# Columbia River Project Water Use Plan
# Kinbasket and Arrow Lakes Revegetation Management Plan

## Addendum for REV5
## Arrow lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis

## Implementation Year 2

## Reference: CLBMON-12

***Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis: Addendum for REV5***

**Study Period: 2013**

**Delphinium Holdings Inc.**
**Castlegar, B.C.**

**November 2013**

Original Report Cover

# CLBMON-12
## ARROW LAKES RESERVOIR MONITORING OF REVEGETATION EFFORTS AND VEGETATION COMPOSITION ANALYSIS:
## ADDENDUM: REV5 2013 DRAFT REPORT

Low Elevation Cottonwood and Willows west of Illecillewaet River; from a slightly different angle; 2011 above, 2013 below

**Submitted to:**

BC Hydro
Water Licence Requirements
Castlegar, B.C.

**by:**

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**2013**

*Citation*: **Enns, K., and J. Overholt. 2013**. CLBMON-12 Arrow Lakes Reservoir Monitoring of Revegetation Efforts and Vegetation Composition Analysis: 2013 Final Report. Addendum: REV5. Unpublished report by Delphinium Holdings Inc. for BC Hydro Generation, Water Licence Requirements, Castlegar, BC.

Cover photo: 2011 Cottonwood and willow west growing in the alluvial clays of Illecillewaet River, low elevation near Revelstoke BC, 2011 above, 2013 below.

# EXECUTIVE SUMMARY

The purpose of this project is to assess potential effects of the REV5 turbine on vegetation in the drawdown zone of Revelstoke Reach and distinguish them from other influences, including the current soft constraints operating regime. This project was added to CLBMON-12 and CLBMON-33 in 2009, using the pre-existing data collection process. CLBMON-12 and CLBMON-33 are vegetation monitoring projects included in the Columbia River Project Water Use Plan. There were no specific management questions or Terms of Reference for this project.

The REV5 turbine was made operational in December, 2010. This addendum represents the measurements and evaluation after three years of operation, including the pre-operational condition in 2010. Although measurements of vegetation were taken in 2009, new plots specific to REV5 were included in 2010 and a larger area per plot was sampled from 2010 forward. Therefore 2010 represents the pre-operation condition.

It was hoped that the CLBMON-12 and CLBMON-33 study designs would capture the effects of REV5. Effects were expected to be most noticeable in the lower elevation zone (434 - 436 m) and the highest elevation zone (438 - 440 m). It was thought that REV5 might increase the duration of inundation of the Revelstoke Reach drawdown zone, which could potentially have an adverse effect on vegetation, and that REV5 could potentially result in the removal of, or reductions in, vegetation cover (Korman and Buszowski, 2007). Potential effects of REV5 operations on drawdown zone vegetation and associated null hypotheses are:

- decreased total vegetation cover, especially at low elevations, due to prolonged inundation periods ($Ho_1$: average total vegetation cover is the same in each elevation band as measured in 2010)
- decreased vegetation heights, especially at low elevations, due to prolonged inundation periods ($Ho_2$: average maximum vegetation height is the same in each elevation band as measured in 2010)
- decreased species diversity, due to the loss of species less tolerant of prolonged inundation or increased water energy ($Ho_3$: average species diversity is the same in each elevation band as measured in 2010).

We examined vegetation plots located from the mouth of Illecillewaet River to Cranberry Creek, in Revelstoke Reach. These plots were established prior to the commencement of REV5 operations and were selected from an existing database to examine time-related changes in the vegetation. There were no plots available in Reach 4 for this comparison, with the exception of the sheltered backwater at Revelstoke Island.

There were no obvious trends in the effects of REV5 operations on the vegetation of the Revelstoke Reach in any of the observation years from 2009 to 2013. Heights and covers of the vegetation are highest at the northern end of Revelstoke Reach, due to the accumulation of clay in soils and invasion by shrubs, even at low elevation. These variables were shown in previous analyses to be important in the retention of vegetation (Enns et al. 2012). Peeling and sloughing of the steeper sands on the Columbia Rivers edge of the Illecillewaet study area was the main cause of loss of vegetation noted in 2013 and in the aerial photography in 2012 (Enns et al. 2012). These losses are not

directly attributable to REV5, however. REV5 has only been operational for three winter seasons and may not yet be distinguishable from baseline inundation or from other causes of variation in vegetation. In fact, the effects of REV5 are most likely contained within Reach 4, in exposed topography. Although there are no clear, detectable influences attributable to REV5 operations, the data show clear alignment of species groups with elevation and inundation in the reservoir, and this is thought to be a response to the overall long-term growing conditions in the Arrow Lakes Reservoir, including reservoir operations. A summary of the Management Questions for CLBMON-12 as they relate to the REV5 Addendum is provided in Table 1.

**Table 1. Status to date of management questions (MQ) for the REV5 portion of CLBMON-12, supporting data and Results Summary. Note that no specific management questions were provided for REV5; therefore relevant CLBMON-12 MQs have been adapted to reflect the objectives outlined by BC Hydro (2008)**

| Management Question | Field data | Results |
|---|---|---|
| MQ1. Has there been a change in vegetation cover, height or species diversity in relation to elevation in the drawdown zone, following the onset of REV5 operations in 2010? | Vegetation cover, height and diversity measurements taken in the field in each sampling year. | Vegetation height was greater at higher elevations (438-440 m), a consistent trend since before the onset of REV5 operations. There were no differences detected in species diversity or average vegetation cover among the three elevation bands, based on data collected in 2010 – 2013. |
| MQ2. Has there been a change in vegetation cover, height or species diversity *within* the three elevation bands following the onset of REV5 operations in 2010? | Species cover, diversity, and height measurements taken in the field in each sampling year. | Average vegetation height and average vegetation cover increased in 2012 in the 436-438 m elevation band compared to the 2010 baseline. Average cover returned to pre-REV5 levels by 2013, while average height values remain slightly elevated. No changes were detected in either the 434-436 m elevation band or the 438-440 m band over time. These fluctuations are mostly likely due to natural variation. |
| MQ3. Can the observed changes (if any) in vegetation cover, height and species diversity by attributed to REV5 operations? | Species cover, diversity, and height measurements taken in repeated plots each sampling year. Daily records of water elevation in Revelstoke Reach were used to determine the number of days that each plot was inundated. The distance | Average vegetation height decreased in vegetation inundated for > 100 days. Average height also decreased with distance from the Revelstoke dam. These observations are attributed to the influence of the Illecillewaet River mouth and its deposition of clays along with stable materials that support more shrubs at low elevation than the sandy poorer |

| | | |
|---|---|---|
| | of each plot from the Revelstoke dam was calculated using GIS software and aerial imagery. | materials to the south. Average cover and species diversity showed no clear pattern in relation to inundation that could be directly attributable to REV5. Aerial photographic comparisons show sloughing directly south of the Illecillewaet that may be attributable to REV5. |

Our recommendations are that the effect of REV5 on water behaviour could be better defined in Reach 4 to the north, and that the use of aerial photography in combination with ground truthing can be used to document the actual impacts of REV5 on vegetation.

## KEYWORDS

REV5, Arrow Lakes Reservoir, Revelstoke Reach, Illecillewaet River, vegetation.

# ACKNOWLEDGEMENTS

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# 1.0 INTRODUCTION

In order to assess the impacts of the soft constraints operating regime on existing and treated vegetation, BC Hydro implemented two ten-year vegetation monitoring programs in the Arrow Lakes Reservoir. The CLBMON-33 project, initiated in 2007, is a repeated aerial photographic survey of the vegetation, with subsequent field measures designed to assess changes in vegetation at the landscape scale. The CLBMON-12 project, initiated in 2008, is a detailed field study designed to monitor changes in pre-existing vegetation, as well as to assess the success of revegetation treatments.

In 2009, the REV5 sub-project was initiated to examine the effects of a fifth generating unit (REV5) at Revelstoke Dam on vegetation in the drawdown zone of the Revelstoke Reach portion of the Arrow Lakes Reservoir. Changes in vegetation in response to REV5 are monitored within both the CLBMON-33 and CLBMON-12 projects.

The reason for the REV5 addendum to both projects was the concern that the addition of a fifth turbine to Revelstoke Dam might negatively impact vegetation in the northern portion of the Revelstoke Reach (closest to Revelstoke Dam). The influence of REV5 was thought to be mainly observable at low elevation in the Revelstoke Reach portion of the Arrow Lakes Reservoir (Korman and Buszowski 2007). Within the existing study areas, the most susceptible areas were thought to be at the mouth of the Illecillewaet River, south of Revelstoke (Enns and Enns 2011), at both low and high elevations. This addendum to the CLBMON-12 report for 2013 includes an examination of the effects of REV5 on the cover and diversity of vegetation at Illecillewaet River and southern locations in Revelstoke Reach after three years of REV5 operations.

The goals of the REV5 portion of the CLBMON-12 monitoring program (BC Hydro 2008) are to:

1) determine if the cover and diversity of vegetation in the drawdown zone occurring between 434 and 440 m as been influenced by the addition of the REV5 generating unit;
2) determine if cover and diversity of vegetation in the Revelstoke Reach portion of the Arrow Lakes Reservoir drawdown zone have been influenced by the addition of the REV5 generating unit at locations both near to and distant from the REV5 generating unit;
3) monitor the response of existing vegetation communities at the local site level to the continued operation of the REV5 generating unit and to other environmental variables.

REV5 became operational in December of 2010. Annual re-measurements have been conducted in selected plots since 2009. The number of pre-operational plots was increased in 2010, and larger plots were used[1]. The first post-operational series of vegetation monitoring plots were completed in 2011 and subsequent field monitoring was conducted in 2012 and in 2013. This report summarizes the results of the third post-

[1] In 2009, three 1m by 1m subplots were randomly located inside a 5m by 10 m rectangular plot. In order to use repeated measures more effectively, the plots were completed in the entire larger plot area from 2010 on.

operational vegetation evaluation of potential effects of REV5 on vegetation in the Revelstoke Reach drawdown zone.

## 2.0 CHARACTERISTICS OF INUNDATION IN THE RESERVOIR

Vegetation in the reservoir has been influenced by dam operations since the mid-1960s, and has adapted to and been shaped by those conditions. Figure 1 illustrates the timing, frequency, duration, and depth of inundation from January, 2006 to June, 2013.

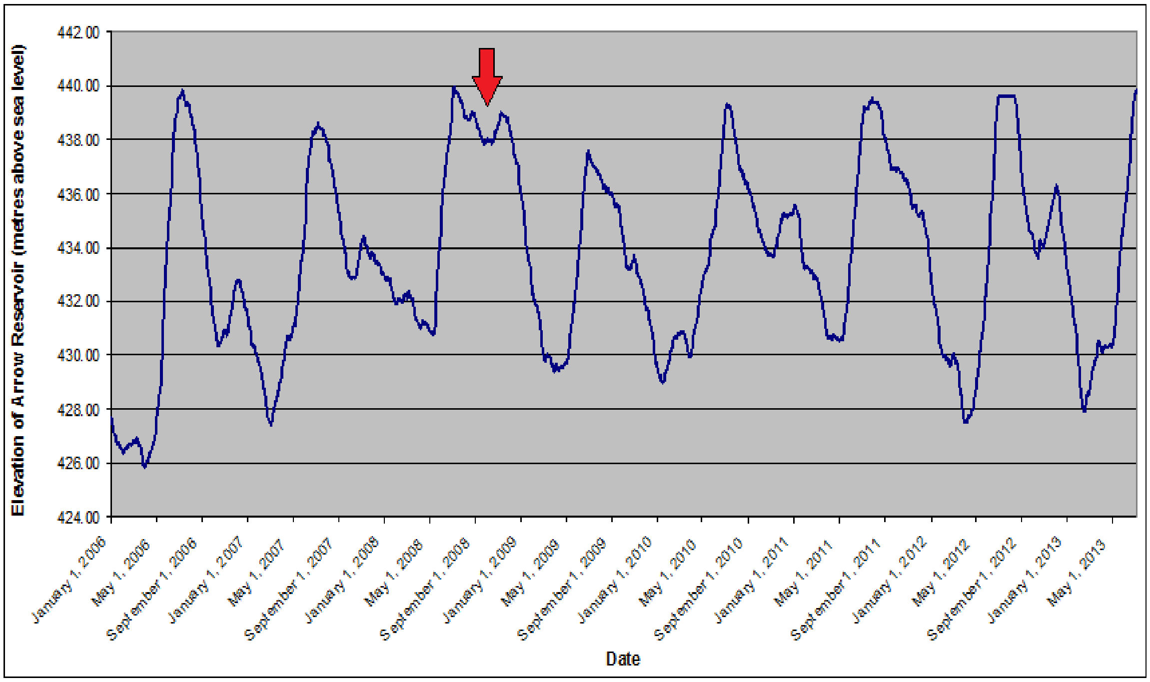



**Figure 1.** **Water levels in the Arrow Lakes Reservoir from 2006 to 2013. The red arrow indicates the commencement date for flows influenced by REV5 operations in December, 2010.**

The patterns of inundation have been similar over the past seven years, although there have been some year-to-year differences in water levels. A long duration of inundation occurred between summer of 2008 and winter of 2009 (red arrow in Figure 1). A temporary reduction in vegetation average covers and heights was noted in 2009, but recovery has since taken place (Enns et al. 2010).

## 3.0 METHODS

The methods describing field data collection, data entry, analysis and interpretation are provided in the main CLBMON-12 report for 2013 (Enns and Overholt 2013) and in Appendix A for that report. The methods specific to the analysis of data for the REV5 addendum are provided in this Addendum. A series of field plots in Revelstoke Reach were assessed annually in 2009 through 2013. The locations of these plots are illustrated in Figure 2.

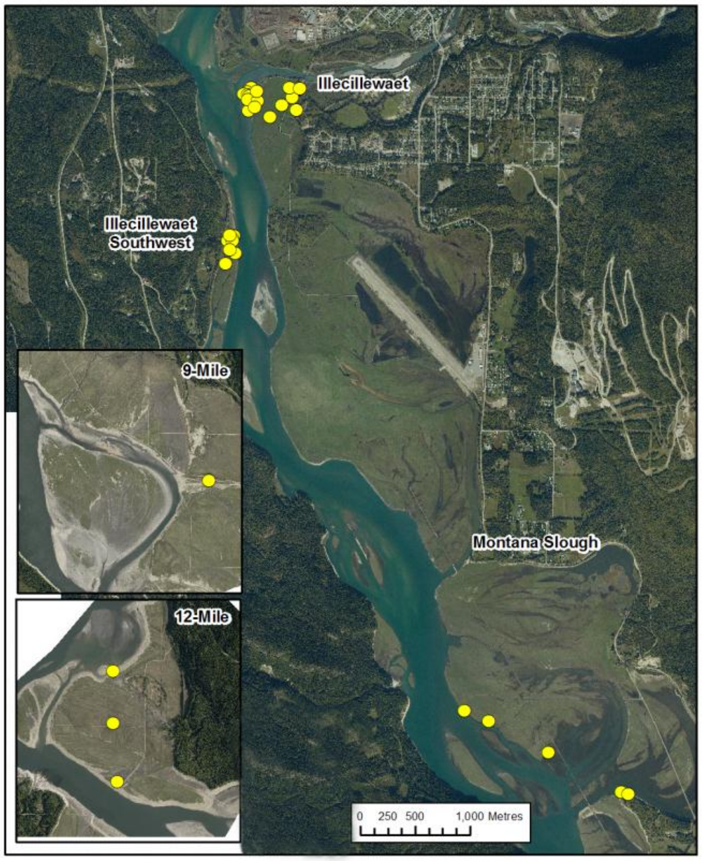



**Figure 2. Locations of 33 field plots (yellow dots) assessed for impacts of REV5 operations within the Revelstoke Reach portion of the Arrow Lakes Reservoir from 2010 to 2013. The scale of insets to the south at 9 Mile and 12 Mile and the main image is 1: 60 000. Some plots are obscured beneath others in the figure. The imagery used in Figure 2 is the property of BC Hydro**

A total of 33 plots in Revelstoke Reach were re-measured from 2010 to 2013 for use in the assessment of REV5 operations on reservoir vegetation. We attempted to sample the same plots annually[2], and include replicates representing the dominant Vegetation Community Types (VCTs) as well as all three elevation bands, at variable distances from the dam. Descriptions of the VCTs are provided in Appendix 1. Boxplots were used to compare the distributions of vegetation cover, height and diversity in plots from 2009 through 2013. Changes in the vegetation over time was evaluated using ANOVA where appropriate. We tested for significant differences in average vegetation height, cover, and distribution between sampling years, elevation classes, and vegetation community

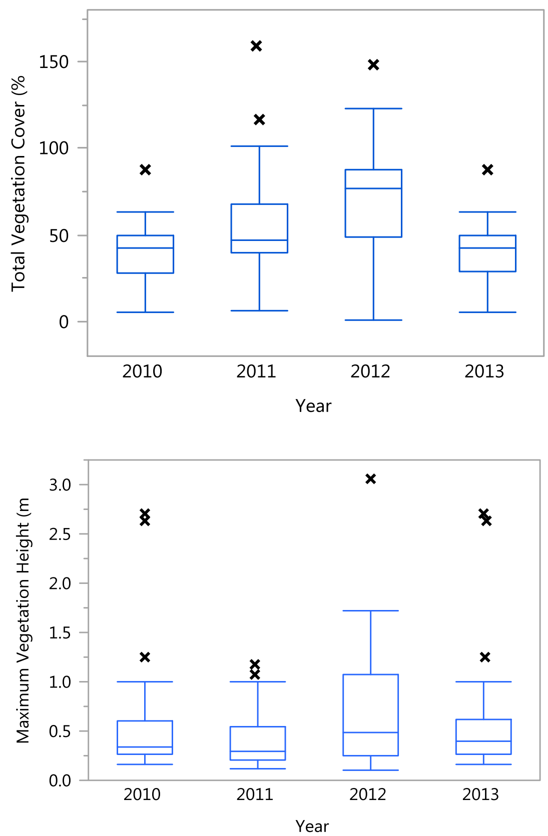
[2] These plots were also sampled for CLBMON-33. It was not always possible to sample annually in some plots due to rapidly rising water during the sample sessions.

types. Vegetation data was tested for agreement with the underlying assumptions of ANOVA analysis such as normality of distribution and equal variances in the groups compared. We also looked for linear relationships between vegetation cover, height and species diversity and the number of days of inundation. No data transformations were used. Data was presented in scatter plots with best linear fit lines for the combined main VCTs. JMP Version 11 was used for all data displays and statistical tests.

# 4.0 RESULTS

## 4.1 Differences in vegetation cover, height and diversity among years and elevation classes

Vegetation cover, height and diversity in repeated vegetation monitoring plots are plotted by sampling year in Figure 3 and by elevation band in Figure 4.



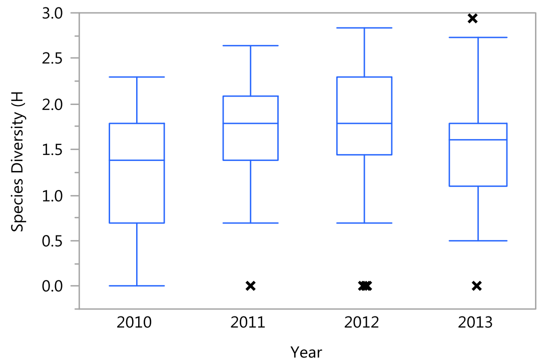
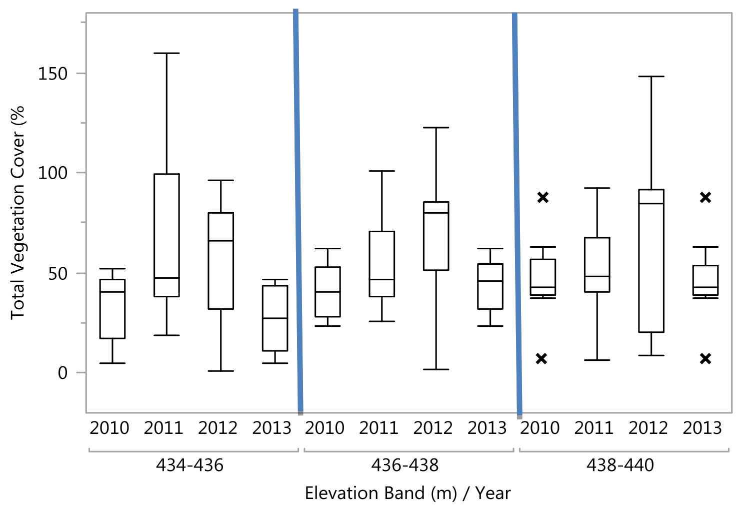
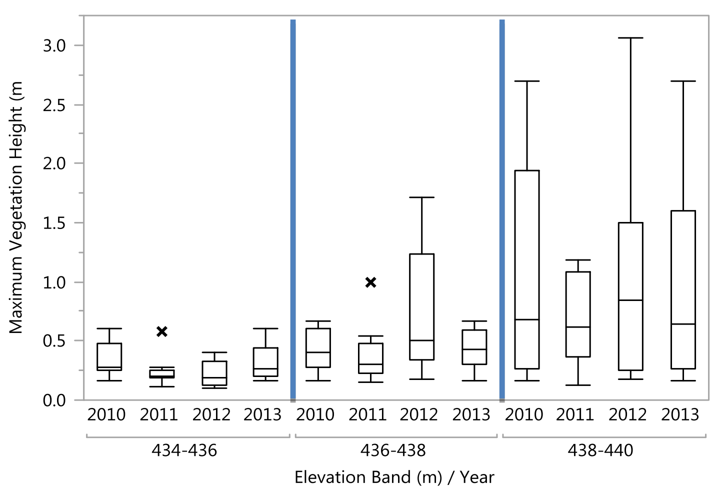



**Figure 3.** **Box plots showing the distribution of total vegetation cover (top), average maximum vegetation height (middle) and average species diversity (bottom) for plots sampled in 2010 through 2013 in Revelstoke Reach, all elevations combined. N = 33 for each year. The 2010 distributions represents a pre-REV5 vegetation baseline.**



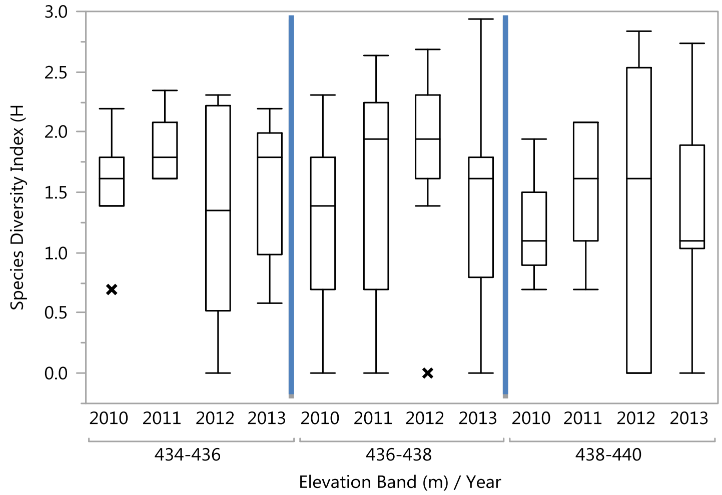



**Figure 4. Total vegetation cover (top), average maximum vegetation height (middle) and average species diversity (bottom) in plots repeated in 2010 through 2013 in Revelstoke Reach, by elevation band. N = 33 for each year. The 2010 distributions represent a pre-REV5 vegetation baseline.**

ANOVA was used to test for responses in vegetation height, cover and diversity among the three elevation bands (Table 2). The statistical tests included plot data collected in 2010 through 2013, and from all VCTs from which a sufficient number of plots had been repeated in each elevation band to make a reliable comparison between elevation bands.

**Table 2. Summary of ANOVA results: average vegetation height, cover and diversity by elevation band. Only statistically significant results are reported here, detailed results are provided in Appendix 2**

| Dependent variable | Elevation band | p-value | Significance |
|---|---|---|---|
| Total vegetation cover | NA | NA | No Significant differences between elevation bands detected |
| | | | |
| Average maximum vegetation height | Elevation band: 434-436 - 438-440 | 0.0001 | Average vegetation height at 438-440 m > 434-436 m |
| | Elevation band: 436-438 - 438-440 | 0.0006 | Average vegetation height at 438-440 m > 436-438 m |
| | | | |
| Shannon-Weiner Diversity Index | NA | NA | No Significant differences between levels detected |

The 438 – 440 m elevation band had significantly taller vegetation, on average, than the other two bands. This result was consistent in each year, and was found to be present in the pre-REV5 vegetation data as well as in subsequent years.

There was no significant difference in average vegetation height between the 436 – 438 m elevation band and the 434 – 436 m band.

There were no significant differences among elevation bands in either species diversity or average vegetation cover.

We also tested for changes over time in vegetation height and cover *within* each of the elevation bands designated for the project (Table 3). Plot data from 2010 through 2013 was used in the analysis.

**Table 3. ANOVA results for vegetation height, cover and diversity index responses over time within each of the three designated elevation bands, based on plots sampled in 2010 through 2013. Only statistically significant results are reported here, detailed results are provided in Appendix 2.**

| Elevation Band (m) | N | Level - Level | p-value | Significance |
|---|---|---|---|---|
| 434-436 | 33 | NA | NA | No significant difference detected among years |
| | | | | |
| 436-438 | 58 | Height: 2011 - 2012 | 0.0144 | Average vegetation height in 2012 > in 2011 |
| | | Height: 2010 - 2012 | 0.0299 | Average vegetation height in 2012 > in 2010 |
| | | Cover: 2010 - 2012 | 0.0015 | Average vegetation cover in 2012 > in 2010 |
| | | Cover: 2013 - 2012 | 0.0046 | Average vegetation cover in 2012 > in 2013 |
| | | | | |
| 438-440 | 33 | NA | NA | No significant differences among levels detected |

Average maximum vegetation height was found to have increased significantly between 2010 and 2012 in the high elevation band (438 - 440 m) only. Total vegetation cover increased in both the high and mid elevation bands, but no change was detected at the low elevation band. These results indicate that there has been no detectable change in vegetation covers or heights at low elevations, where the effects of REV5 operations would likely be most noticeable, and that vegetation covers and heights have increased at higher elevations following the onset of REV5 operations.

Differences in total vegetation cover, height and diversity among sampling years within selected VCTs were examined for data from 2010 through 2013 (Figures 5 through 7). PE and PA vary annually, whereas the other VCTs show similar annual pattern. A smaller sample size in PE VCT plots is responsible for this variation (presented as SE). PE is not a common VCT in the REV 5 study area. Only those VCTs that were sampled in sufficient numbers were compared and were included in the figures. VCTs sampled but not shown are the CR (Cottonwood Riparian), PO (Pond) and BG (Gravelly Beach) types.

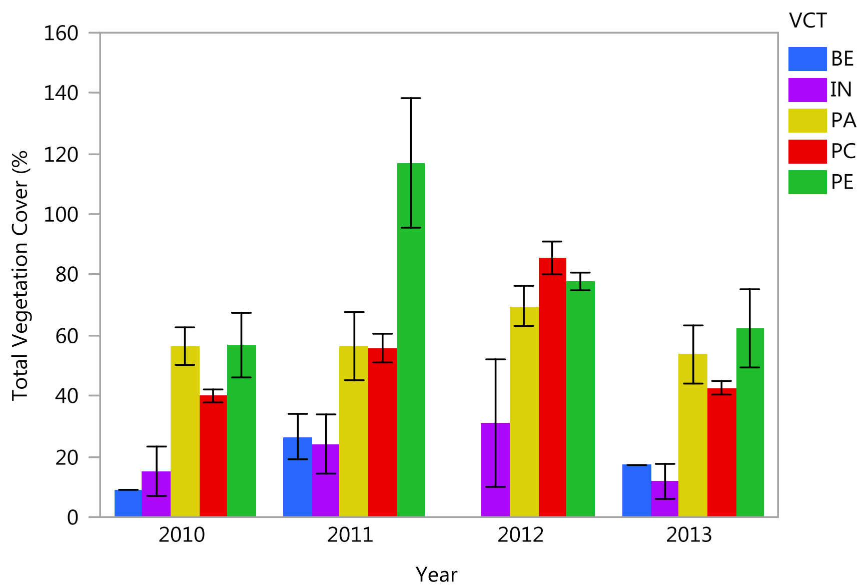



**Figure 5.** **Total vegetation cover by year for selected VCTs. N = 33 for each year. Error bars represent one standard error of the mean and illustrate the variation in relation to sample size. Definitions of VCTs are provided in Appendix 1. Note that PE and PC vary more annually than the other VCTs**

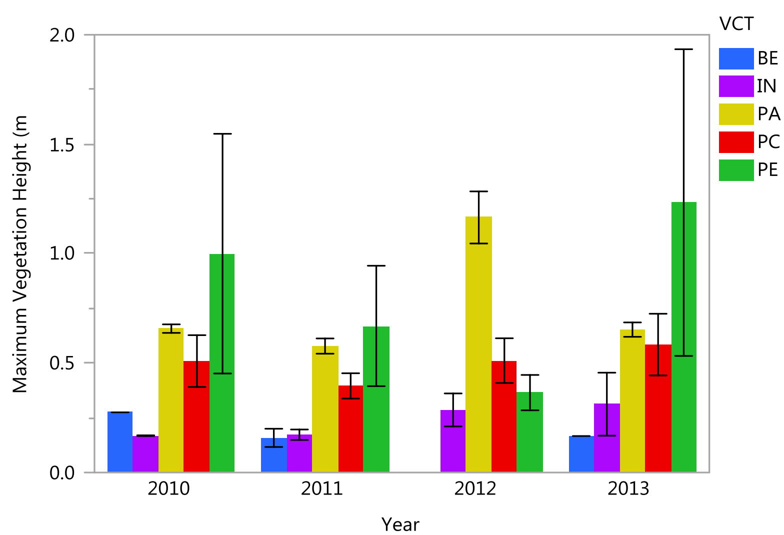



**Figure 6.** **Average vegetation height by year for selected VCTs. N = 33 for each year. Error bars represent one standard error of the mean. Definitions of VCTs are provided in Appendix 1. Note that heights appear to fluctuate annually in permanent plots in the shrub dominated PA type and the sedge dominated PE type**

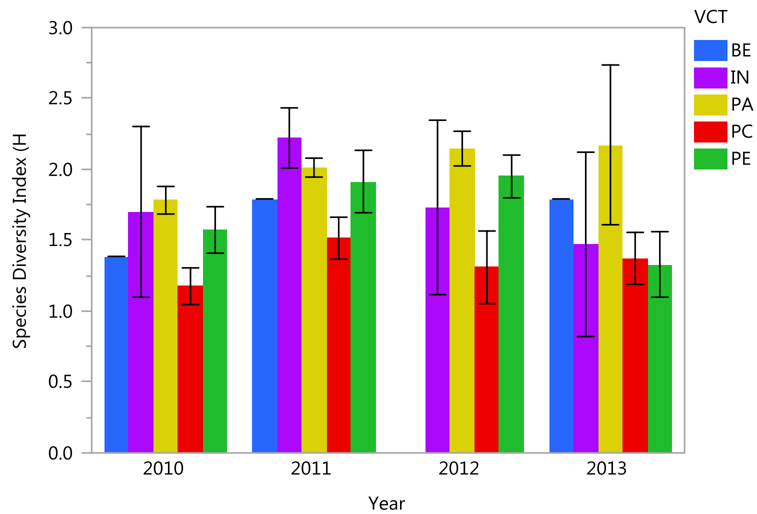


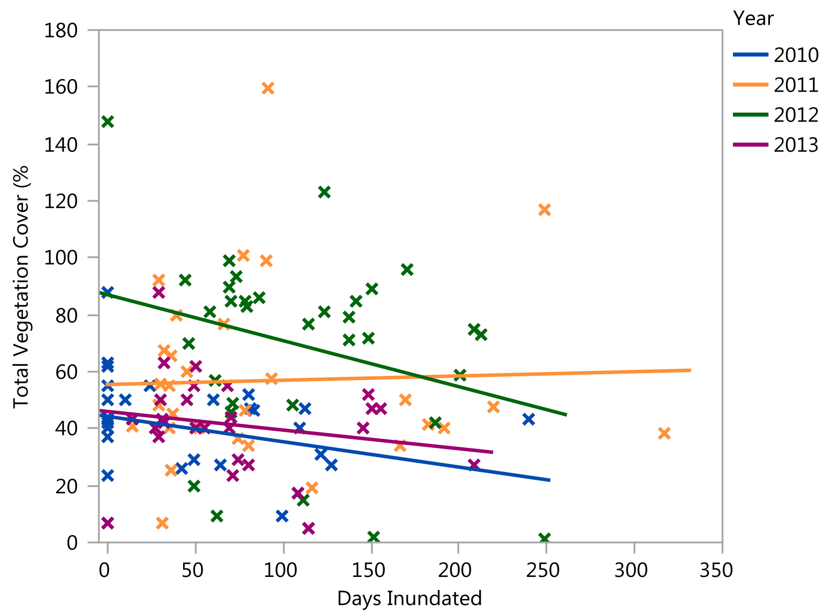

**Figure 7. Shannon-Wiener species diversity index values by year for selected VCTs. N = 33 for each year. Error bars represent one standard error of the mean. Definitions of VCTs are provided in Appendix 1. Note there are no obvious annual trends in diversity**

There was an increase in total vegetation cover in the PE type in 2011 compared to 2010 (ANOVA, Alpha = 0.05, q = 2.97, p = 0.0133), PE cover remained high in 2012 before decreasing again in 2013 (p = 0.0356). However this is based on a small sample size. PE is not common in Revelstoke Reach, the numbers of plots in PE is lower than other types, and it is fairly variable over time. Cover also increased in the PC type in 2011 (p = 0.0066) and again in 2012 (p = 0.0001) before returning to 2010 levels again in 2013. No other significant changes in cover were detected, although a moderate increase in cover occurred in the PA type in 2012. Detailed ANOVA results are provided in Appendix 2. There were no significant changes in vegetation height detected between 2010 and the years following commencement of REV5 operations. A moderate increase in average height was observed in the PA type in 2012, but the increase was not statistically significant and height returned to baseline in 2013. The PE type was found to be highly variable between sampling years, but we do not attribute this variability to REV5 operations as similar patterns have been observed in the reservoir wide monitoring (see Enns 2010). These results indicate that there has been little change in vegetation height since the onset of REV5 operations in 2010. A moderate increase in diversity occurred in several VCTs in 2011 and 2012 compared to the baseline values of 2010, however, none of these increases in diversity were statistically significant. These results indicate that there has been little change in species diversity since REV5 operations began in 2010.

In fact, it is not possible to attribute the differences in cover, height and diversity to REV5 as there are no clear or obvious trends. Average height should not vary annually in repeated shrub dominated plots (PA) unless the average heights are made variable by fluctuation in the heights of understory plants. The time of year of the measurement (Early May to Early June) is essentially a study of seedlings and shrubs which will be highly variable due to the early phenological stage of annual and perennial plants. Due to the time of year of the data collection, no annual trends can be considered reliable.

## 4.2 Effects of Inundation on vegetation cover, height and diversity

The relationships between vegetation cover, height and diversity versus the number of days that each plot was inundated in 2010, 2011, 2012 and 2013 are shown in Figures 9 and 10. Several of the high-elevation plots included in these figures were not inundated at all, particularly in 2010.



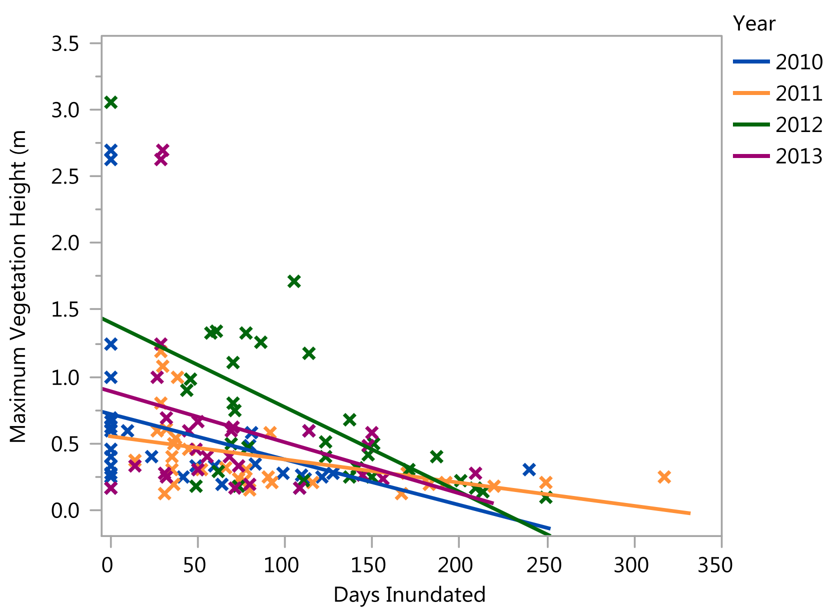



**Figure 8. Total vegetation cover (top) and average maximum vegetation height (bottom) *vs*. number of days inundated in 2010 through 2013 (n = 33 for each year, all vegetation combined). The regression lines are based on the best fit least-squares linear model (Table 4)**

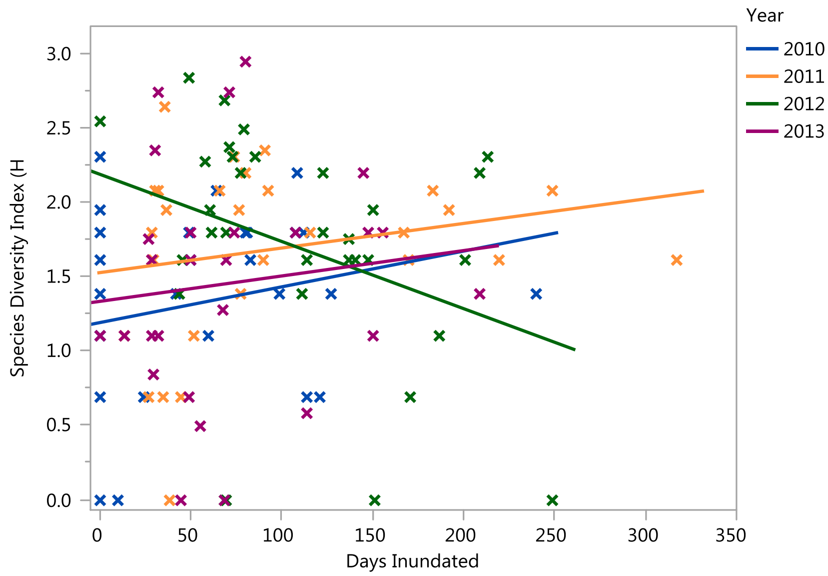



**Figure 9. Shannon-Wiener Diversity Index *vs.* number of days inundated in 2010 through 2013 (n = 33 for all years). The regression lines are based on the best fit least-squares linear model (Table 4)**

Average maximum vegetation height decreased with prolonged inundation in both 2011 and 2012 (see Table 4). Plant heights were lower, on average, in plots with longer periods of inundation, especially for those inundated for more than 100 days. This is mostly due to the small body size of plants adapted to longer periods of inundation (Kozlowski 1984). There was no clear relationship between total plot cover or average species diversity and duration of inundation, therefore H is not presented in Table 4.

**Table 4. Summary of Regression Results: average vegetation height, cover and distribution *vs.* duration of inundation. Significant results are indicated with an asterisk.**

| Year | Rsquare | F Ratio | P value |
|---|---|---|---|
| **Average Vegetation Height** | | | |
| **2010** | 0.1173 | 3.9879 | 0.0550 |
| **2011** | 0.2194 | 8.1523 | 0.0079* |
| **2012** | 0.2551 | 8.9037 | 0.0061* |
| **2013** | 0.0949 | 2.6210 | 0.1180 |
| **Average Vegetation Cover** | | | |
| **2010** | 0.0627 | 2.0063 | 0.1669 |
| **2011** | 0.0014 | 0.0396 | 0.8437 |
| **2012** | 0.0059 | 0.1593 | 0.6929 |

| | | | |
|---|---|---|---|
| **2013** | 0.0382 | 0.9924 | 0.3287 |
| **Average Vegetation Distribution** | | | |
| **2010** | 0.0833 | 2.7244 | 0.1093 |
| **2011** | 0.0411 | 1.2442 | 0.2738 |
| **2012** | 0.0117 | 0.3065 | 0.5846 |
| **2013** | 0.0134 | 0.3401 | 0.5650 |

A weak positive association between species diversity and inundation duration was observed for most of the sampling years. This may be due to the distribution of vegetation community types within Revelstoke Reach, most of the high-elevation plots included in this assessment were of the comparatively species poor PC type, which is largely dominated by reed canary grass. The results of similar analyses performed for the CLBMON-12 project, which included many more plot samples, indicate that species diversity decreases with prolonged inundation (see Enns et. al 2011).

Both species diversity and vegetation cover were high at low elevation sites, even though the period of inundation at this elevation was longer than at high elevation. This was due to the presence of inundation-tolerant plants such as lenticular sedge (*Carex lenticularis*), scouring rushes and horsetails (*Equisetum* spp.) that are tolerant of prolonged inundation.

### 4.3 Observed changes in species composition between years

Repeated plots were examined for changes in species composition between 2010 and 2012. The results of this comparison are presented in Table 5.

**Table 5. Plant species lost or gained between 2010 and 2012 from repeated plots in the Revelstoke Reach portion of the Arrow Lakes Reservoir, arranged by elevation band**

| Elevation Band | Found in 2012 but not in 2010 | |
|---|---|---|
| | **Scientific Name** | **Common Name** |
| 434-436 m | *Drepanocladus aduncus* | common hook-moss |
| | *Mimulus guttatus* | yellow monkey-flower |
| | *Persicaria maculate* | lady's-thumb |
| | *Poa annua* | annual bluegrass |
| 436-438 m | *Brachythecium* sp. | ragged-moss |
| | *Hieracium* sp. | hawkweed |
| | *Hieracium caespitosum* | yellow king devil |
| | *Juncus ensifolius* var. *montanus* | dagger-leaf rush |
| | *Parmelia sulcata* | waxpaper |
| | *Persicaria amphibian* | water smartweed |
| | *Pohlia wahlenbergii* | pale nodding-cap moss |
| | *Polytrichum juniperinum* | juniper haircap moss |
| | *Prunella vulgaris* | self-heal |
| | *Salix bebbiana* | Bebb's willow |
| | *Senecio pauperculus* | Canadian butterweed |
| | *Ulota* sp. | pincushion moss |

| | | |
|---|---|---|
| | *Xanthoria polycarpa* | pincushion orange lichen |
| 438-440 m | *Betula papyrifera* | paper birch (seedling) |
| | *Cornus stolonifera* | red-osier dogwood (seedling) |
| | *Danthonia spicata* | poverty oatgrass |
| | *Epilobium angustifolium* | fireweed |
| | *Erigeron subtrinervis* | triple-nerved fleabane |
| | *Fragaria virginiana* | wild strawberry |
| | *Hieracium glomeratum* | yellowdevil hawkweek |
| | *Hordeum brachyantherum* | meadow barley |
| | *Leucanthemum vulgare* | oxeye daisy |
| | *Pinus monticola* | western white pine |
| | *Rhinanthus minor* | yellow rattle |
| | *Rubus idaeus* | red raspberry |
| | *Rubus parviflorus* | Thimbleberry |
| | *Thuja plicata* | western red cedar |
| | *Trifolium sp.* | clover |
| | *Trifolium pretense* | red clover |
| | *Vicia cracca* | tufted vetch |
| **Elevation Band** | **Found in 2010 but not present in 2012** | |
| | **Scientific Name** | **Common Name** |
| 436-438 m | *Brachythecium albicans* | lawn moss |
| | *Cardamine pensylvanica* | Pennsylvanian bitter-cress |
| | *Carex utriculata* | beaked sedge |
| | *Pleurozium schreberi* | red-stemmed feathermoss |
| | *Polytrichum juniperinum* | haircap moss |
| | *Rumex crispus* | curled dock |
| 434-436 m | *Salix sitchensis* | Sitka Willow |
| | *Trifolium repens* | white clover |

Several species were found in 2012 that had not been observed in previous years, mostly in the 436 - 438 meter elevation band. They were almost all weedy or invasive species, or occurred as seedlings. Most of the species that were lost in 2012 were ephemeral, with the exception of Sitka willow.

The 2011 assessments showed recruitment of six species at low elevation, four at middle elevation and three at high elevation. Meadow-foxtails are annual grasses that have been increasing in frequency of occurrence in the reservoir since 2010. Smooth scouring rush, an inundation tolerant species, has also noticeably increased in abundance. Pineapple weed, lady's-thumb and Norwegian cinquefoil are all weedy annuals and well adapted to conditions in the reservoir. The hawkweed, dandelion and white clover are a similar group of annual weeds but are more adapted to the drier sites above the drawdown zone. Their presence in the 438 to 440 m elevation band in 2011 and 2012 may represent a temporary invasion from the drier variants of the Cottonwood Riparian Forest Vegetation Community Type.

In 2012, several species were recruited, seventeen in the 438 - 440 m elevation band, thirteen in the 436 - 438 m band, and four in the 434 - 436 m band. Thus an overall increase in species diversity was observed in 2012 compared to baseline data from 2010.

These results indicate that species diversity fluctuates in the reservoir in the repeated plots, and given the seedling stage of many of the plants at the time of measurement in May, this variation is not surprising. There has been no decline in species diversity since the commencement of REV5. Rather, diversity appears to have increased slightly, particularly in the higher elevation bands, although many of the new species were weedy or invasive. The relationship between REV5 and species diversity in 33 seedling and early season vegetation dominated plots is not strong, and possibly non-existent.

## 4.4 Effects of environmental variables on vegetation

In 2012, redundancy analysis (RDA) was used to define the vegetation character of the repeated plots in Revelstoke Reach and to examine the relative importance of environmental variables including duration of inundation, soil composition, total annual precipitation and scouring. The results of the analysis were consistent with the findings of the RDAs performed as part of the main CLBMON-33 and CLBMON-12 reports (Enns et. al 2010, 2011, 2012). The RDA results are shown in Appendix 2.

Past RDA has shown that vegetation cover is positively associated with soils containing a high percentage of sand and silt, and negatively associated with scouring, abundance of gravels and boulders, and locations with high wave action. Average vegetation height was positively associated with clays, high average daily temperatures, total annual precipitation, high elevation, and with fewer days of inundation. Vegetation height was negatively associated with sheltered locations. The first principal component accounted for 75 per cent of the predicted values of species cover and 65 per cent of the predicted values of species height. Clay is a common feature of the soils of Illecillewaet at low elevation.

Both vegetation cover and height were negatively associated with distance from the Revelstoke dam (Figures 10 and 11). Slopes are similar across all years. Data points are concentrated, reflecting the relative positions of the sampling locations in Revelstoke Reach. Average vegetation cover and height decreased with distance from the dam (Figures 10 and 11). This is due to the presence of dense vegetation including tall shrubs growing in the stable, gravel imbedded clays at the mouth of the Illecillewaet River and on the gravel bars downstream from the mouth of the Illecillewaet.

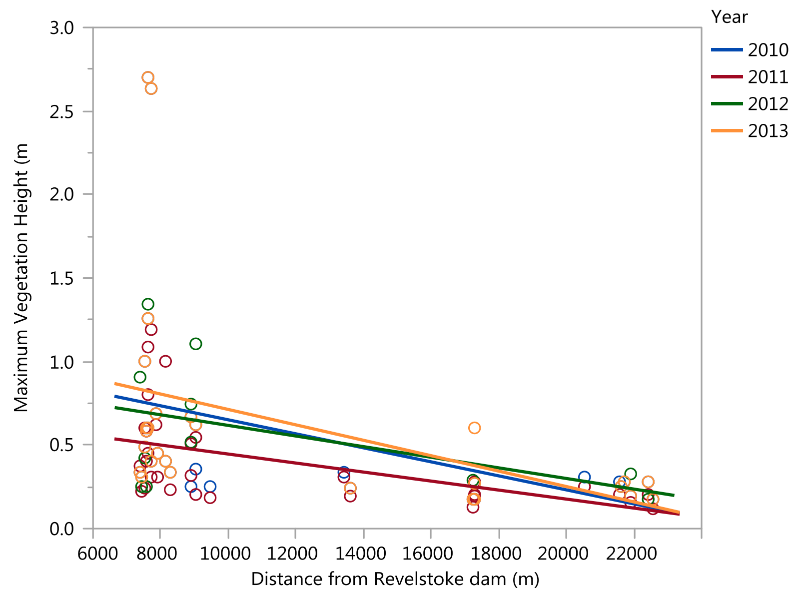



**Figure 10.** **Average maximum vegetation height vs. distance from Revelstoke dam (m), based on data collected from 33 plots sampled in 2010 through 2013. The regression lines are based on the best fit least-squares linear model (Table 6)**

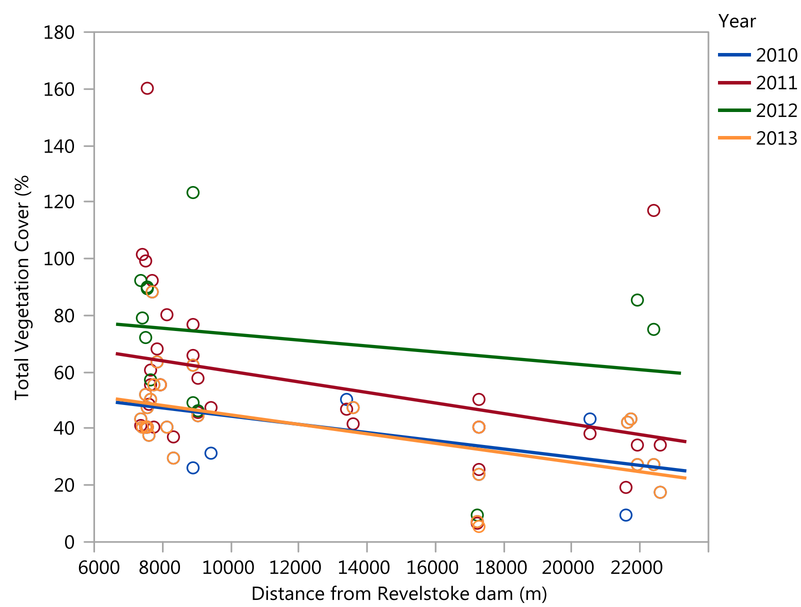



**Figure 11.** **Total vegetation cover vs. distance from Revelstoke dam (m), based on data collected from 33 plots sampled in 2010 through 2013. The regression lines are based on the best fit least-squares linear model (Table 6)**

**Table 6.** **Summary of regression results: average vegetation cover and height *vs.* distance from Revelstoke dam. Non-transformed data were used. Significant results are indicated with an asterisk; n = 33 for each year**

| Year | Rsquare | F Ratio | P value |
|---|---|---|---|
| **Average Vegetation Height** | | | |
| **2010** | 0.1622 | 59,998 | 0.0202* |
| **2011** | 0.2757 | 11.0382 | 0.0024* |
| **2012** | 0.307 | 4.4293 | 0.0616 |
| **2013** | 0.1804 | 5.5043 | 0.0272* |
| **Average Vegetation Cover** | | | |
| **2010** | 0.2971 | 13.1045 | 0.001* |
| **2011** | 0.1094 | 3.5626 | 0.0691 |
| **2012** | 0.1608 | 2.1075 | 0.1745 |
| **2013** | 0.3288 | 12.249 | 0.0018* |

The CR (Cottonwood riparian) and PA (Redtop upland) vegetation community types were consistently found to have the tallest vegetation of all the VCTs in the reservoir, and were mostly confined to elevations above 438 meters (Enns et al. 2010, Enns and Enns 2011, Enns 2012). As mentioned above, patches of shrub dominated PA and CR occur at the junction of the Illecillewaet and the Columbia Rivers at low elevation. These low elevation CR and PA communities are more common close to the Revelstoke dam than they are further south, due to the presence of clay parent materials conducive to their establishment. This suggests that the observed relationship between vegetation height and distance from the dam is due to the distribution of vegetation community types (and parent soil material types) within Revelstoke Reach rather than to changes to the operating regime or the influence of REV5. This conclusion is supported by the fact that both vegetation cover and height decrease with distance from the dam based on the 2010 dataset, which represents the response of reservoir vegetation to operating conditions prior to the completion of REV5. Clay is also important in the support of diverse vegetation at low elevation in the Arrow Lakes portion of the Arrow Lakes Reservoir (Enns et al. 2012).

The mouth of the Illecillewaet River is influenced by flows from the Columbia and the Illecillewaet rivers, and is the CLBMON-12 project study area closest to the Revelstoke Dam[3]. If REV5 is having measurable effects on vegetation, it was assumed they would appear in the vegetation monitoring plots at Illecillewaet. The only consistent change in vegetation has been the decline of Pacific Willow at this location (Enns et al.2012). The reason for this decline is not known.

The most dramatic response in Revelstoke Reach vegetation has been due to site-specific erosion. Figure 12 is a photograph taken south of the mouth of Illecillewaet River, illustrating sloughing of vegetation.

[3] Revelstoke Island plots were not considered representative of Reach 4 as they are sheltered in a backwater away from the effects of scouring.

**Figure 12. Sloughing of soils and vegetation near the Illecillewaet River (from Enns et al. 2012). In 2013, most of the clumps in the failure area had been washed away.**

## 5.0 DISCUSSION

Other than a decline in Pacific Willow in some plots near the Illecillewaet Point, there was no observed response in the vegetation that could be attributed to REV5 operations alone, based on comparison of the 2013 field data to previous years (2010 2011 and 2012). There was a significant increase in average vegetation heights within the 438 to 440 m elevation band and in the total covers of vegetation in the 436 to 438 m band and the 438 to 440 m band. Of the three dependent variables (total vegetation cover, average maximum vegetation height and Shannon-Weiner Diversity Index), only average maximum vegetation height was found to be negatively correlated with length of inundation time. This is most likely a response to the overall operating regime and to environmental variation, and not necessarily a response to REV5. A modest negative association between distance from the dam and both vegetation height and cover was detected. However, this association could not be directly attributed to REV5 operations, and was better explained as a function of deposition of nutrient rich clays and gravels at the entry of the Illecillewaet River, a condition that is repeated to a lesser extent by other stream entries into the Columbia River downstream.

## 6.0 CONCLUSIONS

The only evidence of an impact of REV5 was observational in nature. An increased turbidity and water energy and higher fluctuation in water levels were observed at the mouth of the Illecillewaet in 2012 and again in 2013. The backwater at Illecillewaet Point fills quicker than other backwaters in Revelstoke Reach. This may be the cause of decline of Pacific Willow.

Isolating the effects of REV5 operation from reservoir-wide inundation effects and the effects of the annual variability in environmental variables is not possible within the framework of the CLBMON studies. There are several factors contributing to uncertainty in this study. There were only 33 plots repeatedly measured over four years. These plots were split between 6 types and spread over 3 elevations. At the time of the sampling, between May 12 to June 12, many of the plants were at the cotyledon stage (i.e. between 1 to 3 cm high). These plants grow as we completed the measurements. They do not represent the final annual vegetation outcome, which attains a maximum growth in August to October, depending on climate and exposure (Enns, 2012). Therefore, any suppositions regarding annual trends in the data are tenuous.

The strongest evidence of any trend in vegetation community dynamics in the REV5 study is that the vegetation responds positively or negatively to certain soil and climatic conditions and to water energy and scouring effects (RDA results). These results were similar to the larger overarching annual CLBMON studies. This study indicates that the Illecillewaet River entry plots at the top of the study area have higher heights than further downstream, because of nutrient rich clays and gravels being deposited out on the drawdown zone and allowing shrubs to establish at very low elevation.

From the analysis of field measurements collected in 2010 through 2013, no significant decreases in vegetation cover, height or diversity were found following the onset of REV5 operations in December, 2010. None of the observed changes in cover, heights or diversity can be linked to REV5 operations. The differences are just as likely due to differences in environmental variables, such as average precipitation and mean annual temperature, between field seasons. It is possible however that the effects of changes in inundation duration and depth may not yet be distinguishable from baseline conditions.

## 7.0 RECOMMENDATIONS

The REV5 study should be independent of the CLBMON-12 and CLBMON-33 study design. It should use a larger sample size of repeated measures in geographic areas known to be subjected to the increased velocity of flows from REV5. It should be conducted at the appropriate time of year for vegetation measurements (early fall if possible), consider the response of plants to scouring and not be dependant only response variables typically used in terrestrial studies (covers, heights, diversity). Variables could include patch loss, physical damage, mortality, soil movement and plant removal.

Aerial photographic comparisons using imagery from 2007 and 2010 showed isolated effects of scouring on the vegetation in CLBMON-33 (Enns and Enns draft report 2011). Aerial photography from previous to 2010 is likely available and could be used to identify and describe changes in vegetation and soils near REV5. The use of comparisons of serial aerial photography in combination with ground truthing can be used to document the actual impacts of REV5 on vegetation.

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## Appendix 1: Vegetation community types (VCTs) found in the Revelstoke Reach study area

### Table A1. VCTs found in the Revelstoke Reach portion

| | |
|---|---|
| **BE: Sandy beach**: sandy, mostly non-vegetated to sparsely vegetated with herbaceous plants, seedlings and grasses, occasionally with sedges and mosses. |  |
| **BG: Gravelly beach**: sparsely vegetated mid-slope gravels with grasses and herbaceous plants, especially drought-tolerant weeds and occasionally small cottonwood and willows. |  |
| **CR: Cottonwood riparian**: upland forest edge on relatively deep, occasionally bouldery soils. Includes some managed lands. |  |
| **PA: Redtop upland**: gravelly to sandy upper-elevation beaches, often with remnants of former forested or farmed soils, dominated by shrubs and several species of grasses, drought-tolerant herbs, mosses, lichens and several species of weeds. |  |
| **PC: Reed canary grass mesic**: silt and sand substrate, mostly flat beaches; comparatively species=poor, and dominated by reed canary grass but can include a minor component of mint, horsetail and agronomic species. |  |
| **PE: Horsetail lowland**: lowest-elevation VCT with dense, silty soils often poorly drained and receiving moisture from the reservoir, dominated by wetland species including sedges, rushes and reeds. |  |

**RR: Reed – rill**: submerged seepage tracks extending from high elevation to the reservoir edge, occasionally upwelling, and dominated by herbs, liverworts, wetland grasses, mosses, sedges, rushes and reeds. Uncommon, but does occur in Revelstoke Reach.

## APPENDIX 2: Detailed Analysis of Variance Results (2013)

### Comparisons Among Sampling Years (2010 - 2013)

Average Vegetation Cover by Year (2010 - 2013):
q = 2.605 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| 2012 | 2010 | 29.09091 | 6.394227 | 12.4314 | 45.75045 | <.0001* |
| 2012 | 2013 | 27.79764 | 6.740107 | 10.2369 | 45.35834 | 0.0004* |
| 2011 | 2010 | 16.78977 | 6.496541 | -0.1363 | 33.71588 | 0.0527 |
| 2011 | 2013 | 15.49650 | 6.837248 | -2.3173 | 33.31029 | 0.1118 |
| 2012 | 2011 | 12.30114 | 6.496541 | -4.6250 | 29.22726 | 0.2363 |
| 2013 | 2010 | 1.29327 | 6.740107 | -16.2674 | 18.85397 | 0.9975 |

Average Vegetation Height by Year (2010 - 2013):
q = 2.606 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| 2012 | 2011 | 0.2968577 | 0.1394151 | -0.066418 | 0.6601334 | 0.1498 |
| 2013 | 2011 | 0.2188921 | 0.1456286 | -0.160574 | 0.5983584 | 0.4389 |
| 2010 | 2011 | 0.1601892 | 0.1383718 | -0.200368 | 0.5207463 | 0.6546 |
| 2012 | 2010 | 0.1366685 | 0.1372525 | -0.220972 | 0.4943090 | 0.7521 |
| 2012 | 2013 | 0.0779656 | 0.1445655 | -0.298730 | 0.4546617 | 0.9492 |
| 2013 | 2010 | 0.0587029 | 0.1435596 | -0.315372 | 0.4327779 | 0.9768 |

Average Vegetation Diversity by Year (2010 - 2013):
q = 2.606 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| 2012 | 2010 | 0.3822943 | 0.1719187 | -0.065676 | 0.8302649 | 0.1228 |
| 2011 | 2010 | 0.3689592 | 0.1733207 | -0.082665 | 0.8205831 | 0.1500 |
| 2012 | 2013 | 0.2317742 | 0.1810787 | -0.240065 | 0.7036133 | 0.5774 |
| 2011 | 2013 | 0.2184391 | 0.1824104 | -0.256870 | 0.6937481 | 0.6296 |
| 2013 | 2010 | 0.1505201 | 0.1798188 | -0.318036 | 0.6190761 | 0.8367 |
| 2012 | 2011 | 0.0133351 | 0.1746275 | -0.441694 | 0.4683643 | 0.9998 |

### Comparisons Among Elevation Bands

Average Vegetation Cover by Elevation Band:
q = 2.3729 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| 436-438 | 434-436 | 8.066891 | 6.198255 | -6.6411 | 22.77493 | 0.3971 |
| 438-440 | 434-436 | 5.496970 | 6.998061 | -11.1090 | 22.10289 | 0.7126 |
| 436-438 | 438-440 | 2.569922 | 6.198255 | -12.1381 | 17.27796 | 0.9097 |

Average Vegetation Height by Elevation Band:
q = 2.3732 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| 438-440 | 434-436 | 0.6612033 | 0.1251983 | 0.364085 | 0.9583211 | <.0001* |
| 438-440 | 436-438 | 0.4236438 | 0.1111235 | 0.159928 | 0.6873596 | 0.0006* |
| 436-438 | 434-436 | 0.2375595 | 0.1100331 | -0.023569 | 0.4986877 | 0.0826 |

Average Vegetation Diversity by Elevation Band:
q = 2.3732 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| 434-436 | 438-440 | 0.2181108 | 0.1731805 | -0.192877 | 0.6290988 | 0.4209 |
| 436-438 | 438-440 | 0.1951900 | 0.1538749 | -0.169982 | 0.5603624 | 0.4157 |
| 434-436 | 436-438 | 0.0229208 | 0.1538749 | -0.342252 | 0.3880932 | 0.9878 |

## Comparisons Among Vegetation Community Types

Average Vegetation Cover by VCT:
q = 2.7723 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| PE | BE | 57.16250 | 12.44105 | 22.6769 | 91.64812 | 0.0001* |
| PE | IN | 55.15417 | 8.49885 | 31.5960 | 78.71233 | <.0001* |
| PA | BE | 43.75625 | 12.44105 | 9.2706 | 78.24187 | 0.0056* |
| PA | IN | 41.74792 | 8.49885 | 18.1898 | 65.30608 | <.0001* |
| PC | BE | 31.94169 | 11.43677 | 0.2398 | 63.64353 | 0.0473* |
| PC | IN | 29.93336 | 6.94626 | 10.6789 | 49.18786 | 0.0003* |
| PE | PC | 25.22081 | 6.15889 | 8.1488 | 42.29278 | 0.0007* |
| PE | PA | 13.40625 | 7.86841 | -8.4044 | 35.21687 | 0.4357 |
| PA | PC | 11.81456 | 6.15889 | -5.2574 | 28.88653 | 0.3136 |
| IN | BE | 2.00833 | 12.84906 | -33.6083 | 37.62493 | 0.9999 |

Average Vegetation Height by VCT:
q = 2.7723 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| PA | BE | 0.7430265 | 0.2707802 | -0.007662 | 1.493715 | 0.0538 |
| PA | IN | 0.6880553 | 0.1849781 | 0.175237 | 1.200873 | 0.0028* |
| PE | BE | 0.5540536 | 0.2707802 | -0.196635 | 1.304742 | 0.2511 |
| PE | IN | 0.4990824 | 0.1849781 | -0.013736 | 1.011900 | 0.0605 |
| PA | PC | 0.4378196 | 0.1342246 | 0.065706 | 0.809933 | 0.0125* |
| PC | BE | 0.3052069 | 0.2490168 | -0.385147 | 0.995561 | 0.7365 |
| PC | IN | 0.2502357 | 0.1513419 | -0.169332 | 0.669804 | 0.4669 |
| PE | PC | 0.2488467 | 0.1342246 | -0.123267 | 0.620960 | 0.3483 |
| PA | PE | 0.1889729 | 0.1712564 | -0.285804 | 0.663750 | 0.8044 |
| IN | BE | 0.0549712 | 0.2796606 | -0.720337 | 0.830279 | 0.9997 |

Average Vegetation Diversity by VCT:
q = 2.7723 alpha = 0.05

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| PA | PC | 0.7148762 | 0.1851054 | 0.201705 | 1.228047 | 0.0017* |
| IN | PC | 0.4392672 | 0.2033124 | -0.124379 | 1.002914 | 0.2024 |
| PE | PC | 0.3881220 | 0.1802665 | -0.111634 | 0.887878 | 0.2054 |
| PA | BE | 0.3691041 | 0.3665606 | -0.647118 | 1.385327 | 0.8517 |
| BE | PC | 0.3457721 | 0.3347465 | -0.582252 | 1.273796 | 0.8396 |
| PA | PE | 0.3267542 | 0.2341099 | -0.322273 | 0.975781 | 0.6317 |
| PA | IN | 0.2756090 | 0.2522843 | -0.423803 | 0.975021 | 0.8101 |
| IN | BE | 0.0934952 | 0.3760833 | -0.949127 | 1.136118 | 0.9991 |
| IN | PE | 0.0511452 | 0.2487557 | -0.638485 | 0.740775 | 0.9996 |
| PE | BE | 0.0423500 | 0.3641411 | -0.967165 | 1.051865 | 1.0000 |

**RDA Results from previous REV5 Reports**

**Table 6. Environmental variables used in RDA analysis. Variable names are given as they appear in the RDA summary plot in Figure 11 (Enns et al. 2012)**

| Variable Name | Explanation of Variable |
|---|---|
| Sand | % sand in soil material |
| Silt | % silt in soil material |
| Clay | % clay in soil material |
| Gravels | % gravel in soil materials |
| Boulders | % boulders in soil materials |
| wave ridges | visible wave action effects at ground level (binary) |
| scouring | visible scouring effects at ground level (binary) |
| sheltered | plot physically sheltered from main channel (binary) |
| DistToDam | Straight line distance (m) from dam to plot centroid |
| AVGTMP | average daily temperature of plot while exposed |
| TOTPCP | total precipitation near plot while exposed |
| EXPTIME | number of days plot was exposed (not inundated) per year |
| ELEV_M | elevation of plot centroid (m above sea level) |
| exposed | plot is exposed to main channel when inundated (binary) |

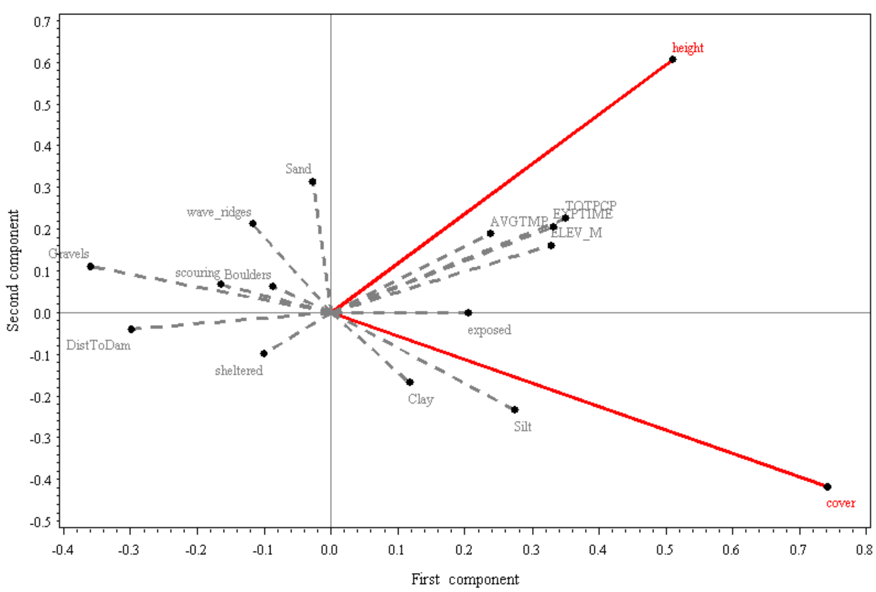


**Figure 10. RDA biplot of total cover and height, and environmental variables from 33 plots in the Revelstoke Reach portion of the Arrow Lakes Reservoir. The dotted line vectors represent environmental variables, vectors that point in the same direction can be considered to have similar effects on the vegetation variables (cover and height). The lengths of the environmental variable vectors indicate the relative strengths of their effects. AVGTEMP = average temperature over the exposure period for the plot in Celsius, ELEV = meters above sea level as a centroid measure, EXPTIME = amount of time in days the plot was exposed and above water, TOTPCP = accumulated precipitation (mm) during exposure, exposed = water supplies from upslope, sheltered = topographic sheltering from scouring or waves. Enns et al. 2012**