Columbia River Project Water Use Plan

KINBASKET AND ARROW LAKES RESERVOIR REVEGETATION MANAGEMENT PLAN

Implementation Year 4

Reference: CLBMON-11B4

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

Study Period: 2013

Okanagan Nations Alliance,
Westbank, BC

and

LGL Limited environmental research associates
Sidney, BC

June 18, 2014

EA3413

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

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

Annual Report - 2013

Prepared for

BC hydro

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

BC Hydro Contract No. EC10-393872

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Suggested Citation:

Miller, M.T. and V.C. Hawkes. 2014. CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Annual Report – 2013. LGL Report EA3413. Unpublished report by Okanagan Nation Alliance and LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 34 pp + Appendix.

Cover photos

From left to right: Cartier Bay, water-milfoil (*Myriophyllum* sp.) in Cartier Bay, Four-spotted Skimmer (*Libellula quadrimaculata*), Airport Marsh. Photos © Virgil C. Hawkes 2010.

EXECUTIVE SUMMARY

CLBMON-11B4 (*Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works*) was commissioned by BC Hydro in 2010 under the Columbia Water Use Plan. The mandate of this 10 year project is to assess the effectiveness of wildlife physical works projects (CLBWORKS-30) at enhancing wetland and wildlife habitat in Revelstoke Reach, part of Arrow Lakes Reservoir in southern British Columbia.

Here, we report results at the four-year mark of pre-implementation monitoring for the four wetland complexes within Revelstoke Reach being considered for physical works projects: Cartier Bay, Airport Marsh, Montana Slough, and Lower Inonoaklin Road (monitored since 2012), as well as for an ecological reference site, the Beaton Arm beaver ponds, monitored since 2012.

Aquatic macrophytes and macroinvertebrates were sampled in early summer (May/June). Point intercept data were collected on macrophyte frequency (calculated as the number of sample points in which a species occurred divided by the total number of sample points), abundance (measured for each species as volume x cover or VC), and biomass (dry weight of plant material collected per rake grab).

As in previous years, Eurasian Water-milfoil, Common Hornwort, Stonewort, and Small Pondweed were the most frequently encountered aquatic macrophytes in Revelstoke Reach in 2013; each was recorded at Cartier Bay and Airport Marsh in at least 30 per cent of point intercept samples. All four taxa showed a trend of increasing frequency at Airport Marsh between 2011 and 2013. At Cartier Bay, trends were more mixed as Stonewort and Small Pondweed showed slightly higher frequencies in 2013 compared to 2011, whereas Common Hornwort had a slightly lower frequency and the frequency of Eurasian Water-milfoil appeared relatively unchanged. Contingency analyses applied to frequency data indicated that at Airport Marsh, observed frequencies were contingent on sampling year ($p < 0.05$) in the case of Stonewort, Floating-leaved Pondweed, and Water Smartweed. At Cartier Bay, only the frequency of Small Pondweed was significantly contingent on year, although the likelihood of encountering Water Smartweed and Richardson's Pondweed was also marginally contingent on year.

Multivariate analyses (RDAs) suggested that water physicochemical variables such as temperature, pH, conductivity, and dissolved oxygen explained very little (3.4%) of the variance in the distribution and local abundance of macrophytes at either Cartier Bay or Airport Marsh. Unless a stronger relationship is demonstrated between these variables and the occurrence rates of macroinvertebrates (an analysis which we have deferred until the next implementation year, when the available data set will be larger and more amenable to ordination analyses), there may be limited rationale for continuing to collect these data, at least during the pre-construction monitoring phase of the project.

As in 2012, the richest site for macroinvertebrates was the Beaton Arm beaver ponds, followed by Airport Marsh. Together with true flies, copepods and water fleas were major constituents of the pelagic fauna at all four sites samples. Due to budgetary constraints, fewer macroinvertebrate samples were assessed in 2013 than in previous years. Consequently, quantitative analyses were not

undertaken. Nevertheless, several previously unreported taxa were added to the macroinvertebrate checklist for Revelstoke Reach as well for Beaton Arm and Lower Inonoaklin Road, implying that the number of recorded taxa is likely to increase with continued sampling.

The following recommendations are based on the 2013 study findings:

1. In the future, consider focusing pelagic sampling within a metre from the shoreline rather than in open water, as per guidelines in Jones et al. (2007), since this is where the highest concentrations of invertebrates tend to be. Boat sampling of the open water column may produce underestimates of taxa richness and abundance.
2. Continue to collect physicochemical variables (temperature, pH, dissolved oxygen (DO), etc.), but to reduce sampling time, limit the collection of these variables to macroinvertebrate sampling locations.
3. Sampling should only be continued at sites potentially affected by the implementation of physical works. For 2014 we recommend that sampling continue at Airport Marsh, Montana Slough, Cartier Bay, and Lower Inonoaklin Creek. Beaton Arm should be dropped from the study because physical works are not proposed for this site.

The status of CLBMON-11B4 after Year 3 (2012) with respect to the management questions and management hypotheses is summarized below:

Management Question (MQ)	Management Hypotheses		Year 4 (2013) Status
i. Are the wildlife physical works projects effective at enhancing wildlife habitat in the drawdown zone?	HA2	HA2A	Wildlife physical works projects are still pending for wetlands in Revelstoke Reach. In each of 2010, 2011, and 2012, pre-impact, baseline data were collected on macrophyte and macroinvertebrate communities at Airport Marsh, Cartier Bay, and Montana Slough. Metrics of species abundance (frequency, cover, biomass) and distribution (diversity, evenness) have been computed. Baseline data were also collected on water depth, turbidity, temperature, and physicochemistry. Improvements with aerial photographs continue to lead to refinements in wetland community mapping. The management question will begin to be addressed in full once the physical works have been completed and post-impact effects can be assessed. The data being collected will permit testing of the management hypotheses.
ii. To what extent do the wildlife physical works projects increase the productivity of habitat in the drawdown zone for wildlife?	HA2D	HA3B	As above.
iii. Are some methods or techniques more effective than others at enhancing wildlife habitat in the drawdown zone?	HA3	HA3B	As above.

HA2A: Wildlife physical works projects do not change the area (m2) or increase the suitability of wildlife habitat in the drawdown zone.
HA2A: Wildlife physical works do not change wildlife use of the drawdown zone.
HA2D: Wildlife physical works projects do not change the abundance (e.g., biomass) and species diversity in the drawdown zone of invertebrates, which are prey for amphibians and reptiles, birds, and mammals.
HA3: The methods and techniques employed do not result in changes to wildlife habitats in the Arrow Lakes Reservoir drawdown zone.
HA3B: The methods used for wildlife physical works do not result in changes to wildlife habitat in the Arrow Lakes Reservoir drawdown zone as measured by indices of habitat suitability, site productivity (e.g., arthropod biomass), and forage production.

KEYWORDS: Arrow Lakes Reservoir, wildlife physical works, monitoring, drawdown zone, operating regime, wildlife, macrophyte, macroinvertebrate

ACKNOWLEDGEMENTS

The authors express their appreciation to the following individuals for their assistance in coordinating and conducting this study: Margo Dennis, Philip Bradshaw, and Guy Martel (BC Hydro); James Pepper, Alan Peatt, and Alexis Friesen (Okanagan Nation Alliance); and Doug Adama, Bryce McKinnon, Janean Sharkey (LGL Limited). A special thanks to Thilaka Krishnaraj, who sorted and identified the macroinvertebrate specimens.

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1.0 INTRODUCTION

The Columbia River Water Use Plan (WUP) was developed as a result 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. The WUP process followed the guidelines established by the Government of British Columbia (Government of British Columbia 1998; BC Hydro 2000) and involved a number of interest groups, First Nations, government agencies and other stakeholders, collectively referred to as the Consultative Committee (CC). Initiated in 2000, the WUP was completed in 2004 (BC Hydro 2005) and was approved by the Comptroller of Water Rights in January 2007 (Comptroller of Water Rights 2007).

During the WUP planning process, a number of reservoir operating alternatives were explored to balance environmental and social values in the Columbia system. While several of these alternatives included changes to the operating regime of the Arrow Lakes Reservoir (specifically maintaining lower, more stable reservoir levels during the spring, summer and fall), the CC recognized that physical works in lieu of operational changes may be a more cost-effective means of achieving environmental and social benefits given the value of the lost power generation associated with these alternatives. Consequently, the CC supported the implementation of physical works (revegetation and habitat enhancement) in the mid-Columbia River rather than changes to reservoir operations to help mitigate the impact of Arrow Lakes Reservoir operations on wildlife and wildlife habitat.

Coupled with habitat enhancements, the CC also recommended monitoring to assess the effectiveness of these physical works at enhancing habitat for wildlife. In particular, nest mortality and impacts to bird populations, along with impacts to reptile and amphibian species and their habitats, were identified as important wildlife concerns in Revelstoke Reach. As a result, 42 potential wildlife physical works projects were identified by the WUP wildlife technical subcommittee (BC Hydro 2005), and the feasibility of completing these wildlife physical works projects in the drawdown zone of Revelstoke Reach was investigated by Golder Associates (2009). Out of this assessment, five potential projects were prioritized and identified for development based on their engineering feasibility and ecological merit. Site plans for these five projects were developed (Golder Associates 2009), and incorporated environmental, engineering and archaeological considerations; three of these will be undertaken by BC Hydro over the period 2013-2019. This includes physical works at Cartier Bay and, potentially, Montana Slough that would increase shallow water habitat in the drawdown zone, as well as a third project at Airport Marsh which is designed to ensure that the wetland retains its current water levels.

Several of the wildlife physical works are intended to increase shallow wetland habitat. As such, there is an expectation that wetland productivity will increase in these areas over time. Nevertheless, multiple years of monitoring (both pre and post-impact) are needed to test the hypothesis that wetland productivity increases in response to physical works.

Several physical parameters and biological response variables may be considered when evaluating wetland productivity, including: (1) changes in the aquatic macrophyte community, (2) changes in aquatic plant biomass and volume, (3) changes in the areal extent of the target habitat type (i.e., shallow wetland habitat), (4) changes in the aquatic invertebrate assemblage associated with each shallow wetland, and (5) changes in the physical parameters (e.g., water depth, spatial extent, water temperature and chemistry) of affected wetlands. To properly assess the efficacy of a given wildlife physical works at enhancing wetland productivity, data related to these physical parameters and biological response variables should be collected before and after the implementation of the proposed physical works.

Here, we report results at the four-year mark of pre-implementation monitoring for the three wetland complexes within Revelstoke Reach being considered for physical works projects: Cartier Bay, Airport Marsh, and Montana Slough. 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 each wetland was also undertaken (Hawkes et al. 2011).

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 each of the three study sites, as well as the associated pelagic and benthic invertebrate communities (Fenneman and Hawkes 2012, Miller and Hawkes 2013). As well, in 2012 we expanded the study scope 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), we continued pre-construction monitoring of Airport Marsh and Cartier Bay, as well as of Beaton Arm Beaver Ponds and Lower Inonoaklin Creek. Montana Slough, which previous years' work had shown to be relatively depauperate with respect to both aquatic macrophytes and macroinvertebrates, was not resampled in 2013.

1.1 Rationale

The primary objective of CLBMON-11B4 is to use aquatic macrophytes and aquatic invertebrates as indicators of the effectiveness of physical works projects in restoring wetland areas in the drawdown zone of Revelstoke Reach and thus improving their suitability for wildlife. Data collection of physical parameters and biological response variables will help determine if the physical works implemented in Revelstoke Reach are successful at achieving the goals and objectives of the physical works, which have been established by the WUPCC and are intended to address concerns related to the impacts to bird, reptile, and amphibian habitats. As the physical works projects are completed, it is anticipated that ecological systems within the created or restored wetland habitats will change. These changes may be positive, in which the ecological function trends towards an established and healthy natural ecosystem, or they may be negative and trend towards a more disturbed environment with low diversity of native species, high abundance of exotic species, or other undesirable factors. The inventory data collected between 2010 and 2013 provide valuable baseline information on conditions at each of the proposed sites prior to the completion of any of the physical works projects, against which future conditions can be compared. Additionally, the 2013 surveys allowed for ongoing evaluation of the study design and sampling methodologies that had been described in 2010 (see Hawkes et al. 2011) to test their efficacy in detecting community-level changes in select biotic and abiotic variables.

2.0 MANAGEMENT QUESTIONS AND HYPOTHESES

2.1 Monitoring Program Objectives

The overall objectives of this study are to:

1. monitor the appropriate physical parameters and biological response variables to assess the effectiveness of the wildlife physical works programs at enhancing wildlife habitat in Revelstoke Reach;
2. assess the effectiveness of wildlife physical works projects at enhancing wetland and associated riparian habitat at both the site and landscape level; and
3. provide recommendations based on the results of the monitoring program to improve wetland enhancement techniques.

2.2 Management Questions

This monitoring program is designed to assess the effectiveness of revegetation programs and wildlife physical works at enhancing wildlife habitat in the drawdown zone of Arrow Lakes Reservoir. The monitoring program will assess the response of several wildlife taxa and habitat elements to wildlife habitat enhancements. The primary management questions to be addressed by the monitoring program are:

1. Are the wildlife physical works projects effective at enhancing wildlife habitat in the drawdown zone?

If so,

2. To what extent do the wildlife physical works projects increase the productivity of habitat in the drawdown zone for wildlife?
3. Are some methods or techniques more effective than others at enhancing wildlife habitat in the drawdown zone?

2.3 Management Hypotheses

The hypotheses to be tested under the proposed monitoring program relate to the effectiveness of the revegetation program and wildlife physical works projects at improving wildlife habitat within the reservoir drawdown zone. Specifically, these hypotheses test the quality and quantity of aquatic vegetation and aquatic macroinvertebrates that become established within the habitats created through the physical works projects. These parameters can then be used to assess the quality of the habitat for other wildlife.

The management hypotheses of CLBMON-11B that specifically relate to this project (CLBMON-11B4) are as follows:

HA_{2}: Wildlife physical works do not change wildlife use of the drawdown zone.

HA_{2A}: Wildlife physical works projects do not change the area (m^2) or increase the suitability of wildlife habitat in the drawdown zone.

HA_{2D}: Wildlife physical works projects do not change the abundance (e.g., biomass) and species diversity in the drawdown zone of invertebrates, which are prey for amphibians and reptiles, birds, and mammals.

HA_{3}: The methods and techniques employed do not result in changes to wildlife habitats in the Arrow Lakes Reservoir drawdown zone.

HA_{3B}: The methods used for wildlife physical works do not result in changes to wildlife habitat in the Arrow Lakes Reservoir drawdown zone as measured by indices of habitat suitability, site productivity (e.g., arthropod biomass), and forage production.

2.4 Objectives and Performance Measures for Revelstoke Reach

The feasibility study for the physical works projects (Golder Associates 2009) identified the overall vegetation-specific objectives for the three sites (see Section 3.5 for a more detailed discussion of these sites):

1. For Site 6A (Airport Slough Outflow) and the adjacent Airport Marsh, the objective is to maintain the existing community. Thus, no significant changes in species diversity, distribution, or relative abundance should be detected over the 10 years of the monitoring program.
2. For Site 14 (Cartier Area), the objective is the eventual establishment of an ecological community similar to that growing in Cartier Bay within the current area of inundation. Existing conditions in Cartier Bay can thus act as a target condition for the newly inundated areas.
3. For Site 15A (Cartier Bay), the general objective is the same as for Site 14: to expand the existing wetland community by increasing the amount of flooded area (Golder Associates 2009) and subsequently establishing a community that is similar to that which currently exists in Cartier Bay.

A fourth site, Site 13 (Montana Slough), was initially also under consideration for habitat enhancement projects (Golder Associates 2009). Baseline monitoring of this site occurred simultaneously to the monitoring of other sites from 2010 to 2012 (Miller and Hawkes 2013). However, as no physical works are currently proposed for Montana Slough, an agreement was reached to cease monitoring of the site as of 2013. There are currently no plans to resume monitoring at Montana Slough (BC Hydro, pers. comm. 2013).

2.4.1 Airport Slough Outflow (Site 6A) performance measures

The following performance measures for Airport Slough Outflow will be assessed solely with reference to possible impacts accruing from channel erosion. Where required for hypothesis testing, the accepted standard for statistical power will be 0.80 or greater.

1. No measurable change greater than 25 per cent from baseline conditions in the areal extent (hectares or square metres) of shallow wetland habitat over 10 years.
2. No change > 25 per cent in overall habitat conditions as measured by indicator habitat elements (e.g., water depth, pH, and turbidity) over 10 years.
3. No change > 25 per cent in cover, biomass, and diversity of aquatic macrophyte species over 10 years.
4. No change > 25 per cent in biomass and diversity of macroinvertebrates over 10 years.
5. No further erosion of Airport Marsh outflow following the completion of the physical works, and no indication that such erosion should be expected in the future. This is based on an assessment of the structural integrity of the physical works during the final year of monitoring to ensure that they are sound.

2.4.2 Cartier Bay (Sites 14 and 15A) performance measures

The following performance measures for Cartier Bay (Sites 14 and 15A) will be assessed with reference to effects accruing from the physical works. Where required for hypothesis testing, the accepted standard for statistical power will be 0.80 or greater.

1. Site 14: creation of at least 1 ha of new wetland habitat within one year following the implementation of the physical works.
2. Site 15A: measurable increase of at least 10 per cent in areal extent (hectares or square metres) of existing shallow wetland habitat within one year following the implementation of the physical works.
3. Measurable increase in wetland productivity:
    a. Successful natural establishment of native macrophytes into newly created wetlands within ten years. “Successful establishment” is here defined as continuous species presence for at least five years.
    b. Increases of at least 25 per cent from baseline conditions in cover and diversity (species richness and evenness) of native macrophytes within 10 years. This includes species that occur in the wetlands and those that become successfully established.
    c. Successful natural establishment of native macroinvertebrates into newly created wetlands within ten years. “Successful establishment” is here defined as continuous species presence for at least five years.
    d. Measurable increases of at least 25 per cent from baseline conditions in biomass and diversity (species richness and evenness) of native macroinvertebrates within ten years. This includes species that occur in the wetlands and those that become successfully established.

4. No measurable increases greater than 25 per cent from baseline conditions in cover and diversity (species richness and evenness) of key undesirable macrophyte species over 10 years. Undesirable macrophytes include any introduced species, particularly those that are considered invasive. In the case of Revelstoke Reach, this term refers primarily to Eurasian Water-milfoil (*Myriophyllum spicatum*), which is the dominant invasive plant of aquatic habitats within the drawdown zone.
5. No measurable increases greater than 25 per cent from baseline conditions in biomass and diversity (species richness and evenness) of key undesirable macroinvertebrate species over 10 years.
6. No erosion or other structural failure of the dikes following the completion of the physical works, and no indication that such events should be expected in the future. This is based on an assessment of the structural integrity of the physical works during the final year of monitoring to ensure that they are sound.

2.5 Key Water Use Decision

Results from this study will aid in more informed decision-making with respect to the need to balance the requirements of wildlife species dependent on wetland and riparian habitats with other values such as recreational opportunities, flood control and power generation. The key water use planning decision affected by the results of this monitoring program is whether revegetation and wildlife physical works are effective at enhancing wildlife habitat in lieu of operational changes to reservoir operations. Results from this study will also assist in refining the approaches and methods for enhancing wildlife habitat through adaptive management.

2.6 Program Linkages

CLBMON-11B4 is directly and indirectly linked to other programs being implemented in the Arrow Lakes Reservoir. The monitoring program developed for CLBMON-11B1 will provide an indication of the efficacy of the physical works implemented in Revelstoke Reach at enhancing wildlife habitat. In addition, data collected as part of that monitoring program are related to several long-term monitoring programs—specifically, CLBMON-37, -40 and -36. The protocol for monitoring physical works implemented in Revelstoke Reach, once developed, could be applied to physical works proposed for mid- and lower Arrow Lakes where wetland enhancement or creation is also the objective (i.e., CLBWORKS-29B).

3.0 STUDY AREA

3.1 Physiography

The Columbia Basin in southeastern British Columbia is bordered by the Rocky, Selkirk, Columbia and Monashee mountains. The headwaters of the Columbia River are at Columbia Lake in the Rocky Mountain Trench, and the river flows northwest along the trench for ~250 km before emptying into Kinbasket Reservoir behind Mica Dam (BC Hydro 2007). From Mica Dam, the river continues southward for about 130 km to Revelstoke Dam. The river then flows almost immediately into Arrow Lakes Reservoir behind Hugh Keenleyside Dam. The entire drainage area upstream of Hugh Keenleyside Dam is approximately 36,500 km2. The Columbia Basin is characterized by steep valley side slopes and short tributary streams that flow into Columbia River from all directions.

The Columbia River valley floor elevation extends from approximately 800 m near Columbia Lake to 420 m near Castlegar. Approximately 40 per cent of the drainage area within the Columbia River Basin is above 2000 m elevation. Permanent snowfields and glaciers are widespread in the northern high mountain areas above 2500 m elevation, and about 10 per cent of the Columbia River drainage area above Mica Dam exceeds this elevation.

3.2 Climate

Precipitation in the Columbia Basin occurs from the flow of moist low pressure weather systems that move eastward through the region from the Pacific Ocean. More than two-thirds of the precipitation in the basin falls as winter snow. The persistence of below freezing temperatures, in combination with abundant precipitation, results in substantial snow accumulations at middle and upper elevations in the watersheds. Summer snowmelt is reinforced by rain from frontal storm systems and local convective storms.

Air temperatures across the basin tend to be more uniform than precipitation. With allowances for temperature lapse rates, station temperature records from the valley can be used to estimate temperatures at higher elevations. The summer climate is usually warm and dry, with the average daily maximum temperature for June and July ranging from 20° to 32°C. The average daily minimum temperature ranges from 7° to 10°C. The coldest month is January, when the average daily maximum temperature in the valleys is near 0°C and average daily minimum is near -5°C.

During the spring and summer months, the major source of water in the Columbia River is water stored in large snowpacks that developed during the previous winter months. Snowpacks often continue to accumulate above 2000 m elevation through May, and continue to contribute runoff long after the snowpack has become depleted at lower elevations. Runoff begins to increase in April or May and usually peaks in June to early July, when approximately 45 per cent of the runoff occurs. Severe summer rainstorms are not unusual in the Columbia Basin. Summer rainfall contributions to runoff generally occur as short-term peaks superimposed on high river levels caused by snowmelt. These rainstorms may contribute to annual flood peaks under the current Columbia River Treaty operations. The mean annual local inflows for the Mica, Revelstoke and Hugh Keenleyside projects are 577 m^3/s, 236 m^3/s, and 355 m^3/s, respectively.

3.3 Biogeoclimatic Zones

Two biogeoclimatic zones occur at the lower elevations surrounding Arrow Lakes Reservoir: the Interior Cedar Hemlock (ICH) and the Interior Douglas-fir (IDF). Most of the reservoir area occurs within the ICH, with three subzones and four variants represented (Table 3-1). The IDF is restricted to the southernmost portion of the area and consists of a single subzone (IDFun); this area is outside of the study area of this project. The subzones are a reflection of increasing precipitation from the dry southern slope of Deer Park to the wet forests near Revelstoke (Enns et al. 2008). The Arrow Lakes Reservoir study is situated primarily within the Arrow Boundary Forest District, but a small portion of its northerly area is in the Columbia Forest District.

Table 3-1: Biogeoclimatic zones, subzones and variants that occur in the Arrow Lakes Reservoir study area

Zone Code	Zone Name	Subzone/Variant Description	Forest Region & District
ICHdw1	Interior Cedar – Hemlock	West Kootenay Dry Warm	Nelson Forest Region (Arrow Forest District)
ICHmw2	Interior Cedar – Hemlock	Columbia-Shuswap Moist Warm	Nelson Forest Region (Columbia Forest District)
ICHmw3	Interior Cedar – Hemlock	Thompson Moist Warm	Nelson Forest Region (Columbia Forest District)
ICHwk1	Interior Cedar – Hemlock	Wells Gray Wet Cool	Nelson Forest Region (Arrow Forest District)
IDFun	Interior Douglas-fir	Undefined	Nelson Forest Region (Arrow Forest District)

Most of the Columbia Basin watershed remains in its original forested state. Dense forest vegetation thins above 1500 m elevation and tree line occurs at ~2,000 m elevation. The forested lands around Arrow Lakes Reservoir have been and continue to be logged, with active logging (2007/2008) occurring on both the east and west sides of the reservoir.

3.4 Arrow Lakes Reservoir

Arrow Lakes Reservoir is a ~230 km long section of the Columbia River drainage between Revelstoke and Castlegar, B.C. It has a north-south orientation and is set in the valley between the Monashee Mountains to the west and the Selkirk Range to the east. The Hugh Keenleyside Dam, located 8 km west of Castlegar, spans the Columbia River and impounds Arrow Lakes Reservoir. Arrow Lakes Reservoir has a licensed storage volume of 7.1 million acre-feet (MAF) (BC Hydro 2007), and the normal operating range of the reservoir is between 440.1 m and 418.64 m ASL.

The study area for CLBMON-11B4 is restricted to Revelstoke Reach at the north end of Arrow Lakes Reservoir (Figure 3-1), from Airport Marsh southeast to Cartier Bay, with all work focused on the east side of the reach. The area hosts several large wetland complexes, large open sedge/grass habitats and several willow-shrub complexes. The combination of elevation, limited topographical relief, and undulating terrain has contributed to the development of important bird, reptile and amphibian habitats within the seasonally inundated drawdown zone of Arrow Lakes Reservoir.

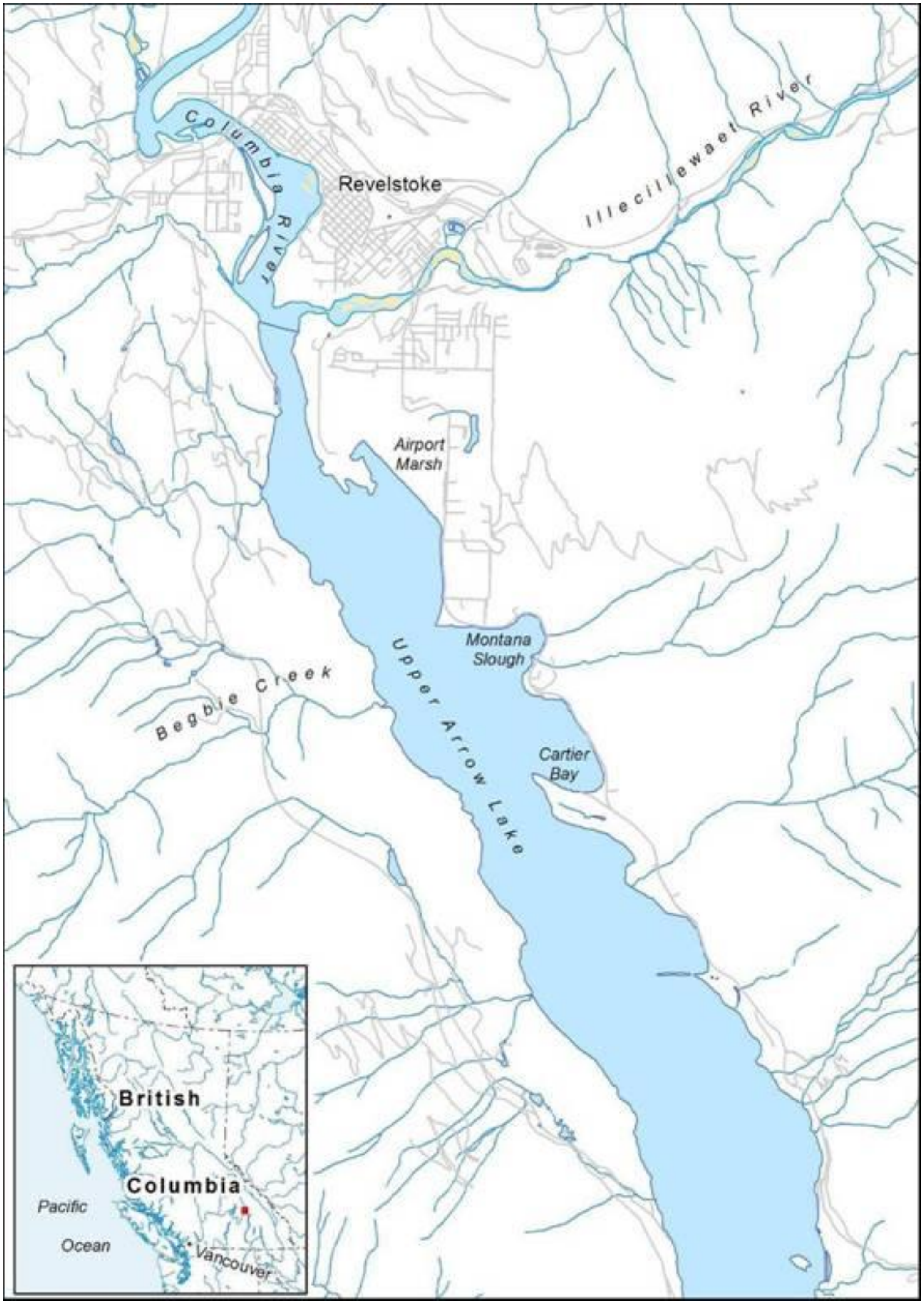

Figure 3-1: Location of Airport Marsh, Montana Slough and Cartier Bay in Revelstoke Reach, Arrow Lakes Reservoir

3.5 Proposed Physical Works – Project Descriptions

The following project descriptions were extracted from Golder Associates (2009). Because physical works are proposed for most of these sites (with the exception of Montana Slough), it is important to obtain baseline data against which further data can be compared. This will ensure the proper implementation of a BACI[1]-style study design and that any comparisons made between data sets are valid.

3.5.1 Site 14: Cartier Bay

Site 14 is located 8 km south of Revelstoke on the east side of the reservoir and immediately north of Cartier Bay. It is approximately 1.3 km south of Site 13 and 300 m north of Site 15A. At Site 14, there is a deep gap in the rail grade that allows for uninhibited drainage of water when the floodplain is not inundated by the reservoir. The proposed project design for Site 14 is a dike with swale to close the gap in the rail grade to retain water and flood low lying ground upstream of the proposed dike. Ancillary habitat works include the placement of coarse woody debris/large woody debris within flooded shallow basins.

3.5.2 Site 15A: Cartier Bay

Site 15A in Cartier Bay consists of an existing pond/wetland complex that historically may have been an oxbow of the Columbia River. The wetland consists of two compartments separated by a gap in an old road bed that bisects a large 24.3 ha pond. The outflow of this pond/wetland complex is through a gap in the rail grade where a collapsed wooden box culvert exists. The persistence of water in this pond/wetland complex is a result of the plugged box culvert creating a rudimentary dike. The proposed design for this project is to replace the ad hoc dike and box culvert with an engineered dike to prevent potential further compression and/or failure of the existing structure, which could be catastrophic to existing habitat values. We also propose to increase the invert elevation of the swale of the constructed dike by 1 m to increase water storage in Cartier Bay and increase the extent of shallow open water habitat behind the new dike. Ancillary habitat work includes placement of loafing logs for turtles and large woody debris/coarse woody debris along the southern shoreline, as well as nest boxes in trees on adjacent high ground for cavity nesting waterfowl.

3.5.3 Site 6A: Airport Slough outflow

Site 6A is a small erosion channel immediately northwest of Machete Island (at the western end of Airport Marsh). The channel begins at the northwest edge of Machete Island and runs northeast towards the old Arrowhead Highway Road bed before splitting into an east and west arm. The west arm is eroding into the surrounding floodplain, whereas the east arm is eroding towards the old Arrowhead Highway Road bed. Site 6A is on BC Hydro land but must be accessed via a road that follows the Illecillewaet River, and includes gated access through a privately operated gravel pit. The physical works proposed for Site 6A include the reinforcing of the erosion channel to ensure that it does not continue to erode and, eventually, fail. In such a scenario, Airport Marsh would

[1] BACI: Before-After Control-Impact

be expected to drain almost completely of water, severely impacting the wetland community that is established there. This project was completed in 2013.

Although the proposed physical works will not alter the existing conditions at Airport Marsh, monitoring of this site is necessary. This is largely due to the importance of the marsh locally for Painted Turtles (Chrysemys picta), many species of waterfowl, and wetland-associated songbirds. Monitoring across time will determine whether the integrity of the marsh is unaffected by the proposed physical works. Furthermore, as the best-established wetland community of all of the study sites, Airport Marsh represents the "Control" wetland for the CLBMON-11B4 study (see Section 4.1, below).

3.5.4 Lower Inonoaklin Creek

Lower Inonoaklin Creek is a proposed wildlife physical works enhancement site south of Needles, B.C. on the west side of the Arrow Lakes Reservoir (Hawkes and Howard 2012). Pre-physical works monitoring of this site under CLBMON-11B4 commenced in 2012 (Miller and Hawkes 2013).

3.5.5 Beaton Arm Beaver Ponds

The Beaton Arm site is a complex of beaver ponds extending in stepwise fashion from the forest edge above the drawdown zone into the drawdown zone itself, which serves as a non-drawdown zone ecological reference site for the Revelstoke Reach wetlands. Pre-physical works monitoring of this site under CLBMON-11B4 commenced in 2012 (Miller and Hawkes 2013). A detailed description of the site is provided in Miller and Hawkes (2013).

4.0 METHODS

Hawkes et al. (2011) provide a detailed discussion of the rationale for this project, as well as a summary of reconnaissance-level sampling that was conducted during 2010. The results from the 2010 sampling season helped develop the methodology that was applied in 2011, 2012, and 2013.

4.1 Study Design

The study design follows that of Hawkes et al. (2011), modified to address monitoring of the Beaton Arm Beaver Ponds and Lower Inonoaklin Creek commencing in 2012 (Miler and Hawkes 2013). The study uses a modified BACI-style design (Before-After Control-Impact) to assess the effects of physical works projects on wetland habitats in the drawdown zone of Arrow Lakes Reservoir, whether they be designed to retain water at its existing level (Airport Marsh) or to flood new areas and create additional wetland habitat that did not exist prior to the physical works (Cartier Bay and Lower Inonoaklin Creek). Because the physical works projects affect the entire study area, the study lacks a statistical control in the traditional sense; instead, we must rely on adjacent wetlands (e.g. Beaver Pond Wetlands) to serve as ecological reference sites (hence "modified" BACI design).

The study uses point intercept samples of aquatic macrophytes, aquatic invertebrates, and wetland physicochemistry collected at random locations in the wetlands prior to the implementation of the physical works projects (the "Before" component) as a baseline against which to compare the conditions of these same parameters in the years following completion of the physical works (the "After" component). Airport Marsh and Beaver Pond Wetlands, which are situated high in the drawdown zone, receive relatively minimal annual inundation from the reservoir, and have much more complex and well-developed wetland communities, will serve as reference wetlands against which to compare the ecological conditions at the "impact" wetland (Cartier Bay). Montana Slough, Baseline monitoring of this site occurred simultaneously to the monitoring of other sites from 2010 to 2012 (Miller and Hawkes 2013). However, as no physical works are currently proposed for Montana Slough, an agreement was reached to cease monitoring of the site as of 2013. There are currently no plans to resume monitoring at Montana Slough.

At all sites except Beaton Arm Beaver Ponds, sample point selection was random and accomplished by overlaying a 25 m X 25 m grid on each study site, identifying which cells were completely within the confines of each wetland, and randomly selecting 20 to 40 grid cells, depending on wetland size (Figure 4-1). A list of UTM coordinates representing the centre of each randomly selected grid cell was then generated. All grid work and site selection was done using ArcMap 9.3.1 and 10. At Beaton Arm, the wetlands were too small to employ this approach, and sampling was done from shore rather than from a boat. In this instance, samples were taken at representative points along the pond perimeter.

Sampling in 2013, which represented the fourth year of the "Before" component of the study, was completed during a single field session in late May and early June. This differed from previous years, in which sampling was conducted both in the spring (pre-inundation) and again in late summer, following inundation (Miller and Hawkes 2013). Experience of past years has shown that the detectability of macrophytes drops off considerably in late summer after the study sites have been flooded by the rising reservoir. The rapid increase in water depth and turbidity, especially at Cartier Bay and Montana Slough, can situate the plants several metres below the water surface making them difficult to reach with the sampling apparatus or to visually assess through a viewing tube. As a result, late summer samples have tended to produce low estimates of cover and abundance compared to spring samples (Miller and Hawkes 2013). Because of this time-sensitive sampling bias, it was deemed preferable to focus resources on spring sampling in 2013.

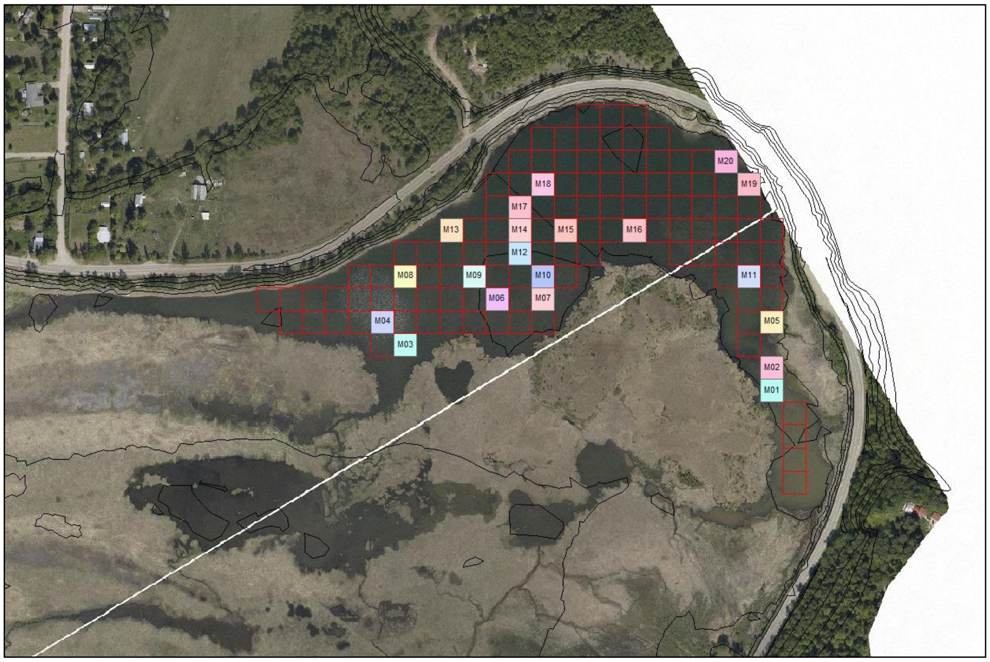

Figure 4-1: Example of the site selection process used for Montana Slough. Grid cells entirely within Montana Slough are shown in red. Coloured cells with alphanumeric labels indicate cells that were randomly selected through GIS

4.2 Aquatic Macrophyte Sampling

Submergent vegetation was sampled using a double-headed rake, as detailed in Alberta Environment (2006), G3 Consulting Ltd. (2010) and Hawkes et al. (2011). Sampling effort was standardized at each location by dropping the rake to the bottom of the water column and dragging it approximately 1 m. A cluster sampling approach was used in which two samples were taken at each location. See Hawkes et al. (2011) for a justification of the use of cluster sampling in this study. Once collected, the volume of the entire sample was estimated (Table 4-1), as was the relative cover of each macrophyte species in the sample (Table 4-2).

Floating vegetation was sampled using a buoyant 1 m x 1 m quadrat frame constructed from PVC pipe (Figure 4-2). Using this frame, one short (2 m x 1 m) belt transect was placed on each side of the boat (total 4 m x 1 m). The per cent cover of the water surface occupied by each floating species was recorded for each of the four quadrats. For analysis, the per cent cover value of each species was averaged among the four quadrats.

Figure 4-2: Buoyant, 1 m x 1 m PVC quadrat frame used for sampling floating aquatic vegetation

In addition to determining the relative abundance of plant species at the study sites, the vegetation samples that were collected within the submergent and floating communities were retained for biomass calculations. Biomass samples (which constituted the entire vegetation sample at a given sampling location) were collected at the first sample point at each site, and at every third sampling point thereafter. The samples were stored in Ziploc bags in the field, and the bags were labelled with the date of collection, study site and sampling point. The samples were shipped to the laboratory, where they were weighed ("wet weight") and then dried in an oven until all moisture had been removed and the sample mass remained constant ("dry weight").

Table 4-1: Volume classes for vegetation samples

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

Table 4-2: Cover classes for vegetation samples

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

4.3 Emergent and Terrestrial Vegetation Sampling

Emergent and terrestrial plant communities within or adjacent to the physical works sites were sampled using a belt transect approach. Each belt transect consisted of four contiguous 1 m x 1 m (1 m^2) quadrats (Figure 4-3). When sampling was done from a boat, the belt transect was divided into two shorter transects each consisting of two 1 m^2 quadrats, with one transect placed on each side of the boat (as for floating macrophyte beds, above). The per cent cover of each vascular plant was recorded within each of the four quadrats at each sampling location. For analysis, the per cent cover value of each species was averaged among the four quadrats.

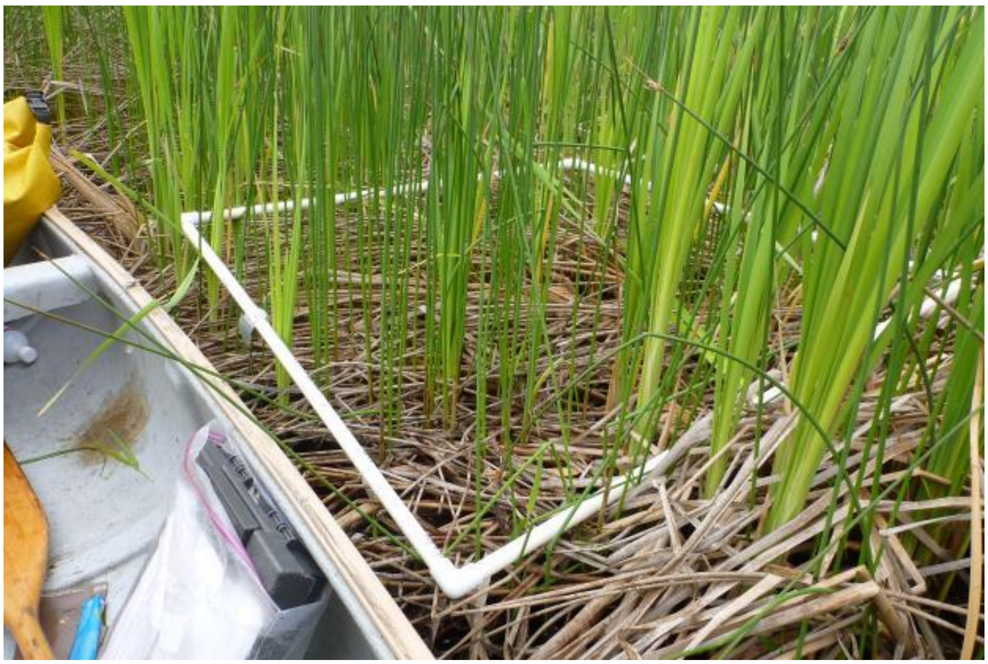

Figure 4-3: 1 x 1 m quadrat frame used to sample emergent wetland vegetation

4.4 Aquatic Invertebrate Sampling

Two different collection methods were used to sample invertebrates at the three sampling sites: epipelagic sampling using a dip net, and benthic sampling using a hand-held Ponar grab (2.4 L). By using these methods, the two primary species groups (epipelagic, benthic) were sampled. Hawkes et al. (2011) provide a more detailed discussion of these and other sampling techniques that were considered for this project.

For epipelagic species of invertebrates, two sweeps of 1 m were completed (one on each side of the boat) at a depth of 20–30 cm using a fine-meshed, 17 cm x 25 cm aquarium dip net. These samples were then transferred to a Whirl-Pak with ethanol (70 per cent concentration) for preservation. For benthic species, the Ponar grab (Figure 4-4) was lowered to the sediment using a rope and then was tripped, thereby capturing a ~2.4 L sample of the upper layers of sediment. Once removed from the water, the sediment sample was strained using a fine-meshed (0.4 mm) dip net as a sieve. A 500 ml subsample was then collected and transferred to a Whirl-Pak® sample bag with an ethanol preservative. Both the epipelagic and benthic samples were stored in refrigerated conditions until they could be sorted following completion of the field sessions.

Invertebrate samples were sorted and identified by Thilaka Krishnaraj following a modified Cabin protocol (RISC 2009). Each sample was sorted using a Marchant box (Marchant 1989) and a minimum of 200 invertebrates were extracted from each sample; in samples containing less than 200 specimens, then entire sample were sorted. Diptera, Coleoptera, Hemiptera, Ephemeroptera, Plecoptera, Trichoptera, Megaloptera and Neuroptera were keyed to family while other taxa were keyed to order or phyla level as per the CABIN protocol (McDermott 2012).

Figure 4-4: ONA researcher deploying the Ponar benthic sampler at Airport Marsh

4.5 Physicochemical Attributes

In addition to aquatic macrophyte and invertebrate samples, the abiotic conditions at each sampling location were noted:

- Water depth (cm)
- Substrate: documented using the Ponar grab, or for shallow/clear water, by visual means. Substrate type was categorized as one (or more) of the following classes: F = fines (clay/silt); S = sand; SM = small gravel; LG = large gravel; C = cobble; B = boulders; BR = bedrock; M = muck (fine organic material); CD = coarse organic detritus; W = wood
- Secchi depth: the relative turbidity of the water was assessed by measuring water transparency (cm) using a Secchi disk
- Dissolved oxygen (mg/L): measured using a YSI-85 meter within 30 cm of the surface

- Conductivity (µS): measured using a YSI-85 meter within 30 cm of the surface
- Water temperature (°C), within 30 cm of the surface
- pH: measured using a pH meter at the surface

4.6 Data Analyses

4.6.1 Vegetation Data

Macrophyte frequency (defined as the proportion of sample plots in which a species or group of species was detected) was compared across sites and time periods using 2 x 2 tables (Madsen 1999, Hawkes et al. 2011).

The analysis of aquatic macrophyte data also entailed derivation of a metric that considered both the relative cover and sample volume of each species as estimated by rake grabs at each sample point. To derive this value we multiplied the volume and the relative cover estimated for each species at each location to produce a single numeric value (VC) representing the overall abundance of the species at each sampling point. Volume classes ranged from 1 through 3, and relative abundance classes ranged from 0.1 (for trace) to 1 through 5 (Table 4-1, Table 4-2). For each sample point, the values were averaged across two rake grabs. Thus, the minimum possible volume value was 0.5 and the minimum possible relative cover value was 0.05. The minimum possible (non-zero) value for the volume x cover metric was then 0.5 x 0.05 = 0.025, and the maximum possible value for the volume x cover metric was 3 x 5 = 15.

Redundancy analysis (RDA) was performed to explore relationships between species abundance metrics (volume x cover metric for submergent vegetation, per cent cover for floating vegetation) and physicochemical variables (pH, conductivity, DO, temperature, water depth, and substrate texture). RDA preserves the Euclidian distance in the ordination spaces and allows the computation of adjusted-R^2 (Legendre and Legendre 2012). The R^2 is the coefficient of determination of the multiple regressions embedded within the canonical analyses; it measures the fraction of variance in Y that is explained by a linear combination of the variables in X (Sokal and Rohlf 1995). The adjusted-R^2 (R^2a) is a modification of the R^2 that accounts for the number of explanatory variables included in the multiple regressions or canonical models. Increasing the number of explanatory variables in a model would automatically increase the R^2 even if the new variables do not improve the model more than would be expected by chance. In other words, any model containing as many variables as the number of data points can be adjusted to perfectly fit the data (Legendre and Legendre 2012). Using the adjusted- R^2 ensures that the proportion of variance of Y that is explained by the variables in X is not influenced by how many variables there are in X. A reduction in the number of independent variables was made prior to the analysis using a forward selection procedure. Variable selection ensures that any variable that does not significantly contribute to the model (by increasing the R^2) is eliminated (Legendre and Legendre 2012).

Different iterations were performed on the 2011-2013 macrophyte data from Cartier Bay, Montana Slough, and Airport Marsh, first using all the point intercept plots as replicates, then by stratifying species abundance by site, season, and year. Environmental variables were averaged per combination of site, season, and year. Qualitative variables were coded as dummy variables. The quantitative variables were standardized prior to computing the similarities, since data had different units and dimensions (Legendre and Legendre 2012). Their mean was divided by two standard deviations to make them comparable with the qualitative binary variables (Gelman 2008). Abundance and cover data was transformed using the Hellinger distance, to make them suitable for ordinations (Legendre and Gallagher 2001). RDAs were performed in the R language (version 3.0.2).

4.6.2 Invertebrate Data

The number of individuals of each macroinvertebrate taxon (order and family) recorded within each sample and site were tabulated. The relative abundance of each taxon at a given study site was calculated as the number of individuals recorded (in all samples) divided by the total number of macroinvertebrates recorded (in all samples). Because the sample size for each identified taxon is very small, species richness, diversity, and evenness indices were not estimated for 2014.

5.0 RESULTS

Aquatic macrophytes and macroinvertebrates were sampled over four days between May 30 and June 2 2013. Reservoir elevations at the time of sampling ranged from 434.86 m to 435.13 m ASL. Sampling occurred just as Arrow Lakes Reservoir levels were impounding the open water habitats at Cartier Bay and Lower Inonoaklin Creek. The Beaton Arm beaver pond complex is situated outside of the drawdown zone.

Fifteen randomly distributed points at Cartier Bay were sampled, 30 points at Airport Marsh, and 12 points at Lower Inonoaklin Creek. Four separate beaver ponds were sampled at Beaton (one sample point for pond). An example of the spatial configuration of samples at Cartier Bay is shown in Figure 5-1 (from Miller and Hawkes 2013). A sample bathymetric map produced for Cartier Bay shows the distribution of shallow and deep areas (Figure 5-2). This map is based on data collected in 2011 and on preliminary bathymetric data from 2010 (from Miller and Hawkes 2013). Water depths of the June 2013 sample points ranged from < 1 m to 2.8 m at Cartier Bay, from 0.1 m to 2.5 m at Airport Marsh, and from 0.25 m to 1 m at Lower Inonoaklin Creek.

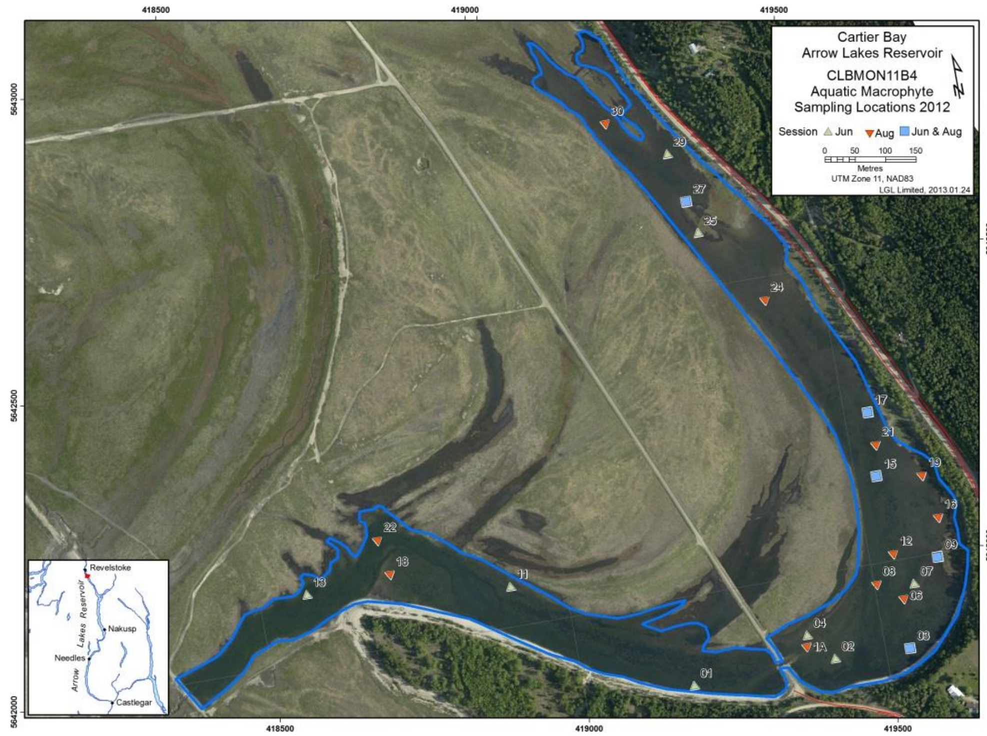

Figure 5-1: Distribution of samples in Cartier Bay in 2012, May and August sessions

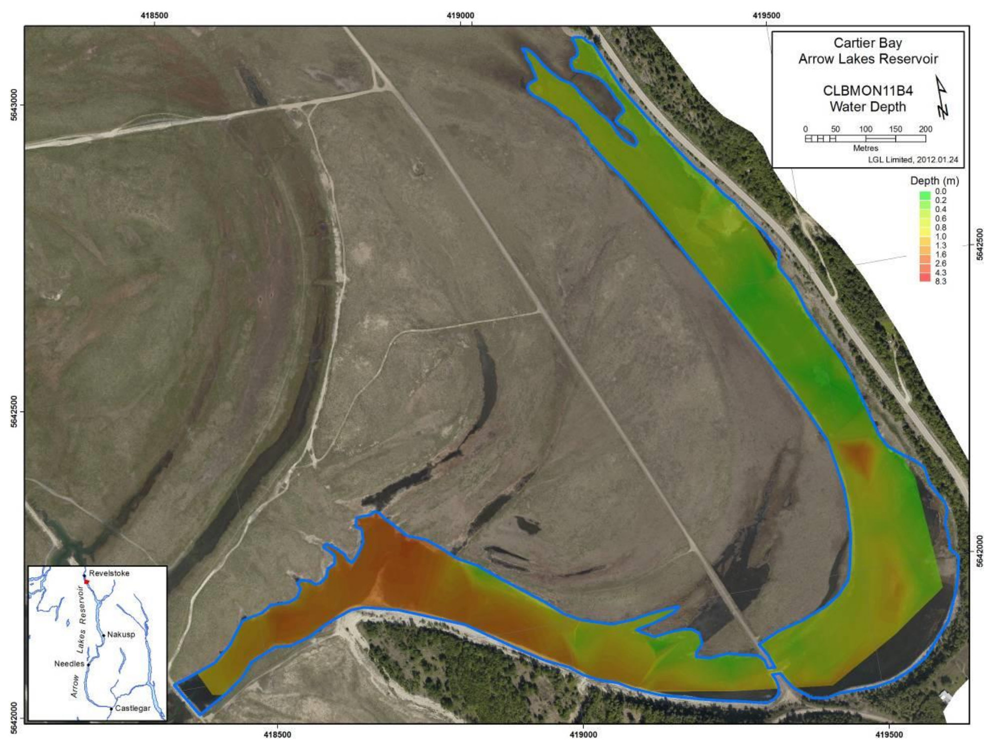

Figure 5-2: Bathymetric map of Cartier Bay, based on water depths collected in 2011 and augmented with depths collected in 2010. Only pre-inundation (May) water depths were used from the 2011 data

5.1 Aquatic Macrophytes

In 2013, per cent frequency ranged from nil (for several species) to a high of 67 per cent (for Eurasian Water-milfoil, Common Hornwort, and Stonewort at Cartier Bay; Table 5-1). Eurasian Water-milfoil, Common Hornwort, Stonewort, and Small Pondweed were the most commonly encountered species overall in Revelstoke Reach in 2013; each was recorded at Carter Bay and Airport Marsh in at least 30 per cent of point intercept samples.

All four taxa showed a trend of increasing frequency at Airport Marsh between 2011 and 2013. At Cartier Bay, trends were more mixed as Stonewort and Small Pondweed showed slightly higher frequencies in 2013 compared to 2011, whereas Common Hornwort had a slightly lower frequency and the frequency of Eurasian Water-milfoil appeared relatively unchanged. At Airport Marsh, observed frequencies were significantly contingent on sampling year (2-way contingency table analysis, Chi-square test for independence, $\alpha = 0.05$) in the case of Stonewort ($p = 0.047$), Floating-leaved Pondweed ($p = 0.029$), and Water Smartweed ($p = 0.016$), and close to significant in the case of Small Pondweed ($p = 0.066$). At Cartier Bay, frequencies were significantly contingent on sampling year in the case of Small Pondweed ($p = 0.032$). The likelihood of encountering Water Smartweed ($p = 0.068$) and Richardson's Pondweed ($p = 0.065$) was also marginally contingent on sampling year.

Comparing species frequencies in 2013 between the two Revelstoke Reach sites (for those species occurring at both sites), Common Hornwort was marginally significantly more likely to be present in point intercept samples at Cartier Bay than at Airport Marsh (2-way contingency table analysis, Fisher Exact Test, $p = 0.055$). Floating-leaved Pondweed ($p = 0.016$) and, less confidently, Water Smartweed ($p = 0.064$), were more likely to be recorded at Airport Marsh. There was no significant effect of site on the observed frequencies of Small Pondweed, Stonewort, or the introduced species Eurasian Water-milfoil (Table 5-1).

Table 5-1: Per cent frequency of aquatic macrophyte species detected in random samples (rake grabs) of the three physical works areas of Revelstoke Reach (Airport Marsh, Montana Slough, Cartier Bay) during the 2011, 2012, and 2013 surveys. Montana Slough was not surveyed in 2013, indicated by n/a. Species presence (but not frequency) is also indicated for two other sites in Arrow Lakes Reservoir that were surveyed for the first time in 2012 (Beaton Arm Beaver Ponds and Lower Inonoaklin Creek). Not all macrophytes listed are strictly aquatic as defined in Warrington (2001); emergent wetland species found rooted underwater at the time of sampling are indicated with a *. A "√" indicates present but not quantified; "-" indicates not present

Species	Airport Marsh (Site 6A)			Montana Slough (Site 13)			Cartier Bay (Site 15A)			Beaton Arm Beaver Ponds	Lower Inon. Ck.
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2013	2013
Eurasian Water-milfoil (*Myriophyllum spicatum*)	35	59	63	13	08	n/a	68	54	67		
Common Hornwort (*Ceratophyllum*	15	34	33	13	25	n/a	74	69	67		

Species	**Airport Marsh (Site 6A)**			**Montana Slough (Site 13)**			**Cartier Bay (Site 15A)**			**Beaton Arm Beaver Ponds**	**Lower Inon. Ck.**
	2011	**2012**	**2013**	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**	**2013**	**2013**
demersum)											
Stonewort (*Chara* sp.)	20	38	56	-	8	n/a	58	54	67		√
Richardson's Pondweed (*Potamogeton richardsonii*)	5	10	7	-	-	n/a	-	15	-		
Small Pondweed (*Potamogeton pusillus*)	10	28	41	-	-	n/a	47	92	60	√	√
Eel-grass Pondweed (*Potamogeton zosteriformis*)	5	3	11	-	-	n/a	16	-	-		
Floating-leaved Pondweed (*Potamogeton natans*)	5	38	33	13	17	n/a	-	8	-	√	
Water Smartweed (*Persicaria amphibia*)	45	10	37	-	-	n/a	-	23	7	√	
Greater Bladderwort (*Utricularia macrorhiza*)	5	14	4	-	-	n/a	-	-	-		
Yellow Pond-lily (*Nuphar polysepala*)	-	-	-	-	-	n/a	-	-	-	√	
Reed Canarygrass (*Phalaris arundinacea*)*	50	21	4	-	-	n/a	-	-	-	√	
Common Mare's-tail (*Hippuris vulgaris*)	5	3	7	-	-	n/a	-	-	-		
Common Spike-rush (*Eleocharis palustris*)*	-	3		-	-	n/a	-	-			
Soft-stemmed Bulrush (*Schoenoplectus tabernaemontani*)*	-	7	-	-	-	n/a	-	-	-		
Small-flowered Bulrush (*Scirpus microcarpus*)*	5	3	-	-	-	n/a	-	-	-		
Narrow-leaved Bur-reed (*Sparganium angustifolium*)	5	3	4	-	-	n/a	-	-	-		
Bur-reed (*Sparganium* sp.)	-	-	-	-	-	n/a	-	-	-	√	
Common Cattail (*Typha latifolia*)*	10	7	-	-	-	n/a	-	-	-		
Marsh Cinquefoil (*Comarum palustre*)*	5	7	-	-	-	n/a	-	-	-	√	
Water Sedge (*Carex aquatilis*)*	-	-	4	-	-	n/a	-	-	-		
Beaked Sedge (*Carex utriculata*)*	-	-	4	-	-	n/a	-	-	-		
Columbia Sedge (*Carex aperta*)	-	-	-	-	-	n/a	-	-	-	√	
Sitka Sedge (*Carex sitchensis*)	-	-	-	-	-	n/a	-	-	-	√	
Hemlock Water-parsnip (*Sium suave*)	5	-	-	-	-	n/a	-	-	-		
Tufted Loosestrife (*Lysimachia thyrsiflora*)	5	-	-	-	-	n/a	-	-	-		

Species	Airport Marsh (Site 6A)			Montana Slough (Site 13)			Cartier Bay (Site 15A)			Beaton Arm Beaver Ponds	Lower Inon. Ck.
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2013	2013
Swamp Horsetail (*Equisetum fluviatile*)	20	7	7	-	-	n/a	-	-	-	√	
Marsh Horsetail (*Equisetum palustre*)	5	-	-	-	-	n/a	-	-	-		
Small-flowered Forget-me-not (*Myosotis laxa*)	5	-	-	-	-	n/a	-	-	-		
Moss sp.*	10	3	-	-	-	n/a	8	-	-		

We further compared the total frequencies of the four dominant submergent macrophytes by pooling the point intercept data for all years and both sample sessions (spring and summer) for each Revelstoke Reach wetland (Figure 5-3). The pooled data suggest that Cartier Bay is overall more densely vegetated, with the four main species more evenly distributed, than either Airport Marsh or Montana Slough. Common Hornwort was the most frequently encountered species at Cartier Bay, while Small Pondweed was nearly as prevalent. At Airport Marsh, Eurasian Water-milfoil was the most frequently encountered species. At Montana Slough, Common Hornwort and Eurasian Water-milfoil had about the same prevalence, though both species were far less common overall (Figure 5-3).

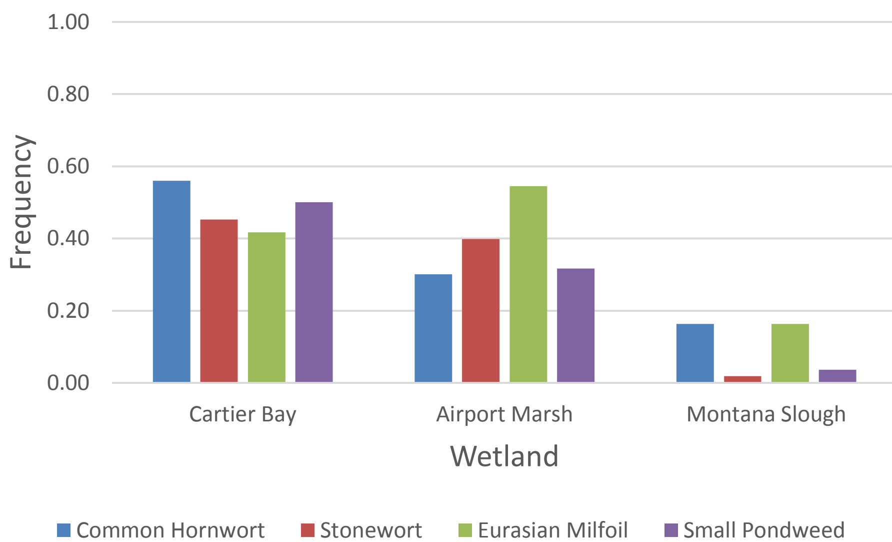

Figure 5-3: Frequencies of the four dominant submergent macrophytes, based on point intercept samples pooled across years and spring and summer samples sessions. For Cartier Bay and Airport Marsh, years were 2011, 2012, and 2013; for Montana Slough, years were 2011 and 2012

Dry weights of biomass samples averaged between 16 and 36 g (Cartier Bay) and between 9 and 98 g (Airport Marsh) over the 2011-2013 period (Table 5-2). As sample sizes for biomass were small and data were non-normally distributed, a Kruskal-Wallis One-Way ANOVA was used to evaluate inter-annual variation in this variable (Zar 1999). The annual difference was statistically significant for Cartier Bay (Kruskall-Wallis statistic = 6.55, p = 0.031) but not for Airport Marsh

(Kruskall-Wallis statistic = 2.82, p = 0.253). Despite statistical significance, the observed variation likely reflects random variation associated with point sampling over a large area, or variation in measurements resulting from differences in timing or water depths, as opposed to real biological differences between years.

Table 5-2: Mean biomass (g dry weight) of May/June rake drag samples at Cartier Bay and Airport Marsh, 2011 to 2013. SD = standard deviation, *n* = sample size. 2011 and 2012 data from Fenneman and Hawkes (2012) and Miller and Hawkes (2013)

Site	Year	Dry weight (g)	SD	*n*
Cartier Bay	2011	36.6	19.6	6
	2012	16.1	26.5	12
	2013	28.2	21.8	6
Airport Marsh	2011	12.3	13.8	7
	2012	98.3	144.9	14
	2013	9.3	10.7	11

At Beaton Arm, as in 2012 (Miller and Hawkes 2013), there was a well-developed macrophyte community, dominated in most ponds by floating beds of Yellow Pond-lily and/or Floating-leaved Pondweed (Figure 5.3). Macrophytes included other Pondweeds (Small Pondweed, Richardson's Pondweed), Bladderwort, Bur-reed, and Water Smartweed. Water Sedge, Columbia Sedge, Swamp Horsetail, Marsh Cinquefoil, and Reed Canarygrass occurred in shallower waters along the shoreline (Figure 5.3).

Aquatic macrophyte cover at the Lower Inonoaklin Road slough was very sparse in 2013, consistent with 2012 findings (Miller and Hawkes 2013). Out of 12 point intercept samples taken via rake drag from the boat on June 1 (Figure 5.4), just one yielded minor amounts of two macrophyte species (Floating-leaved Pondweed and Stonewort).

Figure 5-4: Beaton Arm beaver pond (Pond 1), photographed June 1, 2013.

Figure 5-5: Lower Inonoaklin Road site, with boat used for point intercept sampling, photographed June 1, 2013

5.2 Aquatic Macroinvertebrates – Pelagic

Fifty nine point intercept plots were sampled using pelagic and benthic grabs in late May and early June 2013. However, due to budgetary constraints, a subsample of 22 pelagic grabs was analyzed in the lab for macroinvertebrate content (Table 5-3).

Table 5-3: Distribution of aquatic macroinvertebrate sampling locations by reach

Month	Site	Plots
	Cartier Bay	6
	Airport Marsh	6
	Lower Inonoaklin	6
	Beaton Arm	4

Five out of the 22 samples did not have any fauna present in the samples. The remaining samples had a total of 18 taxa, of which 13 were identified to family. The number of taxa found in the samples varied from one to a maximum of nine per sample (Table 5-4). Copepoda (freshwater crustaceans), Cladocera (water fleas) and Diptera (true flies) were the three commonly identified taxa, with copepods being present in 11 out 17 samples examined, followed by Diptera (specifically Chironomidae) in 9 samples. Taxa such as Gerridae, Corixidae and Haliplidae that are commonly found in the lentic ecosystems were identified from samples collected at Beaton Arm Beaver Ponds. This site (all samples combined) had the most diversity of macroinvertebrates, with 15 out of the 18 identified taxa. The second most speciose site was Airport Marsh, followed by Cartier Bay and Lower Inonoaklin Creek.

Based on their proportional representation in the samples, Cladocera, Hemiptera, and Diptera were three predominant taxonomic orders at Beaton; Cladocera, Copepoda, and Diptera were predominant at Cartier Bay; Cladocera and Diptera were predominant at Airport Marsh; and copepods dominated the macroinvertebrate community at Lower Inonoaklin Road).

Similar results were obtained in 2012 (Miller and Hawkes 2013), when Cladocerans (water fleas) and Copepoda (copepods) were the most ubiquitous and generally the most abundant macroinvertebrates, occurring in four or five of the study areas). However, one of the more ubiquitous groups in 2013, Diptera (true flies), was not recorded at any of the sites in 2012. Other “new” taxa identified in 2013 were Nematoda (nematodes), Hydracarina (water mites) and Oribatida. Hydracarina and Oribatida belong to Phylum Acari, which was noted as present in 2012 though not identified to lower taxonomic levels). Several taxa (e.g., Odonata, Mollusca) identified in 2012 were not present in the 2013 samples), possibly reflecting the smaller samples sizes in 2013 for Airport Marsh and Cartier Bay.

5.3 Physicochemical Attributes

Wetlands differed with respect to abiotic measures (Appendix 9-1). For example, dissolved oxygen levels tended to be higher at Cartier Bay and Montana Slough than at Airport Marsh and the Beaton Beaver Ponds, while all three Revelstoke Reach sites have a higher pH than the reference ponds at Beaton (Appendix 9-1). Nevertheless, wetland physicochemistry does not appear to explain much of the local variation in macrophyte species abundance (as represented by the volume x cover metric VC) in the Revelstoke Reach wetlands (adj-R^2 of 3.4%, RDA, sites and years combined, p = 0.0001). The first axis of this ordination explained 2.4% of the variation and the second axis, 1.45% (results not shown). Other exploratory RDA iterations (stratifying by sites, season, and years) did not yield significant results.

Table 5-4: Pelagic macroinvertebrate abundance (numbers of individuals), by taxon, enumerated from Arrow Lake samples collected during 2013 survey

Taxon Name	Airport Marsh					Beaton Arm				Cartier Bay			Lower Inonoaklin Rd.				
	A-02	A-03	A-04	A-06	A- 07	B-01	B-02	B-03	B-04	C-01	C-03	C-09	L-02	L-03	L-04	L-05	L-06
Baetidae								1									
Caenidae	1																
Ceratopogonidae						2											
Chironomidae	3		1		1	3	1	5	3		4						1
Cladocera	4								1	2							
Collembola											1						
Copepoda		1				4		2	4	6	2		1	1	6	1	4
Corixidae							4										
Daphnidae						4	7			4		1					
Ephemeroptera							3										
Gerridae				1		9											
Haliplidae							1										
Hydrodromidae						1		1									
Hydrozetidae			1			2	1										1
Nematoda								1									
Oligochaeta															1		
Polyphemidae						2											
Sminthuridae							2										
Tipulidae						2											
Total Abundance	**8**	**1**	**2**	**1**	**1**	**29**	**18**	**10**	**8**	**12**	**7**	**1**	**1**	**1**	**7**	**1**	**6**
Total No. Taxa	**3**	**1**	**2**	**1**	**1**	**9**	**6**	**5**	**3**	**3**	**3**	**1**	**1**	**1**	**2**	**1**	**3**

Table 5-5: Aquatic macroinvertebrate orders and families by site and year (only the June 2012 sampling session is shown for comparison). Shaded cells indicates presence in 2012. Values in cells indicate the relative abundance of each taxon (proportion of all individuals recorded) at a given site in 2013. Sample sizes for each site are shown in () following the site names. Montana Slough was not surveyed in 2013, indicated by n/a

		2012					2013				
Phylum/Order	**Family**	**Montana Slough (3)**	**Cartier Bay (13)**	**Airport Marsh (14)**	**Lower Inonoaklin (1)**	**Beaton Arm (5)**	**Montana Slough (0)**	**Cartier Bay (6)**	**Airport Marsh (6)**	**Lower Inonoaklin (6)**	**Beaton Arm (4)**
Acari							n/a	See Hydracarina and Oribatida below (Phylum Acari)			
Amphipoda							n/a				
Annelida*							n/a				
Ephemeroptera											**0.05**
	Baetidae						n/a				**0.02**
	Caenidae						n/a		**0.08**		
Cladocera							n/a	**0.1**	**0.31**		**0.02**
	Daphnidae							**0.25**			**0.17**
	Polyphemidae										**0.03**
Cnidaria							n/a				
Coleoptera											
	Haliplidae						n/a				**0.02**
Collembola							n/a	**0.05**			
	Sminthuridae										**0.03**
Conchostraca							n/a				
Copepoda							n/a	**0.4**	**0.08**	**0.81**	**0.15**
Diptera	Ceratopogonidae						n/a				**0.03**
	Chironomidae							**0.2**	**0.39**	**0.06**	**0.18**
	Tipulidae										**0.03**
Hemiptera											
	Corixidae						n/a				**0.06**
	Gerridae								**0.08**		**0.14**
Hydracarina	Hydrodromidae										**0.03**
Mollusca							n/a				
Nematoda											**0.02**
Odonata							n/a				

Oligochaeta							n/a			**0.06**	
Oribatida	Hydrozetidae						n/a		**0.08**	**0.06**	**0.05**
Ostracoda							n/a				
Trichoptera							n/a				
Taxa per Site		**3**	**4**	**14**	**2**	**14**	n/a	**6**	**6**	**4**	**16**

* Collected at Beaton in August 2012 (Miller and Hawkes 2013)

6.0 DISCUSSION

The main objective of the 2013 CLBMON-11B4 surveys was to extend the existing baseline datasets (Hawkes et al. 2011, Fenneman and Hawkes 2012, Miller and Hawkes 2013) for aquatic macrophytes and macroinvertebrates at proposed wetland enhancement sites in the Arrow Lakes Reservoir (ALR). In 2013, the fourth implementation year of CLBMON-11B4, we continued pre-construction monitoring of Airport Marsh and Cartier Bay, as well as of Beaton Arm Beaver Ponds and Lower Inonoaklin Creek. Montana Slough, which previous years' work had shown to be relatively depauperate with respect to both aquatic macrophytes and macroinvertebrates, was not resampled in 2013 as physical works are no longer planned for this site.

The overall structure of macrophyte communities at these locations has remained generally stable over the monitoring period. The lentic vegetation at Cartier Bay is consistently dominated each year by the same four submergent species, namely, Eurasian Water-milfoil, Common Hornwort, Stonewort, and Small Pondweed. This same species assemblage also characterizes the submergent macrophyte community at Airport Marsh, although the relative dominance of species within the community differs somewhat between wetlands. For example, at Cartier Bay, these four species are encountered at a similar rate in point intercept samples (led slightly by Common Hornwort). At Airport Marsh, which supports a much higher species richness overall, Eurasian Water-milfoil is the most frequently encountered macrophyte species.

Airport Marsh also differs from Cartier Bay in supporting a greater abundance and variety of floating macrophyte beds, consisting of species such as Floating-leaved Pondweed and Water Smartweed. Similar floating macrophyte beds (but comprised mainly of Yellow Pond-lily) also predominate at the Beaton Arm Beaver Ponds. However, such beds are generally lacking at the Lower Inonoaklin Road site. Lower Inonoaklin Road, like Cartier Bay, experiences more rapid spring flooding than either Airport Marsh or the Beaton ponds, which are situated higher in the drawdown zone.

While the overall macrophyte community at Lower Inonoaklin Road remains poorly developed, the same is not true of Cartier Bay. At Cartier Bay, the fast rising ALR water levels during the spring growing season likely limits the establishment of floating macrophyte beds. Here, it appears the rooted stems cannot elongate quickly enough to keep pace with rising water levels, leaving the upper leafy portions of developing plants inundated (M. Miller, pers. obs.). Given this, we expect that one of the early effects of stabilizing early season water levels and extending the fall impoundment period through proposed physical works at Cartier Bay could be increased cover of floating vegetation mats.

Furthermore, changes in this vegetation component may ultimately be more pronounced than changes to the structuring of submergent stands.

Sampled wetlands varied somewhat with respect to physicochemical attributes; not surprisingly, however, differences tended to be most pronounced between the Beaton Arm Beaver Ponds (situated partially above and outside of the reservoir, and thus less exposed to its effects) and the in-reservoir sites (Cartier Bay, Airport Marsh, and Lower Inonoaklin Creek; Appendix 9-1). For example, while all wetlands sampled exhibited basic conditions (pH > 7.0), pH was consistently lower at the Beaton Ponds. Dissolved Oxygen (DO) levels also tended to be lower there, possibly reflecting a higher biological oxygen demand (BOD) associated with greater decomposition of organic matter in this more closed and stable system. At the local scale, results of exploratory multivariate analyses (RDAs) suggest that water physicochemical variables such as temperature, pH, conductivity, and dissolved oxygen explain very little (3.4%) of the variance in the distribution and local abundance of macrophytes at either Cartier Bay or Airport Marsh. Unless a stronger relationship is demonstrated between these variables and the occurrence rates of macroinvertebrates (an analysis which we have deferred until the next implementation year, when the available data set will be larger and more amenable to ordination analyses), there may be limited rationale for continuing to collect these data, at least during the pre-construction monitoring phase of the project.

As in 2012, the beaver ponds at Beaton Arm were the most diverse wetlands in the study area with respect to macroinvertebrates, followed by Airport Marsh. Together with true flies, copepods and water fleas were major constituents of the pelagic fauna at all four sites. For budgetary reasons, fewer macroinvertebrate samples were assayed in 2013 than in previous years, making quantitative comparisons among years and sites difficult. Despite the relatively limited sampling, several previously unreported taxa were added to the macroinvertebrate checklist for Revelstoke Reach as well for Beaton Arm and Lower Inonoaklin Road, implying that the number of recorded taxa is likely to increase with continued sampling.

As noted in Miller and Hawkes (2013), the implementation of physical works in Revelstoke Reach is expected to have a net positive effect on the aquatic macroinvertebrate fauna of Montana Slough, Cartier Bay, and Lower Inonoaklin Creek. This is because the proposed changes to existing shallow wetland habitat include (1) an increase in the spatial extent of these habitats, and (2) a stabilization of these habitats because they will not be influenced by reservoir operations to the current extent. With time, we would expect to see increased convergence in the composition of macroinvertebrate fauna at Cartier Bay, Lower Inonoaklin Creek, and Airport Marsh and, to a lesser extent, convergence between these sites and the Beaton Arm fauna. The expected changes in the structure of the aquatic macroinvertebrate fauna emphasize the need to continue monitoring this group following the implementation of physical work in Revelstoke Reach or mid- and lower Arrow Lakes Reservoir.

Prior to 2013, all sorting and identifying of macroinvertebrate samples was carried out in-house. In 2013, this task was subcontracted to a specialist who made useful recommendations for improving the current macroinvertebrate sampling protocol. Several of these recommendations are listed below:

- Preserve samples initially in 10% buffered formalin, then transfer to 95% ethanol until samples can be sorted.
- Instead of storing samples in Whirl-Paks (which can leak), use plastic (preferred) or mason jars.
- Avoid freezing samples prior to sorting, if possible.
- Focus pelagic sampling within a metre from the shoreline rather than in open water, as per guidelines in Jones et al. (2007), since that is where the highest concentrations of invertebrates tend to be. Boat sampling of the open water column may produce underestimates of taxa richness and abundance.
- For benthic sampling, consider employing the Travelling-Kick-and-Sweep method (Jones et al. 2007), which is typically applied by wading along transects through the habitat of interest, kicking the substrate to dislodge benthos, and collecting dislodged benthos by sweeping a hand-held net through the water.
- Conversely, when sampling for pelagic animals, strive to avoid disturbing the water column as much as possible prior to sweeping (a particular challenge when working from a boat). Also, consider using a larger net that can cover a wide area, to eliminate the need for multiple sweeps through the water. Since sweeping more than once disturbs the fauna causing it to move away from the sampling area, it is preferable to sweep the water column once quickly while cover as large an area as possible.

Prior to the next field season, we will review these recommendations along with the sampling protocols developed for the Ontario Benthos Biomonitoring Network (Jones et al. 2007) to identify potential improvement areas for the macroinvertebrate sampling methods currently being employed under CLBMON-11B4.

7.0 RECOMMENDATIONS

The following recommendations are based on the first four years:

1. Continue to collect physicochemical variables (temperature, pH, dissolved oxygen (DO), etc.), but to reduce sampling time, limit the collection of these variables to macroinvertebrate sampling locations.
2. Sampling should only be continued at sites that will be potentially affected by the implementation of physical works. For 2014 we recommend that sampling continue at Airport Marsh, Cartier Bay, and Lower Inonoaklin Creek. Beaton Arm should be dropped from the study because physical works are not proposed for this site.
3. Continue with mapping of the areal extent of macrophyte communities within study sites so that their growth or reduction can be monitored following the completion of the physical works projects.
4. Continue to gather depth data to improve the bathymetric maps produced for Airport Marsh and Cartier Bay (Fenneman and Hawkes 2012). The collection of

bathymetric data will continue to be a component of the study, and it is expected that the bathymetric maps for these sites will continue to improve as additional data are collected. Understanding the bathymetry of the wetlands will help to better define the boundaries of vegetation communities as well as allow for a more complete understanding of the physiological parameters of the wetlands.

8.0 REFERENCES

Alberta Environment. 2006. Aquatic ecosystems field sampling protocols. Environmental Monitoring and Evaluation Branch, Environmental Assurance Division. Edmonton, Alberta.

BC Hydro. 2000. Principles of water use planning for BC Hydro. BC Hydro Power Corporation, Burnaby, B.C.

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

BC Hydro. 2007. Columbia River project water use plan. BC Hydro Generation, Burnaby, B.C. Comptroller of Water Rights. 2007. Order under the Water Act (File No. 76975-35/Columbia), received by BC Hydro on 31 January 2007.

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

Fenneman, J.D., and V.C. Hawkes. 2012. CLBMON-11B4 Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Annual Report – 2011. LGL Report EA3234. Unpublished report by LGL Limited environmental research associates, Sidney, BC, for BC Hydro Generation, Water Licence Requirements, Burnaby, BC. 41 pp.

G3 Consulting Ltd. 2010. Revelstoke Reservoir macrophytes assessment program, phase I (baseline). Report prepared for BC Hydro and Power Authority, Surrey B.C.

Gelman, A. 2008. Scaling regression inputs by dividing by two standard deviations. Statistics in Medicine, 27: 2865-2873.

Golder Associates. 2009. Arrow Lakes Reservoir wildlife physical works feasibility study, phase II. Report prepared for BC Hydro and Power Authority, Castlegar, B.C.

Government of British Columbia. 1998. Water Use Plan guidelines. Province of British Columbia, Victoria, B.C.

Hawkes, V.C. and J. Howard. 2012. CLBMON-11B-. Wildlife effectiveness monitoring and enhancement area identification for lower and mid-Arrow Lakes Reservoir: mid- and lower Arrow Lakes Reservoir wildlife enhancement prescriptions. LGL Report EA3274. Unpublished report by LGL Limited environmental research associates, Sidney, B.C., for B.C. Hydro Generation, Water Licence Requirements, Burnaby, BC. 64 pp. + Appendices.

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

Hawkes, V.C. and K.N. Tuttle. 2010. CLBMON-37 Kinbasket and Arrow Lakes Reservoirs: Amphibian and Reptile Life History and Habitat Use Assessment. Annual Report – 2009. LGL Report EA3075. Unpublished report by LGL Limited environmental research associates, Sidney, B.C. for BC Hydro Generations, Water Licence Requirements, Castlegar, B.C.

Jones, C., K.M. Somers, B. Craig, and T.B. Reynoldson. 2007. Ontario Benthos Biomonitoring Network: Protocol Manual. Ontario Min. of Environment, Environmental Monitoring and Reporting Branch. 109 pp. Available online: http://www.saugeenconservation.com/download/benthos/2009/OBBN%20Protocol%20Manual.pdf

Legendre, P. and E. Gallagher. 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129: 271-280.

Legendre, P. and L. Legendre. 2012. Numerical Ecology, Developments in Environmental Modelling, Third English Edition. Elsevier, Amsterdam.

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

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

Rosenberg, D.M. 1998. A National Aquatic Ecosystem Health Program for Canada: We should go against the flow. Bull. Entomol. Soc. Can. 30(4):144-152.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry: the principles and practices of statistics in biological research. 3rd edition. New York, 887 pp.

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

Zar, J.H. 1999. Biostatistical analysis. 4th edition. Prentice Hall, Upper Saddle River, NJ.

9.0 APPENDICES

Appendix 9-1 Selected physicochemical attributes for Cartier Bay, Montana Slough, Airport Marsh, Beaton Beaver Ponds, and Lower Inonoaklin Creek recorded during spring (May/June) sampling sessions in 2011, 2012, and 2013: mean (SD) pH, conductivity, dissolved oxygen, temperature, water depth, and Secchi depth

	pH			Conductivity (µS)			Dissolved Oxygen (mg/L)			Temp. (°C)			Water depth (cm)			Secchi (cm)	
Site	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**	**2012**	**2013**
Cartier Bay	8.50 (0.38)	n/a	8.81 (0.39)	203.2 (59.5)	106.4 (14.1)	114.1 (8.5)	9.32 (1.90)	9.24 (0.34)	11.82 (1.40)	19.5 (1.4)	14.3 (1.3)	17.2 (1.7)	101 (59)	161 (66)	182 (53)	80 (16)	195
Montana Slough	8.29 (0.10)	8.0 (0)	n/a	183.0 (17.1)	106.3 (4.7)	n/a	9.51 (0.21)	9.76 (0.40)	n/a	18.1 (1.8)	13.5 (0.4)	n/a	289 (210)	220 (128)	n/a	154 (40)	n/a
Airport Marsh	8.09 (0.39)	8.54 (0.45)	8.62 (0.45)	106.5 (67.9)	101.4 (14.9)	115.8 (32.6)	7.45 (1.94)	8.69 (1.32)	10.09 (0.71)	18.8 (1.5)	18.9 (1.7)	18.9 (1.5)	100 (90)	109 (92)	82 (73)	123 (75)	147 (80)
Beaton Beaver Ponds	n/a	7.67 (0.15)	7.50 (0.26)	n/a	73.0 (17.1)	72.7 (15.7)	n/a	6.80 (0.76)	7.22 (1.57)	n/a	17.3 (1.9)	17.2 (0.8)	n/a	n/a	n/a	n/a	n/a
Lower Inonoaklin Ck.	n/a	n/a	7.93 (0.27)	n/a	n/a	n/a	n/a	9.06	n/a	n/a	19.7	16.1 (0.4)	n/a	n/a	71 (27)	n/a	50 (10)