Columbia River Project Water Use Plan

KINBASKET AND ARROW LAKES RESERVOIR REVEGETATION MANAGEMENT PLAN

Reference: CLBMON-11B4

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

Study Period: 2011

LGL Limited
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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

During the development of the Columbia Water Use Plan, BC Hydro agreed to undertake physical works projects to benefit wildlife in Revelstoke Reach in lieu of altering reservoir operations. A total of 42 such projects were identified, and it was recommended that long-term monitoring be undertaken in order to assess the effectiveness of these physical works projects at increasing wildlife use of the drawdown zone. To date, although numerous wildlife and vegetation monitoring studies have been initiated throughout the reservoir system, none of these projects has been specifically designed to monitor the impacts of reservoir operations and physical works projects on wetland habitat within the drawdown zone.

As a result, 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 Water Use Plan. The mandate of this project included the following components: (1) develop a monitoring program to assess the effectiveness of wildlife physical works projects (CLBWORKS-30) at enhancing wetland and riparian habitat in Revelstoke Reach, (2) monitor the appropriate physical parameters and biological response variables to assess the effectiveness of the wildlife physical works projects at enhancing wildlife habitat in Revelstoke Reach, (3) assess the effectiveness of wildlife physical works projects at enhancing wetland and associated riparian habitat at both the site and landscape level, and (4) provide recommendations based on the results of the monitoring program to improve wetland enhancement techniques.

Wetland productivity, structure and function are considered to be important attributes for assessing habitat condition for wildlife species that use littoral habitats within the drawdown zone. The primary metrics used to monitor changes in these wetland attributes are the presence, distribution, abundance and diversity of macrophytes and aquatic invertebrates. Secondary metrics of interest include hydrological and physicochemical parameters such as water depth, water temperature, substrate, pH and turbidity. The main objective of sampling, which will be done repeatedly at the same locations over multiple years, will be to obtain information on the response of aquatic macrophyte and invertebrate communities to implemented physical works that increase in the extent of shallow water wetlands in Revelstoke Reach.

A BACI-style sampling design was chosen for this study, with the 2011 season representing the Before component of the study design. The primary goal for the 2011 season was to provide baseline data on wetland vegetation and invertebrate communities against which data collected after the completion of the physical works projects can be compared. Additionally, this season provided a second opportunity to test the proposed survey and monitoring methodology that had been developed in 2010. This report is highly descriptive - it describes the diversity and relative abundance/density of aquatic and emergent (and some terrestrial) vegetation communities at each of three study sites, as well as the associated pelagic and benthic invertebrate communities. In total, 80 sampling points were visited during the 2011 sampling sessions: 60 during the May/June session and 57 during the August session (37 of these sites were visited in both sessions). Comparison of the results from these two survey sessions allowed for

testing of the methodology to ensure that it could detect changes in measured variables.

Differences detected in some of these communities between the May/June and August sampling sessions in 2011 suggest that the chosen methodology for this monitoring program is adequate for detecting community level changes in both the macrophyte and invertebrate communities. As such, this methodology (with some minor improvements/alterations) can be incorporated into future sampling sessions with the expectation that notable (>25 per cent) community level changes that occur following the completion of the physical works projects will be detectable.

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

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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, and as such, there is an expectation that wetland productivity will improve in these areas over time. Nevertheless, the possibility that the proposed projects will have the undesired consequence of lowering productivity in some of the existing shallow productive habitat must also be considered. 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.

The monitoring of wetlands in Revelstoke Reach of Arrow Lakes Reservoir stems from the need to determine the trajectory of change within areas enhanced through physical works. In general, physical works prescriptions can be active or passive. A passive approach relies exclusively on the forces of nature to enhance and repair disturbed ecosystem functions, while an active approach, such as the implementation of physical works, requires physical alterations to the landscape. A general model for ecosystem state (Figure 1-1) is one way to visualize the effects of physical works on an ecosystem (Thom 1997). First, it is assumed that there is a positive relationship between the structure[1] and function[2] of an ecosystem (Johnson et al. 2003). Next, the system condition on both axes is divided into subjective categories based on existing function and structure in order to acknowledge two sources of uncertainty: (1) the inability to accurately quantify the relationship between structural and functional ecosystem components, and (2) the inability to accurately predict the dynamic nature of regular periodic and stochastic natural variability associated with structural conditions and functional conditions (Shreffler and Thom 1993; Hobbs and Norton 1996; Johnson et al. 2003). The three levels along each axis are qualitative indicator variables (e.g., square metres) related to the structural condition (e.g., the size of the pond-wetland interface) and the functional conditions (e.g., the spatial extent of natural ecological communities). Therefore, an ecosystem under optimal or enhanced conditions of structure and function can have values that vary over a predictable range because of natural dynamics. Given the stresses placed on wetland ecosystems within the drawdown zone of Arrow Lakes Reservoir through annual inundation, it is not anticipated that any of the monitored wetlands would achieve either optimal function or climax structure but, rather, these would be maintained at an intermediate level into perpetuity (presuming that current reservoir operations are maintained).

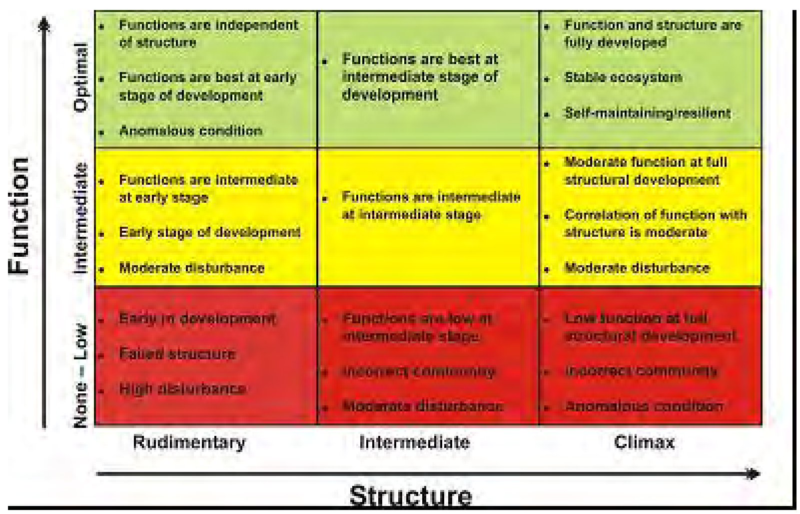

Figure 1-1: Generalized system-development matrix showing the nine states a restored ecosystem can occupy during development (modified from Thom 2000). Cells in red represent undesired conditions; yellow: acceptable condition; green: desired condition

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

[1] Ecosystem structure is defined as the types, distribution, abundances and physical attributes of the plant and animal species comprising the ecosystem.
[2] Ecosystem function is defined as the role the plant and animal species play in the ecosystem, including primary production, prey production, refuge, water storage, nutrient cycling, etc.

wildlife. Data collection associated with 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 2010 and 2011 surveys 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 2011 surveys allowed for an 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 focal 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 objective is 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), is also under consideration for habitat enhancement projects (Golder Associates 2009). No physical works are proposed for Montana Slough at this time. However, because this wetland provides important habitat for many types of wildlife, including turtles and waterfowl, the site will be monitored along with the other sites to obtain baseline data should physical works be implemented in the future. Use of this site as a control for other sites is not desirable given the unique physiochemical and biological conditions that are present at the site and which are very different from those present at the other monitoring sites.

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 qualitative declines in overall habitat conditions as measured by indicator habitat elements (e.g., water depth and turbidity) over 10 years.
3. No measurable signs of erosion over 10 years.

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. Creation of at least 1 ha of new wetland habitat at Site 14 within one year, and measurable increase of at least 10 per cent in the areal extent ((hectares or square metres) of the existing shallow wetland habitat at Site 15A within one year following the implementation of the physical works.
2. Measurable increase in wetland productivity:
    a. Successful natural establishment or 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.
3. 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.
4. 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.
5. 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 (Figure 2-1). 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. Although the protocol for monitoring physical works implemented in Revelstoke Reach is being developed, it could be applied to physical works proposed for mid- and lower Arrow Lakes where wetland enhancement or creation is the objective (i.e., CLBWORKS-29B).

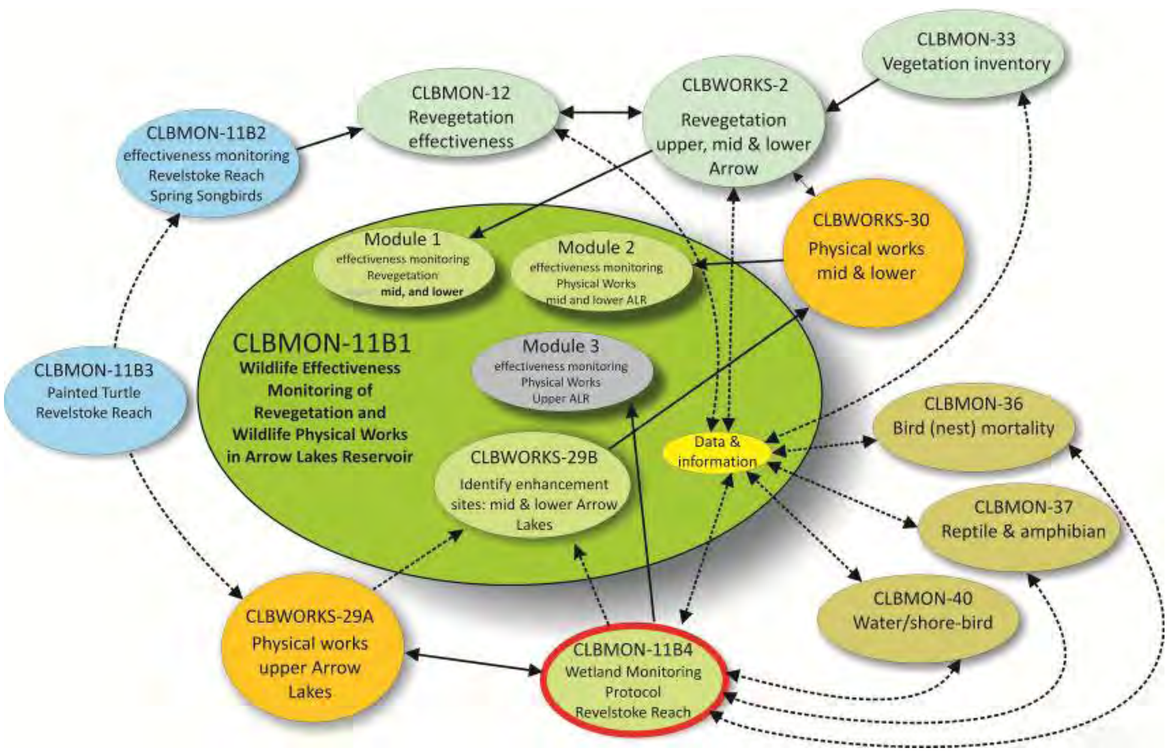

Figure 2-1: The relationship of CLBMON-11B4 (outlined in red) to other physical works and wildlife monitoring projects in Arrow Lakes Reservoir. Direct linkages between relevant projects are shown as solid lines; information flow (e.g., data sharing) is indicated by dashed lines. Module 3 of CLBMON-11B1 has yet to be implemented, and Module 1 of CLBMON-11B1 applies only to mid- and lower Arrow Lakes Reservoir

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 ~2000 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 and 3-2), 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.

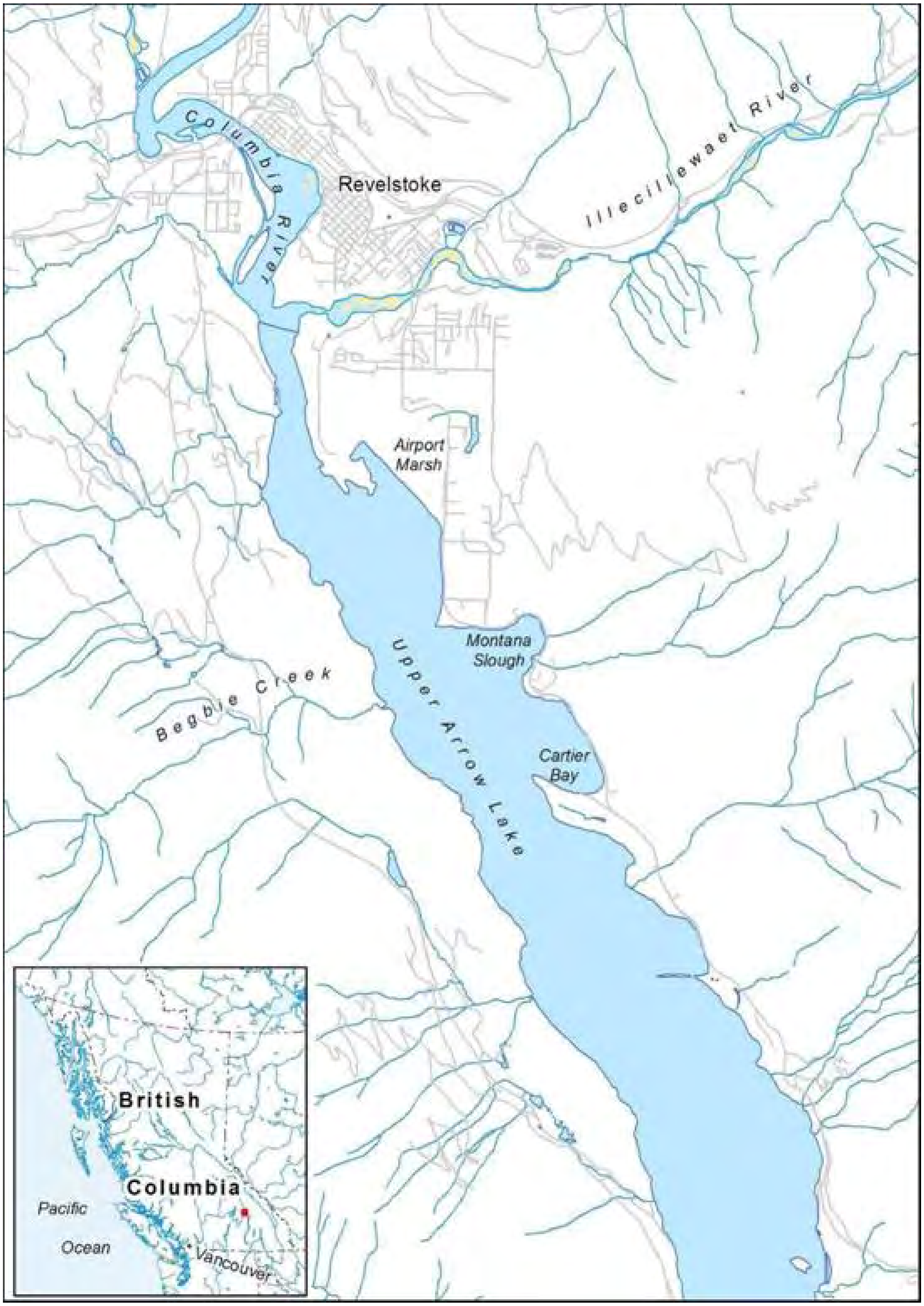

Figure 3-1: Location of Airport Marsh, Montana Slough and Cartier Bay in Revelstoke Reach, Arrow Lakes Reservoir

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[3]-style study design and that any comparisons made between data sets are valid.

[3] BACI: Before-After Control-Impact

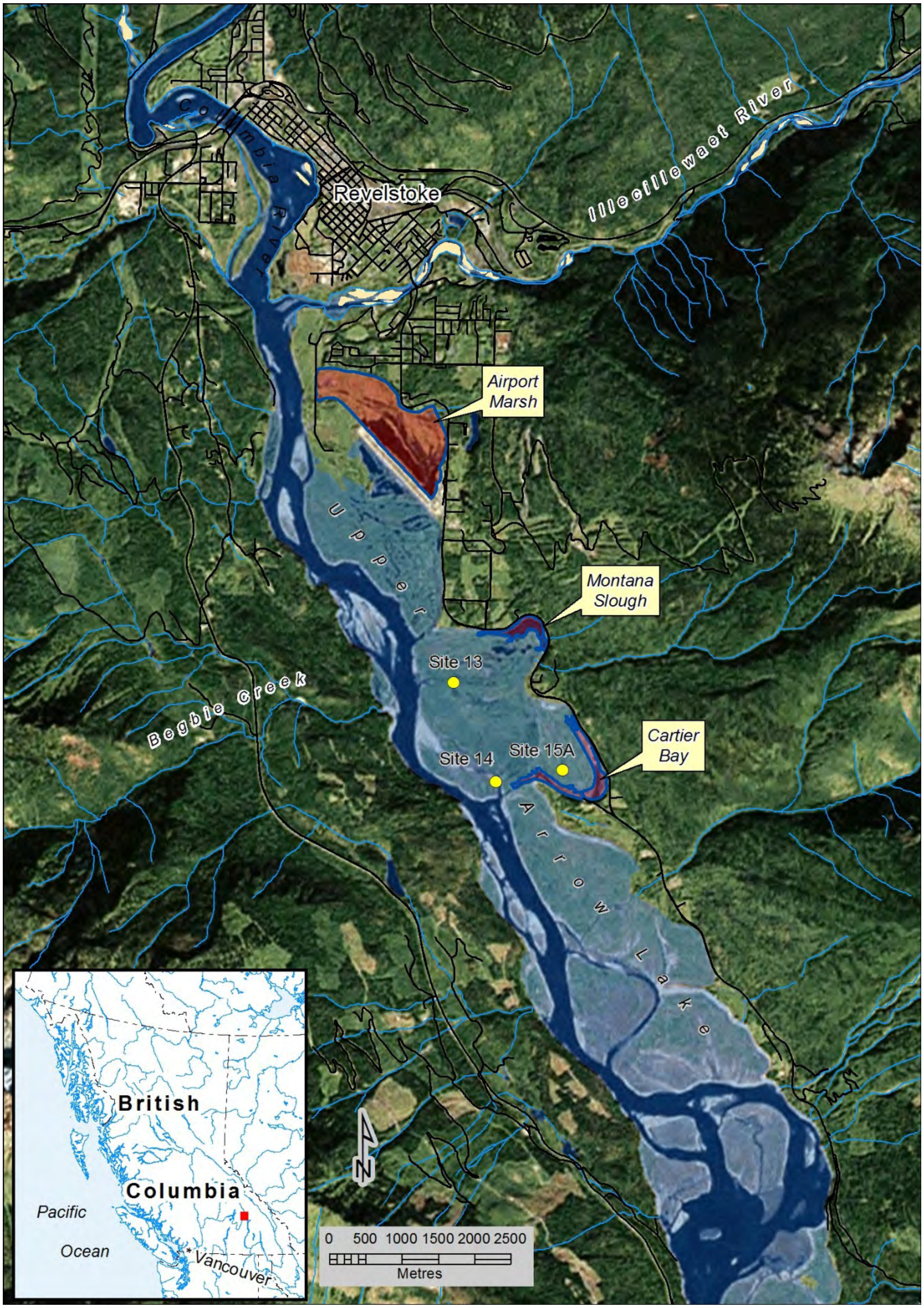

Figure 3-2: Location of proposed wildlife physical works in Revelstoke Reach. The focus of work in Years 1 and 2 (2010 and 2011) was on Site 14, 15A, and 13, or more specifically on Montana Slough, Cartier Bay and Airport Marsh

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 be expected to drain almost completely of water, severely impacting the wetland community that is established there.

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 Montana Slough

No physical works are proposed for Montana Slough at this time. However, because Montana Slough provides important habitat for many species, including Painted Turtles (see Hawkes and Tuttle 2010) and waterfowl, it is necessary to obtain baseline data in the event that physical works are planned and subsequently implemented.

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.

4.1 Study Design

The study design for CLBMON-11B4 follows a traditional BACI-style design (Before-After Control-Impact) which is designed to evaluate whether or not a stress has changed the environment, to determine which components are adversely affected, and to estimate the magnitude of the effects (Smith 2002). In the case of CLBMON-11B4, the "stress" that is being investigated is the effects of the physical works projects on wetland habitats in the drawdown zone of Revelstoke Reach, whether they be designed to retain water at its existing level in the wetlands of interest or rather to flood new areas and create additional wetland habitat that did not exist prior to the physical works.

The BACI study design of CLBMON-11B4 uses ecological data on aquatic macrophytes, aquatic invertebrates, and wetland physiochemistry collected before the implementation of the physical works projects (the "Before" component) and uses this information as a baseline against which to compare the conditions of these same parameters in the years following completion of the physical works projects (the "After" component). Airport Marsh, which is situated high in the drawdown zone, receives relatively minimal annual inundation from the reservoir, and has a much more complex and well-developed wetland community, is suitable as a "Control" wetland for this study, against which to compare the ecological conditions that are detected at the "Impact" wetlands (Cartier Bay, Montana Slough). Wetlands that occur above the drawdown zone, and are thus not impacted by reservoir activities at any time of year, are considered less desirable to use as controls as the conditions that exist at these sites could never be replicated within the drawdown zone.

Sampling in 2011, which represented the second year of the "Before" component of the study, was completed during two separate field sessions: late May/early June and August. This was implemented for two reasons. First, sampling before (May/June) and after (August) the annual inundation of the wetlands by the Arrow Lakes Reservoir enabled an assessment of the sensitivity of the proposed methodology to detect changes in the ecological conditions that were present at the site. Second, sampling early and late in the growing season allows for the detection of a higher diversity of species due to differing species phenologies (i.e., some species are more easily detectable early in the season but not later, and vice versa).

4.2 Selection of Sampling Sites

Site selection was based on the sites identified for physical works by Golder Associates (2009) and the potential to use sites like Airport Marsh as a reference site. All monitoring locations were in Revelstoke Reach; two were in the drawdown zone of Arrow Lakes Reservoir. Hawkes et al. (2011) recommended that each site be stratified based on broad categories of habitat (e.g., emergent vegetation, open water, submergent vegetation), and that a power analysis be used to determine the minimum number of samples required to achieve statistical power of 0.80 assuming a measureable effect size of 0.25 (i.e., 25 per cent change in shallow wetland area or a 25 per cent change in the indices being measures). Using these criteria, we determined that 30 sampling locations should be sampled in Cartier Bay, 20 in Montana Slough, and 40 in Airport Marsh. Site 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 30, 20, or 40 sites. All grid work and site selection was done using ArcMap 9.3.1 and 10. An example of this process is provided in Figure 4-1.

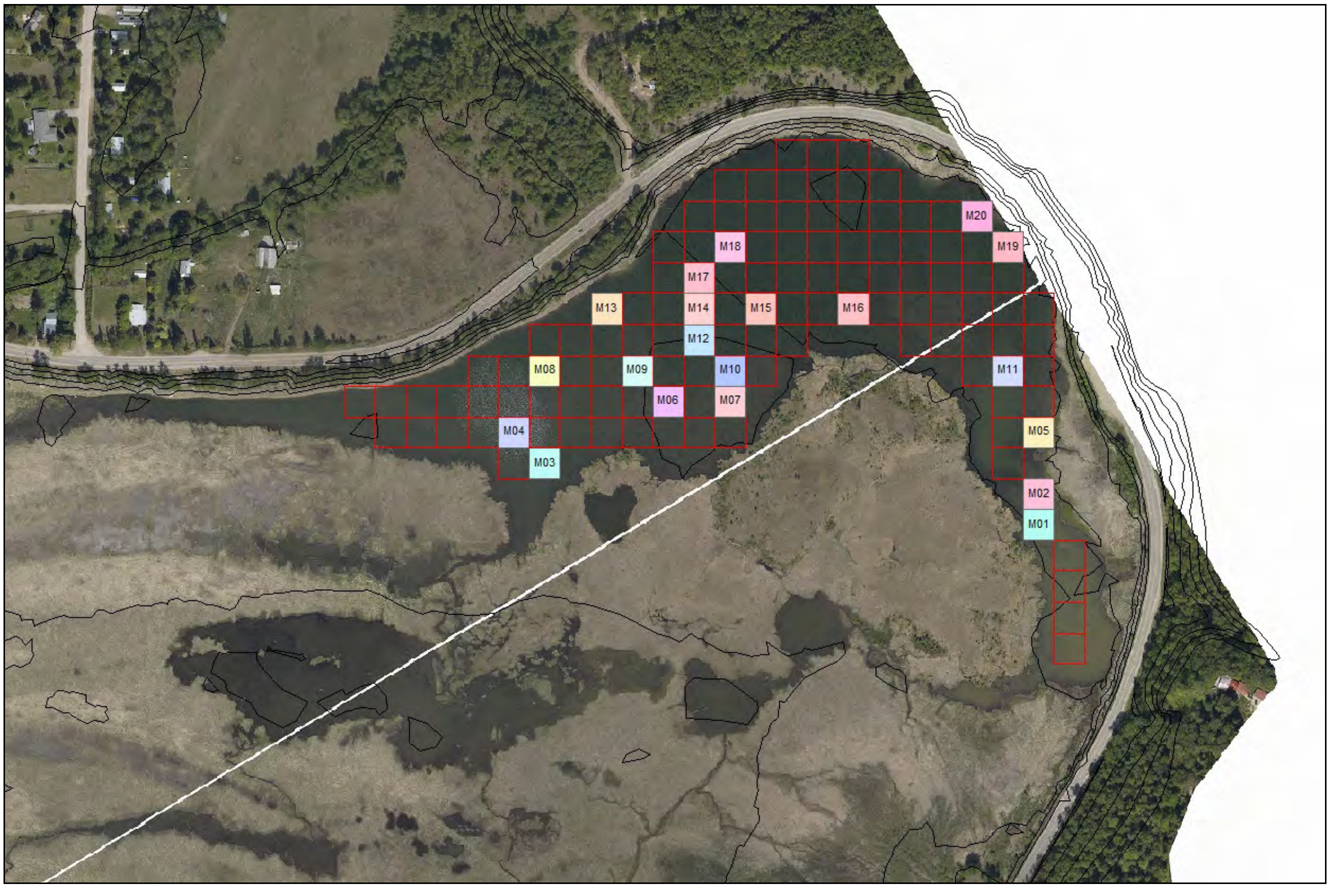

Figure 4-1: Example of the site selection process used for Montana Slough. Grid cells entirely within Montana Slough are shown in red. Coloured cells with alphanumeric labels indicate cells that were randomly selected through GIS

This process was repeated for all three study sites, and a list of UTM coordinates representing the centre of each randomly selected grid cell was generated.

4.3 Aquatic Macrophyte Sampling

Submergent and floating vegetation were sampled using a double-headed rake approach, 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 multiple replicate samples (in this case, two samples) were taken at each sample 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 frequency (“cover”) of each macrophyte species in the sample (Table 4-2).

In addition to determining the relative abundance of plant species at the study sites, the vegetation samples that were collected with the submergent and floating communities were retained for an assessment of the biomass at these sampling points. Biomass samples (which constituted the entire vegetation sample at a given sampling location) were collected at the first sample point at a given site, as well as 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 accurately ("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

4.4 Emergent and Terrestrial Vegetation Sampling

Emergent and terrestrial plant communities within or adjacent to the physical works sites were sampled using 0.75 cm x 0.75 cm (0.5 m2) quadrats in which four quadrats were sampled around each sampling point. The per cent cover of each species was recorded within each of the four quadrats at each sampling location. In addition, the per cent cover of "thatch" (the decayed remains of the previous year's plant growth, usually in reference to Reed Canarygrass [*Phalaris arundinacea*] stems and leaves) was recorded at terrestrial sites. For analysis, data collected from these four quadrats were pooled for each sampling point, and the per cent cover of both live vascular plants and thatch was averaged among the four quadrats.

4.5 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 WhirlPac with ethanol (70 per cent concentration) for preservation. For benthic species, the Ponar grab 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. Note that, under certain conditions, such as on harder substrates, the grab was unable to sample the full 2.4 L; however, because the 2011 sampling was interested only in the presence/absence of various invertebrate taxa in the benthic samples rather than actual abundance (see below), recording the volume of each entire sample was not necessary. Once removed from the water, the sediment sample was strained using a fine-meshed (0.4 mm) dip net as a sieve, and the resulting sample (primarily organic matter) was transferred to a WhirlPac with an ethanol preservative. Both the epipelagic and benthic samples were stored in refrigerated conditions until they could be analyzed following the completion of the field sessions.

The samples were sorted under a dissecting microscope, and the abundance of macroinvertebrates (insects, insect larvae, snails) and microinvertebrates (cladocerans, ostracods, freshwater mites) was recorded for each epipelagic sample. For benthic samples, a subsample of ~1 cm^3 was sorted because the size of the samples (2.4 L) was not conducive to a complete analysis. Each taxon was attributed to an abundance class for epipelagic samples (Table 4-3), but only their presence/absence was noted for the benthic samples due to the difficulty in accurately estimating abundance in the samples as a result of the rapid decomposition of some of the smallest organisms (particularly when the sample contained too much water, thus diluting the ethanol preservative) as well as the difficulties inherent in attempting to accurately count sub-millimeter organisms within a matrix of decomposed organic material.

Table 4-3: Abundance classes for macro- and microinvertebrates in epipelagic samples

Abundance Class	Definition
1	Only one individual present in the sample
2	2–20 individuals present in the sample
3	21–100 individuals present in the sample
4	100+ individuals present in the sample

4.6 Assessment of Abiotic Conditions

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
- Turbidity: the relative clarity of the water was assessed as clear or cloudy to give an indication of relative turbidity
- 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

4.7 Data Analyses

The analysis of aquatic macrophyte data required the derivation of a metric that considered both the per cent cover and volume of each species sampled at each sampling site and in each month. To derive this value we multiplied the volume value and the relative abundance value estimated for each species at each location to produce a single numeric value representing the overall abundance of the species at each sampling point. Numerical values were assigned to each volume and cover class as follows:

Volume Code	Value	Cover Code	Value
1	0.25	T	0.1
2	0.5	1	5
3	0.75	2	15
		3	37.5
		4	62.5
		5	87.5

Difference in the volume x cover metric were summarized through box plots (Massart et al. 2005). Box plots display the differences between groups of data without making any assumptions about their underlying statistical distributions and show their dispersion and skewness (Massart et al. 2005). Boxes represent between 25 per cent and 75 per cent of the ranked data. The horizontal line inside the box is the median. The length of the boxes is their interquartile range (Sokal and Rohlf 1995). A small box indicates that most data are found around the median (small dispersion of the data). The opposite is true for a long box: the data are dispersed and not concentrated around the median. Whiskers are drawn from the top of the box to the largest observation within 1.5 interquartile range of the top, and from the bottom of the box to the smallest observation within 1.5 interquantile range of the bottom of the box.

Monthly differences in the volume x cover metric were tested using multiple one-way ANOVAs. A Bonferonni correction was used to control for the effects of multiple testing.

Seasonal differences (i.e., spring and summer) in species richness (q), diversity (H) and evenness (J) were assessed for each wetland sampled. Species richness was defined as the number of species occurring in each wetland. Diversity was computed as Shannon's entropy and corresponded to a measure of species composition, combining both the number of species and their relative abundances (Legendre and Legendre 1998). For each transect, diversity was computed as:

$$H = -\Sigma (p_i \log p_i)$$

where pi is the relative proportion of species i.

A value of 0 means that the sampling unit contains only one species; H then increases along with the number of species recorded in the sampling unit. A high value of H means that many species were recorded. The diversity value calculated by Shannon's entropy index (H) does not indicate how the species of vegetation are distributed within the transects established in each vegetation community. To determine the distribution of species by transect, vegetation community and landscape unit, Pielou's evenness was computed (Pielou 1966):

$$J = H/H_{max} = (-\Sigma (p_i \log p_i))/\log q$$

where q is species richness.

The more J tends towards 1, the more evenly the different species are distributed; conversely, a value close to zero means that one or more species are dominating the community (i.e., the distribution is uneven).

Using both diversity and evenness indices together provides insight into the composition of the existing communities and revegetated areas, as well as the distribution of species within the plots. For example, the diversity of a plot could be high, but its evenness index low, suggesting that although the plot has a high diversity of species of vegetation, one or two are dominating and the other species occur infrequently (interspecific competition is high). However, the same high diversity index combined with a high evenness index would mean that the plot has a diversity of vegetation species that are equally frequent (interspecific competition is low).

5.0 RESULTS

Table 5-1 shows the aquatic macrophyte (submergent and floating) species detected at each of the three study sites during the 2011 field sessions. Airport Marsh, with nine species, supported the highest diversity of aquatic macrophyte species, while Montana Slough, with only four species, supported the lowest diversity. Other species are likely present in the system and may be encountered during future surveys.

Table 5-1: Aquatic macrophyte species recorded in each of the three physical works areas of Revelstoke Reach (Airport Marsh, Montana Slough, Cartier Bay) during the 2011 survey

Species	**Species Code**	**Airport Marsh (Site 6A)**	**Montana Slough (Site 13)**	**Cartier Bay (Site 15A)**
Eurasian Water-milfoil (*Myriophyllum spicatum*)	MYRI SPI	X	X	X
Common Hornwort (*Ceratophyllum demersum*)	CERA DEM	X	X	X
Richardson's Pondweed (*Potamogeton richardsonii*)	POTA RIC	X		X
Small Pondweed (*Potamogeton pusillus*)	POTA PUS	X	X	X
Eel-grass Pondweed (*Potamogeton zosteriformis*)	POTA ZOS	X		X
Floating-leaved Pondweed (*Potamogeton natans*)	POTA NAT	X	X	
Water Smartweed (*Persicaria amphibia*)	PERS AMP	X		
Greater Bladderwort (*Utricularia macrorhiza*)	UTRI MAC	X		X
Stonewort (Algae) (*Chara* sp.)	CHARA	X		X

5.1 Cartier Bay

Nineteen sampling locations were visited in Cartier Bay on May 29–30, when the reservoir elevation was at ~433 m ASL. At this point, the reservoir had not yet started to inundate Cartier Bay, so the data collected are representative of the pre-inundation conditions. Individual sampling locations were distributed randomly throughout the water body (Figure 5-1). A 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 as well as preliminary bathymetric data from 2010. Water depths at the sampling locations ranged from 0.17 to 2.25 m. The lower (westernmost) reaches of the wetland, closest to the Columbia River, were the deepest areas and had the lowest cover of aquatic macrophytes, while upper reaches were shallower and had extensive cover of aquatic vegetation. Fifteen sampling locations were visited on August 3 (11 of the same sites sampled during the May session, plus four additional sites), when the reservoir elevation was at ~439 m ASL.

In addition to the 19 aquatic sampling locations, six locations outside of the current delineated wetland boundary of Cartier Bay were sampled during the May sampling session. Four of these were revisited in August, with two additional such sampling locations that had not been visited in May also sampled during this second field session. During the August field session, all of these sampling locations were fully inundated by the reservoir. These sampling locations (the six that were sampled in May plus the two additional sites that were sampled in August) supported largely terrestrial vegetation (dominated by Reed Canarygrass [*Phalaris arundinacea*] and Columbia Sedge [*Carex aperta*]). Some isolated pools and ponds were present within this area as well, one of which was incorporated into the sampling. These sampling locations are situated in areas that would be inundated if the physical works project results in the raising of the dike by an additional 1 m over what had initially been planned.

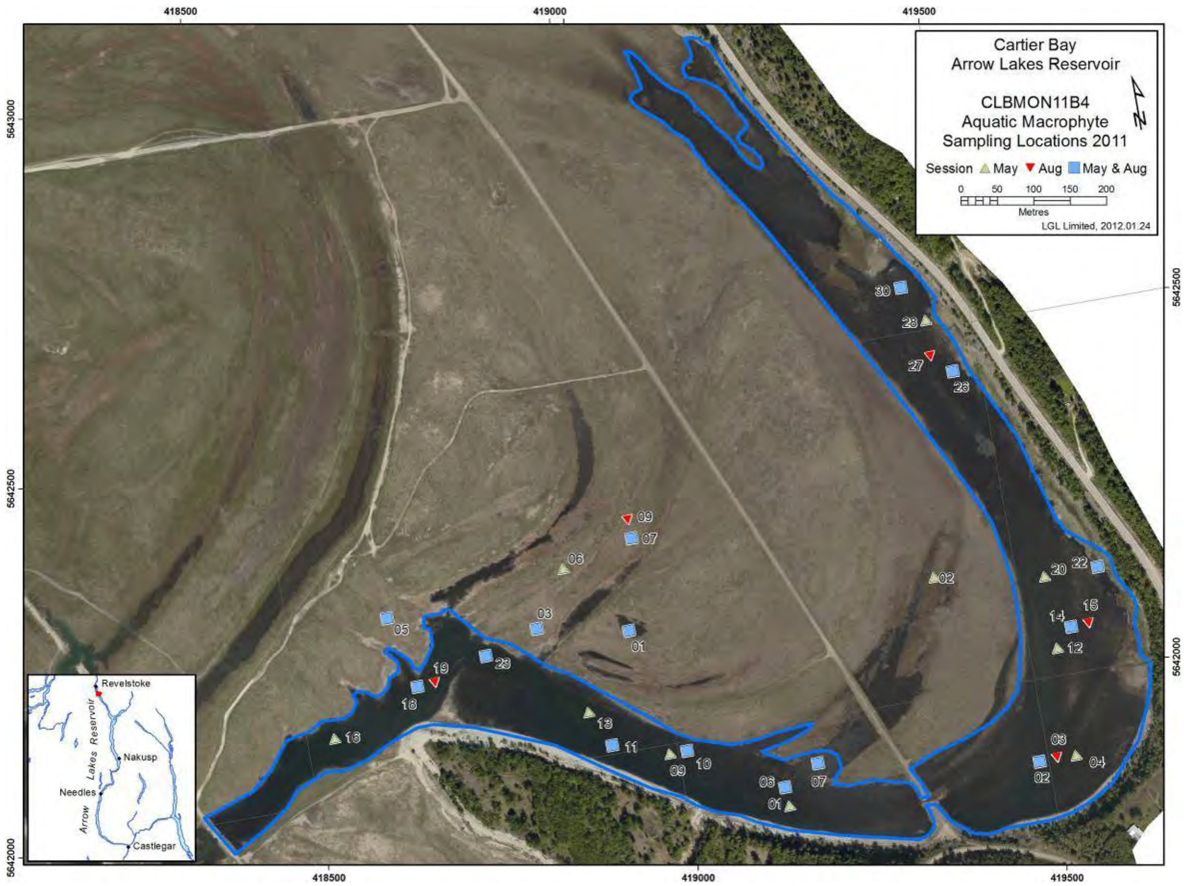

Figure 5-1: Distribution of samples in Cartier Bay in 2011, May and August sessions. Sampling points outside of the blue wetland boundary represent terrestrial plots (see Section 5.1.2)

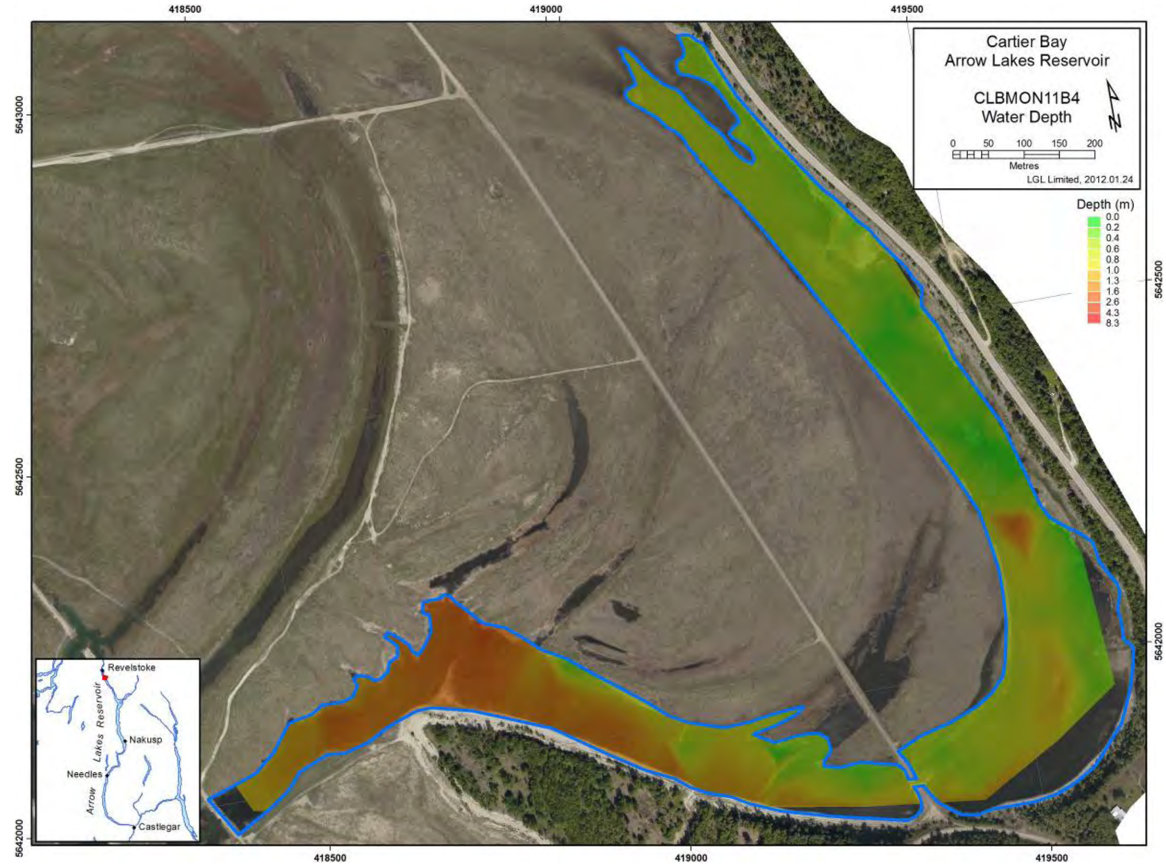

Figure 5-2: Bathymetric map of Cartier Bay, based on water depths collected in 2011 and augmented with depths collected in 2010. Only pre-inundation (May) water depths were used from the 2011 data

5.1.1 Aquatic Macrophytes

Aquatic macrophytes were found at high densities and moderate diversity (seven species; Table 5-1) at Cartier Bay relative to both Airport Marsh and Montana Slough. Aquatic macrophytes were detected at all 19 sample points visited during the May field session and at 12 of 15 points visited during the August field session. Biomass values for the May field session were higher than those in the other sites sampled (Airport Marsh, Montana Slough; Table 5-2). During May, Common Hornwort (*Ceratophyllum demersum*) and stonewort (*Chara* spp.) overwhelmingly dominated the aquatic habitats of Cartier Bay (Figure 5-3), and tended to occur at high densities and with few other species present. Pondweeds, such as Eel-grass Pondweed (*Potamogeton zosteriformis*) and Small Pondweed (*P.pusillus*), typically occurred at lower densities than either hornwort or stonewort, although Small Pondweed often formed a relatively continuous “lawn” beneath the canopy of these species. Eurasian Water-milfoil occurred at relatively low densities and was typically scattered among other more abundant species. Curiously, although water-milfoil was the dominant species at this wetland in 2010 (Hawkes et al. 2011), most of the plants did not reappear in 2011, which allowed for a greater profusion of native species.

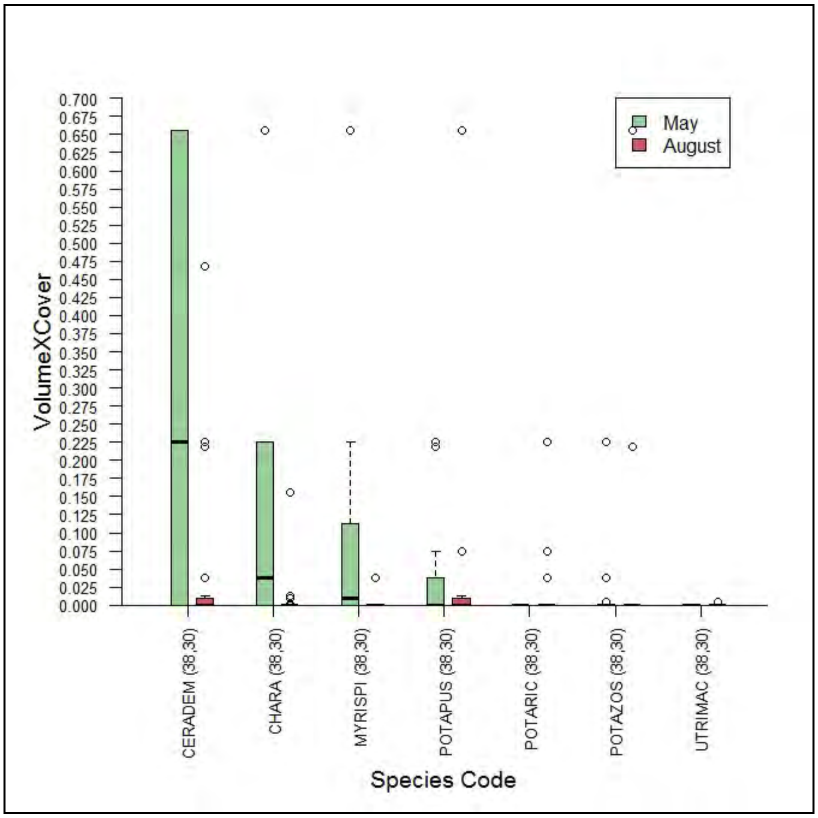

Figure 5-3: Changes in the abundance of aquatic macrophytes at Cartier Bay between May and August 2011. See Section 4.7 for an explanation of the Volume x Cover metric that is used to represent abundance. See Table 5-1 for species codes. The numbers following the species codes represent the number of samples for May and August, respectively

Despite an obvious change in the abundance of aquatic macrophytes observed in Cartier Bay between spring and summer (Figure 5-3), seasonal species richness, diversity, and evenness values were similar (spring: q = 5; H = 0.68; J = 0.98; summer: q = 7; H = 0.73; J = 0.86). This suggests that increasing reservoir elevations impact species abundance more than species richness, diversity, and evenness; however, it is not currently known if these effects are representative of a typical year and more data are required.

In contrast to the May field session, the density/biomass of aquatic macrophytes was lower during August following inundation of the wetland by the rising reservoir water level (Table 5-2; Figure 5-3). The water level rose by 6 m between May and August, which appeared to have resulted in some mortality of aquatic macrophytes. For example, the mean biomass (dry weight) of vegetation samples (Table 5-2) declined ~90 per cent from 36.6 g (SD = 19.6) in May to 3.3 g (SD = 4.8) in August. This was mirrored in the estimates of vegetation sample volume that were recorded at each sampling location (scale = 1 to 3; see Table 4-1 for definitions of the three volume classes), with the mean sample volume falling from 2.7 (SD = 0.6) in May to 1.2 (SD = 1.2) in August. The abundance of the four dominant aquatic macrophytes declined sharply between May and August, and the declines of Common Hornwort (CERADEM), Stonewort (CHARA), and Eurasian Water-milfoil (MYRISPI) were statistically significant at α = 0.1 (CERADEM: $F_{1,66} = 15.2$; $p < 0.001$; CHARA: $F_{1,66} = 23.8$; $p < 0.001$; MRYISPI: $F_{1,66} = 8.5$; $p = 0.004$).

Conversely, perceived lower vegetation densities may have partially been an artifact of the increased water depth because the sampling methodology used (two-headed rake) was less effective at sampling vegetation in deeper water (> 3 m). Nonetheless, the striking reduction in the biomass of aquatic vegetation between May and August suggests that reservoir inundation did negatively affect the growth and persistence of these plants. In addition to the changes in biomass, the vegetation in August was less strongly dominated by Common Hornwort and stonewort than it was in May, the relative abundance of all plant species was distributed more evenly, and no species overwhelmingly dominated the vegetation community. Two additional species (Greater Bladderwort [*Utricularia macrorhiza*] and Richardson's Pondweed [*Potamogeton richardsonii*]) were detected in August, although these scarce species were likely present during May but were not captured during sampling.

Table 5-2: Biomass of aquatic macrophytes at various sampling locations within Cartier Bay during the May and August sampling sessions. Note that depths presented for August sampling were taken after inundation of the wetland by the reservoir, and are therefore not comparable with those presented for May

Sample Point	Sampling Session	Depth (cm)	Sample Wet Weight (g)	Subsampled?	Subsample Wet Weight (g)	Subsample Dry Weight (g)	Total Dry Weight (g)
C02	May	89	507.5	Y	172.5	16.5	**48.5**
C07	May	53	107.5	N	n/a	n/a	**20.8**
C10	May	99	225.0	N	n/a	n/a	**37.0**
C20	May	99	857.5	Y	170.0	13.8	**69.4**
C23	May	225	210.0	N	n/a	n/a	**25.3**
C30	May	44	180.0	N	n/a	n/a	**18.5**
C02	Aug	602	19.8	N	n/a	n/a	**1.7**
C03	Aug	592	0.1	N	n/a	n/a	**0.03**
C10	Aug	635	113.0	N	n/a	n/a	**12.2**
C11	Aug	685	121.0	N	n/a	n/a	**9.5**
C15	Aug	565	0.8	N	n/a	n/a	**0.06**
C19	Aug	735	16.5	N	n/a	n/a	**2.4**
C22	Aug	530	0.3	N	n/a	n/a	**0.04**
C30	Aug	550	0.7	N	n/a	n/a	**0.07**

5.1.2 Terrestrial Vegetation

This section includes results for both semi-terrestrial habitats within the drawdown zone adjacent to Cartier Bay and isolated pools with wetland habitat that were located at an elevation above that of Cartier Bay or were otherwise not connected to the main water body. In total, 10 sample points were visited during the May and August field sessions; six of the 10 were visited during both field sessions. Although these points were well above the reservoir level during the May session, all had been inundated by ~6 m of water by August. The sampling methodology used to document the vegetation prior to inundation was representative of terrestrial sampling, but this approach was not suitable once the area had been inundated. Furthermore, the methodology used to sample aquatic macrophytes was not appropriate for sampling submerged terrestrial vegetation. As a result, the two data sets (May, August) cannot be properly compared.

Of the six sample points visited in May, five were considered to represent "terrestrial" drawdown vegetation, while one was located in an isolated pond that supported vegetation similar to that within the main body of Cartier Bay. Only two macrophyte species were detected at this single wetland sample point—Eurasian Water-milfoil and Small Pondweed—both of which occurred at relatively low densities (overall vegetation abundance was estimated as "2"; relative abundance of each species was estimated as "4" [see Table 4-1; Table 4-2 for an explanation of these values]).

All five terrestrial sampling points were characterized by a moderate to heavy thatch layer that was composed primarily of year-old Reed Canarygrass stems and leaves. Twelve species of vascular plants were detected among the five terrestrial sample points, most of which were representative of species that are widespread and common throughout drawdown zone habitats of Arrow Lakes Reservoir. Reed Canarygrass and Columbia Sedge dominated most of the plots; minor species typically occurred in small openings in the thatch layer where organic soil was exposed. These included Kellogg's Sedge (*Carex lenticularis* var. *lipocarpa*), Spring Water-starwort (*Callitriche palustris*), Shortawn Meadow-foxtail (*Alopecurus aequalis*), European Forget-me-not (*Myosotis scorpioides*), Purple-stem Monkey-flower (*Mimulus floribundus*), Purslane Speedwell (*Veronica peregrina*), Pennsylvania Bitter-cress (*Cardamine pensylvanica*), Lady's-thumb (*Persicaria maculosa*), Common Knotweed (*Polygonum aviculare*), and Common Horsetail (*Equisetum arvense*) (Table 5-3).

Table 5-3: Plot data for terrestrial vegetation plots at Cartier Bay, May 2011. Per cent thatch cover, total number of species, and per cent cover values for individual species represent the average of the four quadrats that comprised each sample

Sample Point	Per Cent Thatch Cover	Total No. Species	Dominant Species (> 10 per cent cover)		Minor Species (< 10 per cent cover)	
			Species	Per Cent Cover	Species	Per Cent Cover
E02	92.3 (range: 88–94)	9	–	–	Kellogg's Sedge Spring Water-starwort Columbia Sedge Reed Canarygrass Shortawn Meadow-foxtail European Forget-me-not Purple-stem Monkey-flower Purslane Speedwell Pennsylvania Bitter-cress	2.25 2.00 1.25 0.75 0.19 0.13 0.13 0.13 0.13
E03	98.5 (range: 98–99)	7	–	–	Reed Canarygrass Lady's-thumb Kellogg's Sedge Pennsylvania Bitter-cress Common Knotweed European Forget-me-not Spring Water-starwort	1.38 0.50 0.50 0.19 0.13 0.13 0.13
E05	88.3 (range: 80–93)	6	Reed Canarygrass	11.25	Kellogg's Sedge Lady's-thumb Common Horsetail European Forget-me-not Common Knotweed	0.63 0.50 0.13 0.13 0.13
E06	64.8 (range: 45–80)	4	Reed Canarygrass Columbia Sedge	17.50 12.75	Common Knotweed Lady's-thumb	0.38 0.13
E07	57.5 (range: 50–65)	3	Columbia Sedge	41.25	Reed Canarygrass Kellogg's Sedge	5.50 2.00

5.1.3 Aquatic Invertebrates

Both benthic and pelagic invertebrates were abundant at Cartier Bay, at least during the May field session. Pelagic invertebrates were present at 11 of 19 sample points during the May field session, with five different groups of organisms represented (Table 5-4). Cladocerans, or water fleas (Phylum Arthropoda, Order Cladocera), dominated: they were present in all 11 samples. These organisms often occurred in relatively high abundance: five samples contained more than 20 individuals, and three contained more than 100 individuals. Snails (Phylum Mollusca, Class Gastropoda, Families Planorbidae and Physidae) and chironomid larvae/pupae were also relatively abundant: each group was present in five of 19 samples. Ostracods, or seed shrimp (Phylum Arthropoda, Class Ostracoda), and freshwater mites comprised a minor component of the pelagic invertebrate fauna: they were detected in two and three samples, respectively. In contrast to the May samples, the August samples contained virtually no invertebrates: only one of the 15 samples contained an invertebrate (a single chironomid larva). The reduction in pelagic invertebrates between the two field sessions was presumably related to the inundation of the productive, heavily vegetated wetland habitat by oligotrophic, unproductive reservoir water.

Table 5-4: Abundance of invertebrates in pelagic samples collected at Cartier Bay in May and August 2011. Numbers represent the number of samples in each abundance class. Abundance classes (per samples): 1 = 1 individual; 2 = 2–20 individuals; 3 = 21–100 individuals; 4 = > 100 individuals

	Abundance Classes							
	May session				August session			
Species Group	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Cladocerans	1	5	2	3	0	0	0	0
Ostracods	1	0	1	0	0	0	0	0
Snails	2	1	2	0	0	0	0	0
Chironomids	1	5	0	0	1	0	0	0
Freshwater Mites	2	1	0	0	0	0	0	0

Benthic samples at Cartier Bay were not as affected by the influx of reservoir water as were the pelagic samples (Table 5-5). Seventeen of the 19 benthic samples taken during the May field session contained benthic invertebrates, representing five broad classes of organisms. Snails and chironomid larvae/pupae (Phylum Arthropoda, Order Diptera, Family Chironomidae) dominated the benthic samples in May, while cladocerans, ostracods and freshwater mites were minor components of the benthic invertebrate fauna. Sixteen points were sampled for benthic invertebrates during the August field session; 11 contained invertebrates. Snails and chironomid larvae/pupae dominated these samples, with ostracods representing a relatively minor component; however, neither cladocerans nor freshwater mites were detected in the August samples.

Table 5-5: Presence of invertebrates in benthic samples collected at Cartier Bay in May and August, 2011. Numbers represent the number of samples in which which each taxon was present

		May	August
	Total Samples Taken	**19**	**16**
	Total Samples with Invertebrates	**17**	**11**
Number of Samples Containing Each Invertebrate Taxon	**Cladocerans**	2	0
	Ostracods	2	3
	Snails	11	6
	Chironomids	12	5
	Freshwater Mites	1	0

There appears to be an adverse impact on the species richness (q), diversity (H), and evenness (J) of macroinvertebrates (pelagic and benthic samples pooled) associated with increasing reservoir elevations (spring: $q = 5$; $H = 0.57$; $J = 0.82$; summer: $q = 3$; $H = 0.48$; $J = 1.00$). These changes are thought to be related to increases in water depth, which reduces light infiltration and temperature; however, this hypothesis requires further consideration.

5.2 Montana Slough

Fifteen sampling locations throughout Montana Slough were visited on May 31 during the first sampling session, when the reservoir elevation was at ~433 m ASL (Figure 5-4). Eleven of these points, plus five new points, were visited on August 4 during the second sampling session, when the reservoir elevation was at ~439 m ASL. Depths gathered during data collection were used to develop a bathymetric map of the site (Figure 5-5). The 2011 depth data were augmented by depth data collected during 2010 to provide an accurate representation of the site's bathymetry.

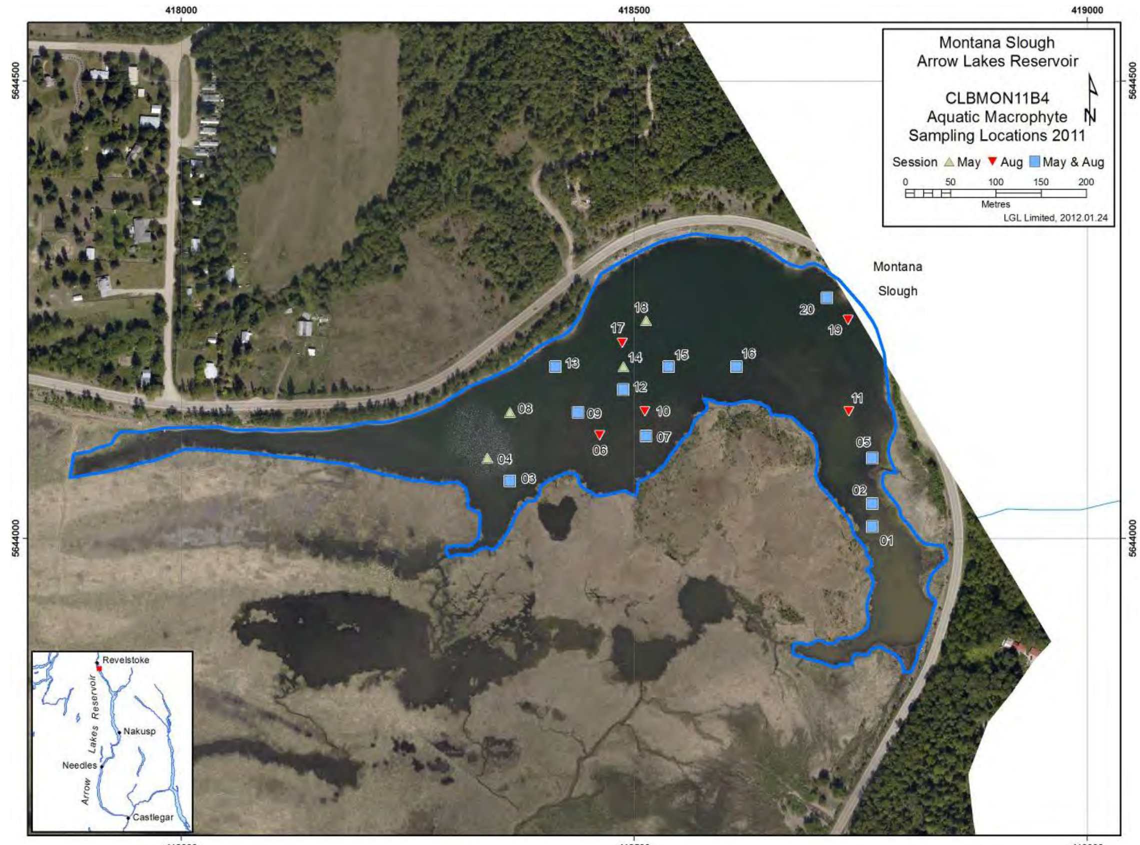

Figure 5-4: Distribution of sampling locations at Montana Slough in 2011, including both the May and August sessions

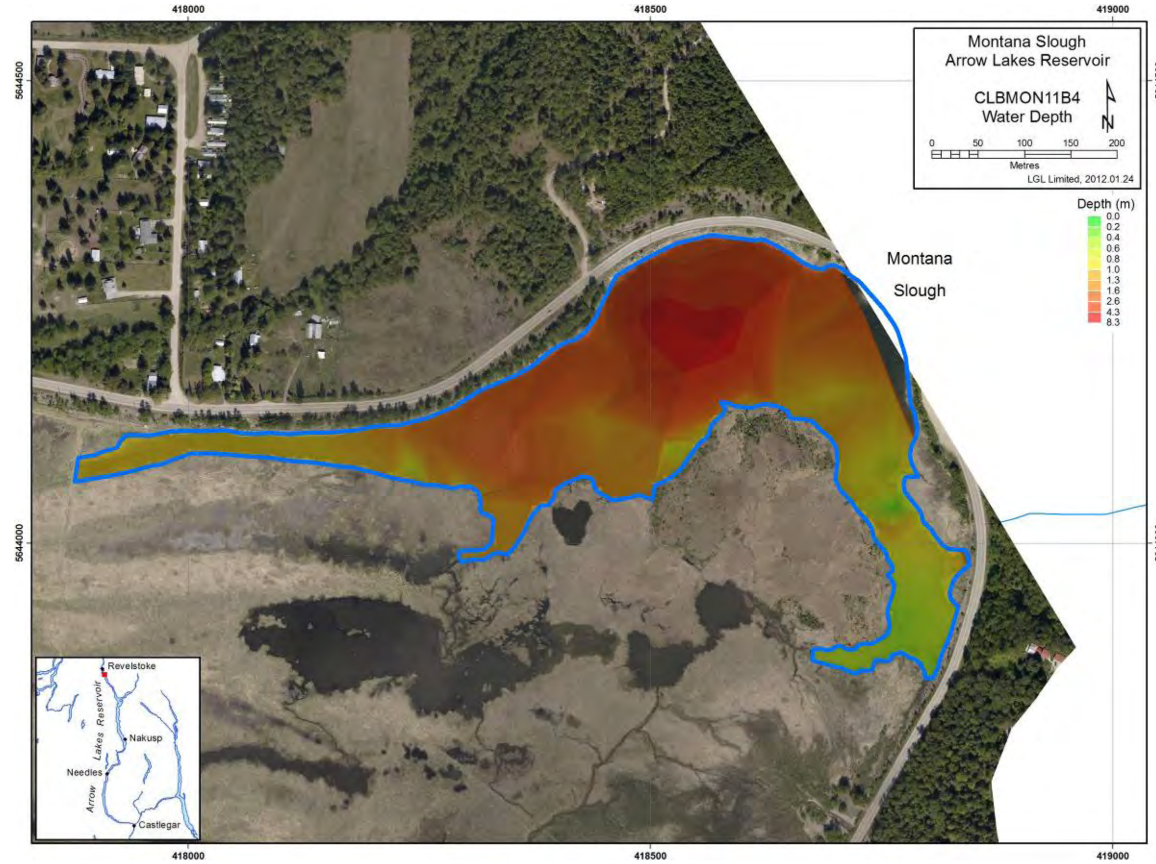

Figure 5-5: Bathymetric map of Montana Slough, based on water depths collected in 2011 and augmented with depths collected in 2010. Only pre-inundation (May) water depths were used from the 2011 data

5.2.1 Aquatic Macrophytes

The input of cold oligotrophic water from Montana Creek has resulted in habitat characteristics that differ greatly from those of the other two study sites. Montana Slough was characterized by deep (up to 8.3 m) and very clear water, soft or muddy substrate, and minimal cover of aquatic macrophytes. Only four species of aquatic macrophytes were documented at the site during the 2011 sampling, and all occurred at very low densities. Localized patches of Common Hornwort, Eurasian Water-milfoil, and Floating-leaved Pondweed (*Potamogeton natans*) occurred sporadically around the perimeter of the slough in waters that were less than 1.5 m deep, as did scattered patches of Floating-leaved Pondweed. Small Pondweed was detected at a single sampling point during the August field session, where it was only minimally abundant. Rocky Mountain Pond-lily (*Nuphar polysepala*) also occurred around the perimeter of Montana Slough, but no patches of this species were captured by the randomly selected sampling points.

Given the minimal vegetation cover at this site, and the little vegetation sampled during either of the sampling sessions, it was difficult to detect any changes in macrophyte abundance between the May and August field sessions (Figure 5-6). Comparison of species presence in May and August suggests that there were few noticeable trends in the prevalence of any species at the site, although any trends were obscured by the very low abundance of vegetation and therefore small sample size available for analysis. The results of the one-way ANOVAs were not significant for each species tested. The scarcity of vegetation also precluded any analysis of biomass as very few samples contained more than a trace of vegetation.

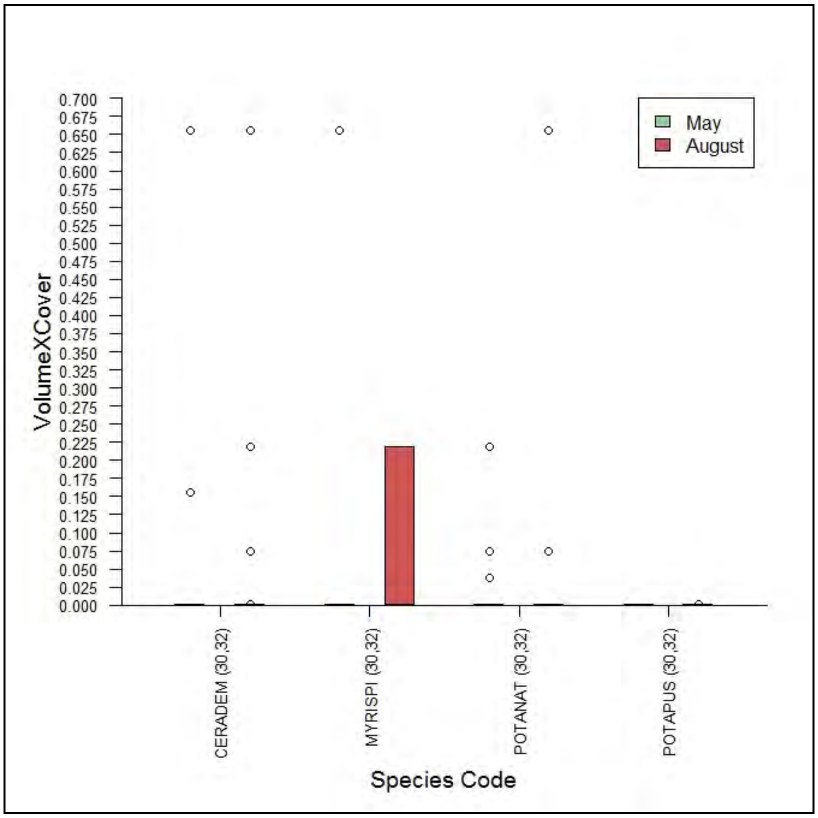

Figure 5-6: Changes in the abundance of aquatic macrophytes at Montana Slough between May and August 2011. The sample size available for analysis was very low at this site due to the scarcity of vegetation. See Section 4.7 for an explanation of the Volume x Cover metric that is used to represent abundance. See Table 5-1 for species codes. The numbers following the species codes represent the number of samples for May and August, respectively

The inability to detect an obvious change in the abundance of aquatic macrophytes observed in Montana Slough between spring and summer (Figure 5-6), was reflected in the seasonal species richness, diversity, and evenness values (spring: $q = 3$; $H = 0.48$; $J = 1.00$; summer: $q = 4$; $H = 0.48$; $J = 0.79$). Species richness and diversity were both low and evenness decreased from spring to summer suggesting that species dominance had changed as a result of increasing reservoir elevations. This could suggest that increasing reservoir elevations impact some species more than others, but more data are required to test this.

5.2.2 Aquatic Invertebrates

Pelagic invertebrates occurred at exceedingly low densities at Montana Slough in 2011, both during pre-inundation surveys in May and post-inundation surveys in August. In fact, among 15 points sampled in May and 16 sampled in August, there was only one capture of a pelagic invertebrate: a single beetle larva (species unknown) was captured during the May surveys. These results indicate that pelagic invertebrates occur very sparsely at Montana Slough.

Benthic organisms occurred at higher densities and diversity than did pelagic organisms: they were recorded at eight sampling points during the May session and nine sampling points during the August session. Snails and chironomid larvae/pupae dominated the May samples: they were recorded at five and four sampling points, respectively. Freshwater mites, which were detected at a single sampling point, were the only other invertebrate group detected during the May session. Snails (five sampling points) and chironomid larvae/pupae (four sampling points) similarly dominated the August samples, but ostracods (three samples), juvenile bivalves (three samples) and freshwater mites (two samples) were also present.

There appears to be an adverse impact on the species richness (q), diversity (H), and evenness (J) of macroinvertebrates (pelagic and benthic samples pooled) associated with increasing reservoir elevations (spring: q = 4; H = 0.60; J = 1.00; summer: q = 5; H = 0.70; J = 1.00). These changes are thought to be related to increases in water depth, which reduces light infiltration and temperature; This is presumably tied to the same factors that have resulted in limited aquatic macrophyte cover and diversity—namely the influx of very cold, highly oligotrophic waters directly into the water body from Montana Creek. This hypothesis requires further consideration.

5.3 Airport Marsh

Twenty sampling points at Airport Marsh were visited between June 1 and 2, 2011, when the reservoir level was at ~433.5 m ASL. Eleven of these points, plus nine additional points, were visited on August 5 during the second field session, when the reservoir level was at ~439 m ASL (Figure 5-7). Of the 20 sites sampled in June, five were located in semi-terrestrial habitats adjacent to the open water of Airport Marsh; thus, these points were sampled in a manner that was more consistent with terrestrial vegetation surveys than aquatic vegetation surveys. This methodology was also used to sample emergent vegetation communities because those communities could not be sampled with the same methods used for submergent species.

Water depths at the sampling points (excluding terrestrial plots) ranged from 2 to 277 cm during the June session and from 11 to 277 cm during the August session. Although depths were collected at all sampling points (excluding terrestrial plots), the occurrence of high water levels at Airport Marsh in 2011 (stemming from unusually high runoff events through the spring) meant that any depth data from 2011 would not be comparable to data from other years. In addition, extensive emergent vegetation often masked the true boundaries of the wetland. This made delineation of the water boundary inaccurate, particularly given that the wetland boundary changed from year to year based on different water levels. Consequently, a bathymetry map for Airport Marsh was not produced in 2011.

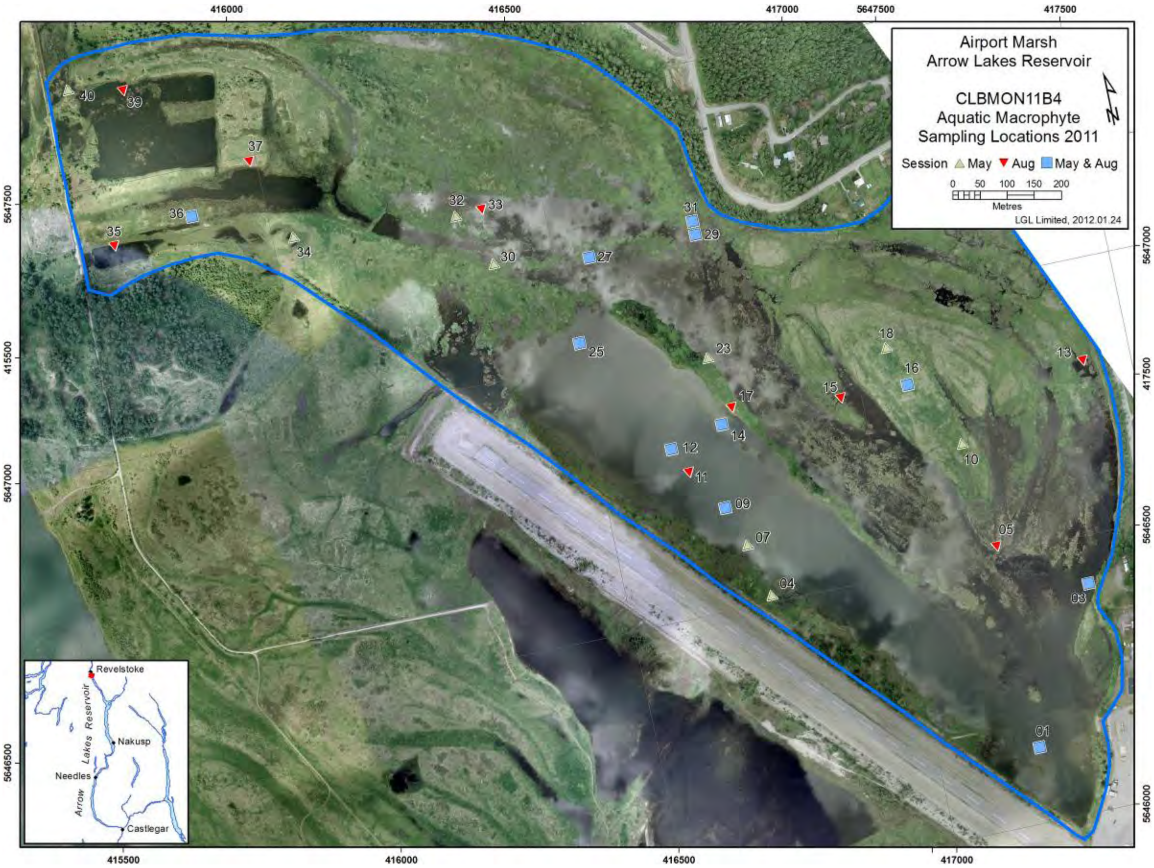

Figure 5-7: Distribution of sampling locations at Airport Marsh in 2011, including both the June and August sessions. The blue boundary represents the broadly defined boundary of Airport Marsh (at the highest water levels), but the water level rarely reaches this boundary except during reservoir inundation

5.3.1 Aquatic Macrophytes

Airport Marsh is considered to be the best established wetland of the three sites visited during this study. The heterogeneity of the substrate and water depth, in combination with the high elevation of the wetland in the drawdown zone (and thus minimal annual inundation by the reservoir), has allowed a relatively diverse community of aquatic and emergent macrophytes to become established at Airport Marsh.

The vegetation at Airport Marsh is characterized by the presence of extensive communities of emergents around the perimeter of the wetland, and a diverse assemblage of submergent species in more open areas as well as throughout the emergent communities. Seven species of submergent and floating species were detected during the June session. Eurasian Water-milfoil, stonewort and Common Hornwort were dominant; pondweeds (including Richardson's Pondweed, Small Pondweed and Eel-grass Pondweed) and Greater Bladderwort comprised a minor component of the submergent vegetation. Three species were documented at the single sample point that occurred within a "floating" community (determined by the dominance of floating-leaved species): Water Smartweed dominated the community, but Small Pondweed and Reed Canarygrass were also recorded.

Unlike at Cartier Bay, aquatic macrophyte diversity and density increased between the first and second field sessions (Figure 5-8). Presumably, this was because there was minimal reservoir inundation in this higher elevation wetland community, which allowed the established vegetation communities to grow and develop naturally and without the dramatic inundation that characterized the two lower elevation study sites. Eight species of aquatic macrophytes were detected during the August field session, including two species (Common Mare's-tail [*Hippuris vulgaris*], and Floating-leaved Pondweed) that were not detected during the first field session. Macrophyte density increased between the two field sessions, but biomass (based on the dry weights of select samples from each sample session) did not mirror this increase (Table 5-6). For most species, the changes in volume x cover were not significant between May and August. However the increase in Stonewort (CHARA) was significant ($F_{1,78}$ = 9.64; p = 0.002).

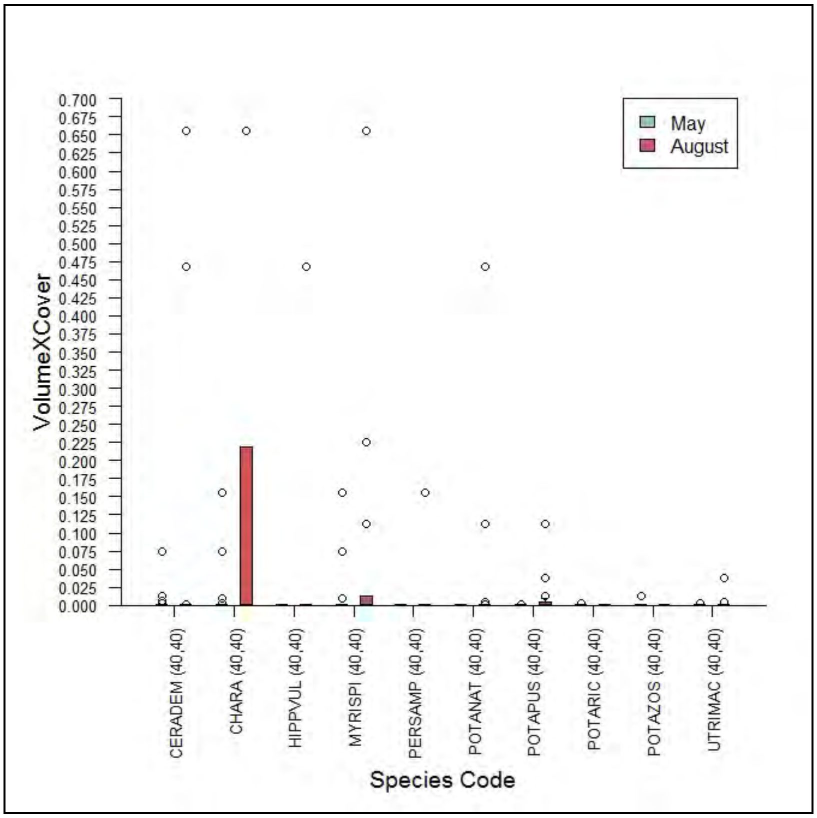

Figure 5-8: Changes in the abundance of aquatic macrophytes at Airport Marsh between May and August 2011. The sample size available for analysis was very low at this site due to the scarcity of vegetation. See Section 4.7 for an explanation of the Volume x Cover metric that is used to represent abundance. See Table 5-1 for the species codes. The numbers following the species codes represent the number of samples for May and August, respectively

Seasonal species richness, diversity, and evenness values of aquatic macrophytes in Airport Marsh were similar (spring: q = 7; H = 0.72; J = 0.85; summer: q = 8; H = 0.85; J = 0.95). Airport March is less impacted by reservoir elevations than either Cartier Bay or Montana Slough and the relatively stable values calculated for 1, H, and J reflect this.

Table 5-6: Biomass of aquatic macrophytes at various sampling locations within Airport Marsh during the June and August sampling sessions. Sampling at point A14 in the June sampling session did not result in any macrophyte detections

Sample Point	Sampling Session	Depth (cm)	Sample Wet Weight (g)	Subsampled?	Subsample Wet Weight (g)	Subsample Dry Weight (g)	Total Dry Weight (g)
A01	Jun	153	95.0	N	n/a	n/a	**10.3**
A03	Jun	107	12.5	N	n/a	n/a	**1.0**
A09	Jun	237	17.5	N	n/a	n/a	**1.3**
A12	Jun	277	147.5	N	n/a	n/a	**10.3**
A14	Jun	68	n/a	n/a	n/a	n/a	**n/a**
A30	Jun	43	215.0	N	n/a	n/a	**30.3**
A40	Jun	110	265.0	Y	160.0	19.8	**32.7**
A01	Aug	210	20.9	N	n/a	n/a	**1.7**
A03	Aug	205	46.2	N	n/a	n/a	**6.4**
A05	Aug	173	162.5	N	n/a	n/a	**19.5**
A12	Aug	372	188.0	N	n/a	n/a	**18.3**
A25	Aug	219	7.3	N	n/a	n/a	**0.8**
A35	Aug	340	32.2	N	n/a	n/a	**3.4**
A39	Aug	210	13.8	N	n/a	n/a	**1.1**

5.3.2 Emergent Vegetation

Emergent vegetation included vegetation communities that occurred in standing water but were dominated by non-submergent vascular plants. Eight points were sampled during the June field session; seven were sampled during the August field session. Depth of samples ranged from 2 to 43 cm. The number of emergent plant species recorded (15 in June; 12 in August) was much greater than the number of aquatic macrophyte species documented. The diversity of species detected was higher during the June field session than the August field session, but overall cover of species was greater in August (Table 5-7). Emergent plant communities were dominated by truly emergent species such as Water Sedge, Water-parsnip (*Sium suave*), Small-fruited Bulrush (*Scirpus microcarpus*), Marsh Cinquefoil (*Comarum palustre*), Swamp Horsetail (*Equisetum fluviatile*), Marsh Horsetail (*Equisetum palustre*), Reed Canarygrass, Bluejoint Reedgrass, Small-flowered Forget-me-not (*Myosotis laxa*), Common Mare's-tail and Tufted Loosestrife (*Lysimachia thyrsiflora*). Submergent and floating-leaved species also occurred beneath the canopy of emergents, and included Water Smartweed, Eurasian Water-milfoil, Narrow-leaved Bur-reed (*Sparganium angustifolium*), Small Bur-reed (*Sparganium natans*), Floating-leaved Pondweed, Richardson's Pondweed and Greater Bladderwort.

Table 5-7: Plot data for emergent vegetation plots at Airport Marsh. Total number of species and cover values for individual species represent the average of the four quadrats that comprised each sample point

Sample Point	Total No. Species	Dominant Species (> 10 per cent cover)		Minor Species (< 10 per cent cover)	
		Species	Per Cent Cover	Species	Per Cent Cover
First Session (June 1–2)					
A27	8	Water Smartweed Water Sedge	20.00 11.25	Water-parsnip Marsh Cinquefoil Swamp Horsetail Marsh Horsetail Reed Canarygrass Eurasian Water-milfoil	0.63 0.50 0.25 0.13 0.13 0.13
A30	6	Water Smartweed	15.00	Water Sedge Narrow-leaved Bur-reed Swamp Horsetail Eurasian Water-milfoil Floating-leaved Pondweed	8.88 6.25 0.50 0.50 0.50
A32	7	Water Sedge	50.00	Eurasian Water-milfoil Water Smartweed Small-flowered Forget-me-not Reed Canarygrass Swamp Horsetail Common Mare's-tail	3.75 2.25 0.56 0.38 0.13 0.13
A36	2	Reed Canarygrass	30.00	Water Smartweed	2.50
A31	5	Water Sedge Common Cattail	13.33 13.33	Water Smartweed Tufted Loosestrife Swamp Horsetail	2.00 0.38 0.13
A29	2	Common Cattail	13.75	Greater Bladderwort	0.25
A10	3	Small-fruited Bulrush	22.50	Reed Canarygrass Water Smartweed	2.63 1.25
A34	2	Reed Canarygrass	27.50	Water Smartweed	1.00
Second Session (August 5)					
A15	5	Water Smartweed	13.75	Greater Bladderwort Reed Canarygrass Water Sedge Small-fruited Bulrush	8.75 5.13 3.75 0.50
A17	5	Reed Canarygrass	70.00	Bluejoint Reedgrass Greater Bladderwort Small-fruited Bulrush Richardson's Pondweed	5.00 3.00 0.75 0.13
A27	4	Water Sedge Water Smartweed	20.00 13.00	Swamp Horsetail Small-fruited Bulrush	3.00 0.25
A29	3	Common Cattail Greater Bladderwort	42.50 11.25	Water Smartweed	0.50
A37	2	Bluejoint Reedgrass Reed Canarygrass	55.00 25.00	–	–
A36	2	Reed Canarygrass Water Smartweed	30.00 10.00	–	–
A31	7	Small Bur-reed	15.00	Water Sedge Water Smartweed Greater Bladderwort Swamp Horsetail Common Mare's-tail Eurasian Water-milfoil	7.50 5.38 4.00 1.00 0.25 0.25

5.3.3 Terrestrial Vegetation

These sampling points were located within the broadly defined boundary of Airport Marsh (Figure 5-7) but were not regularly inundated and, as a result, supported terrestrial vegetation rather than submergent or emergent wetland vegetation. Four terrestrial sample sites were visited during the June sampling session, and nine species of vascular plants were recorded. All four sample points were heavily dominated by Reed Canarygrass, including both live vegetation and a dense thatch of year-old stems and leaves (Table 5-8). This resulted in low species diversity per plot (i.e., three or four species) because the dense thatch cover precluded or limited the establishment of most other species. In addition to Reed Canarygrass, the following eight species were detected at these terrestrial sites: Kellogg's Sedge, willow (*Salix* sp.), Kentucky Bluegrass (*Poa pratensis*), Scouring-rush (*Equisetum hyemale*), Hemp-nettle (*Galeopsis tetrahit*), Bluejoint Reedgrass, Water Smartweed and Water Sedge.

Table 5-8: Plot data for terrestrial vegetation plots at Airport Marsh. Per cent thatch cover, total number of species, and per cent cover values for individual species represent the average of the four quadrats that comprised each sample point

Sample Point	Per Cent Thatch Cover	Total No. Species	Dominant Species (> 10 per cent cover)		Minor Species (< 10 per cent cover)	
			Species	Per Cent Cover	Species	Per Cent Cover
A04	82.5 (range: 80–90)	3	Reed Canarygrass	17.50	Kellogg's Sedge Willow sp.	0.50 0.13
A16	100.0	4	Reed Canarygrass	60.00	Kentucky Bluegrass Scouring-rush Hemp-nettle	5.25 0.50 0.25
A18	100.0	4	Reed Canarygrass	20.00	Bluejoint Reedgrass Scouring-rush Kellogg's Sedge	1.75 0.25 0.13
A23	55.0 (range: 50–60)	3	Reed Canarygrass	37.50	Water Smartweed Water Sedge	7.50 0.25

5.3.4 Aquatic Invertebrates

Both benthic and pelagic invertebrates were abundant at Airport Marsh during both field sessions (June, August). Pelagic invertebrates were present at six of 11 sample points in June and 10 of 18 sample points in August. The greater number of pelagic samples in August is a reflection of higher water levels during that field session. Lower water levels in June resulted in many sampling sites being in either terrestrial habitats or in areas with extremely shallow water, which precluded the sampling of pelagic organisms. As a result, these two data sets cannot be compared directly, but the relative frequency of organisms within each data set can be compared.

Representatives of six different groups of organisms were present in the June samples (Table 5-9). As in Cartier Bay, cladocerans dominated: they were present in all six samples in which invertebrates were detected. However, they did not occur in particularly high abundance relative to Cartier Bay: only one sample contained more than 20 individuals. Chironomid larvae/pupae were also relatively abundant in June: they were present in four of six samples. Snails, ostracods, water boatmen (Phylum Arthropoda, Order Hemiptera, Family Corixidae), and freshwater mites comprised a minor component of the pelagic invertebrate fauna.

Pelagic invertebrate samples collected in August showed a greater diversity of species than those collected in June (Table 5-9), primarily due to the presence of numerous larval insects. Representatives of 14 species groups were detected. Snails (eight samples) and chironomid larvae/pupae (five samples) were most frequently encountered. Other organisms that were detected in more than one sample included ostracods (two samples), amphipods (Phylum Arthropoda, Order Amphipoda [three samples]), freshwater mites (two samples), damselfly larvae (Phylum Arthropoda, Order Odonata [three samples]), water boatmen (two samples), and larval Hemiptera (two samples). Organisms found in only a single sample included cladocerans, copepods (Phylum Arthropoda, Subclass Copepoda), caddisfly larvae (Phylum Arthropoda, Order Trichoptera), mayfly larvae (Phylum Arthropoda, Order Ephemeroptera), predacious diving beetle larvae (Phylum Arthropoda, Order Coleoptera, Family Dytiscidae) and crane fly larvae (Phylum Arthropoda, Order Diptera, Family Tipulidae).

Benthic samples collected at Airport Marsh (Table 5-10) showed a greater diversity of invertebrates than did samples collected at either Cartier Bay or Montana Slough. Seven different species groups of benthic organisms were detected in eight of 16 samples collected in June, and ostracods and chironomid larvae/pupae dominated those samples. Other organisms that occurred in the June samples included cladocerans, snails, amphipods, freshwater mites, and copepods. Benthic invertebrates were similarly abundant and diverse in samples collected in August, occurring occurred in 11 of 19 samples. Chironomid larvae/pupae were the most frequently encountered organism, while ostracods, cladocerans, snails, freshwater mites, biting midge larvae (Phylum Arthropoda, Order Diptera, Family Ceratopogonidae), and amphipods also occurred.

Table 5-9: Abundance of invertebrates in pelagic samples collected at Airport Marsh in June and August 2011. Numbers represent the number of samples in each abundance class. Abundance classes (per samples): 1 = 1 individual; 2 = 2–20 individuals; 3 = 21–100 individuals; 4 = > 100 individuals

	Abundance Classes							
	June session				August session			
Species Group	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Cladocerans	2	4	1	0	0	1	0	0
Ostracods	0	1	1	0	0	1	1	0
Copepods	0	0	0	0	1	0	0	0
Amphipods	0	0	0	0	1	0	2	0
Snails	1	0	1	0	3	4	1	0
Water Boatmen	0	1	0	0	2	0	0	0
Diving Beetle Larvae	0	0	0	0	0	1	0	0
Hemiptera Larvae	0	0	0	0	1	1	0	0
Chironomids	2	2	0	0	0	3	2	0
Crane Fly Larvae	0	0	0	0	1	0	0	0
Damselfly Larvae	0	0	0	0	3	0	0	0
Caddisfly Larvae	0	0	0	0	1	0	0	0
Mayfly Larvae	0	0	0	0	1	0	0	0
Freshwater Mites	1	0	0	0	0	2	0	0

Table 5-10: Presence of invertebrates in benthic samples collected at Airport Marsh in May and August, 2011. Numbers represent the number of samples in which each taxon was present

		June	August
	Total Samples Taken	**16**	**19**
	Total Samples with Invertebrates	**8**	**11**
Number of Samples Containing Each Invertebrate Taxon	**Cladocerans**	3	2
	Ostracods	7	3
	Copepods	1	0
	Amphipods	2	1
	Snails	3	2
	Chironomids	5	7
	Biting Midge Larvae	0	1
	Freshwater Mites	1	1

The number of species (q) and species diversity (H) increased between spring and summer (spring: q = 8; H = 0.63; summer q = 15; H = 0.83; benthic and pelagic data combined), but evenness did not (spring: J = 0.70; summer J = 0.71). This is likely related to the fact that there is little influence of Arrow Lakes Reservoir on Airport Marsh, which allows the marsh to develop through normal patterns of macroinvertebrate phenology. The number of species and the species diversity are expected to increase throughout the summer months as larval individuals either become more prominent as eggs hatch or else metamorphose into adults and can therefore be more easily detected.

6.0 SUMMARY AND RECOMMENDATIONS

The small-scale engineering projects that have been proposed to increase the areal extent of shallow water wetland habitat in Revelstoke Reach (Arrow Lakes Reservoir) are intended to provide lasting benefits for wildlife that use the drawdown zone. Three sites have been targeted for physical works projects and pre- and post-impact monitoring: Airport Marsh, and two sites in Cartier Bay. A fourth site, Montana Slough, has also been identified as a potential future location for physical works and is also included in this monitoring program. The efficacy of these physical works projects can be assessed, in large part, by monitoring selected indicators of wetland habitat condition, such as the composition, structure and diversity of aquatic plant and invertebrate communities and related physical parameters (e.g., water depth and chemistry, areal extent of vegetation communities). The 2011 field session represented the “Before” component of the BACI-style sampling design and was intended to provide baseline ecological information against which to compare the conditions that exist following the completion of the physical works projects.

Although changes in aquatic plant and invertebrate communities are expected, the magnitude and direction of those changes are unknown. The intent of the physical works is to improve habitat quality for wildlife; therefore, monitoring of these ecological and physiochemical indicators will allow the effectiveness of the newly created wetland habitat to be regularly assessed, and will help ensure that its function and productivity is representative of high-quality wetland habitat. Once the physical works projects have been completed, monitoring ecological conditions at enhanced wetlands will require baseline information against which to compare the post-enhancement conditions. The intention of this report is to provide this information.

Surveys of the aquatic macrophyte, emergent and terrestrial vegetation, and invertebrate communities at Cartier Bay, Montana Slough and Airport Marsh in 2011 indicated that these three study sites differ dramatically from each other ecologically. Cartier Bay was characterized by high biomass of aquatic macrophytes, particularly Common Hornwort and stonewort, but relatively low macrophyte diversity. The regular and prolonged annual inundation of this site, resulting from its relatively low elevation within the drawdown zone, has resulted in little or no establishment of emergent plant communities. Invertebrate populations within this wetland occurred at relatively high densities compared to the other two study sites, however, and were heavily dominated by cladocerans and chironomids. High invertebrate density, particularly in pelagic habitats, is likely related to a high abundance of aquatic macrophytes, which provide food, shelter and ecological complexity.

In contrast to Cartier Bay, Montana Slough was characterized by extremely low density and diversity of both aquatic macrophytes and aquatic invertebrates. Pelagic invertebrates were particularly scarce at this site, but benthic invertebrates and aquatic macrophytes also occurred at very low densities. Montana Slough receives direct input of clear, cold, oligotrophic water from Montana Creek throughout the year, which likely prevents the establishment of diverse and abundant ecological communities, such as those associated with the more nutrient-rich wetlands in Cartier Bay and Airport Marsh. The presence of freshwater mussels at Montana Slough but not Cartier Bay or Airport Marsh suggests that the water quality at that site was noticeably different from that at the other two sites. Freshwater mussels are well known bioindicators of unpolluted, standing or flowing waters that are rich in oxygen, calcium and suspended food particles (Helfrich et al. 2009). The conditions at Montana Slough are apparently highly suitable for the establishment of a freshwater mussel population but are not particularly conducive to the establishment of the dense macrophyte community or diverse invertebrate community that would be expected in a higher nutrient, warmer water wetland.

The ecological communities at Airport Marsh were much more developed and diverse than those at either Cartier Bay or Montana Slough, presumably due to the high elevation of the wetland and relatively infrequent and short-term inundation by the Arrow Lakes Reservoir. Extensive communities of emergent vegetation were present throughout much of the wetland, as well as extensive beds of submergent macrophytes (although they were not as extensive as in Cartier Bay). Overall, macrophyte diversity was higher at Airport Marsh than at either of the other two sites, particularly when emergent communities were taken into account. The aquatic invertebrate communities were also well developed. Although invertebrate abundance was lower than at Cartier Bay, the diversity of organisms was much greater. As with Cartier Bay, cladocerans and chironomids dominated the invertebrate communities.

An additional objective of the 2011 surveys was to test the ability of the proposed methodologies to detect community-level changes in selected biotic and abiotic variables resulting from installation of the physical works. Comparison of the results of the May and August field sessions in 2011, which sampled the sites before and after reservoir inundation (respectively), indicated that changes in the abundance or diversity of aquatic vegetation and invertebrate communities that resulted from inundation were detectable using the chosen methodologies. For example, some aquatic macrophytes, the volume x cover values (VC) were found to differ significantly between these two sampling sessions. VC values at Cartier Bay that were calculated for August were significantly lower than those calculated for May. The VC value of one species (stonewort) was significantly higher in August than it was in May at Airport Marsh, and the VCs calculated for all species in Montana Slough did not differ significantly between May and August. Similarly, pelagic invertebrate abundance declined dramatically at Cartier Bay in the August field session following inundation of the site by the reservoir earlier in the summer.

In comparison to Cartier Bay, no significant declines in the cover of aquatic vegetation were noted at either Montana Slough or Airport Marsh. The abundance of vegetation and invertebrates at Montana Slough is so low, and the resulting data so limited, that the sample size was not considered sufficient to detect changes in the communities that inhabit this site.

Conversely, and in contrast to both Cartier Bay and Montana Slough, Airport Marsh (which is inundated much less frequently, more briefly, and later in the year than these other sites) had an increase in the growth of some aquatic macrophytes between the first and second field sessions, This increase in cover is consistent with what would be expected in a naturally occurring wetland outside of the drawdown zone.

Although the reduction in aquatic macrophytes at Cartier Bay may be partially explained by the limitations of the sampling methodologies in deeper water, the magnitude of the change nonetheless suggests that a true reduction in growth occurred. This change is likely attributable to the influx of nutrient-poor reservoir water and the subsequent 6-m increase in the depth of the wetland, which resulted in a reduction in available light and the input of invasive Common Carp [*Cyprinus carpio*], which feed extensively on aquatic vegetation. Carp have been observed annually entering the wetlands of Revelstoke Reach (Nine Mile, Cartier Bay, Montana Slough) following inundation of these sites by the reservoir, but their effects on the biological communities within these wetlands has not yet been investigated. Studies elsewhere in North America (e.g., Bajer et al. 2009; Weber and Brown 2009), however, have associated dramatic declines in rooted aquatic vegetation directly to increasing biomass of introduced carp. The reduction in the cover of aquatic macrophytes at Cartier Bay may therefore potentially be attributed to this species; however, although the association of carp with declining macrophyte cover is a reasonable hypothesis, it remains untested at the present time and is presented here merely in that may help explain the macrophyte declines that were noted following inundation of Cartier Bay.

Based on the results of the 2011 baseline ecological survey, the following recommendations are intended to improve the monitoring program, particularly for the period following the completion of the physical works projects:

1. **Map the areal extent of macrophyte communities within each of the study sites so that their growth or reduction can be monitored following the completion of the physical works projects.** Mapping could likely be accomplished by acquiring digital aerial photos of the wetland that are of higher resolution than those currently available. The photos acquired in 2010 were 10-cm pixels. Acquiring 5-cm pixels photos will likely provide the resolution needed to map wetland vegetation. In contrast to increasing the resolution of the aerial photos, increased sampling may be proposed as a more cost-effective (though more labour-intensive) means of determining the boundaries of the macrophyte communities.
2. **Obtain additional depth data to improve the bathymetric maps produced for Montana Slough and Cartier Bay.** 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.
3. **Put greater effort into mapping the boundaries of Airport Marsh and developing a bathymetric map for this wetland.** The complexity and size of this wetland have presented challenges in developing an accurate bathymetric map and precisely delineating the wetted perimeter of the wetland. During future survey sessions, more effort should be put into these two components of the study.
4. **Install tidbit data loggers in each monitoring location to track water characteristics (e.g., temperature) that are expected to greatly influence the ecological communities within the wetlands.** The collection of continuous physiochemical data rather than spot-sampled data would provide a better

representation of the abiotic characteristics of the wetland environments. The data loggers would be deployed early in the year (during the first field session) and collected in the late summer after the sites have been inundated by the reservoir.

5. **Investigate the impacts of Common Carp on post-inundation wetland productivity.** Results from 2011, particularly at Cartier Bay, suggest that carp may be severely affecting the distribution and abundance of aquatic macrophytes (and, presumably, their vertebrate and invertebrate communities) following inundation by the reservoir. In order to better understand the impact of carp in these ecosystems, a targeted study of these impacts is suggested. Although the details of such a study have not been compiled, one potential option is the analysis of carp stomach contents at each site following inundation.

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