Campbell River Project Water Use Plan

Monitoring Program Terms of Reference

- **JHTMON-4 Upper and Lower Campbell Lake Reservoirs Littoral Productivity Assessment**

Revision 1
December 31, 2015

JHTMON-4 Upper and Lower Campbell Lake Reservoirs Littoral Productivity Assessment Monitoring Program

REVISION RATIONALE

The original Terms of Reference (TOR) developed for JHTMON-4 described a metric called the effective littoral zone (ELZ) that was defined as a function of rate of periphytic algae accrual within a range of depths relative to a top water surface elevation measured in the littoral zone. A thorough review of the ELZ metric revealed some weaknesses with respect to its effectiveness for answering the management questions in the TOR.

A challenge with ELZ, as it is defined in the TOR, is that it does not quantitatively consider environmental factors other than light that are known to modify periphyton accrual over water depths spanning a littoral zone. In the ELZ metric, algal physiological responses to environmental conditions (i.e., algal colonization and growth rate) are lumped in with one growth-limiting factor (light). While light is sufficient to support photosynthesis, production of algae may be limited by nutrient supply (Biggs 2000, Bothwell 1989, Guildford and Hecky 2000, Wetzel 2001) or temperature (Bothwell 1988, Goldman and Carpenter 1974) within available habitat that is influenced by fluctuating reservoir elevations. In the original TOR considerations for these key habitat attributes were not included with the measurement of algal accrual.

Further, the ELZ concept assumes a link between algal accrual and fish production in the littoral zone of the Upper Campbell Lake and Buttle Lake Reservoir (Upper Reservoir) and Campbell Lake Reservoir (Lower Reservoir); however, the link between algal accrual and fish production in reservoir conditions has not been well documented in scientific literature (Chris Perrin pers comm). There are few studies showing direct links between littoral periphyton production and littoral fish productivity in natural lakes systems, for example Hecky and Hesslein (1995). However, there are no reliable studies directly linking periphytic accruals with fish productivity in reservoir conditions (Chris Perrin pers comm).

In contrast there is well known evidence of fish feeding on invertebrates of different origin (e.g., Mehner *et al.* 2005, Perrin *et al.* 2006, Vadeboncoeur *et al.* 2002, Weidel *et al.* 2008) and of littoral invertebrates feeding on detrital matter of different aquatic and terrestrial origins (France 1995, Solomon *et al.* 2008). Part of the challenge in quantifying links between algae and fish is that valued fish species using littoral habitat are commonly opportunistic in their foraging behaviour, targeting invertebrates produced from many sources. This behavior is particularly true in rainbow trout and cutthroat trout (Perrin *et al.* 2006), which are the two most abundant fish species in the Upper Reservoir and the Lower Reservoir (Hocking *et al.* 2015). Hence, there may be some disconnect between the production of algae and benthic invertebrates within a littoral zone and fish use of that habitat in the Upper Reservoir and the Lower Reservoir that cannot be addressed with the ELZ model as it is defined in the current TOR.

In order to address these methodological gaps we propose to include:

- Data collection on seasonal nutrient concentrations – designed to assess the role of nutrient concentration in algal growth;
- Data collection on seasonal depth-specific temperature – designed to assess the role of depth-specific temperature in modifying algal growth;
- Data collection on seasonal fish stomach contents – designed to assess fish diet composition to assess food source;
- Stable isotope analysis (SIA) – designed to trace diet source (littoral vs terrestrial) through carbon and nitrogen isotopes;
- Bathymetric survey – designed to create a digital elevation model to calculate the areas of periphyton accrual as a function of water elevation and used in GIS models to simulate algal production as a function of water elevation and;
- Implement the study over two years of field data collection followed by data analysis period – designed to collect a comprehensive and larger dataset incorporating key habitat attributes known to modify algal growth. In conjunction with the bathymetric digital elevation model, algal production will be simulated for different water elevations.

Year 1 of JHTMON-4 was used as a pilot study to assess the efficacy and utility of some of methods identified above. Results from the pilot year indicated that the changes proposed above are effective and would provide an adequate dataset for answering the management questions. The changes involve an increase in the scope of data collection but a reduction in the number of years of study to two years including a data analysis period. Although there is an overall reduction in years of study, the monitor gains a more comprehensive and larger dataset by including a broader spectrum of habitat attributes and stable isotope analysis. This additional dataset allows for modelling of responses in productivity in the littoral zone of the reservoirs by allowing explicit consideration for key additional habitat attributes and allowing for evaluation of connectivity between littoral productivity and fish production through analysis of stable isotope across the food webs of each reservoir. This will provide a much stronger and thorough analysis and in turn have better success in answering the management questions.

The proposed changes in approach are as summarized in the table 1 below.

Table 1: Key changes to the JHTMON-4 TOR and rationale for their inclusion

Section	Change	Rationale
Overall	• Study scope expanded to include nutrient concentration, temperature, fish stomach content measurements and stable isotope analysis • Added bathymetric survey • ELZ model modified to include key habitat attributes (nutrient and depth-specific temperature profile) • Study period adjusted to 2 years of field data collection followed by data analysis	• Improve effectiveness of the study design to answer the management questions • This additional dataset allows for modelling of responses in productivity in the littoral zone of the reservoirs by allowing explicit consideration for key additional habitat attributes and allowing for evaluation of connectivity between littoral productivity and fish production through analysis of stable isotope across the food webs of each reservoir.
2.1 Objective and scope	• Study period changed to 2 years followed by data analysis	• Align with reduced study period
2.2 Approaches	• ELZ model modified as a multiple regression model to include key habitat attributes such as temperature and nutrient concentration. • Minor text changes to include nutrient concentration and temperature profiles in ELZ estimations	• Improve predictive power of the ELZ metric
2.3.1.2 Periphyton production	• Acrylic plates for periphyton accrual measurement removed • Polystyrene balls added	• Polystyrene balls do not involve scraping or processing data in the field providing better accuracy in periphyton accrual measurements
2.3.1.3 ELZ model	• Minor text change to include regression based ELZ modification • Removed BC Hydro’s responsibility to update the ELZ and added contractor as responsible party for updating ELZ model	• ELZ model improved by including additional variables driving primary productivity in littoral zone • New model updating should be done by contractor as the original course BCH ELZ model is deemed effective
2.3.1.4 Test of littoral productivity following WUP implementation	• Minor text change made to remove BC Hydro’s responsibility for assessing the “before” and “after” WUP scenario analysis • Contractor added as responsible party	• Contractor will build the modified model and the before and after WUP scenario analysis will be done by the contractor who built the model

Section	Change	Rationale
2.3.1.5 link to reservoir fish production	• Stable isotope analysis to link primary-secondary and fish production added • Fish stomach content analysis added • Correlation analysis to infer relationship between periphyton production and fish production kept as supplemental analysis	• In the original methods, the direct link between primary productivity and fish production was weak. Stable isotope approach provides better insight into link between fish and its food source
2.3.1.6 Nutrient concentration	• Nutrient data added as a new component	• Nutrient concentration plays key role in periphyton accrual processes and its inclusion improves the predictive capacity of the modified ELZ model
2.3.1.7 Bathymetric survey	• Bathymetric survey added as a new component	• Bathymetric digital elevation data is needed to improve assessment of extent of periphyton accrual (area) at different reservoir elevations
2.3.3.2 Periphyton Production	• Modified multiple regression based ELZ equation included • Old ELZ equation replaced	• Modified multiple regression equation captures additional key habitat attributes such as nutrient concentration improving predictive capacity of the model
2.3.3.3 ELZ model adjustment	• Reference to old ELZ model removed • Text referring to the improved multiple regression based approach included.	• Modified multiple regression model better captures important habitat attributes driving primary production in the littoral zone. Provides a model with better predictive capacity
2.3.3.4 Test of Littoral Productivity Changes Following WUP Implementation	• Minor text change made to remove BC Hydro’s responsibility for assessing the “before” and “after” WUP scenario analysis • Contractor added as responsible party	• The contractor will build the modified model and the before and after WUP scenario analysis is better done by the contractor
2.3.3.5 Link to reservoir fish productivity	• Stable Isotope analysis added • Stomach content added • Multiple line of evidence and ecological story approach added	• Provide direct evidence of linkage between algae accrual and fish production • Provides for broad ecological approach to assess what support fish production in littoral zone
2.3.3.6 Stable isotope analysis	• Stable isotope data analysis method added	• Improves analysis of link between periphyton production and fish production

Section	Change	Rationale
2.3.4 Reporting	• Reporting timeline changed	• Align reporting timelines with adjusted study period
2.5 Schedules	• New schedule with 2 years of field data collection period added	• Revised schedule needed
2.6 Budget	• Minor text changes	• To confirm no additional costs are incurred

JHTMON-4 Upper and Lower Campbell Lake Reservoirs Littoral Productivity Assessment Monitoring Program Terms of Reference

1 Program Rationale

1.1 Background

Large water level fluctuations generally cause a decline in littoral productivity. This concept is captured in the Effective Littoral Zone (ELZ) performance measure (PM) for reservoirs. However, the ELZ concept itself rests on several untested assumptions (e.g., relationship of soil accumulation to productivity, targeting of macrophytes as the best indicator of littoral production), and most of the biological parameters used in the model (e.g., colonization rates, desiccation rates, species-specific responses to drawdown history, etc.) are estimates based on limited data, often from different reservoirs (Anon. 2004). The extent to which management of reservoir water levels affects littoral productivity is therefore uncertain. This question can be addressed through field measurements of primary and secondary benthic productivity in relation to reservoir water levels. Results from this study will be combined with those from the stable isotope studies (see Monitor 5, “Energy Flows to Fish”) and fish abundance indicators (see Monitor 3, “Fish Population Response to Reservoir Spawning Habitat”) to describe how operations affect littoral productivity and how this productivity ultimately influences fish production.

1.2 Management Questions

The ELZ performance measure used during the WUP process crudely predicts the upper and lower elevation boundaries of primary productivity in the littoral zone based on water level and average depth of the euphotic zone (Anon. 2004). The reliability of the performance measure is unknown, as it has yet to be tested in the field. Thus, one of the key management questions is:

1) Does the ELZ performance measure adequately estimate the change in littoral productivity due to changes in reservoir operation, particularly in relation to changes implemented with the Campbell River WUP and potential future changes?

Several factors could affect the utility and reliability of the ELZ performance measure. These include the rate of colonization of newly inundated habitat, the intensity of photosynthetically active radiation (PAR) as a function of water depth, the rate of primary production as a function of PAR intensity, the survival of primary producers at PAR levels less than 1% of surface values, and survival of primary producers following a dewatering event. Uncertainties in these parameters lead to a second management question:

2) To what extent does colonization rate, PAR penetration, growth rate and survival rate impact the utility and reliability of the ELZ performance measure for WUP decision-making purposes?

At the time of the WUP process, ELZ calculations assumed that colonization was instantaneous, growth was constant regardless of PAR intensity above 1% surface values, and survival was one day regardless of whether it was due to desiccation or low PAR levels. PAR penetration was estimated from Secchi disk measurements. By better incorporating these parameters into the ELZ measure, a more accurate and reliable model is expected.

The ELZ performance measure predicted a 15% increase in littoral productivity following implementation of the Campbell River WUP. Because of the uncertainty in the performance measure, it is unknown whether the predicted increase will be fully realized. This leads to the management question:

3) Following implementation of the Campbell River WUP, does littoral productivity increase as predicted by the ELZ performance measure?

In addition to validating the ELZ model, there is a critical need to understand the link between littoral productivity and fish productivity. One of the fundamental objectives of the WUP was to increase abundance and diversity of native fish in the reservoirs. To this end, it was assumed that increases in littoral productivity would translate directly into increases in fish abundance in the reservoirs. Testing of this assumption is of significant interest for those wishing to assess the efficacy of WUP-related decisions, and will help hone decisions in future reviews of the WUP. The final management question is thus:

4) How does littoral productivity translate into fish production in Campbell River reservoirs?

1.3 Summary of Impact Hypothesis

This Monitor tests four key impact hypotheses, each relating to the management questions above. Direct measurement of total littoral production is difficult and costly, so studies and hypothesis testing will be carried out on measures of periphyton growth. The Campbell River WUP Fish Technical Committee agreed that periphyton growth/production would be a reasonable indicator of littoral productivity as it is the primary pathway by which energy enters the littoral food web.

The first hypothesis tested in the Monitor relates to the validation of the ELZ model as it was used in the WUP process and addresses Management Question 1.

$H_0$1: Upper and lower elevation boundaries of littoral zone periphyton production in Upper Campbell Lake and Buttle Lake Reservoir (Upper Reservoir) do not correlate with ELZ model predictions.

The test of this hypothesis will rely on annual estimates of periphyton production boundaries from data collected throughout the periphyton-growing season (March to October). Although framed here as a testable null hypothesis, the results from this study are more likely to be used in refining the ELZ model, rather than rejecting it outright. Results from a similar study in Stave reservoir suggest that production boundaries may be too crude a measure to detect differences among operational strategies. This is largely the result of the shape of the production curve as a function of water depth. A better approach may be to compare production estimates integrated over the depth of the euphotic zone. To do this requires a more accurate ELZ model that incorporates differential periphyton growth rates as a function of water depth (i.e., intensity of PAR), as well as periphyton survival data in darkness (when PAR is less than ~1% of surface values) and when substrates are dewatered. Also important is the rate of colonization of newly inundated substrate. Because these parameters tend to be reservoir-, species-, and community-specific, they will have to be estimated from data collected *in situ*. Thus, a key component of the

Monitor will be to carry out the studies necessary to develop the values/relationships that characterize these aspects of periphyton growth and survival.

With these data, the ELZ model can be modified as necessary to estimate total periphyton production by integrating production values as a function of water depth. Validation of the modified ELZ model can be carried out by comparing modelled depth integrated periphyton production estimates with field observations. This comparison leads to a second null hypothesis, which relates to Management Question 2.

$H_0$2: There is no significant correlation between the modified ELZ model (which includes depth-integrated periphyton production estimates based on differential growth and survival information) and empirically measured values from the field.

The third null hypothesis is a direct test of whether littoral productivity has increased as expected following implementation of the WUP.

$H_0$3: Primary production in the littoral zone of the Upper Reservoir does not increase following implementation of the Campbell River WUP.

The test of $H_0$3 will be carried out on predictions from the 'modified' ELZ model (i.e., depth-integrated periphyton production estimates). There are no pre-WUP measurements for comparison and changes in periphyton production are expected to be rapid, which would make among-year trend analysis invalid. The analysis will therefore rely on modelled estimates of before and after WUP implementation. Data will consist of results from the 'modified' ELZ model and compare output of the model from observed reservoir elevation data collected prior to the implementation of the WUP, and after implementation of the WUP. The difference between the two treatment periods will be assessed relative to estimates of maximum production using a measure of depth integrated periphyton production in a stable water level environment (derived by suspending periphyton growth substrata from the reservoir surface)

To determine whether changes in littoral productivity are related to fish production in the reservoirs, a correlation test between these two parameters is necessary. We will use two estimates of littoral productivity, direct estimates of periphyton growth and predictions from the ELZ model (modified as necessary based on results from this Monitor). The Monitor will test the following null hypothesis based on fish abundance estimates obtained from Monitor 3. The test will be performed separately for rainbow and cutthroat trout in both the Upper Reservoir and Campbell Lake Reservoir (Lower Reservoir).

$H_0$4: Following implementation of the Campbell River WUP abundance of adult trout is not correlated with littoral productivity during the cohort's first year.

Because rainbow and cutthroat trout are repeat spawners (iteroparous), the test of $H_0$4 will have to be carried out separately for each age class above the age at recruitment to the adult stage t_r. If possible, site-specific age-at-recruitment values will be determined for each trout species.

1.4 Key Water Use Decision

During development of the Campbell River WUP, evaluation of reservoir operations relied heavily on the ELZ PM, yet many of the parameter estimates were based on sparse local data, or data from other locations. Validation of the ELZ will allow more accurate calculations of littoral zone productivity in response to operational changes in the reservoirs, and increased confidence in the application of results. When accompanied with other monitoring studies, this Monitor will help us understand how reservoir operations affect the abundance and diversity of reservoir fish stocks.

The WUP operating regime is expected to increase littoral habitat suitable for primary production in the Upper Reservoir by 15% relative to pre-WUP conditions, and hence is expected to have an impact on estimates of primary production. Results of the Monitor will determine whether the predicted increase is realized and if not, shed light on the reasons why. The investigation will in turn improve evaluation of alternative reservoir operations during future WUP processes.

2 Program Proposal

2.1 Objective and Scope

The objective of this Monitor is to address the management questions presented in Section 1.2 by collecting data necessary to test the impact hypotheses outlined in Section 1.3. The following aspects define the scope of the study:

1) The study area will consist of selected littoral areas in the Upper Reservoir and the Lower Reservoir.
2) The Monitor will be carried out annually for two years followed by data analysis.
3) Sampling will be carried out in a standardized manner and follow a specified schedule to ensure consistency among years in data quality and collection procedures.
4) A data report will be prepared annually, summarizing the year's findings. All data will be archived according to BC Hydro protocols.
5) A summary report will be prepared annually during the study period summarizing the data collected to date, discussing inferences and presenting preliminary conclusions.
6) A final report will be prepared at the end of the Monitor that summarizes the results of the entire Monitor, discusses inferences that can be drawn pertaining to the impacts of the WUP over time, and presents conclusions concerning the impact hypotheses and the management question in Section 1.2.

2.2 Approach

This Monitor has eight components: monitoring of water characteristics, direct measurements of periphyton production, adjustment to ELZ model, test of changes in primary production following WUP implementation, and tests of the link between littoral productivity and reservoir fish abundance. This TOR provides a description of the studies as they are presently conceived, but contractors are encouraged to suggest improvements, provided there is a good rationale for doing so.

1) **Light Intensity:** Photosynthetic rate is ultimately related to availability of solar radiation, in particular the PAR component of the spectrum, which is attenuated with depth. Optical properties of water in the Upper Reservoir will be measured by tracking PAR and water temperature through time. However, 'biofouling' of sensors is a constant problem when measuring light intensity through time. As a result, the time trend of PAR will have to be derived indirectly using a

combination of continuous surface light intensity measurements and spot PAR measurements taken at depth.

2) **Periphyton production:** Littoral productivity will be measured as seasonal rate of periphyton accrual as a function of PAR, nutrients and temperature.

3) **ELZ Model Adjustments:** The ELZ model will be modified as a regression model taking into consideration important habitat attributes such as temperature, nutrient concentration and PAR measurements that are well known to affect algal accrual.

4) **Test of Littoral Productivity Changes Following WUP Implementation:** The modified regression model and digital elevation model will be used to assess productivity before and after WUP implementation using historical water elevation data. Impacts of reservoir operation on fish production in the littoral zone will be assessed in a series of steps to establish effect-pathway as follows:

   a) Link important habitat factor(s) to variations in algal accruals using a regression model.

   b) Link predictors of algal accrual to variations in predictors caused by change in water surface elevation due to reservoir management.

   c) Explore effects of WUP operations on algal accrual using the regression equation and multiple lines of evidence to tell an ecological story that shows implications of reservoir operations on fish production in the littoral zone.

5) **Link to Reservoir Fish Production**: Link to reservoir fish production will be assessed using fish **stomach** content data and stable isotope analysis to model isotopic signatures between periphyton and benthic invertebrates and between benthic invertebrates and fish. This will allow for examination of the relative importance of periphyton contributing to fish using littoral habitat in the Upper Reservoir and the Lower Reservoir. Supplemental analysis will be done using fish abundance data from JHTMON-3 to evaluate correlation between fish abundance and algal production in the Upper Reservoir and the Lower Reservoir.

6) **Nutrient Concentration**: Nutrient concentrations (N and P) will be measured at the beginning and end of the periphyton accrual series.

7) **Stable Isotope**: Stable isotopes of nitrogen and carbon will be measured in samples from fish, benthos, zooplankton, and terrestrial insects. This task will be coordinated with JHTMON-5 program that collects the same data to assess the relative importance of fish energy sources between littoral and pelagic areas. Additional periphyton and benthic invertebrate samples might be collected for stable isotope analysis to complement data from fish and invertebrate data being collected as part of JHTMON-5. Isotopic signatures can then be modelled between periphyton and benthic invertebrates and between benthic invertebrates and fish to examine the relative importance of periphyton contributing to fish using littoral habitat in the Upper Reservoir and the Lower Reservoir.

8) **Bathymetric surveys:** Bathymetric surveys will be conducted to develop a digital elevation model (DEM) to calculate area of periphyton accrual under different water elevations.

2.3 Methods

2.3.1 Data Capture

2.3.1.1 Light Intensity

This study component will require establishing water quality monitoring stations in the Upper Reservoir next to each array of periphyton growth media. Each station will be setup to measure and log, on a continuous basis, light intensity (ideally PAR) at the surface. The purpose of these measurements is to track between-site and day-to-day variability in PAR intensity through time, and therefore obtain a measure of available light for periphyton growth through time.

In addition to the continuous surface measurements, spot measurements at known depths will be taken on a regular basis in order to track the water's light attenuation coefficient through time. The measurements should be taken at the same location as the surface light intensity measurements, and should be taken at intervals suitable to calculate the attenuation statistic accurately (to be determined by the contractor given prevailing field conditions). At a minimum, the light attenuation coefficient for PAR will be measured each time the periphyton growth media are sampled. The more frequent that the light attenuation coefficient is measured the greater the resolution of the time trend, thus such measurements should be taken whenever the opportunity presents itself. By combining the light attenuation data with the surface PAR measurements, depth profiles of PAR intensity can be derived for use in the Monitor that tracks available light for periphyton growth through time and at different depths.

The light measurements made here will require specialized equipment to measure intensity at specific bandwidths of the spectrum. At a minimum, the equipment should be able to measure light in the PAR spectrum. Measurements in the ultraviolet range may also be useful as light in this spectrum is known to inhibit periphyton growth, and can prove to be an important factor in ELZ model refinement.

In addition to light intensity, water temperature data will also be collected to track the depth of the thermocline as it develops and later breaks down through the seasons. A strong thermocline effectively separates the warmer surface layers of water column from the bottom, which could have an impact on the colonization and growth of periphyton on the deeper experimental media. The temperature profile data will be collected using temperature data loggers attached to each of the growth media on the vertical array.

All equipment will be regularly maintained and calibrated to ensure accurate measurement and proper functioning (e.g., no biofouling) and that data are regularly downloaded (ideally at the same time the periphyton growth media are sampled). This monitoring will be conducted over the duration of the WUP implementation period.

2.3.1.2 Periphyton Production

Periphyton production will be measured as chlorophyll *a* accrual using polystyrene balls as growth media deployed over vertical arrays spanning the depth of the littoral zones of the Upper Reservoir and the Lower Reservoir. The main advantage of using polystyrene balls over the traditional acrylic plates is that polystyrene balls do not involve scraping or processing data in the field providing better quality data. Balls will be oriented vertically through use of a weight on one side and attached flotation on the other (Figure 1).

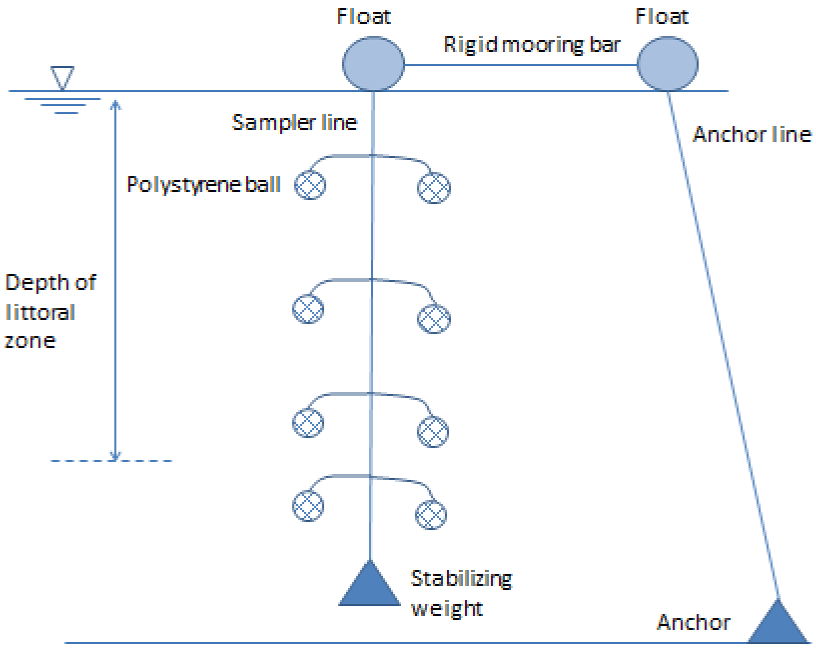

Fig 1. Potential design for periphyton accrual polystyrene balls

Periphyton accrual will be measured four times/year from clean substrata, one sampling series in each season for two years. This will result in 192 observations (4 series x 6 depths x 4 stations x 2 years). Periphyton accrual in the littoral zone will be done over extremes of fall (low temperature, low PAR) and summer (high temperature, high PAR).

Periphyton samples must be kept cool and dark prior to analysis in a certified laboratory, where they should be immediately analyzed for chlorophyll *a*, the measure of periphyton biomass from which productivity will be estimated. Periphyton collected will be extracted and analyzed using protocols for fluorometric analysis published in Standard Methods (APHA et al. 1992). The chlorophyll *a* will be expressed as $\mu g/cm^2$ followed by dividing by the number of days in the sample period to obtain a measure of daily periphyton accrual. The final measure will be to express the periphyton in terms of mass of organic matter per unit area per day ($\mu g^{-1} \cdot cm^{-2} \cdot day^{-1}$). The carbon component of the accrual data will be calculated as 45% of the sample organic matter (Stockner and Armstrong, 1971).

2.3.1.3 ELZ Model Adjustments

The regression based ELZ model will be updated by the contractor, based on data and analysis provided in different monitoring components.

2.3.1.4 Test of Littoral Productivity Changes Following WUP Implementation

The modified regression ELZ model will be used to assess productivity before and after WUP implementation, using water level data from pre-WUP years and post-WUP years.

2.3.1.5 Link to Reservoir Fish Production

This assessment will be done through stable isotope analysis and using multiple lines of evidence telling an ecological story as described below.

Fish Stomach Content Analysis

Stomach content analysis provides information on the recent diet of fish, which could include other fish, zooplankton, terrestrial invertebrates or benthic invertebrates that are dependent on periphyton production. Field crews from JHTMON-5 will collect and provide excised stomachs from up to 90 Cutthroat Trout, Rainbow Trout and Sculpin spp.

Stable Isotope Analysis

Additional mooring lines will be installed to collect stable isotope samples along with the ones used for collecting algal accrual over the depth of the littoral zone. The stable isotope mooring will be acrylic or glass rather than polystyrene that may interfere with the stable isotope analysis. The layout will be limited to sampling only in summer within the top 2 m of the water column where the amount of accumulated biomass at the end of the 60-day incubation is expected to be greatest. The layout will result in 24 samples for analysis of stable isotopes of N and C in periphyton (1 sampling series x 6 stations x 1 depth per station x 4 replicates x 1 reservoir). Benthic invertebrate samples will be collected as part of this project to provide descriptions of the benthic assemblages that are sampled for stable isotope analysis. Four samples will be collected at each periphyton station for a total of 16 samples (4 stations x 4 replicates). At each station, samples of decomposing leaf litter and aquatic macrophytes will also be taken as alternate sources of carbon for benthic invertebrates for use in stable isotope modelling (4 stations x 2 sample types = 8 samples). Either baskets filled with local rock substrate or grab samples using a Ponar or similar device will be used for the invertebrate collections. The choice of sampling device will depend on attributes of the littoral substrate that will be examined as part of JHTMON-5.

Using the collected data, modelling of stable isotopes of nitrogen and carbon between periphyton, benthos, and fish in each of Upper and Lower Campbell reservoirs will be the second line of evidence to determine importance of periphyton supporting fish in littoral habitats.

Supplemental Analysis

If stable isotope analysis reveals littoral food source dominance then supplemental analysis will be performed using fish abundance data from JHTMON-3 to test for increases in fish production following WUP implementation. The supplemental analysis will also assess the correlation between individual fish growth rates and variation in littoral productivity. Fish abundance and growth data will be available from JHTMON-3.

2.3.1.6 Nutrient Concentration

Nutrient concentrations will be measured in water samples collected from the surface and from the bottom of each sampler at the beginning and end of each sampling series. The bottom sample will be collected using a Van Dorn water bottle deployed from a boat. Analyses will include soluble reactive phosphorus (SRP), total phosphorus (TP), total dissolved phosphorus (TDP), ammonium (NH_4-N), nitrate (NO_3-N), and total nitrogen (TN). Water for TDP, nitrate, ammonium, and SRP will be filtered in the field at the time of collection through Waterra 0.45 µm FHT-45 polyethersulphone filters using an Alexis peristaltic pump or equivalent system. All samples will be submitted within 24 hours to ALS labs in Burnaby for analysis using standard methods (APHA 2014).

2.3.1.7 Bathymetric Survey

Bathymetric survey will be done to create a digital elevation model to calculate surface area of periphyton accrual at different water elevations. Lake depth profiles will be completed across transects using a depth sonar to measure water depth and GPS to record position. The sonar and GPS will be mounted on a small vessel with data recorded directly to a computer on the boat. Lake bathymetry surveys will follow the RISC methods defined by the Ministry of Environment (2009): "Bathymetric Standards for Lake Inventories."

2.3.2 Safety

A safety plan must be developed and submitted to the BC Hydro Monitor contact, for all aspects of the study involving fieldwork, in accordance with BC Hydro procedures and guidelines. Boat operators must be certified (Coast Guard) and the boat must be of sufficient size to withstand the changing weather conditions on this reservoir. All snorkelers must be certified in swift water rescue; all divers must be professional commercial-certified divers. Past experience has shown that this work is best-accomplished using professional certified divers. All dives will follow WCB regulations and BC Hydro safety work procedures.

2.3.3 Data Analysis

All data will be entered into a common database in a standard format for subsequent analysis. This will ensure that data collected over the years are compatible and can be extracted and compared without concern regarding differences in file format. BC Hydro will provide direction on data entry and file formats. At the conclusion of the Monitor, power analysis will be used to assess the detectable limits of the Monitor, i.e., the magnitude of change in the data that must occur in order to illicit a statistically significant response in the parameter of interest. Some adjustment may be required to the presentation formats and analyses suggested below, following collection and review of data. Contractors, in consultation with BC Hydro, will be expected to make such adjustments to ensure that the best methods are used for analysis and presentation.

2.3.3.1 Light Intensity

Results of the light intensity component of the present monitoring study will be used to test Impact Hypotheses H_01, H_02 and H_03. Water temperature and PAR data will be summarized graphically and with tables. In particular, the following will be summarized and discussed: daily, seasonal, and annual trends in water temperature, PAR on the surface and at depth, and the light attenuation coefficient.

At a minimum, the light attenuation coefficient '*k*' can be derived from two PAR intensity measurements at different depths:

$$k = (2.3 \cdot (\log I_{d1} - \log I_{d2})) / (d_2 - d_1)$$

where,

I_{d1} = PAR intensity at depth 'd_1'

I_{d2} = PAR intensity at depth 'd_2'

The preferred method would be using several measurements and fitting the following equation using regression techniques (Wetzel 2001):

$$I_{PAR} = I_{d1} e^{-kd}{}_2$$

which can in turn be used directly to calculate PAR as a function of water depth. The PAR data will be used to define the effective euphotic zone within the water column and for littoral areas, and track temporal changes on a daily basis within any given year or overall across all years.

2.3.3.2 Periphyton Production

A quantitative approach will be applied to determine links between environmental factors and accrual of algal biomass in the littoral zone of the Upper Reservoir and Lower Reservoir. Given the potential role of light, nutrient concentrations, and temperature driving biological production in a littoral zone, ELZ will be defined as periphyton biomass (B) accrued on the area of substrata in a littoral zone with modification by habitat conditions over time and space. This performance measure will be called L as described in Equation 1 below. B will be in units of μg chl-a·cm^{-2} (Perrin *et al.* 1987, Bothwell 1988) where chl-a is chlorophyll-a, a primary plant pigment that is commonly used as a measure of biomass in algae (Wetzel 2001, Behrenfeld *et al.* 2005). The area of the littoral zone where periphyton grows will be defined as substrata area within depth strata where PAR in the overlying water column is greater than 1% of that at the water surface (the standard measure of euphotic zone depth, Wetzel 2001).

Area of a littoral zone can therefore be modified by processes that change PAR attenuation.

The definition of L can be specifically stated as follows:

$$L_t = \sum_{i=1}^{n} A_{it} B_{it} \quad \textbf{Equation 1}$$

where;

L is the accrued B that may be modified by habitat conditions and area of flooded littoral habitat at time t

A is the area of stratum i within the littoral habitat having n strata at time t, and

B is the biomass of accrued periphyton at time t in littoral depth stratum i, and

$$B_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \beta_3 x_{3it} + \varepsilon$$ **Equation 2**

Equation 2 is a multiple regression model explaining B at time t in depth stratum i as a function of x independent variables where β_0 is the regression intercept, x_1 is PAR, x_2 is the concentration of a nutrient that limits growth of periphyton, x_3 is water temperature, $\beta_{1...3}$ are regression coefficients, and ε is model error.

The combination of Equations 1 and 2 can be used to answer Management Questions 1 through 3. Management Question 4 will be answered using multiple lines of evidence involving accessing fish stomach content data and conducting stable isotope analysis to link fish production with secondary productivity in littoral zone. Supplemental analysis will be done using fish abundance data from JHTMON-3 to assess correlation between fish abundance and algal production.

2.3.3.3 ELZ Model Adjustments

The ELZ model will be adjusted to a multiple regression based approach as described in Section 2.3.3.2. Reservoir elevation data and information provided in different components of this Monitor will be used to assess productivity before and after WUP implementation in the Upper Reservoir and the Lower Reservoir.

2.3.3.4 Test of Littoral Productivity Changes Following WUP Implementation

The formal test of $H_0 3$ is complicated by the absence of data for pre-WUP reservoir littoral productivity. The test will require a successfully performing ELZ model, which will be used to assess productivity before and after WUP implementation. Pre-WUP productivity will be estimated using historic water level data for years prior to implementation of the WUP and after implementation of the WUP. The analysis will use a simple t-test to compare estimates of annual littoral productivity during the two time periods. This analysis should be accompanied by further analysis comparing monthly or seasonal values and using multiple line of evidence telling an ecological story about impacts of WUP operations.

2.3.3.5 Link to Reservoir Fish Production

This assessment will be done primarily through stable isotope analysis and diet composition data and as well as using multiple line of evidence telling an ecological story of what supports the trout populations of the Upper Reservoir the Lower Reservoir based on habitat use and diet data. If stable isotope analysis showed littoral food source dominance in fish food then a supplemental analysis will be done using fish abundance data from JHTMON-3 to evaluate correlation between fish production following WUP implementation. The supplemental analysis will also assess the correlation between individual fish growth rates and variation in littoral productivity. Fish abundance and growth rate data will be made available from JHTMON-3. The analysis is predicated on the assumption that individual growth rates will be highest when littoral productivity is high.

2.3.3.6 Stable Isotope analysis

Stable Isotope analysis data will be expressed as $\delta^{13}C$ or $\delta^{15}N$, or differences from the given standards, expressed in parts per thousand or per mil (‰). The values are calculated according to the formula (BC Hydro, 2013):

$$\delta X = [(R_{sample}/R_{standard}) - 1] * 1000$$

where (using carbon as an example) $R_{sample} = {}^{13}C/{}^{12}C$ of the sample, and $R_{standard} = {}^{13}C/{}^{12}C$ of the chosen standard (see discussion of isotope standards in Jardine et al. [2003]). R represents the ratio of the abundance of the ions of mass 45 (${}^{13}C^{16}O^{16}O + {}^{12}C^{16}O^{17}O$) to mass 44 (${}^{12}C^{16}O^{16}O$); thus a correction factor for ${}^{17}O$ is required (Craig 1953). Similar calculations can be performed comparing samples and standards for nitrogen [$R = {}^{15}N/{}^{14}N$, as measured by the ratio of the abundance of ions of mass 29 (${}^{14}N^{15}N^{+}$) to mass 28 (${}^{14}N^{14}N^{+}$) (Mariotti 1984)]. The use of ratios magnifies differences among samples, increases resolving power and permits comparisons across analytical laboratories and studies (Peterson and Fry 1987).

Analysis of SIA data should utilize both graphical and numeric analytical techniques. Standard SIA diagrams should be produced, showing mean and standard errors for different functional or taxonomic groups; the literature can be utilized as a guide for appropriate analysis. When organisms have two or more sources of energy for growth (e.g., littoral vs. other sources), mixing models have been employed to determine the relative contribution of the sources. Such models should be used where appropriate to ascertain the relative energy inputs to the food web from littoral, and allochthonous sources. Where fish species are shown to have significantly different isotope signatures, mixing model analysis should be performed separately for each species. Finally, comparisons should be made among the different lake/reservoir types, which can be thought of as experimental “treatments,” with attempts to understand the ecological effects of different management regimes.

Finally, it should be noted that JHTMON-5 will also be undertaking stable isotope assessment but will be assessing the relative energy flows to fish production from littoral and pelagic production sources.

2.3.3.7 Reporting

In general, project reporting will consist of annual data reports and a final report at the conclusion of the Monitor.

Annual data reports will summarize the year’s findings and include a short discussion of how the year’s data compare to that collected in previous years. It will include a brief description of methods, present the data collected that year, and report on the results of all analyses.

At the conclusion of the Monitor, a final comprehensive report will be prepared from all of the data and/or annual reports written to date that:

1) Re-iterates the objective and scope of the Monitor,
2) Presents the methods of data collection and analysis,
3) Describes the compiled data set and presents the results of all analyses, and
4) Discusses the consequences of these results as they pertain to the current BC Hydro operations, and the necessity and/or possibility for future change.

Each annual report will be due in spring of the year following the data collection period. This should provide sufficient time in integrate findings in those years that multiple study component are simultaneously carried out. All reports will be submitted, by BC Hydro to a Monitoring Advisory Committee for review and comment prior to being finalized for general release.

2.4 Interpretation of Results

2.4.1 Impact Hypothesis $H_0$1

This hypothesis tests the utility of the coarse ELZ model used during the WUP. Rejection of $H_0$1 indicates that the coarse ELZ model is inadequate in predicting the upper and lower boundaries of littoral periphyton production. Rejection of the hypothesis provides justification to proceed with modification and adjustment to the model.

Failure to reject $H_0$1 would suggest that the coarse ELZ model might be sufficient for predicting littoral production boundaries. There may be a number of reasons for such a result:

1) The ELZ model is adequate as is,
2) The resolution of the monitor was too low to detect a difference (too small a sample size, depth increments too large in the experimental arrays),
3) The change in reservoir operations was too small to illicit a measurable ecological response (too small a treatment effect),
4) There is some other limiting factor that either that masks the ecological response to operational changes, or
5) Some combination of the above.

The statistical resolution of the monitor will be determined through power analysis at the conclusion of the Monitor when estimates of sampling error can be made. Results of the analysis will indicate the limits of detection for a change in fish population response and will put the results of the Monitor into the proper statistical context.

2.4.2 Impact Hypothesis $H_0$2

This hypothesis assesses the utility of the modified ELZ model, by comparing the re-parameterized model predictions with the empirical results from the experimental periphyton measurements. Rejection of $H_0$2 indicates that the modified ELZ model may not be applicable to the Campbell reservoirs. Adequate testing of this hypothesis will require good empirical data (for comparing to model outputs) and proper assessment of the model’s strength and weaknesses. Given the need for some way of testing the effects of water management decisions on littoral productivity, considerable effort should go into testing the adequacy of the model, and the adjustments to the ELZ model.

Failure to reject $H_0$2 would suggest that operational changes resulting from the WUP’s implementation had no measurable impact on salmonid abundance. There may be a number of reasons for such a result:

1) The modified ELZ is adequate for predicting littoral production in Campbell reservoirs,

2) The resolution of the Monitor was too low to detect a change (too small a sample size, experimental units were inappropriate),
3) The change in reservoir operations was too small to illicit a measurable ecological response (too small a treatment effect),
4) There is some other limiting factor that either that masks the ecological response to operational changes, or
5) Some combination of the above.

The statistical resolution of the Monitor will be determined through power analysis at the conclusion of the Monitor when estimates of sampling error can be made. Results of the analysis will indicate the limits of detection for a change in fish population response and will put the results of the Monitor into the proper statistical context.

2.4.3 Impact Hypothesis $H_0 3$

This hypothesis assesses the value of WUP decisions as they affect littoral production. Testing $H_0 3$ *de facto* assumes a successfully operating ELZ model. Rejection of $H_0 3$ indicates that post-WUP water management has significantly benefited littoral production in Campbell reservoirs.

Failure to reject $H_0 3$ would suggest that operational changes resulting from the WUP's implementation had no measurable impact on littoral primary production. There may be a number of reasons for such a result:

1) The ELZ model performs inadequately in Campbell reservoirs,
2) The resolution of the Monitor was too low to detect a change (too small a sample size, experimental units were inappropriate),
3) The change in reservoir operations was too small to illicit a measurable ecological response (too small a treatment effect),
4) There is some other limiting factor that either that masks the ecological response to operational changes, or
5) Some combination of the above.

The statistical resolution of the Monitor will be determined through power analysis at the conclusion of the Monitor when estimates of sampling error can be made. Results of the analysis will indicate the limits of detection for a change in fish population response and will put the results of the Monitor into the proper statistical context.

2.4.4 Impact Hypothesis $H_0 4$

This hypothesis assesses the value of WUP decisions as they affect littoral production. Testing $H_0 4$ de facto assumes a successfully operating ELZ model. Rejection of $H_0 4$ indicates that post-WUP water management has significantly benefited fish production in Campbell reservoirs, and this change in fish production is correlated with improvements in littoral primary production.

Failure to reject $H_0 4$ would suggest that operational changes resulting from the WUP's implementation had no measurable impact on fish production. There may be a number of reasons for such a result:

1) The ELZ model performs inadequately in Campbell reservoirs,
2) The resolution of the Monitor was too low to detect a change (too small a sample size, experimental units were inappropriate),
3) The change in reservoir operations was too small to illicit a measurable ecological response (too small a treatment effect),
4) There is some other limiting factor that either that masks the ecological response to operational changes, or
5) Some combination of the above.

The statistical resolution of the Monitor will be determined through power analysis at the conclusion of the Monitor when estimates of sampling error can be made. Results of the analysis will indicate the limits of detection for a change in fish population response and will put the results of the Monitor into the proper statistical context.

2.4.5 General

These experiments are field trials in which environmental conditions will vary naturally. BC Hydro operations are only one of the potential causative agents. Testing of hypotheses in this Monitor will consider, to the extent possible, other causes for experimental results. Before accepting or rejecting hypotheses that link BC Hydro operations to population-level effects, it will be necessary to explore other reasons for experimental results, such as specific environmental variables or other development activities in the watershed, and statistical power of experiments. The conclusion that WUP-related changes in operations do not have an impact of reservoir fish ecology will be accepted only if the other causal explanations are reasonably ruled out (i.e., process of elimination).

2.5 Schedule

The revised JHTMON-4 study will be completed over two years of field measurements followed by modeling and sensitivity analyses. Details of is shown in Table 2 below.

Table 2. Schedule of Work

	2015							2016				
Task	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Project Initiation and Tracking	■	■	■	■	■	■	■	■	■	■	■	■
Safety Coordination	■	■		■	■		■	■		■		
Bathymetric Survey and DEM					■	■	■	■				
Benthic Invertebrate Sampling and Lab Work				■	■	■						
Periphyton Briomass Field Sampling and Lab Work		■	■	■	■	■						
Stable Isotope Modelling									■	■		
Analysis of Fish Stomach Content									■			
Solving Equation 2 and Demonstrating Its Application									■	■		
Data Analysis and Reporting								■	■	■	Draft	Final

Draft: Submission of Annual Draft Report
Final: Submission of Annual Final Report

2.6 Budget

The total cost of the Monitor remains unchanged and is estimated to be $528,075 based on a 2014 start.

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