Columbia River Project Water Use Plan

KINBASKET RESERVOIR FISH & WILDLIFE INFORMATION PLAN

Reference: CLBMON-55

Revelstoke Reservoir Macrophyte Assessment – Phase 1

Study Period: July 2009 – October 2010

G3 Consulting Ltd.
Surrey, BC

October 2010

Revelstoke Reservoir

Macrophyte Assessment Program

BC Hydro Project #: CLBMON-55

Phase 1 (2009 Baseline)

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Executive Summary

G3 Consulting Ltd. (G3) was retained by BC Hydro to assess macrophyte communities on the Revelstoke Reservoir. Assessments were part of a two phase study examining pre- (baseline) and post-conditions in the reservoir and potential effects associated with the operation of a new fifth power generating turbine unit (REV 5) at Revelstoke Dam. Assessments were conducted as part of agreements made under the *Columbia River Projects Water Use Plan* and included satellite image acquisition and prediction of macrophyte size and location, using algorithm-based index modeling, accompanied by aerial reconnaissance and ground-truthing (October 2009).

Eight macrophyte species (i.e., *Eleocharis acicularis*, *Equisetum palustre*, *Myriophyllum spicatum*, *Nitella sp*., *Potamogeton alpinus*, *Potamogeton amplifolius*, *Potamogeton foliosus*, *Ranunculus aquatilis*) were identified during 2009 assessments and appeared well adapted to moderate drawdown (i.e., 0.5 m) conditions occurring prior REV 5 start-up. Sediments and water quality were comparable throughout the reservoir; however, sediments were disturbed at creek confluences. Water temperature decreased with increasing distance up reservoir from the Revelstoke Dam. Down reservoir, sites were dominated by *Potamogeton amplifolius*, and *Nitella sp*. dominated up reservoir sites. Three species (*Equisetum palustre*, *Potamogeton foliosus*, *Ranunculus aquatilis*) were only observed at single sites. *Myriophyllum spicatum (*Eurasian milfoil) was observed sporadically (Sites 1 and 5) and likely introduced through public boat launches.

Satellite Imagery and Normalized Difference Vegetation Index (NDVI) were used to assess macrophyte distribution in the reservoir and should be considered for use in Phase 2. Ten long-term monitoring sites were validated during the Phase 1. Phase 2 should be conducted at a comparable time of year and employ similar methods and monitoring sites. Additional land use, sediment (particle size) and water quality data (nutrients) would enhance comparative analyses. Confounding influences (anthropogenic activities, climate change) and effects associated with reservoir water levels and fluctuation frequencies should also be considered.

1.0 Introduction

On behalf of the British Columbia Hydro and Power Authority (BC Hydro), G3 Consulting Ltd. (G3) was retained to complete a baseline Macrophyte Assessment Program that evaluates the potential incremental impacts of operating a fifth generating unit (REV 5) at the Revelstoke Dam, located five kilometers (km) north of Revelstoke, BC. The overall program is comprised of two phases of assessment, with the baseline investigation completed in the year prior to REV 5 operation and Phase 2, a follow-up investigation, completed subsequent to REV 5 start-up.

The comparative baseline investigation outlined in this report was developed as part of a hypothesis-driven, Multiple Before-After, Control-Impact-Paired (MBACIP) statistical design, which takes into account the confounding influences posed by the dynamic and heterogeneous nature of the reservoir and natural spatial and temporal variability posed by both natural phenomena and anthropogenic activities. Further, this baseline investigation examined current and past conditions of the reservoir and its macrophyte communities in an effort to map their surface area, composition and spatial location using high-resolution satellite imagery (Section 2.2.2) and ground-truthing (Section 2.4).

This report provides interpretive text and tables (Chapters 1 through 5), references and appendices. This chapter (Chapter 1) briefly outlines the study objectives for the Macrophyte Assessment Program, with focus on Phase 1, summarizes important information on Revelstoke Dam, general reservoir characteristics and ecology, and the study area. Chapter 2 discusses the study design, including any deviations from that design, and study methodology for all field and laboratory work, as well as data interpretation. Chapter 3 reports study results and Chapter 4 provides discussion on these results. Chapter 5 presents conclusions and recommendations for Phase 2 of the study. References of literatures used and cited are provided after the chapters noted above.

Appendices provide: figures (Appendix 1); photos (Appendix 2); summary tables and charts (Appendix 3); site descriptions (Appendix 4); ecological characteristics of observed macrophytes (Appendix 5); Revelstoke Reservoir satellite-generated basemaps (Appendix 6); the *Safety & Environmental Management Plan* (Appendix 7); and, sample field forms (Appendix 8).

1.1 Study Objectives

To meet the growing demand for clean power at a reasonable cost and to push BC closer to becoming self sufficient for its power needs, BC Hydro decided to install of a fifth turbine unit (REV 5) at the Revelstoke Dam. As part of the BC Hydro application to install the REV 5 generating unit, a joint Environmental Impact Assessment (EIA; BC Hydro, 2006) and Columbia River Water Use Plan (WUP; BC Hydro, 2005) review was undertaken. These resulted in amendments to the BC Comptroller of Water Rights (2007) order to implement the Columbia WUP, as specified in the Revelstoke Unit 5 Core Committee report (Core Committee, 2006) and WUP Addendum (BC Hydro, 2007). While these amendments did not include any operational constraints, they emphasized the need for addition physical works and monitoring programs, in lieu of operational changes. Due to a lack of information regarding potential impacts associated with REV 5 operation on Revelstoke Reservoir macrophyte communities, as well as the general concern expressed during the consultative process, a pre- and post-project assessment of macrophytes was recommended, and subsequently approved, to verify predictions of low impact. This report on the Phase 1 study provides pre-project assessment results.

A number of objectives and management questions were established prior to commissioning the 2009 Macrophyte Assessment Program. Study design and field methodologies were specifically designed to achieve study-specific objectives and answer management questions. Objectives of the Revelstoke Reservoir baseline macrophyte survey were to:

- assess the biodiversity of aquatic macrophytes;
- map the overall distribution of macrophyte communities; and,
- determine the best locations for long-term monitoring stations of macrophyte extent and biodiversity.

Key management questions included:

- what are the diversity and distribution of macrophytes in Revelstoke Reservoir prior to the fifth-unit (REV 5) operation; and,
- would the changes in drawdown and frequency due to fifth-unit operation at Revelstoke Dam have any impact on aquatic macrophytes in Revelstoke Reservoir?

Should potential impacts be confirmed, other management questions also included:

- which species of aquatic macrophytes are most likely (if at all) affected by the operation of REV 5; and,
- what are the best mitigating strategies to minimize any impact to aquatic macrophytes?

1.2 Background & Project Rationale

1.2.1 Revelstoke Dam

Completed in 1984, Revelstoke Dam was originally designed as a six turbine unit facility, with units 1 to 4 currently in operation, providing the dam with a generating capacity of 1,980 MW. Revelstoke Reservoir was created in 1984 following completion of the Revelstoke Dam. The impounded area is a 129 km long section of Columbia River system, down reservoir of the Mica Dam and up reservoir of the Revelstoke Dam and Hydroelectric Generation Station. It is a narrow, deep, cold water body with generally low biological productivity (see Section 1.3.1 for further details).

The system generally flows north to south and is licensed to store 1.5 million acre feet (MAF). Revelstoke Reservoir has a surface area of approximately 11,530 ha and a corresponding volume of approximately 5,300 x 10^6 m^3 at a Maximum Normal Reservoir Level (MNRL) of 573.0 m (BC Hydro, 1999a; Hirst, 1991). In addition, the reservoir has a mean and maximum depth at forebay of 46 m and 125 m, respectively, and a mean water retention time of 75 days.

Monthly turbine flow and Revelstoke Reservoir water elevation (minimum, maximum and average), from January 1984 to December 2009, are provided in Chart 1 (Appendix 3). Daily turbine flow and reservoir elevation from January 1, 2009 to December 31, 2009 are provided in Chart 2 (Appendix 3). Revelstoke Reservoir is normally kept within 1.5 m of the maximum elevation (573.0 m) throughout the year by regulating output at the Mica Dam (into Revelstoke Reservoir) and Revelstoke Dam (BC Hydro, 1999b; RL&L, 1994). Although drawdown is rarely below an elevation of 571.5 m, weather-related emergencies (e.g., uncharacteristically dry summer) may occasionally result in water elevations as low as 568.8 m. Further, there is a maximum potential drawdown of 15.2 m (i.e., El. 557.8 m) following prolonged periods of basin drought or outage at the Mica Powerhouse (BC Hydro, 1998). Maximum drawdown tends to occur between May and the end of July (Axys and RL&L, 1995).

The addition of REV 5, scheduled to come online in 2010, will increase total capacity of the dam by 500 MW from 1,980 MW to 2,480 MW (BC Hydro, 2007). The operating range of Revelstoke Reservoir, after REV 5 installation, is projected to be the same as current conditions, with reservoir fluctuations at the start of REV 5 operations estimated to be less than 0.25 m over 90 per cent of the time (BC Hydro, 2006). Based on a comparison of average daily elevations for the reservoir, the frequency of moderate drawdowns (i.e., drafting to approximately 572.5 m or by 0.5 m) would be greater with five operating units than currently experienced with four units; however, the frequency of low drawdowns (i.e., drafting to ≥571.5 m or by 1.5 m) would be less frequent (BC Hydro, 2006).

1.2.2 Reservoir Characteristics

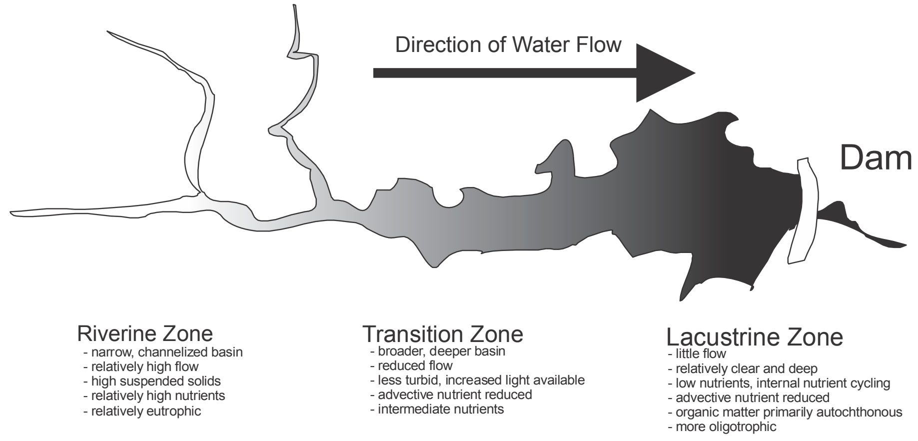
Kimmel and Groeger (1984) describe reservoirs as occupying an intermediate position between rivers and natural lakes on a continuum of aquatic ecosystems. River-flooded reservoirs, such as Revelstoke Reservoir, undergo periods of fluctuating water levels, associated with drawdown of water for hydroelectric power generation. Compared with natural systems, reservoirs are characterized by a large shore development ratio (SDR), dendritic shorelines (many-branched and convoluted), V-shapes bottom profiles, short retention times, large and unstable aridals (barren drawdown zones), high spatial and temporal heterogeneity, unidirectional flow and serial zonation, shorter lifespans and high allochthonous sediment loading due to high watershed-to-lake area ratio (Lind *et al*., 1993; Straskraba *et al*., 1993; Straškrábová *et al*., 2005). The euphotic zone in reservoirs is usually only a few meters deep (Morris and Jiahua, 1998). Sediment inflow and re-suspension of bottom sediments by wave action can increase water turbidity, most notably up reservoir.

Reservoirs are influenced by climatological, hydrological and anthropogenic parameters, with the degree of response depending on the size and volume of reservoirs and varying proportionately to the magnitude of environmental parameters. The different uses of reservoirs and their watersheds may have an impact on water quality, and thus, on aquatic life.

Reservoirs can be divided into three regions (Figure 1-1):

- **Riverine Zone**: the region of a reservoir where the types of processes (e.g., bank erosion, water flow, sedimentation) occurring are more comparable to a river than a lake. This zone is characterized by narrow geometry, shallow waters, significant flow velocities and the transport of silts and clays (Morris and Jiahua, 1998). Allochthonous (i.e., external) organic material predominates in this zone; however, water remains well-oxygenated due to low depths. Water transparency can be reduced by high sediments loading from rivers or high primary productivity (e.g., algae blooms caused by high nutrient inputs from rivers). Many of the original riverine invertebrate and fish species persist. Excessive silting may influence bottom living invertebrates that rely on clean, sediment-free conditions;
- **Transition Zone**: headwaters are often dominated or influenced by the riverine inputs to the region. If inflows have a density greater than lacustrine zone surface waters, the inflows will tend to plunge beneath the lacustrine zone surface. Often a “trash line” of floating debris will indicate such a plunge point. If the inflow water is less dense, it will flow over the lacustrine zone surface. If inflow density is greater than the lacustrine zone surface, but less dense than that of the lacustrine zone bottom waters, these flows may extend into the lacustrine zone or perhaps throughout the lacustrine zone. Such interflows are common where plunging inflows attain depths similar to the penstock opening depth on the dam impounding the lacustrine zone. Substantial inflows (e.g., high flows from occasional precipitation events) can greatly influence the lacustrine zone thermal structure. For instance, inflows with high (or low) temperatures have the potential to change the thermocline depth and, thus, may be a primary factor influencing the thermal structure of the lacustrine zone; and,

- **Lacustrine Zone**: the deepest region downstream from the transition area, where strictly limnetic processes dominate. This zone extends to the dam and has characteristics similar to lakes (e.g., clearer water, lower sediments loading, stratified water column, organic matter mostly produced by reservoir plankton, primary production limited by nutrients loading rather than lack of light; Morris and Jiahua, 1998). True lacustrine phyto- and zooplankton develop in this zone. Floating vegetation, such as the water fern and the water hyacinth, may form extensive mats covering large areas of the reservoir. Lacustrine insects, such as lake flies (chironomids and chaoborids), also colonize this zone.



Information adapted from: Thornton *et al.*, 1981.

Figure 1-1: Reservoir Zonation

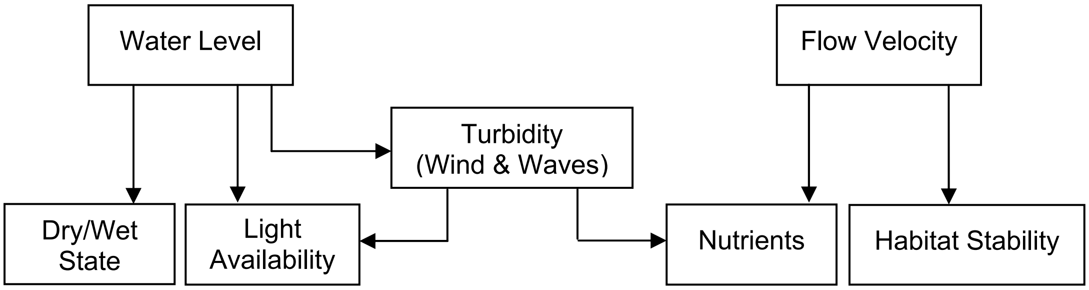
The region in which the lake gradually changes from riverine to limnetic dominance is aptly termed the transition area. This ecotone (i.e., ecological transition) is usually rich and diverse in biota, and dynamic and complex in hydrology. Mixing of riverine and lacustrine waters, when combined with reservoir drawdown cycles and seasonal influences (e.g., winds and related currents, winter freeze-up), result in complicated horizontal and vertical hydrological movements in the transition area. Changing seasonally, these forces produce differences in current and density between riverine and lacustrine waters.

The theoretical retention time of a reservoir is the ratio of reservoir volume to inflow rate. Short retention times prevent significant settling of suspended particles (Cooke *et al*., 2005). Phytoplanktonic and macrophytic production depends greatly on reservoir retention time, specifically with regards to the settling of organic and inorganic suspended particles present in the water column. When retention time is low (e.g., a few days) and the reservoir is shallow, benthic algae dominate autotrophic production (Hargrave, 1969). In reservoirs with greater retention times, colonization by typical lake flora is favoured.

1.2.3 Reservoirs & Macrophyte Ecology

Macrophyte (i.e., emergent, submergent or floating-type plants) communities play an important role in fish and wildlife habitat. While undisturbed macrophyte communities provide spawning, nesting, nursery and feeding habitat for a large variety of aquatic species, over-abundant levels of macrophyte growth, commonly caused by an influx of nutrients, natural or anthropogenic (i.e., eutrophication), can inundate fish habitat and decrease dissolved oxygen (DO) levels, thereby reducing quality and quantity of fish habitat (Peter, 2000). Cowx and Welcomme (1998) identified a number of characteristics which make macrophytes important to fish, including: water purification; nutrient cycling; and, habitat for zooplankton and a range of invertebrates, many of which are an important food source for fish. Aquatic macrophytes are also a source of food for waterfowl, muskrats, beavers and moose (Mitchell and Prepas, 1990).

Growth of macrophytes in reservoirs depends on several environmental parameters (e.g., light energy and nutrient availability, water temperature, water level fluctuations, water velocity; Figure 1-2):



Adapted from Stevenson (1996).

Figure 1-2: Environmental parameters influencing macrophyte growth

The type of substrate and reservoir slope can also have an impact (positive or negative) on macrophytes growth (Cooke *et al*., 2005). Near-shore areas (i.e., littoral vs. limnetic, profundal and benthic) are characterized by better light availability and a high risk of desiccation (Figure 1-3), while deeper zones are characterized by lower light availability and higher flow velocity. The highest macrophyte biomass is typically observed in the littoral zone of reservoirs, especially during periods when water levels are constant (Wetzel, 2001).

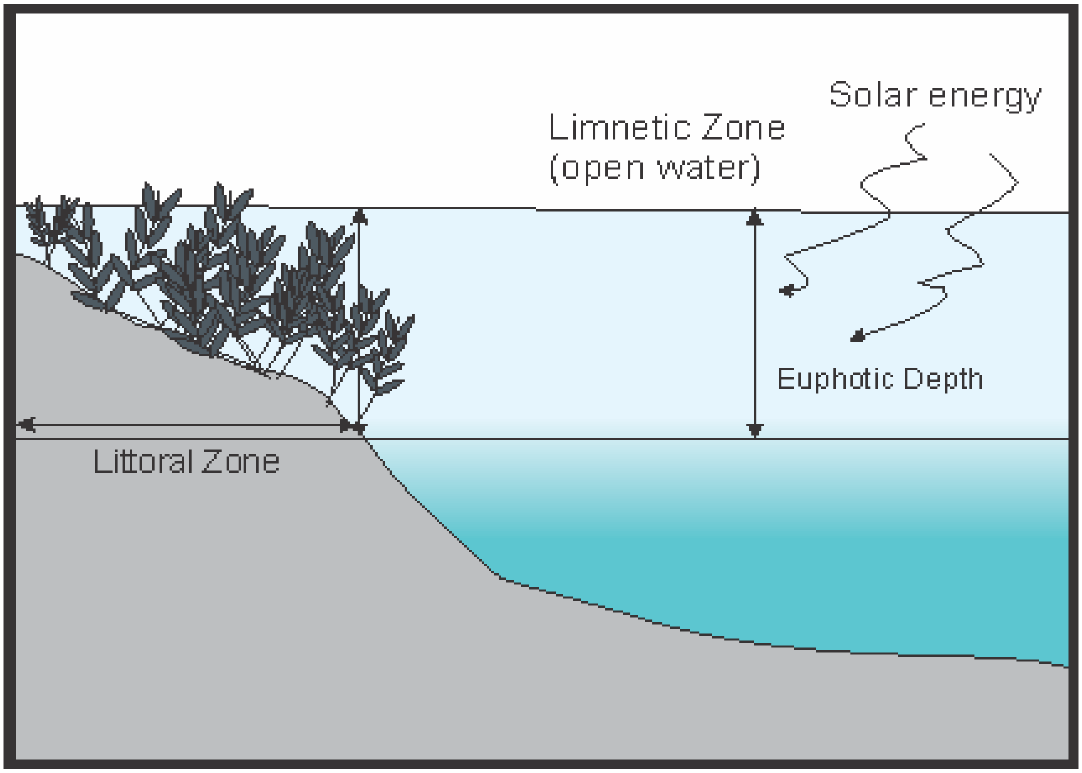


Figure 1-3: Water Zonation within a Reservoir

Biophysical changes in the littoral zone of reservoirs usually have a significant effect (positive or negative) on macrophyte development (Wetzel, 1983; Baxter, 1985; Kimmel and Groeger, 1986; Northcote and Atagi, 1997). Macrophytes mobility is very limited with their development depending on environmental parameters in both reservoir water and sediments. Macrophyte species are sensitive to physical and chemical changes in the surrounding environment and are, thus, good indicators of both current environmental conditions and long-term environmental changes. Given that macrophytes grow in the littoral zone of reservoirs, they are also sensitive to water level fluctuations; therefore, macrophytes are a key indicator of hydromorphological changes in reservoirs.

BC Hydro (2001) developed a conceptual impact model to assess potential impacts of dam operations on reservoir ecology (Figure A-1, Appendix 1). The Revelstoke Reservoir is usually drawn down by 0.9 to 2.4 m in spring and early summer, while daily fluctuations throughout the rest of the year are less than 0.8 m (often less than 0.5 m). Water level fluctuations can result in:

- dewatering of littoral habitats, which in turn can reduce productivity in the reservoir. A large drawdown in the winter could result in exposure, desiccation and freezing of aquatic vegetation that has developed in some areas of the reservoir; and,
- shoreline/drawdown zone erosion and sediment re-suspension, which could affect shoreline stability. Saturation and dewatering of surficial materials would further result in localized slumping. Wave action can erode exposed materials and may result in re-suspension of sediments deposited on the substrate during higher reservoir levels. Increased erosion and subsequent settling of sediments would then further affect reservoir productivity. Erosion of shoreline materials and suspension of organic and inorganic sediments in the water column could generate an increase in nutrients to the reservoir. A significant increase in nutrients in Revelstoke Reservoir may influence (positively or negatively) water chemistry and,

> thus, its aquatic life due to the reservoir's oligotrophic nature. In addition, there exists the potential for increased contaminants (especially mercury) if major bank slumps occur and organic materials are eroded into the reservoir. Changes in nutrients would also result in changes to macrophyte productivity. Changes in shoreline erosion and suspended sediment levels in the water column would affect light (energy) regimes, thereby influencing phytoplankton and macrophyte productivity.

Studies in Canada (Hill *et al.*, 1998) and northern Europe (Rørslett, 1991; Hellsten, 2001) have demonstrated that macrophyte diversity is generally lower in lakes with fluctuating water levels than in lakes with constant water levels; however, the relationship between water level fluctuations and macrophyte diversity is complex. An extensive literature survey of Scandinavian lakes (Rørslett, 1991) showed that general macrophyte richness was primarily correlated (positively or negatively) with the drawdown of water level; yet, regulation amplitude of 1 m to 3 m supported the highest richness. Murphy *et al.* (1990) suggested that a modest increase in disturbance had the potential to create suitable habitats for European aquatic macrophytes. A similar phenomenon was found in reservoirs regulated for hydropower in New Zealand, where an increase in the range of monthly water level fluctuations appeared to have increased biodiversity (Riis and Hawes, 2002). Inundated trees and brush seemed to enhance macrophyte colonization in water bodies with small level fluctuations (Judd and Taube, 1973; Nichols, 1974; Northcote and Atagi, 1997).

A moderate lowering of the water level can also result in increased macrophyte diversity (Lohammar, 1949; Toivonen and Nybom, 1989; Rørslett, 1991), as a newly exposed littoral zone and increased shallowness allow the sublittoral zone to cover a higher area of the water body; however, extensive lowering that causes re-suspension of bottom sediments in reservoirs can drastically change reservoir flora (Scheffer, 1998). Conversely, a sudden increase in water level can also cause erosion, lowering macrophyte community diversity (Nilsson, 1981; Hellsten *et al*., 1996). Macrophyte abundance may decrease more significantly than community diversity in response to increases in water level; therefore, total abundance may be a more sensitive indicator of hydrologic changes than species composition and biodiversity (Nilsson and Keddy, 1988; Coops and van der Velde, 1999; Hellsten *et al*., 1996).

1.3 Study Area & Sample Sites

1.3.1 Study Area Location

The study area for Phase 1 (Baseline) of the Macrophyte Assessment Program is, in general, the entire Revelstoke Reservoir (Figure A-2, Appendix 1), located five kilometres (km) upstream from the town of Revelstoke in southeastern British Columbia, approximately 641 km northeast of Vancouver and 415 km west of Calgary. Situated on the western edge of Mount Revelstoke National Park, much of the area's vegetation is characteristic of the Interior Cedar-Hemlock (ICH) Biogeoclimatic Zone, containing a mixture of coniferous, deciduous and mixed forests. The Columbia River valley surrounds the Revelstoke Reservoir and is bounded by the Monashee Mountains (west) and the Selkirk Mountains (east). The steep-sided nature of the valley allows for little development of the littoral habitat. Many of the 41 main tributaries entering the Revelstoke Reservoir are steep, cold and glacial in origin (Triton, 1992). The reservoir is narrow, with average and maximum widths of less than 1 km and 1.2 km, respectively.

1.3.2 Watershed Land Use

Land use around the Revelstoke Reservoir includes forestry, hydroelectric power generation, recreation, transportation and municipal activities (BC Hydro, 1999b). These types of use represent confounding influences on aquatic vegetation communities and may cause changes in macrophyte distribution throughout the reservoir.

Mica and Revelstoke dams, two sources of hydroelectric power, can influence Revelstoke Reservoir's flow, thermal and nutrient regimes (Schindler *et al*., 2007); however, Mica Dam has the greater influence on thermal and nutrient regimes in the entire reservoir, while Revelstoke Dam's influence is primarily limited to immediately up reservoir of the dam. Mica Dam can also increase dissolved gas levels (TGG, 2008).

Transportation infrastructure includes logging roads, an airstrip, private ferry landing sites, Highway 33 and various minor roads. Forestry activities and transportation corridors can have a negative effect on water quality (e.g., increased sediment inputs to tributary streams and the reservoir, run-off from pesticide applications, changes in nutrient input, effects of watershed nutrient export through log and needle removal and slash burning), as well as potentially altering discharge and thermal regimes. Large areas along the Revelstoke Reservoir have been logged, especially up reservoir of Area 10 (Figure A-2, Appendix 1). These forest-harvesting activities may also impact macrophyte communities (e.g., through loss of riparian habitat, increased shoreline erosion, reduced input of allochthonous material). Cumulative impacts of forestry and hydroelectric operations at Revelstoke include:

- effects of sediment from forestry roads and cutblocks on macrophyte communities;
- effects of changes in stream temperature due to forest canopy removal; and,
- effects of altered hydrologic regime in logged tributaries.

There are several point source discharges entering the Revelstoke Reservoir (e.g., discharge of secondary-treated sewage from Mica Dam into the tailrace, periodic overflow from the deactivated mine tailing ponds connected to Goldstream River, storm water run-off and culvert discharges) which could affect water quality and macrophyte communities. As the waters of Revelstoke Reservoir are nutrient poor (classified as ultra-oligotrophic), the input of additional nutrients from treated sewage may, in part, mitigate the loss of nutrients within the impoundment, which functions as a sediment and nutrient sink. The periodic overflow of deactivated mine tailing ponds to Goldstream River could also potentially increase metals entering Revelstoke Reservoir. Many aquatic plants are capable of assimilating heavy metals from water and soil, with some metals exercising a large role in growth and development (e.g., Fe, Mn, Zn, Cu, Mo, Ni). Certain plants can also accumulate metals which do not have high biological significance (e.g., Cd, Cr, Pb, Co, Se, Hg); however, excessive concentrations of heavy metals can be toxic to most plants (Peterson, 1983, 1993; Salt *et al*., 1995; Lasat, 1996; Rascio, 1997).

1.3.3 Revelstoke Reservoir Ecology

The Revelstoke Reservoir supports a healthy fish community, including Kokanee (*Oncorhynchus nerka*), rainbow trout (*O. mykiss*), mountain whitefish (*Prosopium williamsoni*), burbot (*Lota lota*), white sturgeon (*Acipenser transmontanus*) and populations of Blue-Listed bull trout (*Salvelinus confluentus*; Bray, 2003). The limnology of the reservoir has not been very well documented since its impoundment in 1984. Limited studies have been conducted through the Columbia Basin Fish and Wildlife Compensation Program (CBFWCP), a joint initiative between BC Hydro and the BC Ministry of Environment, which included assessments of reservoir productivity, fish enumeration and spawning surveys (CBFWCP, 2004).

2.0 Study Design & Methods

The Revelstoke Reservoir Macrophyte Assessment Program adopted a MBACIP (Multiple Before-After, Control-Impact-Paired) statistical design from which to assess potential spatial and temporal effects on the heterogeneous reservoir macrophyte communities associated with the installation and operation of a fifth generating unit (REV 5). The MBACIP design uses multiple impact and control sites, assessed over time (Downes *et al*., 2002). Phase 1 of this Macrophyte Assessment Program is the first component of a two year program in which baseline data are established for comparison in the next field assessment (i.e., Phase 2).

Pre-field tasks for this Baseline work phase included summarizing existing information, developing a site-specific Environmental and Safety Plan, collecting satellite imagery, conducting a site reconnaissance via air photos and preparing basemaps. After several repeated attempts, the French satellite SPOT (Satellite Pour l'Observation de la Terre; Section 2.2.2) successfully collected high-resolution, multiple bandwidth (colour spectrum) images of the Revelstoke Reservoir on September 22, 2009. Satellite data collected were then used in a vegetation index (Section 2.2.2) to complete basemaps (with predicted macrophyte locations), direct the overview reconnaissance flight and plan baseline assessment activities. *In situ* macrophyte community assessments were conducted from September 28 to October 3, 2009 and included both aerial surveys (Section 2.3) and ground-truthing (Section 2.4). Methodology employed during office and baseline assessments followed those developed by G3 on other environmental assessment programs, and those of the provincial Resource Inventory Committee (RIC, 1997).

2.1 Start-up Meeting & Communication

Prior to commencing field work, a project start-up meeting was held at the BC Hydro head office (August 12, 2009). This meeting was used to finalize the scope of work (e.g., project objectives, budget, timing, methods/approach), discuss environmental and safety planning and introduce project participants and responsibilities. During the meeting, SPOT data and an example of satellite imagery were provided to demonstrate the technology to be employed.

Communication for project-relevant topics was generally completed via email to maintain a record of discussions. In addition, two status reports were submitted to BC Hydro (November 2009 and January 2010).

2.2 Pre-Field

Extensive pre-field assessments were completed to familiarize personnel with the area and to develop a work plan for baseline assessments. Pre-field assessments included:

- summary of relevant existing information;
- review of current and historical air photos and site maps;
- tasking and acquiring high-resolution, multi-bandwidth SPOT imagery;
- development of site-specific algorithms (Section 2.2.2) and base field maps;
- development and approval (by BC Hydro) of the field work plan; and,
- development and acceptance (by BC Hydro) of a site-specific Revelstoke Reservoir Environmental and Safety Plan in accordance with criteria stipulated.

2.2.1 Summary of Existing Information

Relevant available information on macrophytes in Revelstoke Reservoir (e.g., species list, relative abundance, contributing factors, distribution, etc.) was collected and summarized. In addition, historic reports on similar reservoirs in the area, such as the Arrow Lakes and Kinbasket reservoirs, were reviewed. Information was obtained from grey and peerreviewed literature, queries to agencies (BC Hydro, BC Ministry of Environment) and consultant reports (e.g., AIM Ecological Consultants, Golder Associates).

Aerial photographs and flight paths from 2003 were also collected from the BC Integrated Land Management Bureau, via GeoBC. The original intent of collecting these air photos was to develop an historical trend (i.e., time-series) of events in Revelstoke Reservoir, identifying locations of potential macrophyte presence and land use activities over time; however, the applicability of this approach was limited, given that years in which photos were taken and the overall reservoir coverage were both limited, elevation of photos prevented macrophyte communities from being observed and comparable data were not available. Consequently, air photos were predominantly used in the development of initial basemaps and field planning.

Information collected prior to field surveys was used to assess:

- potential locations and types of macrophyte species thought to be currently present in Revelstoke Reservoir;
- anthropogenic activities that may influence macrophyte growth, either positively or negatively (e.g., municipal communities, forestry, transportation corridors, boat launches);
- issues related to the start-up and operation of the fifth generator and potential effects to macrophyte communities; and,
- history of macrophyte distributions within Revelstoke Reservoir.

Although originally proposed for this study, a meta-analysis was of limited utility. While some data, current and historical, was made available for consideration in developing a historical background profile and comparison with current trend analysis, information was limited; however, a comprehensive evaluation of various terrestrial and aquatic vegetation indices was completed with methods and algorithms undergoing various trials (Section 2.2.2)

An *a priori* appreciation of the potential macrophyte community distribution and composition throughout the reservoir enabled G3 to establish thresholds for calibrating the algorithms used in creating the vegetation index employed to generate the macrophyte distribution maps (Appendix 6). The thresholds were established as a means to distinguish colour attributes associated with the potential presence of macrophytes.

2.2.2 SPOT Technology & Data Acquisition

SPOT Technology

A primary objective of the Revelstoke Reservoir Macrophyte Assessment Program was to investigate the applicability of remote satellite sensing as a means to identify the size and presence of aquatic vegetation communities with time in the reservoir (i.e., compare satellite data collected at different times to track changes in macrophyte community size and presence over time). To this end, a high-resolution, optical imaging earth observation satellite known as SPOT 5 (Satellite Pour l'Observation de la Terre; Photo 1, Appendix 2) was tasked to collect satellite imagery for use in identifying potential locations of macrophyte communities. SPOT 5 is controlled by Spot Image, based in Toulouse, France; all data were acquired through a Canadian distribution company (Lunctus Geomatics Corporation). Initiated in 1986, SPOT satellites have already taken more than 10 million high-quality images. SPOT imagery has a wide range of applications, including agriculture, environment, cartography and engineering. The vegetation application of this satellite enables daily observations of terrestrial ecosystems and the biosphere and is mainly used to assess effects of global change on plant communities.

Vegetation Indices

While several indices were investigated, the most accepted method for determining presence and, to a lesser extent, health of vegetation, using satellite imagery is the Normalized Difference Vegetation Index (NDVI). The premise of this remote sensing technique lies with the reflective properties of vegetative species (Nelson *et al*., 2006). All plant species that have chlorophyll as their primary mode of nutrient transfer absorb light well in the red spectrum (620 to 750 nm) and reflect light very well in the near infrared spectrum (>750 to ~10 nm). The NDVI creates a number line index from the difference in reflectance between these two bandwidths (Dierssen *et al*., 2006). Hall *et al.* (1992) found the difference between NDVI estimates and measurements from SPOT to be less than one per cent.

Another well accepted technique is the Enhanced Vegetation Index (EVI). This technique is based on the same premise as NDVI, except that it also incorporates the use of a blue band (450 – 495 nm) to help remove atmospheric effects due to haze, smoke and even water (Matsushita *et al.*, 2007). The blue spectrum has sensitivities that are sufficiently different from the red and near infrared to assist in filtering out any reflectance values not associated with the red and near infrared spectra. Both methods were initially employed to assess acquired satellite data.

Use of Test Data

Before collection of satellite imagery using SPOT, a number of freely available datasets were downloaded to test the effectiveness of different vegetation index algorithms and establish the methodology to be used in this study. These datasets were collected using the following platforms:

- Landsat 5 Thematic Mapper (TM);
- Landsat 7 Enhanced Thematic Mapper (ETM+); and,
- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

The archived images from Landsat and ASTER platforms were used to determine if:

- simple multi-band, multispectral imagery could be used to isolate macrophyte communities in Revelstoke Reservoir; and,
- there was noticeable differentiation in the target bandwidths across a number of years.

The Landsat data were downloaded from the USGS Global Visualization (GLOVIS) Viewer (http://glovis.usgs.gov), ranging in years from 1985 to 2002. The ASTER data were downloaded from LandData BC. In general, all images were chosen for their temporal proximity to the target field dates proposed for Phase 1 of the Macrophyte Assessment Program (late August to late September) to ensure that the results of pre-project work would be consistent with the project work. Table 2-1 provides the acquisition dates of satellite imagery for each of the datasets collected using the Landsat and ASTER platforms.

Table 2-1: Acquisition Dates of Test Data

Sensor	Acquisition Date
Landsat 5 TM	August 16, 1985
	August 6, 1987
	September 12, 1989
	September 15, 1990
	September 7, 1993
	September 26, 1994
	September 5, 1998
Landsat 7 ETM+	September 16, 1999
	August 18, 2000
	September 5, 2001
	August 23, 2002
ASTER	July 3, 2001

The wavelengths and resolutions for each of the bands used by the Landsat and ASTER platforms are presented in Table 2-2.

Table 2-2: Bands, Wavelengths & Resolutions of Satellite Platforms

Sensor	Bands	Wavelength (micrometres)	Resolution (metres)
Landsat TM (Thematic Mapper)	Band 1 (Blue)	0.45 - 0.52	30
	Band 2 (Green)	0.52 - 0.60	30
	Band 3 (Red)	0.63 - 0.69	30
	Band 4 (Near Infrared)	0.76 - 0.90	30
	Band 5 (Near Infrared)	1.55 - 1.75	30
	Band 6 (Thermal Infrared)	10.40 - 12.50	120
	Band 7 (Near Infrared)	2.08 - 2.35	30
Landsat ETM+ (Enhanced Thematic Mapper)	Band 1 (Blue)	0.45 - 0.52	30
	Band 2 (Green)	0.52 - 0.60	30
	Band 3 (Red)	0.63 - 0.69	30
	Band 4 (Near Infrared)	0.77 - 0.90	30
	Band 5 (Near Infrared)	1.55 - 1.75	30
	Band 6 (Thermal Infrared)	10.40 - 12.50	60
	Band 7 (Near Infrared)	2.09 - 2.35	30
	Band 8 (Panchromatic)	0.52 - 0.90	15
ASTER	Band 1 (Very Near IR)	0.52 - 0.60	15
	Band 2 (Very Near IR)	0.63 - 0.69	15
	Band 3 (Very Near IR)	0.76 - 0.86	15
	Band 4 (Very Near IR)	0.76 - 0.86 (backward scan for stereo)	15
	Band 5 (Short Wave IR)	1.60 - 1.70	30
	Band 6 (Short Wave IR)	2.145 - 2.185	30
	Band 7 (Short Wave IR)	2.185 - 2.225	30
	Band 8 (Short Wave IR)	2.235 - 2.285	30
	Band 9 (Short Wave IR)	2.295 - 2.365	30
	Band 10 (Short Wave IR)	2.36 - 2.43	30
	Band 11 (Thermal IR)	8.125 - 8.475	90
	Band 12 (Thermal IR)	8.475 - 8.825	90
	Band 13 (Thermal IR)	8.925 - 9.275	90
	Band 14 (Thermal IR)	10.25 - 10.95	90
	Band 15 (Thermal IR)	10.95 - 11.65	90

The Landsat data were imported into GRASS GIS version 6.4, enabling the use of the GRASS Mapcalculator tool to perform the image index generation. The algorithm formulas used in image index generation were:

NDVI (Normalized Difference Vegetation Index)

$$\frac{(NIR - RED)}{(NIR + RED)}$$

Where: NIR = near infrared band (band 4 – Landsat)

RED = red band (band 3 – Landsat)

EVI (Enhanced Vegetation Index)

$$G \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times BLUE + L)}$$

Where: NIR = near infrared band (band 4 – Landsat)
RED = red band (band 3 – Landsat)
BLUE = blue band (band 1 – Landsat)
C1 = first coefficient of aerosol term (typically around 6.0)
C2 = second coefficient of aerosol term (typically around 7.5)
L = canopy background adjustment (typically 1)
G = gain factor (specific to imagery; however, a standard of 2.5 is typical)

After running the NDVI and EVI algorithms on Landsat and ASTER imagery, there was a noticeable response for the presence of vegetation in reservoir areas not thought to have any appreciable build-up of macrophytes.

Use of the Landsat imagery combined with the NDVI was abandoned as a possible solution. Essentially, the Landsat images were found to be insufficient in isolating aquatic plant species due to coarse geometric (30 metres) and band widths of the Red and NIR bands. Use of the NDVI algorithm showed little differentiation between reflectance due to water and that of potential macrophytes.

Use of the EVI method with Landsat data was similarly discarded. The EVI techniques initially showed promise; however, the returned values were inverted from what was expected. The areas in the reservoir's centre, where depths are too great for vegetation to be present, exhibited the highest values. After making several adjustments to C1 and C2 (coefficients of aerosol resistance), there was no improvement to the returned values.

As a second check on the efficiency of the NDVI method for identifying macrophyte communities, the algorithm was applied to a set of ASTER images; however, the ASTER satellite platform was ultimately dismissed as a viable data source, Because results were not particularly decisive. In addition, the archived ASTER data were incomplete in coverage, with a large section of Revelstoke Reservoir missing.

Overall, the potential misrepresentations of vegetation in Revelstoke Reservoir using Landsat and ASTER sensors were thought to be a result of either spectral resolution or spatial resolution being too coarse.

Acquisition of SPOT Imagery

To establish the validity of finer spatial resolution imagery, satellite imagery was collected through SPOT Images for pre-fieldwork analysis and targeting. SPOT data were chosen due to their finer geometric resolution (10 metres) and broader spectral coverage in both the NIR and Red bands.

Given that the value of satellite data is highly reliant on climatic parameters (e.g., cloud cover), four attempts at SPOT data acquisition were necessary to capture acceptable imagery. Table 2-3 provides the dates on which efforts were made to collect SPOT 5 imagery, as well as associated outcomes.

Table 2-3: Acquisition Dates of SPOT 5 Imagery

Acquisition Date	Outcome
Mid-August, 2009	**Initial Acquisition Request Made**
September 1, 2009	**Unsuccessful** (~ 65% cloud cover)
September 11, 2009	**Unsuccessful** (Too much cloud cover)
September 15, 2009	**Unsuccessful** (Too much cloud cover)
September 22, 2009	**Successful** (Data used to generate basemaps)

The wavelengths and resolutions for each satellite band are presented in Table 2-4.

Table 2-4: Bands, Wavelengths & Resolutions of SPOT 5

Bands	Wavelength (micrometres)	Resolution (metres)
Band 1 (Green)	0.50 - 0.59	10
Band 2 (Red)	0.61 - 0.68	10
Band 3 (Near Infrared)	0.78 - 0.89	10
Band 4 (Mid Infrared)	1.58 - 1.75	20

The SPOT 5 satellite sensor array does not have a sensor for the “blue” wavelength range. As such, the following equation (developed by the Center for Remote Imaging, Sensing and Processing [CRISP; http://www.crisp.nus.edu.sg/] and published by SPOT Image) can be used to create a pseudo-blue band when executing the EVI:

$$\frac{((3 \times B1) - B3)}{4}$$

Where: B1 = SPOT 5 band 1 (Green)
B3 = SPOT 5 band 3 (Near Infrared)

SPOT captured multispectral, hi-resolution images in both the visible and infrared (HRVIR) spectra. The resolution of the captured areas was at 2.5 and 5 m panchromatic and 10 m multispectral. These images allowed for greatly enhanced basemaps, given that the colour spectrum was able to be separated into four distinct bands (red, green, blue and near infrared), then overlain onto higher resolution panchromatic bands.

SPOT imagery was downloaded locally and imported into GRASS GIS. Given the format of data collected, it was necessary for the reservoir to be initially organized into two tiles (North and South). The images were processed separately due to the potential for loss of spectral fidelity if the images were “stitched.” After the North and South images were received, a key area, Downie Arm, was identified as missing in the original acquisition specifications. Consequently, this additional area was acquired, with the imagery subsequently processed in three pieces.

Image Processing

Identical NDVI algorithms were applied to each of the three tiles. This algorithm initially showed notable differences in processed digital numbers for areas likely to have macrophyte presence; however, there was a considerable level of backscatter (noise) throughout the reservoir which made it difficult to isolate these areas. Adjustments were made to narrow the range of NDVI response values indicating vegetation in the reservoir, with final values ranging from -0.39 to -0.33. In terrestrial environments, this range would indicate no vegetation or vegetation in poor health; however, given the effect of water on response values, these numbers required consideration.

Individual values within this response range did not definitively identify areas containing macrophyte communities; however, grouping these values proved useful. After the processing was completed, an image was created filtering out all pixels except those that fell in the response range. The resultant imagery was overlaid on a "near" true-colour composite of the SPOT imagery. A separate polygon shape file was then created with the same spatial reference system and also overlaid. This overlay map scene was manually inspected by "zooming" to the areas where obvious clumping was present on the NDVI overlay (typically more than 20 pixel linearly in any given direction). The "true-colour" SPOT image was assessed under these "clumps", and, if potential macrophyte communities were present, the area was outlined by digitizing a polygon outlining the area in the aforementioned polygon shape file (see Appendix 6). These polygon areas were used to create potential field assessment areas for which the calibration (i.e., "tightening up") of response values would be made following baseline assessments.

Pre-field Mapping

A series of basemaps (Appendix 6) was created to identify locations of potential macrophyte communities in Revelstoke Reservoir based on the shape file created in the visual image inspection. These areas were delineated using a combination of vegetation index analysis and the aforementioned visual spot checking. Only areas with a > 90% probability of macrophyte presence and of a surface area discernable above 100 m^2 were documented using SPOT imagery and the NDVI algorithm (Appendix 6).

Due to the size of the reservoir, the study area was divided into twenty-five sections, each represented in an area map at a scale of 1:15,000. Twenty-three of these basemaps covered the main body of the reservoir, starting at the south end of Revelstoke Reservoir and moving up reservoir from the Revelstoke to Mica Dam. The final two maps covered Downie Arm. All twenty-five areas in the reservoir are identified in Figure A-2, Appendix 1.

Each map included the background "true-colour" SPOT image and the polygon overlay identifying potential macrophyte communities. For basemaps where polygon(s) were present, a subsequent inset map was created at 1:5,000 showing only the area in which the polygon(s) were shown. These maps were then used by the field crew during the initial flyover and subsequent field assessments.

Post-field Calibration

Areas identified using the NDVI were verified through subsequent aerial reconnaissance (first with air photos, then aircraft flyover), from which eleven sites were short-listed for ground-truthing. Mapped areas were compared with field observations using the basemaps as a guide. Areas shown on the maps varied in accuracy and ranged in size from identical to those observed *in situ* to being located hundreds of metres from where the actual communities were observed. In addition, there were a few macrophyte communities that were not shown on the basemaps.

As a result, the "threshold" for NDVI results was calibrated, as per the steps below, to show, as close as possible, only those areas containing macrophytes:

1. information on macrophyte community boundaries observed in the field was provided to the GIS technician to adjust polygon size and locations;
2. a visual check of satellite imagery was completed and compared with field data to better identify potential macrophyte communities;
3. each of these visually identified areas was subsequently digitized into a new polygon layer;
4. the NDVI output raster file was subjected to a zonal statistics analysis, whereby the minimum and maximum values lying within the visually identified polygon areas were established, along with other statistics (e.g., the mean value used to establish an output threshold);
5. the NDVI algorithm was then re-run, limiting the results to within the range gleaned from the zonal statistics exercise; and,
6. NDVI results, along with visual inspections, were used to produce a new polygon overlay on a series of near true colour maps.

The areas identified above were also used as index evaluation and calibration sites in a "fuzzy-k" classification, which was an attempt to identify areas of highest potential for macrophyte existence, based on image reflectance properties. This technique was used to perform a pixel-to-pixel comparison using a 9-pixel window, moving over the entire image and attempting to find related areas, using "fuzzy-logic" techniques. This technique attempted to identify all areas in the image completely related to the areas of field assessment; however, the method had limited success given the following three reasons (all of which are sensitive to the time of year):

1. satellite imagery was acquired at the end of the macrophyte growing season due to a number of factors, including late approval to acquire the imagery and poor weather conditions throughout most of September 2009;
2. time of year can have an effect on the ambient light, which may limit the ability to discriminate between macrophyte communities and the ambient reservoir environment; and,
3. physical and chemical constituents of the reservoir (e.g., silting, dissolved chemicals, swells in the lake due to wind) can cause poor spectral response for vegetative mapping purposes. Metals and other compounds discharged to the reservoir, through erosion, freshet and other processes, can cause backscatter of spectral light reducing the effectiveness of the imagery and complicating interpretation.

NDVI vs. In Situ Polygons

Two methods were applied to compare polygons predicted by NDVI and those observed *in situ*:

1. **Comparison of polygon-estimated areas:** using basemap satellite polygons and data collected in the field, the surface area of NDVI-predicted and *in situ* macrophyte communities were calculated using GRASS GIS version 6.4 (see Appendix 4). Differences in surface area (ha) between NDVI polygons and those observed *in situ* were calculated for each site to evaluate accuracy of NDVI predictions; and,
2. **Comparison of polygon E-Lines:** the E-Lines method (RISC, 1999) involves establishing the maximum length and width dimensions of a polygon (see Appendix 4). Subsequent comparisons between the maximum lengths and widths of both NDVI and *in situ* polygons for a given site were then performed.

2.2.3 Revelstoke Reservoir Environmental & Safety Plan

Prior to conducting baseline assessments, G3 developed a project-specific Environmental and Safety Management Plan in accordance with BC Hydro safety protocols. The *Safety & Environmental Management Plan* (Appendix 7) included detailed protocols on:

- radio and communication;
- job hazards;
- fixed-wing aircraft transport;
- field emergencies;
- Emergency Action Plans;
- water rescue;
- field mobility and activities (i.e., boat and aircraft safety);
- field check-in procedures; and,
- emergency and program contacts (e.g., local fire, SAR, police, medical, BC Hydro, G3, etc.).

This plan was submitted to, and subsequently accepted by, BC Hydro prior to field crew deployment and followed BC Hydro Standard Operating Procedures (SOPs) and Occupational Safety and Health (OSH) guidelines. Safety procedures were reviewed by a BC Hydro representative during field assessments.

2.3 Overview Reconnaissance Flight

Prior to commencing baseline assessments, an overview flight of the Revelstoke Reservoir was conducted using a single engine Cessna (Photo 2, Appendix 2). Three G3 personnel and a pilot from Silver Tip Aviation conducted the survey on September 28, 2009. Safety guidelines, as outlined in the Revelstoke Reservoir Safety Plan and BC Hydro Flight Survey SOPs, were employed. A flight path was chosen that followed the shoreline of the reservoir at an average altitude and flight speed of 2,100 ft and 95 mph, respectively.

During the flight, the front seat passenger was responsible for visually recording the reservoir shoreline using a digital Panasonic video camera, while rear passengers compared actual macrophyte locations observed with those predicted by the NDVI algorithms (as illustrated on basemaps; Appendix 6). One rear passenger was responsible for informing the other passengers when the aircraft was approaching a suspected macrophyte community using a list of satellite-detected macrophyte polygon coordinates and a GPS unit. The second rear passenger would then document any observed macrophyte communities on basemaps generated specifically for this purpose, including communities detected using the NDVI algorithm and any additional communities not previously predicted. Observed discrepancies were subsequently conveyed to the GIS technician for map revision (see Section 2.2.2). The overview flight lasted approximately two hours.

The reconnaissance flight enabled G3 to assess and calibrate the basemaps and identify any key observations (e.g., macrophyte communities not detected by SPOT). The flight also enabled further note of potential areas of the reservoir suitable for monitoring, where biophysical analyses and sample collections could be conducted.

2.4 Baseline Assessments

2.4.1 Research Vessel

A 6.7 m aluminum river boat with a 340 hp inboard jet drive engine (Photo 3, Appendix 2) was used to conduct field studies and was launched from various entry points along the eastern shoreline of the reservoir. The vessel was transported using a single axle EZ-load trailer, rated for highway transport and compliant with Transport Canada regulations. The boat was equipped with an emergency kit that included six life jackets, a survival kit, flashlights, a bail bucket, two oars, a rope, a life ring, flares and a VHF radio.

2.4.2 Selection of Long-term Study Sites

Given the recognized spatial zonation of the reservoir, and associated spatial distribution of macrophytes within these, a south-north, systematic gradient approach was used for site selection. Field personnel travelled to areas previously identified as being potentially suitable for long-term study based on satellite-generated basemaps and the overview flight. Upon field examination of an area, a study site was chosen if macrophyte presence was confirmed visually and the site was considered capable of being accurately surveyed and represented as part of a long-term sampling program. Additional criteria employed when choosing potential long-term monitoring stations included, but were not limited to:

- ease of access;
- sensitivity (e.g., presence of *SARA* listed species);
- potential entry point for invasive species (e.g., boat launch, municipal communities);
- representative of macrophyte communities within Revelstoke Reservoir; and,
- ability to be influenced by changing water levels (based on topography and slope).

Long-term sites were also chosen to be representative of various types of areas of the reservoir (e.g., undisturbed, located near creek confluences or exposed to anthropogenic activities). In total, eleven study sites were selected, located throughout the reservoir (Figure A-3, Appendix 1). Areas in which long-term study sites were located include 2, 3, 4, 9, 10, 13, 14, 15, 19, 22 and 23 (Figure A-2, Appendix 1). Further details on these study sites (e.g., geographical location, ecology, habitat characteristics) are provided in Section 3.0.

2.4.3 Site Layout

After selecting a study site, the northern, southern, near-shore and furthest from shore boundaries of the macrophyte community were delineated using a digital Lowrance LCX-15MT depth sounder, and visual observations of the macrophyte bed were made by an in-boat field technician wearing polarized sunglasses. An onshore field technician then marked northern and southern site boundaries, based on cues received via radio from personnel on the research vessel, and measured the distance between these points using a hip chain. In addition, three transects (South [S], Centre [C] and North [N]) were marked, first setting the C Transect equidistant from the site boundaries, then spacing S and N transects equidistant from the centre mark and their corresponding south and north boundaries. Each transect extended perpendicular from the shoreline (Figure 2-1).

Site boundaries and transects were marked using survey stakes and/or other permanent onshore markers (e.g., tree, boulder, stump). Stakes and/or permanent markers (e.g., tree trunks, large boulders) were tagged with the appropriate identifier (boundary or transect) and flagged with orange marking ribbon and marking paint. The location of all boundaries and transect markers was recorded using a Garmin XT handheld GPS. The onshore technician then used a Bushnell Yardage Pro 450 range finder to measure the length and width of observed macrophyte communities, recording in field notebooks the distance from each pre-established marking stake to the study boat when positioned at outer and inner edges of the macrophyte community.

Three sampling plots were established along each transect representing three separate ecological zones, associated with distance from shore and depth. Zones sampled at each study site included:

1. Near-Shore (Zone A);
2. Mid-Distance from shore (Zone B); and,
3. Farthest Distance from shore (Zone C).

Zone B was established at mid-distance between the high water mark (HWM; i.e., Point of Commencement [POC]) and the farthest point from shore where macrophytes were observed (i.e., Point of Termination [POT]). Zone A was set equidistant between B and the HWM, while Zone C was equidistant between B and the farthest boundary at which macrophytes were observed (Appendix 4). Each site was comprised of nine sample plots (i.e., S/A, S/B, S/C, C/A, C/B, C/C, N/A, N/B, N/C). UTM coordinates for each sample plot were recorded using an Omnistar Differentially-corrected DGPS receiver (interfaced directly with the Lowrance depth sounder) and noted in field notebooks.

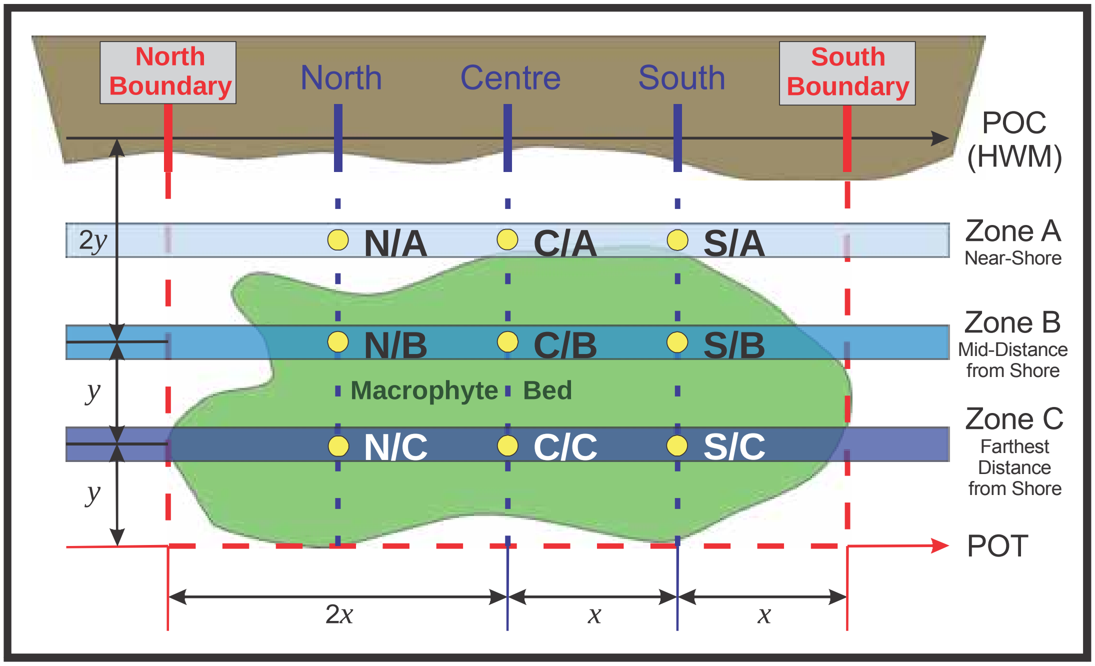


Figure 2-1: Layout schematic for macrophyte site surveys

During baseline assessments, one of the selected monitoring sites (Site 6) deviated from the traditional site layout even though the same methodology was applied. Site 6 was located in a highly convoluted and embayed area and was classified as undisturbed. S, C and N transects were established perpendicular to the shoreline; however, since the shoreline was concave the transects converged to a single point in Zone C. Sites 8 and 11 also differed slightly from the sampling protocol, with the site layout instead being set based on completion of a sub-sample of the macrophyte community present. This divergence in methodology was due to the large size of macrophyte communities observed at these sites (Appendix 4). In addition to size, the decision to sub-sample Site 11 was based on the discovery of a concentrated macrophyte patch (located in Zone B and directly exposed to a run-off drainage channel) that was much greater in density than any other community observed during October 2009 baseline assessments.

Given that delineations of macrophyte community boundaries were contingent on use of a depth sounder (see Section 2.4.4), misinterpreted sounder data had the potential to bias site layout. For example, field technicians were unable to collect macrophytes in all or parts of Zone C at Sites 4, 6 and 10 (i.e., no macrophytes were collected at C/C and S/C of Sites 4 and 10, and All/C of Site 6), even though sampling site boundaries were established using sounder data. In these cases, the points of termination for each community were set based on the point furthest from shore where macrophytes were detected; however, the 1 m^2 sampling plots in Zone C were not always located where macrophytes were present. Macrophytes were similarly not collected in Zone C of Site 7, with the 1 m^2 plot area located outside the community's outer boundary (point of termination), established based on a visually observed community.

2.4.4 *Depth Sounding*

Once each study site was properly delineated, the extent of macrophyte communities in the water column was assessed using a digital Lowrance LCX-15MT depth sounder interfacing directly to an Omnistar Differentially-corrected DGPS receiver (measured in UTM coordinates, NAD83, Zone 11). This particular sounder is proficient even in highly turbid waters and was also used to distinguish bottom substrate densities (i.e., sediment vs. sand vs. gravel) by portraying varying colour profiles. The sounder was used to record depth and identify macrophyte mats, relative substrate condition and bottom slope. Information was stored in real-time and correlated with real-time collection of differentially-corrected GPS data. Cross-sectional mapping images of each long-term monitoring site were also collected to enable subsequent comparative analysis (Phase 2). This technology enabled real-time, sub-meter spatial positioning accuracy. It was especially useful in detecting macrophyte communities located in deeper areas which were present, though not visually observed from the boat or via satellite.

It is important to note, however, that depths within macrophyte mats recorded using the sounder were very inconsistent, rising and falling frequently within short distances and, thus, misrepresenting the actual bathymetry (i.e., study of underwater depth) of monitoring sites. Essentially, the acquisition of depth measurements within macrophyte communities was obscured by macrophytes at many of the monitoring sites. Given that sound is transmitted in "loose" waves, the echo-sounder beam has a large spread/distance ratio, meaning the waves were quite wide when they hit macrophyte communities and subsequently bounced back. When sound was able to penetrate the macrophytes, there was not typically enough transmission energy to reach the bottom and bounce back. Nevertheless, depths measured at the perimeter and within each site were accurately determined based on use of a calibrated Secchi disk, dropping a weighted tape measure and sonar readings collected when stationary.

2.4.5 *Collection of Biological and Physical Data*

Three main biological and physical components were assessed at each monitoring site. These were:

- macrophyte communities;
- *in situ* water quality; and,
- general sediment characteristics.

Distribution and size of macrophyte communities detected at the eleven potential long-term sites predicted using the NDVI algorithm were assessed via *in situ* observations, with differences in community size (satellite imagery vs. *in situ*) documented (Section 3.2.3).

Water quality and general sediment characteristics found at each site were also compared to identify trends associated with land use and geographical conditions (Section 3.3.1).

Macrophyte Collection

The physical collection of macrophytes at each sample plot employed two different methods, depending on depth and macrophyte species present. The collection methods were:

1. *Macrophyte Sampling Rake*: used in all three zones (Photo 4, Appendix 2). The macrophyte sampling rake consisted of two standard 0.5 m wide metal garden rakes, bolted together and weighted at the collection end. A 30 m long braided nylon rope was fastened to the handle to allow for easy deployment and retrieval; and,
2. *Aqua-tiller*®: a commercial product used to collect macrophytes in the deepest sampling zone, when necessary (Photo 5, Appendix 2). The Aqua-tiller® consisted of a rotating drum with grapples positioned the length and circumference of its body. A 30 m long braided nylon rope was fastened to a harness attached at both ends of the drum.

When sampling at each of the transect points, the primary collection method employed was the macrophyte sampling rake. The rake was lowered onto the sampling plot and dragged for approximately one linear meter. This procedure was repeated three times at each transect point, regardless of whether macrophytes were collected. The sampling rake was generally effective in collecting all types of macrophytes; however, it was not always effective in Zone C, perhaps due to retrieval of the instrument from deeper plots.

The Aqua-tiller® was employed in Zone C (furthest from shore) when no or minimal macrophytes were collected using the sampling rake and poor visibility in the water prevented field personnel from determining conditions on the reservoir bottom. In such cases, the Aqua-tiller® was lowered onto the sampling plot and dragged for approximately one linear meter using the study boat. Only a single pass was made with this instrument when it was employed. In some instances, though not all, the Aqua-tiller® was successful in collecting macrophyte samples where the sampling rake was not; however, the Aqua-tiller® was relatively ineffective in collecting smaller macrophyte species (e.g., *Nitella sp*.) due to the larger distance between grapples as compared to prongs on the rake.

Once successfully collected, macrophyte specimens were brought to the surface, removed from the sampling device and placed in pre-labelled sample containers (specific to transect point) for processing. Each container was filled with water to ensure macrophytes did not dehydrate. Rudimentary identification was completed *in situ* to determine which species were present at a given site and ensure at least one specimen of each species was retained from each study site.

Representative plant specimens from each plot were placed in a site-specific plant press and dried (see site descriptions, Appendix 4). Each specimen included stem, leaves and reproductive structures, when present. Specimens were labelled according to transect and zone (e.g., N/C), depth and date, along with any other distinguishing features. Photos were taken of each new species collected at a site. Observations were recorded in G3-developed biophysical field forms (Appendix 8), including data relating to site location, sample plot depths, transect distances, dominant and sub-dominant substrate and vegetation, and site layout.

Estimation of Per cent (%) Macrophyte Coverage

When possible, an estimation of per cent (%) macrophyte coverage was made at each sample plot. These assessments were made from the research vessel, with two field technicians separately estimating the level of reservoir bottom covered by aquatic plants.

Values were then averaged to yield the estimated per cent (%) coverage of a macrophyte community at a given transect point. The estimates were then recorded in biophysical observation forms (Appendix 8).

There were four sites at which an estimation of coverage could not be made at all nine sample plots (i.e., Zone C [Sites 1 and 9]; N/C [Site 4]; S/B [Site 6]) due to depth and/or poor water visibility. As such, mean macrophyte coverage could not be compared between these monitoring sites.

In Situ Water Quality

A 6600-ORP-M YSI Sonde was used to assess *in situ* water quality at the mid-distance (Zone B) sample plot of each transect (i.e., South, Centre, North; Photo 7, Appendix 2). Each study site received three *in situ* water quality readings (i.e., S/B, C/B, N/B locations). A total of 33 *in situ* water quality readings were taken, representing the three regions of the reservoir (Section 1.2.2). The YSI meter was calibrated each day, prior to baseline assessments. Duplicate measurements were taken at each site to verify accuracy of recordings. Water quality parameters assessed included temperature, conductivity, dissolved oxygen (DO), turbidity, pH and salinity. Measurements of each parameter were saved to the YSI Sonde hard drive. Data were subsequently uploaded to a back-up external hard-drive each night following field activities.

A Secchi disk was used to measure water clarity at the centre of each study site in cases where the bottom could not be visually observed. In such cases, Secchi disk measurements were completed in Zone B of the centre transect (i.e., transect point C/B) using a calibrated line on the shaded side of the boat. Recordings were documented in field notebooks.

Sediment

A stainless steel, 6-inch petite Ponar was used to collect sediment samples from each study area (Photo 8, Appendix 2). Samples were collected at mid-distance and farthest distance from shore zones of each Centre Transect (i.e., C/B and C/C), then placed in a field bucket for evaluation. Only sediment grabs more than approximately 75 per cent full were considered acceptable samples.

Qualitative assessments of each sample were made by a field technician *in situ*, with descriptions recorded according to sediment field forms developed by G3 specifically for this study (Appendix 8). In addition, qualitative near-shore evaluations were completed based on visual assessments of the onshore technician. The gross sediment characteristics assessed, based on the Environmental Effects Monitoring (EEM) Working Group (EWG) and USEPA National Benthic Workshop (PTI, 1993), included:

- overall sediment characteristics (i.e., texture, colour, consistency, odour, presence of debris and presence of fauna);
- vertical profile characteristics (i.e., homogeneity, layering, oily sheen, varves); and,
- other distinguishing features.

Photographs of each sediment sample are provided in Site Descriptions in Appendix 4.

2.4.6 Site Photos, Data and Observations

Photographs were taken at each study site (Appendix 2) using a 10-megapixel, Olympus Stylus Tough waterproof camera. Photos captured images from a number of monitoring site vantage points, including:

- facing out from the shoreline;
- facing toward the shoreline; and,

- facing north and south of the sampling site.

Once baseline assessments commenced, photographs were taken of each new macrophyte species collected at a site, substrate samples collected using the petite Ponar at mid-distance and furthest from shore zones, substrate composition near-shore and methodologies employed. Macrophyte beds at select sites were also recorded using a digital Panasonic video recorder (Photo 9, Appendix 2) to provide an indication of overall community coverage. All images captured were downloaded to a back-up external hard-drive following field activities each night to ensure no data would be lost.

Macrophyte and substrate data were recorded *in situ* on study-specific field forms, while water quality data collected using the YSI water quality meter was saved to the instrument's hard-drive. Secchi disk measurements were documented in waterproof field notebooks. Any confounding influences observed at monitoring sites (i.e., anthropogenic activities, creek confluences, other factors that may influence outcomes of the study) were also noted in field notebooks

2.5 Post-Field

2.5.1 Taxonomy

Following field surveys, macrophyte samples were transported to the G3 laboratory, then unpacked for subsequent taxonomic analysis. Samples were checked against field forms, with any discrepancies rectified by examining corresponding site photographs. Pressed and dried macrophyte specimens were then individually identified by examining appropriate morphological structures and comparing feature with diagnostic characteristics in *Flora North America 1993* (FNAEC, 1993)*, The Vascular Plants of British Columbia 1989* (MOF, 1989), and/or other appropriate published keys. Morphological structures were examined under a Leica S8 APO dissecting microscope. Slide-mounting of structures was required to distinguish taxonomically difficult specimens. Slide mountings were examined with a Leica 2500 DM research-grade compound microscope. Specimens were identified to the closest possible taxonomic level and stored in a secure, cool, dry environment until all were identified. Quality assurance procedures during the identification of macrophytes involved a comparison of specimens with other confirmed verified specimens.

2.5.2 Reference Collection

The macrophyte specimens best preserved and most representative of a given species were compiled into a reference collection. Samples were pressed onto 11 x 17 album paper and laminated to preserve sample integrity. Each reference sample includes a site ID card listing the following:

- genus, species and common name;
- sample site collected from;
- date of sample collection;
- general habitat collected from (water depth, sediment, etc.); and,
- method of collection.

Any additional macrophyte species found during Phase 2 of the Revelstoke Reservoir Macrophyte Assessment Program will be subsequently added to this reference collection.

2.5.3 Photo Database

All G3 project photos were uploaded and entered into the 2009 Revelstoke Reservoir Macrophyte Assessment Photo Database. Photo Collector was used to create the database and chosen based on a number of beneficial traits including: ease of use; compatibility; and, functionality. Key information about each photograph was attached as a tag and can be searched using a query tool. The information attached to each photo includes, but is not limited to:

- site name;
- photo date and time;
- photographer;
- photo caption;
- file details (format, file size, resolution and colour);
- camera details (type, flash, zoom, focal length and aperture); and,
- additional notes.

2.5.4 Data Assessment

A Multiple Before-After, Control-Impact-Paired (MBACIP) design with multi-variate statistical analysis was adopted for this investigation. The MBACIP, which utilizes multiple impact and control sites over time (Downes *et al.*, 2002) improves on the insufficient spatial and temporal replication from which earlier BACI designs suffered (Underwood, 1994). Given that MBACIP designs assess spatial and temporal variation in matrices tested, potentially confounding influences are better accommodated. Each site becomes a comparative control (both spatially and temporally) to each other. This should result in more meaningful and relevant conclusions regarding effects of the fifth generating unit on the heterogeneous macrophyte community and the reservoir community as a whole. This approach considers that the distribution of macrophytes is related to localized habitat conditions and reservoir spatial zonation, with the upper portion of the reservoir community inhabiting a more riverine part of the reservoir and at a higher altitude that is subjected to lower air temperatures.

Given the many interrelated environmental and anthropogenic factors that influence the distribution, structure and productivity of macrophyte communities in a dynamic system such as Revelstoke Reservoir, it was imperative that any investigation designed to evaluate effects from a single stressor consider the system's natural variability and stressors that contribute to a community's characteristics. Factors which may affect macrophyte communities in the reservoir include both natural and anthropogenic influences, such as climate-related changes affecting water quality (e.g., temperature, light, flow), nutrient inputs from human activity (e.g., septic fields, municipal discharge, surface runoff), and changes to littoral slope and quality from shoreline activities, both natural and human-induced.

In the second, comparative phase of this project, hypotheses involving multivariate factors (e.g., multi-species community data, multi-factor habitat tests) will be used to assess variance patterns in overall macrophyte (or substrate) composition based on multiple factors (species or habitat factors). Exploratory analyses of this type are typically based on some form of pair-wise similarity measure of the overall macrophyte composition between samples/sites/times. In this study, Phase 1 has provided the baseline (i.e., 'Before') data that will be paired with data collected in Phase 2 (i.e., 'After') to assess the potential effects associated with REV 5 operations on macrophyte communities in Revelstoke Reservoir. From this pair-wise compilation of similarities, various graphical displays will be used to illustrate temporal and spatial floral patterns. The graphical method selected may be some form of spatial gradient plot, frequency plot, cluster analysis or ordination.

Cluster analyses provide visual and interpretive simplicity, an ability to combine all data from all sites of the two years into a 2-dimensional array, and a lack of "parametric" assumptions of normality in what is typically non-normal data. The cluster method is agglomerative, using an unweighted, pair group, mean-average sort (Sneath and Sokal, 1973).

To avoid compromising results and promoting Type I or Type II statistical errors, the 'Before' and 'After' design will:

1. characterize natural variability by incorporating sufficient replication in a full range of representative environments, habitats and co-variables within the system being evaluated; and,
2. include (and characterize) other influences on the community being assessed (e.g., micro-climate, consumer populations, physical changes such as light and turbidity, sediment and water quality), so these may be accommodated and do not confound results.

Following Phase 2 of this Macrophyte Assessment Program, the null hypothesis that "*selected biotic factors are the same for 'Before' vs. 'After' for the same location(s) throughout different habitat types, depths and reservoir longitudinal zones*", will be tested using multiple ANOVA for macrophyte abundance, species number, Simpson's Diversity Index (SDI) and abundance of dominant flora groups.

Multivariate statistical analyses will utilize dissimilarity coefficients (e.g., Bray and Curtis, 1957) and include multi-species community data with multi-factor (e.g., sediment and water quality, depth, spatial area in reservoir such as riverine or lacustrine zone). The null hypothesis would be tested using a "bootstrap" method called SIGTREE (Nemec and Brinkhurst, 1988).

As part of both the multivariate statistical analysis and ecological investigation, major factors within the reservoir's heterogeneous ecosystem, such as water quality, sediment quality, hydrological and biophysical dynamics, micro-climate and other environmental factors will be evaluated and included in the comparative assessment.

The Bray-Curtis (Bray and Curtis, 1957) dissimilarity coefficient will be used to compare pair-wise floral composition for each sample. This measure is strongly influenced by the most abundant species and, therefore, is sensitive to high dominance effects.

Using replicate data for each station, a statistical re-sampling or "bootstrap" method called SIGTREE (Nemec and Brinkhurst, 1988) will be used to generate multiple simulations to test the generalized null hypothesis (H_o) at each cluster linkage that two sampling site groups being linked together are homogeneous (not significantly different). The method is non-parametric and makes no assumptions about the underlying distribution of the multivariate data. The method examines the relative variability within and between sampling site groups independently for each linkage, to determine whether or not a cluster grouping is statistically valid.

A variable significance level (p) will then be used to reject the null hypothesis, depending on the total number of linkages being tested in a given analysis. This is because the overall Type I error of the cluster dendrogram increases (additively) as the number of linkages being tested increases. The total potential Type I error will be kept between 15 and 20 per cent. Sampling sites which are linked together at a probability greater than the critical level, but are linked as a group with the other groups at a probability of less than the critical level, would therefore be significantly distinct and homogeneous from all other sites; however, if a significantly distinct and homogeneous grouping is present, then all other stations are, by definition, distinct from that group, even if the linkage between the homogeneous grouping and other stations has a probability greater than the critical level.

The statistical power calculated for each linkage in SIGTREE will be included as an output result for each SIGTREE analysis. For exploratory analyses, this output is not relevant. In practice, the “power” estimate in the SIGTREE output is useful only for determining how reliable the rejection of the null hypothesis is for each linkage, based on the data used. For example, if a given linkage is rejected at the critical level, it may be concluded that the two groups in the linkage are not the same; however, if the power is low, (high type II or Beta error) the opposite could not be concluded (i.e., that the two groups were different). The bootstrap distribution for the alternate hypothesis (H_a) simulations may not support this conclusion given the variability within the data. In essence, the H_a testing provides a confidence interval for the result (range dependant on the critical p-value for Beta).

2.6 QA/QC and Data Management

A set of *Quality Assurance and Quality Control* (QA/QC) procedures and practices were implemented throughout this Phase 1 Baseline Assessment to ensure program integrity at every level. QA/QC objectives were incorporated into work plans, established in the management strategy, and included protocols for handling and recording information (in the field and office) and criteria used to confirm accuracy and precision of that information. QA/QC objectives included established protocols for literature management to ensure accurate citations and relevance based on date and source of publication.

Sampling was undertaken using both replication and duplication for measures taken in the field. Further, all instrumentation was calibrated daily to ensure accurate performance, while alternate meters were used to verify or support measures taken. Transcription or entry errors were checked through cross-referencing and review of original field notes and forms by alternate staff members on 20-25 per cent of entered data. When an error greater than five per cent was encountered, the entire dataset was scrutinized.

In accordance with BC Hydro protocol, a quality assurance field audit inspection was conducted by BC Hydro representative on September 30, 2009. The field audit evaluated a number of study elements which included, but were not limited to:

- project organization (e.g., schedule, field crew competency);
- study design (e.g., clearly stated objectives in project plan, field crew familiarity with study design and respective responsibilities);
- sampling methodology (e.g., sampling protocols consistent with regulatory standards, adherence to sampling protocols, appropriate field forms); and,
- data management (e.g., specific procedures for data entry and management, data storage compatible with BC Hydro).

Evaluation of study elements was found to be satisfactory in every instance.

An audit of safety procedures and practices was also performed by the BC Hydro representative while out in the field. Features of the field safety plan evaluated include, but are not limited to:

- work practice/procedures (e.g., availability of safety plan on-site, tools and equipment in good condition and used in an appropriate manner, emergency/rescue numbers and protocol established);
- personal protective equipment (e.g., appropriate field foot wear, appropriate weather protection, PPE in good working order and in a sanitary condition); and,
- boat use (e.g., boating safety equipment list reviewed, required number of PFDs available, Transport Canada inspection valid).

These audits similarly found that all relevant safety requirements were satisfactory.

3.0 Results

This section provides baseline results for the 2009 (Phase 1) Revelstoke Reservoir Macrophyte Assessment Program (i.e., multispectral image analysis, aerial photo analysis, aerial reconnaissance, ground-truthing). The extent of macrophyte distribution (e.g., location, depth, relative abundance, biodiversity) within Revelstoke Reservoir was assessed at each of the eleven long-term study sites prior to implementation and operation of a fifth generating unit (REV 5) at Revelstoke Dam. Physical (i.e., water quality, sediment) and biological (i.e., species identification and coverage) data were collected to aid in the understanding of macrophyte ecology within Revelstoke Reservoir prior to start-up of REV 5.

Climate characteristics (i.e., mean, maximum and minimum monthly temperatures, total annual precipitation, mean monthly wind speed) in the Revelstoke Reservoir area (1984 to 2009) are reported in Table 1 and Charts 3 to 5, Appendix 3 (TuTiempo, 2010). Mean annual temperatures ranged from 5.0°C (1996) to 8.9°C (1998), with a mean value for years from 1984 to 2009 of 7.1°C. Mean temperature in 2009 (6.8°C) was similar to mean values observed in previous years and fell within the standard deviation (7.1°C ± 0.8°C). Between 1984 and 2009, annual maximum and minimum temperatures ranged from 31.8°C (August 1997) to 38.0°C (July 2003) and -12.5°C (January 1999) to -29.5°C (January 1991), respectively. Between 1984 and 2009, the mean maximum and minimum temperatures were 34.8°C to -20.7°C, respectively. In 2009, the maximum temperature recorded was 34.7°C (July), and minimum temperature was -18.3°C (January). 2009 maximum and minimum temperatures were within the 1984 to 2009 standard deviation (i.e., 34.8 °C ± 1.8°C and -20.7°C ± 4.8°C, respectively).

Mean monthly temperatures in October (month of baseline assessments) from 1984 to 2009 ranged from 4.8°C (2002) to 8.2°C (1988), with a mean value of 6.6°C. Mean temperature in October 2009 (5.1°C) was lower than the 1984 to 2009 standard deviation (6.6°C ± 0.9°C). Between 1984 and 2009, maximum and minimum temperatures in October ranged from 13.4°C (2007) to 23.7°C (2003) and 1.0°C (1998) to -10.8°C (1984), respectively. Mean maximum and minimum temperatures for October between 1984 and 2009 were 18.4°C and -3.5°C, respectively. In October 2009, the maximum temperature (17°C) was within the 1984 to 2009 standard deviation (18.4°C ± 2.9°C); however, the minimum temperature (-7°C) was lower than the corresponding standard deviation (-3.5°C ± 2.9°C).

Total annual precipitation ranged from 450.4 mm (1993) to 1,197.1 mm (1988), with a mean of 867.9 mm (1984 to 2009). Total precipitation in 2009 was 790.1 mm, which was within the standard deviation (867.9 mm ± 205.8 mm). Total precipitation in October from 1984 to 2009 ranged from 0 mm (1991) to 173.2 mm (1985), with a mean of 87.8 mm. In October 2009, total precipitation (142.5 mm) was greater than the standard deviation (87.8 mm ± 42.3 mm).

Mean monthly wind speed between 1984 and 2009 ranged from 4.4 km/h (1988) to 7.6 km/h (1990), with an overall mean of 6.0 km/h. Mean wind speed in 2009 was 6.1 km/h and within the 1984 to 2009 standard deviation (6.0 km/h ± 0.7 km/h). Mean wind speed in October, from 1984 to 2009, ranged from 1.6 km/h (1995) to 9.0 km/h (1984), with a mean of 5.1 km/h. In October 2009, mean wind speed (5.6 km/h) was within the standard deviation (5.1 km/h ± 2.0 km/h). Wind speed during baseline assessments in October 2009 were >10 km/h at times.

3.1 Revelstoke Reservoir Area

Land use in the Revelstoke Reservoir watershed has been previously documented by BC Hydro (2001). Although much of the information provided in the report is now outdated, it still provides an indication of the types of activities influencing the watersheds surrounding the reservoir. A summary of these land use activities is provided below.

3.1.1 Forestry

In 2001, forest harvesting occurred within the Revelstoke Timber Supply Area under three tree farm licenses (TFLs), renewable forest licenses and the Small Business Forest

Enterprise Program. Forestry tenures within the Revelstoke Reservoir basin (MOF, 1999; Cornerstone, 1994a, 1994b) included TFL #55 (held by Louisiana Pacific Ltd.), TFL #56 (held by the Revelstoke Community Forest Corporation) and TFL #38 (private holdings located adjacent to the shoreline in the northern part of Revelstoke Reservoir). Other forestry companies that operated in the Revelstoke Reservoir basin included Downie Street Sawmills Ltd., Bell Pole Co. Ltd. and Pope and Talbot Ltd.

Ferries remain the main mode of access for timber harvesting on the west side of Revelstoke Reservoir, with log transport to other regions on the east side of the reservoir via Highway 23. Locations of industrial barge access points include Big Eddy (north of Frisby Creek, across from Mars Creek), Fifty Mile (between Liberty and Kirbyville, across from Noranda Mine access), Sixty Five Mile (south of Scrip Creek), Twenty One Creek (south of Pat Creek) and Pat Creek (north of Pat Creek). In addition, there is an airstrip at Bigmouth Creek reserved for Forest Service use.

3.1.2 Waste Discharges

Waste discharges into the Revelstoke Reservoir include discharge of secondary-treated waste from the Mica Dam powerplant facility to the tailrace, and periodic overflow from the deactivated mine tailings ponds to Goldstream River. Commercial facilities (i.e., Downie Resort, Canadian Mountain Holidays lodge in the Goldstream Creek basin) and various logging camps, discharge wastewater to septic fields; however, discharges from camper holding tanks and waste generated at camping sites may contribute to a degradation of reservoir quality (e.g., elevated coliform levels in localized areas).

3.1.3 Water Licences

Water licenses are required for water withdrawals for domestic, commercial or industrial purposes. Revelstoke Reservoir provides storage for licensed use of the Columbia River by BC Hydro for power generation. In 2001, the only other water user identified by the Ministry of Environment, Lands and Parks (MELP; now known as the Ministry of Environment) was the Parks Branch, holding a license for an “enterprise” (2,500 gal/d) and for “watering” (4,625.6 m^3).

3.1.4 Transportation Rights-of-Way

Highway 23 runs along the entire eastern shore of Revelstoke Reservoir, from Revelstoke Dam to Mica Dam; a distance of approximately 144 km. At the time of the BC Hydro (2001) report, a gravel forest access road extended for approximately 20 km north along the western shore of the reservoir; however, it is likely that this forest access road system has grown in the last decade. Various minor tributary roads lead off from Highway 23, while logging roads extend through much of the basin (Cornerstone, 1994a).

3.1.5 Recreation Sites

Recreational activities around Revelstoke Reservoir are generally concentrated in the summer months, with the peak period occurring between May and September. Of the numerous recognized recreation sites on the reservoir in 2001, only two did not have road access. These sites were located on the western shore and accessible only by boat.

Boat-based fishing is one of the more popular recreational activities on the reservoir, with four public boat launch ramps located at Five Mile Creek recreation site, Martha Creek Provincial Park, Downie Creek and Mica townsite. There is also a private launch located at Downie Creek RV Resort, with other private and industrial launches not intended for general public use. Other boat access points (i.e., undeveloped sites, including the remains of old roads or sloping beaches) on Revelstoke Reservoir are located at Carnes Creek, Pitt Creek and numerous other informal sites.

There are ten formal recreation sites on the reservoir: one provincial park (Martha Creek Provincial Park); four designated Ministry of Forests recreation sites (Five Mile Recreation Site, Carnes Creek Recreation Site, Carnes West Recreation Site, Pitt Creek Recreation Site); two undesignated boat launch facilities; and, three private facilities (Downie RV Resort, Monashee Outfitting, Revelstoke Rowing Club). In 2001 (BC Hydro, 2001) there were twenty-three recognized informal recreation sites, with five of these considered to be high-use sites, seven as medium-use sites and eleven as low-use sites. Informal sites are freely used and not regularly maintained or managed by any group or agency. Typically, few facilities are present at these sites and visitors are required use small access roads along the eastern side of the reservoir. Given increasing demand for recreational camping opportunities in BC, it is likely that the number of informal sites with access to Revelstoke Reservoir has increased considerably since 2001.

3.1.6 Land Tenure (Mining, Rights-of-Way & Other Land Uses)

Prior to 2001, there was no information on existing or planned industrial activities in the Revelstoke Reservoir basin other than forestry. Previous mining activity included the old Noranda copper and zinc mine (17 km east of Revelstoke Reservoir in the Goldstream River basin), which closed in 1984. Pan American Minerals Ltd. and Equinox Resources conducted exploration of a gold deposit near Carnes Creek in the early 1990s; however, no further work was carried out (Urban Systems, 1990).

3.2 Macrophyte Ecology (September 2009)

3.2.1 SPOT Satellite Detection & Overview Flight Observations

Fifty-six polygons were generated from SPOT observations, obtained September 22, 2009 (see basemaps in Appendix 6). Forty-four of these polygons were subsequently confirmed during an overview flight reconnaissance (September 28, 2009) with varying degrees of accuracy (size and shape; see Site Descriptions in Appendix 4). Twelve of the polygons detected by SPOT satellite were not observed *in situ*. The number and location (coordinates) of polygons detected by SPOT in each area, polygons observed during the overview flight and additional aerial observations are provided in Table 2 (Appendix 3). The fifty-six polygons detected were located in twenty of the twenty-five Revelstoke Reservoir basemap areas using the Normalized Difference Vegetation Index (NDVI). This remote sensing technique uses reflective properties to locate vegetative species. .

In addition to the polygons identified using the NDVI, there were a number of instances throughout the reservoir where satellite imagery and NDVI modeling suggested the presence of macrophytes; however, these macrophyte communities did not fall within the NDVI algorithm threshold range employed to delineate polygons. Macrophyte communities were observed for some, but not all, of these suggested areas during the overview flight. As such, adjustments and calibration of the model, using ground-truthing data, enabled refinement such that future community detection and accuracy may be improved.

3.2.2 Selected Long-term Study Sites

Of the forty-four macrophyte communities detected using the NDVI, and confirmed during the overview flight, eight were selected as potential long-term study sites (Figure A-3, Appendix 1) as based on selection criteria described in Section 2.4. Following aerial reconnaissance, three other communities (i.e., Sites 4, 6, 9), not specifically detected using satellite imagery, were also chosen as potential long-term study sites based on criteria listed in Section 2.4. These three sites were relatively close to NDVI polygons, and were considered more representative of existing reservoir conditions.

Sites chosen for long-term study were divided into three general categories:

1. **Undisturbed** (not influenced by anthropogenic activities and/or creek inflows): Sites 6 (Area 13), 8 (Area 15) and 9 (Area 19);
2. **Located Near Creek Confluences**: Sites 2 (Area 4, La Forme Creek), 3 (Area 7, Big Eddy Creek), 4 (Area 9, Bourne Creek) and 7 (Area 14, Kirbyville Creek); and,
3. **Exposed to Anthropogenic Activities**: Sites 1 (Area 2, downstream of Martha Creek BC Provincial Park Campground), 3 (Area 7, downstream of a private ferry landing and logging road), 5 (Area 10, downstream of Downie Creek RV Resort), 10 (Area 22, up reservoir of Mica Creek Village) and 11 (downstream of a bridge crossing and directly exposed to a run-off drainage channel).

As shown above, Site 3 (Area 7) was classified as being located both near a creek confluence (Big Eddy Creek) and exposed to anthropogenic activities (downstream of a private ferry landing and logging road). Maps and *in situ* observations for each long-term study site are provided in Section 3.3 and Appendix 4.

3.2.3 SPOT Satellite Imagery vs. In Situ Observations

Comparing polygons generated using SPOT satellite data, and those derived from *in situ* observations, is an effective approach to evaluating the accuracy of NDVI predictions. Two methods of comparison have been applied in this study: surface area and E-Lines.

Surface Area Comparison

An evaluation of NDVI derived polygons vs. *in situ* macrophyte observations identified three categories for surface area comparison:

1. **Direct Comparison**: polygons observed *in situ* were found in the same location as those derived by the NDVI algorithm, enabling direct comparison of surface areas;
2. **Percent Error Calculation**: communities observed *in situ* were found to overlap to a large degree with NDVI polygons; however, configuration (size and shape) of the NDVI communities appeared influenced by other factors (e.g., suspended silt, metals, depth, scattered light, wave action, satellite orientation, etc.). Consequently, a per cent error (i.e., difference between the polygon area estimated using NDVI vs. area observed *in situ*) was calculated; and,
3. **Comparisons Not Possible**: communities observed *in situ* were not found in the same location as those detected by modeling (though in many instances were detected in the same general area), precluding direct comparisons between macrophyte polygon areas.

Polygons detected by NDVI modeling at six of the eleven selected study sites were found to have comparable areas to those observed *in situ*. Conversely, comparisons were not possible for four of the selected study sites and one NDVI polygon could be compared to *in situ* observations, though calculation of a per cent error estimate (i.e., per cent of satellite-generated polygon not comparable to field observations) was necessary, given that only a small portion of the two polygons overlapped. Table 3-1 provides comparison between NDVI-derived polygons and *in situ* observations for the eleven selected long-term sites.

Table 3-1: NDVI Predicted Polygons vs. *In Situ* Observations (Revelstoke Reservoir, 2009)

Site	NDVI Polygon Area (ha)		*In Situ* Polygon Area (ha)	Difference in Polygon Areas (ha)
Category 1: NDVI & *In Situ* Polygons Located in the Same Area				
1	0.76 (7,600 m^2)		1.54 (15,400 m^2)	+0.78 (+7,800 m^2)
2	0.85 (8,500 m^2)		0.76 (7,600 m^2)	-0.09 (-900 m^2)
3	0.43 (4,300 m^2)		0.38 (3,800 m^2)	-0.05 (-500 m^2)
5	1.47 (14,700 m^2)		1.52 (15,200 m^2)	+0.05 (+500 m^2)
8	2.67 (26,700 m^2)		5.91 (59,100 m^2)	+3.24 (+32,400 m^2)
11	2.67 (26,700 m^2)		3.22 (32,200 m^2)	+0.55 (+5,500 m^2)
Category 2: NDVI & *In Situ* Polygons Partly Overlap (with Other Influences Present)				
10	3.91 (39,100 m^2)	90% Error Calculated	0.23 (2,300 m^2)	-3.68 (-36,800 m^2)
Category 3: NDVI & *In Situ* Polygons Located in Different Areas				
4	0.27 (2,700 m^2)		0.4 (4,000 m^2)	N/A
6	3.31 (33,100 m^2)		0.09 (900 m^2)	N/A
7	1.25 (12,500 m^2)		0.14 (1,400 m^2)	N/A
9	0		0.20 (2,000 m^2)	N/A

N/A – Not Applicable (polygons are not comparable)

In general, study sites where NDVI predictions were not accurate had areas less than 0.4 ha (except Site 3), suggesting the satellite/vegetation index tends to be more accurate for the detection of larger macrophyte communities.

In the first category of potential long-term monitoring sites, macrophyte communities observed *in situ* were larger in size at four of six sites predicted by NDVI (i.e., +0.78 ha [+7,800 m^2; Site 1], +0.05 ha [+500 m^2; Site 5], +3.24 ha [+32,400 m^2; Site 8], +0.55 ha [+5,500 m^2; Site 11]; Table 3-1). The remaining two sites were smaller (i.e., -0.09 ha [-900 m^2;Site 2], -0.05 ha [-500 m^2;Site 3]). NDVI polygons were notably accurate at Sites 1, 3 and 8. NDVI estimates and *in situ* observations for Sites 1 and 3 both indicated macrophytes were present in the mid-distance and regions farthest from shore zones (Zones B and C), though not the near-shore zone (Zone A). Further, a large macrophyte community was identified in all three zones of Site 8 by both NDVI modeling and *in situ* observations.

In some instances NDVI and field observations both identified macrophytes in a given area; however, NDVI did not fully estimate growth at all transect points where growth was seen *in situ*. For example, NDVI did not predict macrophytes at three of the nine transect points of Site 3 (S/A, S/B and S/C) and Site 5 (C/A, C/C and N/C) and one transect point (i.e., N/C) at Site 10. In addition, NDVI did not predict macrophyte communities in the near-shore and mid-distance zones of Sites 2 and 11.

At the time of the SPOT satellite data collection (September 22, 2009), the mean Revelstoke Reservoir elevation was 572.05 m, while slightly higher (ranging between 572.41 and 572.65 m) during baseline assessments (September 28 to October 3, 2009). This difference in reservoir elevation may explain, in part, why field observations could not always confirm the presence of macrophyte communities in deeper areas (e.g., reduced water transparency).

Differences in polygon surface areas of Category 1 sites ranged from 0.05 ha (500 m^2; Site 5) to 3.24 ha (32,400 m^2; Site 8). According to NDVI predictions, the surface area of macrophyte communities observed increased with increasing distance up reservoir from the Revelstoke Dam (except at Site 3). *In situ* observations did not identify a trend in polygon surface area with distance up reservoir from Revelstoke Dam.

Overall, the greatest difference between polygon surface area was observed at Site 10 (a Category 2 site), where the macrophytes observed *in situ* had a surface area approximately 3.68 ha (36,800 m^2) less than the NDVI predicted surface area (i.e., 3.91 ha vs. 0.23 ha [39,100 m^2 vs. 2,300 m^2]). In this case, the Normalized Difference Vegetation Index (NDVI) appeared to be detecting metals associated with suspended silt (e.g., from Mica Creek Village activity, weathering of soils and rocks, etc.). The NDVI also predicted potential macrophyte communities at Site 7; however, *in situ* observations confirmed only the presence of suspended silt plumes. NDVI did not detect macrophyte communities that were observed *in situ* at Sites 4, 7 or 9. NDVI did predict a large macrophyte community at Site 6 in depths beyond field observation.

E-Lines Comparison

A comparison of E-Lines was completed as another method of evaluating differences between macrophyte communities predicted by NDVI and communities observed *in situ*. Further, E-Lines were used to confirm accuracy of the previous polygon surface area comparison. Maximum length and width of each polygon (i.e., polygon predicted by NDVI and polygon observed in the field) are provided for each potential long-term site in Table 3-2.

Table 3-2: E-Line Lengths (Revelstoke Reservoir, October 2009)

Site	Polygon Predicted by NDVI		Polygon Observed *In Situ*		Difference in Polygon E-Lines	
	Length (m)	Width (m)	Length (m)	Width (m)	Length (m)	Width (m)
1	151	72	151	103	0	+31
2	122	92	112	103	-10	+11
3	107	51	104	45	-3	-6
4	71	62	142	38	+71	-24
5	236	90	191	113	-145	+23
7	197	109	108	17	NC	NC
			18	14		
8	164	69	279	93	+115	+24
9	N/A		76	41	N/A	
10	344	203	79	41	NC	NC
			35	17		
11	410	79	348	104	-62	+25

N/A – Not Applicable (no NDVI polygon was present in the immediate area of assessment)

NC – Not Comparable (two *in situ* polygons observed)

Site 6 was excluded from E-Line comparison, given that this site was removed from further consideration as a longer monitoring station. Comparisons between *in situ* and satellite polygon E-Lines could not be performed for Site 9 (a NDVI polygon was not detected in the immediate vicinity) and Sites 7 and 10 (two *in situ* polygons were observed). Further, the NDVI polygon for Site 10 could not be used for comparison, given that delineation of this polygon was largely due to a silt plume influencing the NDVI prediction. Site 4 NDVI and *in* *situ* polygons were separated by a distance of nearly 150 m, suggesting the community assessed in the field was very different from that predicted by NDVI; therefore, direct comparisons are of limited utility. Comparisons of polygon length and width using E-Lines were feasible for the remaining six sites.

The difference in polygon E-lines between NDVI predictions and *in situ* observations ranged from -145 m (Site 5) to +115 m (Site 8) for length and -6 m (Site 3) to +31 m (Site 1) for width (-24 m at Site 4 was not considered, as per the rationale provided above). Polygons predicted by NDVI and those observed *in situ* generally had comparable configurations at Sites 1, 2, 3, 5, 8 and 11.

The NDVI polygon at Site 1 was accurate in length, having the exact same measurement as the polygon observed *in situ* (i.e., 151 m). Width of the NDVI polygon was approximately 30 per cent smaller than that of the *in situ* polygon, with the NDVI not detecting macrophytes collected in the farthest from shore zone during field assessments.

The *in situ* polygon observed at Site 2 had a smaller length (-10 m) and a larger width (+11 m) than that predicted by NDVI, suggesting NDVI detection was accurate based on the total length and width of found in the field (i.e., 112 m and 103 m, respectively); however, the two polygons were not fully superimposable, given the *in situ* polygon was located closer to shore.

NDVI prediction at Site 3 was very accurate, with the difference in length and width being only 3 m and 6 m, respectively. Further, the two polygons were found to superimpose almost perfectly. Site 3 had one of the smallest communities sampled in the reservoir (104 m long and 45 m wide), suggesting NDVI technology can be applied with accuracy to smaller communities.

The NDVI polygon at Site 5 was less accurate, having a length 145 m greater than the *in situ* polygon (i.e., approximately 124 per cent longer) and field observations determining a width 23 m greater than satellite detection. In addition, the NDVI polygon extended further south than the community observed *in situ*.

Site 8 had a long (279 m) and wide (93 m) community. The NDVI polygon was smaller (164 m length; 69 m width); however, the two polygons had comparable configurations and were completely superimposable. These findings suggest NDVI predictions were generally accurate in identifying general shape and location of macrophyte beds.

Site 11 had the longest macrophyte community of the eleven long-term monitoring sites (i.e., 348 m). The NDVI polygon was longer (410 m) and narrower (79 m vs. 104 m) than the community observed *in situ*, though both were observed to have a similar shape and could generally be superimposed on one another; therefore, NDVI prediction of polygon size and shape was accurate.

3.3 Macrophyte Communities & Habitat Characteristics

Appendix 4 provides macrophyte community and habitat characteristics for each potential long-term monitoring site, including location and orientation of polygons (predicted by NDVI vs. delineated in the field), depth with distance from shore at each transect (i.e., South, Centre, North), macrophyte community characteristics, and sediment and water quality observations.

3.3.1 Habitat Characteristics

Macrophyte Bed Elevations

Mean water elevation at Revelstoke Dam ranged between 572.5 and 572.7 m from September 29 to October 2, 2009 (Chart 2, Appendix 3). Reservoir water elevation during field study was similar to the 2009 mean elevation of 572.5 m. Elevation can have an effect (positive or negative) on macrophyte communities, given that some species are more sensitive to elevation change than others (e.g., minimum water depth requirements, minimum light energy requirements). To assess the potential influence of elevation on macrophyte communities in Revelstoke Reservoir during the time around baseline assessments, differences in water elevation between Mica Dam tailwater and Revelstoke Dam forebay were compared and are presented in Table 3-3.

Table 3-3: Mean Water Elevation (masl) at Mica & Revelstoke Dams (October 1 to October 3, 2009)

Location	October 1, 2009	October 2, 2009	October 3, 2009
Mica Dam Tailwater	572.542	572.650	572.667
Revelstoke Dam Forebay	572.604	572.651	572.641
Difference	0.062	0.001	0.026

Over the course of a short period of time, rapid water level changes, due to climate influence (e.g., heavy rain) and/or dam operation, have the potential to influence macrophytes; however, differences in elevation between the eleven study sites were not considered significant during October 2009 field surveys and were not anticipated to have an effect (positive or negative) on macrophyte communities during the survey.

Mean bottom elevation (based on depth measured and reservoir elevation at the time of assessment) of each site and where macrophyte beds were observed *in situ* is listed in Table 3-4. Elevations of transect points at each site are provided in Table 3 (Appendix 3). Mean site and macrophyte bed elevations for each site transect are listed in Table 4 (Appendix 3). The mean macrophyte bed elevation for a given site was derived from the mean elevation of transect points at which macrophytes were observed, extrapolated to near-shore and furthest from shore site perimeter, as determined *in situ*. In the subsequent work phases (i.e., post REV 5 start-up), comparisons of macrophyte community coverage at each given transect point, and corresponding elevation, should be undertaken and the two periods compared.

Table 3-4: Long-term Monitoring Site Mean Elevations (Revelstoke Reservoir, October 2009)

Site	Mean Site Elevation at Bottom (m)	Mean Macrophyte Bed Bottom Elevation (m)	Min / Max Macrophyte Bed Depth (m)
1	570.4	568.8	567.8 / 571.9
2	570.7	570.5	570.3 / 570.8
3	571.2	570.1	567.6 / 571.4
4	569.8	569.3	566.6 / 571.0
5	571.8	571.6	570.4 / 572.2
6	566.3	570.4	567.8 / 572.3
7	572.0	572.0	571.8 / 572.3
8	570.9	570.9	570.1 / 572.5
9	570.4	569.7	567.7 / 571.8
10	571.9	572.1	571.7 / 572.5
11	572.0	572.0	571.1 / 572.6

Mean site elevation at bottom was relatively high at the potential long-term monitoring sites, ranging from 566.3 m (Site 6) to 572.0 m (Sites 7 and 11). Sites 1 to 5 and Site 9 exhibited mean macrophyte elevations lower than the mean site elevation (568.8 m vs. 570.4 m, 570.5 m vs. 570.7 m, 570.1 m vs. 571.2 m, 569.3 m vs. 569.8 m, 571.6 m vs. 571.8 m and 569.7 m vs. 570.4 m, respectively), suggesting that macrophytes species at these sites tend to prefer mid- and furthest distances from shore, which are typically deeper. Conversely, mean macrophyte elevations were greater than mean site depths at Site 6 and 10 (570.4 m vs. 566.3 m and 572.1 m vs. 571.9 m, respectively); suggesting macrophyte species at these sites prefer near-shore and mid-distance zones. Consequently, near-shore communities at Sites 6 and 10 may be more sensitive to larger drawdowns (i.e., reduced water levels). Mean site bottom elevations and macrophyte bed elevations were comparable at Sites 7 (572.0 m), 8 (570.9 m) and 11 (572.0 m), as macrophytes were observed from near-shore to furthest from shore zones.

Bottom elevations at Sites 1 to 6 were generally lower than those at Sites 7 to 11. This trend is more evident for mean macrophyte elevations observed. Mean macrophyte bed elevations (from the bottom) ranged from 569.3 m (Site 4) to 572.1 m (Site 10), with minimum and maximum values of 566.6 m (Site 4) and 572.6 m (Site 11), respectively. The difference between minimum and maximum macrophyte bed elevation varied from 0.5 m (Sites 2 and 7) to 4.5 m (Site 6). There was no discernable trend in the macrophyte bed elevation ranges of each site with distance from Revelstoke Dam.

Subsequent to REV 5 start-up, maximum water level fluctuations in the reservoir will be approximately 0.25 m, 90 per cent of the time (BC Hydro, 2006), compared to a maximum elevation of 573.0 m. Frequency of moderate drawdown (i.e., drafting to approximately 572.5 m or by 0.5 m) would be greater, while frequency of low drawdowns (i.e., drafting to ≥571.5 m or by approximately 1.5 m) would be lower. At the time of field surveys, the reservoir water elevation ranged from approximately 572.5 to 572.7 m (0.2 m), indicating that moderate to daily variations in drawdown were already occurring. Consequently, only a low drawdown or change in drawdown frequency were considered as factors potentially influencing macrophytes communities in post REV 5 start-up compared to those assessed in October 2009.

Low drawdown could influence ~47 per cent of transect points selected for potential long-term sites (i.e., 46 out of 97 points), 33 per cent of which had macrophyte communities in October 2009 (i.e., 32 out of 97 points; Table 3-5).

Table 3-5: Transect Points Potentially Influenced by Low Drawdown

Site	Transect	Zone	Bottom Elevation (m)	Macrophytes Species Observed
1	S	A	572.2	None
	C		572.2	
	N		572.2	
3	S	A	572.4	None
	C		572.3	
	N		572.3	
	C	B	571.5	*Potamogeton amplifolius*

Table 3-5: Transect Points Potentially Influenced by Low Drawdown (Cont.'d)

Site	Transect	Zone	Bottom Elevation (m)	Macrophytes Species Observed
5	S	A	572.2	*Eleocharis acicularis*
	C		571.9	
	N		571.9	*Eleocharis acicularis*, *Potamogeton amplifolius*
	S	B	571.9	*Eleocharis acicularis*, *Potamogeton amplifolius*, *Nitella sp.*
	C		572.1	*Eleocharis acicularis*
	N		571.6	*Potamogeton amplifolius*
6	S	A	571.8	*Potamogeton amplifolius*, *Eleocharis acicularis*, *Equisetum palustre*
	C		572.0	None
	N		571.8	*Potamogeton amplifolius*
7	S	A	572.2	*Eleocharis acicularis*
	C		572.2	None
	N		572.2	*Eleocharis acicularis*
	S	B	572.0	None
	C		572.0	*Eleocharis acicularis*, *Potamogeton amplifolius*
	N		571.8	*Potamogeton amplifolius*
	S	C	572.6	None
	C		572.1	
	N		572.2	
8	S	A	571.6	*Potamogeton amplifolius*, *Nitella sp.*
	C		572.0	*Potamogeton amplifolius*
	N		572.0	*Potamogeton amplifolius*, *Nitella sp.*
	S	C	571.7	*Potamogeton foliosus*, *Nitella sp.*
9	S	A	571.6	*Nitella sp.*, *Potamogeton alpinus*
	N		571.8	*Nitella sp.*, *Potamogeton alpinus*
10	S	A	571.7	*Nitella sp.*
	C		572.3	
	N		572.3	*Nitella sp.*, *Eleocharis acicularis*
	S	B	571.7	*Nitella sp.*, *Potamogeton alpinus*
	N		572.2	*Eleocharis acicularis*
	S	C	571.8	None
	C		571.9	
	N		571.9	*Nitella sp.*
11	S	A	572.6	*Eleocharis acicularis*
	C		572.5	
	N		572.6	
	C	B	571.5	*Nitella sp.*
	S	C	572.4	*Nitella sp.*, *Eleocharis acicularis*
	C		572.4	
	N		572.4	

Transects: S – South; C – Centre; N – North

Zones: A – Near-Shore; B – Mid-Distance from Shore; C – Farthest Distance from Shore

Sites 1, 3 and 5 to 11 have the potential to be influenced (positively or negatively) by low drawdowns after REV 5 start-up. Sites 2 and 4 were not colonized by macrophytes, at the time of the baseline assessment, at depths influenced by low drawdown (i.e., macrophytes were collected at elevations lower than 571.5 m), suggesting these sites may be of lesser interest for consideration as long-term monitoring sites, except where macrophyte communities comprise species of interest (e.g., endangered, invasive, sporadic).

Substrate Characteristics

Qualitative substrate observations were made at the near-shore, mid-distance and farthest from shore zones of the Centre Transect (i.e., C/A, C/B, C/C) for each site (Table 3-6).

Table 3-6: Substrate Characteristics (Revelstoke Reservoir, October 2009)

Site	Zone	Colour	Consistency & Texture	Odour	Other Features
1	A	Grey-Brown	Gravelly (with sand and cobbles)	Odourless	N/A
	B	Black	Gritty; watery; mixture of sand and gravel	Odourless	Abundant small organic debris (sticks, bark pieces); heterogeneous
	C	Dark Brown	Unconsolidated; silky; gritty	Odourless	Abundant organic debris; homogenous throughout
2	A	Grey-Brown	Gravelly (with cobbles and sand)	Odourless	N/A
	B	Black-Grey	Thick like pudding; silky, gritty, watery	Light H_2S odour	No woody debris, many macrophyte roots; homogenous throughout
	C	Dark Brown	Unconsolidated; watery; mixture of gravels, sand and clay	Odourless	Some small twigs; homogenous throughout
3	A	Dark Brown-Grey	Thick like pudding; silky; gritty	H_2S odour	N/A
	B	Dark Brown-Grey	Thick like pudding; silky; gritty	H_2S odour	Abundant macrophyte roots; small woody debris; flakes of mica/silica; homogenous throughout
	C	Dull Grey	Unconsolidated; gritty, gravelly	H_2S odour	Very little debris; few macrophyte roots; heterogeneous
4	A	Brown-Grey	Gritty; Gravelly (with sand and cobbles)	Odourless	N/A
	B	Dull Grey	Thick like pudding; silky	H_2S odour	Abundant macrophyte roots, small woody debris and macrophyte pieces; homogenous throughout
	C	Dull Grey	Unconsolidated; watery; silky (with gravels and cobbles)	H_2S odour	Abundant small debris (macrophyte roots, wood flakes); heterogeneous (silty layer on top of gravels/cobbles)
5	A	Brown	Gritty; sandy (with some gravel)	Odourless	N/A
	B	Dull Grey	Unconsolidated; gritty; gravelly	Odourless	Homogenous throughout (top layer of grass with fine sands underneath)
	C	Black	Thick like pudding; silky	H_2S odour	Abundant macrophyte roots, dead macrophytes and woody debris; homogeneous throughout
6	A	Brown	Silky; gravelly (with sand and cobbles)	Odourless	N/A
	B	Dull Grey	Unconsolidated; gritty	H_2S odour	Thick layer of woody debris over top of sand and clay; heterogeneous
	C	Dull Grey	Thick like pudding; silky	H_2S odour	Little debris; homogenous throughout

Table 3-6: Substrate Characteristics (Revelstoke Reservoir, October 2009) (Cont.'d)

Site	Zone	Colour	Consistency & Texture	Odour	Other Features
7	A	Grey-Brown	Gritty; gravelly (with sand and cobbles)	Odourless	N/A
	B	Dull Grey-Green	Thick like pudding; silky	Odourless	Few small macrophyte roots; homogenous throughout
	C	Dull Grey	Unconsolidated; gritty	Odourless	Small layer of debris (e.g., grass roots) on top of silt and clay; heterogeneous
8	A	Brown	Gritty (with sand)	Odourless	N/A
	B	Black & Rusty Brown	Gel-like; very silky	H_2S odour & Odourless	Very little debris; heterogeneous; black layer (H_2S odour) on top of rusty brown layer (odourless)
	C	Black	Thick like pudding; very silky	H_2S odour	Abundant macrophyte roots and pieces; homogenous throughout
9	A	Brown	Gritty (with sand)	Odourless	N/A
	B	Black	Thick like pudding; silky	Odourless	Little debris and some macrophyte roots; homogenous throughout
	C	Black	Thick like pudding; silky	Odourless	Abundant woody debris and *Nitella sp*. at the surface; homogenous throughout
10	A	Grey	Cobbles (with gravels, sand and boulders)	Odourless	N/A
	B	Black & Dull Grey	Unconsolidated; thick like pudding; silky; gritty (with sand and mica/silica)	Odourless	Small woody debris and macrophyte roots; heterogeneous; black layer (thick like pudding) on top of dull grey layer (gritty with sand and mica/silica)
	C	Dull Grey	Unconsolidated; gritty	Odourless	Some woody debris and lots of mica/silica; homogenous throughout
11	A	Brown	Silky (little sand, gravels and cobbles)	H_2S odour	N/A
	B	Black	Thick like pudding; silky	H_2S odour	Some macrophyte roots; homogenous throughout
	C	Light Brown	Gel-like; silky	Odourless	Some macrophyte roots; heterogeneous; grey streaks observed

Zones: A – Near-Shore; B – Mid-Distance from Shore; C – Farthest Distance from Shore

N/A: Not Applicable (only surface sediments observed in the near-shore zone)

Four dominant substrates were observed during baseline assessments: cobbles (64-256 mm diameter), gravels (2-64 mm diameter), sand (0.0625-2 mm diameter) and clay (< 0.0625 mm diameter). Cobbles and gravels appeared to be more abundant in the southern part of the reservoir, while sand was more dominant in the south and north.

No trends were observed in other substrate characteristics. Consistency and texture of sediment varied throughout the reservoir, ranging from gritty and gravelly to silky to thick and pudding-like to gel-like. *In situ* observations found sediment to be odourless in most cases, while some samples exhibited a hydrogen sulphide (H_2S) odour. Organic debris (e.g., macrophyte roots, macrophyte pieces, small woody debris) were generally noted in samples collected in mid-distances and furthest from shore. Sediment was homogenous in fourteen samples, while the remaining eight were heterogeneous in consistency.

Transect points located in undisturbed areas (i.e., Sites 6, 8, 9) were found to have brown-appearing sediments near-shore and grey-to-black sediment furthest from shore. Sediment consistency was silky near-shore and pudding-like with a silky texture furthest from shore. Transect points located near creek confluences (i.e., Sites 2, 3, 4, 7) tended to have grey-brown sediment colour near-shore and were generally dull grey and heterogeneous in consistency furthest from shore. Sediment consistency was more gravelly with notable sand and cobbles near-shore (except Site 3), and being more thick, pudding-like and silky at mid-distances from shore. Substrate at transect points located near anthropogenic activities (i.e., sites 1, 3, 5, 10, 11) did not have any consistency in colour, texture or smell.

Soil erosion, associated with precipitation, is a main source of sediment input into creeks and rivers, subsequently transporting and depositing these materials to reservoirs (Morris and Jiahua, 1998). Several studies have reported that tributary inflow does not readily mix with main stream flow, resulting in abrupt changes to sediment colour for some distance downstream from the confluence (Murthy, 1996; Cohen, 2003; Vanoni, 2006).

Sediments at Site 1 (the potential long-term monitoring site closest to Revelstoke Dam) had similar characteristics (e.g., colour, consistency) to those of Site 2, suggesting Site 1 was far enough from the dam so as not to be located in any area of existing high sediment deposition. Flows in a reservoir tend to decrease with proximity to the dam. This decrease in flow results in a loss of transport capacity and subsequent deposition of sediments; however, smaller sediment particles travel farther into the reservoir before deposition (USACE, 1997). Deep reservoirs, such as Revelstoke Reservoir, do not fully mix and are more conducive to the formation of turbidity currents (i.e., where currents dominated by suspended solids plunge and travel along the sloping bottom as an underflow, or an interflow in a stratified system where the density of the underflow equals that of the water column).

Hydrogen sulfide (H_2S) imparts sediments with a distinctive smell (i.e., odour reminiscent of rotten eggs), and usually indicates anoxic sediments (i.e., lack of oxygen). Anthropogenic activities are usually an important source of organic matter in reservoirs and can cause anoxic sediments. No notable trend in hydrogen sulfide odour was evident at sites near anthropogenic activities (i.e., Sites 1, 3, 5 and 11), given that all sediments collected at Site 1 and most sediments collected Site 5 were odourless, while H_2S odours were more prevalent at Sites 3 and 11. Wood and macrophyte debris were observed in sediments collected along the reservoir, though no correlation was discernable between hydrogen sulphide odour and debris present in sediment. During 2009 baseline assessments in the Revelstoke Reservoir, there was no obvious trend in sediment odour (e.g., with distance from shore, water depth).

Water Quality

The mean values of temperature, conductivity, pH, redox, turbidity and dissolved oxygen (DO) for water by site are provided in Table 3-7.

Table 3-7: Water Quality Characteristics by Site (Revelstoke Reservoir, October 2009)

Parameter	1	2	3	4	5	6	7	8	9	10	11
Temperature (°C)[1]	12.55	14.46	13.33	13.39	12.92	11.92	10.07	11.70	7.88	7.38	7.65
Conductivity (µS/cm)[2]	98	96	96	100	102	104	86	102	148	129	131
pH	7.93	7.94	7.92	7.90	7.79	7.95	7.57	7.78	7.88	7.83	7.88
Redox (mV)	187	201	182	201	203	185	181	196	189	228	230
Turbidity (NTU)[3]	42.9	1.9	0.6	7.4	2.2	11.1	3.9	8.9	3.7	1.2	25.6
DO (mg/L)	9.67	9.42	10.32	10.26	10.52	10.56	11.05	10.60	11.10	11.64	11.67
DO (%)	90.8	92.3	98.6	98.2	99.6	98.0	98.0	97.7	93.5	96.8	97.6

1. Darker shading represents increasing temperature.
2. Darker shading represents conductivity measurements > 110 µS/cm.
3. Darker shading represents turbidity measurements > 10 NTU.

Temperature

Water temperature is an important variable that affects the suitability of an ecosystem for aquatic organisms. Factors which can influence water temperature include seasonal and daily changes in sunlight energy, shade, air temperature, stream flow, water depth, inflow of groundwater or surface water, and the colour and turbidity of the water. Mean air temperature in 2009 was slightly lower than the mean air temperature from 1984 to 2009 (Table 1, Appendix 3), suggesting the mean water temperature of Revelstoke Reservoir in 2009 may also be slightly lower than previous years. Water temperatures, consistently outside of the optimal temperature range for aquatic life (i.e., above 15-20°C; EPA, 1998) may stress inhabiting organisms, thus having a negative effect on sensitive species. Given that baseline assessments took place in October, all temperatures measured were predictably below the optimal range of 15-20°C, ranging from 7.38°C (Site 10) to 14.46°C (Site 2). Consequently, these lower temperatures were likely a contributing factor to the declining growth of macrophyte species.

High water temperatures (up to an organism-specific limit) generally increase biological activity for many organisms (Fidler and Oliver, 2001; Haidekker, 2005). Temperature also affects biological activity by influencing water chemistry. Warm waters contain less dissolved oxygen (DO) than cooler waters, as solubility of oxygen in water is temperature-dependent (Mel'nichenko *et al.*, 2008). Such reduced DO levels may be insufficient to support development of macrophyte communities. In the Revelstoke Reservoir, mean temperatures during the October 2009 baseline assessments decreased gradually with increasing distance up reservoir from the Revelstoke Dam. Mean temperatures were generally higher at down reservoir sites compared to up reservoir, tending to be more favourable to vegetation growth closer to Revelstoke Dam vs. sites further up reservoir. Air temperature may have had a greater influence on water temperature up reservoir, given that sites located closer to Mica Dam were much shallower. In October, when seasonal air temperatures decline, shallower sites become correspondingly colder more quickly, preventing later seasonal growth of most macrophyte species.

Sites located near anthropogenic activities (e.g., forestry, waste discharges, transportation rights-of-way, recreation sites) in the Revelstoke Reservoir (i.e., Sites 1, 3, 5, 10, 11) did not have temperatures higher than other selected sites, suggesting Revelstoke Reservoir waters were not influenced by thermal pollution. Anthropogenic activities might have a greater effect at other time of the year; however, *in situ* water quality profiles only provide information at the time of field survey. Anthropogenic activities may cause thermal pollution (i.e., degradation of water quality by any process that changes ambient water temperature). Discharge of heated water from industrial processes can increase the reservoir water temperature (Brown et al., 1983). Removal of shading vegetation along reservoir banks and increases in water turbidity due to anthropogenic activities can be other sources of thermal pollution (Henry and Heinke, 1996).

Dissolved Oxygen (DO)

Dissolved oxygen (DO) analysis measures the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. Oxygen dissolves into water by diffusion from the surrounding air, by aeration (rapid movement) and as a waste product of photosynthesis (Poppe, 1987). Water at each of the eleven potential study sites in Revelstoke Reservoir was well oxygenated, with DO levels ranging from 9.42 mg/L (Site 2, located at the confluence with La Forme Creek) to 11.67 mg/L (Site 11). Riverine waters are usually more oxygenated than lacustrine waters, given that water movement tends to cause more oxygen to be introduced into the water, thus explaining why up reservoir sites were slightly more oxygenated than those down reservoir. Higher DO levels at up reservoir sites may also be attributed to lower water temperatures (due to shallower depths) at these sites.

Per cent (%) DO levels ranged from 90.8% (Site 1) to 99.6% (Site 5). Total dissolved gas concentrations in water entering Revelstoke Reservoir from Mica Dam are typically below the provincial water quality guideline of 110% saturation throughout most of the year (BC Hydro, 2001). DO levels above 90% (and 5 mg/L) are favourable to the development of macrophyte communities (EPA, 2002). Smith (1990) noted that Revelstoke Reservoir DO levels were at saturation in surface waters and generally above 70% saturation in the remainder of the water column. DO measurements taken in the Revelstoke forebay between August 1996 and July 2000 showed similar trends (BC Hydro, 2001). DO levels measured as a per cent (%) were lowest and highest at sites located near anthropogenic activities (90.8% [Site 1] and 99.6% [Site 5]), suggesting that land use may not have imparted a discernable effect on DO levels.

Conductivity

Conductivity provides an estimate of the amount of total dissolved ions in water. Many factors influence the conductivity of freshwater, including geology, watershed size, input from point and non-point sources of nutrients and minerals, atmospheric fallout, evaporation rates, precipitation and bacterial metabolism (McNeil and Cox, 2000). Revelstoke Reservoir had a mean conductivity of 126 µS/cm prior to the impoundment phase, a measurement which did not change significantly with season or depth (Triton, 1992). Conductivity measurements collected during 2009 field surveys ranged from 86 µS/cm (Site 7) to 148 µS/cm (Site 9). These low values suggest depleted nutrient and mineral levels throughout the reservoir. Conductivity was generally higher at up reservoir sites (i.e., Sites 9 to 11) compared with those assessed downstream, suggesting releases from upstream sources through the Mica Dam provide nutrient inputs to Revelstoke Reservoir. Nevertheless, conductivity measurements remained low throughout the reservoir during field surveys (i.e., 86 to 148 µS/cm). As such, it is unlikely that a discernable difference in effect (positive or negative) was imparted by conductivity between macrophyte communities located at sites up reservoir and those down reservoir.

Conductivity measurements, both prior to the impoundment phase and in October 2009, were similar, suggesting changes in land use activities (e.g., logging, urbanization) throughout the Revelstoke Reservoir watershed between 1984 and 2009 did not appear to have a notable effect on nutrient inputs at selected potential long-term sites; however, given that conductivity data were not available for macrophyte sampling sites between 1984 and 2009, this hypothesis could not be confirmed.

Conductivity can have an influence on the distribution and health of macrophytes, with some species being more sensitive to excessively high or low values than others. For example, Holmes and Whitton (1975) reported that *Ranunculus aquatilis* was negatively correlated to conductivity (i.e., increases in conductivity lead to corresponding decreases in *R. aquatilis* coverage), while several species of *Potamogeton* can be positively correlated to conductivity; however, there were no notable correlations between species and specific environmental parameters.

pH

pH is a measure of the hydrogen ion concentration (or acidity) in water. A pH of 7 is considered neutral. Values lower than 7 are considered acidic, while values higher than 7 are basic. Many important chemical and biological reactions are strongly affected by pH. In turn, chemical reactions and biological processes (e.g., photosynthesis, respiration) can influence pH (CCME, 1999). Prior to the impoundment phase, the reservoir had a mean pH of 7.5, a measurement which did not significantly change with season or depth (Triton, 1992). In October 2009, pH values ranged from 7.57 (Site 7) to 7.94 (Site 2), and were slightly lower at up reservoir sites than those assessed down reservoir. If water becomes either too alkaline or acidic, it can be inhospitable to many species of macrophytes. Revelstoke Reservoir water was found to be slightly basic at all sites studied, suggesting that pH could prevent or cause certain species to grow, though it did not impart a decisive influence on macrophyte community presence or absence between potential long-term sites.

Redox

The decomposition of organic matter proceeds in a succession of redox reactions oxidizing an organic substance to yield carbon dioxide and water. Oxidation-reduction (i.e., redox) reactions are characterized by the flow of electrons between oxidized and reduced states toward equilibrium (Wetzel, 2001). When oxygen is dissolved in water, a redox potential (Eh) is generated. Dissolved organic compounds effectively lower redox potential in sediment and reduce the depth to the redox discontinuity (RPD) layer, a zone of rapid change from positive to negative Eh values (the transition between oxic, oxidizing and anoxic reducing layers; Sampou and Oviatt, 1991; Levington, 1995). High rates of organic matter loading eventually create anoxic sediments with Eh levels of less than 0 mV and surface RPD (Hargrave *et al.*, 1997). In freshwater, redox can range between +500 mV in the oxic zone to approximately -200 mV in the sulfidic- and methane-based zones (Mackie, 2004). The dimensions of these zones vary depending on the concentration of decomposed organic substances in sediment and turnover rates of those sediments. Redox values can often fluctuate in the range of ±50 mV (Schüring et al., 2000).

During October 2009 baseline assessments, redox ranged from 181 mV (Site 7) to 230 mV (Site 11), and did not exhibit any obvious trend with distance from Revelstoke Dam. Redox values were representative of an oxic zone environment at each of the eleven potential long-term study sites. Redox values in freshwater ecosystems mostly depend on the type of rocks present in the watershed (Schüring et al., 2000), explaining why there are few differences between measurements at selected sites. Reductive agents (e.g., organic compounds) are a contributing factor in the decrease of oxygen in water. Reductive agents also decrease the redox potential, indicating the deterioration of water quality.

The lowest redox values measured among monitoring sites were reported at Site 3 (182 mV; located at the confluence with Big Eddy Creek and downstream of a private ferry landing and logging road), Site 7 (181 mV; located at the confluence with Kirbyville Creek) and Site 6 (185 mV; located in an undisturbed area). Consequently, there was no discernable trend in redox values with distance from the Revelstoke Dam and/or with land use activities. Macrophyte absence at Sites 3 (Zone A), 6 (C/A, C/B, Zone C) and 7 (C/A, C/B, Zone C) may be partially attributed to low redox values; however, redox measurements at these sites were representative of an oxic zone. Consequently, the influence of other parameters (e.g., depth, temperature) is likely to be a greater determinant in macrophyte absence at these sites.

Turbidity

Turbidity is a measure of water clarity. Turbidity in water is caused by suspended matter (e.g., clay, silt, organic matter, plankton, other microscopic organisms) that interferes with the passage of light through water (APHA, 1998). Very clear water, however, is not necessarily a sign of good water quality, as suspended particles can be induced to fall (decreasing turbidity readings) by high acid or salt conditions. Turbidity of natural waters tends to increase during runoff events due to increased overland flow, stream flow and erosion. Increased turbidity reduces light penetration, thereby decreasing the growth of aquatic plants and organisms (Gradall and Swenson, 1982). Further, very turbid waters will reduce the diversity and coverage of macrophyte communities.

In October 2009, Revelstoke Reservoir turbidity ranged from 0.6 NTU (Site 3) to 42.9 NTU (Site 1). Turbidity typically ranges from 0 to 1,000 NTU in freshwater ecosystems (i.e., lakes and rivers), with values exceeding 10 NTU considered turbid (Gradall and Swenson, 1982). Turbidity exceeded 10 NTU at Sites 1 (42.9 NTU), 6 (11.1 NTU) and 11 (25.6 NTU); however, only Site 6 water was observed to be slightly turbid. Sites 1 and 11 waters were clear; however, slightly elevated turbidity readings were reported which may be attributed to sediment being stirred up during study boat operation. The water quality profile collected at Site 6, an undisturbed site, occurred under windy conditions where deposited sediments were likely stirred into the water column from the site bottom. Lower turbidity values measured at other sites indicated no discernable correlation between anthropogenic activities and/or creek confluences and turbidity. Of note, Revelstoke Reservoir is usually more turbid in the spring when several glacial tributaries transport sediments (Downie Creek being one of the major contributors; Hirst, 1991).

Studies implemented in the Kinbasket Reservoir, upstream of Golden, measured turbidity levels less than 2 NTU, except in the vicinity of large rivers such as the Sullivan (NTU = 50.0; BC Hydro, 2009). Turbidity measurements during October 2009 field surveys in the Revelstoke Reservoir were slightly higher (Table 3-7), likely as a result of climate conditions (e.g., wind, rain). Climate conditions were similar at all monitoring stations during baseline assessments. Turbidity did not appear to influence macrophyte community composition and distribution between down reservoir and up reservoir sites in October 2009.

Transparency

Water transparency was based on *in situ* visual observations and Secchi disk readings, and was high in the reservoir. Macrophyte communities present at most transect points could be seen from the boat. Secchi depths were measured at Sites 4 (2.5 m), 6 and 9 (2.9 m at both). Water transparency was also reported as high in previous studies (Fleming and Smith, 1988; Triton and Summit, 1995). Secchi depths measured in 1991 indicated that water transparency varied between 6 and 8 m in November.

Water bodies with medium and dense macrophyte cover are characterized by a low concentration of suspended sediments and, thus, high water transparency. Such high water transparency enables light to penetrate deeper into the reservoir's water column and decreases attenuation of photosynthetically active radiation (PAR) with depth, thereby facilitating colonization of macrophyte communities (usually adapted to low irradiances) in deeper areas (O'Sullivan and Reynolds, 2004). Conversely, water transparency decreases where coverage and density of aquatic macrophytes are reduced, such as in cases of eutrophication (Hargeby *et al*., 1994). In freshwater ecosystems, where macrophytes reappear after a period of absence, water transparency gradually improves with increasing vegetation cover. The lowest water transparencies, as measured using a Secchi disk, were reported at Sites 9 (2.9 m), 4 (2.5 m) and 6 (2.9 m). Sites 9 and 6 were located in undisturbed areas, while Site 4 was at a creek confluence. Secchi readings confirmed turbidity measurements taken concurrently at study sites in October 2009 and suggested that climate conditions (e.g., wind, rain) may impart a greater effect on water transparency than land use or the given site location. The research of Shulman and Bryson (1961) further substantiates the influence of climate conditions on water transparency, with the depth of wind frictional influence observed to be between 2 and 3.5 m on a moderate-sized lake (Lake Mendota).

3.3.2 Macrophyte Coverage

Macrophytes were observed qualitatively and quantitatively (dominance ranking based on estimated per cent [%] cover) through visual (boat-based) observations. A list of the macrophyte species found in Revelstoke Reservoir during the October 2009 baseline assessment is provided in Table 3-8.

Table 3-8: Macrophyte Species Found in Revelstoke Reservoir (October 2009)

Species	Ecology	Notes
Alpine Pondweed *Potamogeton alpinus*	Common aquatic perennial weed found in shallow cold water ponds and lakes. Plants submersed with narrow leaves below water surface and broader leaves found on water surface.	Yellow Listed
Big-leaf Pondweed *Potamogeton amplifolius*	Commonly confused with Leafy Pondweed and found in similar habitats. Plants submersed with leaves below water surface and on water surface.	Yellow Listed
Brittlewort/stonewort *Nitella sp.*	Bright green algae commonly found in shallow to deep water of soft water to acidic lakes and bogs (conductivity <110). Often grows in deeper water than other flowering plants and frequently forms thick mats along the bottom.	Not listed
Common Water-crowfoot *Ranunculus aquatilis*	Annual/perennial aquatic plant generally found in bogs, ponds slow streams and marshes at shallow depths <1 m. Majority of plant is submerged with flowers at surface. Leaves are common when plant is only partially submerged in slow moving water, but may be absent in streams.	Yellow Listed
Dwarf Hairgrass *Eleocharis acicularis*	Annual or perennial spike sedge with long, grass-like stems to about 15 cm in height. Generally found in exposed moist organic soils and in shallow water up to 1 m in depth. Commonly occurs is marshes, vernal pools and bogs where it forms large, rooted mats.	Yellow Listed

Table 3-8: Macrophyte Species Found in Revelstoke Reservoir (October 2009) (Cont.'d)

Species	Ecology	Notes
Eurasian water-milfoil *Myriophyllum spicatum*	Submersed aquatic perennial herb, where the whorled leaves are present near the surface and flowers are formed above the surface of the water body. A serious invasive aquatic weed found in a range of habitats throughout North America. Generally plants are found in water depths between 0.5 to 7 m.	Exotic (Invasive)
Leafy Pondweed *Potamogeton foliosus*	Common aquatic perennial weed found in a range of habitats including brackish waters. Plants are generally submersed with leaves below and on top of water surface. Generally found in 0.5 to 2.5 m of water.	Yellow Listed
Marsh Horsetail *Equisetum palustre*	Submerged perennial herb found in nutrient-rich, wet to moist soils and occasionally in submerged areas of bogs marshes and lakes.	Yellow Listed

(MOE, 2010; USDA, 2010).

The estimated per cent (%) coverage of taxa observed in Revelstoke Reservoir during October 2009 baseline assessments is listed in Table 3-9. The coordinates for the transect points of each site (in UTMs) are identified in Table 5, Appendix 3. Additional information on taxa dominance is provided in the Appendix 4 (Site Descriptions).

Table 3-9: Estimated Percent (%) Coverage of Macrophytes (By Transect Survey Point), Revelstoke Reservoir (October 2009)

Species	Transect		1	2	3	4	5	6	7	8	9	10	11
Eleocharis acicularis	A	S					100	20	60				30
		C					100						20
		N					50		70			10	5
	B	S					70						
		C					100		50				
		N										90	
	C	S											40
		C											50
		N											10
Equisetum palustre	A	S						20					
		C											
		N											
	B	S											
		C											
		N											
	C	S											
		C											
		N											
Myriophyllum spicatum	A	S											
		C											
		N											
	B	S	5										
		C	5										
		N	5										
	C	S	ind				10						
		C											
		N					50						
Nitella sp.	A	S								50	90	100	
		C									80	100	
		N								50	90	90	
	B	S					<10				60	95	100
		C	5							50	80		100
		N	5		<5					30	80		100
	C	S								30	ind		40
		C	ind	<5						70	ind		50
		N	ind		<5					50	ind	10	60
Potamogeton alpinus	A	S									5		
		C											
		N									5		
	B	S	40								10	5	
		C									10		
		N	80								10		
	C	S		<5									
		C								20			
		N								50			
Potamogeton amplifolius	A	S		90		70		55		50			
		C		90		85				100			
		N					10	90		50			
	B	S	40	90	85	80	20	ind					
		C	80	90	65	60			50				
		N		90	85	50	90	80	75	30			
	C	S	ind		85		90						
		C	ind		65		85						
		N		90	85	ind	50						
Potamogeton foliosus	A	S											
		C											
		N											
	B	S								90			
		C								50			
		N								30			
	C	S								70			
		C								10			
		N											
Ranunculus aquatilis	A	S											
		C											
		N											
	B	S											
		C											
		N											
	C	S											
		C											
		N			<5								

Indeterminant (ind) - Species present, though per cent (%) coverage could not be estimated given poor water visibility due to suspended sediments and/or depth of site.

Darker shading represents transect points with higher per cent (%) coverage.

Categories are 0-20%, 20-40%, 40-60%, 60-80% and 80-100%.

Eight macrophyte taxa were observed in Revelstoke Reservoir in October 2009: *Eleocharis acicularis* (needle spikerush), *Equisetum palustre* (marsh horsetail), *Myriophyllum spicatum* (Eurasian water-milfoil), *Nitella sp.*, *Potamogeton alpinus* (alpine pondweed), *P. amplifolius* (large-leaf pondweed), *P. foliosus* (leafy pondweed) and *Ranunculus aquatilis* (white water crowfoot). Their distribution is discussed in Section 4.2.1, while the ecology of each species is described in Appendix 5.

Nitella sp. and *P. amplifolius* were considered "common" taxa, with each taxon observed at eight of the eleven survey sites and found to be frequently dominant. Per cent (%) coverage of *Nitella sp.* was especially high at up reservoir sites, with values as great as 100% (Sites 10 [S/A and C/A] and 11 [S/B, C/B and N/B]), while *P. amplifolius* coverage was generally greater at down reservoir locations, reaching 100% for one transect point (Site 8, C/A).

Eleocharis acicularis and *P. alpinus* were both observed at five of the eleven survey sites, while *Myriophyllum spicatum* was observed at two. Coverage of *Eleocharis acicularis* was highest at Site 5 (100% at S/A, C/A and C/B), *P. alpinus* coverage reached 80% (Site 1, N/B) and *Myriophyllum spicatum* coverage peaked at 50% (Site 5, N/C). *Equisetum palustre*, *P. foliosus* and *Ranunculus aquatilis* were considered "rare" species, given that each was observed at only one site. Of these three taxa, only *P. foliosus* was observed to have notable coverage (up to 90% at Site 8, S/B).

Potamogeton species were dominant in the southern portion of the reservoir (from Site 1 to Site 8), particularly *P. amplifolius*, which was dominant in each ecological zone (i.e., near-shore, mid-distance, farthest from shore). *P. alpinus* and *P. foliosus* were only dominant in mid-distance and furthest from shore zones. In addition, *P. alpinus* was sub-dominant nearest to shore and mid-distance from shore at Site 9, and mid-distance from shore at Site 10 (i.e., northern portion of the reservoir).

Nitella sp. was observed in all ecological zones and most dominant in northern reaches of the reservoir (Sites 8 to 11). This species was also dominant in zones furthest from shore at Sites 1 and 2, and sub-dominant in mid-distance zones of Sites 1 and 3 and the zone furthest from shore zone at Site 3.

Eleocharis acicularis was dominant at Sites 5, 7, 10, 11 and sub-dominant at Site 6, suggesting this species was more adapted to up reservoir sites. *E. acicularis* was primarily dominant in nearest and mid-distance zones, though also dominant furthest from shore at Site 11. Further, *E. acicularis* was sub-dominant nearest to shore at Sites 6 and 10 and furthest from shore at Site 11.

Myriophyllum spicatum was only dominant furthest from shore at Site 5, and sub-dominant at the mid-distance and furthest from shore zones of Site 1. *Ranunculus aquatilis* was sub-dominant in the furthest from shore zone of Site 3, while *Equisetum palustre* was found nearest to shore at Site 6.

4.0 Discussion

This section provides a discussion of baseline results for the 2009 (Phase 1) Revelstoke Reservoir Macrophyte Assessment Program. Discussion focuses on: a review of the techniques used during reservoir reconnaissance and site selection; ecological descriptions of observed macrophyte communities; evaluation of environmental parameters influencing macrophyte distribution; and, assessment of potential influences to macrophyte communities that may result from start-up of REV 5 operations.

4.1 Reservoir Reconnaissance & Site Selection

SPOT Satellite Imagery was captured on September 22, 2009, just prior to the start of baseline assessments on September 28, 2009, to ensure that macrophyte communities were at a comparable stage of growth for satellite data acquisition, aerial reconnaissance and field survey. Although these three data collection methods were complementary, each approach had advantages and disadvantages.

Using the SPOT satellite imagery and Normalized Difference Vegetation Index (NDVI; Section 2.2.2), overview basemaps and inset maps of Revelstoke Reservoir macrophyte communities were generated at scales of 1:15,000 and 1:5,000, respectively (Appendix 6). Given that macrophyte communities have not previously been assessed in the Revelstoke Reservoir, use of basemaps was an effective method to evaluate the 129 km length of reservoir, extending from the Mica to Revelstoke dam. Small macrophyte communities (<250 m) were illustrated using pixel points, while larger communities were delineated within polygons. In general, only communities delineated within polygons were considered as potential long-term assessment sites.

The satellite-based remote sensing component was, to a large degree, effective in delineating macrophyte communities. After various trials and revisions, the chosen algorithm and satellite dataset enabled prediction of areas with high potential for macrophyte communities; however, estimation of macrophyte coverage area was less accurate and required both supportive aerial and *in situ* confirmations. Calibration of SPOT imagery, based on *in situ* observations, was conducted to ensure that macrophyte boundaries were appropriately represented.

The reconnaissance flight was used as a transition tool between NDVI-generated imagery and baseline assessments. Given this was the first time in which the SPOT satellite was used to assess aquatic plant communities in the Revelstoke Reservoir, the reconnaissance flight enabled confirmation of macrophyte presence over large areas delineated by NDVI polygons. The overview flight was also effective in identifying the presence of other macrophyte communities not previously detected using NDVI algorithms. Twenty potential long-term sites were selected prior to the reconnaissance flight, with eleven of these sites subsequently selected for baseline assessment and considered most representative of the varying conditions and locations of reservoir (e.g., undisturbed, near a creek confluence, near anthropogenic activity, etc.). Aerial observation was a useful method for attaining a more accurate view of macrophyte communities; however, this approach would not have been effective without satellite imagery, given the difficulties associated with trying to observe all communities at high plane speeds and altitudes.

Macrophyte community boundaries were established at each selected study site during baseline assessment. The same protocol was applied at each of the eleven sites (see Section 2.4.3); however, the shoreline of Site 6 was highly convoluted and embayed, resulting in all of the three transects (i.e., south, centre, north) converging at the same, furthest from shore, transect point (see Site 6 in Appendix 4). As such, Site 6 was only assessed qualitatively in comparisons with other long-term monitoring sites.

Further refinement of satellite imagery, using data collected during the reconnaissance flight and field surveys, was limited, given a number of factors listed in Section 2.2.2, and including time of imagery acquisition and physical and chemical constituents present in the reservoir. Satellite imagery was effective in confirming presence of macrophyte communities based on comparison of polygon surfaces with *in situ* observations; however, caution should be used when applying NDVI imagery at smaller scales (e.g., site scale).

4.2 Assessment of Macrophyte Communities

4.2.1 Macrophytes Distribution (October 2009)

Phase 1 (baseline) of the Revelstoke Reservoir Macrophyte Assessment Program provided information on the richness of macrophyte communities at eleven sites selected as potential long-term monitoring sites, as well as per cent (%) coverage of each species as documented at each transect point used to represent the long-term sites. Trends in macrophyte coverage and taxa richness with distance up reservoir from the Revelstoke Dam (i.e., from Site 1 to Site 11) were not similar, nor trends in the presence of macrophyte beds increasing with distance from shore (Chart 6, Appendix 3). The absence of such trends may be attributed to a number of factors, including:

- not all macrophyte species have the same morphology. For example, *Eleocharis acicularis* is small in size with no leaves, while *Potamogeton amplifolius* has large leaves and, as such, smaller numbers can still produce comparatively large spatial coverage;
- in shallow depths, water level fluctuations and wave erosion regularly and repeatedly create open patches in macrophyte communities where pioneer/opportunistic species (i.e., r-strategist species) can develop, thereby helping to maintain diversity near-shore. Shallow depths typically produce diverse communities, dominated by equilibrium species (i.e., K-strategist species) with low coverage rates; and,
- some extremely productive macrophytes have morphological adaptations that effectively reduce the opportunity (out compete) for other aquatic plants to colonize a site. *Myriophyllum spicatum* has a high canopy-forming capability that often results in mono-specific communities.

Macrophyte communities showed two distinct distributions for two dominant species (i.e., *Potamogeton amplifolius*, *Nitella sp*.). *Potamogeton amplifolius* was found to be dominant at down reservoir sites (i.e., Sites 1 to 8; see Appendix 4), while *Nitella sp*. was dominant at transect points of up reservoir sites (i.e., Sites 8 to 11). Sebastian *et al.* (1995) divided the Revelstoke Reservoir into three zones based on depth and morphometry. Zone 1 (the most lacustrine-like and southernmost zone), was located between Revelstoke Dam and Downie Creek (i.e., Sites 1 to 5) and had maximum water depths usually greater than 80 m. Zone 2 (a transitional zone in the reservoir mid-section) was located between Downie Creek and Ruddock Creek (i.e., Sites 6 to 8), with maximum depths between 40 and 80 m. Zone 3 (a riverine-like zone in the reservoir's northernmost section) was located between Ruddock Creek and Mica Dam (i.e., Sites 9 to 11) and had maximum depths less than 40 m. Given that *Potamogeton amplifolius* was dominant in southern and mid-sections of the reservoir; this zonation suggests the species is competitive at locations where reservoir depths are high. The competitive nature of *P. amplifolius* (an r-strategist species) may be attributed to its large leaves, which enable greater use of PAR and facilitate colonization of deeper waters. Conversely, the zonation suggests *Nitella sp.*, a species having less surface area available for absorption of PAR, is more likely to colonize shallower areas, such as those in the northernmost section of the reservoir.

In shallow water, macrophyte production is limited by water volume and disturbance created by wave action and herbivory activities. Small taxa, such as *Nitella sp*., usually dominate in a mosaic of vegetated, disturbed shallow patches (Gilman *et al.*, 2008). Conversely, macrophyte communities in deep water are limited by low light intensity. Species tolerant to low light and capable of rapid growth upward into improved light conditions tend to dominate. *Potamogeton amplifolius* is evergreen, with large leaves, thick stems and sturdy shoots that arise from underground rhizomes (see Appendix 5). These traits explain the long-term persistence of this species through reduced herbivory and rapid re-establishment of individual plants (Magnuson, 1990).

In October 1998, the reservoir's upper strata were nearly isothermal at approximately 11°C to a depth of approximately 60 m. During fall and winter, the reservoir's surface waters were cool to near freezing, with ice forming on the reservoir during extended cold periods in some years (BC Hydro, 2001). Submerged macrophytes may resist the effects of this periodic freezing by colonizing depths below the zone of surface ice formation, as compared with emergent or floating species that become exposed to freezing temperatures. Consequently, *Potamogeton amplifolius*, a floating-leaved, rooted species which has two leaf types (i.e., floating and submerged; USDA, 2010), may be vulnerable to cold winters when floating leaves have developed and, therefore, primarily limited to deep, lower elevation sites where water temperatures may be warmer. *Nitella sp.*, a submerged species, may be less sensitive to winter effects and, therefore, would be better able to colonize shallower waters, contributing to its dominance at up reservoir sites.

When assessing macrophytes, sampling procedures represent a critical component of plant community studies, particularly for deep-water submerged species that are not easily observed. Sampling rakes were the primary method used to collect macrophytes during the October 2009 baseline assessments; however, use of an Aqua-tiller® was required at deeper transect locations (i.e., those located at down reservoir sites; see Section 2.4.5). This device may have favoured sampling of larger macrophytes and appeared less effective in collecting smaller species. Capers (2000) found that small macrophyte species were particularly vulnerable to underestimation in boat surveys. The more frequent use of this device at down reservoir sites may have resulted in a bias by underestimating coverage of small species (e.g., *Nitella sp.*) at these sites.

Eleocharis acicularis was typically observed at depths less than 1 m (i.e., elevations greater than 571.6 m at Site 5 and 571.7 m at Sites 10 and 11) and at sites located near anthropogenic activities (i.e., Site 5 [downstream from Downie Creek RV Resort], Site 10 [up reservoir of Mica Creek Village], Site 11 [downstream from a bridge crossing the Revelstoke Reservoir and directly exposed to a run-off drainage channel]; see macrophyte community general characteristics, Appendix 4). *E. acicularis* usually colonizes areas with high organic content (Aiken *et al.*, 1999) and silt, thus explaining its presence at Site 7 (located at a creek confluence). Mats of *E. acicularis*, buried under silt, are capable of re-establishing themselves by internodal elongation and can produce new communities. *E. acicularis* tends to be located where water current is negligible and substrate texture is silt-clay (Rothrock and Wagner, 1975). Clay was one of the main substrates at Sites 5, 6 (located in an undisturbed area), 10 and 11, where *E. acicularis* was also observed.

Potamogeton alpinus was observed in a wide range of habitats, including undisturbed sites (i.e., Sites 8 and 9), sites near anthropogenic activities (i.e., Sites 1 and 10) and at the confluence of La Forme Creek (i.e., Site 2; see Appendix 4). *P. alpinus* usually grows in shallow and cold waters; however, depth and water temperature did not appear to be limiting factors during this baseline assessment, as this species (collected at elevations 569.3 m [Site 9 S/B] to 572.6 m [Site 11 S/A and N/A]) was observed in areas with water temperature ranging from 7.38°C (Site 10) to 14.46°C (Site 2).

Invasive Species

Macrophyte communities present in Revelstoke Reservoir have been influenced by water impoundment and management since construction of the Mica (1973) and Revelstoke dams (1984). Forest clearing, roads and other land use activities may also have influenced macrophyte communities. Anthropogenic activities have the potential to alter macrophyte habitat quality and result in the introduction of invasive species.

One invasive species encountered in the reservoir, *Myriophyllum spicatum* (see photo in Appendix 4), was observed sporadically (i.e., at Sites 1 and 5) in the October 2009 survey (see macrophyte community general characteristics, Appendix 4). Sites 1 and 5 were located in areas near anthropogenic activities (i.e., downstream from Martha Creek BC Provincial Park Campground and Downie Creek RV Resort, respectively; Figure A-3, Appendix 1), suggesting recreational boaters may have been a primary vector for introducing *M. spicatum* through use of public boat launches. *M. spicatum* was most likely introduced to Revelstoke Reservoir via boat motors, trailers, nets, boat propellers and fishing gear (Eiswerth *et al.*, 2000; Reed, 1977; Rothlisberger *et al.*, 2010). *M. spicatum* is also a popular aquarium plant that is commonly introduced into various water sources (e.g., wetlands, lakes, streams, rivers; Reed, 1977).

When introduced in a new water body, *M. spicatum* is extremely adaptable, able to tolerate a variety of environmental conditions. Relative to other macrophyte species, *M. spicatum* requires low turbidity and high PAR levels, has a high photosynthetic rate, and can grow over a broad temperature range (Aiken *et al*., 1979; Barko and Smart, 1981; Madsen *et al*., 1991). Sites 1 and 5 had clear waters and comparable water temperature (12.55°C and 12.92°C, respectively; see Table 3-7). *M. spicatum* is known to grow best on fine-textured, inorganic sediments and relatively poorly on highly organic sediments. Over the spectrum of infertile to enriched aquatic systems, this species appears to prefer those representing a mid-range. Substrates differed between Sites 1 and 5 (cobbles and gravels [Site 1] vs. sand and clay [Site 5]), suggesting that *M. spicatum* was tolerant to substrate changes.

Myriophyllum spicatum can have a negative influence on aquatic ecosystems by forming dense canopies that often shade out native vegetation. Johnson and Blossey (2002) reported ecological effects include suppression of macrophytes, macroinvertebrates, fish spawning and growth, as well as waterfowl avoidance of aquatic areas infested by the plant. Dense *Myriophyllum spicatum* mats can alter water quality by raising pH, decreasing oxygen under the mats and increasing temperature. The decomposition of high *M. spicatum* biomass at the end of the growing season can also increase the internal loading of nutrients (e.g., phosphorus, nitrogen) to the water column (Eiswerth *et al.*, 2000). Further, redox potential can influence (positively or negatively) the primary productivity and decomposition of *M. spicatum*. In oligotrophic environments, such as the Revelstoke Reservoir, there are few electron-accepting species (e.g., NO_3^-, Fe^{3+}, Mn^{4+}, SO_4^{2-}), thus, contributing little to regulation of soil redox potential. As such, redox potential is mostly influenced by changes in water level and oxygen concentration (Koch-Rose *et al*., 1994). Redox potential is, therefore, a measurement that is relevant to primary productivity due to its positive correlation with oxygen availability to *Myriophyllum spicatum* roots (Wheeler, 1999; Pezeshki, 2001).

The ecological effects from *Myriophyllum spicatum* invasions in British Columbia include:

- replacement of native plant communities;
- obstruction of swimming, boating, waterskiing and fishing;
- reduced beach appeal due to plant debris accumulation;
- impediments to flood control, water conservation, drainage potable water intakes, irrigation works; and,
- reduced economic benefits from tourism where dense growth limits recreational opportunities (Province of British Columbia, 1976).

In eastern Washington, *Myriophyllum spicatum* affects power generation and irrigation by clogging dam trash racks and intake pipes (Gibbons *et al*., 1994). *Myriophyllum spicatum* infestations can also threaten human health, creating ideal habitat for mosquitoes, including *Culex spp*., which has been implicated in the spread of West Nile Virus (Eiswerth *et al.*, 2000).

Myriophyllum spicatum growth can be managed by water level control. Parameters to take into consideration for efficient management include, but are not limited to, sediment areas exposed to drought, time of exposure, climate over the year and weather at time of drawdown (Vermont Agency of Natural Resources, 1989). Further, Greening and Gerritsen (1987) reported that drawdowns at a high frequency may reduce macrophyte species diversity and favour tolerant plants which eventually dominate the reservoir.

Myriophyllum spicatum was first observed in Okanagan Lake in 1970 and has since spread to several lakes and rivers in British Columbia (Province of British Columbia, 1976). The plant is able to survive in a wide range of environmental conditions and grows quickly, suggesting a continued distribution throughout Revelstoke Reservoir.

"Rare" Species

A third of all macrophyte taxa observed during October 2009 field survey (i.e., *Potamogeton foliosus*, *Ranunculus aquatilis*, *Equisetum palustre*; see species description, Appendix 5) were considered to be comparatively "rare" species (i.e., found at only one long-term monitoring site). *P. foliosus* was found to be more abundant at Site 8 than *R. aquatilis* and *E. palustre* at Sites 3 and 6, respectively (Chart 6, Appendix 3). The dominant substrate at Site 8 (sand) favoured *P. foliosus* growth, given that this species usually develops in soft sediment soils. *P. foliosus* also typically grows in areas no greater than 0.6 m deep (ISU, 2009); however, it was observed between 0.9 and 2.3 m (elevations from 570.3 m to 571.7 m) in Revelstoke Reservoir during this baseline assessment. Site 8 was located in an undisturbed area with clear water (i.e., a deeper photic zone), suggesting *P. foliosus* may use light energy to grow to depths up to 2.3 m (elevation of 570.3 m).

R. aquatilis was observed at Site 3 at an elevation of 571.3 m (i.e., depth of 1.3 m) in an area dominated by clay substrate (see Appendix 4). Boeger (1992) found that the highest levels of *R. aquatilis* growth were muddy substrates; however, Crowder *et al.* (1977) found that this species grows over a wide range of substrate-types. *R. aquatilis* usually colonizes shallow waters, less than 2.1 m (University of Wisconsin, 2010) and is able to tolerate a moderate amount of disturbance from desiccation and grazing (NCC, 1989).

E. palustre typically grows along the edge of water bodies and does not often grow in water (Simonavičiūtė and Ulevičius, 2007), possibly explaining why the species was only observed in an aquatic form at one near-shore transect point (Site 6). Overwintering structures (structures adopted by plant species to withstand winter conditions) may have a significant effect on rare species distribution (Jeppesen *et al*., 1997). For example, *E. palustre* is a perennial species that does not rely on seed production, instead forming sprigs that lie latent on bottom substrates (when in water), awaiting for the opportunity to grow. Combined with the timing of ice melt off the littoral zone and potential changes to this zone associated with REV 5 operations, this latency may significantly affect the ability of *E. palustre* to be productive during the growing season.

4.2.2 Environmental Parameters & Potential Influences on Macrophyte Communities

Substrate Characteristics

Colonization of submerged, rooted macrophyte species depends on sediment bed characteristics, given that they are a source of nutrients and means of plant anchorage (Clarke and Wharton, 2001). Consequently, some macrophyte species may be sensitive to both physical and chemical sediment characteristics. Further, there may be potential for interactions (e.g., competition, niche partitioning) among both individual plants and species related to sediment conditions. Macrophyte communities may also be influenced by the physical structure (e.g., particle size) and chemical nature (e.g., pH, nutrient load) of sediment. For example, coarse sediments are a good habitat for species with tough stems, roots and adventitious roots (e.g., *Myriophyllum spicatum*; Hynes, 1970); however, *M. spicatum* is a tolerant species that has also been observed in fine-textured, inorganic sediments (DCR, 2004). Finer sediments usually support fragile stoloniferous (i.e., capable of forming branches at their base that produce new plants) species and species with buried rhizomes such as some *Potamogeton spp*. (Hynes, 1970).

During the October 2009 baseline assessments, only the physical appearance of sediments (i.e., colour, consistency and texture, odour, other features) was assessed; however, once rooted, macrophytes are able to modify the sediment and flow environment. Consequently, the effect of sediment particle size may only be important in facilitating initial colonization and establishment of macrophytes (Clarke and Wharton, 2001). Macrophytes may be restricted to sediments of a particular physical structure (i.e., species with a particular root character may only anchor in particular sediments; Haslam, 1978); however, there is likely to be an interdependent effect on macrophyte growth between sediment particle size and sediment nutrient concentration (e.g., fine sediments are often more fertile due to greater porewater retention and binding capacity; Golterman, 1995). As such, it is difficult to isolate the influence of sediment particle size, and ability of species to anchor within sediments, from sediment fertility in assessments occurring over multiple years.

Sediment characteristics measured in October 2009 are summarized in Table 4-1. The table identifies changes in sediment colour, consistency/texture, odour and presence of debris in Revelstoke Reservoir and associated potential influences on macrophyte communities. Parameters exhibiting a notable trend between the eleven long-term monitoring sites, based on distance up reservoir from Revelstoke Dam and/or activities in the area (i.e., undisturbed, near a creek confluence, near anthropogenic activities), are considered to potentially influence macrophyte community distribution and/or richness. Degree of potential influence (i.e., low, moderate, high) is based on the ability of the parameter to affect macrophyte communities in the reservoir.

Table 4-1: Summary of Bottom Substrate Characteristics (Revelstoke Reservoir, October 2009)

Parameter	Effect & Location	Potential Influence on Macrophyte Communities
Colour	Change depends on activities in the area (i.e., undisturbed vs. near confluence vs. near anthropogenic activities)	Yes (Low)
Consistency & Texture	Change depends on activities in the area (i.e., undisturbed vs. near confluence vs. near anthropogenic activities)	Yes (Low)
Odour	No discernable trend in changes with distance from Revelstoke Dam or activities in the area	No
Other Features	Little debris observed throughout the reservoir	No

Colour and consistency/texture of sediments changed between sites in October 2009, potentially depending on activities in the area (i.e., undisturbed site vs. near a creek confluence vs. near anthropogenic activities). Odour and debris observed in sediments did not exhibit any trends with increasing distance up reservoir from the Revelstoke dam and/or watershed land use.

Sediment characteristics may have influenced reservoir macrophyte communities in October 2009, especially at long-term monitoring sites located near creek confluences. The interaction between flows of river water and sediment composition is complex and, consequently, macrophytes respond to both flow and sediment particle size. Sediments from watershed soil erosion can be transported by creeks and deposited in the reservoir near creek confluences. Variation in substrate composition and sediment stability due to water flow may favour colonization of opportunistic macrophyte species and/or prevent colonization by more sensitive species. Areas with many different substrates may be more likely to harbour opportunistic species than areas with homogenous substrate. Though not observed in the Phase 1 (baseline) study, a comparative analysis, including Phase 2 data, will be done to test this correlation.

Anthropogenic activities may also influence sediment distribution and composition; however, no notable similarities in macrophyte community structure (i.e., taxa richness and macrophyte distribution) were observed between monitoring sites located near anthropogenic activities and monitoring sites located farther from such activities (i.e., near creek confluences or in undisturbed areas). Small organic debris and macrophyte roots were found at many monitoring sites, indicating organic matter input from terrestrial riparian vegetation and watershed runoff.

Table 4-2 provides a comparison between the main sediment characteristics and macrophyte communities observed in October 2009. Particle size and total organic content were not assessed in this program.

Table 4-2: Sediments and Macrophyte Species Associated (Revelstoke Reservoir, October 2009)

Site	Sediment Characteristics	Dominant Macrophyte Species	Sub-Dominant Macrophyte Species
1	Gravels with sand and cobbles. Abundant organic debris.	*Potamogeton amplifolius*, *Potamogeton alpinus*, *Nitella sp.*	*Myriophyllum spicatum*, *Nitella sp.*, *Potamogeton amplifolius*
2	Gravels with sand, cobbles and clay. No woody debris.	*Potamogeton amplifolius*, *Potamogeton alpinus*, *Nitella sp.*	None
3	Silt/clay with gravels. Little woody debris.	*Potamogeton amplifolius*	*Nitella sp.*, *Ranunculus aquatilis*
4	Silt/clay with gravels, sand and cobbles. Abundant small woody debris.	*Potamogeton amplifolius*	None
5	Sand with gravels and silt/clay. Abundant debris.	*Eleocharis acicularis*, *Potamogeton amplifolius*, *Myriophyllum spicatum*	*Potamogeton amplifolius*, *Nitella sp.*, *Myriophyllum spicatum*
6	Silt/clay with gravels, sand and cobbles. Abundant woody debris.	*Potamogeton amplifolius*	*Eleocharis acicularis*, *Equisetum palustre*
7	Gravels with silt/clay, sand and cobbles. No woody debris.	*Eleocharis acicularis*, *Potamogeton amplifolius*	None
8	Silt/clay with gravels. Very little debris.	*Nitella sp.*, *Potamogeton amplifolius*, *Potamogeton foliosus*, *Potamogeton alpinus*	*Nitella sp.*, *Potamogeton alpinus*, *Potamogeton foliosus*

Table 4-2: Sediments and Macrophyte Species Associated (Revelstoke Reservoir, October 2009) (Cont.'d)

Site	Sediment Characteristics	Dominant Macrophyte Species	Sub-Dominant Macrophyte Species
9	Silt/clay with gravels and sand. Some woody debris.	*Nitella sp.*	*Potamogeton alpinus*
10	Cobbles with silt/clay, gravels, sans and boulders near-shore. Some woody debris, mica/silica.	*Nitella sp.*, *Eleocharis acicularis*	*Eleocharis acicularis*, *Potamogeton alpinus*
11	Silt/clay with little sand, gravels and cobbles. No woody debris.	*Nitella sp.*, *Eleocharis acicularis*	*Eleocharis acicularis*

Most species were collected from different substrate types and did not seem sensitive to substrate changes between sites: *Potamogeton amplifolius*, *P. alpinus*, *Nitella sp.* and *Eleocharis acicularis* were each collected in substrates with different particle size (e.g., gravels, sand, silt/clay) and different amounts of woody debris. *Myriophyllum spicatum* was collected only in substrates with abundant organic debris, suggesting that this species is able to colonize substrates with a high amount of organic matter.

Water Quality

Most aquatic life, including macrophytes, requires oxygen. Although high DO levels observed during the 2009 baseline assessments appeared favourable to macrophyte growth, a low productivity typical for many reservoirs was observed in this system. This low biological productivity was also reported in a previous study (Triton, 1992), based on low phosphorus and nitrogen concentrations (1978 to 1991). In the 1992 report, concentrations of phosphorus and nitrogen were sufficiently low to classify the Revelstoke Reservoir as an ultra-oligotrophic reservoir. Phosphorus levels varied significantly with depth, though not between seasons. Nitrogen concentrations did not vary significantly between seasons or with depth. In general, low nutrient levels (particularly phosphorus) were likely a limiting factor in the production of macrophytes in the reservoir. Low productivity reported in October 2009 may also be reflective of low nutrient content in Revelstoke Reservoir, rather than depletion in oxygen. Nutrients were not assessed in this program.

Water quality parameters, recorded in October 2009 field surveys, are summarized in Table 4-3. Parameters exhibiting a notable trend between the eleven long-term monitoring sites based on distance up reservoir from Revelstoke Dam and/or activities in the area (i.e., undisturbed, near a creek confluence, near anthropogenic activities) may have a potential influence on macrophyte communities. Potential influence (i.e., low, moderate, high) is based on the ability of the parameter to change distribution and/or richness of macrophyte communities in the reservoir.

Table 4-3: Summary of Water Quality Parameters (Revelstoke Reservoir, October 2009)

Parameter	Effect & Location	Potential Effect on Macrophyte Communities
Temperature	Generally decreased with increasing distance up reservoir and away from the Revelstoke Dam	Yes (low)
Conductivity	Greater at Sites 9 to 11	Yes (low)
pH	Moderately greater at down reservoir sites	No

Table 4-3: Summary of Water Quality Parameters (Revelstoke Reservoir, October 2009) (Cont.'d)

Parameter	Effect & Location	Potential Effect on Macrophyte Communities
Redox	Representative of an oxic zone at all monitoring sites	No
Turbidity	Highest at Sites 1, 6 & 11	No
Transparency	Lowest at Sites 4, 6 & 9	No
DO (mg/L)	Moderately higher at up reservoir sites	No
DO (%)	No discernable trend with changes in distance from Revelstoke Dam or activities in the area	No

Water temperature and conductivity are two water quality parameters that may have had an influence on macrophyte distribution in Revelstoke Reservoir. In winter, macrophytes usually stop growing. In October 2009, water temperatures had already begun to decrease, with macrophyte coverage also anticipated to decrease accordingly. Higher temperatures measured at down reservoir sites, which generally were of greater depth, were associated with the thermal retention properties of water and may have enabled some species, more sensitive to low temperatures (e.g., *Potamogeton amplifolius*), to grow in the reservoir for a longer period.

Conductivity was slightly higher from Sites 9 to 11, suggesting there may have been a higher input of nutrients and minerals to the reservoir at these three sites. As is typical for this type of system, the origin of higher inputs was attributed to releases from Mica Dam or other anthropogenic activities (e.g., Mica Creek Village). Logging activities can also increase nutrient inputs to the reservoir as a result of higher runoff; however, logging typically increases inputs of sediment as well. Given that turbidity measurements at Sites 9 to 11 were not much greater than at other long-term sites, logging activities were not identified as an obvious source of nutrient input at Sites 9 to 11.

Other water quality parameters (pH, redox, turbidity, transparency, dissolved oxygen, Secchi disk readings) exhibited slight differences between sites; however, they were all favourable to macrophyte community growth in the reservoir and did not exhibit extreme values that could affect growth of sensitive species.

4.3 Potential Influence of REV 5 Operations

Macrophyte communities present in the Revelstoke Reservoir have adapted in response to current Mica and Revelstoke dam operations. Water level fluctuations, associated with a fifth-unit operation (REV 5) at Revelstoke Dam, are projected to be similar to current water level fluctuations (i.e., less than 0.25 m over 90 per cent of the time), though with more frequent moderate drawdowns (i.e., drafting to approximately 572.5 m or by 0.5 m) and less frequent low drawdown (i.e., drafting to 571.5 m or by 1.5 m; BC Hydro, 2006). Hestand *et al.* (1973), as well as Nichols (1975) suggested that macrophytes are characterized by differentiated growth and development that reflect fluctuating water levels in shallow water bodies. Nichols identified five submersed species that either recovered, or increased in coverage, following repeated water fluctuations from a controlled drawdown to inhibit invasive macrophyte proliferation. Drawdowns that were not properly planned or managed resulted in excessive macrophyte growth. Consequently, timing and frequency of drawdown are important parameters in determining which species will be influenced by REV 5 operations.

4.3.1 Low Drawdown Influence

During the 2009 baseline survey, the mean water elevation in Revelstoke Reservoir ranged from 572.5 m (September 29, 2009) to 572.7 m (October 2, 2009), suggesting that the drawdown level was between a moderate level (i.e., 0.5 m) and daily variations (i.e., 0.25 m), as compared to the maximum reservoir water elevation of 573.0 m. Macrophyte communities observed already exist under moderate drawdown and have adapted to these daily variations and moderate drawdown conditions. Low drawdown (i.e., approximately ≥1.5 m from the maximum reservoir elevation) would affect macrophyte communities located in deeper areas still submerged during the October 2009 baseline assessment.

Low drawdown corresponds to a drawdown ranging from 1.0 m (for sites sampled September 29) to 1.2 m (for sites sampled October 2) based on surface water elevations recorded during the October 2009 baseline assessments. Transect points for each potential long-term monitoring site as potentially influenced by low (i.e., ~1 m) drawdown are listed in Table 4-4. The table also identifies the estimated per cent (%) of macrophyte coverage influenced by water level changes (compared to total macrophyte coverage at each site) and species present at potentially influenced transect points. Where per cent (%) coverage estimates for a given transect point could not be made in the field (given water depth or water clarity), no comparison was made to the total macrophyte coverage at that site.

Table 4-4: Transect Points Influenced by REV 5 Low Drawdown (Revelstoke Reservoir, October 2009)

Sites	Effect Extent^{1,2,3,4}	Low Drawdown (1.5 m)
1	Transect Point	S/A, C/A, N/A
	% Zone	0%
	% Site	0%
	Species	None
3	Transect Point	S/A, C/A, N/A, C/B
	% Zone	27% Zone B
	% Site	14%
	Species	*Potamogeton amplifolius*
5	Transect Point	S/A, C/A, N/A, S/B, C/B, N/B
	% Zone	100% Zones A & B
	% Site	66%
	Species	*Eleocharis acicularis, Potamogeton amplifolius, Nitella sp.*
6	Transect Point	S/A, C/A, N/A
	% Zone	100% Zone A
	% Site	Not calculated[5]
	Species	*Potamogeton amplifolius, Eleocharis acicularis, Equisetum palustre*

Table 4-4: Transect Points Influenced by REV 5 Low Drawdown (Revelstoke Reservoir, October 2009) (Cont.'d)

Sites	Effect Extent[1,2,3,4]	Low Drawdown (1.5 m)
7	Transect Point	All transect points
	% Zone	100% Zones A, B & C
	% Site	100%
	Species	*Eleocharis acicularis*, *Potamogeton amplifolius*
8	Transect Point	S/A, C/A, N/A, SC
	% Zone	100% Zone A, 33% Zone C
	% Site	45%
	Species	*Potamogeton amplifolius*, *Nitella sp.*, *Potamogeton foliosus*
9	Transect Point	S/A, N/A
	% Zone	70% Zone A
	% Site	Not calculated[6]
	Species	*Nitella sp.*, *Potamogeton alpinus*
10	Transect Point	All transect points, except C/B
	% Zone	100% Zones A, B & C
	% Site	100%
	Species	*Nitella sp.*, *Eleocharis acicularis*, *Potamogeton alpinus*
11	Transect Point	All transect points, except S/B & N/B
	% Zone	100% Zones A & C, 33% Zone B
	% Site	65%
	Species	*Nitella sp., Eleocharis acicularis*

Shading: at least one transect point may be influenced. Transect point was colonized by macrophytes in October 2009.

Transects: S – South; C – Centre; N – North.

Zones: A – Near-Shore; B – Mid-Distance from Shore; C – Farthest Distance from Shore.

1. Transect point(s) influenced by low drawdown.
2. Per cent (%) macrophyte coverage influenced at each zone (i.e., near-shore [Zone A], mid-distance from shore [Zone B], furthest from shore [Zone C]).
3. Per cent (%) macrophyte coverage influenced at a given site.
4. Species potentially influenced by low drawdown.
5. Per cent (%) macrophyte coverage could not be calculated for Site 6, given that all three transects converged to a single point (All/C).
6. Per cent (%) macrophyte coverage could not be calculated for Site 9, given that coverage at all Zone C transect points could not be estimated in October 2009.

Macrophyte Per Cent (%) Coverage Influenced by Low Drawdown

Low drawdowns (to surface water elevations of ≥571.5 m or by approximately 1.5 m from a maximum water elevation of 573.0 m) are anticipated to influence Revelstoke Reservoir macrophyte communities at the potential long-term sites assessed; however, this influence may not be as notable at down reservoir sites (i.e., Sites 1 to 4). Only near-shore transect points (i.e., S/A, C/A, N/A) of Site 1 would be potentially influenced by low drawdown and these three points were not colonized by macrophytes in October 2009. As such, water level changes may not have an effect on Site 1 macrophyte communities as they currently exist. For Sites 2 and 4, the maximum elevation of transect points where macrophytes were observed (i.e., 571.0 m [N/C, Site 2]; 570.3 m [S/A, Site 4]) was lower than elevations influenced by normal reservoir drawdown conditions (i.e., areas deeper than would be influenced by low drawdown). Consequently, water level changes in Revelstoke Reservoir would not be anticipated to have an effect on macrophyte communities observed at Sites 2 and 4 in October 2009.

Low drawdown would also have the potential to influence near-shore points and one mid-distance point (i.e., C/B) at Site 3. No macrophytes were collected near-shore at Site 3; however, *Potamogeton amplifolius* was found at transect point C/B. As a result, approximately 27 per cent of total macrophyte coverage in Zone B and approximately 14 per cent of total site coverage would be influenced by low drawdown conditions. Per cent (%) of macrophyte coverage influenced by low drawdown in a zone, and for a site, was calculated by comparing estimated coverage at each potentially influenced transect point with the mean estimated coverage of the zone in which the transect point was located and mean estimated coverage for all site transect points, respectively.

Sites 1, 2 and 4 were all located in deep areas with steep slopes, while Site 3 had two shallow transects (i.e., Centre and North). Slope differences may explain why Site 3 macrophyte communities may be more influenced than the other sites located down reservoir.

Total macrophyte coverage of up reservoir sites (i.e., Sites 5 to 11) potentially influenced by low drawdown ranged from 45 per cent (Site 8) to 100 per cent (Sites 7 and 10). Site 8 was shallower than other up reservoir sites; however, slope was steep, which may in part explain why the site was less influenced by low drawdown compared to other up reservoir (with lower slope) sites. Macrophyte communities observed at Sites 7 and 10 could be completely influenced by low drawdown, supporting their inclusion for long-term study; however, Sites 7 and 10 macrophyte communities may also be influenced by confounding sources. Site 7 is at a confluence with Kirbyville Creek, which may lower the drawdown effect due to creek inflows. Creek inflows can change water quality and sediment characteristics at the confluence, thereby changing macrophyte habitat quality. Site 10 is located just up reservoir of Mica Creek Village and, thus, considered as potentially influenced by the boating and fishing activities of residents and tourists residing there.

Sites 5 and 11 had similar levels of macrophyte coverage and also appeared to be influenced by low drawdown (i.e., 66 per cent and 65 per cent coverage, respectively). Site 5 had two transects (i.e., South and Centre) shallower (i.e., maximum depth of 1.3 m and 1.5 m, respectively) than transects established at further down reservoir sites (i.e., Sites 1 to 4). Site 11 had a gentle slope with maximum depths ranging from 1.2 m (Centre Transect) to 1.6 m (North Transect). These shallower macrophyte communities would be anticipated to be more influenced by low drawdown periods.

Low drawdown effects on transect points furthest from shore (Zone C) at Site 6 were not estimated, given that the three transects at this site converged; however, low drawdowns are anticipated to influence 100 per cent of macrophyte coverage in the near-shore zone. At Site 9, 70 per cent of macrophyte coverage in Zone A is likely to be influenced by low drawdown, though total per cent (%) coverage estimates for this site could not be estimated given the depth of macrophytes growth and poor water visibility.

Macrophyte Species Influenced by Low Drawdown

There were eight macrophyte species identified in Revelstoke Reservoir during the October 2009 baseline assessment. Six of these eight species were collected at sites potentially influenced by low reservoir drawdown (i.e., drafting to 571.5 m or by 1.5 m; BC Hydro, 2006). These species are:

- *Eleocharis acicularis*;
- *Nitella sp*.;
- *Potamogeton amplifolius*;
- *Potamogeton foliosus*;
- *Potamogeton alpinus*; and,
- *Equisetum palustre*.

Eleocharis acicularis is a species well-adapted to fluctuating water levels, usually growing in marshes and shallow water of lakes, ponds and streams. Of sites identified to be potentially influenced by low drawdown, this species was observed at Sites 5, 6, 7, 10 and 11. Several studies have shown that *Eleocharis acicularis* is capable of rapid reproduction, rapid seed production and a flexible survival strategy (Nilsson, 1981; Rørslett, 1989; Renman, 1989; Hill *et al*., 1998). *E. acicularis* can spread rapidly when conditions are favourable. This small r-strategist (e.g., able to reproduce quickly in highly unstable environments) species is also resistant to erosion and bottom freezing (Hellsten, 2000). Goldsby and Sanders (1977) observed an increase in *E. acicularis* biomass at depths influenced by drawdown in a Louisiana lake, indicating a shift in lake vegetation to an earlier successional stage (i.e., a stage where r-species [species with high fecundity, small body size, early maturity onset, short generation time, ability to disperse widely] are dominant). Both terrestrial and aquatic forms of *E. acicularis* are genetically identical and freely interconvertible (Rothrock and Wagner, 1975). Low drawdown in Revelstoke Reservoir is not anticipated to have a negative effect on *E. acicularis* growth or distribution in the reservoir. Low drawdown may even increase distribution of this species if such water regulation restricts other species growth, thereby reducing inter-species competition.

Nitella sp. may be influenced by low drawdown at Site 5 and Sites 8 to 11. *Nitella sp*. was observed sporadically at Site 5 and was more common in deeper waters at sites further up reservoir, suggesting lower drawdown levels may reduce *Nitella sp.* coverage at these sites; though the species would be anticipated to remain present. At Site 5, *Nitella sp.* represented less than 10 per cent of the coverage at one transect point. *Nitella sp.* can spread to deeper areas via spores transported by wildlife or form new plants from vegetative fragments, suggesting this species may be capable of moving to deeper waters at Site 5 if lower drawdown conditions become frequent, although low drawdown is expected to be less frequent after REV 5 start-up. Phase 2 assessments (post start-up) would verify the continued presence and coverage of *Nitella sp*. at Site 5. All transect points established at Site 10 are anticipated to be influenced by low reservoir drawdown; therefore, monitoring macrophyte communities at this site should be a focus of Phase 2 assessments.

Researchers at the University of California (2001) identified different types of effects on macrophyte species depending on their tolerance to water drawdown, and noted that *Potamogeton amplifolius* growth was restricted by water drawdown levels (drafting from approximately 0.3-0.5 m to 1.2-1.5 m), while *Myriophyllum spp.* growth was found to be enhanced. Further, growth of *Potamogeton foliosus*, a species identified only at Site 8 in October 2009, was moderately regulated by water drawdown (University of California, 2001). Given that this species was found at a site moderately influenced by low reservoir drawdown, the influence of REV 5 operations on this community would be anticipated to be moderate, with a slight decline in coverage possible after start-up; however, *Potamogeton foliosus* should still remain at Site 8 and be recorded during Phase 2 assessments.

Similar to *P. foliosus*, *Equisetum palustre* was also noted at only one site (Site 6) in the October 2009 baseline survey. *E. palustre* is capable of developing a terrestrial form (see Section 4.2.1), which may reduce the extent to which it is affected by the drawdown. Previous studies (Nilsson, 1978; Hellsten, 2000) have shown that water elevation, especially increases in water level, can result in the decline of some species unable to tolerate the instability of bottom substrates (resulting from water-related erosional forces), including *E. fluviatile* (a species of the same genera as *E. palustre*). These findings suggest that *E. palustre* may be sensitive to flooding events that occur after drawdowns. Site 6 does not seem to be a pertinent long-term site due to its morphology and given that it was not predicted by NDVI; however, *E. palustre* was only identified at this site, and it may be advantageous to examine Site 6 during Phase 2 assessments for qualitative comparison purposes.

Two species collected in October 2009 were observed at elevations below the low water mark (571.5 m): *Myriophyllum spicatum* (maximum elevation of 571.3 m at Site 5 S/C) and *Ranunculus aquatilis* (maximum elevation of 571.3 m at Site 3 N/C). Given that the maximum elevation of these two species (571.3 m) was very close to the low drawdown limit (571.5 m), *M. spicatum* and *R. aquatilis* could be influenced by extreme drawdowns (greater than 1.5 m). *M. spicatum* has the capacity to develop a land form where water evaporates slowly and individuals gradually become stranded, suggesting that in cases of extreme drawdown, this species may be able to survive, if not flourish. *R. aquatilis*, an amphibious macrophyte, is capable of heterophylly where it develops three different types of leaves (submerged divided leaf, terrestrial divided leaf, and entire leaf which has a normal expanded blade borne on a petiole; Cook, 1969). The submerged type of leaf can develop in terrestrial or submerged conditions under short photoperiods (exposure time to light; 10 hours or less), though under longer photoperiods (14 hours or more) it can only develop on submerged stems. The terrestrial type of leaf is formed only under long photoperiods in terrestrial conditions. The entire leaf, which occupies the air-water interface, can only develop under long photoperiods in submerged conditions. As such, changes in *R. aquatilis* leaf form depend on the water clarity and light energy available at the site.

Some macrophyte species can tolerate lower water levels, while others are capable of improved growth in such conditions. In the Chippewa Flowage of Wisconsin, a water body that has received repeated winter drawdowns for fifty years, Nichols (1975) identified five submersed species that either recovered or increased in coverage after repeated water fluctuations. In a separate study of several North-American lakes, Davis and Brinson (1980) observed that *Potamogeton sp. affinity pusillus* moved 4 to 5 m closer to shore after re-flooding of a prairie pothole marsh. In addition, emergent species also had a tendency to germinate and invade the submersed zone during drought periods, such that biomass and species richness of the zone increased after re-flooding. This illustrates that although some submersed species may be severely affected by extreme water level fluctuations (especially species not rooted), others are able to adapt through a shift in zonation. Considering the community as a whole, Davis and Brinson found that, irrespective of life form, water level fluctuation imparted little overall change to community production and diversity. As such, the ability of macrophytes to adapt to changes in water level suggests that the macrophyte communities observed in Revelstoke Reservoir during October 2009 field surveys will not be significantly influenced by REV 5 operations. Further, all species collected in this baseline (Phase 1) study should remain in the reservoir over the long-term.

4.3.2 Maximum Elevation of Macrophyte Communities

In October 2009, macrophyte communities were observed from the water's edge at Site 6 and very close to shore at Site 11. A notable break between macrophyte communities and the shoreline was recorded at all other monitoring sites. The maximum elevations at which macrophyte communities were observed are provided in Table 4-5. Elevations are extrapolated from daily depth measurements made at the shoreline (0 m water depth) and at each point along the South, Centre and North Transects of each potential long-term site (1 to 11).

Table 4-5: Maximum Elevation (m) of Observed Macrophytes Growth (Revelstoke Reservoir, October 2009)

Transect	1	2	3	4	5	6	7	8	9	10	11
South	570.7	570.4	568.3	570.7	572.2	572.6	572.2	571.7	569.5	571.7	572.6
Centre	571.9	570.6	571.4	570.2	571.9	572.6	572.2	572.1	571.6	572.4	572.6
North	571.0	570.8	571.1	571.0	571.7	572.6	572.3	572.1	571.6	572.3	572.6

Shading represents macrophyte communities observed at or very close to the shore line.

Maximum elevations where macrophytes (rooted at the bottom) were observed in the October 2009 baseline assessments ranged from 568.3 m (Site 3, South Transect) to 572.6 m (Site 6 at water surface level and Site 11). In general, maximum elevations at which macrophytes were observed were slightly lower at down reservoir sites than up reservoir sites and attributed to shallower depths at up reservoir sites. These typically shallower sites were colonized by small species capable of growing in minimal water levels, but requiring large amounts of light to survive. Conversely, most macrophyte species colonizing down reservoir sites required less light and were less sensitive to water depth. As a result, macrophyte communities at down reservoir sites tended to colonize deeper areas that were closer to shore (due to steeper slope). The lack of aquatic vegetation in the zone between the foreshore water line and where macrophytes start to grow suggests that these communities may already be adjusting to changes in water elevation resulting from reservoir drawdown, given that the communities do not colonize the area of the reservoir most influenced by water level fluctuations (drawdown zone). Further evaluation of this trend should be a focus of Phase 2 assessments.

4.3.3 Confounding Influences

Macrophyte communities assessed during the 2009 Baseline survey may change with time due to confounding influences such as environmental parameters and/or anthropogenic activities. For the purposes of this study, confounding influences refer to factors, unrelated to REV 5 operations, which may influence outcomes of the study. In some cases, such confounding factors can be addressed in the program study design; however, many factors of influence may be unknown at the time of study design and should be considered during data analyses and evaluation.

To understand what changes in macrophyte communities may occur between Phase 1 and Phase 2, and the cause of these changes, relevant parameters (which could have a significant effect on macrophyte communities) that may change following REV 5 start-up should be assessed. Table 4-6 identifies pertinent confounding sources that may have an influence on macrophyte communities present at potential long-term sites between Phase 1 and Phase 2. Transect slopes and site elevations are two other parameters affecting macrophyte establishment and should continue to be assessed.

Table 4-6: Confounding Sources & Potential Influences on Macrophyte Communities (Revelstoke Reservoir, October 2009)

Confounding Source	Potential Influence on Macrophytes
Sediment particle size	Determinant for macrophyte settlement. Can change with time, especially at creek confluences.
TOC + Debris in sediments	Correlates with level of organic matter and degree of substrate disturbance.
Climate	Influence on water chemistry and light available for macrophyte growth.
Water temperature	Less influence on macrophytes than fauna, but can restrain or improve macrophytes growth significantly.
Water conductivity	Correlates with nutrients available for macrophyte growth.
Creek confluence	Disturbs substrates and change water quality at confluence.
Anthropogenic activities	Physically disturb macrophyte community (e.g., boating) or change water quality.

Macrophyte communities may be influenced by other confounding factors and, as such, could potentially show change in coverage and richness in part due to these factors. Confounding influences include environmental characteristics (available light, air temperature, total precipitation) and anthropogenic activities influencing Revelstoke Reservoir watersheds. A list of anthropogenic activities reported for Revelstoke Reservoir watersheds was provided in Section 3.1. Environmental factors should be considered as having an important role in regulating the amount of water available to macrophyte communities and would, therefore, be a confounding aspect in the interpretation of causative factors influencing macrophytes.

Inflow water sources can be a primary determinant of macrophyte distribution and species composition, in addition to drawdown fluctuations, in ecosystems influenced by water level fluctuations such as the Revelstoke Reservoir. Submergent macrophytes are susceptible to desiccation in the drawdown zone, except where external water sources are present. Inflows from streams may reduce drawdown effects and better support growth, richness and distribution of macrophyte communities present at long-term monitoring sites near creek confluences (i.e., Sites 2, 3, 4, 7). To further evaluate this possibility, a comparison of changes in macrophyte coverage and richness between these sites and others far from creek confluences should also be considered in Phase 2 assessments.

During field surveys in October 2009, groundwater inflows (i.e., seepage and upwelling) were not observed or investigated; however, groundwater upwellings may be present in areas with steep slopes (Buttle *et al*., 2002).

5.0 Summary & Recommendations

Revelstoke Reservoir was created in 1984 following completion of the Revelstoke Dam, a six turbine facility, with four units currently operating. Prior to installation of a fifth power generating turbine unit (REV 5) at the Revelstoke Dam, an Environmental Impact Assessment and Columbia River Water Use Plan review was undertaken. As part of the agreements resulting from these reviews, G3 Consulting Ltd. (G3), on behalf of BC Hydro, initiated a Macrophyte Assessment Program to determine the potential effects of REV 5 operation on macrophyte communities in Revelstoke Reservoir. This report represents the first phase (Phase 1) of the program and provides a baseline assessment of macrophyte communities in the reservoir.

5.1 Program Summary

Land use around the Revelstoke Reservoir includes forestry, hydroelectric power generation, recreation, transportation and municipal activities. Infrastructure includes logging roads, an airstrip, private ferry landing sites and highways. Forestry activities and transportation corridors can have a negative influence on water quality and potentially alter discharge and thermal regimes. Large areas along Revelstoke Reservoir have been logged. These sources and activities can influence macrophyte distribution and, were thus considered in this study. In addition to reservoir flow, the (up reservoir) Mica and (down reservoir) Revelstoke dams influence the thermal and nutrient regimes of the reservoir.

This 2009 Phase 1 Baseline Assessment of macrophyte communities in Revelstoke Reservoir included an evaluation of aquatic macrophyte biodiversity, mapping of community distribution and establishment of long-term monitoring sites. The baseline investigation examined current and past conditions of the reservoir and associated macrophyte communities in an effort to accurately map their size, composition and spatial location using high-resolution satellite imagery, aerial reconnaissance and ground-truthing. Basemaps generated from SPOT satellite imagery and a Normalized Difference Vegetation Index (NDVI) algorithm were effective tools to predict Revelstoke Reservoir macrophyte communities *a priori* to field work; however, accuracy of this method is limited at smaller scales and requires further refinement.

Basemaps were created for twenty-five areas and provided polygons delineating predicted macrophyte communities. Twenty polygons were selected as potential long-term sites prior to an aerial reconnaissance flight conducted to confirm macrophyte locations. Based on this aerial reconnaissance, eleven potential long-term monitoring sites were selected for further field assessment. Site assessments were conducted throughout the reservoir, initiated in the southern portion near Revelstoke Dam and concluded at the northernmost up reservoir end, near Mica Dam. Sites 6, 8 and 9 were located in undisturbed areas (Figure A-3, Appendix 1), Sites 2, 3, 4 and 7 near creek confluences, and Sites 1, 3, 5, 10 and 11 near anthropogenic activities. The mean surface water elevation of the reservoir during the field survey ranged from 572.5 m (September 29, 2009) to 572.7 m (October 2, 2009).

There were eight species of macrophytes recorded. *Potamogeton amplifolius*, a BC provincial government yellow-listed species, was dominant at sites in the southernmost and mid-sections of the reservoir (Site 1 to 8) where it was generally deeper. Conversely, *Nitella sp.*, another yellow-listed species, was dominant at sites in the mid- and northernmost sections of the reservoir (Site 8 to 11) where it was generally shallower. *Eleocharis acicularis* was typically observed at depths less than 1 m and at sites with clay substrates located near anthropogenic activities (Sites 5 and 11). *Potamogeton alpinus*, also a yellow-listed species, was found to be tolerant, as it was observed in a wide range of habitats, including undisturbed sites (Sites 8 and 9), sites near anthropogenic activities (Sites 1 and 10) and at the confluence of a creek (Site 2). *Myriophyllum spicatum* (commonly known as Eurasian milfoil), an invasive species, was reported in areas near anthropogenic activities (down reservoir from Martha Creek BC Provincial Park Campground and Downie Creek RV Resort), suggesting that this species may have been introduced into the reservoir through public boat launches. *Ranunculus aquatilis*, *Equisetum palustre* (both yellow-listed species) and *Potamogeton foliosus*, were each collected at one potential long-term site (Sites 3, 6 and 8, respectively).

The colour and consistency/texture of site sediments at potential long-term monitoring stations varied between sites located near creek confluences and those that were undisturbed or near anthropogenic activities, potentially restricting the growth of species sensitive to substrate change in these areas. There were no observed anthropogenic influences on sediment quality during October 2009 field surveys.

Low water temperatures and low conductivity were present throughout the reservoir, consistent with historic results, which may affect low productivity at down reservoir and up reservoir sites; however, anthropogenic activities and creek confluences did not appear to have a notable influence on water quality during field assessments.

Water level fluctuations associated with the start-up of the fifth-unit (REV 5) at Revelstoke Dam are projected to be similar to current water level fluctuations (less than 0.25 m over 90 per cent of the time), though with more frequent moderate drawdowns (drafting to approximately 572.5 m or by 0.5 m) and less frequent low drawdown (drafting to 571.5 m or by 1.5 m; BC Hydro, 2006). A moderate drawdown occurred during baseline assessments and assessments of effects focused on low drawdown scenarios.

Low drawdowns are not anticipated to have a notable influence (positive or negative) on macrophyte communities at Sites 1, 2 and 4, and to have a limited influence on macrophyte coverage at Site 3 (i.e., 14 per cent of that site). At up reservoir sites, influence of drawdown is expected to be moderate, potentially reducing macrophyte coverage. Low drawdown will potentially have the greatest influence at Sites 7 and 10, where 100 percent of macrophyte coverage is located above the low drawdown elevation (571.5 m).

Six of the eight species (*Eleocharis acicularis*, *Nitella sp*., *Potamogeton amplifolius*, *P. foliosus*, *P. alpinus*, *Equisetum palustre*) identified during the October 2009 baseline assessments are anticipated to be influenced by low drawdowns. *Eleocharis acicularis* and *Equisetum palustre* can have both terrestrial and aquatic forms, suggesting that these species will not be as vulnerable to water level fluctuations as other macrophyte species more sensitive to temporary exposure. *Nitella sp.* can be move to deeper areas (through spores) where low drawdowns could potentially be detrimental. *Potamogeton* species tend to be more sensitive to water level fluctuations, as they are less mobile and do not have terrestrial forms. *Myriophyllum spicatum* and *Ranunculus aquatilis* fall within the extreme drawdown zone (drafting by greater than 1.5 m); however, *M. spicatum* growth is usually enhanced by water level fluctuations as it is very competitive and able to quickly colonize disturbed environments (r-strategist), while *R. aquatilis* can develop a terrestrial form. As such, Revelstoke Reservoir drawdowns are not anticipated to adversely affect these two species.

5.2 Recommendations

5.2.1 Satellite Imagery & NDVI Predictions

Satellite imagery and the Normalized Difference Vegetation Index (NDVI) were considered effective to delineate community boundaries and to predict macrophyte presence during Phase 1. These technologies were key components in identifying potential long-term macrophyte monitoring stations in Revelstoke Reservoir; however, a lack of previous field ground-truthing (index calibration prior to use in the October 2009 field survey) restricted the accuracy of image processing techniques prior to initial delineation of potential macrophyte areas. The following recommendations are intended to improve the application of satellite imagery in Phase 2:

- have field crew familiar with the Phase 1 reservoir macrophyte communities analyze the new (Phase 2) satellite imagery using large size, colour versions of the images to identify and compare areas containing macrophytes prior to field work;
- use constituent components within satellite algorithm-detected areas to adjust the response threshold and establish a per cent (%) error associated with the image analysis;
- use a higher (more expensive) spectral resolution (hyperspectral), where budget permits.

5.2.2 Long-Term Monitoring Sites Selection

A primary objective of the 2009 Baseline assessments was to identify potential long-term monitoring sites during Phase 1, for comparison in Phase 2 (post REV 5 start-up). Of the twenty sites selected prior to aerial reconnaissance, eleven were shortlisted and assessed as potential long-term monitoring sites. Based on the assessment, ten are recommended for subsequent evaluation in Phase 2. Particular focus should be afforded to monitoring the macrophyte community at Site 10, given that all transect points for the site are anticipated to be influenced by low reservoir drawdowns. Site 6 was found to be unsuitable for further study, given its morphology, and the means by which this site was surveyed, which also limits its utility in Phase 2.

5.2.3 Field Assessments

Methods and timing in Phase 2 should be comparable to those of the 2009 Baseline survey, with field assessments conducted in early fall. Water elevation and fluctuations prior to and during these assessments should also be carefully considered as an important aspect of comparisons conducted between study years.

Field assessments in October 2009 used a high resolution, digital colour sounder. While effective in delineating macrophyte communities, communities could not always be distinguished from bottom profiles given the density of plants. While prohibitively expensive in this program, other programs should consider use of a multi-beam echo sounding (MBES), multi-directional instrument (i.e., vertical and side-scan) where high quality, accurate bathymetry is required.

Knowledge of macrophyte ecology in Revelstoke Reservoir would be further enhanced with the inclusion of additional data on reservoir characteristics and land use. Analysis of nutrients in water and particle size in sediments would also be helpful in correlation analyses (between and amongst sites and years), providing additional quantitative data to ensure a statistically robust study.

5.2.4 Public Education

An invasive species (*Myriophyllum spicatum*) was identified at two long-term monitoring sites located near boat launches in October 2009. Public education and signage (if not already in place) should be considered to assist in reducing the spread of this invasive species.

6.0 References

Aiken, S.B., P.R. Newroth and I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. *Can. J. Plant Sci*. 59: 201-215.

Aiken, S.G., M.J. Dallwitz, L.L. Consaul, C.L. McJannet, L.J. Gillespie, R.L. Boles, G.W. Argus, J.M. Gillett, P.J. Scott, R. Elven, M.C. LeBlanc, A.K. Brysting and H. Solstad. 1999. *Flora of the Canadian Arctic Archipelago: Descriptions, Illustrations, Identification, and Information Retrieval*. Ottawa, ON: NRC Research Press.

American Public Health Association (APHA). 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edition. L.S. Clesceri, A.E. Greenberg and A.D. Eaton (eds.) Washington, DC: American Public Health Association.

Axys Environmental Consulting Ltd. and RL&L Environmental Services Ltd. 1995. Environmental impact assessment associated with emergency drawdown of the Revelstoke Reservoir. Draft Report Prepared for BC Hydro, Castlegar, BC by Axys Environmental Consulting Ltd., Vancouver, BC and RL&L Environmental Services Ltd., Edmonton, AB. 161 pp. + 4 app.

Barko, J.W. and R.M. Smart. 1981. Comparative influences of light and temperature on the growth and metabolism of selected submersed freshwater macrophytes. *Ecological Monographs*. 5: 219-235.

Baxter, R.M. 1985. Environmental effects of reservoirs. In: *Microbial processes in reservoirs*. D. Gunnison (ed.). Netherlands: Kluwer Academic Publishers. pp. 1-26.

BC Comptroller of Water Rights. 2007. Letter addressed to Renata Kurschner, BC Hydro, dated August 23, 2007. Reference 94249.

BC Hydro Engineering, Aboriginal Relations and Generation (BC Hydro EARG). 2007. Columbia River Water Use Plan. Draft addendum for Revelstoke Unit 5. Revised June 2007.

BC Hydro. 2009. Columbia River Projects Water Use Plan - Kinbasket Reservoir White Sturgeon Inventory and Habitat Use Assessment. 15 pp. + Appendix.

BC Hydro. 2006. Revelstoke Unit 5 Project – Environmental Assessment Certificate Application. Volume 1: Supplemental Information Report; Volume 2: Background Supporting Documentation. Burnaby, BC.

BC Hydro. 2005. Columbia River Water Use Plan. Consultative Committee Report. Volume 1.

BC Hydro. 2001. Environmental Data Summary and Gap Analysis - Volume 1: Mica and Revelstoke Water Use Plan – Part C: Revelstoke Dam. 269 pp.

BC Hydro. 1999a. System Operating Order No. 4P-22, Mica Project Prepared by BC Hydro Power Facilities. 13 pp.

BC Hydro. 1999b. Revelstoke dam and generating station water use plan. Prepared by BC Hydro Power Supply, Vancouver, BC. Report no. MEP341. 37 pp. + 4 app.

BC Hydro. 1998. System Operating Order No. 4P-30, Revelstoke Project Prepared by BC Hydro Power Facilities. 14 pp.

Boeger, R.T. 1992. The influence of substratum and water velocity on growth of *Ranunculus aquatilis* L. (Ranunculaceae). *Aquatic Botany*. 42(4): 351-359.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs*. 27: 325–349.

Bray, K.E. 2003. Lake Revelstoke Reservoir Bull Trout Radio Telemetry Progress Report 2002-2003. 6 pp. + Appendix.

Brown, R.D., R.P. Ouelette and P.N. Chermisinoff. 1983. *Pollution Control at Electric Power Stations: Comparisons for U.S. and Europe*. Boston, MA: Butterworth-Heinemann. 113 pp.

Buttle, J.M., P.W. Hazlett, C.D. Murray, I.F. Creed, D.S. Jeffries and R. Semkin. 2002. Prediction of groundwater characteristics in forested and harvested basins during spring snowmelt using a topographic index, *Hydrological Processes*, 15(18): 3389-3407.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg, MB.

Capers, R.S. 2000. A comparison of two sampling techniques in the study of submerged macrophytes richness and abundance. *Aquatic Botany*. 68(1): 87-92.

Clarke, S.J. and G. Wharton. 2001. Using Macrophytes for the Environmental Assessment of Rivers: The Role of Sediment Nutrients. R&D Technical Report E1-S01/TR. Queen Mary and Westfield College, University of London. London, UK: Environmental Agency. 90 pp.

Cohen, A.S. 2003. *Paleolimnology – The History and Evolution of Lake Systems*. New York, NY: Oxford University Press. 528 pp.

Columbia Basin Fish and Wildlife Compensation Program (CBFWCP). 2004. 2003/2004 Program Fish and Wildlife Project Handbook: A Guide for Projects and Partners in the Columbia Basin. http://www.cbfishwildlife.org.

Cook, C.D.K. 1969. On the determination of leaf form in *Ranunculus aquatilis*. *New Phytologist*. 68(2): 469-480.

Cooke G.D., E.B. Welch, S. Peterson and S.A. Nichols. 2005. *Restoration and Management of Lakes and Reservoirs*. 3rd Edition. Boca Raton, FL: CRC Press, Taylor & Francis Group. 616 pp.

Coops, H., N. Geilen, G. Van der Velde. 1999. Helophyte zonation in two regulated estuarine areas in the Netherlands: Vegetation analysis and relationships with hydrological factors. *Estuaries*. 22: 657-668.

Core Committee for the Revelstoke Unit 5 Project (Core Committee). 2006. Core Committee Report: Revelstoke Unit 5 Project Consultative Process.

Cornerstone Planning Group (Cornerstone). 1994a. Emergency drawdown of Lake Revelstoke Reservoir. Land use and recreation impact assessments. Prepared by Cornerstone Planning Group for BC Hydro, Environmental Affairs, Vancouver, BC. 45 pp. + 3 app.

Cornerstone Planning Group (Cornerstone). 1994b. Land use and recreation impact assessments. Revelstoke Unit 5 Project. Prepared by Cornerstone Planning Group for BC Hydro, Environmental Affairs, Vancouver, BC. 44 pp. + 2 app.

Cowx, I.G. and R.L. Welcomme (eds.). 1998. *Rehabilitation of Rivers for Fish*. Oxford, UK: Fishing News Books. 160 pp.

Crowder, A.A., J.M. Bristow and M.R. King. 1977. The aquatic macrophytes of some lakes in southeastern Ontario. *Naturaliste Canada*. 104: 457-464.

Davis, C.J. and M. Brinson. 1980. Responses of submersed vascular plant communities to environmental change. US Dept. Interior. Fish and Wildlife Service. 70 pp.

Dierssen, H.M., R.M. Kudela, J.P. Ryan and R.C. Zimmerman. 2006. Red and black tides: Quantitative analysis of water-leaving radiance and perceived color for phytoplankton, colored dissolved organic matter, and suspended sediments. *Limnology and Oceanography*. 51(6): 2646-2659.

Downes, B.J., L.A. Barmuta, P.G. Fairweather, D.P. Faith, M.J. Keough, P.S. Lake, B.D. Mapstone and G.P. Quinn. 2002. *Monitoring Ecological Impacts: Concepts and Practice in Flowing Waters*. Cambridge, UK: Cambridge University Press. 446 pp.

Eiswerth, M.E., Donaldson, S.G. and W. Johnson. 2000. Potential Environmental Impacts and Economic Damages of Eurasian Watermilfoil (Myriophyllum spicatum) in Western Nevada and Northeastern California. *Weed Technology*. 14: 511-518.

Environmental Protection Agency (EPA). 2002. Delivering Timely Water Quality Information to Your Community – The Chesapeake Bay and National Aquarium in Baltimore, EMPACT Projects. Report EPA/625/R-02/018. Cincinnati, OH.Environmental Protection Agency (EPA). 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in Pacific Northwest and Alaska. EPA #910/9-91-001.

Environmental Protection Agency (EPA). 1998. Lake and Reservoir Bioassessment and Biocriteria: Technical Guidance Document. 204 pp.

Fidler, L.E. and G.G. Oliver. 2001. *Towards a water quality guideline for temperature in the Province of British Columbia.* Water Quality Section, Water Management Branch, British Columbia Ministry of Environment, Lands and Parks. Forest Products Association of Canada (FPAC). 2008. Best Management Practices Guide for Nutrient Management in Effluent Treatment. April 25, 2008.

Fleming, J.O. and H.A. Smith. 1988. Revelstoke Reservoir aquatic monitoring program. Progress report. Prepared for BC Hydro Report No. ER 88-03.

Flora of North America Editorial Committee (eds.). (FNAEC). 1993. *Flora of North America: North of Mexico*. Volume 1. New York, NY: Oxford University Press. 400 pp.

G3 Consulting Ltd. (G3). 1996. Cycle Two Environmental Effects Monitoring Program – Williston Reservoir. Final Report. Prepared for Fletcher Challenger Canada and Donohue Forest Products Inc. 239 pp.

Gibbons, M.V., H.L. Gibbons, Jr., and M.D. Sytsma. 1994. *A citizen's manual for developing integrated aquatic vegetation management plans*. First Edition. Washington State Department of Ecology. Olympia, WA. 148 pp.

Gilman, B.A., J.C. Foust and B. Zhu. 2008. Composition, seasonal standing crop biomass and estimated annual productivity of macrophyte communities in Owasco Lake. In: *A water quality study of Owasco Lake, New York 2007*. J.D. Halfman, M.E. Balyszak, S.A. Meyer and S. Holland (eds.). Geneva, NY: Finger Lakes Institute, Hobart and William Smith Colleges. 15 pp.

Goldsby, T.L. and D.R. Sanders. 1977. Effects of consecutive water fluctuations on the submersed vegetation of Black Lake, Louisiana. *Journal of Aquatic Plant Management*. 15: 23-28.

Golterman, H.L. 1995. The labyrinth of nutrient cycles and buffers in wetlands: results based on research in the Camargue (Southern France). *Hydrobiologia*. 315: 39-58.

Gradall, K.S. and W.A. Swenson. 1982. Responses of brook trout and creek chubs to turbidity. *Trans. Am. Fish. Soc*. 111: 392–395.

Greening, H.S. and J. Gerritsen. 1987. Changes in macrophyte community structure following drought in the Okefenokee Swamp, Georgia. USA. *Aquatic Botany*. 28: 113-128.

Haidekker, A. 2005. The effect of water temperature regime on benthic macroinvertebrates – A contribution to the ecological assessment of rivers. Fakultät für Biologie und Geografie. Hamburg. 142 pp.

Hall, F.G., K.F. Huemmrich, S.J. Goetz, P.J. Sellers and J.E. Nickeson. 1992. Satellite Remote Sensing of Surface Energy Balance: Success, Failures, and Unresolved Issues in FIFE. *J. Geophys. Res.* 97(17): 19061-19089.

Hargeby, A., G. Andersson, I. Blindow and S. Johansson, 1994. Trophic web structure in a shallow eutrophic lake during a dominance shift from phytoplankton to submerged macrophytes. *Hydrobiologia*. 279/280: 83-90.

Hargrave, B.T. 1969. Epibenthic algal production and community respiration in the sediments of Marion Lake. *J. Fisheries Res. Board Can*. 26: 2003-2026.

Hargrave, B.T., G.A. Phillips, L.I. Doucette, M.J. White, T.G. Milligan, D.J. Wildish and R.E. Cranston. 1997. Assessing benthic impacts of organic enrichment from marine aquaculture. *Water, Air and Soil Pollution*. 99: 641-650.

Haslam, S.M. 1978. *River Plants.* Cambridge, UK: Cambridge University Press. 450 pp.

Hellsten, S. 2001. Effects of lake water level regulation on aquatic macrophyte stands in northern Finland and options to predict these impacts under varying conditions. *Acta Botanica Fennica.* 171: 1-47.

Hellsten, S. 2000. Environmental factors and aquatic macrophytes in the littoral zone of regulated lakes – Causes, consequences and possibilities to alleviate harmful effects. Acta Univ Oulu. 42 pp.

Hellsten, S., M. Marttunen, R. Palomäki, J. Riihimäki and E. Alasaarela. 1996. Towards an ecologically-based regulation practice in Finnish hydroelectric lakes. *Regul. Rivers: Res. Manage*. 12: 535-545.

Henry, J.G. and G.W. Heinke. 1996. *Environmental Science and Engineering*. 2nd Edition. Newark, NJ: Prentice Hall International. 778 pp.

Hestand R.S., B.E. May, D.P. Schultz and C.R. Walker. 1973. Ecological implications of water levels on plant growth in a shallow reservoir. *Hyacinth Cont. J*. 11: 54-58.

Hill, N.M., P.A. Keddy and I.C. Wisheu. 1998. A hydrological model for predicting the effects of dams on the shoreline vegetation of lakes and reservoirs. *Environmental Management*. 22: 723-736.

Hirst, S.M. 1991. Impacts of operation of existing hydroelectric developments on fishery resources in British Columbia. Volume II. Inland Fisheries Canadian Manuscript Report of Fisheries and Aquatic Sciences 2093: 200 pp.

Holmes, N.T.H. and B.A. Whitton. 1975. Submerged bryophytes and angiosperms of the River Tweed and its tributaries. *Trans. Bot. Soc. Edinburgh*. 42: 383-395.

Hynes, H.B.N. 1970. *The Ecology of Running Waters.* 1st Edition. Toronto, ON: Toronto University Press. 555 pp.

Iowa State University (ISU). 2009. Managing Iowa Fisheries – Aquatic Plant Management. Ames, IA: ISU Fisheries Extension.10 pp.

Jeppesen, E., M. Søndergaard, M. Søndergaard and K. Christoffersen. 1997. The Structuring Role of Submerged Macrophytes in Lakes. Ecological Studies 131. New York, NY: Springer. 429 pp.

Johnson, R.L. and B. Blossey. 2002. Eurasian Watermilfoil. In: R. Van Driesche, S. Lyon, B. Blossey, M. Hoddle and R. Reardon. *Biological Control of Invasive Plants in the Eastern United States*. USDA Forest Service Publication: FHTET200204. 413 pp.

Judd, J.B. and S.H. Taub. 1973. The effects of ecological changes on Buckeye Lake, Ohio, with emphasis on largemouth bass and aquatic vascular plants. Biological Notes of the Ohio Biological Survey 6. 51 pp.

Kimmel, B.L. and A.W. Groeger. 1984. Factors controlling primary production in lakes and reservoirs: a perspective. Proceedings of the Third Annual Conference of the North American Lake Management Society, Oct. 18-20, 1983, Knoxville, TN. USEPA. *Lake Reserv. Manage*. 2: 277-281.

Kimmel, B.L. and A.W. Groeger. 1986. Limnological and ecological changes associated with reservoir aging. In: *Reservoir fisheries management: strategies for the 80's*. G.E. Hall and M.J. Van den Avyle (eds.). Bethesda, MD: American Fisheries Society. 327 pp.

Koch-Rose, M.S., K.R. Reddy and J.P. Chanton. 1994. Factors controlling seasonal nutrient profiles in a subtropical peatland of the Florida Everglades. *Journal of Environmental Quality*. 23: 526–533.

Krebs, C.J. 1989. *Ecological Methodology.* 2nd Edition. New York, NY: Harper and Row Publishers. 624 pp.

Lasat, M.M. 1996. The use of plants for the removal of toxic metals from contaminated soil. *Plant Physiol*. 118: 875-883.

Levington, J.S. 1995. *Marine Biology: Function, Biodiversity, Ecology*. 2nd Edition. New York, NY: Oxford University Press. 560 pp.

Lind, O.T., T.T. Terrell and B.L. Kimmel. 1993. Problems in reservoir trophic-state classification and implications for reservoir management. In: *Comparative Reservoir Limnology and Water Quality Management*. M. Straskraba, J.G. Tundisi and A. Duncan (eds.). Netherlands: Kluwer Academic Publishers. 304 pp.

Lohammar, G. 1949. Uber die Värenderungen der Naturverhältnisse gesenkter Seen. *Verh. Int. Ver. Theor. Angew. Limnol*. 10: 266-274.

Mackie, G.L. 2004. *Applied Aquatic Ecosystem Concepts*. Dubuque, IA: Kendall/Hunt Publishing. 784 pp.

Madsen, J.D., C.F. Hartleb and C.W. Boylen. 1991. Photosynthetic characteristics of *Myriophyllum spicatum* and six submersed aquatic macrophyte species native to Lake George, New York. *Freshwater Biology*. 26: 233-240.

Magnuson, J. J. 1990. Long-term ecological research and the invisible present: uncovering the processes hidden because they occur slowly or because effects lag years behind causes. *Bioscience*. 40: 495-501.

Massachusetts Department of Conservation and Recreation (MDCR). 2004. Rapid response plan for Eurasian watermilfoil (*Myriophyllum spicatum*) in Massachusetts. 17 pp.

McNeil, V.H. and M.E. Cox. 2000. Relationship between conductivity and analyzed composition in a large set of natural surface-water samples, Queensland, Australia. *Environmental Geology*. 39(12): 1325-1333.

Mel'nichenko, N.A., A.M. Koltunov, A.S. Vyskrebentsev and A.V. Bazhanov. 2008. The temperature dependence of the solubility of oxygen in sea water according to the pulsed NMR data. *Russian Journal of Physical Chemistry A, Focus on Chemistry*. 82(5): 746-752.

Ministry of Environment (MOE). 2010. BC Species and Ecosystems Explorer. http://a100.gov.bc.ca/pub/eswp/.

Ministry of Forests (MOF). 1999. Revelstoke and area land use planning. Final recommendations. Prepared for Ministry of Forests by the Revelstoke Minister's Advisory Committee, Revelstoke, BC.

Ministry of Forests (MOF). 1989. The Vascular Plants of British Columbia. Special Report Series 1. G.W. Douglas, G.B. Straley and D. Meidinger (eds.). Victoria, BC.

Minnesota Invasive Species Program. 2005. Invasive Species of Aquatic Plants and Wild Animals in Minnesota: Annual Report for 2004. Minnesota Department of Natural Resources, St. Paul, MN. 140 pp.

Minnesota Invasive Species Program. 2006. Invasive Species of Aquatic Plants and Wild Animals in Minnesota: Annual Report for 2005. Minnesota Department of Natural Resources, St. Paul, MN. 125 pp.

Mitchell, P.A. and E.E. Prepas (eds.). 1990. Atlas of Alberta Lakes, The University of Alberta Press. (detailed information on 100 Alberta lakes: author of introduction on Water Quality and six lake chapters, coauthor on nine lake chapters). 690 pp.

Morris, G.L. and F. Jiahua. 1998. *Reservoir Sedimentation Handbook: Design and Management of Dam, Reservoirs and Watersheds for Sustainable Use.* New York, NY: McGraw-Hill Book Co. 848 pp.

Murphy, K.J., T.O. Robson, M. Arsenovic, and W. Van Der Zweerde. 1990. Aquatic weed problems and management in Europe. In: *Aquatic weeds: the Ecology and Management of Nuisance Aquatic Vegetation*. A.H. Pieterse and K.J. Murphy (eds.). Oxford, UK: Oxford University Press. 593 pp.

Murthy, C.R. 1996. Particle pathways of Niagara river water in Lake Ontario affecting bottom sediment contamination. *Hydrobiologia*. 322(1-3): 1573-5117.

Nature Conservancy Council (NCC). 1989. Aquatic Communities. In: *National Vegetation Classification*. Lancaster, UK: Nature Conservancy Council. 133-162 pp.

Nemec, A.F.L. and R.O. Brinkhurst. 1988. Using the bootstrap to assess statistical significance in the cluster analysis of species abundance data. *Canadian Journal of Fisheries and Aquatic Sciences*. 45: 965-970.

Nichols, S.A. 1975. The impact of overwinter drawdown on the aquatic vegetation of the Chippewa Flowage. Wisconsin. *Wisc. Acad. Sci. Arts Lett*. 63: 176-185.

Nichols, S.A. 1974. Mechanical and habitat manipulation for aquatic plant management: a review of techniques. Technical Bulletin of the Wisconsin Department of Natural Resources 77. 34 pp.

Nilsson, C. 1978. Changes in the aquatic flora along a stretch of the River Umeälven, N. Sweden, following hydro-electric exploitation. *Hydrobiologia*. 61: 229-236.

Nilsson, C. and P.A. Keddy. 1988. Predictability of change in shoreline vegetation in a hydroelectric reservoir, northern Sweden. *Can J Fish Aquat Sci.* 45: 1896-1904.

Nilsson, C. 1981. Dynamics of the shore vegetation of a North Swedish hydro-electric reservoir during a 5-year period. *Acta Phytogeogr. Suec*. 69: 1-94.

Northcote, T.G. and D.Y. Atagi. 1997. Ecological interactions in the flooded littoral zone of reservoirs: the importance and role of submerged terrestrial vegetation with special reference to fish, fish habitat and fisheries in the Nechako Reservoir of British Columbia, Canada. B.C. Ministry of Environment, Lands and Parks, Skeena Region Report SK-1 I 1. 64 pp.

O’Sullivan, P.E. and C.S. Reynolds (eds.). 2004. *The Lakes Handbook: Limnology and Limnetic Ecology*. Malden, MA: Blackwell Publishing. 709 pp.

Peter, T. 2000. Interactions between fish and aquatic macrophytes in inland waters. A review. *FAO Fisheries Technical Paper*. No. 396. 185 pp.

Peterson, P.J. 1983. Adaptation to toxic metals. In: *Metals and micronutrients: Uptake and utilization by plants*. D.A. Rabb and W.S. Pierpoint (eds.). London, UK: Academic Press. 341 pp.

Peterson, P.J. 1993. *Plant adaptation to environmental stress: metal pollutant tolerance*. L. Fowden, T. Mansfield and J. Stoddart (eds.). London, UK: Champan & Hall. 346 pp.

Pezeshki, S.R. 2001. Wetland plant responses to soil flooding. *Environmental and Experimental Botany*. 46: 299-312.

Poppe, W.L. 1987. Dissolved oxygen in streams and reservoirs. *Water Pollution Control Federation*. 59(6): 512-513.

Province of British Columbia. 1976. Briefing paper on Eurasian watermilfoil (Myriophyllum spicatum L.). Ministry of the Environment. Water Investigations Branch. Report file 0316533.

PTI Environmental Services (PTI). 1993. Recommendations for Assessing Adverse Benthic Effects in Puget Sound. Prepared for Department of Ecology Sediment Management Unit. Olympia, WA.

Rascio, W. 1997. Metal accumulation by some plants growing on Zn mine deposits. *Oikos*. 29: 250-253.

Reed, C.F. 1977. History and distribution of Eurasian watermilfoil in United States and Canada. *Phytologia*. 36(5): 417-436.

Renman, G. 1989. Distribution of littoral macrophytes in a north Swedish riverside lagoon in relation to bottom freezing. *Aquat. Bot*. 33: 243-256.

Resources Inventory Committee (RIC). 1997. Lake and Stream Bottom Sediment Sampling Manual. http://www.ilmb.gov.bc.ca/risc/pubs/aquatic/lake-stream/index.htm#TOC.

Resources Information Standards Committee (RISC). 1999. Bathymetric Standards for Lake Inventories. http://www.ilmb.gov.bc.ca/risc/pubs/aquatic/bathymetric/index.htm.

Riis, T. and I. Hawes. 2002. Relationships between water level fluctuation and vegetation diversity in shallow water of New Zealand lakes. *Aquat. Bot*. 74: 133-148.

RL&L Environmental Services Ltd. (RL&L). 1994. Revelstoke Dam unit 5 project, aquatic resources scoping and potential impact review. Draft Report Prepared for BC Hydro, Columbia Basin Development Program. RL& L Report No. 429D: 46 pp.

Rørslett, B. 1989. An integrated approach to hydropower impact assessment. II. Submerged macrophytes in some Norwegian hydro-electric lakes. *Hydrobiologia*. 175: 65-82.

Rørslett, B. 1991. Principal determinants of aquatic macrophyte richness in northern European lakes. *Aquat. Bot*. 39: 173-193.

Rothlisberger, J.D., W.L. Chadderton, J. McNulty and D.M. Lodge. 2010. Aquatic Invasive Species Transport via Trailered Boats: What is Being Mowed, Who is Moving It, and What Can Be Done. *Fisheries*. 35(3): 121-132.

Rothrock, P.E. and R.H. Wagner. 1975. Eleocharis acicularis (L.) R.&S.: The autecology of an acid tolerant sedge. *Castanea*. 40: 279-289.

Salt, D.E., M. Blaylock, N.P.B.A. Kumar, V. Dushenkov, B.D. Ensley, I. Chet and I. Raskin. 1995. Phytoremediation: A novel strategy for removal of toxic metals from the environment using plants. *Nature Biotechnology*. 13(5): 468-474.

Sampou, P. and C.A. Oviatt. 1991. Seasonal patterns of sedimentary carbon and anaerobic respiration along a simulated eutrophication gradient. *Mar. Ecol. Prog. Ser*. 72: 271-282.

Scheffer, M. 1998. The role of characean algae in the management of eutrophic shallow lakes, *J. Phycol.* 34: 750-756.

Schindler, E., D. Sebastian and H. Andrusak. 2007. Arrow Lakes Reservoir Fertilization Program, 1999-2004 Technical Report. Project No. 199404900. 57 pp.

Schüring J., H.D. Schultz, W.R. Fisher, J. Böttcher and W.H.M. Duijnisveld (eds.). 2000. *Redox Fundamentals, Processes and Applications*. Berlin, Germany: Springer. 234 pp.

Sebastian, D., G. Scholten, D. Addison, M. Labelle and D. Green. 1995. Results of the 1991-1993 hydroacoustic surveys at Kinbasket and Revelstoke reservoirs. BC Ministry of Environment, Lands and Parks, Stock Management Unit Report No. 1. 37 pp.

Shulman, M.D. and R.A. Bryson. 1961. The vertical variation of wind-driven currents in Lake Mendota. *Limnol. Oceanogr*. 6: 347-355.

Simonavičiūtė, L. and A. Ulevičius. 2007. Structure of phytocenoses in beaver meadows in Lithuania. *Ekologija*. 53(3): 34-44.

Smith, H.A. 1990. Revelstoke Reservoir (Columbia River system) biophysical status to 1987. In: *Joules in the water: Managing the effects of hydroelectric development*. C.E. Delisle and M.A. Bouchard (eds.). A symposium sponsored by the Canadian Society of Environmental Biologists, Montreal, April 6-7, 1989. Collection Environnement et Geologie, Vol. 9, Universite de Montreal. 650 pp.

Sneath, P.H.A. and R.R. Sokal. 1973. *Numerical Taxonomy: the principles and practice of numerical classification*. San Francisco, CA: Freeman. 573 pp.

Spink, A.J. 1992. The ecological strategies of aquatic *Ranunculus* species. Ph.D. Thesis. Glasgow, UK: University of Glasgow. 360 pp.

Straskraba, M., J.G. Tundisi and A. Duncan. 1993. State-of-the-art of reservoir limnology and water quality management. In: *Comparative Reservoir Limnology and Water Quality Management*. M. Straskraba, J.G. Tundisi and A. Duncan (eds.). Netherlands: Kluwer Academic Publishers. 304 pp.

Straškrábová V., K. Šimek and J. Vrba. 2005. Long-term development of reservoir ecosystems - changes in pelagic food webs and their microbial component. *Limnetica*. 24(1-2): 9-20.

Thornton, K.W., R.H. Kennedy, J.H. Carroll, W.W. Walker, T.C. Gunkel and S. Ashby. 1981. Reservoir sedimentation and water quality – an heuristic model. In: *Proceedings of the Symposium on Surface Water Impoundments*. G.H. Stefan (ed,). American Society of Civil Engineers, New York, NY. 1724 pp.

Toivonen, H., and C. Nybom. 1989. Aquatic vegetation and its recent succession in the waterfowl wetland Koijärvi, South Finland. *Ann. Bot*. 26: 1-14.

Transboundary Gas Group (TGG). 2008. Transboundary Gas Group at Revelstoke, BC. Meeting Minutes. 8 pp.

Triton Environmental Consultants Ltd. (Triton). 1992. Revelstoke aquatic monitoring program – an assessment of Revelstoke Reservoir ecology and recommendations for future monitoring. Report Prepared for BC Hydro Environmental Resources by Triton Environmental Consulting Ltd. 41 pp. + App.

Triton Environmental Consultants Ltd., and Summit Environmental Consultants Ltd. (Triton and Summit). 1995. Revelstoke Unit 5 fish and aquatic issues. 39 pp. + Appendices.

TuTiempo. 2010. Historical Weather: Revelstoke, Canada. http://www.tutiempo.net/en/Climate/Revelstoke/718820.htm.

Underwood, A.J. 1994. On Beyond BACI: Sampling Designs that Might Reliably Detect Environmental Disturbances. *Ecological Applications*. 4: 3-15.

United States Army Corps of Engineers (USACE). 1997. Engineering and Design – Hydrologic Engineering Requirements for Reservoirs. Publication Number: EM 1110-2-1420. 115 pp.

United States Department of Agriculture (USDA). 2010. Plant Database. http://plants.usda.gov/index.html.

University of California. 2001. *Aquatic Pest Control*. Pesticide Application Compendium, Volume 5. Publication 3337. Oakland, CA: UC Agriculture and Natural Resources. 168 pp.

University of Wisconsin. 2010. Ranunculus aquatilis L. var. diffusus. Robert W. Freckmann Herbarium. http://wisplants.uwsp.edu/scripts/detail.asp?SpCode=RANAQUvDIF.

Urban Systems Ltd. (Urban Systems). 1990. Lake Revelstoke recreation and tourism development opportunities. Prepared by Urban Systems Ltd. for the Columbia-Shuswap Regional District. Report 7047635.1. 49 pp. + 1 app.

Vanoni, V.A. 2006. Sedimentation Engineering. ASCE Manuals and Reports on Engineering Practice No. 54. 424 pp.

Vermont Agency of Natural Resources. 1989. The Lake Bomoseen drawdown: An Evaluation of its Effects on Aquatic plants, wildlife, fish, invertebrates, and recreational uses. Report prepared for the Vermont Legislature. Waterbury, VT.

Wetzel, R.G. 1983. *Limnology*. 2nd Edition. New York, NY: Saunders. 860 pp.

Wetzel, R.G. 2001. *Limnology - Lake and River Ecosystems*. 3rd Edition. New York, NY: Academic Press. 1006 pp.

Wheeler, B.D. 1999. Water and plants in freshwater wetlands. In: *Eco–hydrology: Plants and Water in Terrestrial and Aquatic Environments*. A.J. Baird and R.L. Wilby (eds.). London, UK: Routledge. 424 pp.