# Campbell River Project Water Use Plan

# Monitoring Program Terms of Reference

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

**June 20, 2013**

# 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, but 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?

There are several factors that could impact the utility and reliability of the ELZ performance measure, including 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 WUPs. 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 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 Upper Campbell Lake 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 10 years prior to the implementation of the WUP, and 10 years post-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 Upper and Lower Campbell 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 Upper Campbell Lake 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 Upper Campbell Lake Reservoir.
2) The Monitor will be carried out annually until the next WUP review period (10 years following WUP implementation).
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 every five years 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 five 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 terms-of-reference 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 Upper Campbell 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 using periphyton as an indicator. Periphyton production will be measured using shore-based (horizontal) and open water (vertical) substrate arrays deployed in the Upper Campbell Lake Reservoir, the reservoir with the greatest drawdown. These arrays will be used to assess colonization and production in relation to water depth.
3) **ELZ Model Adjustments.** The ELZ model will be adjusted based on *in situ* measurements of water optical properties and periphyton colonization and growth rates.
4) **Test of Littoral Productivity Changes Following WUP Implementation.** The modified ELZ model will be used to assess productivity before and after WUP implementation, using water level data for 10 years prior and 10 years after.
5) **Link to Reservoir Fish Production.** Water level changes associated with the WUP were implemented with the intent of improving fish production in the reservoirs. Data from this Monitor and from Monitor 3 will be used to assess whether the WUP has benefited fish as expected, by testing whether fish production changed significantly after implementation.

## 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 Upper Campbell Reservoir next to each array of periphyton growth plates. 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 accurately calculate the attenuation statistic (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 plates 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 plates. The temperature profile data will be collected using temperature data loggers attached to each of the plates 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 plates are sampled). This monitoring will be conducted over the duration of the WUP implementation period (10 years). In Years 4-10 when no periphyton growth plates are sampled this data will be collected/downloaded on a quarterly basis.

#### 2.3.1.2 Periphyton Production

Methods for estimating periphyton production will build on experience from similar studies in Stave Lake and Clowhom Lake reservoirs (see Beer 2004 and Bruce 2005). The basic strategy will be to measure periphyton accrual on experimental colonization plates deployed in vertical and horizontal arrays. Shore-based estimates of periphyton productivity will be compared to open water estimates to calculate proportional loss of littoral productivity as a result of reservoir operations. Four replicates will be used: two horizontal and two vertical transects. The following describes one potential deployment method, though others are possible and may be preferable.

Both transect types will use the same basic design for experimental colonization plates: vertically suspended, lightly roughened, acrylic plates, with a known area marked on its surface. A sampling area of 100 $cm^2$ (10 cm × 10 cm) is considered sufficient for detection of small temporal changes in periphyton biomass in most oligotrophic lakes and reservoirs (Shortreed et al. 1984). Plates will be oriented vertically through the use of a weight on one side and attached flotation on the other (Figure 4-1). The plates can be strung together to form a chain, which can be arranged vertically (suspended from a single float) or placed horizontally along the substrate. Stringing plates together in a chain facilitates retrieval of the units. The vertical orientation of plates avoids shading and sedimentation effects, but is assumed to be neutral with respect to periphyton colonization.

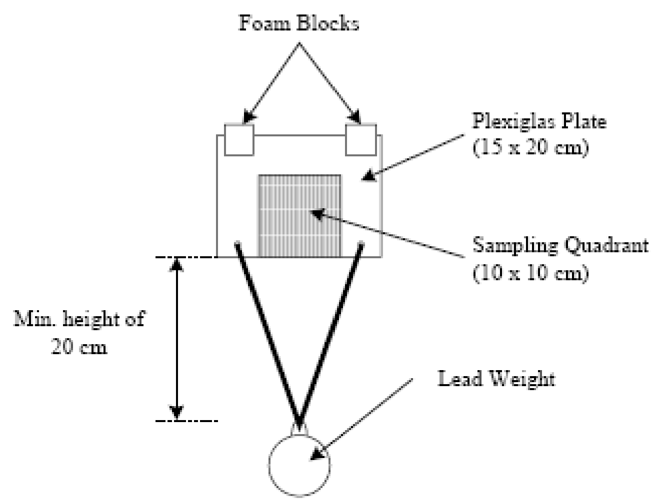


**Figure 4-1. Potential design of periphyton accrual plate.**

Experimental plates will be placed in transects from near the surface to a depth near or below the lower limit of the euphotic zone at low reservoir elevation. The euphotic zone in Upper Campbell Reservoir has not been well-defined, but mid-summer Secchi disk depths of up to 12.5 m have been measured in Buttle Lake (BC Hydro WUP data), immediately upstream of Upper Campbell Reservoir. Using approximate equations (Wetzel 2001), a Secchi depth of 12.5 m translates into almost 34 m as the depth of 1% surface light intensity, so experimental transect will need to extend to a considerable depth. The contractor will be expected to refine the depth estimation based on site conditions

Horizontal transects will extend perpendicularly from the shore, vertical transects will be suspended nearby at an offshore location. On both vertical and horizontal transects vertical spacing between plates of approximately 2 m is expected to allow sufficient resolution of vertical patterns in growth and colonization. Note that, unlike the horizontal transects, vertical arrays will move vertically as water level changes and should never come in contact with lake's bottom. Site selection should consider experimental requirements as well as access and visibility (i.e., the potential for vandalism). The system used to anchor, retrieve and re-deploy the colonization plates will be developed by the contractor to suit experimental requirements and local topography, building on the experience gained in other systems (Stave and Clowhom Lake reservoirs).

All four sites will be sampled at least seven times over the year starting in mid-February and ending in early November. Sampling periodicity will be such that one sample is collected in the winter followed by two samples each for the spring, summer and fall seasons. This sampling schedule represents the minimum necessary to calculate annual productivity in the reservoir so that stable and variable water level comparisons can be made. Periphyton growth studies will be conducted for a period of three years, a period believed sufficient to capture annual variation in environmental conditions and littoral productivity.

During each sample period, the 100 $cm^2$ sample area of all plates, regardless of whether the plates contain visible evidence of periphyton growth, will be scraped clean of periphyton using a clean microscope slide or razor blade as a scraper and placed into individually labelled collection jars containing distilled water. The scraping and the microscope slide are rinsed into the jar using distilled water. The entire plate is then scraped and rinsed clean (this scraping is discarded) before redeployment. When retrieving and sampling the plates, care must be taken to prevent the plates from drying out, both before and after scraping. They should be sampled immediately following retrieval, kept under cover and kept moist by occasionally spraying them with a fine mist of distilled water. After the last plate has been sampled at a given site, the array should be immediately re-deployed, taking care that the alignment is nearly identical to the original arrangement.

Periphyton samples must be kept cool and dark prior to analysis in a certified laboratory, where they should be immediately analysed for chlorophyll *a*, the measure of periphyton biomass from which productivity will be estimated. Periphyton collected on glass fibre filters will be extracted and analysed using protocols for fluorometric analysis published in Standard Methods (APHA et al. 1992). Using the known area of substrate scraped and the fluorometry results, 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 ELZ model will be updated by BC Hydro staff, based on data and analysis provided in the above two monitoring components. ELZ measures, tests and summaries will be made available as needed.

#### 2.3.1.4 Test of Littoral Productivity Changes Following WUP Implementation

The modified ELZ model will be used to assess productivity before and after WUP implementation, using water level data for 10 years prior and 10 years after. This test will be performed by BC Hydro staff, since these same persons will calculate the ELZ measures.

#### 2.3.1.5 Link to Reservoir Fish Production

BC Hydro will ensure that the fish abundance data from Monitor 3 are made available to allow completion of this study component. Results from the hydro-acoustic survey in Monitor 3 are to be used to build an indicator of fish abundance in Upper Campbell Reservoir, preferably by species and age class. It is expected that the indicator will be built on biomass data for rainbow and cutthroat trout, though the exact nature of the indicator will require analysis of real data. As part of Monitor 3, this indicator will be used to assess whether the WUP has benefited fish as expected, by testing whether fish production changed significantly after implementation. In addition to this analysis, and as part of this Monitor, a correlation test will be performed to investigate the link between littoral productivity and fish production. The details of this analysis are described in the Data Analysis section.

### 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 field work, 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 snorkellers 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 $H_0 1$, $H_0 2$ and $H_0 3$. 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

Productivity estimates based on the periphyton samples collected at each site will be summed across all depths to obtain a depth-integrated estimate of periphyton productivity (DIPP). Shore-based estimates of periphyton productivity ($DIPP_{littoral}$) will be compared to the open water estimates ($DIPP_{pelagic}$) to calculate proportional loss of littoral productivity as a result of reservoir operations:

$$\text{Proportional Loss of Littoral Productivity} = DIPP_{littoral} / DIPP_{pelagic}$$

This measure assumes that DIPP is a good indicator of littoral productivity in general, and specifically is a good indicator of littoral productivity available to fish. The measure also assumes that $DIPP_{pelagic}$ is a good indicator of littoral productivity when water levels are stable. Thus, values near 1 suggest little or no loss in littoral productivity due to water level fluctuations, while values near 0 indicate a near absence of littoral production.

The proportional loss statistic will be calculated separately for each littoral transect and for each sampling period. The proportional loss statistic will then be compared across time to detect within- (e.g., seasonal) and among-year differences. This will help to identify variability in periphyton production, and by comparing it to the summary statistics of PAR and temperature, reservoir water level and sampling location (i.e., the orientation of the sampling arrays relative to the sun), identify factors that may explain some of the variability. This analysis will be carried out using multiple regression and ANOVA techniques. Assumptions of normality, linearity, homoscedasticity, and multicolinearity will be examined prior to statistical testing and where necessary, data transformations will be carried out. For example, it may be necessary to arcsine transform the DIPP data to meet assumptions of normality, as the measure is a proportion.

Final selection of an indicator to summarize reservoir hydrology is uncertain at this time, and will require exploratory analysis. Given the complex nature of the interaction between water level fluctuation and littoral periphyton growth, it is conceivable that construction of a single indicator is not possible. If this is true, a causal relationship can only be established through the development and use of a temporal model such as the ELZ model. This difficulty in choosing a summary statistic may also apply to the light intensity and water level data set, as they too are not necessarily additive over time.

#### 2.3.3.3 ELZ Model Adjustments

The ELZ model will be tested and adjusted during several steps, including tests of Impact Hypotheses $H_0 1$ through $H_0 4$. Parameterization of the ELZ model will occur at the end of each year after collecting and analysing the periphyton accrual data and the monitoring of light and water characteristics. These results will be tested by comparing the model's predictions with the following year's empirical data. This will be repeated throughout the duration of the Monitor, meaning that there will be three years of data for model parameterization, and two comparison periods for model testing/validation (Year 1 vs. Year 2, and Year 2 vs. Year 3). All ELZ model adjustments will be performed by BC Hydro staff.

The model development process will begin by using the vertical array data to develop an average, daily periphyton accrual profile for each time interval between sampling periods. These average daily vertical profiles are calculated by dividing the AFDW of each sample plate (i.e., at each water depth) by the number of days since the last time it was sampled (Section 2.3.1). A nonlinear regression analysis of the depth-based accrual data set is then done to transform the discrete sequence of data into a continuous function PA(z1, p) where PA is periphyton accrual ($g \cdot m^{-2} \cdot d^{-1}$), z1 is water depth (m) relative to water surface, and p is the sampling period. Assuming that these profiles do not change with reservoir water level, these continuous functions of daily accrual are then used in the ELZ model to predict periphyton accrual at the two littoral sites. This is done by simply summing the daily, continuous, accrual profile functions over time and taking into account changing reservoir elevations. Thus for a given sampling period p the predicted profile $ELZ(z_2,p)$ is calculated as;

$$ELZ(z_2,p) = \sum_{day=1}^{x} PA(El_{day} + z_1, p)$$

where,

| | | |
|---|---|---|
| $PA(z_1,p)$ | = | periphyton accrual at depth z and period p |
| $z_2$ | = | water depth relative to maximum water elevation |
| $p$ | = | sampling period |
| $x$ | = | time interval (days) between sampling periods |
| $El_{day}$ | = | daily reservoir water elevation |

Validation of the model will be done using regression analysis to compare ELZ($z_2$, $p$) to actual accrual data collected from the transect periphyton sampling plates throughout the year. The regression analysis will be done separately for each sampling period *p*. Part of the validation methodology will be to evaluate the distribution of prediction errors, and to determine whether they are normally distributed or functionally related with depth. If functionally related with depth, a 'calibration' or correction term (or an equation if necessary) will be added to the ELZ model in order to calibrate future model predictions and normalize the distribution of errors. It is assumed that such an error term would likely reflect the differences in $PA(z_1, p)$ from where it is measured in open waters, and that which would actually be found at the transect site.

The model parameterization process above will be repeated each year of the Monitor. Annual data will be integrated in two ways. The first will use ANCOVA techniques to assess calibration terms, which will be compared between sampling periods, transect sites, and years. In the case where correction equations are necessary, this assumes that the calibration terms can be transformed into linear relationships (if deemed necessary) with a common transformation algorithm to estimate slope and intercept. If no significant differences are found, then the period-specific calibration curves will be collated into a single term (or equation parameters). Conversely, if significant differences are found, then regression analysis will be used in an attempt to develop predictive equations for the calibration slope and intercept values. Failure to find significant relationships will be viewed as an indication of model failure.

The other way in which annual data will be integrated into the model is by characterizing annual differences in period-specific $PA(z_1,p)$ profiles, which will in turn be used to develop a predictive model (i.e., a predictive model that gives a PA profile based on light intensity, time of year, etc.). For each year of data, period-specific $PA(z_1,p)$ profiles will be transformed into linear regressions and compared using ANCOVA techniques. Much like the calibration terms explained above, if no significant differences are found, the slope and intercept parameters that describe each annual $PA(z_1, p)$ will be averaged to give an average value for the sampling period. Conversely, predictive equations of slope and intercept will be developed as necessary if significant differences are found (i.e., equations that predict the slope and intercept of the linear $PA(z_1, p)$ function). If successful, the resulting regressions will be used in future years when no PA data will be empirically available. As above, failure to detect significant relationships when $PA(z_1,p)$ profiles vary between years will be viewed as an indication of model failure.

Formal test of $H_02$ will be based on comparisons between the $DIPP_{littoral}$ / $DIPP_{pelagic}$ ratios of measured and modelled periphyton production data (i.e., $ELZ(z_2,p)$). The comparison will be done using regression analysis, which may require arcsine transformation of the data to ensure the assumption of normality is met. As with the other analyses, assumptions of linearity and homoscedasticity will be tested.

#### 2.3.3.4 Test of Littoral Productivity Changes Following WUP Implementation

The formal test of $H_03$ 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 10 years prior and 10 years after implementation of the WUP. This test will be performed by BC Hydro staff, since these same persons will calculate the ELZ measures. The analysis will use a simple t-test to compare estimates of annual littoral productivity in the two time periods. This analysis should be accompanied by further analysis comparing monthly or seasonal values.

#### 2.3.3.5 Link to Reservoir Fish Production

Monitor 3 uses fish abundance data to test for increases in fish production following WUP implementation. Results of this monitor will indicate trends in fish production, but does not test hypotheses for specific mechanisms except for those linked to redd incubation conditions. An outcome of the present Monitor (No. 4) is to expand the scope of causal analyses by assessing the link between fish production and littoral productivity.

A formal test of $H_04$ will involve several steps, and for the most part be somewhat indirect. All of the steps assume *a priori* that inter-annual variation in littoral productivity will be sufficient to detect correlated changes in fish production, and rely on a successfully performing ELZ model. The validity of these assumptions is unknown at present. The first step will assess the correlation between individual fish growth rates and variation in littoral productivity. Individual fish growth rate data will be obtained in Monitor 3, based on scale and otolith samples, and will be made available for this analysis. Regression analysis will be used to assess the correlation between littoral productivity as predicted by the ELZ model and fish growth rates. The analysis is predicated on the assumption that individual growth rates will be highest when littoral productivity is high. The second step will involve testing the correlation between cohort abundance and littoral productivity. Data for age class strength will be obtained in Monitor 3 and will be made available for this analysis. Regression analysis will be used to assess the correlation between abundance of rainbow and cutthroat age classes in relation to littoral production as predicted by the ELZ model. The analysis is predicated on the assumption that age class strength will be highest when littoral productivity is high.

Finally, it should be noted that Monitor 5 will also be assessing this question. Using stable isotope analysis, Monitor 5 will be assessing the relative energy flows to fish production from littoral and pelagic production sources.

### 2.3.4 Reporting

In general, project reporting will consist of annual data reports, summary reports every five years, and a final report at the conclusion of the Monitor. Reporting requirements will be different for each component of the monitor as they have different durations.

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. For the first three years, these reports will be fairly extensive as they will include the periphyton sampling and ELZ model refinement components of the monitor. Following this initial period, these data reports will be fairly short as they will only report on the light intensity data collected that year, along with the ELZ modelling results.

The CC have requested that a summary report be prepared in Year 5 to collate all the data collected to date, summarize all the analyses, and discuss in detail the results as they pertain to the impact hypotheses, and more importantly, as they pertain to the management questions in Section 1.2. This will provide an early indication of the success or failure of the program to detect littoral production changes and the consequences to fish production. It will also provide an early assessment of the WUP, though the implementation interval would likely be too short to determine with certainty whether the WUP was successful in meeting the expected reservoir littoral productivity gains.

At the conclusion of each component 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 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 may 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 reparameterized 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, to the extent possible, consider 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 majority of the work pertaining to the littoral productivity monitor will be carried out annually during the first three years of the 10 year monitoring period. Only light intensity measurements will be carried out annually for the full duration of the monitor. The periphyton production measurements and associated ELZ model testing and refinement procedures will only be carried out in Years 1 to 3. It is assumed that this would provide sufficient time to refine the model, especially given the work carried out in other BC Hydro reservoirs

Periphyton sampling, spot light intensity measurements and data logger downloading will be carried out each month of the first year, and seven times per year in Years 2 and 3, starting in mid-February. In Years 2 and 3 sampling will end in early November. The expectation of this sampling schedule is to build on the result from the Stave reservoir periphyton monitor by producing year- round growth rates in Year 1, and confirming the rates of the Campbell River periphyton growing season in subsequent years. Where possible, the contractor will endeavour to carry out these studies during the same weeks each year to ensure between-year compatibility of the data.

In Years 5 and 10 of the monitor, the refined ELZ model will be run to provide estimates of littoral periphyton production to test for changes since WUP implementation, as well as assess the linkage between littoral productivity and reservoir fish production. This component of the monitor will rely on the fish abundance data provided by Monitor 3 and the radio-isotope work of Monitor 5 to carry out these assessments.

A data report will be prepared each year, due in spring of the year following data collection. In Year 5, the data report will be more comprehensive, summarizing all of the data and analyses collected to date, including that of other study components in the Campbell River Watershed Water Licence Requirements monitoring program, and provide a preliminary discussion of the findings, particularly as they pertain to the Management Questions and Hypotheses presented Sections 1.2 and 1.3. Data collected in Year 10 will be the last under the present program. As with the previous reports, the final report will be due in spring of the following year and will include a formal evaluation of the WUP issues discussed in the Year 5 report.

### 2.6 Budget

The total cost of the 10-year littoral productivity monitor is estimated to be $528,075 based on a 2014 start.

## 3 References

Anon. 2004. Campbell River Water Use Plan: Consultative Committee Report. Prepared on behalf of the Consultative Committee for the Campbell River Water Use Plan. 132 pp. + App.

APHA, AWWA, and WEF. 1992. Standard methods for the examination of water and wastewater, 18th ed. American Public Health Association, Washington, DC.

Beer, J.A. 2004. Littoral zone primary productivity in a coastal reservoir ecosystem. M.Sc. Thesis. University of British Columbia. Vancouver , BC. 96 pp. + App.

Bruce, J.A. 2005. Clowholm Water Use Plan: Monitoring Program. Prepared for BC Hydro, Regulatory Relations, Water Use Plan Implementation, Burnaby, BC. 50p.

Hatfield, T. 2003. Campbell River Water Use Plan: Monitoring proposals for fish and aquatic resources. BC Hydro Report No. WUP-JHT-TR-F10. Prepared for BC Hydro Water Use Plans by Solander Ecological Research, Victoria, BC. 50 pp.

Shortreed, K.S. A.C. Costella and J.G. Stockner. 1984. Periphyton biomass and species composition in 21 British Columbia lakes: seasonal abundance and response to whole-lake nutrient additions. Can. J. Bot. 62: 1022-1031.

Stockner, J.G. and F.A.J. Armstrong. 1971. Periphyton of the Experimental Lakes Area (ELA), northwestern Ontario. J. Fish. Res. Board Can. 28: 215-229.

Wetzel, R.G. 2001. Limnology. Lake and River Ecosystems, Third Edition. Academic Press. San Diego. 1006 pp.