor for possible compositional changes following physical works. The GPS track recorded in 2019 was compared with 2016 ortho-imagery to assess for changes to the wetland boundary following physical works; this track can also serve as a georeferenced baseline for future trend monitoring.

4.7.2 Data Collection

Fieldwork was carried out by a team of two researchers and occurred over two days in May 2020 (May 13-14). 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.* 2020a), the reservoir elevation in 2020 did not surpass 434.045 m (the height of the repaired box culvert and approximate threshold for Cartier Bay inundation) before sampling was completed.

Prior to fieldwork, 100 surface sample points in Cartier Bay were randomly placed using GIS. A total of 94 of these points (26 in the west compartment, 78 in the larger east compartment) were sampled (Figure 2-4; Table 4-6). Water depths of sample points at the time of sampling ranged from < 0.5 m to 2.2 m. The methods implemented at various points are described below under the subheadings **Aquatic Macrophyte Sampling** (4.7.2.1); **Riparian Vegetation Sampling** (4.7.2.2); and **Water Chemistry and Depth 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 4-5) and the species composition of the macrophyte sample was recorded.

The volume of the vegetation sample was described on a categorical scale from 0 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 scores ranged from 0 through 3, and relative abundance scores 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, for two combined samples, the minimum possible (non-zero) volume score was (1+0)/2 = 0.5 and the minimum possible relative cover score was 0.1/2 = 0.05. The minimum possible (non-zero) score for the volume x cover metric was then 0.5 x 0.05 = 0.025, and the maximum possible score for the volume x cover metric was 3 x 5 = 15.

Because the samples for each compartment came from the same pond, the individual data points (rake grabs) represented pseudo-replicates and could not be treated as independent of each other. Thus, for analysis, we calculated a single VC value (the average value over all samples) for each macrophyte species in each year. For each pond (west and east), this yielded a total *n* of 6 – one average VC value per species per year of monitoring. The number of annual point samples aggregated to derive each data point is shown in Table 4-6.

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

Figure 4-5: Rake sample of aquatic macrophytes, Cartier Bay wetland, May 2019. Surveyor: Mike Miller.

Table 4-4. Volume classes for macrophyte samples.

Volume Class	Sample Volume	Definition
0	Nil	Species does not appear in rake sample
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
0.1 (trace)	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

Table 4-6. Number of aquatic points sampled each year in the west (lower) and east (upper) pond compartment of Cartier Bay from 2011 to 2018.

Pond (wetland compartment)	Year	No. of aquatic point samples (*n*)
West	2011	10
East	2011	9
West	2012	3
East	2012	10
West	2013	7
East	2013	8
West	2018	34
East	2018	70
West	2019	52
East	2019	77
West	2020	16
East	2020	78

4.7.2.2 Riparian Vegetation Sampling

In 2019, sampling was conducted to assess riparian vegetation conditions at the terrestrial-aquatic interface (Miller *et al*. 2020b). For completeness, those methods (and results) are repeated here. 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 2-4, Figure 4-6). 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 2-4).

Figure 4-6: **Supplemental riparian vegetation plot just above permanently wetted zone, Cartier Bay.** Photographed May 14, 2019. Surveyor: Dixon Terbasket.

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%. 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.* 2018a).

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 between 2013 and 2019 (and until 2020 in the case of water depth):

- 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, 2018-2019) 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*: 391; RMSE [cm]: 32.5).

4.7.3 Statistical Analysis (Macrophytes)

The frequency of occurrence of each macrophyte species, which gives a measure of ubiquity within the habitat, was determined by counting the number of point samples in which a species was present and dividing by the total number of points sampled. Before-after analyses were then made with Chi-square analysis using the actual count of samples with and without the species (Madsen 1999).

We fitted negative binomial generalized linear mixed models (GLMM) using a log-link function with years as a random effect to assess the significance of differences in the relative abundance metric, VC, between the two sample periods (pre- and post-WPW). Since VC values were categorical (non-integers), we rounded the values up to the nearest upper integer to estimate integers. We used function glmmTMB from library glmmTMB in R (R Core Team 2021). Since the models were fitted with a log-link, the effect size of the post-WPW period as compared to the pre-WPW period was expressed by taking the exponent of the regression coefficient. We assessed a series of diagnostic plots to determine model fit and only showed results from models with a reasonably good fit (i.e., good residual plots without patterns, normality of residuals, etc.). We also checked for the presence of temporal autocorrelation in the residuals by looking at the acf plots. We computed models separately for all seven species occurring in both the east and west compartments.

5.0 RESULTS

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

The four methods used to monitor erosion at Site 6A indicate that the physical works implemented in 2013 successfully halted erosion in the east channel. In contrast, extensive head cutting, slumping, bank undercutting, bank failure and channel incision continue unabated in the west channel — lengthening, widening, and deepening the channel over time.

5.1.1 Visual Inspection

Little evidence of erosion was observed at the riprap-floodplain interface in the east channel. As in prior years, surveys conducted in 2020 found the riprap has integrated nicely into the floodplain (Figure 2-2), and again, no evidence of channelling was observed. However, as reported previously (Miller et al. 2020 and 2020b), bank undercutting, slumping, and bank failure of the fine-textured soil are an ongoing concern at the confluence of the east and main erosion channels (Figure 5-1).

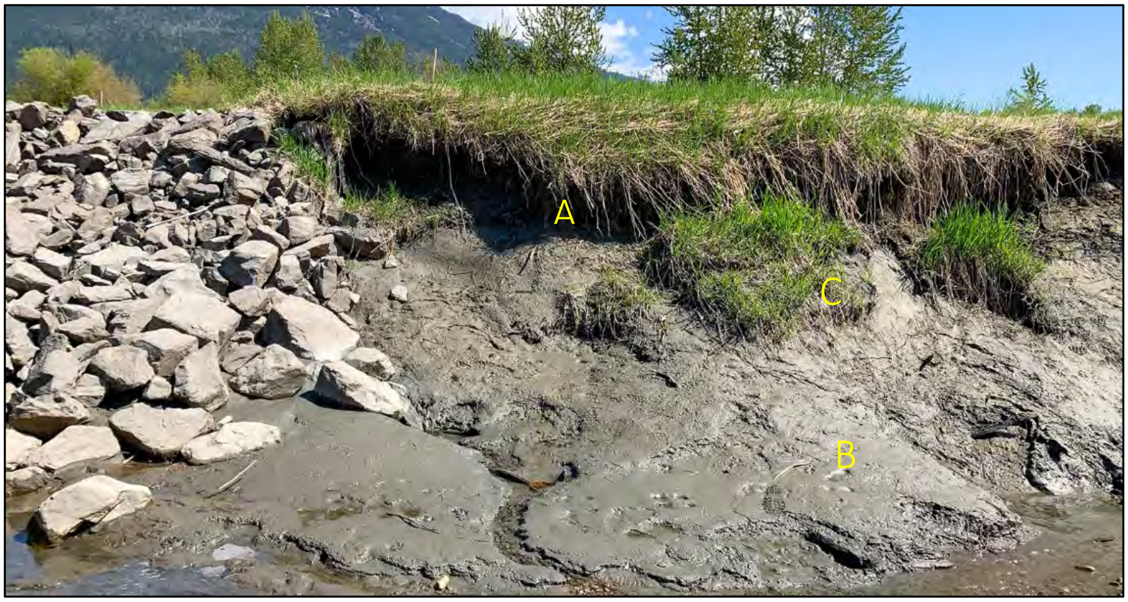

Figure 5-1: Bank undercutting (A), slumping (B), and bank failure (C) at the mouth of the east channel of WPW-6A. May 13, 2020.

5.1.2 Survey measurements

Survey measurements indicated minimal soil movement and slumping occurred along the east channel's margin (Table 9-1). Over the 5 years, the average slumping rate was 0.5 cm/yr (SD = 0.6); a rate of 0.8 cm/yr (SD = 1.3) was observed between 2016 to 2018 period, followed by a rate of 0.2 cm/yr (SD = 0.4) observed between 2019 and 2020.

As expected, soil movement was higher in the west channel than in the east channel (Table 9-1). The average slumping rate was 2.0 cm/yr (SD = 2.0); however, this value underestimates the actual slumping rate as slope failure occurred at a third (3 of 9) of the survey pins between 2018 and 2020. The estimated slumping rate was 6.7 cm/yr (SD 11.1) between 2016 and 2018 and 1.3 cm/yr (SD 1.0) between 2019 and 2020.

The variable topography created by the riprap resulted in unreliable measurements in the east channel. The results indicated an average invert of the riprap of 67cm in 2018, 49cm in 2019, and 78cm in 2020; however, the variability of measurements within and across years makes it challenging to identify any trends (Table 9-2). The 6.5 cm drop in the riprap invert at the head of the channel (between pins E1.4 and E1.6) may indicate the riprap settling or erosion of the sediment below the riprap. Alternatively, it may be an artifact of sampling errors caused by the topographic variability of the riprap.

The average thalweg depth in the west channel increased by 18cm (SD = 14cm) from 236cm in 2018 to 254cm in 2020 (Table 9-2), corresponding to a rate of 6 cm per year. The largest increase in channel depth occurred at the head of the channel between pins 2.4 and 2.6 (Figure 4-1; Table 9-2). Due to the flat surface of the floor of the west channel (Figure 4-4), obtaining thalweg measurements in the west channel was more straightforward than measuring the invert of the riprap, giving us more confidence in these estimates.

5.1.3 Bank Erosion Hazard Index

BEHI scores (Table 5-1; Appendix 9.3) were low for the east channel (mean values between 5.5 to 6.6) and high for the west channel (mean values between 28 to 29.3) over the three years of assessments (2018 to 2020). Differences in BEHI scores between the two channels were due to higher scores in all criteria in the west channel, indicating a higher erosion hazard.

Table 5-1: Summary of BEHI score from 2018 to 2020

Channel	Year	Bank Height (cm)	RDH Score	Surface Protection Score	Bank Angle Score	Bank Material (Score)	BEHI
East	2018	63.9	2.8	1.5	1.2	1.1	6.6
	2019	45.1	1.9	1.2	1.2	1.1	5.4
	2020	63.1	2.6	1.2	1.2	1.1	6.0
West	2018	231.1	7.5	4.4	6.1	10	28.0
	2019	248.0	7.5	4.0	6.9	10	28.4
	2020	250.3	7.5	5.3	6.5	10	31.8

BEHI scores varied slightly among years in the east channel and were primarily due to differences in bank height measurement among years, which resulted in differences in RDH scores (root depth to bank height scores). These differences were likely due to the irregular surface of the riprap, which resulted in variable bank height measurements.

BEHI scores in the west channel increased over the three years, and differences among years were due to bank angle and surface protection scores. Slumping and bank failure created heterogeneous channel topography, resulting in variable bank angle measurements at the sampling stations. Similarly, surface protection also varied as sections of the channel bank calved off and migrated downslope into the channel over time, and the dense reed canarygrass sod provided a measure of protection to the exposed banks.

In contrast, extensive head cutting, slumping, bank undercutting, bank failure, and scouring continued unabated in the west channel — lengthening, widening, deepening the channel (Figure 5-2). Although not monitored, a similar pattern of erosion was observed in the main channel (Figure 5-3).

5.1.4 Aerial Imagery Interpretation and erosion rates

Delineation of the erosion channels at Site-6A from aerial orthoimages indicates that the east channel's length, area, and volume have stabilized following physical works in 2014 (Table 5-2; Figure 5-4). The minor differences in channel length, area, and volume in the east channel from 2014 to 2020 are likely due to measurement errors influenced by differing image resolutions. In contrast, the west erosion channel continued to increase in size (length, area and volume), although the annual rate of increase varied from year to year (Table 5-2; Figure 5-5).

Figure 5-2: **Before and after images taken at the confluence of the east and west erosion channels.** Image dates April 09, 2009 (above) and May 13, 2020 (below). The west channel is noticeably wider, longer, and deeper in the lower image.

Figure 5-3: **Before and after images taken at the confluence of the main erosion channel.** Image dates April 09, 2009 (left) and May 13, 2020 (right). The main channel is noticeably wider and deeper in the image taken in 2020.

Prior to project implementation, the length of the east channel increased at a rate of 0.53 m/year. After WPW-6A was completed, the length of the east channel lengthened at a rate of 0.02 m/year, which is in the realm of measurement error. In contrast, the length of the west channel advanced by 11.1 m between 2008 and 2020, at an average rate of 0.93 m/year; the most significant increase was between 2012 and 2014 (Table 5-2).

Between 2008 and 2012, the footprint (area) of the east channel increased from 223^2 m to 270 m^2 at an average rate of 11.9 m^2/yr. Between 2012 and 2014, the channel area increased by nearly 20% (53.3 m2); however, this increase was partially due to the channel bank's excavation in preparation for the placement of riprap. After the completion of WPW-6A, the channel's footprint changed very little, 323.8 m^2 in 2014 to 328.7 m^2 in 2020 and differences between years are likely due to measurement error (Table 5-2). On the other hand, the area of the west channel increased by 38% from 2008 to 2020, increasing from 5.5 m^2 to 14.7 m^2 per year, which is comparable to the rate observed in the east channel prior to the completion of WPW-6A.

The volumetric rate of erosion in the east channel was estimated to be 23.7 m^3/yr (approximately three dump truck loads at 8 m^3 per load) prior to project implementation (2014) and was negligible afterwards (0.04 m^3/yr; 2014 to 2020) – again, within the realm of measurement error. The volumetric erosion rate in the west channel was estimated to be 22.9 m3/yr between 2008 and 2012. In 2019 and 2020, when higher resolution drone imagery was captured and the DEMs were created, the amount (volume) of soil loss was estimated to be 60.3 m3/yr (7.5 dump trucks of soil per year; Table 5-2). The increased erosion in 2019 and 2020 was likely due to an increase in the channel's area (footprint) and depth as the channel length did not significantly change.

It is important to note that the annual rates of erosion in the east channel prior to WPW-6A and in the west channel over the study period were highly variable across the measurement periods indicating low rates of erosion and channel development in some years punctuated by much higher rates in others.

Volumetric estimates of the west channel obtained from the drone acquired DEM were considerably lower than estimates obtained using the area delineated from the imagery (Table 5-2). This is likely due to the soil remaining in the channel following bank failure and slumping (e.g., Figure 5-2). In addition, the drone-acquired DEM does not differentiate slumped material from the channel floor, thus underestimating channel volume. As a result, the calculated measurements assume a flat bottom and likely overestimate the channel volume.

Potential surface flows along the floodplain were identified using the DEM to identify erosion-prone areas in the vicinity of the erosion channels (Figure 5-6). The arrows correspond to potential surface flow based on elevation and ephemeral channels. Primarily ephemeral surface flows from spring runoff, and reservoir dewatering primarily leads to the heads of the east and west erosion channels ("A "and "B" in Figure 5-6). However, secondary flows may also contribute to the lateral erosion along the west and main channels, creating new knickpoints along the channel bank. ("C" in Figure 5-6). The DEM also shows the location of smaller ephemeral channels (e.g., "D" in Figure 5-6).

Table 5-2: **Length and area of the east and west erosion channels at WPW-6A obtained from aerial imagery between 2008 and 2020.** Air photo images were available for 2008 to 2016 and drone acquired imagery was captured for 2019 and 2020. No imagery was available or captured in 2018.

Channel	Image Year	Channel Length (m)	Annual rate of change (m/yr)	Channel Area (m^2)	Annual rate of change (m^2/yr)	Channel Depth (m)*	Channel Volume (m^3) **	Annual rate of change (m^3/yr)**	Dump trucks of soil/year ††
East	2008	35.6	-	223		est. 2.0	446.0	-	-
	2010	35.8	0.1	232.5	4.8	est. 2.0	465.0	9.5	1.2
	2012	37.7	1.0	270.5	19.0	est. 2.0	541.0	38.0	4.7
	2014†	39.6	1.0	323.8	26.7	est. 0.7	226.7	.	.
	2016	39.6	0.0	324.0	0.1	0.7	226.8	0.1	0.0
	2019	39.6	0.0	331.5	2.5	0.7	232.0 (233.2)	1.7	0.3
	2020	39.7	0.0	328.7	-2.8	0.7	229.2 (240.4)	-1.9	-0.2
West	2008	49.5	-	344.7		est. 2.0	689.5	-	-
	2010	49.5	0.0	365.2	10.2	est. 2.0	730.4	20.5	2.6
	2012	55.4	3.0	390.0	12.4	est. 2.0	780.0	24.8	3.1
	2014	57.5	1.1	413.5	11.8	est. 2.0	827.1	23.5	2.9
	2016	59.9	1.2	424.4	5.5	est. 2.0	955.0	64.0	8.0
	2019	60.4	0.2	468.6	14.7	2.47	1157.3(798.4)	67.4	8.4
	2020	60.6	0.2	475.1	6.6	2.54	1206.8 (862.5)	49.4	6.2

* Channel data were lacking for 2008 to 2016. We assumed an average depth of 2 m for both channels for those years. We used 0.7 m for the east channel for 2016 and beyond based on measurements of the riprap invert. Actual values were used for the west channel for 2016 to 2020.

** Channel volumes were calculated from the area and depth measurements. The values in brackets for 2019 and 2020 were calculated from the DEM surface volumes. 472 m^3 of rip rap was placed in the east channel in 2014 (Golder Associates and Watson Engineering 2014), which compares favourably to the estimated volume of the channel.

† WPW implementation year

†† Dump truck capacity is 8 m^3

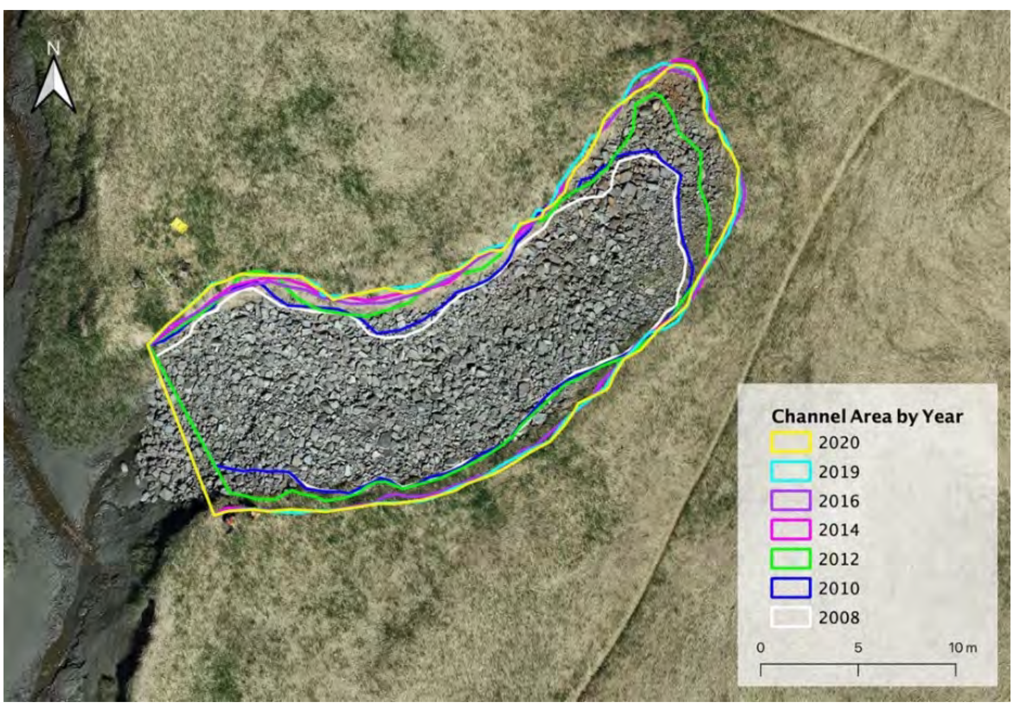

Figure 5-4: **Size of the east erosion channel delineated by year.** Background image: May 13, 2020.

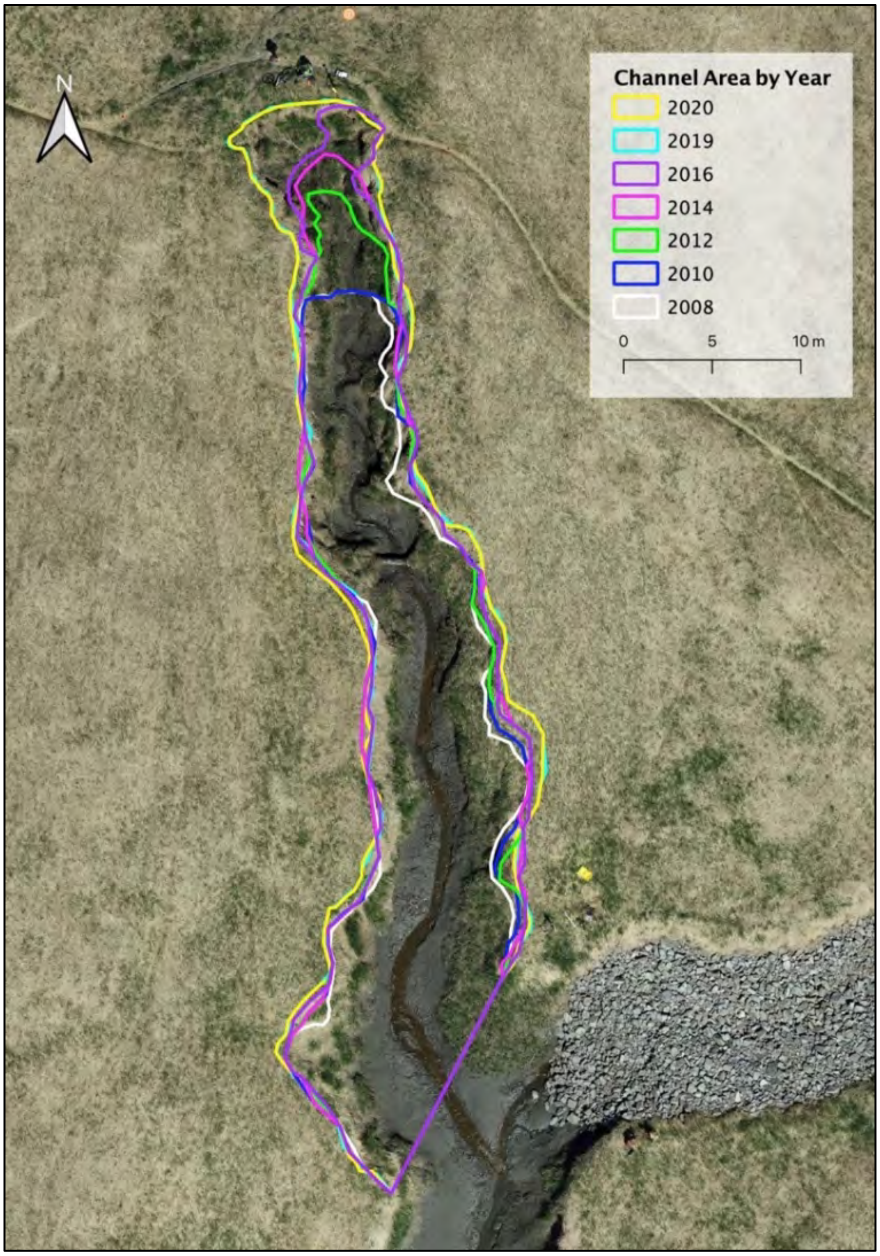

Figure 5-5: **Size of the west erosion channel delineated by year.** Background image: May 13, 2020.

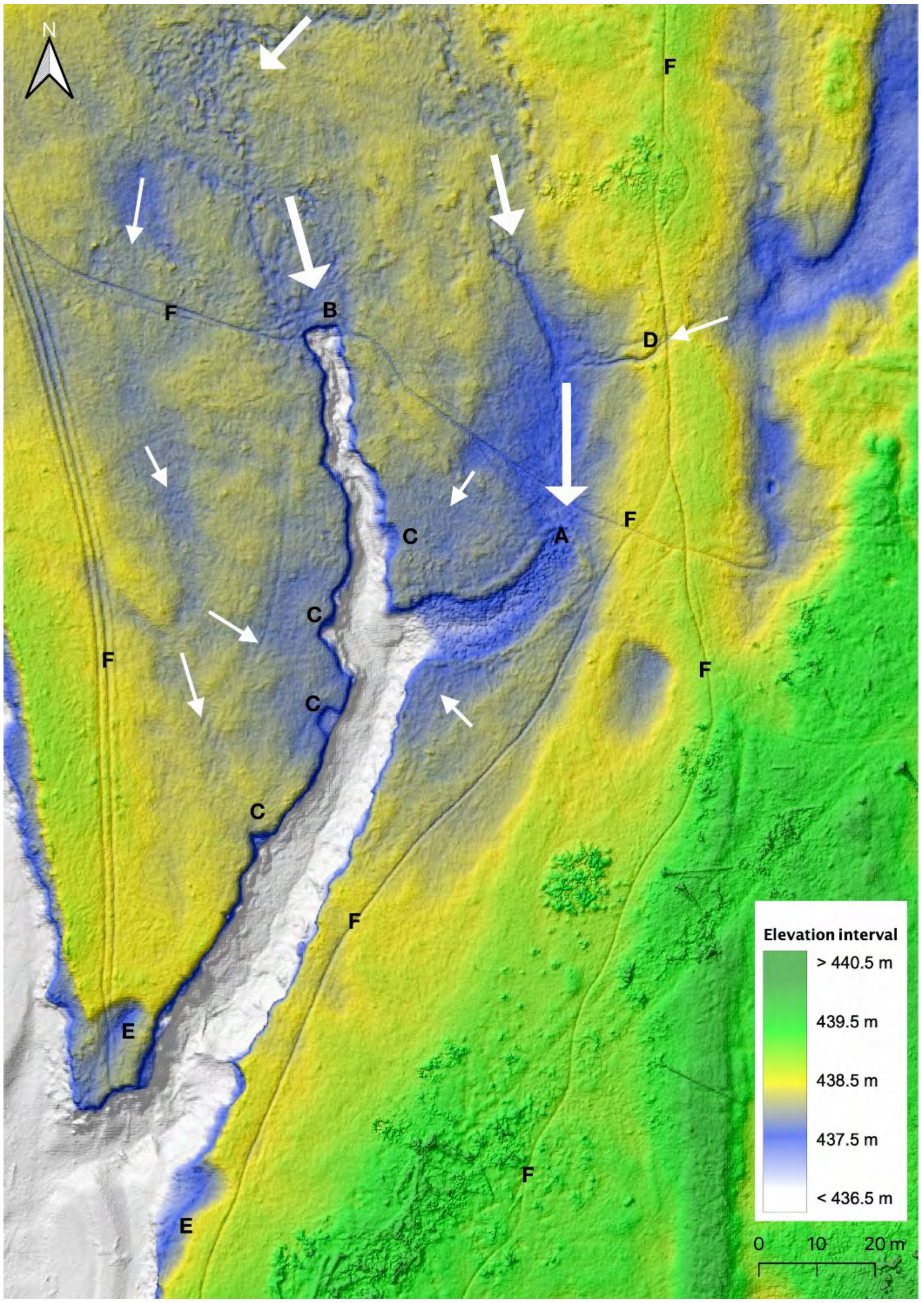

Figure 5-6: **Digital Elevation Model shows the floodplain surface's elevations surrounding the erosion channels.** Areas below 437m are shaded white and include the Columbia River and the main and west erosion channels. Blue shading indicates low areas of the floodplain, and white arrows identify potential surface flows on the floodplain into the channels. The large arrows indicate the primary ephemeral surface flows, and the smaller arrow indicate possible secondary surface flows. The terminus of the east and west erosions channels denoted by "A" - east and "B" - west. "C" identifies potential sites of lateral bank erosion where the channel bank has collapsed forming new knickpoints. "D" identifies a small channel that drains from Airport marsh. "E" identifies low areas at the mouth of the main channel that are actively eroding. A network of footpaths and off-road trails are denoted by "F".

5.2 Erosion Monitoring at WPW-15A

No sign of erosion was observed along the riprap margin or at the swale invert during visual assessments of WPW-15A. In addition, survey elevations were similar in all three years to the values reported by Watson Engineering, confirming that no erosion has occurred on the surface of the swale invert since construction (Table 5-3).

Table 5-3: Survey elevation of the constructed swale at WPW-15A.

Year	Swale Elevation (m)	Source
2016	434.05	Watson Engineering
2018	434.05	Miller et al. 2020a
2019	434.07	Miller et al. 2020b
2020	434.05	Ibid

5.3 New Erosion Site in Cartier Bay

During a joint visit to Cartier Bay on 15 May 2020, at the tail end of the 2020 field sampling session, H. van Oort (BC Hydro) and M. Miller (LGL Limited) observed the existence of a recently formed and active erosion channel and head-cut originating from a low point part way up the north bank of the west Cartier Bay wetland compartment (Figure 5-7). Water from this exit point was flowing directly across the dirt road access to WPW-15A; the ~1-m high head-cut was situated just downstream (north) of this road and appeared to be in the process of eroding back towards the road and, potentially, towards the wetland outlet itself (Figure 5-8). A concern was identified at this time that if the head-cut were allowed to erode all the way to the wetland outflow point, it could result in a significant wetland draining event and subsequent lowering of the water level in the west compartment by up to 1 m (or as deep as the final height of the head-cut).

The reason for the overflow could not be definitively determined at the time. However, it was surmised that, as a result of the impoundment (dike) repair and stabilization work at WPW-15A, the impoundment is now retaining slightly more water in the west compartment during spring run-off than before, allowing the water to back up and exit from a slightly lower point in the wetland (Figure 5-7) during periods of elevated water.

These observations and concerns were relayed to BC Hydro and, in early October of 2020, BC Hydro installed a temporary (sandbag) dike at the overflow point to reduce the escapement of water and stem the erosion process. That work is not detailed in the present report. However, an assessment of this mitigation effort is currently underway.

Figure 5-7. Location of recent erosion channel and head-cut (indicated by yellow arrow) caused by overflow from the west compartment of Cartier Bay wetland.

Figure 5-8. Overflow from the west compartment of Cartier Bay wetland where it crosses an access road near WPW-15A, with associated erosion channel and head-cut adjacent to the road. Photographed 15 May 2020.

5.4 Wetland and Riparian Habitat Monitoring at WPW-15A

5.4.1 Water Depth and Water Chemistry

Average water depth at surface sample points was 0.82 m (Table 5-4). Average measured depths tended to be greater in the west compartment of Cartier Bay (1.49 m) than in the east compartment (0.67 m). Depths in the east compartment ranged from 0.1-1.52 m; those in the west, from 0.51-2.24 m; Figure 5-9).

An updated bathymetric map for Cartier Bay, generated from all depth measurements (*n*=391) collected during surface sampling between 2011 and 2020, shows the distribution of shallow and deep areas within the wetland (Figure 5-10).

Table 5-4. **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 2019, and mean water depth (SD) from 2013 to 2020**

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)
2020 (94)	0.82 (0.50)	n/a, visible to bottom	n/a	n/a	n/a	n/a

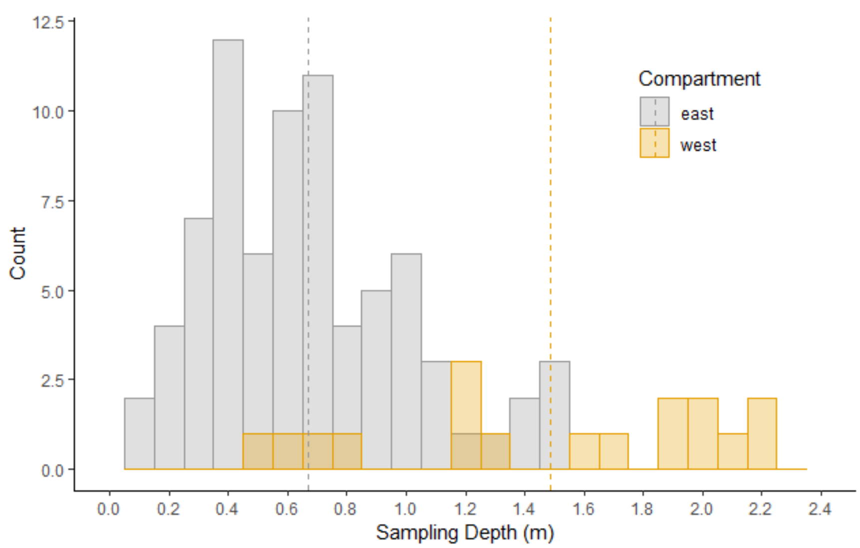

Figure 5-9. **Sampling depth distributions for the east and west compartments of Cartier Bay wetland in 2020.** "East" compartment refers to the area east of the eroded roadbed bisecting the wetland; "west" compartment refers to the area west of the roadbed and east of WPW-15A (Figure 2-4). Dashed lines represent the average sampled depths.

Measurements of dissolved oxygen (DO), pH, conductivity (µS/cm), and temperature (°C) recorded in the 2018-2019 samples fell within the range of variation obtained for the pre-works monitoring period (Table 5-4).

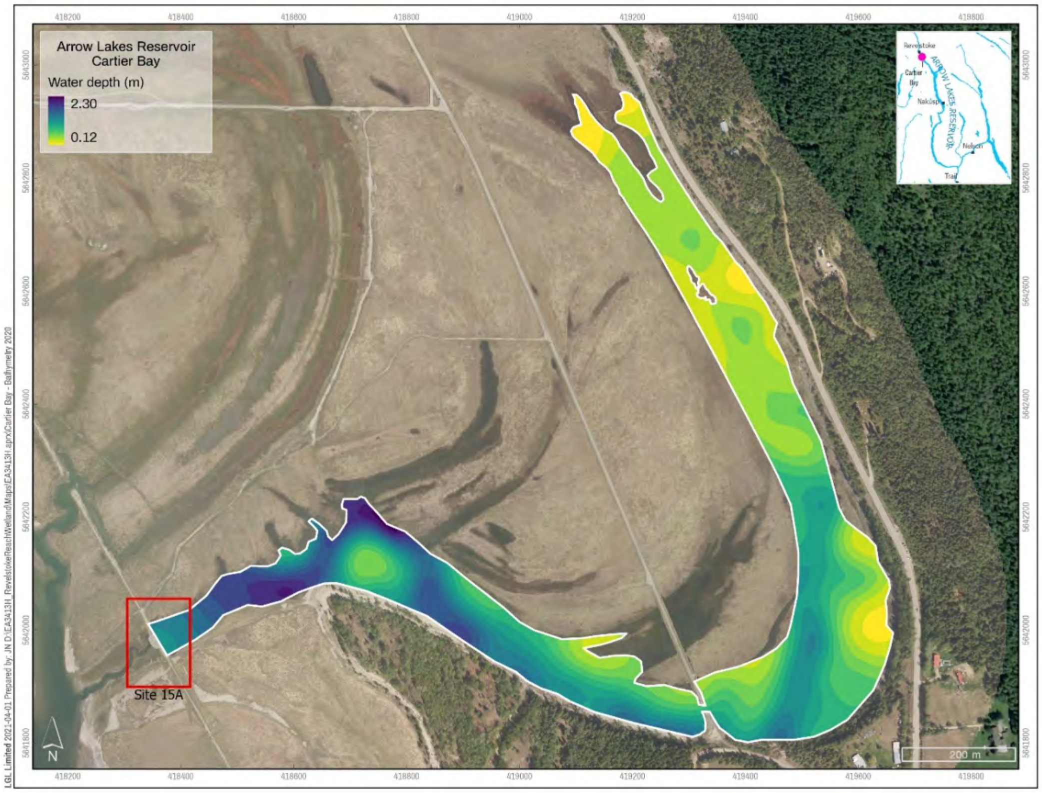

Figure 5-10: **Bathymetric map of Cartier Bay wetland, based on depth sound measurements made during surface sampling in 2011, 2012, 2013, 2018, 2019, and 2020 (*n*=391).** The red rectangle indicates the location of WPW15A. The bathymetric interpolation method used was Simple Kriging, with a Gaussian model and a smoothing weighting factor. Overlapping points were averaged prior to interpolation. 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.

5.4.2 Macrophyte Frequency

In 2020, the third year of post-works monitoring, frequency of macrophyte species in samples at Cartier Bay west compartment (Figure 5-11b) ranged from nil (small pondweed) to highs of 1.0, 0.81, and 0.56 for (for stonewort [a green algae], common hornwort, and Eurasian water-milfoil, respectively). Two other pondweeds (Richardson's and eel-grass) were only encountered sporadically. Stonewort and eel-grass pondweed showed a weak trend of increasing frequency since 2011-12, while small pondweed and common hornwort showed a declining trend since the pre-WPW period. Similar patterns were observed, with the possible exception of common hornwort, in the east compartment (Figure 5-11a), suggesting that frequencies in the two compartments were responding to some common macroscale factor (e.g., reservoir inundation in the prior year) rather than to compartment-specific influences. Furthermore, while frequencies of all species in both compartments fluctuated annually, and these fluctuations were generally as pronounced as the directional trends (Figure 5-11).

Chi-square analyses were significant for both compartments (west: $\chi2=18.7$, $p=0.002$; east: $\chi2=12$, $p=0.066$). For the west compartment, post-hoc tests showed that frequency of Richardson pondweed was significantly lower than expected and that of small pondweed significantly higher in the pre-WPW period (although note that Richardson's pondweed was rare and had <5 expected counts, so this result should be viewed with caution). For the east compartment, post-hoc tests showed that frequency of eel-grass pondweed was significantly lower than expected while that of small pondweed, as in the west compartment, was significantly higher in the pre-WPW period ($\alpha=0.05$, corrected for 12 simultaneous tests [west compartment] and 14 simultaneous tests [east compartment] following Bonferroni correction; Table 5-5). When the plant guild was considered as a unit (with all macrophyte species pooled), frequency was 100 per cent in each year and did not vary (i.e., no samples in any year had zero macrophyte presence; results not shown). Thus, we found no strong evidence that macrophyte community composition in Cartier Bay was directly affected by WPW-15A implementation.

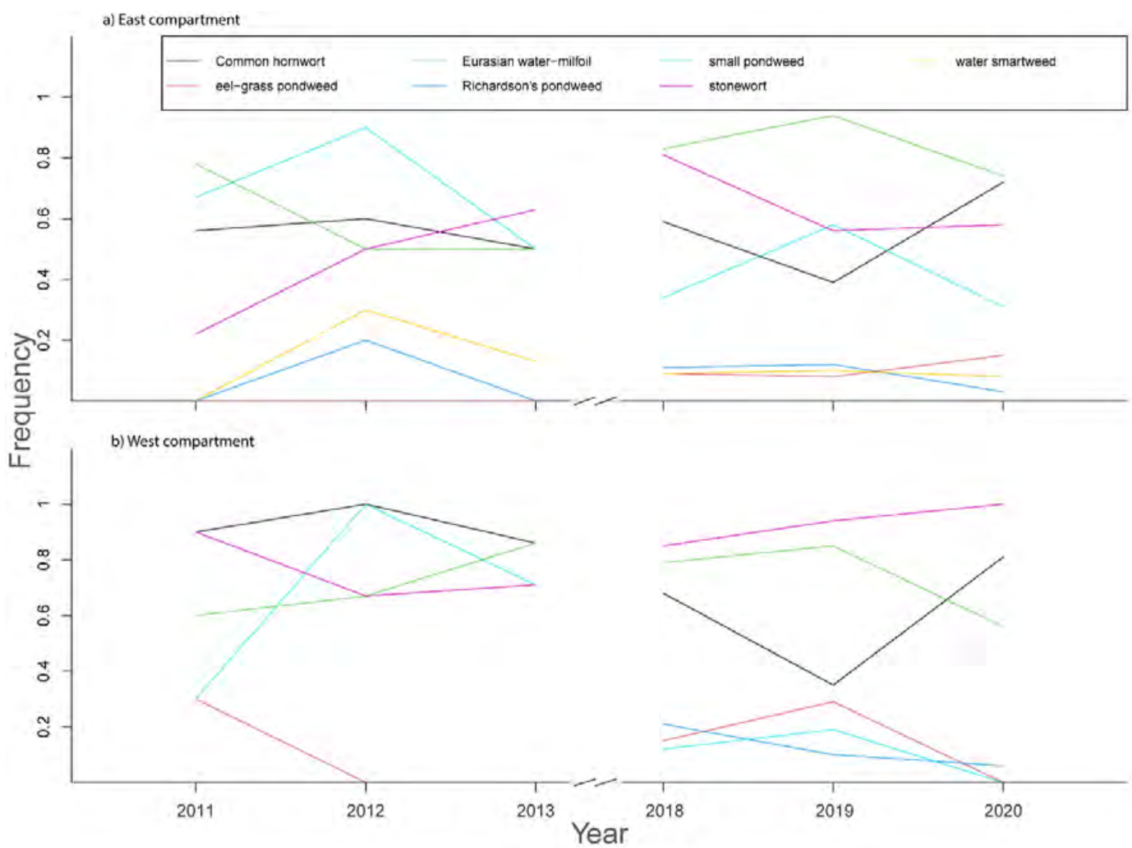

Figure 5-11. **Variation in the proportion of samples (frequency) in which seven aquatic macrophyte species were recorded in random surface samples (rake grabs) at the east (a) and west (b) compartments of Cartier Bay wetland during the pre- and post-WPW sampling periods.** Before: 2011-2013. After: 2018-2020. *n* = 19, 13, 15, 104, 131, and 94 in 2011, 2012, 2013, 2018, 2019, and 2020, 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* sp.; water smartweed: *Persicaria amphibia.*

Table 5-5. **Observed and expected (in bracket) frequencies for each macrophyte species recorded before and after physical works in Cartier Bay.** * represents significantly lower than expected frequencies whereas ** represents significantly higher than expected frequencies, based on the analysis of the Freeman-Tukey deviates.

Wetland compartment	Species	2011-2013 (pre-WPW)	2018-2020 (post-WPW)
West	common hornwort	18 (13)	54 (59)
	eel-grass pondweed	3 (5)	23 (21)
	Eurasian water-milfoil	14 (17)	80 (77)
	Richardson's pondweed	0 (2) **	13 (11)
	small pondweed	11 (5) *	14 (20)
	stonewort	16 (20)	94 (90)
East	common hornwort	15 (14)	127 (128)
	eel-grass pondweed	0 (2)**	24 (22)
	Eurasian water-milfoil	16 (20)	188 (184)
	Richardson's pondweed	2 (2)	19 (9)
	small pondweed	19 (11) *	93 (101)
	stonewort	12 (16)	145 (141)
	water smartweed	4 (2)	20 (22)

5.4.3 Macrophyte Abundance

The metric of relative local abundance, VC, was highly variable both within years and between years for most sampled species (Figure 5-12). The within-year variation in samples likely reflects both the natural high heterogeneity of the benthic habitat, and the technical challenge of obtaining consistently accurate estimates of benthic-rooted vegetation from the surface using indirect methods (rake grabs). At the west compartment, average VC trended downward from 2011 levels in the case of small pondweed, common hornwort, and stonewort. Eurasian water-milfoil showed a slight increasing trend, while other species showed consistently low or nil relative abundance across sampling periods. Those trends were generally mirrored in the east (non-impacted) compartment, except for stonewort which may be increasing in the latter location (Figure 5-13).

As with species frequencies, above, temporal trends that would suggest a project effect (e.g., linear trend with a breakpoint coinciding with project implementation; non-linear monotonic trend; or step change) were not well defined. Except possibly for small pondweed, which declined in both compartments over time but to a greater degree in the west pond, trends were either characterized by large inter-annual fluctuations or, to the extent they exhibited linearity, appear to have commenced prior to project implementation (e.g., common hornwort, stonewort), continuing in a generally similar direction over the intervening years between 2013 and 2018. The three most locally dominant species in the west compartment of Cartier Bay in 2013 (Eurasian water-milfoil, common hornwort, stonewort) continued to be the most abundant species in 2020. Although the relative ranks of the three species, in terms of VC, fluctuated over time, the ranks were the same in 2020 as in 2011 (1: common hornwort, 2: Eurasian milfoil, 3: stonewort).

Generalized linear mixed models (GLMMs) incorporating years as a random effect indicated that differences in VC among periods were non-significant for common hornwort, eel-grass pondweed, Richardson's pondweed, and stonewort. Eurasian water-milfoil underwent a (marginally) significantly increase in abundance in the post-WPW period compared to the pre-WPW period in the east compartment (z=1.75, p=0.08), but not the west. Small pondweed underwent a significant decline in abundance (by an average factor of 0.13) in the post-WPW period compared to the pre-WPW period in the west compartment (z=1.75, p=0.08), but not the east. However, the diagnostic plots associated with all these models were quite poor (results not shown), indicating that the model fits were also poor. Given the high degree of replicate variation within year, the high year-to-year variability, the likelihood of temporal autocorrelation, and the relatively short time series (3 + 3 years), this outcome is not surprising. Therefore, model results should be regarded with caution. Until more years of observation become available, it is probably more instructive to base trend interpretations on a visual inspection of the data (Figure 5-12, Figure 5-13) rather than on the p-values of the GLMM models.

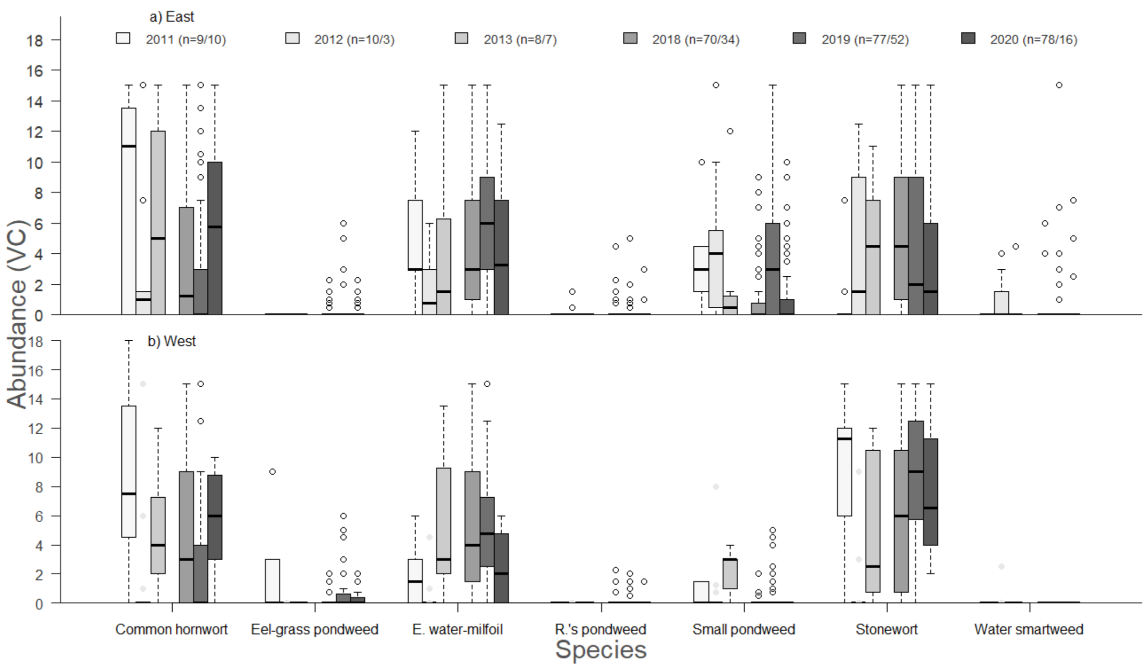

Figure 5-12. Variation in local abundance or VC (sample volume x relative cover) of seven species of aquatic macrophyte in random surface samples (rake grabs) at the east (a) and west (b) compartments of Cartier Bay wetland during the pre- and post-WPW sampling periods. Pre: 2011-2013. Post: 2018-2020. Numbers in () besides the years in the legend are the sample size on each year in the east and west compartments, respectively.

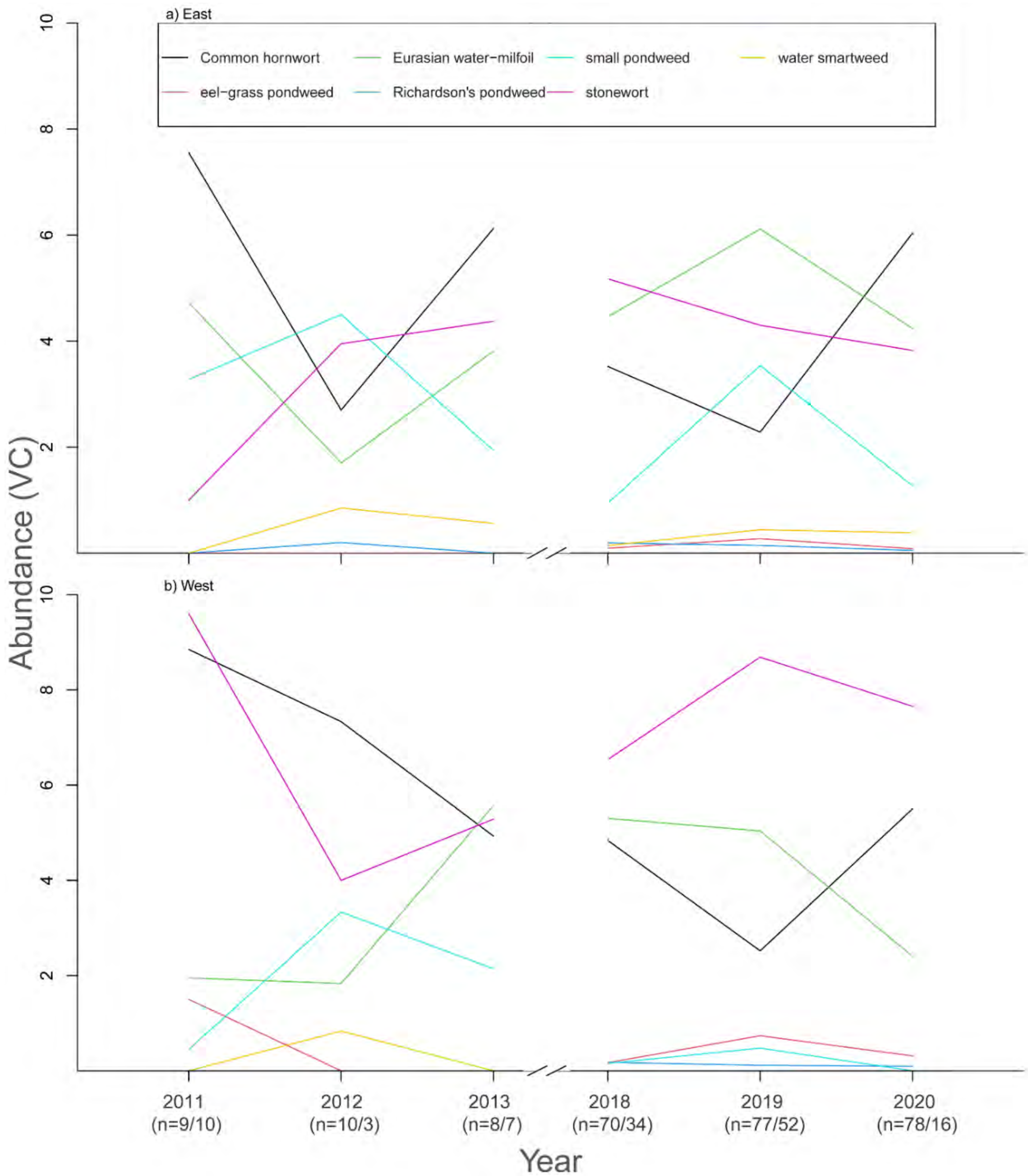

Figure 5-13. Local abundance, as represented by the average VC metric (sample volume x relative cover), of each of seven species of aquatic macrophyte at Cartier Bay wetland during the pre- and post-physical works sampling periods. Before: 2011-2013. After: 2018-2020.

5.4.4 Macrophyte 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 lower (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 5-15). 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 upper (east) compartment (i.e., east of the old roadbed), cover is co-dominated by stonewort, Eurasian water-milfoil, and common hornwort (Figure 5-16), 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 5-17). 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 5-16).

5.4.5 Riparian Vegetation

The clayey substrates of the exposed shoreline support a different complement of riparian plant species (and species associations) than the siltier soils at slightly higher elevations in Cartier Bay, which are largely dominated by reed canarygrass (*Phalaris arundinacea*) and Columbia sedge (*Carex aperta*; Miller *et al.* 2020). Shoreline plant assemblages consist primarily of variants of two vegetation community types (VCTs; Miller *et al.* 2018a): the PC-Sedge VCT, characterized here by a mix of native sedges (*Carex* spp.); and the PE VCT, consisting here of mudflat associations dominated variously by wool-grass (*Scirpus atrocinctus*), toad rush (*Juncus bufonius*), the terrestrial form of water smartweed (*Persicaria amphibia*), spring water star-wort (*Callitriche palustris*), and mosses (Figure 5-18).

Figure 5-14. Rake samples illustrating concentrations of stonewort (left) and Eurasian water-milfoil (right) in the lower (western) compartment of Cartier Bay wetland, May 2019.

Figure 5-15: **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 5-16: Floating mats of water smartweed, north end of Cartier Bay wetland (upper, east compartment), May 2019.

Figure 5-17: 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; wool-grass stand (close-up); wool-grass stand (overview); moss cover; water smartweed association. Surveyor: Dixon Terbasket (ONA).

PC-Sedge type habitats are 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 support relatively high species richness and relatively high covers of moss, toad rush, water smartweed, and wool-grass (Figure 5-19). Overall, cover is 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, are still in the process of receding in May (the typical survey month). This means that the lower shoreline has 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, allowing for only a very brief growing season. From that perspective, the occurrence at this elevation band of a nascent community of perennials and annuals 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 5-19). 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.

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 in the future, 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).

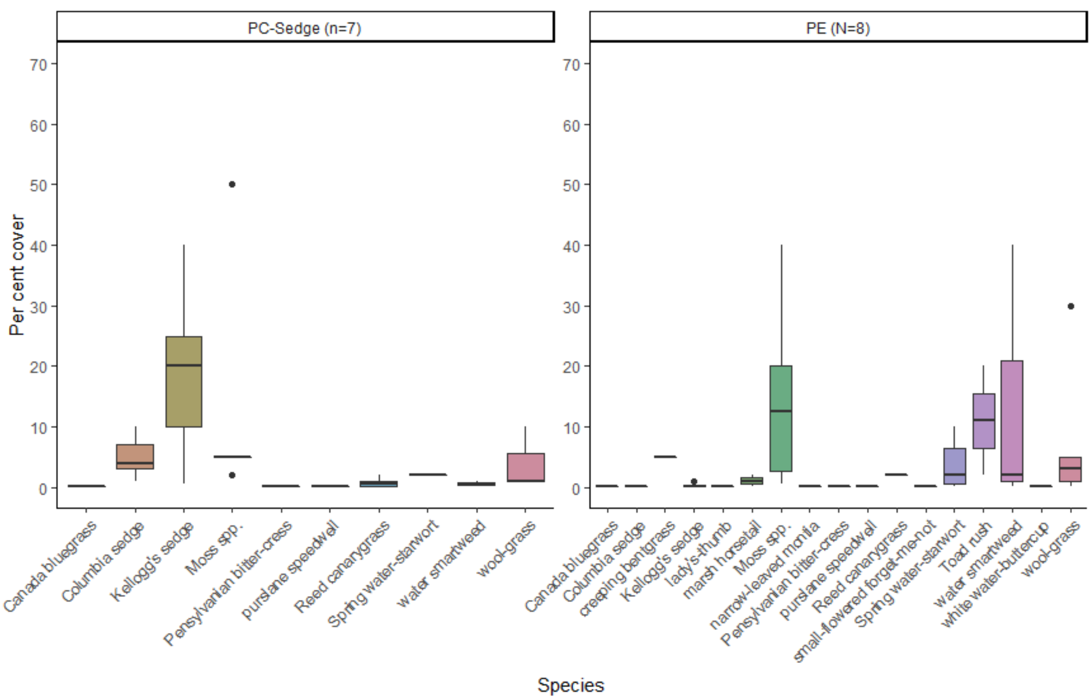

Figure 5-18. Plant species and covers for different riparian vegetation community types (VCTs) sampled around the perimeter of the Cartier Bay wetland in May 2019. See **Figure 2-4** for sample locations. See Miller *et al.* (2020) for VCT code definitions and descriptions.

6.0 DISCUSSION

6.1 Management Question 1. Are the wildlife physical works projects effective at protecting wildlife habitat quality and quantity for nesting and migratory birds and other wildlife?

This management question is addressed under the following three sub-questions.

6.1.1 Management Question 1A: 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?

Site 6A

Site 6A consisted of a "Y" shaped erosion channel approximately 1.0 to 4.5 meters in depth that have formed in fine-textured soils in a floodplain between the Illecillewaet River and Machete Island. The main channel was 90 m in length, while the west and east arms were 49.5 m and 35.6 m, respectively. The floodplain area where the erosion channels occur was dominated by non-native reed canarygrass and had marginal habitat values for wildlife (CBA 2013; CBA 2014a). It was observed by Golder (2009a and 2009b) that the east erosion channel was lengthening towards Airport Marsh putting at risk the highly productive and regional important wetland and riparian habitats of Airport Marsh. Airport Marsh supports a diversity of mammals (including river otter, beaver, and muskrat), songbirds, marshbirds, waterfowl, amphibians, reptiles, including Bald Eagles, Great Blue Heron and the SARA listed Western Painted Turtle (Basaraba 2014; Craig and Gill 2020; Duncan 2016; Hawkes et al. 2020; Gill and Craig 2020).

Four types of erosion appear to be operating in the floodplain at Site 6A. Lateral erosion of the channel banks, vertical erosion, slumping, and head cutting. Lateral erosion is caused by hydraulic action acting on the channel banks and is aggravated by hourly and daily water level fluctuations resulting in the erosion of fines. This process results in bank undercutting, cantilevering, and ultimately bank failure (Thi and Minh 2019). Vertical erosion is caused by hydraulic action acting on the channel floor aided by the abrasion (scouring) of fine sediments carried in water, resulting in channel deepening/incision. Slumping occurs when the portions of the channel bank slowly slide into the channel floor. This process is aided by soil saturation, which increases the mass of the soil and decreases the cohesiveness of fines. Slumping accumulates bank material within the channel, and the fines are scoured and removed from the channel over time. Finally, head-cutting is caused by the water spilling over a riffle or bank (initially called a knickpoint), leading to a plunge pool. This process causes the channel terminus or side channel to move upstream and lengthen over time (the primary concern that led to WPW-6A). These four types of erosion collectively constitute 'gully erosion' and result in the formation and propagation of gullys/channels.

Site 15A

Site 15A consists of an eroding gap in an old rail grade on the western edge Cartier Bay. The rail grade partially impounds Cartier Creek on the upstream side, forming a shallow open water wetland (Cartier Bay wetland). Construction activities for WPW-15A were restricted to the surface of rail grade gap (i.e., the sill) and did not directly affect any valued wildlife habitat.

The wetland itself is positioned approximately 6 m below the full pool elevation of Arrow Lakes Reservoir (440.1 m ASL) and remains submerged for more than half the year, resulting in a highly modified ecology. Prior to project implementation, the wetland was devoid of emergent vegetation and, except for some shallower areas of the east (upper) compartment, supported few floating macrophyte beds. Submergent macrophytes were abundant, but the diversity of species was not high (seven in the east compartment and six in the west compartment). Species included common hornwort, stonewort, Eurasian water-milfoil, water smartweed, and three pondweeds. The non-native Eurasian water-milfoil comprised much of the aquatic biomass. Stonewort, a mat-forming green algae, dominated the benthic ground cover. There was a minor amount of riparian woody vegetation (willow) on the elevated margins separating the main pond from the low mud draws to the northwest. The outer (southeast) banks of the pond were steeply sloped and characterized by course materials (boulders, gravels) or sand, with intermittent shrub and herbaceous presence. The inner shorelines were gently sloped, consist of finer materials (clay/silt/sand), and were vegetated with a low layer of semi-terrestrial sedges (Columbia sedge [*Carex aperta*], Kellogg's sedge [*C. kelloggii*], wool-grass [*Scirpus atrocinctus*]), herbs (water and grasses (primarily reed canarygrass [*Phalaris arundinacea*]).

Although the Cartier Bay wetland supported a reduced plant assemblage compared to the nearby Airport Marsh (Hawkes *et al.* 2011), it still sustained considerable ecological function and was considered one of the most important wildlife habitat assets remaining within the 433-435 m elevation band of Arrow Lakes Reservoir (Hawkes *et al.* 2015). It was known to be the single most important stopover site for migrating dabbling and diving ducks in Revelstoke Reach and was a favoured foraging habitat for Great Blue Herons, Osprey, and for a variety of shorebirds during their migration (CBA 2014, Gill *et al.* 2018). At least eight bird species were known to utilize the shoreline of the wetland including American Pipit (the most frequently observed bird), Killdeer, Least Sandpipers, Spotted Sandpiper, Wilson's Snipe, Savannah Sparrow, Dowitcher, and Lesser Yellowlegs (Hawkes *et al.* 2015). During transect surveys, over 60% of American Pipit detections were within 10 m of the water's edge, while a relatively large proportion (>30%) of pipits observed within 10 m were using a narrow 1-m strip of habitat next to the water (CBA 2011, Craig and Cooper 2017).

The airspace above the Cartier Bay wetland was heavily used by aerial insectivores during the spring migration (e.g., Vaux's Swift, Tree Swallow, Violet-green Swallow, Northern Rough-winged Swallow, etc.). During the early breeding season, Killdeer, Savannah Sparrow and Spotted Sandpiper commonly utilized the Cartier basin prior to inundation by the reservoir. Other species noted to use the Cartier area included Belted Kingfisher, Bald Eagle, and Turkey Vulture (Hawkes *et al.* 2015).

Cartier Bay was recognized as one of the more important sites within the drawdown zone of Arrow Lakes Reservoir for the SARA listed Western Toad as it provided scarce shallow water breeding habitat (water < 50 cm deep). The shallow ponded area in the eastern compartment of the wetland was especially productive; large aggregations of Western Toad toadlets were observed there in all years of monitoring associated with CLBMON-37 (Hawkes *et al.* 2020; (Figure 6-2). Other species of amphibians and reptiles observed using the wetland included the Long-toed Salamander, Columbia Spotted Frog, Pacific Chorus Frog, and Western Painted Turtle (Hawkes *et al.* 2020). Detections of these species were likewise concentrated in the east compartment (Figure 6-2). The differential detection rates for the two compartments may have been partly a function of distance from upland habitat (the west compartment is further away) and partly a function of habitat suitability. The upper compartment, which is bordered by the road and a bank of riprap, provides better basking habitat for snakes and lizards, which likely explains the higher number of observations of those species there. This compartment is also shallower and provides better breeding habitat for toads than the deeper, faster channel of the west compartment (where observations of toad tended to be concentrated around the shallower northern margins; Figure 6-2). The tadpoles produced in the east compartment in turn provide an abundant food resource for snakes. That said, a formal comparison between compartments was not attempted and it is possible that some of the differences in detections were due to differential sampling effort within the two compartments during amphibian and reptile active periods (V. Hawkes, pers. comm.).

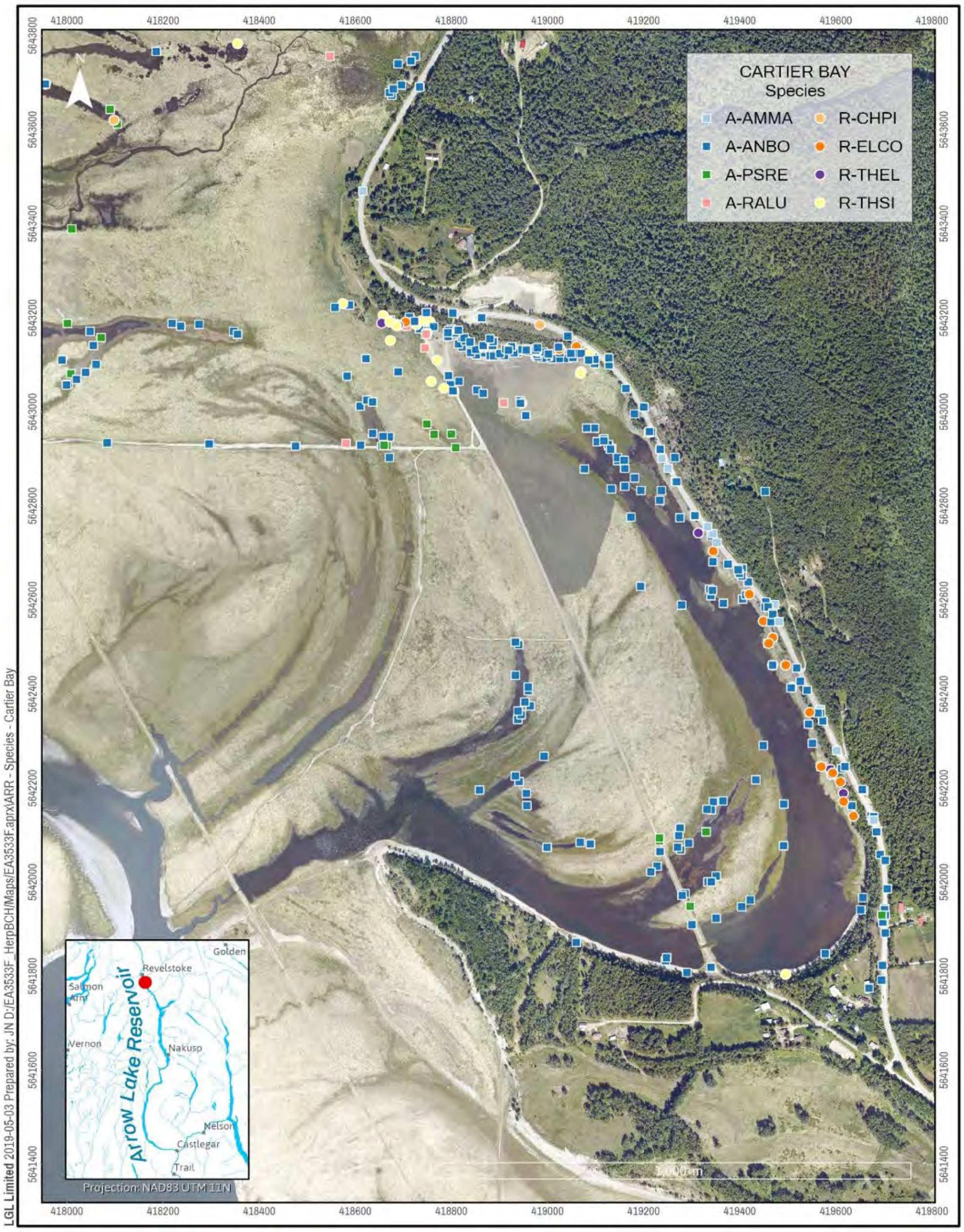

Figure 6-1. Distribution and occurrence of amphibian and reptile species documented in the Cartier Bay area (Revelstoke Reach), Arrow Lakes Reservoir between 2008 and 2018. A-MMA: Long-toed

Salamander. A-ANBO: Western Toad. A-PSRE: Pacific Chorus Frog. A-RALU: Columbia Spotted Frog. R-CHPI: Painted Turtle. R-ELCO: Northern Alligator Lizard R-THEL: Western Terrestrial Garter Snake. R-THSI: Common Garter Snake. From Hawkes et al. (2020).

During the Columbia River Water Use Plan (WUP), the Western Painted Turtle was identified as a species that may be vulnerable to fluctuating water levels resulting from operations of the reservoir (BC Hydro 2005). The population that occurs near Revelstoke is one of the most northern populations and has regional importance. The turtle population of Revelstoke Reach has been monitored in three DDZ sites under the CLBMON-11B3 study: Airport Marsh, Montana Slough, and Cartier Bay. Over the course of this study, however, few turtles were observed using Cartier Bay (Hawkes *et al.* 2020). The low site occupancy and detection rate for turtles here compared to neighboring Montana Slough (~2 km north) suggests that the habitat may have low suitability in its current state. This could be due to landscape-level factors (e.g., spatial proximity/connectivity to other wetlands, disturbance history) or site-level factors (e.g., water depth, physicochemistry, topography, soil substrate, vegetation, forage/prey availability, nest site availability, overwintering habitat suitability, reservoir inundation patterns, etc.; Hawkes *et al.* 2015).

The wildlife utilization of Cartier Bay is highly seasonal. Migrating waterfowl quickly populate the wetland each spring as the ice thaws. Usage diminishes as the habitat becomes impounded in spring (late May or early June), then increases again as water levels decline in the late summer or early fall (Gill and Craig 2020). Western Toads congregate at the site to breed in the spring (typically late April or early May), with adults spending approximately two to three weeks in the wetland before dispersing to upland summer habitats. Western Toad eggs develop into tadpoles and eventually emerge as metamorph toadlets in late July or early August, following the re-inundation of the wetland by the reservoir. Despite this pre-dispersal yearly inundation, the fecundity of Western Toad remains high (Hawkes *et al.* 2020).

6.1.2 Management Question 1B: 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?

The physical works at Cartier Bay appear to have been successful in stabilizing the collapsed box culvert at WPW-15A. However, it is now clear that the project as built in 2016, by elevating the water level slightly to cause a new erosion channel to form which is working its way towards the wetland, has failed to ensure long-term maintenance of permanent water in the wetland. BC Hydro is currently planning to make corrective adjustments to address this structural issue.

Notwithstanding the near-term erosion concern, the ecological character of the wetland has been otherwise well-maintained since project completion, with the slight increase in water level appearing to have minimal impact on the function and productivity of the wetland. One macrophyte species, small pondweed, did decrease both in frequency and abundance in the west compartment in the period following physical works implementation, and it is possible the riprap installation could have influenced its performance. However, it is difficult to identify a causal mechanism that would account for this effect. The installation did not impinge directly on small pondweed habitat, although by briefly raising water levels in the pond by a few cm during the spring growing season, the project may have slightly reduced the amount of light available to establishing plants at depth. In general, lack of light is the single most important factor limiting the occurrence of aquatic plants (Mackenzie and Moran 2004). Light levels diminish with increased water depth and turbidity, and the depth to which rooted aquatics occur in shallow open water wetlands largely depends on the clarity of water (Mackenzie and Moran 2004). In Cartier Bay, the water tends to be fairly turbid, with light penetration often extending <1 m (Table 5-4); consequently, less competitive species such as small pondweed may be especially sensitive to minor changes in water depth. That said, several other, equally plausible factors could also have contributed to the decrease in small pondweed, such as an increase in competitive pressure from co-occurring macrophytes like stonewort, or changes to the timing, depth, or duration of reservoir inundation.

The case of small pondweed aside, aquatic macrophyte vegetation in the Cartier Bay wetland remained, overall, both compositionally and quantitatively like that which existed in the bay prior to implementation of physical works in 2016. While there have been some non-linear changes over time in macrophytes species frequency and abundance, such fluctuations can be expected in a highly dynamic, reservoir-impacted environment such as Cartier Bay. There were no obvious step changes in overall abundance or composition coinciding with project implementation that would indicate a clear project effect.

6.1.3 Management Question 1C: How did the wildlife physical works projects affect the suitability of wetland and associated riparian habitat for nesting and migratory birds and other wildlife?

Site 6A

i. *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?*

ii. *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?*

iii. *Did the wildlife physical works at Airport Outflow WPW-6A affect: physical signs of erosion; aerial extent of wetland habitat?*

Wildlife physical works at Site-6A (WPW-6A) itself did not affect the area (m^2) or suitability of wetland and associated riparian wildlife habitat for nesting birds, reptiles or amphibians; nor did it affect the aerial extent of wetland habitat. Instead, WPW-6A halted the advancement of the east erosion channel, which threatened the habitat values of Airport Marsh (Golder 2009a and 2009b).

Visual assessments, survey measurements, BEHI, and air photo measurements confirmed that WPW-6A significantly reduced erosion in the east erosion channel. No evidence of channelling, head cutting, or channel lengthening was observed. The only sign of erosion observed in the east channel was at the mouth of the east channel beyond the edge of the riprap.

It is unknown how long it would have taken for the east erosion channel to reach the old Arrowhead highway that separates Airport Marsh from the Columbia River floodplain. The lengthening rate in the east channel between 2008 to 2014 was 0.5 m, and it might have many years. However, there is a risk that the erosion rate would have increased and that the channel would again branch, resulting in even higher mitigation costs if left untreated.

As expected, erosion continued in the west channel, which was monitored for comparison. During the study period, the west channel continued to deepen, lengthen, and increase in size. Between 2014 and 2020, the west channel has lengthened by 1.6 m, and its footprint has increased in size by 15%. Between 2018 and 2020, the depth of the channel increased by 17.6 cm on average. Erosion was also observed in the main channel. Although not monitored, the main channel appears to have gotten both wider and deeper. There is a risk that both the west and main channels will continue to erode deeper, and new lateral branches may form along knickpoints, if left unchecked. There is also a risk that the deepening of the main channel could eventually impact the slope of riprap at the head of the east channel.

Erosion was also observed along the Old Arrowhead Highway, which acts as a berm between Airport Marsh and the Columbia River floodplain. The authors first noted erosion of the roadbed surface in 2013, and by 2020 the erosion appears to have progressed further. If the erosion of Old Arrowhead Highway continues to proceed, a knickpoint and plunge pool could form on the opposite side of the road from Airport Marsh. Alternatively, if the erosion of the road surface changes the direction of water across the Old Arrowhead Highway, it could change surface flows towards Site 6A and create a new point of erosion.

Over time, continued erosion at the west channel, main channel, and the old Arrowhead highway could threaten the wildlife habitat values of the surrounding habitat (e.g., Airport Marsh and Machete Island). Therefore, further investigation of these sites by a geotechnical engineer is warranted.

Site 15A

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 Cartier Bay Site 15A affect: erosion; aerial extent of wetland habitat; cover, species richness, and evenness of undesirable macrophyte species; water depth and turbidity?*

While there is concern over the long-term success of WPW-15A as-built (see below), thus far wildlife habitat quality and quantity within Cartier Bay has been well-maintained, consistent with the project's general objective of protecting the status quo. In 2019, the measured May wetland perimeter aligned closely with the wetted perimeter as indicated by aerial imagery captured in May 2016 prior to implementation of physical works (Figure 2-4), suggesting that the wetland's spatial extent has, until recently, also been maintained. Abiotic water indices (e.g., depth, turbidity, DO, pH, and conductivity) also remained within the same overall range of variability recorded during the 2011-2013 baseline monitoring period.

However, the chance discovery in 2020 of a new erosion channel and head-cut developing near an (unintentional) outflow point on the north bank of the west compartment has raised concerns over the future stability of the wetland. The immediate concern is that the head-cut will continue to erode further upstream into the wetland and that this could engender a dewatering event and subsequent lowering of the water level in the west compartment by up to 1 m (or as deep as the final height of the head-cut). In late 2020, BC Hydro took initial steps to address the situation by installing a temporary dike/berm at the new outflow with the aim of reducing the escapement of water and stemming the erosion process. The near-term outcomes of this intervention will require monitoring to assess its effectiveness.

It is likely that the physical works are responsible for the fact that the pond has begun to overflow its northern bank. Prior to physical works implementation, the elevation of the ad hoc dike and wooden box culvert was 433.962 m ASL. The final elevation of the swale after improvements (addition of riprap and filter blanket) was 434.045 m ASL (Watson Engineering 2016). The possibility that the impoundment may now be retaining slightly more water (~10 cm) in the west compartment during spring run-off, resulting in higher back filling of the compartment, raises other concerns. One is that increased water depth could affect utilization of the compartment by waterfowl such as dabbling and diving ducks. A map of waterfowl distributions (Figure 6-2) shows that when reservoir elevations were between 433.8 m and 434.75 m, dabbling ducks continued to concentrate in the permanent wetland area, but their distribution within the wetland shifted away from the deepest parts of the pond (i.e., the west compartment) towards the shallower east compartment. Diving ducks were uncommonly observed in either location when the wetland was impounded (Hawkes *et al.* 2015).

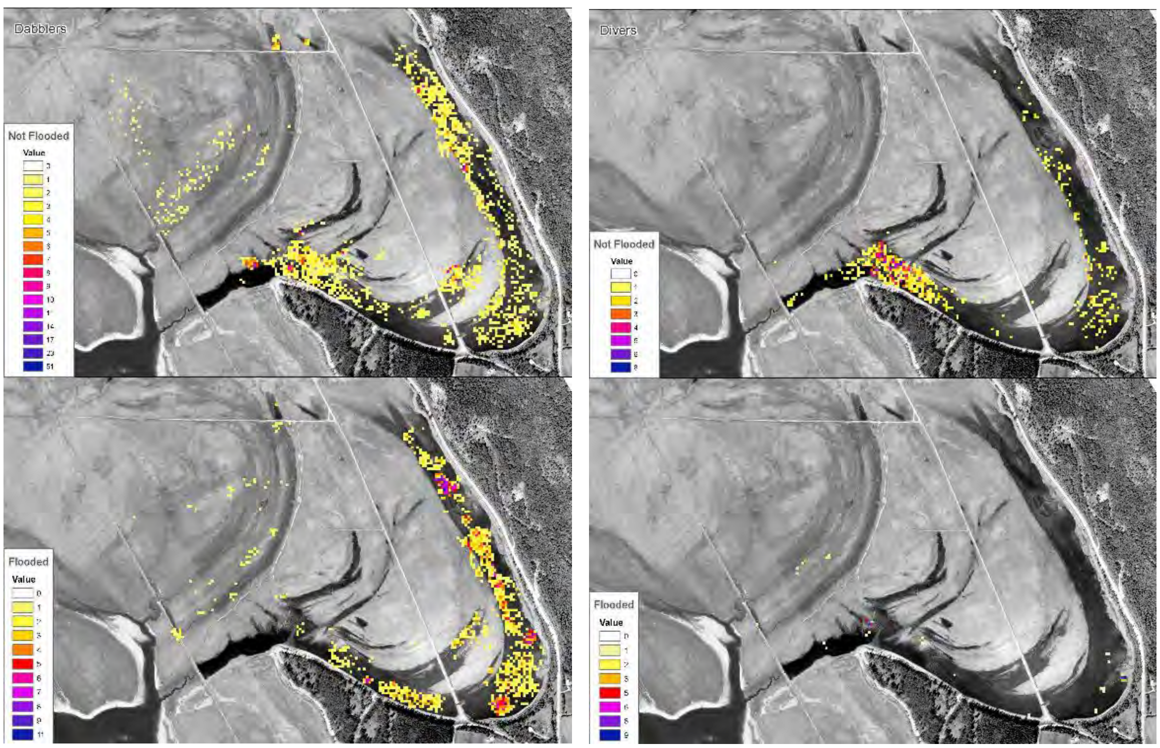

Figure 6-2. **Mapped distribution of dabbling ducks (left panels) and diving ducks (right panels) in conditions unaffected by reservoir operations (top) and when reservoir elevations are between 433.8 and 434.75 (bottom).** From Hawkes *et al.* (2015).

Further, a higher water level during spring runoff could result in an associated truncation of open foreshore habitat along this stretch of wetland shoreline, which in turn could lead to a loss of available foraging habitat for shorebirds as well as for American Pipit, which are known to heavily select this narrow habitat strip during the spring migration (CBA 2011). It should be noted that any foreshore impacts from slightly higher water levels would likely be limited to the west compartment, since the east compartment (which contains the majority of open foreshore habitat in Cartier Bay) is impounded by the old highway grade (not the outer dike) and sits at a slightly higher elevation in the wetland.

Because the Cartier Bay basin floods early in the breeding season, there is relatively little nesting or brood-rearing activity in the area (CBA 2013, 2014b). However, Killdeer and Spotted Sandpiper occasionally nest near the WPW-15A footprint area (CBA 2011b) and suffer nest failure due to reservoir operations. Presumably, an increase in the water level of the east compartment could affect nesting habitat along the shoreline for the same reasons outlined above; however, in this case there is abundant nesting habitat available for these species outside of the Cartier Bay area. Impounding the area at a higher level may cause these shorebirds to nest in other locations where the risk of nest flooding is reduced. Due to the low number of nests involved, any effect (positive or negative) is likely to be minor (Hawkes *et al.* 2015).

Amphibian breeding and foraging habitat (Hawkes *et al.* 2020) also has the potential to be affected by an increase in water level and associated reduction in open shoreline habitat in the west Cartier Bay compartment. For example, Western Toads have been documented utilizing the shallow margins here, especially in the wetted shallows that interject along the northern bank (Figure 6-2). However, most documented amphibian usage, by far, has been concentrated in the east compartment (Figure 6-2), where usage is unlikely to be impacted by minor hydrologic changes in the west compartment.

6.2 Management Question 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?

To date, two approaches to erosion control have been implemented to protect existing habitat values within the drawdown zone. One measure uses strategic riprap placement to prevent further channelization of a floodplain downstream of a wetland, while the other uses similarly-directed riprap placement, and associated sill repairs, to protect an extant wetland outlet. Both approaches appear to offer a generally effective technique for stemming erosion and strengthening potential weak points along the wetland-reservoir interface.

Fine soils beds often occur along the margins of reservoirs and are highly prone to gully erosion processes (head-cutting, lateral erosion, slumping, and bank undercutting). In addition, fluctuating reservoir water levels can exacerbate gully erosion leading to the rapid formation and advancement of gullies and erosion channels (Mazaeva et al. 2019). Because of the unpredictability of gully erosion (particularly within a reservoir), it is generally advisable to address it early if important resources are threatened.

As demonstrated with Site 6A, the infilling of the channel with riprap has been successful in arresting channel lengthening in an established fine-sediment erosion channel. Some of the advantages of riprap are that it is stable and durable, relatively easy to install (provided the site is accessible to heavy equipment), and easy to maintain. Drawbacks of riprap are that it can be costly to install, appears unnatural, entrap fish and wildlife (e.g., amphibians), and cause erosion problems upstream and downstream due to altered surface flows. Riprap can also negatively impact fish habitat by providing minimal cover, creating turbulent conditions, and preventing the establishment of riparian shoreline vegetation where it is placed. Because of these drawbacks, the use of riprap to control gully erosion should be considered only where other approaches are unlikely to be effective.

In Cartier Bay, the persistence of functional wetland habitat is closely tied to the unintentional impoundment of water behind anthropogenic features such as former (historical) highway and railway grades. Ensuring the long-term continuance of these berm-like features via the periodic application of targeted repairs is probably a relatively efficient method of maintaining the status quo with respect to existing wetland habitat. By contrast, revegetation efforts implemented under CLBWORKS-2 have not proven widely effective (Miller *et al.* 2018b) and probably do not offer, at present, a viable alternative erosion control strategy for Revelstoke Reach. Achieving woody plant establishment within the zone of inundation is made difficult by the regular, prolonged inundation periods that can exceed the physiological tolerances of planted species. Without changes to the operational regime, revegetation efforts below ~438 m ASL are unlikely to meet with broad success in the absence of other, complementary physical site ameliorations (e.g., artificial mounding to produce elevated island habitats, such as is currently being trialed under CLBWKS-30B at Burton Creek).

That said, the specific physiographic conditions that have gone into producing the Cartier Bay wetland are not closely replicated elsewhere in Revelstoke Reach. Hence, it is unclear how generally applicable the specific erosion control methods applied here will prove to be for other portions of the Reach that lack a similar physiography. Furthermore, monitoring showed that such measures have the potential to produce unintended outcomes, such as, for example, the development of new, compensatory erosion channels at other, lower points within the floodplain. These results have made clear that the topographical and hydrological characteristics of the local surrounding terrain, especially when the terrain has minimal topographical relief, must be considered carefully when designing these interventions to ensure that potential risks to non-target areas from altered water storage and other processes are minimized.

As noted above, the Revelstoke Reach floodplain, with its low relief and silty soils, is naturally highly erodible. Under current reservoir operations, it is expected that river banks will continue to slump and outflow channels will continue to develop, sometimes in unexpected locations. Consequently, erosion will likely continue to pose a long term and serious threat to wetland stability and persistence. Targeted erosion control measures such as riprap placements can, we think, be a valuable tool in the 'toolbox' of available strategies for prolonging the functional life of wetlands within the drawdown zone—as well as potentially that of riparian vegetation communities and terrestrial plant habitat that may also be lost a result of increasing channelization. Because erosion tends to become more difficult to manage the farther it advances, this approach is most likely to be effective over the long term when it is implemented proactively before serious problems are allowed to develop. This in turn will require ongoing geotechnical monitoring of the landscape (and associated hydrological modeling) so that potential issues can be identified before, or as, they arise.

We note that the primary objective of erosion control in the present context is to protect or secure existing wetland values (i.e., to maintain the status quo vis-à-vis wildlife habitat). As such, we do not regard this as a habitat enhancement technique per se. Various project ideas for enhancing habitat and increasing the productivity of the drawdown zone were considered previously under the CLBWORKS-29A program (Golder and Associates 2009a, b) and are not reprised here.

7.0 SUMMARY

This report presents the final results of scheduled post-physical works monitoring at Airport Outflow WPW-6A (2016, 2018-2020) and Cartier Bay WPW-15A (2018-2020) under the CLBMON-11B4 program. Monitoring at WPW-6A commenced the year following implementation of physical works, while post-works monitoring at WPW-15A followed upon three years of baseline (pre-works) monitoring carried out between 2011 and 2013. 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.

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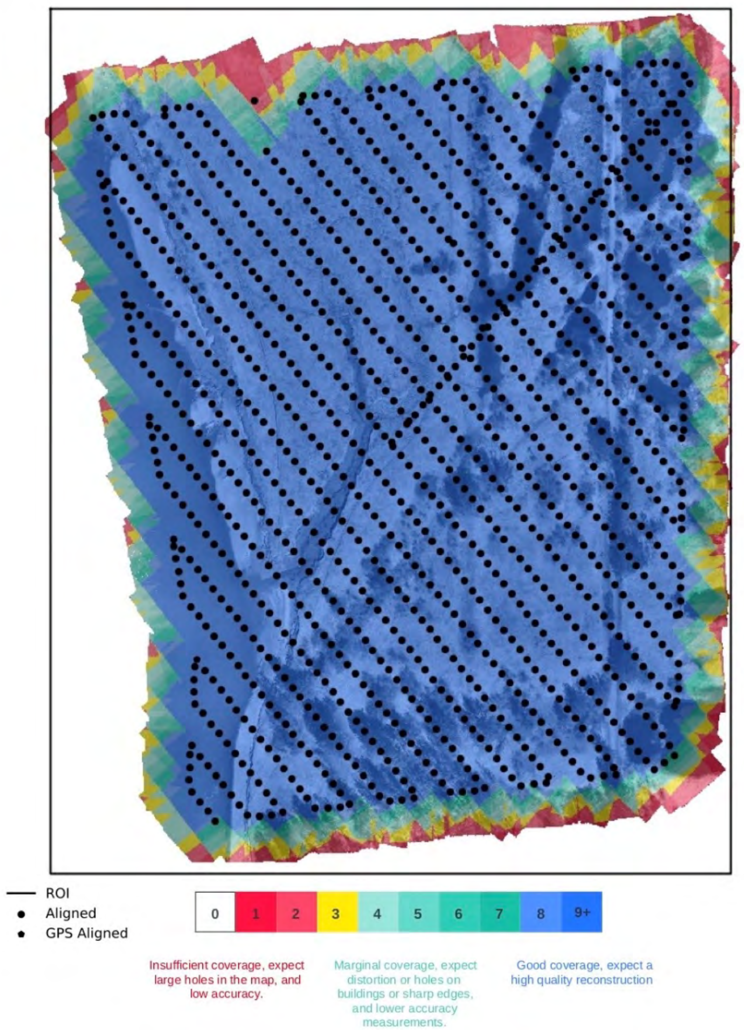
9.0 APPENDIX

9.1 Drone Photogrammetry Coverage (Site 6A).



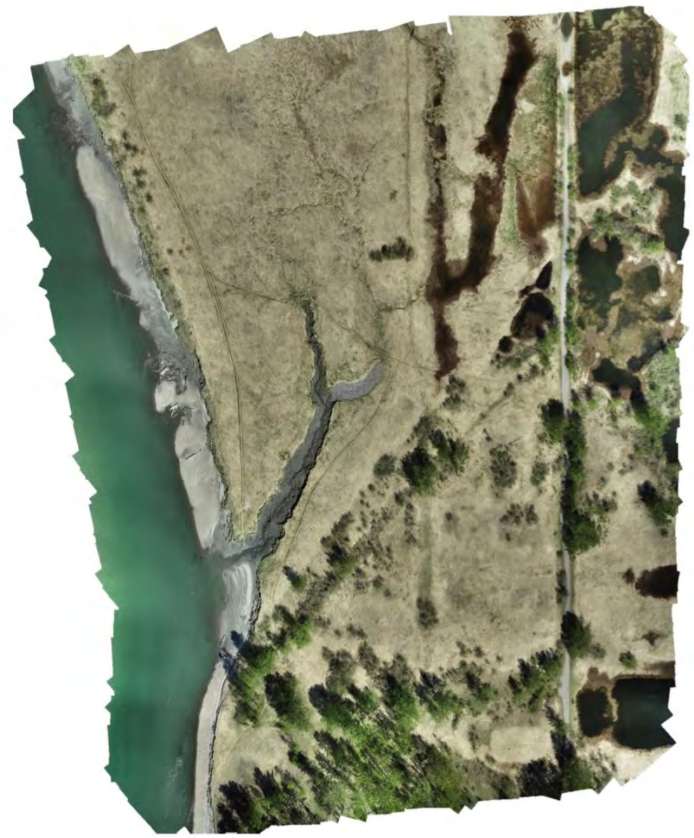


Figure 9-1: Images showing drone photogrammetry flight path (left) and coverage (right) of Site 6A on May 13, 2020.

9.2 Erosion Survey Measurements

Table 9-1: 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)	2020 Pin to Stake Distance (cm)	Annual rate of soil movement between 2018 and 2016 (cm/yr)	Annual rate of soil movement between 2018 and 2019 (cm/yr)	Annual rate of soil movement between 2019 and 2020 (cm/yr)	Annual rate of soil movement between 2016 and 2020 (cm/yr)
East	1.1	122	129	129	130	3.5	0.0	1.0	1.6
	1.2	122	127	127	127	2.5	0.0	0.0	1.0
	1.3	122	123	125	126	0.5	2.0	1.0	0.8
	1.4	122	122	122	122	0.0	0.0	0.0	0.0
	1.5	120	120	120	120	0.0	0.0	0.0	0.0
	1.6	122	123	123**	123	0.5	0.0	0.0	0.2
	1.7	122	122	122	122	0.0	0.0	0.0	0.0
	1.8	120	120	120	120	0.0	0.0	0.0	0.0
	1.9	122	123	126	126	0.5	3.0	0.0	0.8
					Mean	**0.8**	**0.6**	**0.2**	**0.5**
					SD	1.3	1.1	0.4	0.6
West	2.1	122	122	125.0	126.0	0.0	3.0	1.0	0.8
	2.2	122	122	124.5	125.0	0.0	2.5	0.5	0.6
	2.3	122	124.5	124.5	125.0	1.3	0.0	0.5	0.6
	2.4	122	134	144.0	slope failed*	6.0	10.0	NA	NA
	2.5	122	193	slope failed*	slope failed*	35.5	NA	NA	NA
	2.6	122	135.5	140.5	slope failed*	6.8	5.0	NA	NA
	2.7	122	137.5	149.0	151.0	7.8	11.5	2.0	5.8
	2.8	122	125	129.0	132.0	1.5	4.0	3.0	2.0
	2.9	122	125.5	132.0	133.0	1.8	6.5	1.0	2.2
					Mean	**6.7**	**5.3**	**1.3**	**2.0**
					SD	11.2	3.9	1.0	2.0

*Pin missing due to slope failure.
** incorrectly recorded as 130 cm in 2019.

Table 9-2: **Thalweg depths and riprap invert measurements (in cm) obtained in 2018, 2019, and 2020 for the east and west erosion channels.** Measurements were obtained from the lowest points between the survey pins located along the east and west channel banks (**Figure 4-1**).

Channel	Survey Pins	Thalweg depth /Riprap Invert(cm)			Total Change (cm)
		2018	2019	2020	
East	E1.1 - E1.9	112	92	108	-4
	E1.2 - E1.8	95	67	86	-9
	E1.3 - E1.7	64	37	77	+13
	E1.4 - E1.6	11	5	11	0
	Average	**70**	**50**	**70**	**0**
West	W2.1 - W2.9	254	274	274	20
	W2.2 - W2.8	257	255	255	-2
	W2.3 - 2.7	240	239	256	14
	W2.4 - W2.6	193	221	230	37
	Average	**236**	**247**	**254**	**17.3**

9.3 Bank Erosion Hazard Index (BEHI) scores for 2018, 2019, and 2020.

Table 9-3: Bank Erosion Hazard Index (BEHI) scores for the east and west erosion channels, 2020

Channel	Pin	Bank Material Score	Bank Height	Root Depth	RDH ratio	RDH Score	Surface Protection (%)	SP Score	Bank Angle (degree)	BA Score	Total Score
East	1.1	5	99	46	0.5	5	100	2.5	19	1	13.5
East	1.2	0	81	46	0.6	2.5	100	1	7	1	4.5
East	1.3	0	87	46	0.5	2.5	100	1	6	1	4.5
East	1.4	0	17	46	0.9	1	100	1	2	1	3
East	1.5	0	5.5	46	1.1	1	100	1	7	1	3
East	1.6	0	6	46	1.5	1	100	1	11	1	3
East	1.7	0	67	46	0.7	2.5	100	1	12	1	4.5
East	1.8	0	90	46	0.5	2.5	100	1	15	1	4.5
East	1.9	5	117	46	0.4	5	100	1	20	2.5	13.5
	Mean	1.1	63.1			2.6		1.6		1.2	6.0
West	2.1	10	278	46	0.2	7.5	100	2.5	42	2.5	23.5
West	2.2	10	255	46	0.2	7.5	100	2.5	17	1	22
West	2.3	10	254	46	0.2	7.5	100	2.5	46	2.5	23.5
West	2.4	10	235	46	0.2	7.5	100	10	90+	10	40
West	2.5	10	225	46	0.2	7.5	100	5	90+	10	40
West	2.6	10	224	46	0.2	7.5	100	7.5	90+	10	40
West	2.7	10	258	46	0.2	7.5	80	7.5	90+	10	40
West	2.8	10	254	46	0.2	7.5	100	5	55	2.5	23.5
West	2.9	10	270	46	0.2	7.5	100	5	90+	10	40

Mean	10	250.3	7.5		5.3		6.5	31.8

Table 9-4: Bank Erosion Hazard Index (BEHI) scores for the east and west erosion channels, 2019

Channel	Pin	Bank Material	Bank Height (cm)	Root Depth (cm)	RDH ratio	RDH Score	Surface Protection (%)	SP Score	Bank Angle (degree)	BA Score	Total Score
East	1.1	5	79	46	0.6	2.5	80	2.5	16	1	11
East	1.2	0	66	46	0.7	2.5	90	1	12	1	4.5
East	1.3	0	22	46	2.1	1	100	1	10	1	3
East	1.4	0	4	46	11.5	1	95	1	18	1	3
East	1.5	0	5	46	9.2	1	100	1	7	1	3
East	1.6	0	6	46	7.7	1	90	1	7	1	3
East	1.7	0	51	46	0.9	1	100	1	15	1	3
East	1.8	0	68	46	0.7	2.5	100	1	14	1	4.5
East	1.9	5	105	46	0.4	5	95	1	25	2.5	13.5
	Mean	**1.1**	45.1			**1.9**		**1.2**		**1.2**	**5.4**
West	2.1	10	230	46	0.2	7.5	95	1	45	2.5	21
West	2.2	10	238	46	0.2	7.5	75	2.5	30	2.5	22.5
West	2.3	10	255	46	0.2	7.5	70	2.5	38	2.5	22.5
West	2.4	10	281	46	0.2	7.5	20	7.5	90+	10	35
West	2.5	10	270	46	0.2	7.5	50	5	90+	10	32.5
West	2.6	10	271	46	0.2	7.5	40	5	80	7.5	30
West	2.7	10	247	46	0.2	7.5	40	5	90+	10	32.5
West	2.8	10	247	46	0.2	7.5	50	5	65	5	30
West	2.9	10	217	46	0.2	7.5	65	2.5	90+	10	30
	Mean	**10**	248			**7.5**		**4**		**6.9**	**28.4**

Table 9-5: Bank Erosion Hazard Index (BEHI) scores for the east and west erosion channels, 2018

Channel	Pin	Bank Material	Bank Height (cm)	Root Depth (cm)	RDI Ratio	RDH Score	Surface Protection (%)	SP Score	Bank Angle (degree)	BA Score	Total Score
East	1.1	5	100	46	0.5	5	75	1	0	1	13.5
East	1.2	0	87	46	0.5	2.5	90	1	0	1	4.5
East	1.3	0	71	46	0.6	2.5	95	1	0	1	4.5
East	1.4	0	10	46	4.6	1	100	1	0	1	3
East	1.5	0	12	46	4.0	1	85	1	0	1	3
East	1.6	0	13	46	3.7	1	100	1	0	1	3
East	1.7	0	58	46	0.8	2.5	80	2.5	0	1	6
East	1.8	0	103	46	0.4	5	100	1	0	1	7
East	1.9	5	124	46	0.4	5	100	1	25	2.5	15
	Mean	**1.1**	64			**2.8**	93.3	**1.5**		**1.2**	**6.6**
West	2.1	10	258	46	0.2	7.5	100	1	45	2.5	21
West	2.2	10	259	46	0.2	7.5	80	1	30	2.5	21
West	2.3	10	236	46	0.2	7.5	80	2.5	38	2.5	28.5
West	2.4	10	197	46	0.2	7.5	30	7.5	90+	7.5	32.5
West	2.5	10	193	46	0.2	7.5	50	5	90+	10	32.5
West	2.6	10	190	46	0.2	7.5	40	5	80	5	32.5
West	2.7	10	244	46	0.2	7.5	30	5	90+	10	32.5
West	2.8	10	254	46	0.2	7.5	50	5	65	5	32.5
West	2.9	10	251	46	0.2	7.5	40	7.5	90+	10	32.5
	Mean	**10**	231			**7.5**	56.1	**4.4**		**6.1**	**28.0**

9.4 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** (9.4.1), **Richardson's** and **eel-grass pondweeds** (9.4.2), **common hornwort** (9.4.3), **water smartweed** (9.4.4), **Rocky Mountain pond-lily** (9.4.5), **greater bladderwort** (9.4.6), and **Eurasian water-milfoil** (9.4.7).

9.4.1 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).

9.4.2 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).

9.4.3 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).

9.4.4 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).

9.4.5 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).

9.4.6 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).

9.4.7 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.* 2020). 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.

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

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