Campbell River Project Water Use Plan

Upper and Lower Campbell Lake Reservoirs Shoreline Vegetation Model Validation

Implementation Year 1

Reference: JHTMON-10

JHTMON-10: Upper and Lower Campbell Lake Reservoirs Shoreline Vegetation Model Validation Year 1 Monitoring Report

Study Period: 2015

Laich-Kwil-Tach Environmental Assessment Ltd. Partnership
Ecofish Research

November 27, 2015

JHTMON-10: Upper and Lower Campbell Lake Reservoirs Shoreline Vegetation Model Validation

Year 1 Monitoring Report

BC Hydro Water Licensing Requirements
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EXECUTIVE SUMMARY

Water Use Plans (WUPs) were developed for most of BC Hydro's hydroelectric facilities through a multi-stakeholder consultative process. WUP's and the corresponding Order were developed and designed as a means to balance power production with other water uses such as fish and wildlife, recreation, and power generation. The WUP Order also directs BC Hydro to undertake specific actions including multi-year environmental monitoring studies, with specific management questions and hypotheses.

The Campbell River WUP Order established the JHTMON-10 monitoring program to address uncertainty associated with the accuracy of the shoreline vegetation model (SVM) created to predict the response of riparian and emergent vegetation to operational changes proposed during WUP development. Model predictions of the elevations of boundaries between riparian vegetation communities were used to evaluate the expected changes in the aerial extent and distribution of shoreline vegetation community types in the Campbell River hydroelectric system, and infer associated effects to wildlife.

The management questions and associated hypotheses for JHTMON-10 monitoring program aim to validate the SVM, both for the Upper Campbell Lake Reservoir and for the other reservoirs in the Campbell River hydroelectric system. The five management questions are:

1. Does the lacustrine shoreline vegetation model accurately predict the reservoir elevation bands that bound the predefined plant community types?
2. If the model is in error, is the magnitude of the error such that it would warrant a change in the predicted outcome of the WUP?
3. Are there changes to the modelling approach that could improve its accuracy for implementation in future WUP reviews?
4. Is it reasonable to expect that most riparian plant ecosystems require shoreline slopes to have a gradient less than 15% to perpetuate?
5. Has the distribution of riparian plant ecosystems changed following implementation of the WUP and if so, can the change be attributed to the WUP operation?

The three hypothesis are:

H_01 Measured elevation bands defining the upper and lower extents of each vegetation community type in the area are not significantly different than those predicted by the shoreline vegetation model.

H_02 The likelihood that a particular plant ecosystem type occurs within a predicted reservoir elevation band is not dependent on shoreline gradient.

H_03 Plant community distribution following implementation of the WUP does not differ significantly from the measured state prior to implementation.

The model, developed by Bruce (2002), was parameterized with vegetation community and water elevation data from Upper Campbell Lake Reservoir collected in 2001. Year 1 of this 10 year program serves to re-establish the baseline data for the Upper Campbell Lake Reservoir and collect baseline data for the Lower Campbell Lake Reservoir and Brewster Lake. The Year 1 data collection focused on collecting vegetation community boundary data from transect surveys, installing a hydrology gauge on Brewster Lake, monitoring water levels in Upper Campbell Lake Reservoir, Lower Campbell Lake Reservoir and Brewster Lake, and mapping the areal extent of the key riparian vegetation communities through air photo interpretation of current photogrammetry. Year 1 data analysis focused on preliminary validation of the SVM for Upper Campbell Lake Reservoir (Management Question 1 and 2) and the initial analysis and identification of the gradient on which vegetation occurs in all three waterbodies (Management Question 4). In addition, recommendations were made to improve model accuracy (Management Question 3), and observed changes in the distribution of riparian plant ecosystems are presented (Management Question 5).

In Year 1, SVM predictions for the Upper Campbell Lake Reservoir satisfied the two predefined tests of model accuracy. Specifically, when all community boundaries were pooled, the modelled and measured boundary elevations were shown to be not statistically significantly different and the mean model error was not statistically significantly different from zero (Management Question 1). The model error was typically relatively low for the four lowest elevation riparian vegetation community boundaries (Lake Mudflat to tall Sitka willow- Water sedge) but relatively high for the boundary of the highest elevation riparian community (tall Sitka willow – Water sedge) with the Upland Forest vegetation community. When community boundaries were analysed separately, there were statistically significant differences between SVM predictions and field measurements. The effect of this error on the aerial extent of riparian communities was not examined in Year 1. However, it is of value to note that initial results from Year 1 demonstrate a general downwards shift of individual community boundaries. Furthermore, observed errors between predicted and modelled data are expected to decrease for the Upper Campbell Lake Reservoir over time as communities become further established and the boundaries between the communities become better defined. Nevertheless, the effects of these errors on the predicted outcome will vary depending both on the magnitude of the error, the specific vegetation boundary and the slope at which the community ceases to occur. Hence, Management Question 2 will be able to be more fully addressed in Year 10, when more data will be available.

During the WUP process, the model was applied with the assumption that most riparian plant ecosystems occur on slopes with a gradient of less 15%. Slopes greater than 15% were assumed to be too steep to allow soils to accumulate and support plant growth. Investigation of the SVM assumption that riparian plant ecosystems require shoreline gradients of less than 15% to perpetuate was examined with field transect data and GIS data and analysis. The distribution of vegetated and unvegetated areas was only found to be dependent on whether slope is greater or less than 15% in the Upper Campbell Lake Reservoir (Management Question 4). Further, there is a statistically significant difference between the slope of unvegetated and vegetated shoreline vegetation communities along the Upper Campbell Lake Reservoir, for all vegetation community combined and by individual vegetation community type. In contrast, data from Lower Campbell Lake Reservoir and Brewster Lake demonstrated only weak and inconclusive relationships between the slopes measured on the ground and vegetation presence and the gradients of unvegetated and vegetated GIS polygons. Weaknesses between the detected relationship between slope and vegetation for the two smaller waterbodies are likely partially attributed to the narrow range of slopes sampled on the ground and the low resolution of elevation data available for input into the digital elevation model. Further data collection and analysis will be required to determine the maximum slope at which vegetation communities can persist on, which in turn will inform the model and allow a more accurate estimate of the aerial extent of lake shoreline riparian vegetation communities in the Campbell River hydroelectric system.

A general downwards shift in all vegetation communities in the Upper Campbell Lake Reservoir was observed between 2001 and Year 1 field measurements. The observed change in vegetation community distribution follows a similar trend to that predicted by the SVM and is likely attributed to WUP operations (Management Question 5). This question will be analysed in more detail in Year 10 for Upper Campbell Lake Reservoir and for Lower Campbell Lake Reservoir and Brewster Lake once baseline and monitoring data have been collected.

Key recommendations for the study are made pertaining to field sampling and analysis. In brief, vegetation transects should be executed with a laser survey rod to capture both the top of the lowest vegetation community and the bottom of the highest vegetation community, and be completed during the lowest water level conditions possible to optimize utility of the data. Additional slope data should be collected in the field for slopes over 15% to better define the optimal slope to incorporate into the model. The level of detail and extent of air photo interpretation should be repeated in Year 10 to create comparable datasets. GIS analysis of the slope hypothesis for Lower Campbell Lake Reservoir and Brewster Lake would be more valuable with higher resolution and more accurate DEMs, and if more unvegetated polygons were defined and analysed. Additional statistical methods would also assist in determining the best slope with which to apply the model. Validating the SVM should include: (1) comparing differences in boundary elevations both between *individual* transects (using repeated measures tests) and between *all* transects (using pooled data for each waterbody) to examine inter-site variation, and thus the extent that boundary elevations should be the same throughout each waterbody; (2) comparing SVM results with hydrology data input up to the previous year to results when hydrology data includes the current year up to the time of sampling, to evaluate the effect of recent inundation on community distribution; and (3) determining whether the vegetation communities on small lakes have similar hydrological requirements to those found in similar equivalent relative elevation bands on large lakes to assess whether the SVM can accurately predict vegetation community elevations in these lakes. In addition, collecting an additional year of vegetation community data during the intermediate years (i.e. Year 5) would provide further insight into model error and thus provide the opportunity to create a more robust model. A review of current literature should be conducted again in Year 10 specifically that includes review of BC Hydro reservoir vegetation monitoring projects.

Subsequent to Year 1, water levels will be monitored annually, from Year 1 through Year 10, for the three waterbodies, with BC Hydro monitoring the water levels of Upper and Lower Campbell Lake Reservoirs and Ecofish Research Ltd. (Ecofish) monitoring the water level of Brewster Lake.

In Year 10, hypothesis testing will be completed for the Upper Campbell Lake Reservoir, Lower Campbell Lake Reservoir and Brewster Lake. Field data collection will replicate Year 1 data collection, with the addition of any method refinement required to address the management questions and hypothesis. At this time adequate water level data will have been collected to develop SVM predictions for each waterbody, and vegetation communities will have more fully responded to operational changes. Ultimately, sufficient data should be available to determine whether the model can also be applied to all reservoirs and diversion lakes in the Campbell River hydroelectric system.

MON-10 STATUS of OBJECTIVES, MANAGEMENT QUESTIONS and HYPOTHESES after Year 1 (2015)

Study Objectives	Management Questions	Management Hypotheses	Year 1 (fiscal year 2014-2015) Status
1. Determine if the Shoreline Vegetation Model accurately predicts the elevation of the plant community types.	1. Does the lacustrine shoreline vegetation model accurately predict the reservoir elevation bands that bound the predefined plant community types?	$H_0$1. Measured elevation bands defining the upper and lower extents of each vegetation community type in the area are not significantly different than those predicted by the shoreline vegetation model.	a) This management question has been partially addressed for the Upper Campbell Reservoir which had 2001 baseline vegetation community elevation data and 14 years of hydrology data. This question has not been addressed for Lower Campbell or Brewster which have baseline data collection from 2014 only. An additional future year of vegetation baseline collection and interim hydrology data is needed to populate and test the model on these lakes. b) The study is on track to answer the management question and hypothesis in Year 10 using the current approach and study design.
2. Determine if any errors in model predictions will warrant a change in the predicted outcome of the WUP.	2. If the model is in error, is the magnitude of the error such that it would warrant a change in the predicted outcome of the WUP?		a) The magnitude of errors for Upper Campbell were analysed in Year 1. However the observed errors are expected to shrink by Year 10. As the model was not populated for Lower Campbell and

			Brewster Lakes in Year, errors were not generated. b) The study is on track to be able to determine if the model is in error, the magnitude of potential error and analyse the potential effects on the predicted outcome of the WUP in Year 10.
3. Determine if changes to the modelling approach could improve its accuracy.	3. Are there changes to the modelling approach that could improve its accuracy for implementation in future WUP reviews?		a) Additional parameters and techniques that could improve model accuracy are presented but not tested. b) Recommendations for improving the model will be presented in Year 10. The extent to which these will be tested will depend on the remaining budget. Additional data is being collected to facilitate modifications to the modelling approach if necessary.
4. Determine whether the riparian plant ecosystems in question require a gradient less than 15% to perpetuate.	4. Is it reasonable to expect that most riparian plant ecosystems require shoreline slopes to have a gradient less than 15% to perpetuate?	$H_0$2. The likelihood that a particular plant ecosystem type occurs within a predicted reservoir elevation band is not dependent on shoreline gradient.	a) This question has been answered for Upper Campbell. However additional data and analysis could provide a more precise slope at which the specific riparian plant ecosystems in question are unlikely to persist. b) This question can be better answered in Year 10 for

			Lower Campbell and Brewster Lakes with either the acquisition of higher resolution and more accurate digital elevation data or with the collection of more slope data on the ground. Thus the study is on track to answer this question by Year 10.
5. Determine whether the distribution of riparian plant ecosystems have changed following implementation of the WUP, and determine whether the change is attributed to the WUP.	5. Has the distribution of riparian plant ecosystems changed following implementation of the WUP and if so, can the change be attributed to the WUP operation?	$H_0$2. Plant community distribution following implementation of the WUP does not differ significantly from the measured state prior to implementation.	a) For the Upper Campbell Lake Reservoir distribution of riparian plant ecosystems has changed following implementation of the WUP and this change can be at least partially attributed to WUP operation. This management question and hypothesis can be better and more thoroughly addressed in Year 10 for Upper Campbell Lake with the collection of additional data and given additional time for vegetation communities to establish, and will be able to be answered for the two other lakes in Year 10. b) The study is on track to answer this management question and hypothesis in Year 10.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ECOFISH RESEARCH

LIST OF MAPS

LIST OF APPENDICES

1. INTRODUCTION

1.1. Water Use Planning

BC Hydro engages in water use planning with the objective of providing a balance between competing uses of water that include fish and wildlife, recreation, and power generation. Water Use Plans (WUPs) were developed for most of BC Hydro's hydroelectric facilities through a consultative process involving local stakeholders, government agencies, First Nations and other interested parties. Under the provision of the BC *Water Act* (2006), the Comptroller of Water Rights issued WUP related Orders which prescribed operational requirements that balance power production with other water uses. The Orders also direct BC Hydro to undertake specific actions including multi-year environmental monitoring studies. The objectives of these monitoring studies are to address outstanding uncertainties, management questions and test associated hypothesis in the years following the implementation of a WUP.

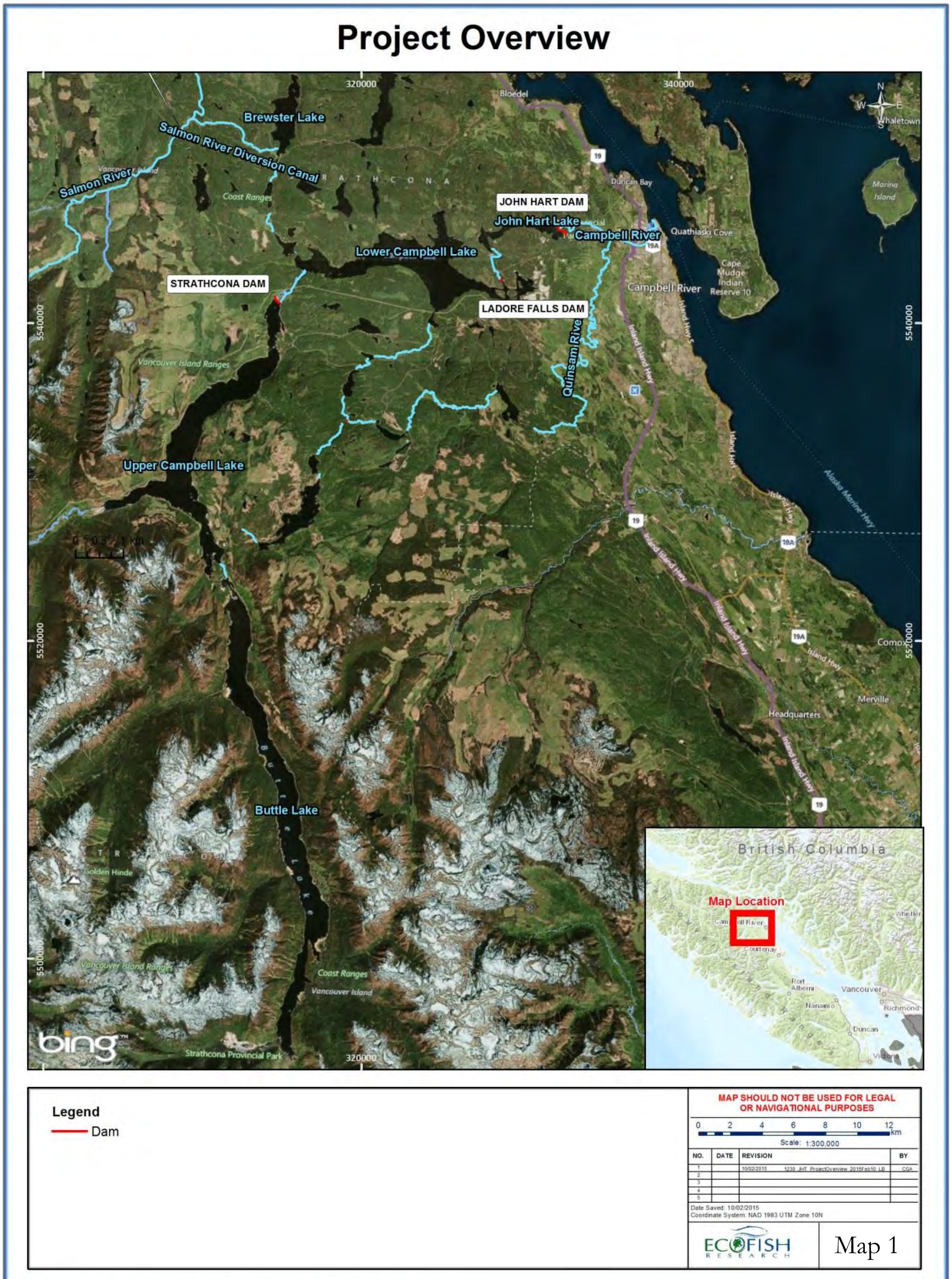
The Campbell River WUP and related Order prescribed several monitoring programs (BC Hydro 2012). One of the programs is to monitor shoreline vegetation to validate the newly-developed, lacustrine shoreline vegetation model (SVM) that was used to predict changes in shoreline plant ecosystems in response to operational change in the Campbell River hydroelectric system (Bruce 2002). Changes in the aerial extent and location of shoreline plant ecosystem types[1] predicted by the model were utilized to infer effects to wildlife. Based on the proposed operational changes, the potential effects on wildlife were predicted to be either benign or positive. Although the Wildlife Technical Committee (WTC) thought the SVM to be technically sound, relatively high level of uncertainty remained as the model was largely untested. Consequently, the WTC accepted the results of the model under the provision that the *"Upper and Lower Campbell Lake Reservoirs Shoreline Vegetation Model Validation"* monitoring program (JHTMON-10) be executed to validate the model (BC Hydro 2013).

1.2. BC Hydro Infrastructure, Operations and the Monitoring Context

The overarching objective of JHTMON-10 is to examine the validity and accuracy of the SVM model in three waterbodies within the Campbell River watershed, located on Vancouver Island, British Columbia: (1) the Upper Campbell Lake Reservoir (Upper Campbell and Buttle Lakes), (2) Lower Campbell Lake Reservoir, and (3) Brewster Lake (Map 1). All three waterbodies are within 33 km west of the City of Campbell River, British Columbia and are primarily bounded by Strathcona Provincial Park, private managed forest lands, and other private land.

[1] The management questions and hypothesis in the TOR use 'plant ecosystem' and 'vegetation community' interchangeably, and this is reflected in this report.

Map 1. Overview of the JHTMON-10 study area.



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The study area covers two variants of the Very Dry Maritime Coastal Western Hemlock biogeoclimatic subzone (CWHxm): (1) CWHxm1, the eastern variant, which extends from approximately Loveland Bay on Lower Campbell Lake Reservoir to the east, and (2) CWHxm2, the western variant which covers the remainder of the study area. The CWHxm occurs at lower elevations (up to 700 m) on the east side of Vancouver Island and is characterised by warm, dry summers, and moist, mild winters with little snowfall (Green and Klinka 1994). Vegetation growth is constrained by water deficits over the long growing season. Zonal sites are dominated by Douglas-fir (*Pseudotsuga menzeisii*), with western hemlock (*Tsuga heterophylla*) and some western redcedar (*Thuja plicata*). Dominant understory species include salal (*Gaultheria shallon*), dull Oregon-grape (*Mahonia nervosa*), red huckleberry (*Vaccinium parviflorum*), step moss (*Hylocomium splendens*) and Oregon beaked moss (*Kindbergia oregana*).

1.2.1. Upper Campbell Lake Reservoir

The Upper Campbell Lake and Buttle Lake Reservoirs (Upper Campbell Lake Reservoir) are effectively a single reservoir that comprise the largest and most southern and western components of the Campbell River hydroelectric system. The largest tributaries are the Thelwood River, entering the system at the south end of Buttle Lake, and the Elk River which enters the west side of Upper Campbell Lake Reservoir.

The Upper Campbell Lake Reservoir is impounded by the Strathcona Dam. The dam also provides primary flow regulation for the Ladore and John Hart Dam's which are located downstream. The Strathcona dam was constructed between 1955 and 1958 with a second generating unit installed in 1968. The reservoir's historic operational water elevation has been between 210.0 m and 221.0 m. The current maximum and minimum operating levels are 212.0-220.5 m respectively (as measured at Strathcona Dam), although the 'preferred' operating zone (as determined based on the WUP targets such as recreation, flood risk, fish etc.) varies throughout the year, with a relatively high elevation 'preferred' zone in the summer (217.0-220.5 m) (BC Hydro 2012).

The SVM was parameterized with Upper Campbell Lake Reservoir data during development of the WUP. The model was then applied, and results considered. The Upper Campbell Lake Reservoir is expected to have the largest change in hydrologic regime in the Campbell River hydroelectric system from the implementation of the WUP. Therefore it should be the most robust test of the SVM (BC Hydro 2013).

1.2.2. Lower Campbell Lake Reservoir

Lower Campbell Lake Reservoir is located to the east, and at the outflow of, the Upper Campbell Lake Reservoir (Map 1). It is impounded by the Ladore Dam. The reservoir is located 15 km east of Campbell River. The Ladore Dam was originally completed in 1949, and two generating units were added in 1957. The reservoir's historic operational water elevation has been between 178.3 m and 174.0 m, which is the same as the current maximum and minimum operating levels. The 'preferred' zone in the summer is a minimum of 176.5 m and a maximum of 177.5 m (BC Hydro 2012).

Changes to historic operational water levels in the Lower Campbell Lake Reservoir in the WUP are minor and therefore this reservoir will be used to test the models sensitivity. During development of the WUP, the SVM was applied to Lower Campbell Lake Reservoir. However, due to insufficient data from the reservoir, it was parameterized with Upper Campbell Lake Reservoir data, resulting in uncertainty in the results (BC Hydro 2013).

1.2.3. Brewster Lake

Brewster Lake is approximately 23 km northwest of Campbell River, it has an approximate elevation of 190 masl. The southern tip of Brewster Lake is approximately 6 km north of the west end of Lower Campbell Lake Reservoir, and 10 km north of the northeast end of Upper Campbell Lake Reservoir.

Brewster Lake is the most northern, and first lake on the Salmon River diversion, a system which diverts water from the Salmon River, south into the Lower Campbell Lake Reservoir. The Salmon River flows from Strathcona Provincial Park in a general northwards direction to the mouth at Sayward, BC. Major tributaries include Grilse Creek, the Memekay River and the White River, all of which drain the western side of the Salmon River watershed.

The Salmon River Diversion infrastructure was initially constructed in 1958. The diversion dam is a 69 m long rock-filled timber crib dam that diverts water into the Campbell River watershed. Water is diverted from the mainstem of the Salmon River via an intake channel, through a radial gate and into a concrete-lined canal that conveys water to Brewster Lake which is upstream of Lower Campbell Lake reservoir. Non-diverted water is returned to the mainstem downstream, either via the main spillway, an undersluice, a trimming weir, or the fishway.

In Year 1, Brewster Lake was selected to apply the model to a diversion lake, as it is the largest lake along the Salmon River diversion and therefore likely provides the most variability in site characteristics and the highest number of potential sample sites. It was important to add a diversion lake to the monitoring program to test the models applicability to non-reservoir environments. Previously, the model had been quantitatively applied only to the reservoirs (Upper and Lower Campbell Lake) where water levels were better understood, and the principles only conceptually applied to the diversion lakes, where there was uncertainty regarding the impact of flow changes on water elevation (BC Hydro 2013).

1.3. Management Questions and Hypothesis

The WTC identified four management questions to be addressed by JHTMON-10. Answers to these questions are necessary to validate the model by gaining an increased understanding of the accuracy of the models predictions, the magnitude of error, and by testing assumptions made in application of the model. In addition, the TOR lists a fifth question to assist with understanding potential changes to the distribution and extent of shoreline vegetation communities, and if potential observed changes can be attributed to the WUP. Answers to these questions can be used to better understand the likely operational impacts of the WUP on shoreline vegetation communities, and the associated obligate and facultative aquatic and terrestrial wildlife (BC Hydro 2013).

The monitoring program aims to address the following five management questions:

6. Does the lacustrine shoreline vegetation model accurately predict the reservoir elevation bands that bound the predefined plant community types?

   This will be initially examined in Year 1 for the Upper Campbell Lake Reservoir based on Year 1 vegetation community survey data and water level data for the period 2001-2013. In Year 10, this will be examined for each of the three waterbodies (identified in Section 1.2). Key tests to examine whether the model predictions can be deemed 'accurate' have been identified to address the following question: 1) Do the predicted vegetation elevation bands differ significantly from the measured elevations; 2) Are the errors between model predictions and ground measurements significantly different from zero (BC Hydro 2013)?

7. If the model is in error, is the magnitude of the error such that it would warrant a change in the predicted outcome of the WUP?

   This will be initially examined for Upper Campbell Lake Reservoir during Year 1 SVM validation. In Year 10, this will be examined for each of the three waterbodies.

8. Are there changes to the modelling approach that could improve its accuracy for implementation in future WUP reviews?

   The potential for changes to the model will be initially assessed in Year 1 based on the outcomes of the SVM validation for Upper Campbell Lake Reservoir and field observations. In Year 10, this will be examined for each of the three reservoirs.

9. Is it reasonable to expect that most riparian plant ecosystems require shoreline slopes to have a gradient less than 15% to perpetuate?

   The present SVM assumes that shoreline gradient would have to be 15% or less to allow soils to accumulate and hence allow for plant growth. This gradient assumption was decided upon by the WTC based on professional experience and has not been validated. It will therefore be examined during Year 1 through analysis of data collected using two methods: 1) ground slope measurements along vegetation transects, and; 2) GIS derived slopes of vegetation community polygons delineated through air photograph interpretation.

10. Has the distribution of riparian plant ecosystems changed following implementation of the WUP and if so, can the change be attributed to the WUP operation?

    This question was not explicitly requested by the WTC; however, the monitoring program is designed to provide the necessary information to address this key question in Year 10 (BC Hydro 2013).

In addressing the management questions, the monitoring program is designed to test the following three null hypotheses:

$H_0$1: Measured elevation bands defining the upper and lower extents of each vegetation community type in the area are not significantly different than those predicted by the shoreline vegetation model.

This hypothesis will be tested separately in each of the three waterbodies where the SVM is applied to allow an evaluation of model predictions on the respective vegetation communities and under the respective hydraulic regimes. Failure to reject this hypothesis would suggest the SVM accurately predicts vegetation community boundary elevation bands in the respective waterbody. Rejection of this hypothesis would lead to a detailed evaluation of the modelling error; firstly, to determine whether the error is large enough to significantly affect the deliberations and conclusions of the WTC (Management Question 2); and secondly, to uncover shortcomings in the modelling process so that, if possible, changes can be made to improve future model accuracy (Management Question 3).

$H_0$2: The likelihood that a particular plant ecosystem type occurs within a predicted reservoir elevation band is not dependent on shoreline gradient.

The hypothesis will be tested separately for each plant ecosystem, as well as for all types as a group that occur within the drawdown zone. During the WUP, the WTC assumed that a 15% gradient formed a reasonable threshold for plant growth. The 15% gradient will be tested along with other gradients, including the possibility that plant growth is independent of gradient (i.e., $H_0$2 is accepted) (Management Question 4). This will involve analysis of the slopes observed in vegetation transects, as well as geostatistical analysis of plant ecosystem polygons overlaid on a digital elevation model (DEM).

$H_0$3: Plant community distribution following implementation of the WUP does not differ significantly from the measured state prior to implementation.

This hypothesis will be tested separately for each of the three waterbodies. If the SVM proves valid (i.e., $H_0$1 is accepted), then it can be inferred that observed changes (i.e., $H_0$3 is rejected) are likely be attributed to WUP operations (Management Question 5). Addressing this hypothesis will involve extrapolating the model results over the DEM and calculating the aerial extent of each vegetation community. Vegetation community distributions 'before' and 'after' implementation of the WUP will be assessed.

1.4. Scope of JHTMON-10

The JHTMON-10 program has been designed to answer the management questions and hypothesis listed in Section 1.4. The objectives of these questions are to determine how well the SVM predicts elevation boundaries of riparian vegetation community types based on water elevations, and to determine how the vegetation community distributions correlate with slope, to formally develop a means of calculating aerial extent and location of shoreline plant ecosystem types. Gaining a greater understanding of these two aspects will facilitate an understanding of whether reservoir operations have affected the distribution of riparian vegetation communities and hence resulted in potential adverse effects on wildlife.

Riparian habitats are generally defined as the interface between aquatic and terrestrial ecosystems (MWLAP 2006). These habitats provide important ecological functions (Richardson *et al.* 2005, Hoover *et al.* 2006). Riparian habitats are typically associated with more valuable wildlife habitat than adjacent upland areas as they are productive and structurally diverse (DFO and MELP 1998, Richardson 2003, MWLAP 2004). Moreover, riparian habitats provide critical migratory, feeding and breeding habitats for amphibians, birds, and other terrestrial wildlife. Riparian habitats can be divided into two types based on soil conditions and influences: (1) soils that are influenced by the hydrologic regime of adjacent waterbodies, and (2) soils which are not (McLennan and Veenstra 2001). The focus of this monitoring program is on those shoreline riparian communities with soil characteristics that are primarily affected by the hydrologic regime of the adjacent waterbody, and are therefore likely to be directly affected by the WUP. Reservoir operations have the potential to directly and indirectly affect riparian habitats through the alteration of water levels. Excess or insufficient water levels can adversely affect vegetation community composition (Wilcox and Meeker 1991). The effects may differ depending on the temporal nature of the fluctuations and the floristic composition (Riis and Hawes 2002, Nilsson and Keddy 1988, Van Eck *et al.* 2006). In addition, riparian communities can be affected by the scouring effect of drawdown and surcharge of reservoirs on soils and establishing communities (BC Hydro 2013). Thus, the JHTMON-10 program design focuses on the ecosystem structure, composition, and function of shoreline and riparian communities that may be affected by modifications to operations as prescribed in the WUP.

1.5. Approach

There are multiple data collection and data analysis components that will contribute to the validation and refinement of the shoreline vegetation model, including the gradient assumption (Table 1). Each of these study components contribute to answering the five management questions and three hypotheses during this 10 year monitoring program.

In Year 1, data collection will re-establish a baseline for the monitoring program. Data will include vegetation community transects, water elevation data summaries, and air photo interpretation of the study area. These data will provide the opportunity to conduct preliminary analysis of the management questions and hypothesis associated with the Upper Campbell Lake Reservoir SVM (Management Question 1, 2, 3, and $H_0$1) and associated gradient assumptions (Management Question 4, and $H_0$2).

In Year 10, data will be sufficient to answer and test all five management questions and hypotheses associated with the SVM for the Upper Campbell Lake Reservoir, Lower Campbell Lake Reservoir, and Brewster Lake. Data will consist of 10 years of daily average water surface elevations for the three waterbodies, and Year 10 replicates of the vegetation community transects, and air photo interpretation.

Table 1. Demonstration of how each project component contributes to answering the project's management questions and hypotheses over the ten year period.

Phase	Study Component	Management Question 1	2	3	4	5	Hypothesis 1	2	3
Data collection	Vegetation Community	x		x	x	x	x	x	x
	Water Elevation	x					x		x
	Air Photo Interpretation	x			x	x	x	x	x
Analysis	SVM Validation	x	x	x		x	x		x
	Vegetation Community Gradient				x	x		x	x

1.5.1. Shoreline Vegetation Model

The SVM was developed to predict the relationship between water levels and the distribution of riparian shoreline (littoral) vegetation in the Campbell River watershed (BC Hydro 2013, Bruce 2002). Specifically, the SVM was used to quantitatively predict vegetation community elevation bands and qualitatively assess impacts to shoreline vegetation and riparian habitats surrounding the diversion lakes. Furthermore, the SVM predictions provided pertinent information to evaluate potential impacts on wildlife dependent on shoreline and riparian habitats.

The model relates historic water levels (1984 to 2000 inclusive) (Figure 1) to the mean elevation boundaries of the six main vegetation communities that were present on the shore of Upper Campbell Lake Reservoir (Upper Campbell Lake and Buttle Lake) during surveys conducted in 2001 (McLennan and Veenstra 2001) (Table 2). Based on historical water levels, the SVM is designed to predict the elevation boundaries between the six dominant vegetation community types that occur around Upper Campbell Lake Reservoir (i.e., as noted in Figure 2).

Figure 1. Daily water level in the Upper Campbell Lake Reservoir, 1984–2000.

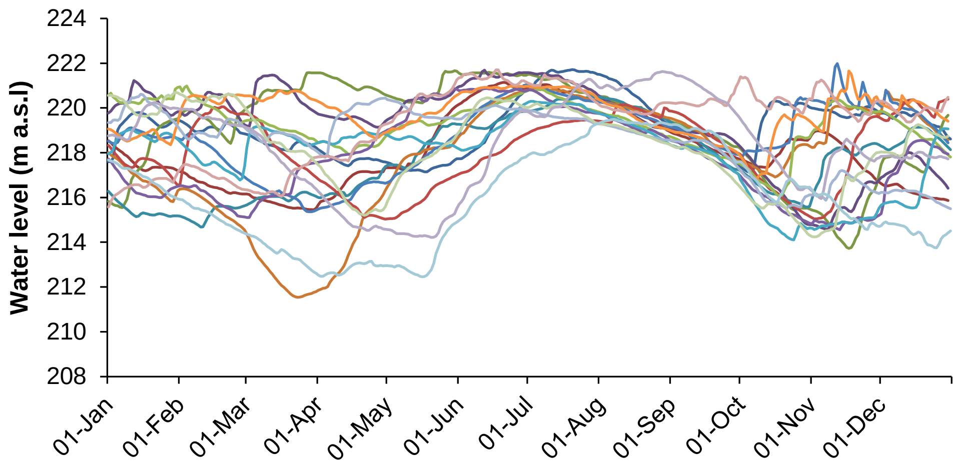


Table 2. Summary of mean elevation boundaries of vegetation communities surveyed by McLennan and Veenstra (2001). Reproduced from Bruce (2002).

No.	Vegetation Community Name	Map Code	Boundary Elevation (m)	
			Lower	Upper
1	Lake Mudflat	MF/MFl[1]	211.5	218
2	Spearwort Lakeflat	SL	218	219.2
3	Hairgrass – Water sedge	HS	219.2	219.8
4	Sitka willow - Water sedge (short)	WS_s	219.8	220.5
5	Sitka willow - Water sedge (tall)	WS_t	220.5	221.2
6	Upland Forest	UF	221.2	222

[1]The Lake Mudflat community is denoted as both MF and MFl throughout this document reflective of background sources.

Figure 2. Conceptual elevation diagram of the vegetation communities in the Shoreline Vegetation Model (SVM_{2002}).

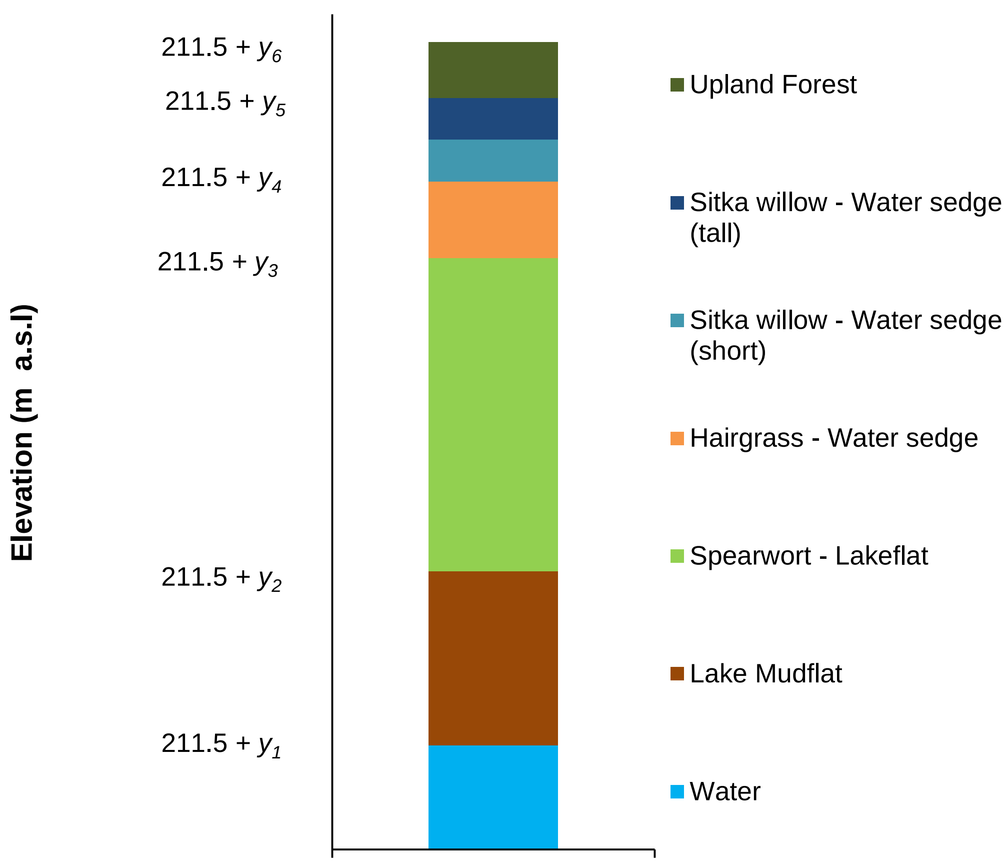
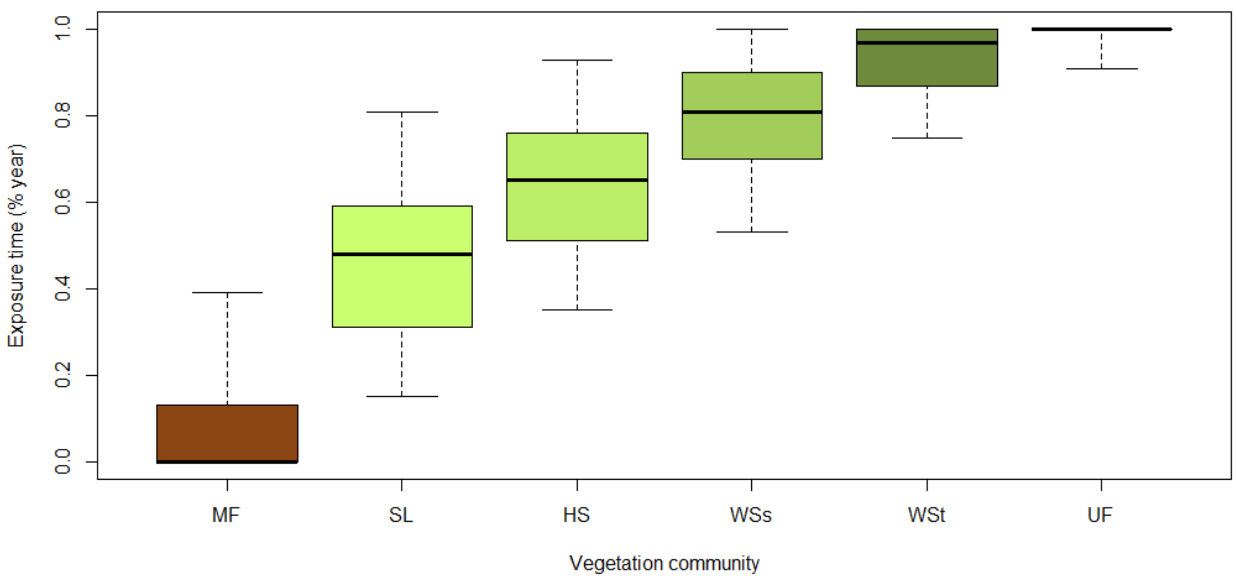


Figure 3 presents a graphical summary of the cumulative frequency distributions of the air exposure times of the six vegetation communities that were surveyed. The figure is based on daily water level measured during 1984–2000 inclusive. The premise of the SVM is that each vegetation community is adapted to a specific regime of drying and wetting, as illustrated in Figure 3. If the wetting/drying regime (i.e., annual water level fluctuations) changes, then the upper and lower elevation bounds of vegetation communities are presumed to shift so that the optimum wetting/drying regime for each community is restored. Thus, applying the model to predict the effects of alternative operational regimes involves: (i) constructing a water level record that corresponds to the new regime; (ii) optimizing the boundary elevations of each vegetation community to match the cumulative exposure times in Figure 3.

Figure 3. Summary of the air exposure times of the six vegetation communities included in the Shoreline Vegetation Model (Bruce 2002). Thick lines denote the median, boxes denote the interquartile range and whiskers denote the 5th and 95th percentiles. Vegetation community codes are defined in Table 2.



The SVM is based on several key assumptions:

1. Variability in historic lake water level is the dominant control on the vertical distribution of shoreline vegetation.
2. The shoreline flora of Upper Campbell Lake reservoir, and other diversion lakes, is well characterized by the six main vegetation communities.
3. All six vegetation communities are present along the shoreline, aligned in the same sequence with respect to elevation (see Figure 2).
4. The limits of tolerance to inundation for each vegetation community can be well quantified using water level data for the same duration.

5. Each vegetation community is assumed to be sensitive to the duration but not the *timing* of inundation. Thus, for each vegetation community, there is equal sensitivity to water level fluctuations in all prior years that are included in the model, e.g., each community that was surveyed in 2001 is assumed to be equally sensitive to changes in water level that occurred both in the previous year (2000) and 17 years prior to the survey (1984). Similarly, individual communities are assumed to be equally sensitive to inundation, regardless of the season during which it occurs.
6. At any one time, the variability in the elevation of a given vegetation community between sites is insignificant relative to the variability in the elevations of different vegetation communities at a single site.

2. METHODS

2.1. Literature Review

A review of scientific literature was conducted prior to initiating field work to summarize the current knowledge of the effects of water level fluctuations on lacustrine riparian plant communities. The review focused on scientific literature, and included previous works conducted in the study area and literature on local plant communities.

Relevant articles were primarily located using scholarly database search tools (e.g., Google Scholar), although several researchers who are active in this area of research were also contacted directly. Synopses and citation details of relevant articles were saved in a database, and all publicly available literature was stored in an electronic folder. Sources other than primary literature are referenced throughout the document and can be provided upon request.

2.2. Data Collection

2.2.1. Vegetation Community

The purpose of collecting vegetation community transect data is twofold. Firstly, the data provide measured elevations of lacustrine riparian vegetation community occurrences that can be used to test the SVM elevation predictions ($H_0$1). Secondly, the data provides gradients for each vegetation community that can be used to analyse the relationship between slope and vegetation ($H_0$2). The results of these two hypotheses are instrumental in understanding if the vegetation community distribution changes following implementation of the WUP ($H_0$3).

Vegetation community transect data were collected at Upper Campbell Lake Reservoir, Lower Campbell Lake Reservoir and Brewster Lake during four sampling periods: September 3-5, October 7-9, and December 2-3, 2014, and January 14-15, 2015. Sample dates aimed to occur during the growing season, while the water levels were predicted to be lowest and after receiving air photographs captured in 2014, to provide optimal context and sampling conditions. However, due to logistical constraints and changing hydrological conditions, adaptive changes were made to the fieldwork program, and sample dates to effectively survey vegetation communities. Where possible, transects were located near to where they were conducted during the 2001 baseline sampling program for the Upper Campbell Lake Reservoir (McLennan and Veenstra 2001). However, none of the previous benchmarks were located, warranting installation of new benchmarks in close proximity to the previous geographic coordinates.

Benchmarks were installed at the base of trees, approximately 30 cm off the ground, as bedrock was infrequently located at the lower extent of adjacent upland forest types. Transects were laid out perpendicular to the water from the benchmark to the water's edge with 60 m Eslon transect tapes. The vegetation community boundaries were defined and temporarily marked, and the distance from the benchmark to each community boundary bisected by the tape recorded. The height of each vegetation community boundary was measured from the benchmark to the water with a survey station (optical Futtura level [Sept. 3-5], laser rotating Futtura level [subsequent surveys]). The data was related to real time water elevation readings obtained from BC Hydro's online live transmission and reservoir data site for Strathcona Dam (Upper Campbell Lake Reservoir), and the Ladore Dam (Lower Campbell Lake Reservoir) (BC Hydro 2014). Water elevations at Brewster Lake were corrected to an Ecofish gauge, and are relative to the gauge as the precise actual elevation of the gauge is not available (approximately 190 m) (see Section 2.2.2).

Due to logistical constraints, and unpredicted dramatic changes in water levels associated with predicted rain storms, some surveys were conducted during high water conditions when target communities were submerged. This was managed by recording the elevation of the water's surface and subtracting measured heights at the community boundaries for those measurements falling below the water surface.

2.2.1.1. Vegetation Community Identification

Transect surveys were conducted to collect baseline data on the relative elevations of vegetation communities and their relative distance from the benchmark. In Year 10, the transect surveys will be replicated. Vegetation communities recognized by McLennan and Veenstra (2001) were identified, including the six vegetation communities characteristic to large reservoirs, the four vegetation communities characteristic of small reservoirs, and unvegetated shoreline. These communities are described in the results Section 3.2.1. Additional attributes were recorded at each site and along each transect to provide additional variables for potential future quantitative analysis of the model, considerations for qualitative analysis of the effectiveness of the model, and to assist with recommendations as per management question 3 (Table 3). Transect sites were selected, and laid out by a terrestrial ecologist familiar with local vegetation communities and experienced in ecosystem identification in the CWHxm. Vegetation community boundaries were identified in the transition zone between communities based on modal vegetation species composition. New transect locations attempted to capture multiple riparian vegetation communities, cover a variety of aspects, and be dispersed around each waterbody. Initially, new transects were to be chosen following preliminary vegetation community delineation on orthophotographs, however, these were not received until November 14th, 2014, thus new transect locations were selected after completing repeat transects, conducting a reconnaissance of the study area, by reviewing previous polygon delineation work completed in 2001 and by reviewing publically available orthoimagery (e.g. google earth). Ability to install a benchmark, ease of access, and ease of surveying were considered when locating a transect.

Table 3. Site and transect data attributes.

Data Level	Attribute	Description
Site data	Site name	Transect label following format 'JHT-SVM00'
	Waterbody	Upper Campbell, Lower Campbell or Brewster Lake
	UTM start	UTM zone, easting and northing of benchmark
	UTM end	UTM zone, easting and northing of end point
	Benchmark #	Benchmark tag number
	Direction	Transect direction (and aspect of vegetation community) from benchmark to end in degrees from magnetic north
	Slope	Transect slope in percent
	Transect length	Total length of transect
	Photographs	Site overview photographs including benchmark and cardinal directions from top and bottom of transect
	Time at water	Time of gauge reading at which height measurements were taken at water's surface
	Water elevation	Water elevation at time of gauge reading
	Location	Description of site and benchmark location
	Invasive species	List of invasive species observed. Note that no additional effort was applied to identification or searching
	Wildlife	Wildlife observations or sign
	Comments	Other comments included anthropogenic impacts and disturbances
Transect data	Occurrence	Sequential number of communities measured
	Dominant community	Dominant vegetation community
	Sub-dominant community	Subdominant or emergent vegetation community
	Start distance	Nearest boundary along transect from benchmark
	End distance	Furthest boundary along transect from benchmark
	Start height	Rod height at nearest boundary relative to survey station
	End height	Rod height at furthest boundary relative to survey station
	Start elevation	Elevation at nearest boundary as calculated from water surface elevation
	End elevation	Elevation at furthest boundary as calculated from water surface elevation
	Slope	Slope of individual vegetation community
	Community vigour	Vigour of the community ranked from 0-4 (0=dead, 1=poor, 2=fair, 3=good, 4=very good)[1]
	Vegetation cover	Categorical assessment of vegetation cover (V=vegetated, S=sparse, B=bare) Sparse is considered less than 10% cover[1]
	Vegetation % cover	Estimated percent cover of vegetation
	Photographs	Photo of community from the top down and the bottom up taken from 1 m beyond each boundary and capturing the ground cover starting at a meter from where the photographer was standing

[1] MOFR 2010, RIC 1998

2.2.2. Water Elevation

Water elevation data is required to assess the potential impact of operational changes (specifically reservoir water levels through time) on shoreline vegetation community types (emergent to riparian vegetation) and distribution ($H_0$3), and is used, along with measured boundary elevations, to derive inundation-duration probability distribution functions (pdfs), which are key parameters in the SVM ($H_0$1). Daily average water surface elevations in the Upper and Lower Campbell Lake Reservoirs are recorded by BC Hydro at the Strathcona and Ladore Dams (BC Hydro 2014). Daily average water depths for Brewster Lake are derived from the gauging station installed by Ecofish.

The hydrometric gauging station was installed in Brewster Lake on June 30, 2014 to record lake water levels (Appendix A). Installation, maintenance, and operation of the gauge followed, and will continue to follow, provincial guidelines (RISC 2009, LWBC 2005). The gauge (BRE-LG01) is comprised of a KPSI Series 500 SDI-12 pressure transducer connected to a Unidata Neon C data logger. The gauge was installed on the west shore approximately 1.5 km north of the lake outlet. A standpipe fastened to shoreline bedrock provided a protective housing for the submerged pressure transducer (Figure 4). The pressure transducer has a depth range of 0-4 m, and is programmed to log average water depth and temperature every 2 minutes calculated from scans taken at a 15 second interval (Appendix A). The 2 minute average data records are stored on the logger and transmitted via satellite every 4 hours. A 12 VDC sealed lead acid battery charged via a solar panel powers the data logger. The data logger and battery are installed in waterproof housings mounted to a nearby tree (Figure 5).

Three permanent benchmarks were installed in the bedrock in proximity of the transducer (Appendix A). Each benchmark was numbered, photo documented, and a relative level survey was completed to permit future quality assurance checks on the gauged water level data. A field team will re-visit the Brewster Lake Gauging Station in upcoming years to establish coordinates for the benchmarks and transducers with a GPS unit. After establishing coordinates for the transducer, water depths will be converted to water surface elevations in metres above sea level (masl). On-going maintenance to the gauging station will be performed as required.

Figure 4. Brewster Lake gauging station (BRE-LG01) installed on June 30, 2014.

Figure 5. Brewster Lake gauging station data logger, solar panel, and battery box tree mounted, as installed on June 30, 2014.

2.2.3. Air Photo Interpretation

Air photo interpretation was conducted to produce a map of the aerial extent of the key riparian vegetation communities, identified by McLennan and Veenstra (2001), within the study area. Ecosystem mapping can be used to record site conditions and provide a framework for monitoring ecosystem response to management (RIC 1998). There are two main uses for this map. Firstly, the average slope of each polygon was calculated to provide a spatial dataset of average vegetation community slopes that was used to analyse the relationship between slope and vegetation ($H_0$2). Secondly, in Year 10, the map can be used to compare the aerial extent of the vegetation communities as delineated to those extrapolated from the model, and provide a contingency method of monitoring and measuring change to riparian vegetation communities in the Campbell River Watershed following implementation of the WUP ($H_0$3).

Air photographs were taken in Year 1 by BC Hydro's photogrammetry department on September 7, 2014. The flight was scheduled during a time of year when water level is low and when vegetation types can be adequately recognized. The 1:10,000 digital photographs were orthorectified by BC Hydro and received by Ecofish on November 14th, 2014.

Riparian vegetation communities were delineated on the orthophotos in ArcMAP (v. 10) based on the *Standard for Terrestrial Ecosystem Mapping in British Columbia* (TEM) (RIC 1998, RIC 2000), the methods employed in 2001 (McLennan and Veenstra), and other local mapping projects (Green 2009). Polygons were delineated by a terrestrial ecologist experienced in air photo interpretation and familiar with ecosystems in the CWHxm. Polygons were delineated at a maximum scale of 1:2,000. Vegetation community delineation focused on those communities that have a soil moisture regime directly associated with the adjacent waterbodies hydrologic regime and previously identified by McLennan and Veenstra (2001). A sub-sample of upland forest types that occurred adjacent to the water was delineated, focused on those in transition from having a soil regime associated with lake levels (often young alder or conifer stands). In addition, a subset of polygons with no or sparse vegetation growth was delineated as a means for testing slope ($H_0$2).

A number of attributes were recorded for each polygon delineated through air photo interpretation. These included: interpretation of decile (proportion of polygon dominated by a site series [vegetation community]), site series map code, and structural stage; calculation of mean slopes and areas for each polygon; and assignments\ of mapsheet numbers and biogeoclimatic zones (Table 4). Terrain and soil attributes were not included in the database; however, they are reflected in adoption of the bioterrain approach to polygon delineation.

Table 4. Attribute table associated with air photo interpretation polygon shapefile.

Attribute	Label	Description
FID	FID	Unique polygon identifier
Mapsheet	Mapsheet	1:20,000 mapsheet number
FC_ID	FC_ID	Same as FC_TAG
FC_TAG	FC_TAG	Mapsheet Number and Polygon Number used for unique identification of a polygon under format mapsheet#_polygon#
BEC zone	BEC_ZONE	The first-rank unit in the hierarchical Biogeoclimatic Ecosystem Classification (BGC) system[1]
BEC subzone	BEC_SUBZONE	The second-rank unit in the BGC system[1]
BEC variant	BEC_VRT	A third-rank unit in the BGC system occurring within particular subzones[1]
Decile 1	SDEC_1	The proportion of the polygon covered by Component 1, in deciles. Deciles in components 1–3 must total 10. Decile 1 must be greater or equal to Decile 2, which must be greater or equal to Decile 3
Site series 1	Site_S1	Site series map code[2]. Site series is a vegetation community association based on the sites ability to produce specific climax vegetation within a particular BGC Subzone or Variant
Structural stage 1	STRCT_S1	The structure of the vegetation cover at the time of survey, ranging from 1-7[1]
Structural stage modifier 1	STRCT_M1	Substage of structural stage used for stages 1-3[1]
Decile 2	SDEC_2	See above
Site series 2	Site_S2	See above
Structural stage 2	STRCT_S2	See above
Structural stage modifier 2	STRCT_M2	See above
Decile 3	SDEC_3	See above
Site series 3	Site_S3	See above
Structural stage 3	STRCT_S3	See above
Structural stage modifier 2	STRCT_M3	See above
Comments	COMMENTS	Additional pertinent information regarding the polygon, primarily from ground verification but also as observed on air photographs
Check	CHECK_	Field verified with visual check (V) or blank
Water body	Water_Body	Study lake or reservoir name
Mean slope	MEAN_SLP%	Average slope of the polygon as calculated from DEM
Area	Area_m	Area in m^2
Decile 1 area	Dec1_area	Relative area of decile 1 (Decile 1*.1*area)
Decile 2 area	Dec2_area	See above
Decile 3 area	Dec3_area	See above

[1]Described in *Field Manual for Describing Ecosystems in the Field* (MOFR 2010) and RIC 1998

[2] MOE 2006

2.2.3.1. Quality Assurance

Provincial standards for ecosystem mapping include guidelines for the percentage and density of polygons ground-truthed and the intensity of the actual ground-truthing, in relation to project scale and objectives. The appropriate survey intensity level depends on the use of the data. The guidelines list a range of survey intensity from 1-5, plus a reconnaissance level (RIC 1998).

RISC methodology recommends that 5-14 % of polygons are ground-truthed for ecosystem representation, forest productivity, local resource planning applications and wildlife capability (RIC 1998).

The accuracy and consistency of air photo interpretation was verified through three methods. Firstly, after initial field reconnaissance of the three waterbodies and delineation of a subset of polygons, visual inspections were conducted. Visual inspections, one of three types of field inspection methods defined in the TEM standards (RISC 1998), verify line work and site series assignment. Thus, visual inspections were conducted on a subset of the polygons delineated through air photo interpretation at predetermined and opportunistic locations (Table 4). Verification of each polygon included a visual check of the site series and structural stage, and accuracy of a portion of the line work. Visual checks were primarily conducted on December 4-5; however, verification did occur during the entire sampling period. Visual checks focused on both capturing a representative number of polygons of each vegetation community type and on polygons that were delineated with lower certainty. Georeferenced photographs and travel routes were collected with an iPad using GPSKit. Moreover, vegetation communities delineated along transects were used as a method of visual check, and provided a good means of verifying the field-measured ground distance of vegetation community boundaries from the benchmark to those measured on the orthophoto in ArcMAP. Secondly, the delineation of polygon boundaries and site series assignment (vegetation community designation) were also compared with those delineated by McLennan and Veenstra (2001). Thirdly, the shapefile and database were reviewed by a GIS technician for consistency and integrity of line work and attributes.

2.3. Data Analysis

2.3.1. SVM Validation

The testing and validation of the SVM, developed by Bruce (2002), to predict the distribution of riparian vegetation communities in response to the WUP, is the core objective of the JHTMON-10 program ($H_0$1 and $H_0$3).

In Year 1, the validation involves applying the SVM that was developed using water level data for 1984-2000 (SVM_{2001}), and ground measurements of vegetation communities from 2001, to predict the 2014 boundary elevations of vegetation communities along the shores of Upper Campbell Lake Reservoir (Upper Campbell Lake and Buttle Lake), based on water level data for 2001-2013 (SVM_{2014}). The objective is to quantitatively evaluate whether the error between model predictions and field measurements is sufficiently small to conclude that the model performance is satisfactory.

In particular, statistical tests will be used to address two key management questions (BC Hydro 2013), with negative answers to these questions assumed to provide evidence of the validity of the SVM:

1) Are the predicted elevation boundaries significantly different from the field measurements? (Management Question 1)
2) Are the values of model error (i.e., measured - predicted) significantly different from zero? (Management Question 2)

Satisfactory model performance will show that the model can be used to predict how alternative reservoir water level management operations affect vegetation communities. Unsatisfactory model performance will indicate that the predictive capability of the SVM should be improved before it is used as a management tool.

In Year 10, SVM validation will be repeated for Upper Campbell Lake Reservoir (Upper Campbell Lake and Buttle Lake). The SVM will also be applied to assess whether the model can be used to predict the boundary elevations of vegetation communities along the shores of Lower Campbell Lake Reservoir and Brewster Lake.

2.3.1.1. Water Level Comparison

Mean daily water level data were compared between the SVM_{2001} (1984-2000) and the SVM_{2014} (2001-2013) modelling periods using a Kolmogorov-Smirnov goodness-of-fit test. This non-parametric test is used to establish whether the differences between two continuous distribution functions are statistically significantly different from zero (i.e., whether the distributions are the same) (Zar 1999). This test (and all other inferential statistical tests; see below) was undertaken using R (version 3.1.0; R Core Team 2014) with a significance criterion (α) of $p < 0.05$. The *ks.test* function in R was used to calculate the test statistic (D) and associated p-value.

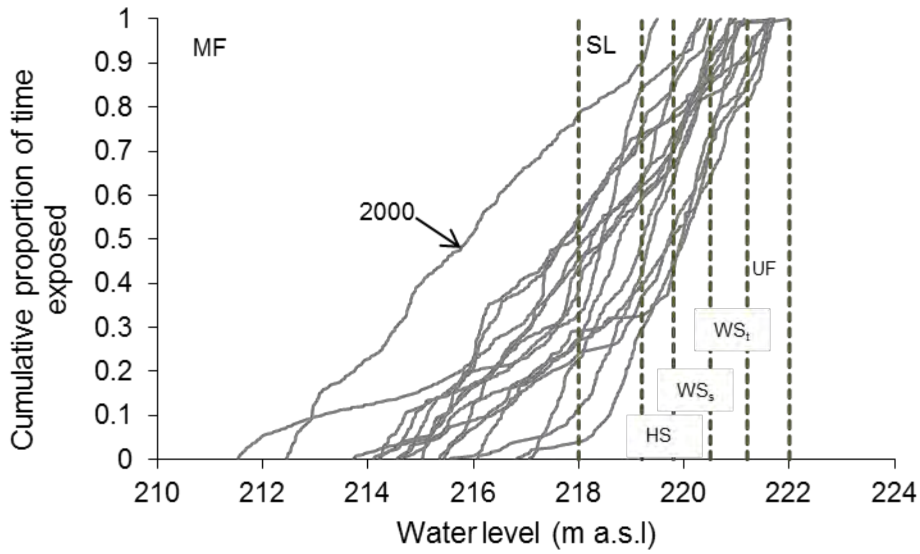
2.3.1.2. Year 1 Elevation Boundary Predictions

Creating the SVM

The SVM was built as described in Bruce (2002), although original calculations were unavailable. Thus, water level data for Upper Campbell Lake Reservoir were reanalysed to derive community-specific cumulative frequency distributions of observed air exposure times for the period 1984–2000 that were originally derived by Bruce (2002) (Figure 6). Data for two periods of ten consecutive days in 1985 and 1986 were missing; the mean values of adjoining days were substituted for these periods.

Cumulative frequency distribution curves were constructed using daily mean water level data for each year, as shown in Figure 6. Each curve therefore quantifies the total proportion of the overall year that water level was at or below a given elevation, as shown in the context of the mean elevations of the boundaries between the vegetation communities surveyed by McLennan and Veenstra (2001). For example, the curve for year 2000 (Figure 6) indicates that water levels were unusually low during this year, with the water level being lower than the mean upper boundary of Lake Mudflat (MF) for approximately 75% of the year.

Figure 6. Cumulative frequency distributions of mean daily water levels for individual years during 1984–2000. Vertical dashed lines denote mean elevation boundaries between vegetation communities surveyed by McLennan and Veenstra (2001). Vegetation community codes are defined in Table 2.



The distributions of the values represented by the curves in Figure 6 for each of the six vegetation communities are summarized in Table 5; forming the basis of the SVM (see Figure 3 for a graphical representation). Thus, Table 5 was produced by first separating the daily values shown in Figure 6 into the six elevation bands. For an individual vegetation community, values were selected which were greater than (>) the lower elevation boundary and less than or equal (≤) to the upper elevation boundary. Individual percentiles were then calculated for the separate vegetation communities. Note that the lower boundary for the MF community was set as 210.00 m which is equal to the lower limit of the historical operating range of Upper Campbell Lake Reservoir and approximate to the water level at which Buttle Lake Reservoir becomes isolated (BC Hydro 2012). The upper boundary of the Upland Forest (UF) community was set as 224.00 m which is 2 m above the current Critical Level that the WUP requires the reservoir to be maintained below (*ibid*). The '0' and '1' values for the MF and UF communities, respectively, therefore reflect that the upper and lower bounds lie outside of the range of historic water levels.

Table 5. Percentile values of annual cumulative frequency distributions of shoreline air exposure times for 1984-2001 (Figure 6). Vegetation community codes are defined in Table 2.

Percentile	Community Specific Percentile Values					
	MF	SL	HS	WSs	WSt	UF
0.05	0.00	0.15	0.35	0.53	0.75	0.91
0.15	0.00	0.28	0.42	0.61	0.81	0.99
0.25	0.00	0.31	0.51	0.70	0.87	1.00
0.4	0.00	0.40	0.62	0.78	0.92	1.00
0.5	0.00	0.48	0.65	0.81	0.97	1.00
0.6	0.01	0.54	0.69	0.84	1.00	1.00
0.75	0.13	0.59	0.76	0.90	1.00	1.00
0.85	0.22	0.66	0.82	0.95	1.00	1.00
0.95	0.39	0.81	0.93	1	1	1

There are some minor differences between Table 5 and the corresponding table provided in Bruce (2002 – Table 2). These differences are quantified in Table 6 which is shaded in proportion to the magnitude of the absolute differences. Most of the percentiles in the two tables are identical and all differences are very minor. These likely reflect rounding errors and/or differences in the method used to divide the data between vegetation boundaries, e.g., whether a '<' or a '≤' operator was used to filter water levels less than an upper boundary. Although the data files originally used to prepare Bruce (2002) could not be sourced, the model's author has reviewed the methods described here and confirmed that the procedure was followed correctly to determine percentiles (Bruce, pers. comm. 2015). Thus, the values presented in Table 5 of this report were used for the SVM validation to ensure that any minor differences in methods were applied consistently.

Table 6. Absolute differences between percentile values shown in Table 5 of this report and the corresponding table presented in Bruce (2002). Shading denotes magnitude of absolute differences.

Percentile	Community Specific Percentile Values					
	MF	SL	HS	WSs	WSt	UF
0.05	0.00	0.01	0.01	0.03	0.01	0.01
0.15	0.00	0.01	0.00	0.01	0.00	0.01
0.25	0.00	0.01	0.00	0.00	0.01	0.01
0.4	0.00	0.00	0.00	0.00	0.01	0.00
0.5	0.00	0.00	0.00	0.00	0.00	0.00
0.6	0.05	0.00	0.00	0.00	0.00	0.00
0.75	0.05	0.01	0.00	0.00	0.00	0.00
0.85	0.03	0.00	0.01	0.00	0.00	0.00
0.95	0.03	0.00	0.03	0.00	0.00	0.00

Predicting Elevation Boundaries

The SVM was used to predict 2014 vegetation community boundary elevations for Upper Campbell Lake Reservoir, based on water level data for 2001 to 2013 inclusive (SVM_{2014} predictions). Water elevation data for 2014, the year of vegetation sampling, was not included in the model to ensure consistency with the approach taken by Bruce (2002).

Cumulative frequency distributions of mean daily water level were first constructed for individual years. A boundary search procedure, as outlined by Bruce (2002), was then used to predict the five elevation boundaries between the six vegetation communities. The procedure involved an iterative process that sought to identify the elevation boundaries that best satisfy the community-specific air exposure times presented in Table 5. The procedure was initially used to predict the lowest elevation boundary between MF and Spearwort Lakeflat (SL). A starting elevation was chosen and the corresponding percentile values of the annual exposure times for the MF community were then calculated (i.e., the values specified in the 'MF' column in Table 5). A sum of squared differences statistic (SS_{MF}) was then calculated based on the differences between the calculated values and the corresponding values shown in Table 5. Specifically:

$$SS_i = \sum_{P=0.05}^{P=0.95} \left(P_{trial,P} - P_{measured,P}\right)^2$$

where SSi is the sum of squared differences for vegetation community i, $P_{trial,P}$ is the value of percentile P for the trial elevation, and $P_{measured,\ P}$ is the value of percentile P based on the SVM_{2001} predictions (Table 5).

The process was then repeated for different elevations to identify the elevation (nearest 0.1 m) that corresponded to the minimum value of SS_{MF}. This elevation was defined as the upper boundary of the MF community and was thus set as the lower bound of the next community (SL). This process was repeated until all five boundaries were defined.

2.3.1.3. Model Error and Validation

Model error was calculated by subtracting SVM_{2014} predicted boundary elevations from elevations that were measured in the field. Mean error, absolute mean error and the square root of the mean of the squared error values (RMSE) were calculated separately for each boundary type and for all boundary types combined. Mean error provides a measure of model bias (i.e., whether predictions are systematically too high or too low) whereas absolute mean error and RMSE provide a measure of model accuracy, with RMSE placing greater weight on accounting for errors that are large rather than small.

Three statistical approaches were conducted to evaluate model validity. Firstly, a one-way analysis of variance (ANOVA) was conducted to assess whether there were significant differences between mean values of modelled and measured elevations. ANOVA was undertaken using the *aov* function in R to compare mean and measured elevations, with values pooled for all boundary types (e.g., MF and SL, SL and HS etc.). Secondly, a non-parametric Mann-Whitney-Wilcoxon test was used to test whether there were significant differences between modelled and measured boundary elevations for individual boundary types. Note that a non-parametric test was necessary because, for an individual boundary type, the modelled elevation that corresponded to each measurement was the same, and therefore the modelled values had zero variance. The Mann-Whitney-Wilcoxon was undertaken using the *wilcox.test* function in R. Lastly, a *z*-test (Zar 1999) was conducted to test the null hypothesis that the mean error was not significantly different from zero. Normal quantile plots were used to check data prior to conducting parametric tests (ANOVA and the *z*-test), with transformations undertaken where necessary to improve normality.

2.3.2. Vegetation Community Gradient

During development of the WUP the SVM was applied with the assumption that shoreline gradients of less than 15% are required to allow soils to accumulate and persist in the operational zone, and support plant growth ($H_0$2). However, this assumption was never examined, and therefore may not be correct. This assumption was examined in Year 1 using two datasets: (1) ground slope measurements from vegetation community transects, and (2) slopes interpolated from the DEM onto vegetation community polygons (delineated by air photo interpretation).

2.3.2.1. Vegetation Community Transects

Field data were analysed to examine whether individual vegetation community cover (%) was dependent on slope (%). Scatter plots of the relationship between slope and cover were examined for separate waterbodies and individual vegetation community types that were dominant (ten or more measurements available). Linear regression was used to test whether there was a statistically significant relationship between slope (x variable) and cover (y variable), with both variables $\log_{10}(x+1)$ transformed to improve normality.

2.3.2.2. Air Photo Interpretation

A DEM of the study area was generated in ArcMAP (vers 10.1) from bathymetry, 1:20,000 TRIM contour lines and elevation points, and LiDAR data received from BC Hydro (August 13, 2014). Specifically, the DEM for the Upper Campbell Lake Reservoir was created from a high resolution stereo DEM for the area between 122.90 to 228.0m (Upper Campbell Lake), and 214.58 to 228.0 m (Buttle Lake), single beam bathymetry that criss-crossed the lake and 2009 multibeam bathymetry of Strathcona dam forebay to 200 m upstream, and preflood information from 1949 NTS maps and 1951 BC government maps. The DEM for the Lower Campbell Lake Reservoir was created from basic 1947 preflood 5 foot contour pdfs that were best fit to current lake outline at 177.4 m, and high resolution stereo DEM points around the three dams (Strathcona and Ladore). Gaps were filled with TRIM data. The DEM for Brewster Lake was created using TRIM data.

A grid of points was generated in which a point was placed in the middle of each DEM pixel so that each point had a slope value equal to its respective pixel. The slope values of all points falling within a vegetation polygon were averaged to produce an average slope for each polygon.

Mean Slopes

Mean polygon slope was analysed for polygons containing a dominant vegetation community, where ‘dominant’ was defined as ≥ 70% coverage by a single community type. In total, 446 (81%) of the 551 polygons were dominated by a single community type.

An independent two-group t-test was used to compare the average of mean slope values between polygons dominated by unvegetated shoreline and polygons dominated by vegetation communities. ANOVA was used to examine whether there was a statistically significant difference in mean polygon slopes between vegetation community types. A posthoc Tukey HSD test (*TukeyHSD* function in R) was used to identify statistically significant differences between the average values of mean polygon slope for individual communities and for un-vegetated shoreline. This test was restricted to community types that dominated three or more polygons.

Mean Area-Weighted Polygon Slope

The relative area that each community in a polygon represented was calculated by weighting the area a community occupied by the proportion of the polygon it occupied. A single area-weighted mean slope (%) was calculated for each community as follows:

$$AWS_i = \frac{\sum \overline{SLOPE}_i \times AREA_i}{\sum AREA_i}$$

Where AWS_i is mean area-weight slope for community i, $\overline{SLOPE}_i$ is mean slope (%) of an individual polygon dominated by community i, and $AREA_i$ is the area (m^2) of the polygon dominated by community *I*, calculated as the product of the polygon area and the proportion of community cover (0.7 to 1).

Contingency Tables

Two × two contingency tables were constructed to explicitly test whether areas with slope > 15% are more likely to be un-vegetated ($H_0$2). For each waterbody, tables were constructed that quantified the number of vegetated and un-vegetated (US) polygons with mean slope < 15% and > 15%. Fisher's exact test was then used to test the null hypothesis that the distribution of vegetated and un-vegetated areas is independent of whether slope is greater or less than 15% (*fisher.test* function in R).

3. RESULTS

3.1. Literature Review

The review predominantly identified site-specific studies of the ecological effects of water level fluctuations. Several articles were also identified that considered the tolerance of specific plant types to inundation, in addition to a small number of review articles that more broadly synthesized understanding of the topic. Appendix B provides a synopses and citation details for a total of 16 relevant articles.

Two reviews of the general ecological effects of water level fluctuations on lakes were identified, both of which contained only minor sections related to effects on riparian vegetation communities. One of these reviews noted that "*much less attention has been paid to terrestrial plant communities, although terrestrial species are very sensitive to water-level changes*" (Leira and Cantonati 2008). The second review highlights the potential for water level fluctuations to cause a shift in primary productivity from the littoral (macrophytes – aquatic plants) to the pelagic (phytoplankton) (Zohary and Ostrovsky 2011).

Numerous articles highlighted case studies of adverse effects to riparian vegetation as a result of both insufficient and excess water level fluctuations following water management operations (e.g., Wilcox and Meeker 1991). Few studies, however, had adopted a modelling approach to derive more general understanding of the effects of water level fluctuations. Hill *et al.* (1998) proposed a general model to maintain diversity of shoreline herbaceous wetlands based on the ratio of within-year water level variability to among-year variability. Nilsson and Keddy (1988) conducted a study that has some similarities with JHTMON-10. They undertook shoreline vegetation surveys and measured water levels over ten years in a Scandinavian reservoir. Regression models were then developed to predict vegetation richness and abundance based on water level history. The results showed that the apparently simple system was surprisingly unpredictable, with water level changes only able to explain ~40% of the variability in species abundance and richness.

Temporal dependence on water level fluctuations was observed in several studies. For example, Van Eck *et al.* (2006) showed that certain grass species could survive for longer under floods in winter than in summer, with the elevational distribution of species strongly related to their tolerance to summer (not winter) flooding. Temporal dependence was also observed by Riis and Hawes (2002) who attempted to relate water level history to aquatic macrophyte diversity in 21 lakes. Their study showed that ecological significance of extreme events (e.g., droughts) was greatest for events that occurred most recently. Similarly, the study by Nilsson and Keddy (1988) demonstrated in their model that the duration of flooding in the previous year was the best explanatory variable in predicting riparian vegetation characteristics.

Northcote and Atagi (1997) presented the only study that makes specific reference to the JHTMON-10 study sites. This report provides a review of potential trophic upsurge effects in a reservoir elsewhere, although it notes that "*macrophyte growth in reservoirs subject to much fluctuation in water level usually is restricted to the lowermost drawdown point or below, as was evident in Buttle Reservoir (Vancouver Island, B.C.) in October 1996 (TGN personal observations)*". The report also includes a summary of the history of inundation to Buttle Lake and Upper Campbell Lake Reservoir, including aerial photographs.

3.2. Data Collection

3.2.1. Vegetation Community

Thirty-one transects (the maximum number stated in the TOR) were established in the study area in Year 1: 11 on the Upper Campbell Lake Reservoir (Map 2), 10 on the Lower Campbell Lake Reservoir (Map 3) and 10 on Brewster Lake (Map 4). Appendix C provides detailed transect survey data, habitat characteristics, observations and photographs for each transect.

Shoreline vegetation community composition differed between the three waterbodies. The differences are likely a result of lake type, hydrologic regimes and soil conditions. McLennan and Veenstra (2001) described differences in shoreline vegetation composition between large reservoir lakes and small lakes along the diversion. Consistent with their findings, the shoreline vegetation communities along the Upper Campbell Lake Reservoir (large lake) were quite different from Brewster Lake (small diversion lake). Lower Campbell Lake Reservoir hosted a mosaic of the vegetation communities, characteristic of both large and small lakes.

3.2.1.1. Relative elevations of Shoreline Vegetation Communities

The measured elevations of riparian vegetation communities located along each transect are presented for Upper Campbell Lake Reservoir (Figure 7), Lower Campbell Lake Reservoir (Figure 8), and Brewster Lake (Figure 9).

Figure 7. Vegetation transect survey results for the Upper Campbell Lake Reservoir.

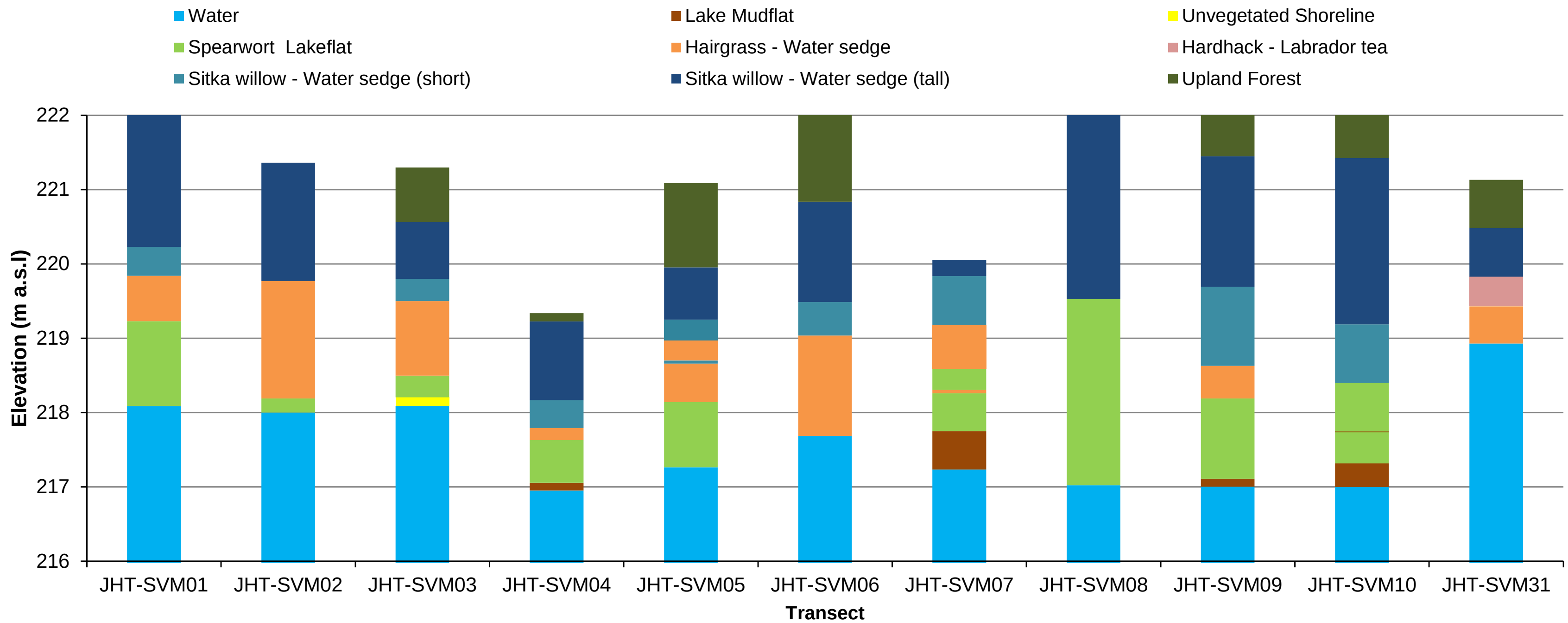


Figure 8. Vegetation transect survey results for the Lower Campbell Lake Reservoir.

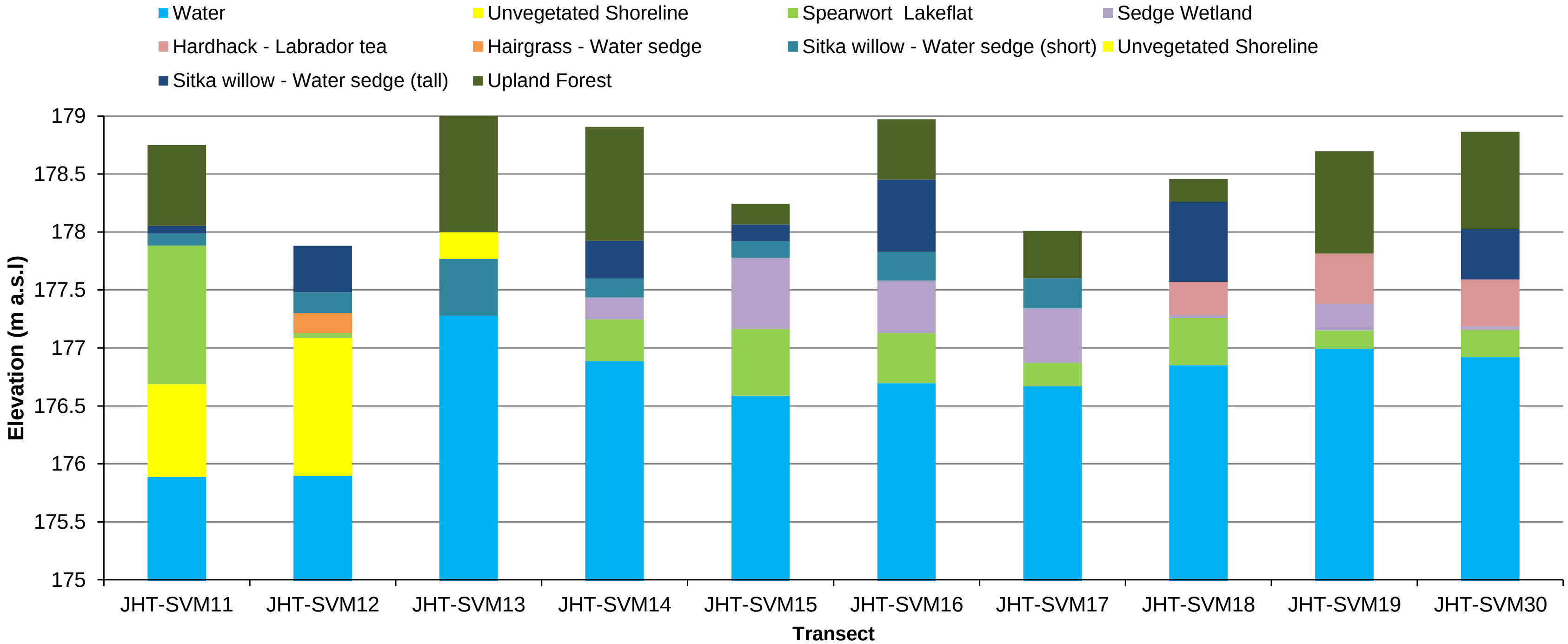
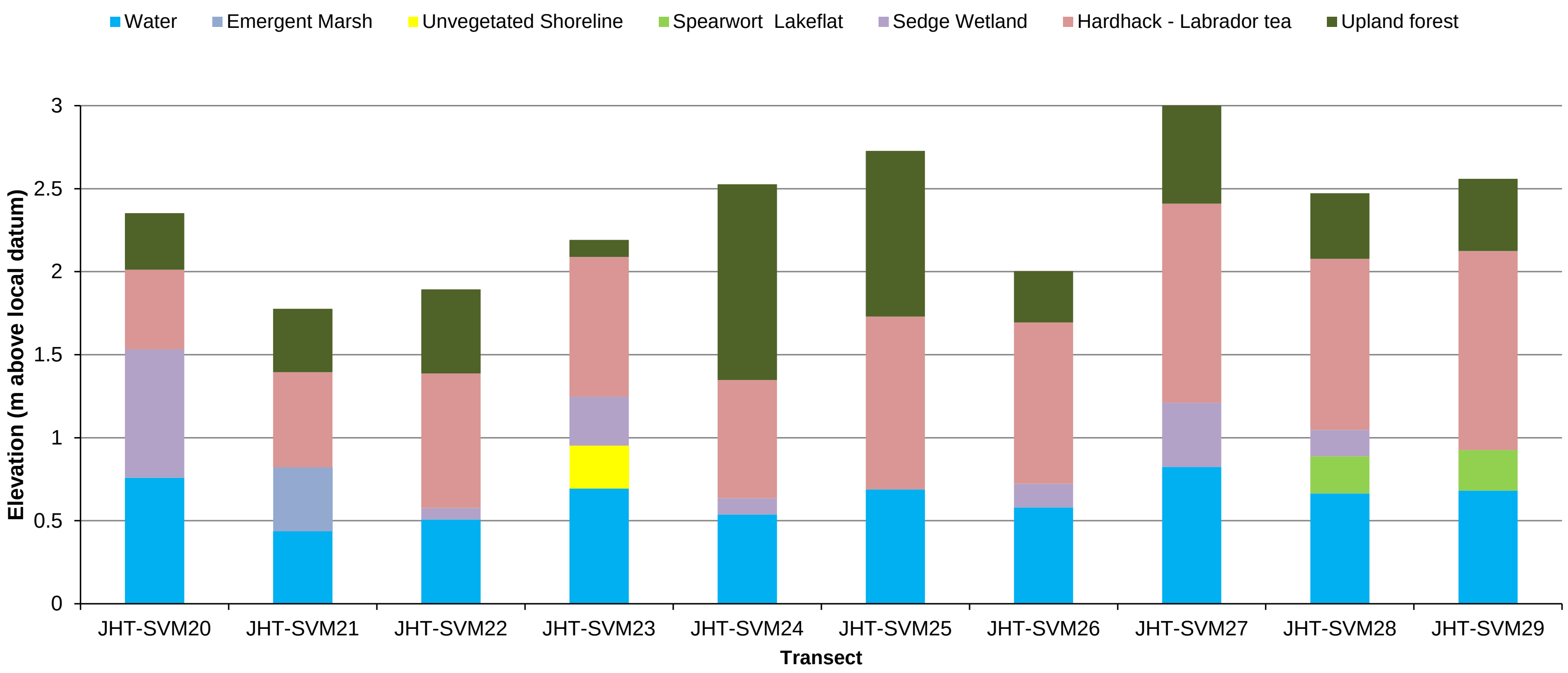


Figure 9. Vegetation transect survey results for Brewster Lake.



3.2.1.2. Dominant Shoreline Vegetation Communities

Large lakes

Riparian vegetation communities on large lakes in the Campbell River system typically occur on alluvial fans and other floodplains. These features are most prominent in the Upper Campbell Lake Reservoir (Upper Campbell and Buttle Lakes), and form only a minor component of the Lower Campbell Lake Reservoir. On floodplains and alluvial fans, gradients are lower and soils are typically composed of fine sediments that have been accumulated over time, in comparison to steeper shorelines around the lakes where soils have been washed away. In general, the remainder of the shoreline ranges from steeper gradient beaches with a substrate dominated by large gravels to steep rock bluffs. McLennan and Veenstra (2001) described six vegetation communities that occur along the shoreline of large lakes (Table 2). Of these six, four are briefly described below, Spearwort Lakeflat, Hairgrass – Water sedge, and Sitka willow – Water sedge, which consist of both the tall and short Sitka willow (*Salix sitchensis*) structural stages as identified by the SVM. Lake Mudflat is not described because it was rarely observed because it was usually inundated, and primarily acts to mark the lower boundary of the Spearwort Lakeflat community in the SVM. Upland Forest is not described because it is not a vegetation community that's soil moisture regime is directly dependant on the hydrologic regime of the reservoir.

Spearwort Lakeflat (SL)

On larger lakes, extensive Spearwort Lakeflat (SL) communities were frequently located on the lower elevations of fluvial lakeflats below the Hairgrass – Water sedge (HS) community, as observed at all but two transects in the Upper Campbell Lake Reservoir (Figure 7, Figure 10). The vegetation community was often more sparsely represented (less than 10% cover) in its respective elevation band within the drawdown zone of Upper and Lower Campbell Lake Reservoirs where floodplains were less extensive or absent, and shoreline substrates coarser (e.g., JHT-SVM03, JHT-SVM08, JHT-SVM11, JHT-SVM12, etc.) (Figure 11). Sedges, rushes and grasses, and in some areas other herbs, were present in clumps at the upper extent of the SL community, while the lower extent was often a mosaic of lesser spearwort (*Rannunculus flammula*), sparse other emergent aquatic vegetation, and exposed sandy or mudflat substrate. Even though SL communities are dominant on large lakes, SL was also detected on mudflat substrates at two transects on Brewster Lake (JHT-SVM28, JHT-SVM29) (Figure 9).

Figure 10. Spearwort Lakeflat at JHT-SVM04 on Upper Campbell Lake Reservoir, September 4, 2014.

Figure 11. Sparse occurrence of Spearwort Lakeflat on exposed gravel beach of JHT-SVM11 on Lower Campbell Lake Reservoir, September 5, 2014.

Hairgrass – Water Sedge (HS)

The Hairgrass – Water sedge (HS) community typically occurred along the shoreline of Upper Campbell Lake Reservoir in the drawdown zone between the Sitka willow – Water sedge (WS) community and the Spearwort Lakeflat (SL) community (Figure 12, Figure 7). On the Upper Campbell Lake Reservoir, it was present along all but two transects, one that had a steep bank (JHT-SVM08) and one that transitioned from being dominated by the Sitka willow – Water sedge (short) directly to Spearwort Lakeflat (JHT-SVM10) (Figure 7). HS occurred along one transect on Lower Campbell Lake Reservoir (JHT-SVM12) (Figure 8). The most extensive presence of HS appeared to be near the outflows of streams on alluvial fans, as observed at JHT-SVM08 (Figure 7, Figure 12). Various herbs and grasses were often present at the upper extent of the community. Large water sedges were often present at the middle portion of the band and smaller sedges in the lower portions. Grasses (including some likely exotic species) often transcended the band from the short WS through HS down to the SL. The HS community occasionally appeared vigourous when the Sitka willow – Water sedge community above demonstrated a lower vigour (e.g., Figure 12). HS was rarely present in the steeper areas riparian fringe surrounding most of the lake shoreline. In these areas, HS was replaced by unvegetated shoreline or a sparse HS (<10%) composed of sedges (*Carex* sp.) and grasses on a gravel substrate.

Figure 12. Hairgrass - Water sedge community along a creek outflow at JHT-SVM09 on Upper Campbell Lake Reservoir, September 3, 2014.

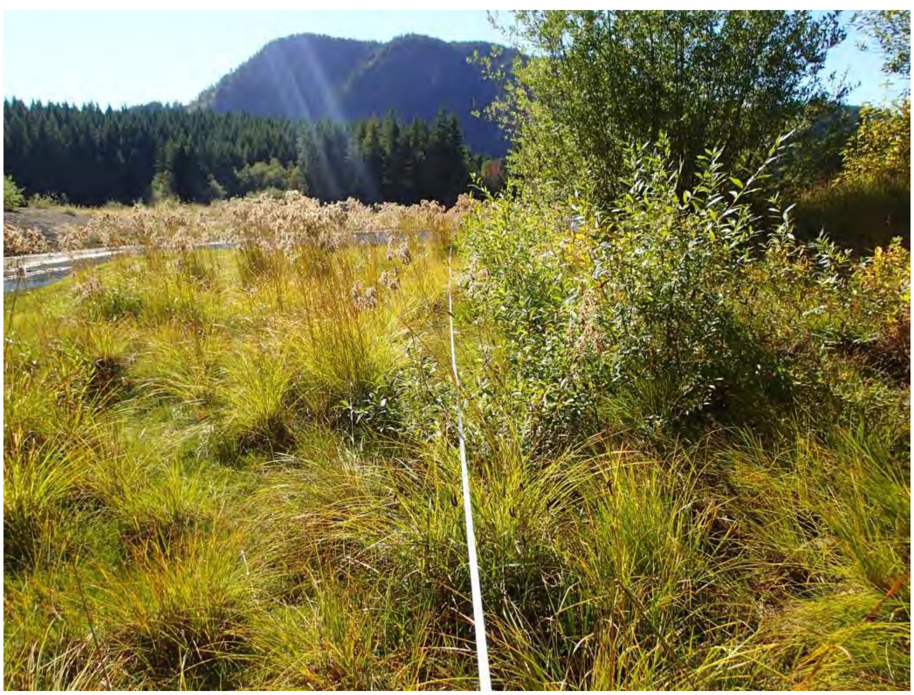
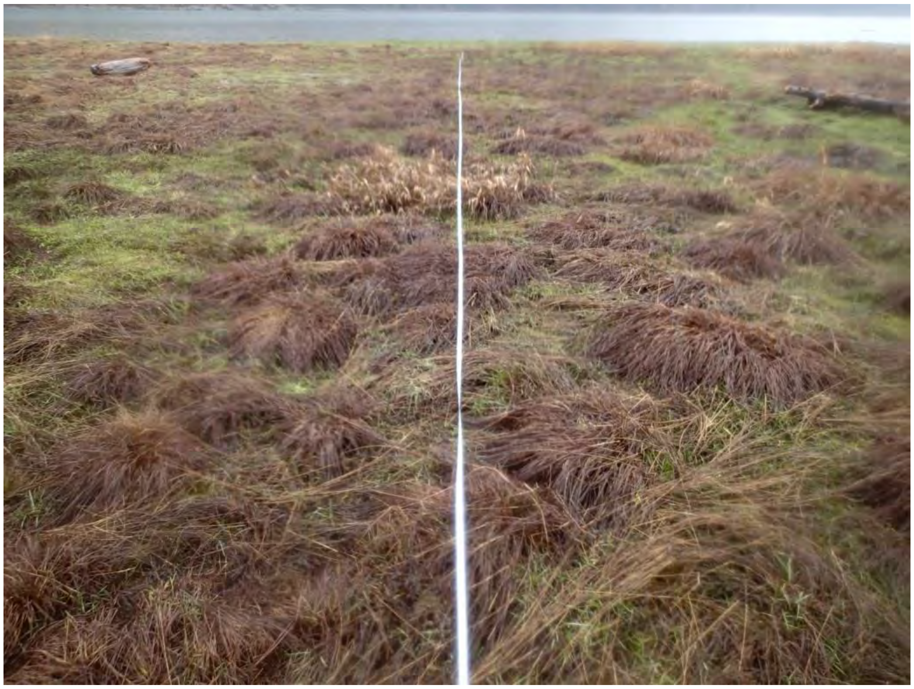


Figure 13. Hairgrass - Water sedge community at JHT-SVM02 on Buttle Lake, January 15, 2015.



Sitka willow – Water sedge (WS)

The Sitka willow – Water sedge (WS) community typically occurs along the shoreline of larger lakes and provides a transition between the Hairgrass – Water sedge (HS) and Upland Forest (UF) communities. The community demonstrates two distinctive structural stages: a tall (3b) stage and a short (3a) stage. The taller stage consistently occupies a higher elevation band than the shorter stage. The community was primarily detected around the Upper Campbell Lake Reservoir, where eight of the eleven transects had both tall and short stages of WS and the remaining three had only tall WS (Figure 7).

The WS community experiences periodic, seasonal flooding. The short (3a) structure of this community experiences inundation for more extensive time periods. Vegetation was typically dominated by Sitka willow with components of other willows such as Pacific willow (*Salix lasiandra*). Red alder (*Alnus rubra*) and sweet gale (*Myrica gale*) were often present. In some drier sites, especially on Upper Campbell Lake Reservoir, where gravels dominated the substrate, Scotch broom (*Cytisus scoparius*) composed a significant portion (up to 50%) of the shrub layer (Figure 14). In moister sites, more often found on Buttle Lake, salmonberry (*Rubus spectabilis*) and red elderberry (*Sambucus racemosa*) were more often present. The understory vegetation at lower elevations was typically composed of sedges and exotic and native grasses. The upper elevations were composed of a variety of herbs that ranged from drought tolerant strawberry (*Fragaria virginiana*), and trailing blackberry (*Rubus ursinus*), as well as invasive St. John's wort (*Hyperacum perforatum*) and oxeye daisy (*Leucanthemum – vulgare*), to more moisture dependant grasses and ferns.

Many of the areas that had been occupied by the tall WS community during previous baseline studies (McLennan and Veenstra 2001) were now transitioning to Upland Forest types and were occupied by approximately 13 year old red alder or coniferous species. In some of these areas, particularly those dominated by alder (which after 13 years were taller than conifers of a similar age), the willow had completely died off or were observed decadent in the stand. When tall willows were intermixed with conifers, they were often approximately the same height (Figure 15).

A narrow band of the WS community was present on small floodplains (creek inflows) around the Lower Campbell Lake Reservoir. In the Lower Campbell Lake Reservoir, the WS elevation band was often occupied by the Hardhack – Labrador tea (HL) in more confined bays with slower moving waters, or as a mosaic of WS and HL in areas that had site characteristics representing an intermediate state between large and small lakes. On Lower Campbell Lake Reservoir, WS is also found in association with the Sedge Wetland (SW) community which is characteristic of small lakes (Figure 8).

Figure 14. Tall Sitka willow - Water sedge community with high component of Scotch broom observed at JHT-SVM09 on Upper Campbell Lake Reservoir, September 2, 2014.

Figure 15. Tall Sitka willow - Water sedge community in transition to conifer forest observed at JHT-SVM02 on Buttle Lake, January 15, 2015. Note that this transect is laid out on a mowed strip connecting the campsite to the lake.

Small lakes

Riparian vegetation communities on small diversion lakes are directly influenced by the frequency and duration of flooding from diverted waters (McLennan and Veenstra 2001). These shrub-fen ecosystems were observed on Brewster Lake and in the more confined bays and upper end of Lower Campbell Lake Reservoir (inflow area). Vegetation communities observed in small lakes were not parameterized by the SVM nor were they included in transect surveys during 2001 baseline studies.

Sedge Wetland (SW)

The Sedge Wetland (SW) vegetation community typically occurred along the shoreline of smaller lakes or in the shallow, confined arms and bays of larger lakes. The community was observed in Lower Campbell Lake Reservoir (Figure 16), and Brewster Lakes (Figure 9, Figure 17). SW typically occurs in a narrow elevation band below the Hardhack-Labrador tea (HL) ecosystem. The community occurs on soils that are typically saturated year-round, and may be completely flooded during portions of the year. SW occurs on organic peat soils. Vegetation is dominated by large water sedges such as Sitka sedge (*Carex sitchensis*), slender sedge (*Carex lasiocarpa*), and beaked sedge (*Carex utriculata*), and some smaller sedges (McLennan and Veenstra 2001).

Figure 16. Fringe of the Sedge Wetland community at JHT-SVM16 on Lower Campbell Lake Reservoir, October 9, 2014.

Figure 17. Sedge Wetland community at JHT-SVM22 on Brewster Lake, October 7, 2014.

Hardhack – Labrador Tea (HL)

The Hardhack - Labrador tea (HL) vegetation community typically occurred along the shoreline of smaller lakes or in the shallow, confined arms and bays of larger lakes. The community was observed in Lower Campbell Lake Reservoir (Figure 8, Figure 18) and Brewster Lakes (Figure 9, Figure 19), and at one site on Upper Campbell Lake Reservoir in a shallow bay at JHT-SVM31 (Figure 7). The community experiences prolonged soil saturation and periodic flooding during winter or high-water conditions. Vegetation is typically composed of Hardhack (*Spiraea douglasii*), sweet gale, and some willow, and a sparse to well-developed understory of sedges (*Carex* sp.) or boggy shrubs. The often sparse moss layer is sometimes dominated by sphagnum (*Sphagnum* sp.) and/or ribbed bog moss (*Aulacomnium palustre*) (Mackenzie and Moran 2004, McLennan and Veenstra 2001). Mosses often were observed in the upper sections of the band, while the lower portion's ground cover was dominated by sedge.

Figure 18. Hardhack-Labrador tea community observed at JHT-SVM18 on Lower Campbell Lake Reservoir, October 9, 2014.

Figure 19. Hardhack-Labrador tea community observed at JHT-SVM26 on Brewster Lake, October 8, 2014.

Western redcedar/Sitka spruce - Skunk cabbage (RC)

Forested Western redcedar/Sitka spruce - Skunk cabbage (RC) ecosystems typically occupy a narrow band between the Hardhack-Labrador tea (HL) and Upland Forest (UF) vegetation communities. RC typically occurred along the shoreline of smaller lakes or in the shallow, confined arms and bays of larger lakes. The community was observed in Lower Campbell Lake Reservoir (Figure 8, Figure 20) and Brewster Lakes (Figure 21). Mostly the shrub stage of this ecosystem was observed. This community typically develops in seasonally flooded areas where soil is saturated for large portions of the year. The tree layer is dominated by western redcedar and red alder, and the shrub layer is dominated by red-osier dogwood with a small component of Sitka willow and hardhack in depressions. Although the understory is typically dominated by kneeling angelica (*Angelica genuflexa*), common horsetail (*Equisetum arvense*) and bluejoint grass (*Calamagrostis canadensis*), all sites verified in 2014 had an understory dominated by sedges.

Figure 20. Transition of Hardhack - Labrador tea community to the Western redcedar/Sitka spruce - Skunk cabbage communities at JHT-SVM17 on Lower Campbell Lake Reservoir, October 9, 2014.

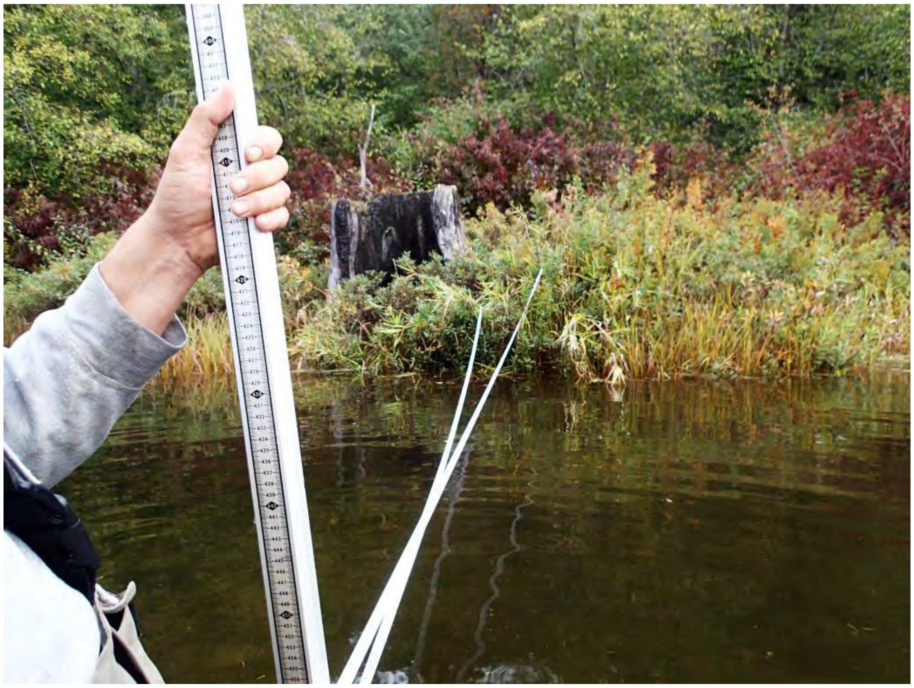


Figure 21. Forested Skunk cabbage community (RC) at JHT-SVM24 on Buttle Lake, October 7, 2014.

3.2.2.Water Elevation

Appendix C reports, for the 2014 study period, the daily average water surface elevations in the Upper and Lower Campbell Lake Reservoirs as recorded by BC Hydro and the daily average water depths measured at Brewster Lake as recorded by the gauging station installed by Ecofish. Figure 22 shows a graph of the annual water elevations in Upper Campbell Lake Reservoir between the years 2001-2014, representing the date range of hydrology data added to the model. Figure 23 shows a time series of the average daily water level for each year between 1984 and 2014, with the mean water level for each SVM period.

Figure 22. Daily water level in the Upper Campbell Lake Reservoir 2001-2013.

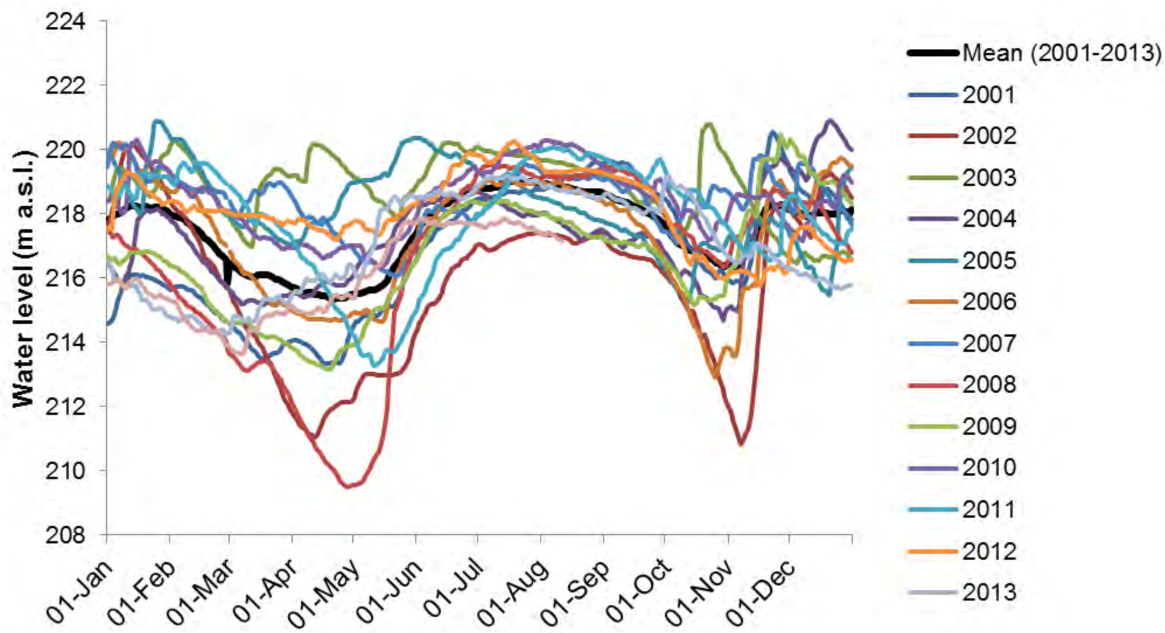
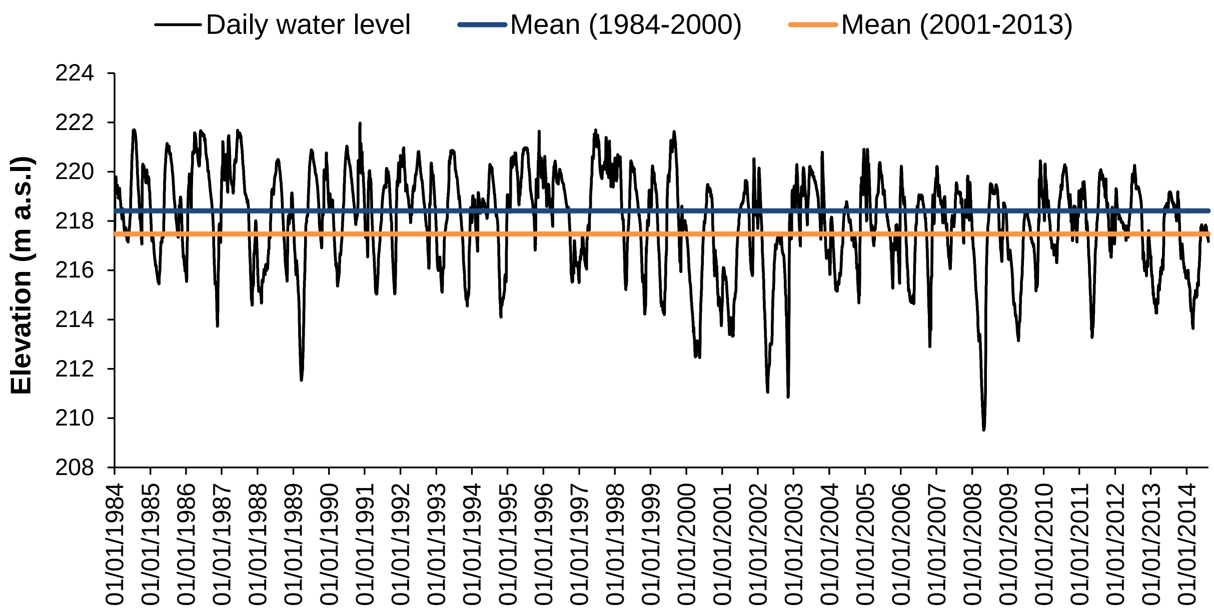


Figure 23. Time series plot of the average daily water level in the Upper Campbell Reservoir for each year between 1984 and 2014. The mean water level for each SVM period is presented.



3.2.3. Air Photo Interpretation

The mapped aerial extent of each vegetation community type, including site series, within each waterbody is collated in Table 7. The site series of each vegetation community type is presented based on classifications of site associations available at the time of the 2001 baseline study (McLennan and Veenstra 2001). Appendix D presents all the mapped vegetation community polygons. A grey line between polygons of the same colour indicates polygons delineated as different structural stages (i.e., tall Sitka willow – Water sedge is 3b, while short Sitka willow – Water sedge is 3a) indicating separate polygons structural stage is differentiated in the shapefile.

Table 7. Aerial extent of vegetation communities surrounding each waterbody, as mapped with air photo interpretation.

Ecosystem type	Vegetation Community Name	Map Code	Site Series	Areal Extent			
				Upper Campbell *total (ha)*	Lower Campbell *total (ha)*	Brewster *total (ha)*	Total (ha)
Lakeshore - large lakes	Lake Mudflat	MFl		199.01	4.65	0.46	204.11
	Spearwort Lakeflat	SL	00	117.92	19.77	0.68	138.38
	Hairgrass - Water sedge	HS	00	76.27	5.92	0.00	82.19
	Sitka willow - Water sedge	WS	00	77.16	5.94	0.00	83.10
Lakeshore - small lakes	Emergent Marsh	EM	00	0.00	0.00	0.33	0.33
	Sedge Wetland	SW	00	4.49	0.31	2.72	7.52
	Hardhack - Labrador tea	HL	00	0.00	22.03	10.61	32.64
	Western redcedar/Sitka spruce - Skunk cabbage	RC	12	14.04	0.03	3.54	17.61
Upland Forest	Douglas-fir/Western hemlock - Salal	DS	03	0.00	0.25	0.00	0.25
	Western hemlock/Douglas-fir - Kindbergia	HK	01	9.71	0.38	0.00	10.09
	Lodgepole pine - Sphagnum	LS	11	0.00	0.00	0.52	0.52
	Western redcedar - Foamflower	RF	07	11.42	0.00	0.00	11.42
	Western redcedar - Swordfern	RS	05	16.52	0.17	0.00	16.68
	Western redcedar - Slough sedge	CS	15	0.00	0.00	0.46	0.46
Floodplain	Cottonwood - Willow	CW	10	52.09	0.00	0.00	52.09
	Sitka spruce - Salmonberry	SS	08	64.90	0.00	0.00	64.90
Unvegetated	Unvegetated Shoreline	US	-	38.35	3.22	1.63	43.19
	Gravel Bar	GB	-	21.65	0.00	0.00	21.65
	Pond (open water)	PD	-	1.80	1.33	0.00	3.13
Total				312.12	33.66	19.81	365.59

3.2.3.1. Quality Assurance

For this project, visual inspections were conducted for 185 polygons, representing 34.8% of all polygons (Table 8). This corresponds with a survey level intensity of 3. However, the intensity of ground-truthing is typically higher for this level of survey intensity, including detail of data collection such as full plots and ground inspection plots. A survey level intensity of 3 is appropriate for 1:10K-1:50 K mapping projects or a study area of 5,000-50,000 hectares (RIC 1998). This level of survey intensity is also recommended for habitat enhancement prescriptions. Given that only 365.59 ha of riparian habitat were delineated along the shoreline of the study waterbodies, the survey intensity in practice was estimated at higher than a level 3.

Table 8. Number and percent of each polygon type verified for each waterbody.

Ecosystem type	Vegetation Community Name	Map Code	Upper Campbell		Lower Campbell		Brewster		Total	
			#	%	#	%	#	%	#	%
Lakeshore - large lakes	Lake Mudflat	MFl	0	0.0%	0	0.0%	1	50.0%	1	20.0%
	Spearwort Lakeflat	SL	16	25.8%	7	19.4%	1	33.3%	24	23.8%
	Hairgrass - Water sedge	HS	26	33.8%	5	13.9%	-		31	27.4%
	Sitka willow - Water sedge	WS	36	45.6%	12	30.8%	-		48	40.7%
Lakeshore - small lakes	Emergent Marsh	EM	-	-	-	-	4	66.7%	4	66.7%
	Sedge Wetland	SW	-	-	1	33.3%	10	50.0%	11	47.8%
	Hardhack - Labrador tea	HL	-	-	2	14.3%	20	58.8%	22	45.8%
	Western redcedar /Sitka spruce - Skunk cabbage	RC	2	50.0%	-	-	7	70.0%	9	64.3%
Upland Forest	Douglas-fir /Western hemlock - Salal	DS	-	-	-	-	-	-	-	-
	Western hemlock /Douglas-fir - Kindbergia	HK	6	50.0%	0	0.0%	-	-	6	42.9%
	Lodgepole pine - Sphagnum	LS	-	-	-	-	-	-	-	-
	Western redcedar - Foamflower	RF	5	50.0%	-	-	-	-	5	50.0%
	Western redcedar - Swordfern	RS	2	20.0%	1	100.0%	-	-	3	27.3%
	Western redcedar - Slough sedge	CS	-	-	-	-	-	-	-	-
Floodplain	Cottonwood - Willow	CW	5	62.5%	-	-	-	-	5	62.5%
	Sitka spruce - Salmonberry	SS	2	33.3%	-	-	-	-	2	33.3%
Unvegetated	Unvegetated Shoreline	US	9	29.0%	2	33.3%	2	20.0%	13	27.7%
	Gravel Bar	GB	1	20.0%	-	-	-	-	1	20.0%
	Pond (open water)	PD	0	0.0%	0	0.0%	-	-	0	0.0%
Total			110	34.2%	30	21.1%	45	52.3%	185	**34.8%**

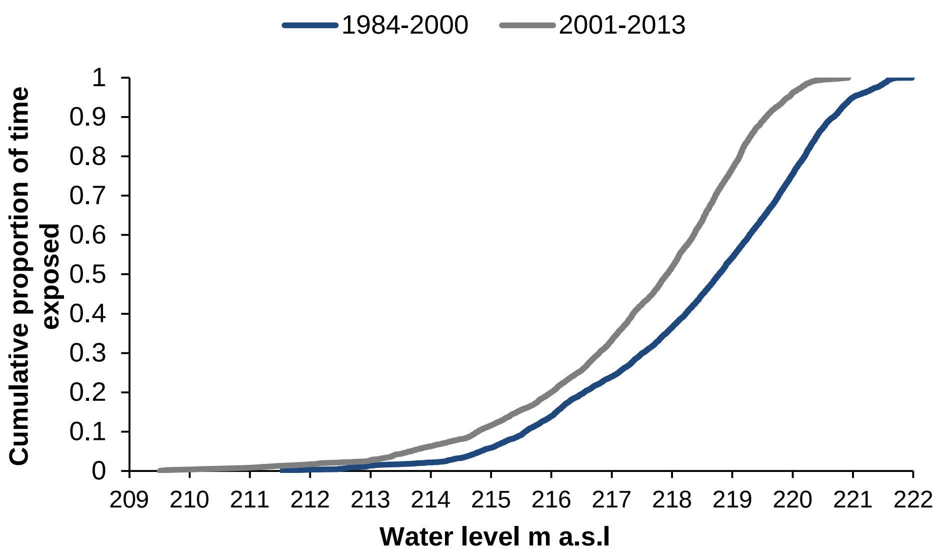
3.3. Data Analysis

3.3.1. SVM Validation

3.3.1.1. Water Level Comparison

Results from the Kolmogorov-Smirnov goodness-of-fit test show that the frequency distribution of mean daily water levels during the SVM_{2014} period (2001-2013) differs from the distribution for the SVM_{2001} period (1984-2000; $D = 0.2515$; $p < 0.001$). In general, mean daily water levels in Upper Campbell Lake Reservoir were lower during the SVM_{2014} period (2001-2013) compared with the SVM_{2001} period (1984-2000), prior to implementation of the WUP (Figure 1, Figure 22, Figure 24).

Figure 24. Cumulative frequency distributions of daily mean water levels in Upper Campbell Lake Reservoir for the SVM_{2001} (1984-2000) and SVM_{2014} (2001-2013) periods.

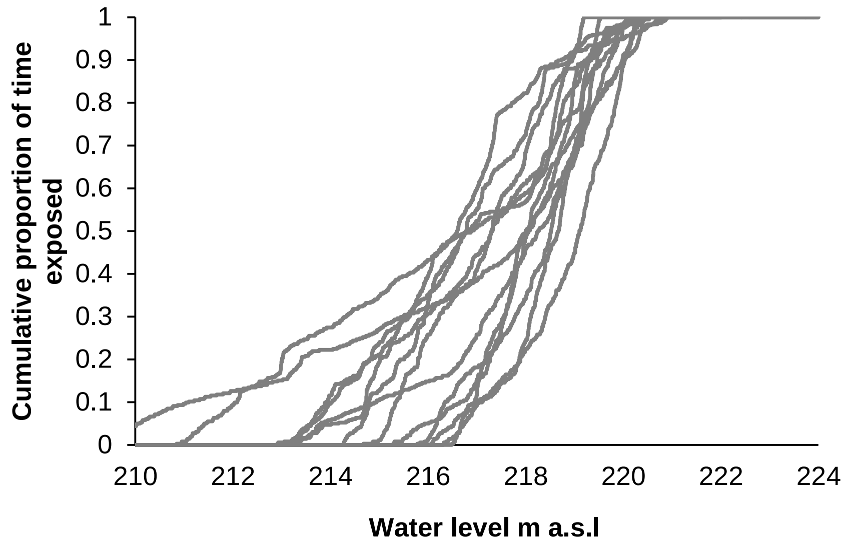


3.3.1.2. Year 1 Boundary Elevation Predictions

Creating the SVM

Annual cumulative frequency distributions of mean daily water level for 2001-2013 (Figure 25) show inter-annual differences in water levels and highlight further that water levels were generally lower during this period compared to 1984-2000 (Figure 6). Water levels were particularly low during 2008 when the level was less than the SVM lower bound of 210 m for a total of nine days (minimum = 209.506 m).

Figure 25. Cumulative frequency distributions of daily water level for individual years during 2001–2013.



Predicting Elevation Boundaries

The results of the boundary elevation search procedure used to predict the upper boundaries of the communities in Year 1 are shown in Figure 26, while the predicted upper and lower boundary elevations are presented in Table 9.

Figure 26. Results of the boundary search procedure to define upper elevation boundaries of vegetation communities. The minimum value of SS (sum of squared differences) represents the boundary.

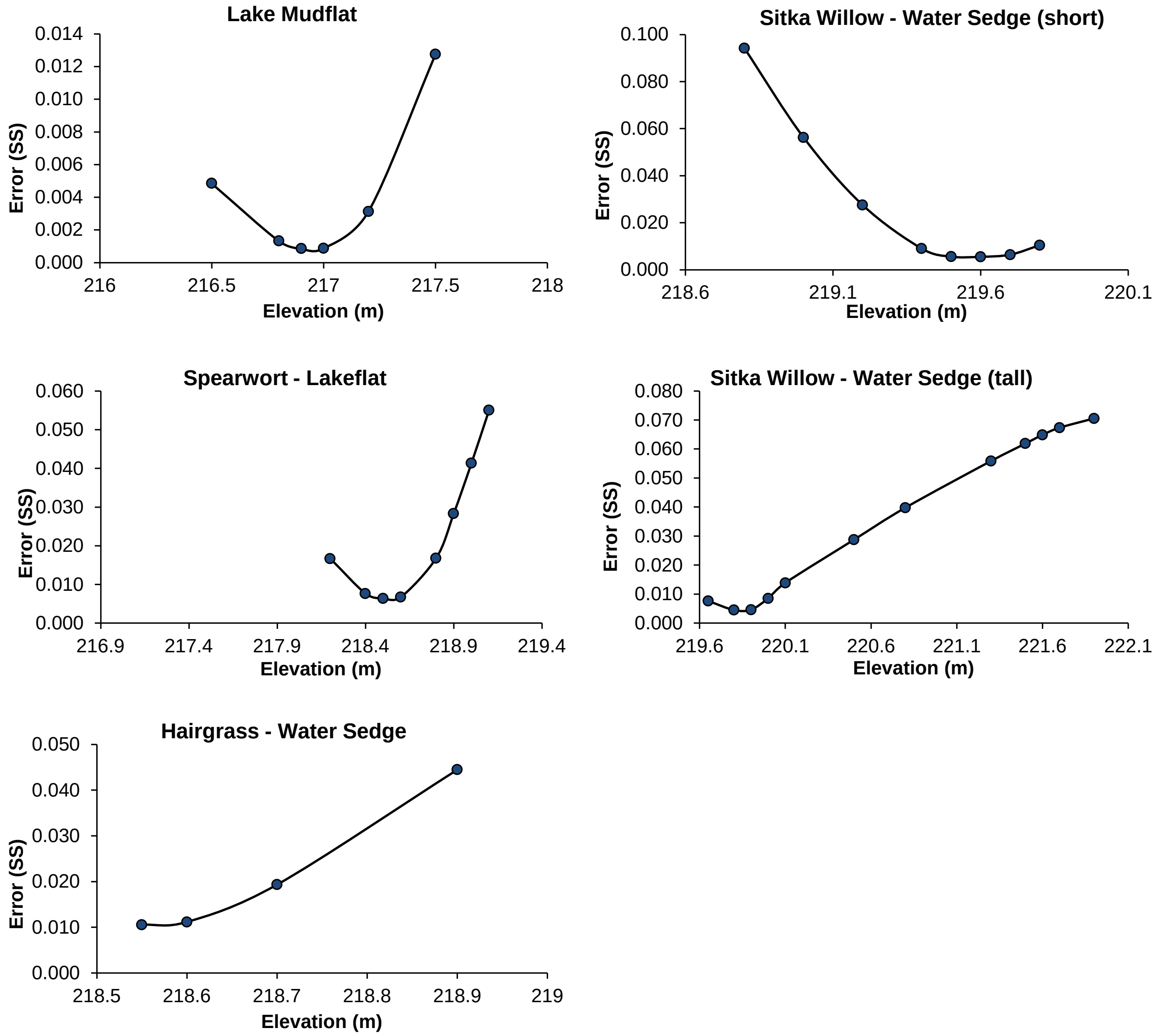


Table 9. 2014 predicted boundary elevations of vegetation communities at Upper Campbell Lake Reservoir, as predicted by the SVM$_{2014}$.

Vegetation Community Name	Map Code	SVM$_{2014}$ boundary elevation predictions (m a.s.l)	
		Lower	Upper
Lake Mudflat	MF	-	216.9
Spearwort Lakeflat	SL	216.9	218.5
Hairgrass – Water sedge	HS	218.5	218.6
Sitka willow - Water sedge (short)	WS_s	218.6	219.6
Sitka willow - Water sedge (tall)	WS_t	219.6	219.7
Upland Forest	UF	219.7	-

The elevation boundaries for the six key vegetation communities defined by McLennan and Veenstra (2001) (Table 2) shifted from those those predicted by the SVM$_{2014}$ (Figure 27). The shift likely reflects the generally lower water levels since 2001. Specifically, the SVM$_{2014}$ predicted colonization of Lake Mudflat at lower elevations. The model also predicted expanded communities of Spearwort – Lakeflat and Sitka willow – Water Sedge and the presence of Upland Forest near the shoreline (Figure 27).

Figure 27. Comparison of vegetation boundary elevations determined by McLennan and Veenstra (2001) (Table 2) with Year 1 boundaries predicted by the SVM$_{2014}$.

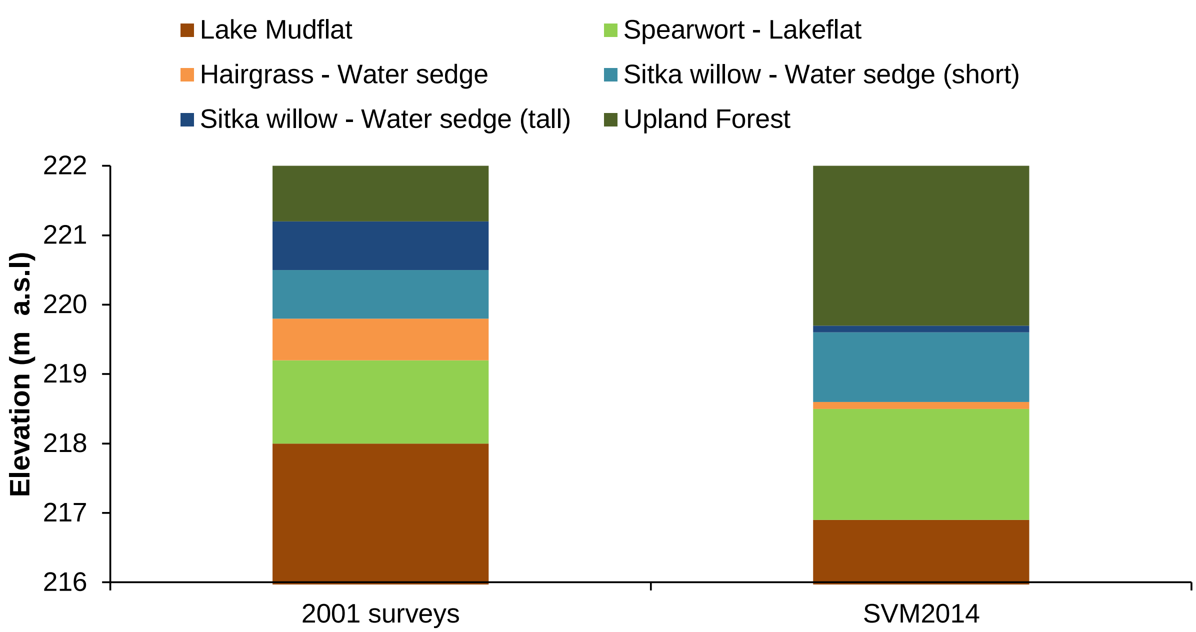
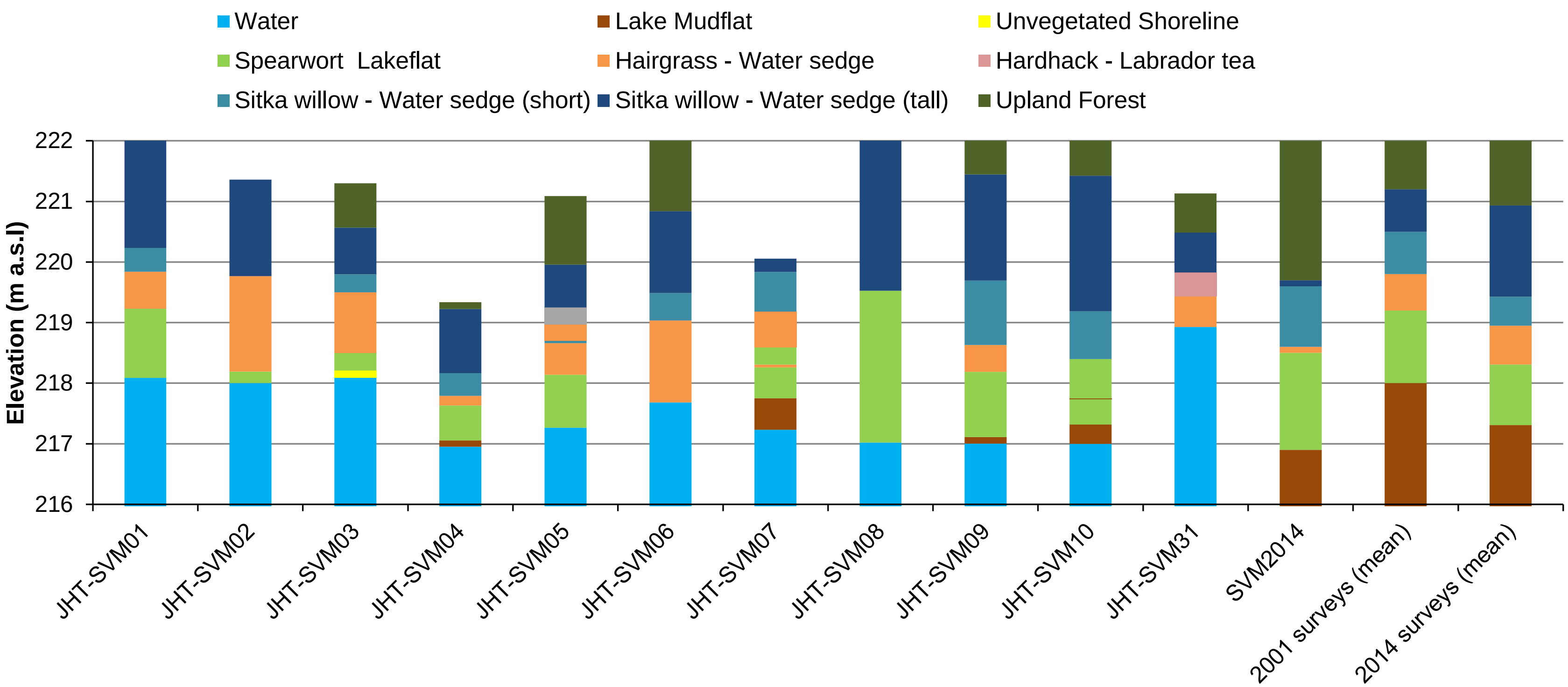


Figure 28 presents a comparison of the SVM_{2014} predictions with Year 1 vegetation transect data for Upper Campbell Lake Reservoir. This highlights some important differences between results from the vegetation surveys and the SVM. Specifically:

1. The SVM assumes that there are six vegetation communities along each transect. One of the eleven vegetation transects (JHT-SVM03) included an area of unvegetated shoreline. This category was also recorded for transects on the other waterbodies (Section 3.2.1) and is not represented in the SVM. Another transect (JHT-SVM31) combined a small zone (0.4 m) of Hardhack – Labrador tea with the adjacent Hairgrass-Water sedge (HS) community for the purposes of model validation.
2. The SVM assumes that a particular community is present in only one discrete area along each transect. Three of the eleven transects that were surveyed have 'repeating' communities that grow in two locations along a single transect (JHT-SVM05, JHT-SVM07, and JHT-SVM 10), where the ground undulates.
3. Most significantly, the SVM assumes that *all* six communities are present on each transect in a defined sequence (Figure 2). All six of the communities were present along only two of the eleven transects surveyed (JHT-SVM04 and JHT-SVM 09).

The differences outlined above limit the number of measurements that can be considered during the SVM validation. The validation focuses on measuring the error between the predicted and measured elevations of the five boundaries; however, the boundaries are not present between all community types for most transects. This is typically because the communities were not aligned as the model predicted, e.g., only seven of the eleven transects had an Hairgrass-Water sedge (HS) community present adjacent to, and upslope of, an Spearwort Lakeflat (SL) community, as predicted by the SVM. In the case of the Lake Mudflat (MF) community, the absence of the expected upper boundary (with SL community) in the transect data may reflect sampling conditions as the ML community may have been submerged and undetectable at the time of sampling (or the community may have simply not been present at the site). The lower end of each of the 11 transects ended above the predicted SL/MF boundary (216.9 m) (Figure 28). In total, there were 34 measurements of boundary elevations available for model validation, out of an expected total of 55, due to the three above listed reasons. Thus, validation could be undertaken for only 62% of expected boundaries using the model. The proportion of the expected boundaries could be increased to 68% if the MF/SL boundary is not considered, based on the rationale that the boundary may have been present at each transect yet high water levels prevented its measurement. Note that in Figure 28, the mean boundary between SL and MF for the 2001 and 2014 surveys denotes the survey end (i.e. the water surface) and not the edge of the Lake Mudflat community, as compared to the SVM_{2014} which is a prediction of the MF/SL boundary.

Figure 28. The 2014 vegetation transect survey results for the Upper Campbell Lake Reservoir compared with the Shoreline Vegetation Model predictions (SVM_{2014}) and mean 2001 survey results.



3.3.1.3. Model Error and Validation

Comparison of 2001 and 2014 Field Data

The variance in field measurements was compared between the surveys in 2001 (McLennan and Veenstra 2001)[2] and the Year 1 (2014) data collection (Table 10) for Upper Campbell Lake Reservoir. This provides insight into whether the variability in the field data that was observed in Year 1 is representative of the variability of the data used to originally construct the SVM. This comparison shows that the boundary elevation measurements were generally more variable in Year 1 compared with 2001; for example, values of the standard deviation and the coefficient of variation for measurements of individual boundaries were all higher in Year 1 relative to 2001. In particular, there was considerable variability in the measurements of the uppermost boundary (WS_t/UF) which exhibited a range of 4.29 m and a standard deviation of 1.28 m. At least a portion of the increased variability in field data in Year 1, as compared to 2001, is likely due to the transitional state of the vegetation communities downwards in response to the WUP, which resulted in difficulties in defining the boundaries between communities.

Table 10. Comparison of data collected for individual vegetation community boundaries during 2001 and 2014 at Upper Campbell Lake Reservoir. σ, standard deviation; CV, coefficient of variation.

Downslope community	Upslope community	2001 surveys[1]					Year 1 surveys				
		# transects with boundary (max = 10)	% of transects with boundary	Elevation range (m)	σ (m)	CV (%)	# transects with boundary (max = 11)	% of transects with boundary	Elevation range (m)	σ (m)	CV (%)
MF[2]	SL	-	-	-	-	-	4	31	0.70	0.32	0.15
SL	HS	7	70	1.05	0.36	0.16	8	62	1.60	0.48	0.22
HS	WS_s	7	70	0.68	0.24	0.11	8	62	2.05	0.67	0.31
WS_s	WS_t	8	80	0.79	0.26	0.12	10	77	2.06	0.61	0.28
WS_t	UF	5	50	0.71	0.30	0.14	9	69	4.29	1.28	0.58

[1]McLennan and Veenstra (2001)

[2]MF community is not recorded for the transect data provided (Appendix 6 of McLennan and Veenstra 2001)

Summary of Model Error

Due to the fact that not all community boundaries predicted by the model were measured at each transect, the following results relate only to the measured community boundary elevations that can be directly compared with model predictions. Also, for transects with 'repeating' communities (i.e.

[2] Note that there is some uncertainty regarding the 2001 measurements. Data were transcribed from a document provided by BC Hydro (Appendix 6 of McLennan and Veenstra 2001); however, it is not certain that these are the exact measurements that were used for the SVM development as the mean elevation boundaries do not directly correspond to those presented in Bruce (2002), and no record is present for MF communities.

there are two boundaries between two specific communities), as seen at JHT-SVM07 and JHT-SVM1, only the lower-most boundary was used for the validation.

Table 11 presents a summary of the SVM_{2014} predictions and the measured boundary elevations for transects for which the respective boundary was present. Individual values of the error between SVM_{2014} predictions and the measured boundary elevations (where present) are presented in Figure 29. With the exception of the MF/SL boundary, the SVM_{2014} predictions were within the range of the field measurements. Overall, model error was highest for the WS_t/UF boundary for which mean absolute error was 1.23 m and RMSE was 1.71 m. SVM_{2014} predictions of the WS_t/UF boundary was underestimated (mean error = 1.35 m), meaning the measured community boundary was detected at a lower elevation than predicted (219.7 m vs. 221.0 m). The predictions were less biased for the other four boundaries. Mean absolute errors for the four lowest boundaries were 0.40 m (SL/HS) to 0.58 m (HS/WS_s). It is notable that the SVM_{2014} predicted especially narrow elevation bands for both the HS and WS_t communities, whereas the field data show that, where present, the elevation bands occupied by these communities were generally much wider (Figure 28).

Table 11. Comparison of SVM_{2014} boundary elevation predictions with Year 1 vegetation transect data.

Downslope community	Upslope community	SVM_{2014} boundary elevation prediction (m)	Year 1 surveys				Model error (m)		
			Number of transects with boundary present (max = 11)	Mean elevation (m)	Minimum elevation (m)	Maximum elevation (m)	Mean error	Mean absolute error	RMSE
MF	SL	216.9	4	217.31	217.06	217.75	0.41	0.41	0.49
SL	HS	218.5	7	218.31	217.63	219.23	-0.19	0.40	0.49
HS	WS_s	218.6	7	218.95	217.79	219.84	0.35	0.58	0.71
WS_s	WS_t	219.6	8	219.43	218.17	220.23	-0.17	0.41	0.59
WS_t	UF	219.7	8	221.00	219.23	223.51	1.23	1.35	1.71
All communities combined							**0.33**	**0.66**	**0.97**

Figure 29. SVM_{2014} model error (m) by boundary type. Positive values denote model under-estimates and vice versa. Points denote raw values.

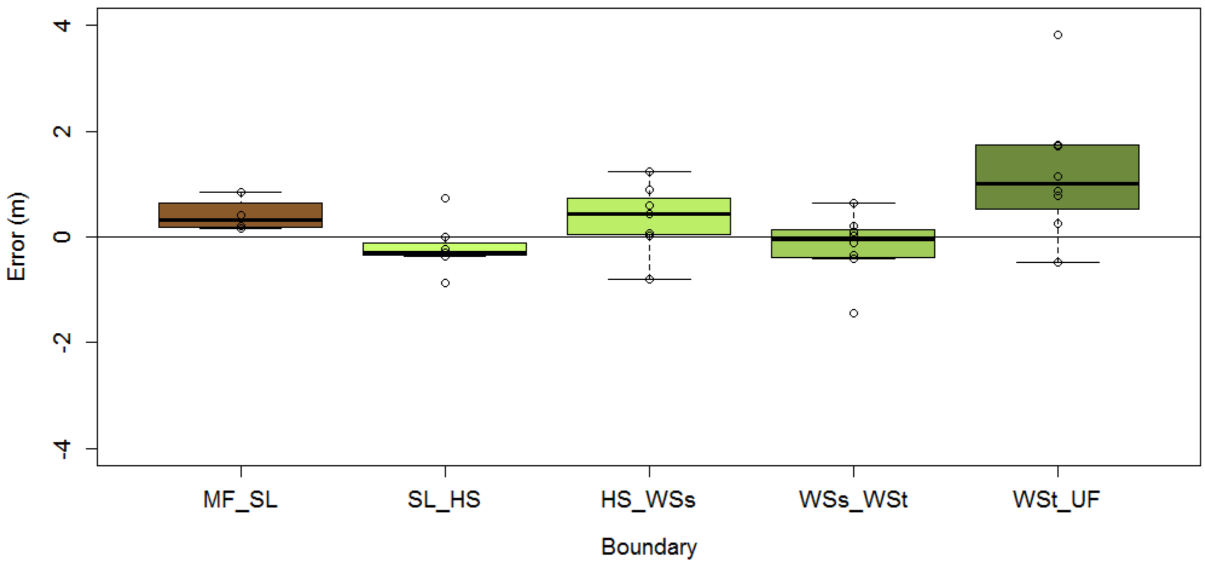


Table 12 provides context of how the error in SVM_{2014} predictions of boundary elevations corresponds to error in distances parallel to the ground, based on the mean slope of the downslope communities. These estimates therefore provide some indication of how the SVM_{2014} errors relate to errors in estimated areas of vegetation community that might be derived using the model. The greatest error relates to the WS_t/UF boundary, indicating that the SVM_{2014} error for this boundary corresponds to a prediction that the UF community was approximately 18.1 m closer to the reservoir than observed. This error between measured distances and SVM prediction is likely because the WSt community has not fully transitioned to UF. UF takes longer to establish and grow than the other communities (Figure 15). In contrast, the mean SVM_{2014} error for the prediction of the WS_s/WS_t boundary corresponds to a prediction that the WS_t community was approximately 2.6 m further from the reservoir than observed. These two errors therefore account for the result that the predicted width of the WS_t community was generally much narrower than the field measurements (Figure 28). Similarly, compounding errors also account for the result that the predicted width of the HS community was generally much narrower than the field measurements.

Table 12. Estimates of how the error in SVM_{2014} predictions of elevation correspond to error in distance on the ground of slope boundaries, based on the mean slope of downslope communities. Positive values denote model underestimates and vice versa.

Boundary type		Mean community slope (%)	Mean model error (m)	Estimated mean error as distance parallel to ground (m)
Downslope community	Upslope community			
MF	SL	11	0.41	3.74
SL	HS	5.54	-0.19	-3.51
HS	WS_s	3.32	0.35	10.50
WS_s	WS_t	6.57	-0.17	-2.61
WS_t	UF	6.84	1.23	18.05

Statistical Test Results

When modelled and measured elevations for all boundaries were pooled, comparison of the mean elevations for the two groups showed that there is no statistically significant difference between the model predictions and the measurements (one-way ANOVA, $F = 1.18$, $p = 0.24$, $n = 34$).

However, when boundary types were considered individually, there were statistically significant differences between the modelled and measured elevations for the following three boundary types: MF/SL, SL/HS and WS_t/UF (Table 13).

Table 13. Results of a non-parametric Mann-Whitney-Wilcoxon test to compare modelled and measured vegetation community boundary elevations for individual boundary types. Bold *p*-values denote statistically significant differences ($\alpha = 0.05$). *n*, sample size; *W*, test statistic.

Downslope	Upslope	*n*	*W*	*p*
MF	SL	4	0	**0.021**
SL	HS	7	42	**0.020**
HS	WS_s	7	7	**0.020**
WS_s	WS_t	8	32	1.000
WS_t	UF	8	8	**0.008**

The results of a z-test[3] showed that the mean of the pooled error values (n = 39) was not significantly different from zero (df = 33, z=1.1, p=0.29, data $\log_{10}(x+2)$ transformed).

3.3.2. Vegetation Community Gradient

3.3.2.1. Vegetation Community Transects

Scatterplots demonstrate that vegetation cover decreases as the slope of the ground increases for Upper Campbell Lake Reservoir vegetation communities (Figure 30). However, clear relationships were generally absent for communities around Lower Campbell Lake Reservoir (Figure 31) and Brewster Lake (Figure 32), the smaller lakes. Linear regression results show that the negative relationship between cover and slope was statistically significant when all communities around Upper Campbell Lake Reservoir were analysed (r^2 = 0.41, p<0.001, n = 69). However, linear regression of cover on slope did not yield a statistically significant relationship for communities around Lower Campbell Lake Reservoir (n = 56) and Brewster Lake (n = 43).

[3] The project Terms of Reference (BC Hydro 2013) stipulated that this analysis should be undertaken using a z-test. Note that this requires knowledge of the population standard deviation which was estimated based on the sample standard deviation. This is typically valid when the sample size is very large, although in this case, that assumption is questionable (n=39). When sample sizes are smaller, it is more typical to undertake a t-test which assumes that the sample is drawn from a population that is t-distributed, rather than normally distributed. This generally has a minor effect on test outcomes and, indeed, repeating the test using a one sample, two-sided Student's t-test also results in a non-significant result with similar p-value (t = 1.10, df = 33, p = 0.28) (Zar 1999, p. 92-93). Thus, given the subjectivity involved in test selection, and the matching results of the two tests, the results of the z-test are presented here.

Figure 30. Relationships between vegetation cover and slope for all (a) and dominant vegetation community types (b-e) sampled in Upper Campbell Lake Reservoir.

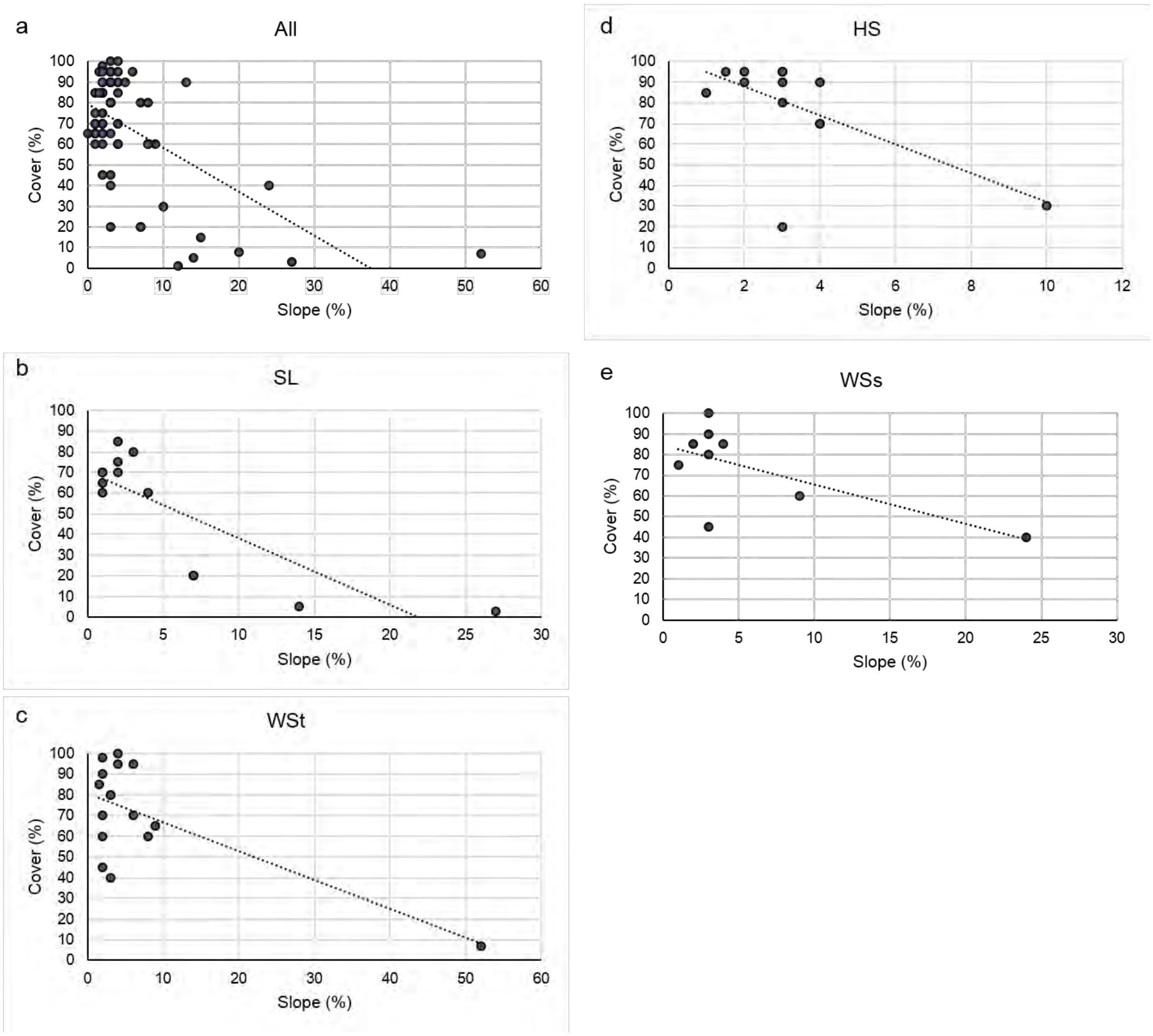


Figure 31. Relationships between vegetation cover and slope for all (a) and dominant vegetation community types (b, c) sampled in Lower Campbell Lake Reservoir.

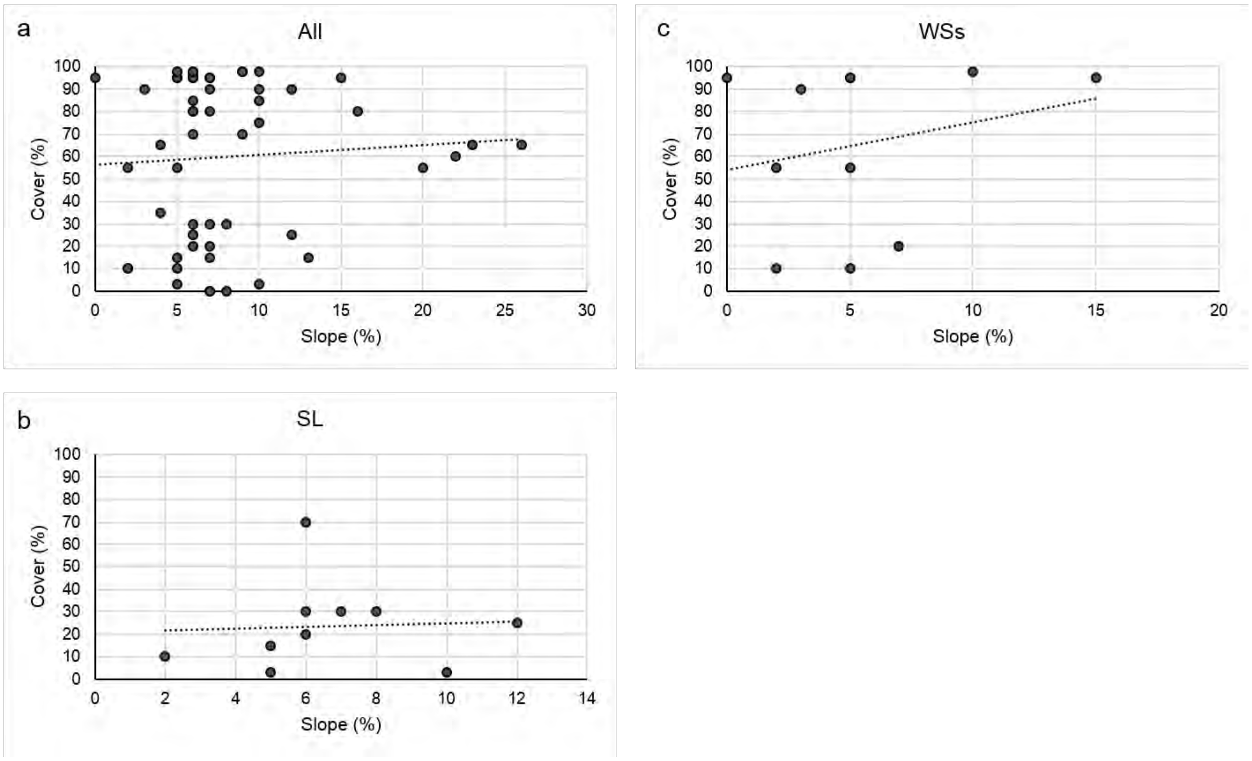
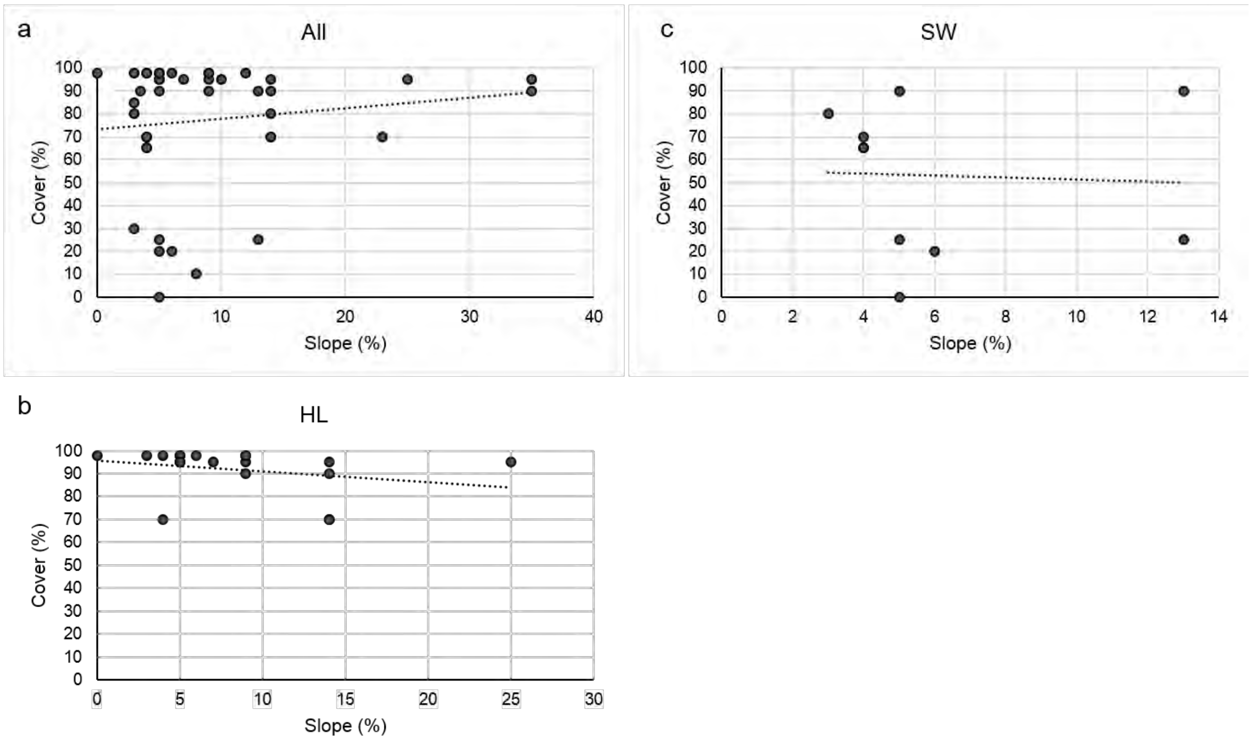


Figure 32. Relationships between vegetation cover and slope for all (a) and dominant vegetation community types (b, c) sampled in Brewster Lake.

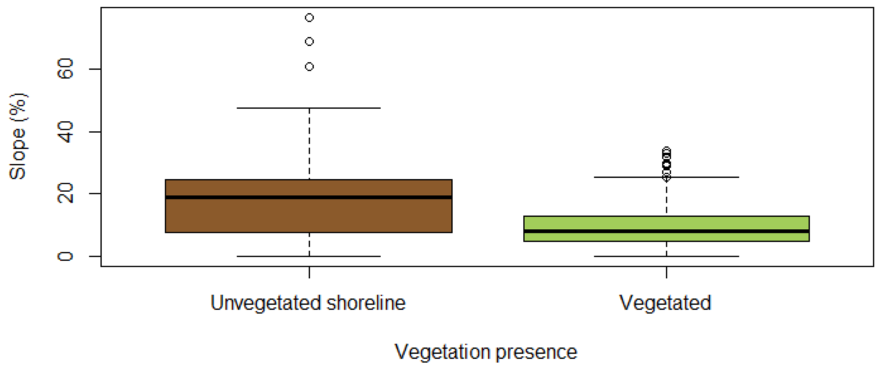


3.3.2.2. Air Photo Interpretation

Means Slopes

Slopes dominated by unvegetated shoreline were higher than those dominated by all other vegetation community types. The mean value of the mean polygon slopes was 21.0% for polygons dominated by unvegetated shoreline and 9.3% for polygons dominated by other vegetation community types (Figure 33). The difference in these mean values is statistically significant ($t = 4.21$, $df = 41$, $p < 0.001$).

Figure 33. Boxplot of mean polygon slopes for polygons dominated by un-vegetated shoreline (n = 41) and polygons dominated by vegetation (all other community types; n = 405)



Mean polygon slopes for individual vegetation communities are summarized in Figure 34 and Table 14. With the exception of three community types, mean polygon slopes were statistically significantly lower for polygons dominated by all individual vegetation communities compared with polygons dominated by unvegetated shoreline. One of the exceptions is an upland forest community (Douglas-fir/Western hemlock – Salal (DS)) that is not reliant on the hydrologic regime of the waterbody. The remaining two exceptions, Lake Mudflat (MFl) and Gravel Bar (GB), are commonly present unvegetated types in riparian areas (Table 14).

Figure 34. Boxplot of mean polygon slopes for dominant vegetation community types.

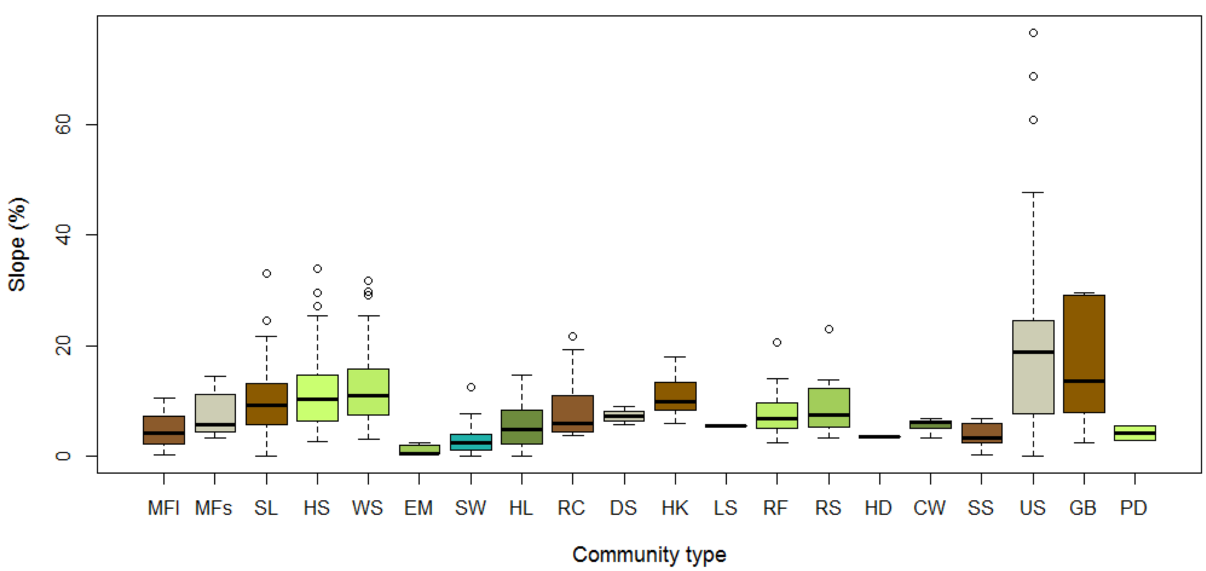


Table 14. Summary of mean polygon slopes by dominant vegetation community type. *p* denotes the p-value corresponding to statistical comparison of the average of mean slope values between community type and un-vegetated shoreline. Bold denotes statistical significance (see text for further details).

Ecosystem type	Vegetation Community Name	Map Code	n	Mean (%)	Minimum (%)	Maximum (%)	Standard deviation (%)	*p*
Lakeshore - large lakes	Lake Mudflat	MFl	3	4.9	0.1	10.4	5.2	0.057
	Spearwort Lakeflat	SL	84	9.9	0.0	33.1	5.9	**<0.001**
	Hairgrass - Water sedge	HS	94	11.1	2.5	34.0	6.3	**<0.001**
	Sitka willow - Water sedge	WS	78	12.1	3.1	31.7	6.3	**<0.001**
Lakeshore - small lakes	Emergent Marsh	EM	5	1.0	0.1	2.4	1.1	**<0.001**
	Sedge Wetland	SW	22	3.0	0.0	12.4	2.9	**<0.001**
	Hardhack - Labrador tea	HL	40	5.0	0.0	14.7	3.6	**<0.001**
	Western redcedar/Sitka spruce - Skunk cabbage	RC	13	9.1	3.5	21.7	6.2	**<0.001**
Upland Forest	Douglas-fir/Western hemlock - Salal	DS	3	7.2	5.6	8.9	1.6	0.227
	Western hemlock/Douglas-fir - Kindbergia	HK	12	10.6	5.9	18.0	3.4	**0.007**
	Lodgepole pine - Sphagnum	LS	1	5.4	5.4	5.4	-	NA
	Western redcedar - Foamflower	RF	9	8.1	2.2	20.6	5.9	**0.001**
	Western redcedar - Swordfern	RS	10	9.2	3.1	22.9	5.9	**0.002**
Floodplain	Cottonwood - Willow	CW	5	5.4	3.1	6.8	1.4	**0.004**
	Sitka spruce - Salmonberry	SS	7	3.8	0.2	6.7	2.4	**<0.001**
Non-vegetated	Unvegetated Shoreline	US	41	21.0	0.0	76.7	17.6	NA
	Gravel Bar	GB	5	16.4	2.3	29.5	12.4	0.999
	Pond (open water)	PD	2	4.0	2.7	5.4	-	NA

Mean Area-Weighted Polygon Slope

Mean area-weighted polygon slopes are presented for individual vegetation communities from Upper Campbell Lake Reservoir (Figure 36), Lower Campbell Lake Reservoir (Figure 35), and Brewster Lake (Figure 35). For Upper Campbell Lake Reservoir, the unvegetated shoreline community had the highest mean slope of 22.6% which was more than twice the mean slope of the other communities present. For Lower Campbell Lake Reservoir, mean area-weighted slope was 16.4% for unvegetated shoreline. This was higher than all riparian vegetation community types. However, the mean area-weighed slope was highest for the Western redcedar – Swordfern (RS) upland forest community (22.9%) which was represented by a single polygon (1,524 m^2). These results are likely at least partially due to the low resolution of the DEM from which the slopes were derived. Moreover, upland forest types are generally steeper than riparian communities. For Brewster Lake, mean area-weighted slope of the unvegetated shoreline polygons (n = 7) was 4.0% and therefore substantially lower than the other waterbodies and most of the other vegetation communities surrounding Brewster Lake. Only the Sedge Wetland (SW) community had a lower slope than the unvegetated shoreline (Figure 35). The DEM for Brewster Lake, from which slopes were derived, was low resolution and did not include bathymetry data. The DEM did align well with the orthophotos from which the polygons were delineated. So although the relative slopes of each community presented in Figure 35 reflect what would be expected, inferences should not be taken from this assessment.

Figure 35. Area-weighted mean slope (%) of individual vegetation community types along the Upper Campbell Lake Reservoir. Vertical bars denote +/- 1 one standard deviation of mean slope measured for individual polygons in which community types were dominant.

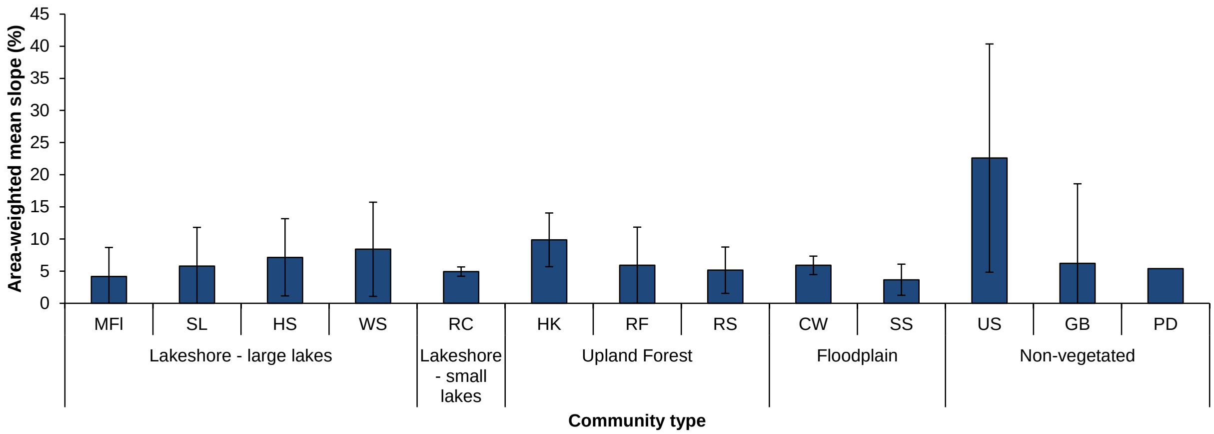


Figure 36. Area-weighted mean slope (%) of individual vegetation community types along the Lower Campbell Lake Reservoir. Vertical bars denote +/- 1 one standard deviation of mean slope measured for individual polygons in which community types were dominant.

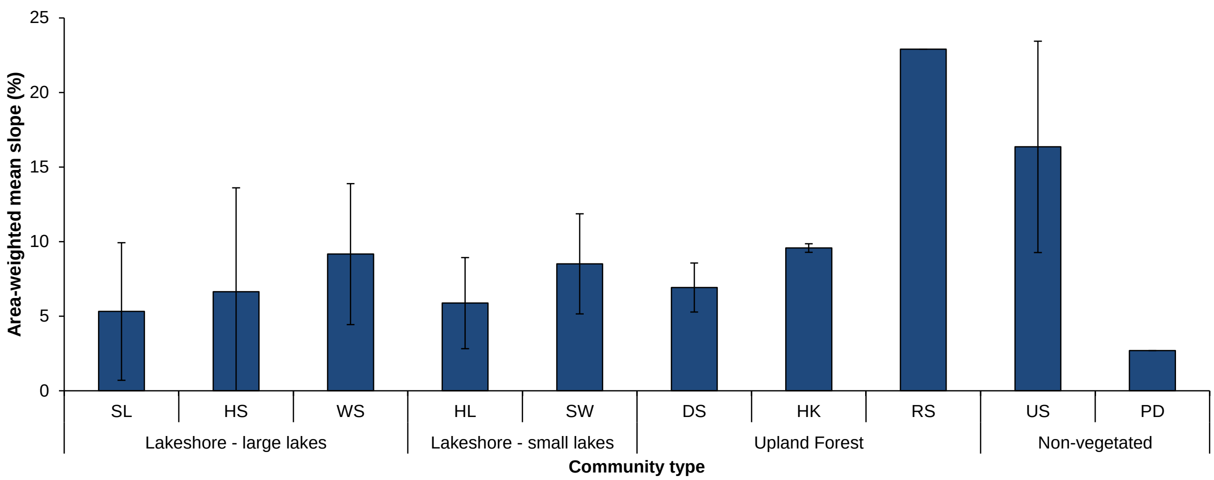
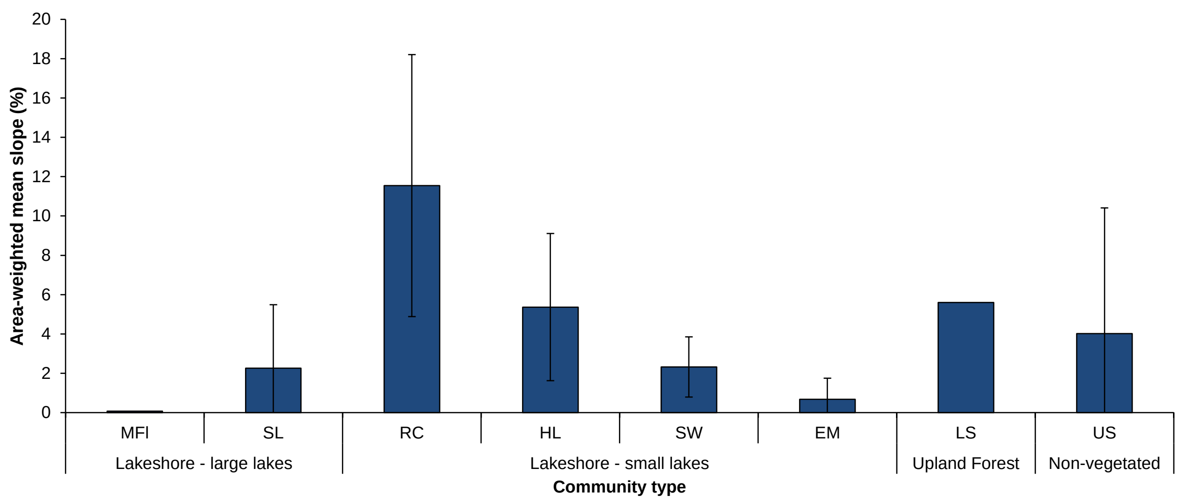


Figure 37. Area-weighted mean slope (%) of individual vegetation community types along Brewster Lake. Vertical bars denote +/- 1 one standard deviation of mean slope measured for individual polygons in which community types were dominant.



Contingency Tables

Contingency tables are presented below for Upper Campbell Lake Reservoir (Table 15), Lower Campbell Lake Reservoir (Table 16), and Brewster Lake (Table 17). The tables present both polygon count data, in addition to the polygon areas (corrected by a factor of 0.7-1 based on dominant community coverage [i.e., weighted-area]) for each category. The results of Fisher's exact tests conducted using the polygon count data (Table 18) show that the null hypothesis can be rejected for Upper Campbell Lake Reservoir only. Thus, for the Upper Campbell Lake Reservoir, the distribution of vegetated and unvegetated areas is dependent of whether slope is greater or less than 15%. Inspection of the contingency tables relative distribution of polygon area for both Lower Campbell Lake Reservoir and Brewster Lake demonstrate that the number of vegetated and unvegetated polygons is not contingent on the two slope categories.

Table 15. Contingency table of Upper Campbell Lake Reservoir data. Percentages in parentheses denote proportion of total number or polygons/polygon area in each of the four categories.

	Vegetated		Unvegetated	
	# polygons	Area (m^2)	# polygons	Area (m^2)
<15%	179 (73%)	5,124,552 (95%)	3 (1%)	23,814 (<1%)
>15%	41 (17%)	126,226 (2%)	23 (9%)	127,259 (2%)

Table 16. Contingency table of Lower Campbell Lake Reservoir data. Percentages in parentheses denote proportion of total number or polygons/polygon area in each of the four categories.

	Vegetated		Unvegetated	
	# polygons	Area (m^2)	# polygons	Area (m^2)
<15%	96 (79%)	482,919 (92%)	4 (3%)	8,979 (2%)
>15%	20 (16%)	18,623 (4%)	2 (2%)	11,706 (2%)

Table 17. Contingency table of Brewster Lake data. Percentages in parentheses denote proportion of total number or polygons/polygon area in each of the four categories.

	Vegetated		Unvegetated	
	# polygons	Area (m^2)	# polygons	Area (m^2)
<15%	68 (86%)	147,871 (88%)	7 (9%)	7,811 (5%)
>15%	3 (4%)	12,226 (7%)	1 (1%)	320 (<1%)

Table 18. *p*-values for Fisher's exact tests performed on polygon count data presented in contingency tables for individual waterbodies (Table 15 to Table 17). Bold values denote statistical significant, i.e., rejection of the null hypothesis that the distribution of vegetated and unvegetated areas is independent of whether slope is greater or less than 15%.

Waterbody	*p*
Upper Campbell Lake Reservoir	**< 0.001**
Lower Campbell Lake Reservoir	0.295
Brewster Lake	0.353

4. DISCUSSION AND CONCLUSIONS

4.1. Management Questions

Data have been collected and analysed during the Year 1 JHTMON-10 study with the purpose of working towards answering the five key management questions for the monitoring program which will be addressed in greater detail in Year 10:

1. ***Does the lacustrine shoreline vegetation model accurately predict the reservoir elevation bands that bound the predefined plant community types?***

At this stage, this question can be partially addressed for the Upper Campbell Lake Reservoir. This question will be further addressed for this reservoir, and the other two waterbodies, following vegetation surveys in Year 10. This will involve applying the SVM using hydrology data collected for the individual reservoirs during 2014 to 2024, with appropriate corrections for differences in elevation. Validation tests consistent with those applied in Year 1 will then be used to compare modelled and measured vegetation data. The aim is to initially test whether the SVM that was developed for Upper Campbell Lake Reservoir can be applied to predict community boundaries for all three waterbodies. This assumes that communities in the current SVM are representative of those found in all three watersheds, and that these communities exhibit the same tolerances to inundation throughout the study area. Should the results of analysis in Year 10 show that a single configuration of the SVM cannot be applied successfully to one or more of the smaller waterbodies, then it may be necessary to consider calibrating separate versions of the SVM that are specific to each waterbody to provide accurate (if not general) predictive tools. For Lower Campbell Lake Reservoir and Brewster Lake, this would involve parameterizing the model using water level data (Year 1 to Year 10) and Year 10 vegetation data, with further data collection necessary to validate the models[4].

In summary, the SVM_{2014} predictions for Upper Campbell Lake Reservoir satisfied the two predefined tests of model accuracy (BC Hydro 2013). Specifically, when all community boundaries were pooled, the modelled and measured boundary elevations were shown to be not statistically significantly different, and the mean model error was not statistically significantly different from zero. The model error was typically relatively low for the four lower-most boundaries (MF/SL, SL/HS, HS/WSs, WSs/WSt) (mean absolute error ≈ 0.5 m), although the error was highest for the lower boundary of the highest community (upland forest), for which the modelled height was 1.23 m below the average measured boundary.

In assessing model performance, it should be noted that only moderate insight can be gained from the result that the mean model error was not statistically significantly different from zero. It is possible for the model to over- and under-estimate boundaries by large magnitudes, yet this criterion may still be satisfied due to cancellation of positive and negative errors. In addition, although measured and modelled boundary elevations were not statistically different when all data were pooled, there were statistically significantly differences between predictions and measurements for three of the five boundary types when boundaries were considered individually. In some cases, these errors in elevation predictions related to relatively large errors in terms of distance parallel to the ground; for example, based on the mean of measured slope, the SVM_{2014} error for the uppermost boundary corresponds to a prediction that the Upland Forest community was approximately 18 m

[4] Water level data for Lower Campbell Lake Reservoir were provided to us from mid-2014 onwards. If earlier water level data for this waterbody can be sourced (e.g., 2001 to 2013), then Year 1 vegetation survey data can be used to validate the application of the SVM to Lower Campbell Lake Reservoir at an earlier stage.

closer to the reservoir (water) than was observed. This error may reflect that an assumption of the model is that communities are in equilibrium with the water level regime yet, in reality, communities may have not yet equilibrated to a regime of lower water levels, particularly in the case of vegetation communities such as Upland Forest that exhibit relatively slow rates of succession.

Evidence of such transition was reflected in field observations; e.g., in areas with lower gradients (i.e., low slope banks), the tall Sitka willow – Water sedge community was often in transition to either a red alder or conifer-dominated upland forest type (Figure 15). The Upland Forest component of the transition areas is presented in the field data as a subdominant community; however, the subdominant community is not considered by the model. Defining the elevation boundary between Upland Forest communities and the tall Sitka willow – Water sedge community also presented a challenge on steep slopes that divided the two communities that were sparsely vegetated or unvegetated. It is therefore possible that, over time, these errors will be reduced as communities become more established, assuming that the current general water level regime remains the same and that the development of these communities is primarily dependent on the water regime. Analysis in Year 10, will occur approximately 25 years after implementation of the WUP, and should allow this hypothesis to be tested for all vegetation communities.

Another important factor to consider is that there were some marked differences between the transect data and the way that the vegetation communities are conceptualized in the model. In the field, vegetation communities sometimes occurred in repeating patterns over undulating ground, or were altogether absent. Only two of the eleven transects had vegetation communities aligned exactly the same way as conceptualized in the SVM. This meant that only 62% of the anticipated 55 elevation measurements (eleven transects × five boundary elevations) were available to use for model validation. This was not unexpected; any model is inherently a simplification of reality that is intended to only encompass the most important aspects of the system under consideration. In general, the representation of communities in the model matched the way that communities were distributed with respect to elevation (Figure 28). Although expected communities were occasionally absent from transects, the sequence of the six communities in the model generally matched the field data. The most common 'missing' boundary in the field data was that between the two lowermost communities (MF/SL), which was likely located below the water's surface during the survey period(s). Two extra communities were detected in two of the Upper Campbell Lake Reservoir transects, one had an occurrence of unvegetated shoreline, and the other Hardhack-Labrador tea. However, the six communities that form the basis of the model were by far the dominant communities present in transects on Upper Campbell Lake Reservoir. Reservoir water levels are typically higher than this boundary during the growing season and most of the year (Figure 22). Relatively high water levels at the time of sampling meant that water levels were often above the elevation at which this boundary was expected to occur (Figure 27, Figure 28). Note that the four validated measurements of this boundary were all underestimates, suggesting that crews were only able to sample instances where this boundary was unusually high. This indicates that this issue is in part related to sampling conditions, and not solely attributable to discrepancy between the model and field conditions. In most years under the WUP, the water level infrequently drops to the historic elevation of the Lake Mudflat/ Spearwort Lakeflat boundary (216.9 m). Finally, it should be noted that all expected boundaries were not present in the 2001 field data (McLennan and Veenstra 2001) (Table 10). In addition, variability between field measurements for individual boundaries is higher in 2014 compared with 2001, suggesting that the elevations of the community boundaries are now less consistent than when the SVM was developed. The reason for this difference is unknown, and a variety of reasons could be hypothesized; these include: challenges with classifying communities in transition; surveyor errors; increased spatial heterogeneity due to more variable soil conditions or other site characteristics; or anthropogenic disturbance (e.g., invasive species, public use).

2. ***If the model is in error, is the magnitude of the error such that it would warrant a change in the predicted outcome of the WUP?***

The SVM_{2014} predictions for the Upper Campbell Lake Reservoir satisfied the two predefined tests of model performance. However, as discussed under Management Question 1, there were some substantial errors between the predicted and measured boundary elevations for individual communities (see Table 12). When extrapolated over the watershed DEM, these errors may result in significant differences in the aerial distribution of each community and therefore may indicate deviations from the predicted outcome of the WUP. The effects of these errors on the predicted outcome will vary depending both on the magnitude of the error and the specific boundary type. However, a visual analysis of the differences between mean Year 1 measured vegetation community bands and predicted bands indicates that the difference between modelled and predicted elevations, and Year 1 and 2001 measured bands may suggest that any error may be positive or benign to wildlife in general.

This question will be fully addressed in Year 10 for the Upper Campbell Lake Reservoir, allowing vegetation communities more time to transition into established communities. In addition, data for the other two waterbodies will be available in Year 10 to validate the model.

3. ***Are there changes to the modelling approach that could improve its accuracy for implementation in future WUP reviews?***

The magnitude of model error for the Upper Campbell Lake Reservoir varied between the five boundary types (Figure 29, Table 11). This suggests that different communities vary in their sensitivity to the way that inundation is represented in the model, i.e., the SVM assumes that each community has varying sensitivity to the frequency of inundation, but the duration over which the frequencies are calculated is the same for each community (i.e., 2001 to 2013 for SVM_{2014} predictions). Therefore, the SVM_{2014} assumes that all communities sampled in Year 1 were equally sensitive to water level fluctuations that occurred in 2002 (for example), as they were to fluctuations that occurred in 2013. Likewise, the SVM assumes that communities are equally sensitive to inundation during the growing season, as to inundation during winter (see Section 1.5.1 for further details on model assumptions). These assumptions are inconsistent with studies of the effects of shoreline inundation elsewhere which show that vegetation communities display varying sensitivity to inundation depending on how recently it occurs (e.g., Nilsson and Keddy 1988, Riis and Hawes 2002), and the time of the year at which it occurs (e.g., Eck *et al.* 2006).

Thus, a successful way to improve model performance is likely to involve optimizing the model to reflect differences in temporal (i.e. between-year and within-year) dependence on water level history between community types, e.g., add further complexity to reflect the fact that some communities are more dependent on recent water level fluctuations than others. However, given the somewhat satisfactory model performance results for Year 1, and the advantages of adopting a parsimonious modelling approach, we recommend that validation during Year 10 should firstly be undertaken to establish whether model performance is acceptable before further model development is pursued. Should further model development be required, it is advantageous to have data available that were collected at several times throughout the water level record. However, although the current program is designed to collect data for a reasonably large number of transects at each waterbody, data will only be available a limited number of times, i.e., three times for Upper Campbell Lake Reservoir (2001, 2014 and 2023) and twice for the other two waterbodies (2014 and 2023).

4. ***Is it reasonable to expect that most riparian plant ecosystems require shoreline slopes to have a gradient less than 15% to perpetuate?***

On Upper Campbell Reservoir riparian plant ecosystems require shoreline slopes to have a gradient less than approximately 15% to perpetuate. More data will need to be collected and analysis conducted to determine the slopes on which vegetation is likely to occur on Lower Campbell and Brewster Lakes. In addition, the slope tolerances for different vegetation communities differ and more precise and accurate analysis of the areal extent of each community could be conducted if the maximum slope on which each of these communities occurs was determined. Conclusions for the two analysis methods (field transect data and GIS data) are discussed. The distribution of vegetated and unvegetated areas (GIS polygons) was only dependent on whether slope is greater or less than 15% for the Upper Campbell Lake Reservoir. For the Upper Campbell Lake Reservoir, there is a statistically significant difference between the slope of unvegetated (21.0%) and vegetated shoreline vegetation communities (9.3%), when grouped together (as vegetated areas), or independently (by vegetation community type) (Figure 33, Figure 34, Table 14). In contrast, data from Lower Campbell Lake Reservoir and Brewster Lake demonstrated only weak and inconclusive relationships between the gradients of unvegetated and vegetated polygons.

Scatterplots of transect data show a statistically significant negative relationship between slope and percent vegetation cover for Upper Campbell Lake Reservoir (Figure 30). On the Lower Campbell Lake Reservoir and Brewster Lake, there is no statistically significant relationship; however, vegetation was only detected on slopes up to 27% on Lower Campbell (Figure 31), and 35% (most under 15%) on Brewster Lake (Figure 32). This is likely due to the low resolution, and sometimes inaccurate data used to create the DEM's for these two waterbodies.

The field data was limited in that it only included slopes for areas that were selected for transects which corresponded to areas with the most extensive shoreline communities. If it is determined that the field data method is the most reliable method of testing slope assumptions, in Year 10, additional slope and percent vegetation cover data should be collected on a wider range of slopes that correspond with the elevations of the various vegetation communities. Additional data would assist with further and more detailed analysis. This data, especially for Lower Campbell Lake Reservoir and Brewster Lake, may be necessary to determine the optimal slope to apply with the model.

5. ***Has the distribution of riparian plant ecosystems changed following implementation of the WUP and if so, can the change be attributed to the WUP operation?***

The distribution of riparian plant ecosystems has changed on the Upper Campbell Reservoir following implementation of the WUP. This change will be described and associated to WUP operations in more detail in Year 10. Nevertheless, initial results from Year 1 show differences in the community boundaries measured in 2001 and in Year 1. Firstly, there has been a general shift downwards in the elevations of the vegetation community boundaries (Figure 28), consistent with the generally lower water levels since 2001 (Figure 24). Secondly, there is evidence that the elevations of individual community boundaries are now less consistent compared with the 2001 surveys (Table 10).

4.2. Hypotheses

The three JHTMON-10 study hypotheses will be addressed in Year 10. Nevertheless, the interim responses to the management questions presented above provide preliminary results for the three null hypotheses.

5. RECOMMENDATIONS

. Recommendations have been made based on Year 1 data collection and analysis to improve the study and ultimately the ability to adequately address the management questions and hypotheses set out in the terms of reference for the monitoring program (BC Hydro 2013). These recommendations are numbered, under each study component/methodological approach, to facilitate discussion and future tracking.

5.1. Literature Review

1. Conduct review of current literature pertaining to the relationship between vegetation and reservoirs and slope of occurrence, including current monitoring reports from BC Hydro reservoir vegetation monitoring projects.

5.2. Data Collection

5.2.1. Vegetation Community

1. Conduct transects with a laser survey level (or instrument with similar capacity) instead of an optical level for ease of data collection and to increase accuracy and decrease risk of human

measurement error. In addition, extensive trimming of vegetation will be necessary to improve the feasibility of long transects through dense riparian vegetation.

2. Ensure that transects extend up to the Upland Forest community or to the upper elevation boundary considered in the model (222 m in SVM_{2014}). This would increase sampling effort (i.e. some transects would need to be extended) but it would improve representation of the uppermost boundary (i.e., WSt/UF).

3. Make efforts to survey to the lowest elevation boundary (i.e., MFl/SL), even if it is below the water surface, when feasible. Generating SVM predictions prior to sampling will assist with estimation of the elevation at which this boundary occurs.

4. Plan transect surveys to be conducted when water levels are at a minimum (while vegetation is easily identifiable) to maximize the opportunity to collect measurements at low elevations. Year 1 surveys were aimed to occur after receiving air photographs captured in 2014, and while water elevations were predicted to be lowest during the growing season, to provide optimal context and sampling conditions. Due to logistical constraints and changing hydrological conditions, adaptive changes were made to the fieldwork program at short notice, and although some surveys corresponded with low water levels, others did not. Nonetheless, water levels were too high to capture the lowermost boundary in the model for most transects (MF/SL).

5. Repeat transect surveys, in Year 10, at the same locations as Year 1 (on all waterbodies), with further transect locations added if resources allow and if deemed necessary to increase confidence and statistical significance in the elevations of specific communities. Year 1 transect surveys attempted to replicate 2001 surveys in Upper Campbell Lake Reservoir. However, none of the original benchmarks were located. In Year 1, benchmarks were typically installed in trees due to the lack of permanent features such as bedrock. As such, surveyors should be prepared to reinstall benchmarks, if necessary.

6. Collect additional slope and percent vegetation cover data, especially for slopes close to and above 15%, and for those communities with less data, to further test $H_0 2$ and determine the optimum slope (if any) to define as a threshold above which land is un-vegetated (see Management Question 4, Section 4).

5.2.2. Air Photo Interpretation

1. Ensure that the scope, detail and extent of air photo interpretation are similar to that completed in Year 1 so that results are comparable. In Year 1, air photo interpretation was done at a finer scale, and consequently higher level of detail, than for the 2001 baseline. If the SVM fails to provide reliable results, air photo interpretation will most likely be used as the primary method of assessing vegetation response to the WUP, thus thorough mapping will be necessary.

5.3. Data Analysis

5.3.1. SVM Validation

1. Analyze individual waterbodies to compare differences in boundary elevations both between *individual* transects (using repeated measures tests) and between *all* transects (using pooled data for each waterbody). The model assumes that shifts in boundary elevations with time should be the same both within one transect and among all transects; this analysis would test this assumption and provide insight into the extent of inter-site variations, and therefore the extent to which it is reasonable to assume that boundary elevations should be the same throughout each waterbody.

2. Compare, in Year 10, the SVM with hydrology data input up to the previous year to results when hydrology data includes the current year up to the time of sampling. In Year 1, similar to 2001, hydrology data from the year that ground measurements were taken were not integrated into the model. This may have been done because there was not a complete year of data, and because the model does not consider the temporal nature of flooding, solely the cumulative amount of time the communities have been inundated. However, the distribution of vegetation measured in the current year is likely influenced by water levels occurring that year, particularly in the growing season (Eck *et al.* 2006). Comparing the two methods of hydrology data input would indicate if additional data provides more accurate results.

3. Determine whether characteristics of vegetation communities of small lakes (which host a different association of vegetation communities from large lakes) have similar hydrological requirements to those found in similar equivalent relative elevation bands on large lakes, and therefore can be substituted into the model (e.g., Sedge Wetland replaces Hairgrass – Water sedge, or Hardhack – Labrador tea replaces Sitka willow – Water sedge). If small lake vegetation communities do not reasonably align with those of large lakes, the model that was developed for Upper Campbell Lake Reservoir will not be able to be applied to Lower Campbell Lake Reservoir and Brewster Lake. In contrast, the model will need to be parameterized for Lower Campbell Lake Reservoir and Brewster Lake and validated in future years, if it is to be applied.

4. Collect additional data in intermediate years to strengthen the dataset and increase the potential for more rigorous analysis. The current JHTMON-10 study design will result in vegetation community data being compiled for three years for Upper Campbell Lake and Buttle Lake reservoirs (2001, 2014 and 2027) and only two years for Lower Campbell Lake reservoir and Brewster Lake (2014 and 2027). This will result in data for a small number of time periods for future validation of the SVM, or to use for any future model development. Repeating the vegetation surveys more frequently would provide further insight into model error, which in turn would assist in developing of a more robust model. For example, surveys could be repeated in Year 5, with the additional data analysis and validation undertaken during the analysis scheduled for Year 10. This would also help to examine

whether varying rates of succession between communities is a potential confounding factor, i.e., if the water level regime remains similar for the next five years, then a reduction in model error in Year 5 may indicate that communities are still equilibrating to the adjusted water level regime.

5.3.2. Vegetation Community Gradient

1. Complete additional statistics on vegetation transect data to determine the optimal slope to apply to the model, as current data analysis presents differing results for the Upper Campbell Lake Reservoir, Lower Campbell Lake Reservoir or Brewster Lake Reservoir.

2. Complete additional statistics on GIS data to determine an appropriate break point to indicate the optimal slope to apply to the model. Methods recommended in the TOR (a.k.a 2x2 contingency table) render an analysis of the 15% theory but do not lead to selection of a more appropriate slope. Addition analysis should be done both for individual waterbodies and for all waterbodies combined. Consequently, more slopes need to be recorded over a wider range of gradients to have more confidence in a potential break point slope at which vegetation can reasonably be assumed not to occur.

3. Increase the sample size of unvegetated polygons to provide more insight into the relationship between slope and vegetation cover. Relatively few unvegetated polygons were delineated in Lower Campbell Lake Reservoir (5% of polygons and 5% of area). Delineation of additional un-vegetated polygons in Brewster Lake would also improve the utility of the dataset.

4. Collect detailed elevation data for Brewster Lake and Lower Campbell Lake Reservoir to gain a more precise estimate of the extent of riparian communities along these waterbodies. The DEM for Brewster Lake was based on 1:20,000 TRIM data only (ends at lake surface), and the DEM for Lower Campbell Lake Reservoir on old (~1950) bathymetry data and low resolution elevation data. Additionally, the Brewster Lake DEM does not align with the 2014 orthorectified air photos, so many vegetation community polygons occur under water (represented by the water's surface). More accurate and high resolution DEM's, especially for Brewster Lake, will be needed in order to reliably calculate the areal extent of riparian communities on Brewster Lake. This could be done by collecting LIDAR data during the same overflight on which air photos are captured.

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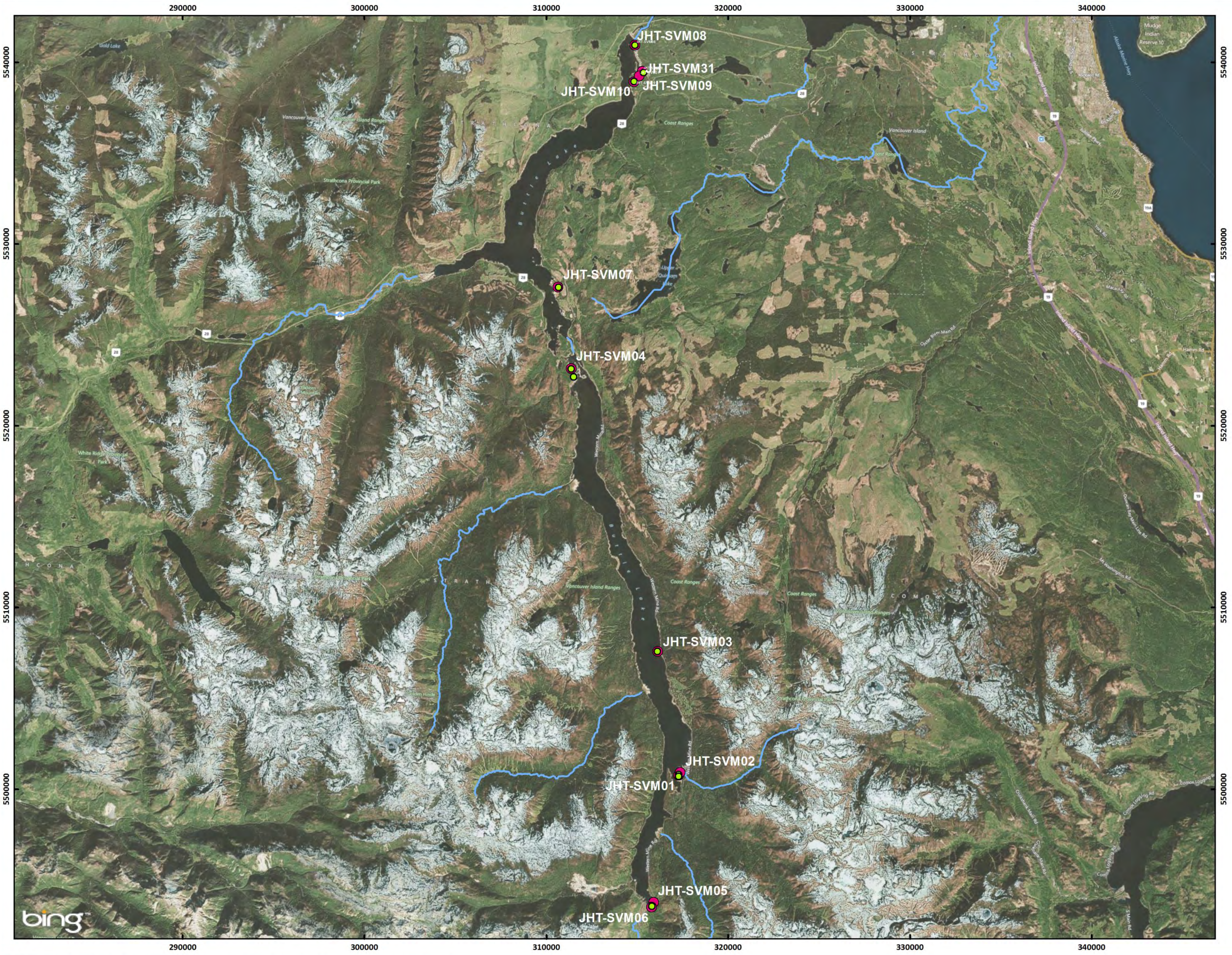
PROJECT MAPS



JHTMON Campbell River Water Use Plan

Upper Campbell and Buttle Lake Vegetation Transect Locations

Legend

- 2014 Vegetation Transects
- 2001 Vegetation Transects
- Streams

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

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ECOFISH RESEARCH

Map 2

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JHTMON Campbell River Water Use Plan

Lower Campbell Lake
Vegetation Transect Locations

Legend

- 2014 Vegetation Transects
- 2001 Vegetation Transects
- Streams

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

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Map 3

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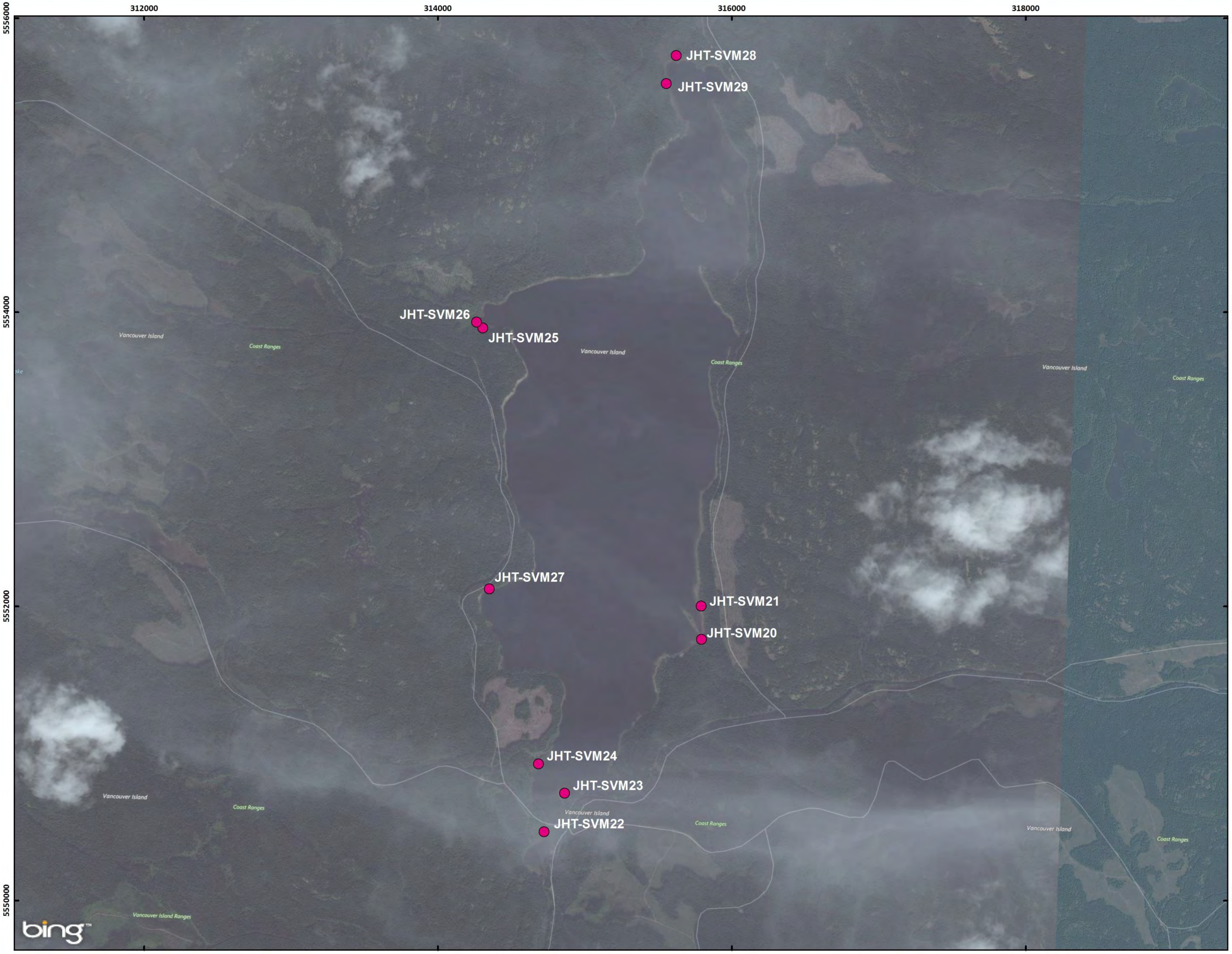
JHTMON Campbell River Water Use Plan

Brewster Lake
Vegetation Transect Locations



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● 2014 Vegetation Transects

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Map 4

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