Columbia River Project Water Use Plan

Kinbasket and Arrow Lakes Reservoir Recreation Management Plan

Mid-Columbia River Bank Erosion Protection and Monitoring Program

Implementation Year 5

Reference: CLBWORKS #35

Final Report

Study Period: 2009 to 2015

Kerr Wood Leidal Associates Ltd.
200 – 4185A Still Creek Drive
Burnaby, BC
V5C 6G9
(604) 294-2088

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Executive Summary

This report provides a summary of the BC Hydro program CLBWORKS #35. This program was initiated in 2009 after a multi-stakeholder review of the Columbia River Water Use Planning (WUP) process in response to the proposed installation of a fifth generating unit at Revelstoke Dam. CLBWORKS #35 is part of a large suite of physical works and monitoring projects developed under the WUP for the Columbia River system. 2015 is the final year of monitoring on CLBWORKS #35.

The purpose of CLBWORKS #35 is to implement and test the performance of bioengineering treatments to reduce erosion in sections of the Columbia River downstream of Highway 1, with a total of 400 m of bioengineering works required under the Terms of Reference. Four bioengineering sites were selected in the reach approximately 800 m to 4.6 km downstream of the Highway 1 bridge. Three of the sites were further split to increase the total number of samples in the statistical analysis (N = 7). Construction of the bioengineering works was completed in 2012.

The bioengineering treatments feature a combination of slope re-grading and biotechnical slope stabilization techniques, including: plantings, using vegetated soil wraps and brush layers, and creating higher elevation soil mounds and planting them with upland trees and shrubs to promote long-term bank stability.

Table E-1: CLBWORKS #35: Status of Objectives, Management Questions & Hypotheses after Year 4

Objectives	Management Questions	Management Hypotheses	Year 4 (2015) Status
The primary objective of this program is to develop, implement and monitor bioengineering erosion protection measures at selected sites along the Mid-Columbia River between the TransCanada Highway Bridge and Begbie Creek.	“The present document [CLBWORKS #35 Terms of Reference] is solely concerned with the installation of bank erosion protection measures and monitoring to quantify the benefits of these mitigative measures.”	**H_0**: Shoreline erosion does not differ significantly ($\alpha = 0.05$, $\beta = 0.8$) between sites with bioengineering works and sites without such measures.	**Erosion pin data**: • Both erosion and deposition were observed at treatment and control sites (Figure 4-1, p. 4-7) • Although treatment sites show higher average erosion than control sites, **H_0 cannot be rejected** for the 2011 to 2015 period (Table 4-2, p. 4-8). **Cross-section data**: • Both erosion and deposition were observed at treatment and control sites but cross-section data indicate greater erosion at treatment sites than control sites (Figure 4-2, p. 4-9). • **H_0 is rejected** for the 2011 to 2015 time period (Table 4-4, p.4-10).

Study results from 2011 to 2015 indicate that untreated sites eroded less than treated sites. These results are counterintuitive but may suggest that a strictly bioengineering treatment is not sufficiently robust for these sites. Bioengineering relies on the ability of the plantings (which impart strength to the bank) to survive and thrive in this harsh weather and water environment. Site water level records indicate that the effects of long duration inundation from Arrow Lake Reservoir and rapid fluctuation of local water levels due to hydropeaking are substantial, causing logistical challenges for in-stream construction as well as a potential limitation for establishment and growth of plantings due to a short growing season.

Future bioengineering designs in this reach should consider limiting plantings to a sufficiently high, site-specific, elevation where growth is unlikely to be compromised, and to incorporate additional ‘hard’ elements at lower elevations that are capable of withstanding the observed inundation and discharge fluctuations typical of this environment.

1. Introduction

This report provides a summary of BC Hydro program CLBWORKS #35. The purpose of CLBWORKS #35 is to provide information regarding bank erosion along the mid-Columbia River downstream of the Revelstoke Dam. The management question of interest for CLBWORKS #35 is:

- Does the installation of bioengineering bank protection works result in a significant decrease in bank erosion?

1.1 Background

The proposed installation of a fifth generating unit at Revelstoke Dam resulted in a multi-stakeholder review of the Columbia River Water Use Planning (WUP) process.

As a result of the WUP review, it was recommended that two programs be undertaken:

- **CLBWORKS #35**: Develop and implement a bank erosion monitoring and mitigation program to identify and address current and future shoreline erosion concerns attributable to the Revelstoke Unit 5 project downstream of Revelstoke Dam (mid-Columbia River between the TransCanada Highway Bridge and Begbie Creek; locations shown in Figure 1-1).
- **CLBWORKS #36**: Monitor long-term erosion rates along the mid-Columbia River from Revelstoke Dam downstream to Shelter Bay (study reach location shown in Figure 1-1).

Given the complementary nature of the two studies, these two physical works programs were combined into one project, which BC Hydro awarded to Kerr Wood Leidal Associates Ltd. (KWL) in summer 2009. The fifth generating unit at Revelstoke Dam became operational in December 2010.

No work was scheduled or performed on CLBWORKS #36 in 2015. As such, this report concerns CLBWORKS #35 only. Year 4 is the final year of CLBWORKS #35 (see Table 1-1 and Table 1-2).

1.2 Project Schedule

Table 1-1 summarizes the project schedule for CLBWORKS #35.

Table 1-1: CLBWORKS #35 Project Schedule

Year	CLBWORKS#35	Month
2009	Y1 – Site Selection	August-September
2010	Y1 – Design Entry in operation, REV5	January - June December
2011	Y1 – Permitting Y1 – Bioengineering Construction • Site A1 • Site A2 • Site B • Site C Y1 – Monitoring • All sites	April – May October October (completed) October (completed) October November
2012	Y2 – Completion of Bioengineering Construction • Site A1 • Site C Y2 – Monitoring • A1 • A2, B & C	 May May June April
2013	Y3 – Monitoring	April
2014		
2015	Y4 – Monitoring	April

1.2.1 2015 Work

Project work completed during 2015 is summarized in the following table.

Table 1-2: 2015 Work Program (CLBWORKS #35)

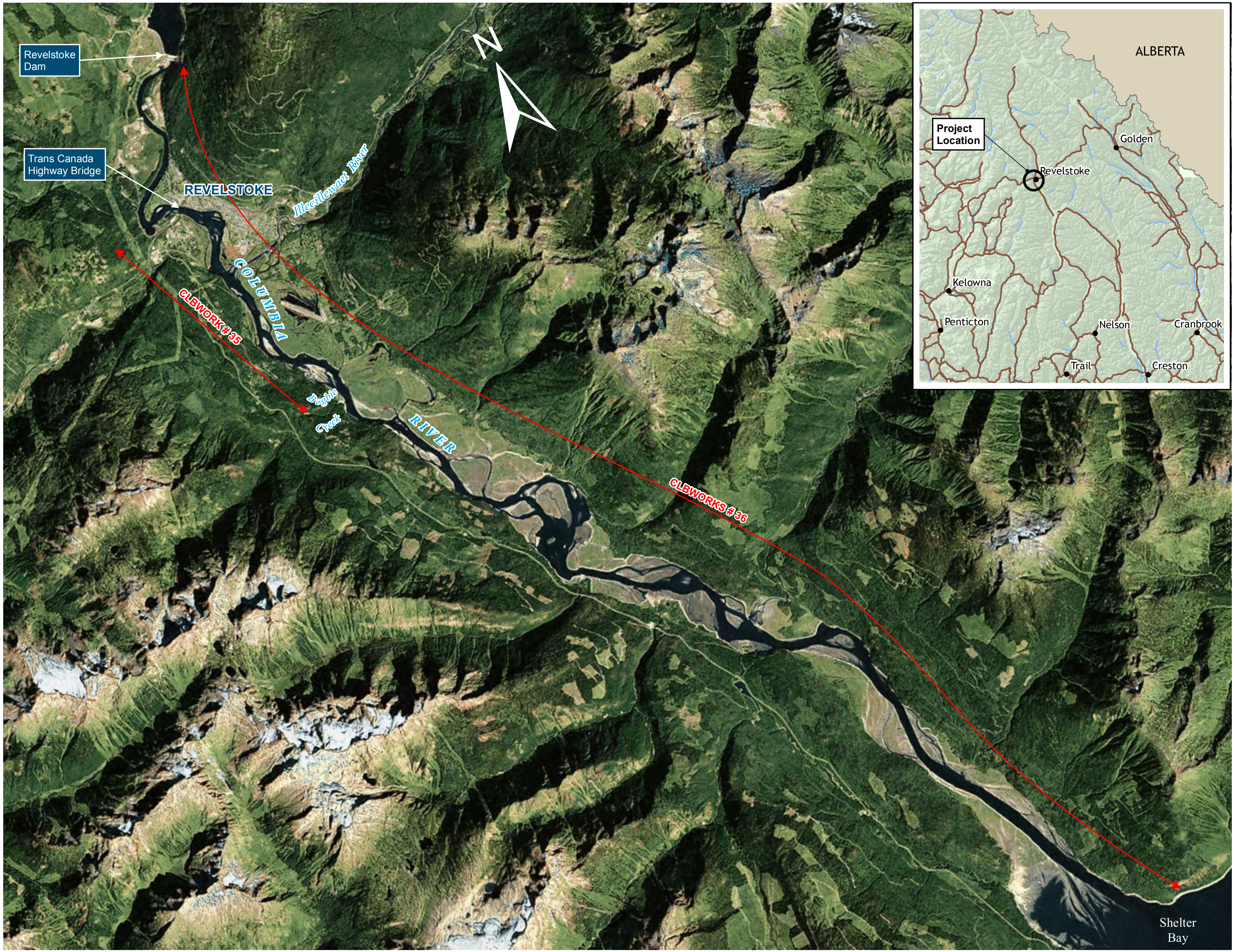
Task	Description
Bioengineering Works (Y4 - Monitoring)	• Measurement of Erosion Monitoring Pins • Cross-section surveys
2015 Data Entry and Analysis	• Populate GIS Database • Data Analysis
2015 Final Report	• Final Report for CLBWORKS #35

1.3 Project Team

Key project personnel for this project include KWL staff and sub-consultants listed in Table 1-3.

Table 1-3: **Key Project Personnel**

Name, Organization	Title	Project Role
Erica Ellis, M.Sc., P.Geo. – KWL	Fluvial Geomorphologist	Project Manager
Dave Murray, AScT, CPESC, P.Eng. – KWL	Senior Water Resources Engineer	Senior Technical Review
Sarah Lawrie, M.A.Sc., P.Eng. – KWL	Environmental Water Resources Engineer	Bioengineering Design Erosion Assessment
Jack Lau – KWL	GIS Specialist	GIS
Peter Tapp, Civil Technologist – KWL	Survey Coordinator	Survey Oversight and Coordination
Bruce VanCalsteren – KWL	Survey Technologist	Topographic Survey and Field Data Collection
Tony Minchenko – KWL	Technologist	Topographic Survey and Field Data Collection
Nick Page, B.L.A., M.Sc., R.P.Bio. (Raincoast Applied Ecology)	Professional Biologist	Planting Design
Leska S. Fore, M.S., M.A. (Leska, S. Fore, Statistical Design)	Statistician	Statistical Design Statistical Analysis of Erosion Monitoring Data



BC Hydro
CLBWorks No. 35 and 36
Mid-Columbia Erosion Protection
and Long Term Monitoring

Reference: Orthophoto from Bing aerial image map.

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2,500 0 2,500 (m)
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Project No.	Date
478-081	November 2011

Location Plan

Figure 1-1

Path: O:\0400-0499\478-081\430-GIS\MXD-Rp\2011\478081Fig1-1.mxd Date Saved: 11/29/2011 1:32:23 PM
Author: jlau

2. CLBWORKS #35 Design

The purpose of CLBWORKS#35 is to implement and test the performance of bioengineering treatments on sections of the Columbia River at Revelstoke between Highway 1 and Bebgie Creek.

A field investigation was undertaken in August and September 2009 to identify appropriate sites for the bioengineering study. Potential treatment sites were selected to include the following key characteristics:

1. active erosion at the site;
2. access and appropriate site conditions to facilitate construction; and
3. the most potential for treatment success given frequent inundation in the area.

Paired control sites also were identified based on similarity of hydraulics, location, and site conditions (e.g., bank angle, bank composition, and existing vegetation).

Given the natural variability of the environment, it should be noted that it is almost impossible to have control sites that are perfect replicates of the treatment sites but differences were minimized through site selection.

2.1 Study Design

BCH Terms of Reference (ToR) specified a regulatory goal of a total of 500 m of constructed bioengineering works (paired design: 2 X 250 m treatment sites, two paired control sites). As this yields a sample size of N = 2, KWL initially proposed that the number of sites be increased to four in order to increase the sample size (N = 4). The increase in number of sites was off-set by a decrease in length (sites ranged between 100 m and 180 m in length).

N equal to four is a very small sample size and it would be difficult to detect change with this sample size. For this reason, the three bioengineered (treatment) sites were divided into two parts, and three additional control sites were added. The treatment sites were split to increase the sample size and to avoid increasing the installation work required to treat another site. It should be noted that even the sites that are not contiguous are quite close and it would be difficult to make a case that sites B and C, for example, are independent in terms of river processes (and therefore pseudoreplication is a possible issue).

Splitting the sites means that they are contiguous. Close proximity increases the potential for a similar response at different sites due to similar processes operating on the site. The greatest concern with sites that are not independent is that they will have similar outcomes and artificially inflate the power to detect a difference by increasing the sample size and lowering the statistical difference that is significant. If a significant difference is detected between treatment and control sites, a check will be performed to see if sites that are closest to each other are exhibiting a similar pattern of change. If so, consideration will be given to combining the split sites back into a single site and testing for statistical significance. This is discussed further in Section 4.

The revised, final design splits three of the four sites (A1, A2 and C) by locating the bioengineering treatment in the middle of the site with control sections at either end (Figure 2-1). Site B is not split. The bioengineering treatment section is divided and paired with its adjacent upstream or downstream control section. Thus, each split site yields two comparisons rather than one, which yields a total sample size of N = 7.

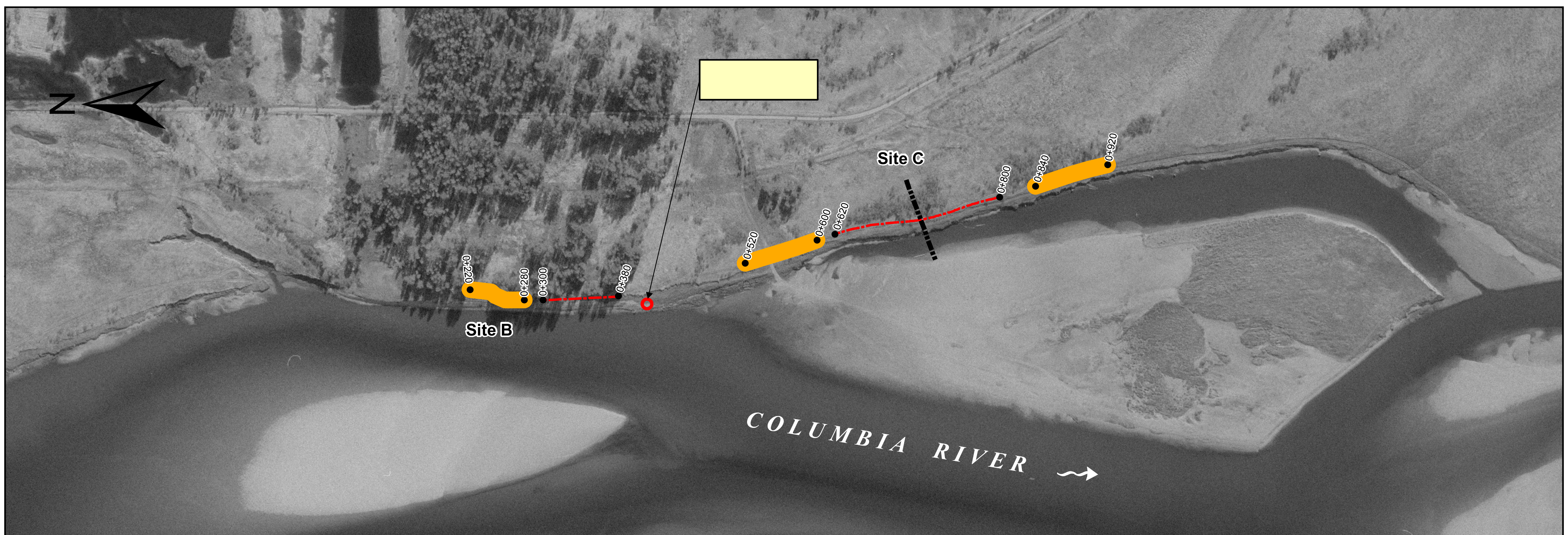
A sample size of 7 is relatively small. Based on the observed standard deviations of the 2011 to 2013 data, minimum detectable differences were estimated for this study ($n = 7$, $\alpha = 0.05$, $\beta = 0.2$). Estimated minimum detectable differences are as follows:

- Erosion pin data: range from about 1 cm to about 3 cm,
- Cross-section data: range from about 0.3 m to about 0.4 m.

For erosion pins, these minimum detectable differences appear to be reasonable in light of the expected magnitude of actual erosion and deposition, and the resolution of the pin measurements (about 0.5 cm). In the case of the cross-section measurements, some of the mean measurements are on the order of the minimum detectable difference (or less than the minimum detectable difference), suggesting that it may be challenging to detect statistically significant differences between control and treatment sites.

Statistical analysis for the most recent monitoring period (2013 to 2015) and the full project period (2011 to 2015) is presented in Section 4.

Sites A1/A2



Sites B/C

CLBWorks No. 35 and 36
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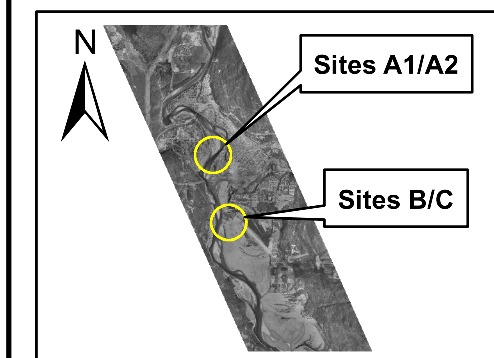
and Long Term Monitoring

Legend

Bio-engineering Treatment

Control

Bioengineering Site Split Location



Reference: 2007 Orthophoto from BC Hydro.

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Project No.	Date
478-081	October 2013

Location of Bioengineering and Control Sites

Figure 2-1

2.2 Bioengineering Treatments

The bioengineering treatments feature a combination of slope re-grading and biotechnical slope stabilization techniques. In general, the biotechnical bank stabilization treatments include:

- planting the lower elevations with willow stakes, grasses and sedges,
- using vegetated soil wraps and brush layers along the upper elevations, and
- creating higher elevation soil mounds with the spoil material and planting them with upland trees and shrubs to promote long-term bank stability.

Bank geometry and configuration resulted in some differences in bioengineering treatments between sites as summarized in Table 2-1.

Table 2-1: Bioengineering Treatment Summary

Site	Treatment
Sites A1, A2 & C	• Re-grading of bank • Willow live staking • Vegetated soil wraps and willow brush layers placed along upper elevations • Soil mounds created on upland areas and planted with native shrubs and trees
A1	• Large wood and boulder clusters installed in lower bank • Aquatic bench planted with grasses and sedges constructed mid-bank
B	• Modified brush layers only

Appendix A includes detailed record drawings of the constructed bioengineering works. A complete list of plant species (including Latin names) and planting distribution is provided in Drawing SD1 (*Mid-Columbia River Bank Protection Works BC Hydro Standard Details*; Appendix A).

Timeline

Detailed design of the bioengineering works and preparation of construction specifications were completed in 2010. The construction of bioengineering works was initiated in October 2011 following approval by BC Hydro. The bulk of the bioengineering works for CLBWORKS #35 Sites A1, A2, B and C were installed in October and November 2011. However, due to elevated water levels in fall 2011, isolated low water work (comprising large wood, boulder installation, and aquatic bench creation) was delayed until May 2012, once snow had left the floodplain.

Additional bioengineering works installed in 2012 include;

- placement of large woody debris (LWD) in the lower elevations of Site A1;
- re-grading of two sections of over-steepened banks in the downstream section of Site C; and
- selective willow live staking at Site A1, as well as planting of potted plants in the upper bench regions of Sites A1 to C.

The erosion monitoring pins were installed in the bioengineering and control sites in November 2011 and measurements were first taken in April 2012. Lower-elevation erosion monitoring pins at Site A1 were installed after the completion of construction in April 2012.

The following tables summarize the timing of construction and topographic surveys for each site.

Table 2-2: Construction Period for Each Bioengineering Site

Site Name	Construction Period
Site 'A1'	October 31, 2011 May 6 to 14, 2012
Site 'A2'	October 26 to 31, 2011
Site 'B'	October 14 to 20, 2011
Site 'C'	October 21 to 26, 2011 May 17th, 2012

Table 2-3: Timing of Topographic Surveys at Each Site

Site	Dates of Topographic Survey				
Site 'A1'	Sept 16-24, 2009	Nov. 9-10, 2011	**Jun. 5, 2012**	**Apr. 23-24, 2013**	**Apr. 21-23, 2015**
Site 'A2'	Sept 16-24, 2009	**Nov. 9-10, 2011**	**Apr. 17 & 25, 2012**	**Apr. 23-24, 2013**	**Apr. 21-23, 2015**
Site 'B'	Sept 16-24, 2009	**Nov. 9-10, 2011**	**Apr. 17 & 25, 2012**	**Apr. 23-24, 2013**	**Apr. 21-23, 2015**
Site 'C'	Sept 16-24, 2009	Nov. 9-10, 2011	**Apr. 17 & 25, 2012**	**Apr. 23-24, 2013**	**Apr. 21-23, 2015**

Note:
Cells shaded in grey are pre-construction surveys. **Bold text** indicates surveys conducted after construction was completed. 2012 survey at Site C includes some cross-sections at which construction was complete, and some at which it was not.

3. 2015 Site Observations

Field measurements of the bioengineering treatment and control sites were conducted on April 21 to 23, 2015. Field conditions during 2015 monitoring were favourable. Dry weather and low river levels facilitated the location and measurement of erosion pins, and cross-section surveys.

Site observations from 2015 are summarized in Appendix B, including photos.

2015 measurements were added to the project database and provided to the project statistician for analysis, which is presented in Section 4.

4. Statistical Analysis

A total of seven sites were treated with bioengineering methods designed to provide erosion resistance. Each site was paired with a control site that was not treated. The site pairs were evaluated for change (erosion or deposition), by measuring:

- the length of exposed pins in subsequent years; and
- the change in horizontal distance between repeat surveys of cross-sections.

The following sections summarize the methodology of the field (and office) measurements, and the statistical analyses of the erosion pin and cross-section data.

4.1 Measurement Methods

Erosion Pins

The erosion pins are metal pins (re-bar) that are hammered into the bank material, perpendicular to the local bank angle. Each pin has a unique identifier tag.

Photo 4-1: Example Erosion Pin Showing Identifier Tag (April 2012).

Photo 4-2: Erosion Pin Covered by Deposition of Sediment (April 2012).

When first placed in the bank, the length of pin protruding beyond the bank is measured. During subsequent rounds of measurements, the pins are located and the length of pin extending from the bank (or depth of burial) is recorded: the change in the bank is the difference in exposed pin length from one measurement to the next (on the same pin). As erosion progresses, exposing more of the pin, pins are re-set into the bank and the new ‘baseline’ is measured.

The site mean change (erosion or deposition) is calculated as the average of all the pin changes measured over the specified time period.

Toppled Erosion Pins

Occasionally rapid erosion will result in the pin ‘toppling’, in which case no measurement can be made and the pin is re-set (but noted to be toppled). In previous CLBWORKS #35 progress reports, toppled pins were not included in the statistical analysis because the amount of erosion that actually occurred was unknown: the erosion that occurred prior to toppling, as well as the erosion (or deposition) that may have occurred while the pin was toppled. As well, it is possible for toppling to occur as a result of human or animal intervention. However, by not including the toppled pins, for sites at which rapid (natural) erosion is likely to have resulted in pin toppling, rates of erosion based on pins will have a bias that will yield lower rates of erosion than the "true" rate. This is likely to be reflected in discrepancies between the erosion rates estimated based on cross-sections vs. those based on pins.

For the final year of CLBWORKS #35 we have assumed a nominal erosion of 50 cm for toppled pins and incorporated the toppled pin results into the analysis. The erosion allowance for toppled pins is based on evaluating the exposed length data from all pins at all sites through all sampling events. Based on our observed data, the longest length of exposed pin for un-toppled pins is 50 cm (total pin length is 60 cm). Therefore, it was decided that toppling was more likely once the exposed length of pin is greater than 50 cm. Assuming a nominal erosion value of 50 cm for toppled pins appears to be reasonable in light of the observed pin length data.

Cross-Sections

For each treatment/control site pair, multiple cross-sections were also surveyed at each site and changes evaluated between different time periods on each cross-section. The surveyed cross-sections document distance and corresponding elevation (i.e., X, Y) from the top of the bank to the river's edge. The end point of each cross-section line was marked by a survey benchmark placed on the bank so that the same location on the bank could be measured during each cross-section survey.

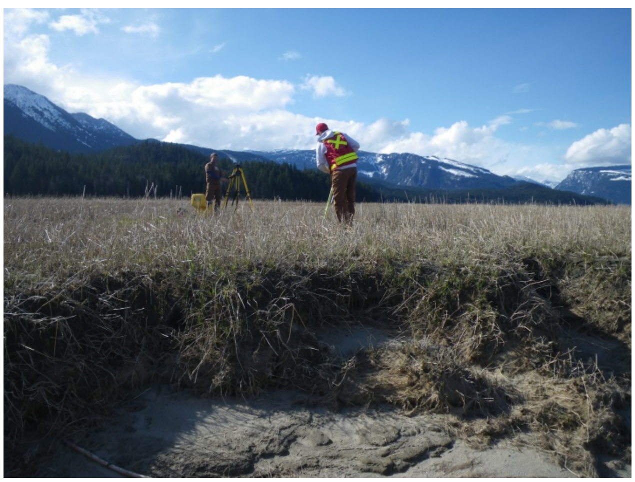


Photo 4-3: Typical Topographic Survey of Cross-Section (April 2012).

Photo 4-4: Layout of Cross-section Line (Rope, indicated) (April 2013).

To make comparisons of the cross-sections through time, measurements were made between cross-sections at three points on the cross-section line. The points were defined by dividing the total height of each cross-section into three equal ranges from the highest elevation (at the top of the bank) to the lowest elevation (at the river edge). The measurement approach is shown schematically in Figure 4-1.

As indicated in Figure 4-1, if the surveyed elevation along a cross-section ranged from 400 m to 415 m, the total elevation range of 15 m would be divided into three equal elevation bands as follows:

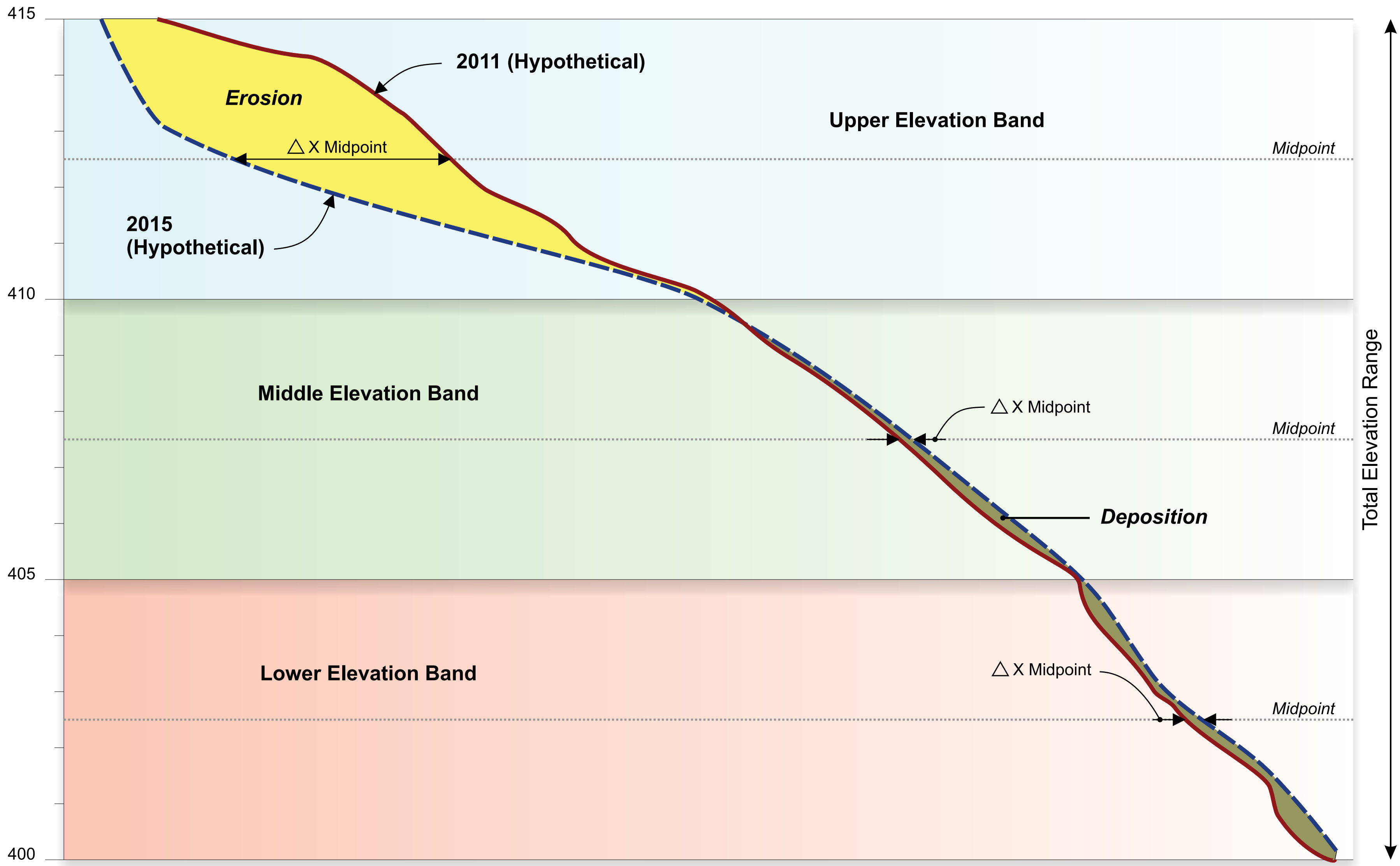
- **lower elevation band**: 400 m – 405 m;
- **middle elevation band**: 405 m – 410 m; and
- **upper elevation band**: 410 m – 415 m.

'Round' numbers have been used to illustrate this example: the actual elevations that define the upper, middle and lower elevation band at a given cross-section vary between cross-sections and sites.

Bank erosion or deposition between years was calculated for each elevation band (lower, middle and upper) at the midpoint elevation of each band, yielding the measurement "Δx midpoint". Δx midpoint is negative for erosion, and positive for deposition. This is illustrated graphically in Figure 4-1.

For each site, the mean Δx midpoint was calculated as the average of all the individual cross-section Δx midpoint values. The mean value is used because this is a physical measurement. Measures such as height, width, and length are usually summarized with simple averages (means) because they typically follow a normal distribution. When the underlying processes that created the measures of interest tend to be distributed as non-normal, for example, with many high values, a median value may be used. For deposition and erosion, we assumed that measures are normally distributed because they can increase or decline by similar amounts, and because the data did not include extreme values.

In the hypothetical cross-section shown in Figure 4-1, the overall result for the cross-section indicates erosion because there is a large amount of erosion in the upper elevation band and smaller amounts of deposition in the middle and lower elevation bands.



Demonstration of Cross-Section Analysis to Measure Erosion/Deposition

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Figure 4-1

4.2 Results – Erosion Pins

Statistical Model

The statistical model used to evaluate change in site condition is a before/after control/impact design (BACI; Stewart-Oaten et al., 1992[1]; Stewart-Oaten and Bence, 2001[2]). A BACI model tests for change at an impacted site relative to a control site. The expectation is that influences outside the experiment, (e.g., a high water year, climate), will influence both the control and treatment sites in similar ways so that the change in the treatment site can be benchmarked against the change observed at its paired control site. In this case, the impacted sites are those treated with bioengineering designs to prevent erosion. Control sites were not treated.

Both control and treatment sites are measured through time and each site is compared with itself through time. This approach controls for the potential influence of site location because each site is paired with itself. The difference in exposed pin length over time is calculated and averaged for each site.

Next, each site was compared with its control site: the average pin length difference for the treatment site was subtracted from the average pin length difference for the control site (i.e., a 'difference of differences'). This approach controls for influences outside of the paired sites. The subtracted difference between each site pair is used to evaluate the amount of change (erosion or deposition) associated with bioengineering methods at the treatment sites.

The test statistic is the 'difference of the differences'. A Student's one-sample t test was used to determine whether the test statistics are significantly greater than or less than 0. A statistically significant result could be due to more or less deposition (or erosion) at the treatment sites.

The null hypothesis being tested can be stated as:

> $\mathbf{H_0}$: Shoreline erosion (as measured by change in pin length) does not differ significantly between sites with bioengineering works and sites without such measures.

Summary of Erosion Pin Results

Measured pin length changes (including the assumed value for toppled pins) are presented in Table 4-1 for two time periods:

- 2013 to 2015: the most recent monitoring period, and
- 2011 to 2015: the complete project time period.

Appendix C contains an expanded version of Table 4-1, which includes additional time periods (2011 to 2012, 2012 to 2013), as well as a table presenting N and standard deviation corresponding to each mean.

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[1] Stewart-Oaten, A., J. R. Bence, and C. W. Osenberg. 1992. Assessing effects of unreplicated perturbations: no simple solutions. Ecology 73:1396-1404.

[2] Stewart-Oaten, A. and Bence, J.R. 2001. Temporal and spatial variation in environmental assessment, Ecological Monographs 71: 305–339.

Table 4-1: Mean Change in Pin Length at Control (C) and Treatment (T) sites, and Differences (C – T) (Test Statistic)

Site name	Mean Change in Pin Length (1) 2013 to 2015 (cm)			Mean Change in Pin Length (1) 2011 to 2015 (cm)		
	C (2)	T (3)	Test Statistic C - T	C (2)	T (3)	Test Statistic C - T
A1 Upstream	-15.07	-9.38	-5.69	-18.21	-15.41	-2.80
A1 Downstream	0.50	-8.93	9.43	1.58	-12.29	13.87
A2 Upstream	-7.25	-11.79	4.54	-11.21	-14.71	3.50
A2 Downstream	-17.73	-30.23	12.50	-24.39	-42.04	17.65
B	-3.35	3.86	-7.21	-3.65	2.84	-6.49
C Upstream	1.38	-5.19	6.57	6.63	-1.42	8.04
C Downstream	3.18	1.04	2.14	4.55	6.81	-2.26

Notes:
1. Measured changes as well as estimated erosion value for toppled pins. Negative values indicate erosion, and positive values indicate deposition.
2. C = control.
3. T = treatment.

The results in Table 4-1 are presented in Figure 4-2 as a ‘box-and whisker’ plot. In interpreting Figure 4-2 (and other box-and-whisker plots contained in this report), please note the following points:

- the median (50th percentile) of the data is the heavy black line within the box,
- the top of the box is set at the 75th percentile of the data and the bottom of the box is set at the 25th percentile of the data,
- the length of the box is called the interquartile distance,
- the ‘whiskers’ are the maximum and minimum, and
- outliers (small black circles) represent values outside 1.5 times the interquartile distance.

The size of the box gives an indication of the sample variability. The position of the box relative to the whiskers, and the median within the box, give an indication if the data are symmetric or skewed.

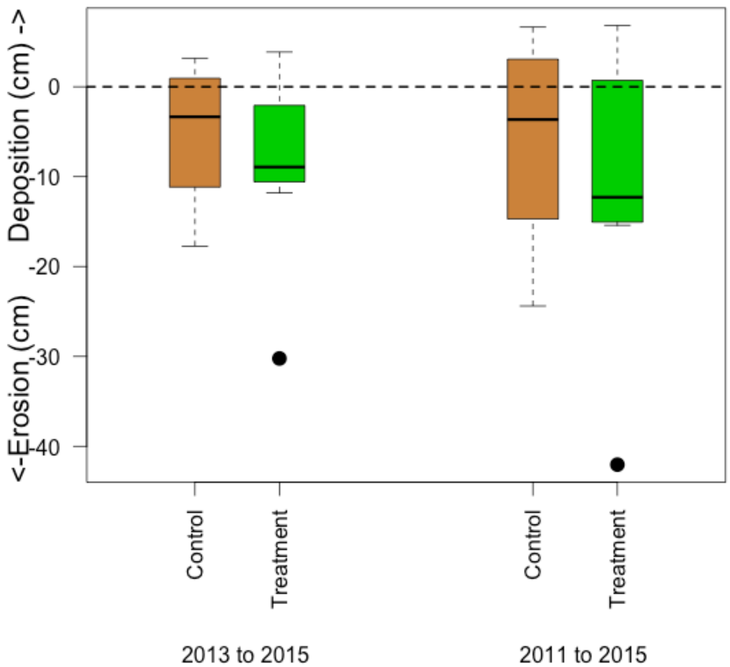

Figure 4-2: Change in Pin Length for All Sites for Most Recent Monitoring Period (2013-2015) and Full Project Period (2011-2015)

The Student's one-sample t test was used to test the statistical significance of the mean difference in pin length changes. Summary results are presented in Table 4-2. It should be noted that in Table 4-2 a negative sign of the test statistic (C – T) does <u>not</u> indicate erosion due to the effect of the algebraic expression.

As shown in Table 4-2, neither the more recent monitoring period (2013 to 2015) nor the full project period (2011 to 2015) yielded a statistically significant result ($p < 0.01$). Both treatment and control sites exhibited erosion, and the magnitude of erosion measured at treatment sites was greater than in control sites, but the difference was not statistically significant.

As indicated in the expanded tables included in Appendix C the only period that yielded a statistically significant result was the 2012 to 2013 period.

Table 4-2: Test Results for Comparison of Control and Treatment Sites as Measured By Difference (Control – Treatment) of Changes in Pin Length

Change Measured As:	Period	Mean (cm)	St. Dev.	N	St. Error	Df.	T Stat	P Value
Difference in change in pin length (cm)	2013 to 2015	3.18	7.38	7	2.79	6	1.14	0.30
Difference in change in pin length (cm)	2011 to 2015	4.50	9.07	7	3.43	6	1.31	0.24
Notes: 1. Students one-sample t-test.								

4.3 Results – Cross-Sections

The number of established cross-sections per site varied from two to four.

Cross-sections were measured at 12 out of 14 of the sites in 2011, and at all 14 sites in 2012, 2013 and 2015 (see Table 2-2 and Table 2-3 for a summary of construction and survey timing). In 2011, two sites (A1 Upstream and A1 Downstream) were not measured because the installation was completed later than the other sites. To make the comparison to 2015, 2012 survey data were substituted for 2011 at these two sites.

Treatment and control sites were paired, and a similar BACI statistical model was used to test for a difference in the amount of change in erosion (or deposition) for each pair of sites.

The null hypothesis being tested can be stated as:

> $\mathbf{H_o}$: Erosion (as measured by Δx midpoint) does not differ significantly between sites with bioengineering works and sites without.

Δx midpoint for each of the three elevation bands was calculated for each cross-section within each time period, and averaged for the site. The average Δx midpoint was compared for each pair of control and treatment sites. To test for a statistically significant change, the difference for each site pair was calculated (control – treatment) and tested for a significant differences from 0 (one-sample t test).

Table 4-3 presents a summary of mean change (Δx midpoint) for each site, for two time periods:

- 2013 to 2015: the most recent monitoring period, and
- 2011 to 2015: the complete project time period.

Appendix C contains an expanded version of Table 4-3, which includes additional time periods (2011 to 2012, 2012 to 2013), as well as N and standard deviation corresponding to each mean.

Table 4-3: Mean Change (Δx midpoint) at Control (C) and Treatment (T) Sites and Differences (C – T) (Test Statistic). To assess change between 2011 and 2015, values from 2012 were substituted for A1_US and A1_DS (blue shaded cells).

Site Name	Change: 2013 to 2015 (m)			Change: 2011 to 2015 (m)		
	C	T	C - T	C	T	C - T
A1 Upstream	-0.11	-0.09	-0.02	-0.15	-0.39	0.24
A1 Downstream	0.18	-0.37	0.55	0.02	-0.97	1.00
A2 Upstream	0.29	-0.55	0.84	-0.02	-0.81	0.79
A2 Downstream	-0.52	-0.56	0.04	-0.66	-1.63	0.98
B	0.01	0.02	0.00	0.15	0.02	0.13
C Upstream	0.26	-0.16	0.42	0.44	-0.44	0.88
C Downstream	0.32	-0.09	0.41	0.22	-0.10	0.32

Notes:
1. Negative values indicate erosion and positive values indicate deposition.
2. Treatment sites at A1 Downstream and A1 Upstream were not measured in 2011.

The results in Table 4-3 are summarized graphically in Figure 4-3, below.

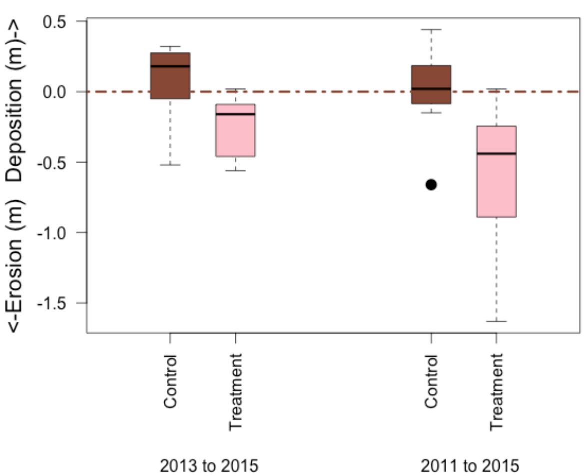

Figure 4-3: Bank Change (Δx midpoint) For All Sites for Most Recent Monitoring Period (2013-2015) and Full Project Period (2011-2015)

The Students one-tailed t test was used to test the statistical significance of the mean difference in Δx midpoint between treatment and control sites. Summary results are presented in Table 4-4. It should be noted that in Table 4-4 a negative sign of the test statistic (C – T) does <u>not</u> indicate erosion due to the effect of the algebraic expression.

Treatment sites had statistically significantly greater erosion than their paired control sites during both the 2013 to 2015 and 2011 to 2015 time periods (Table 4-4). The average difference between treatment and control pairs was 62 cm from 2011 to 2015.

Table 4-4: Test Results for Comparison between Control and Treatment Sites as Measured by Difference (Control – Treatment) of Δx midpoint. Yellow highlighting indicates statistically-significant result.

Change Measured As	Period	Mean	St. Dev.	N	St. Error	Df.	T Statistic	P Value
Difference in Midpoint averages (m)	2013 to 2015	0.32	0.32	7	0.12	6	2.58	0.04
Difference in Midpoint averages (m)	2011 to 2015	0.62	0.38	7	0.14	6	4.36	0.01

Notes:
1. Students one-sample t-test.

Overall, control sites showed erosion during the first years of the project (2011 through 2013), but deposition increased in the later years. In contrast, treatment sites with bioengineering works eroded relatively steadily over time. See Appendix C for expanded results.

Effect of Site Splitting

As mentioned in Section 2.1 there is a concern with splitting sites that they will not be independent: they will have similar outcomes and artificially inflate the power to detect a difference by increasing the sample size and decreasing the difference that is statistically significant. A significant difference was detected between treatment and control sites for the cross-section analysis; therefore, a second statistical test was done after combining the each of the split sites back into a single site. This was done to see if the same pattern of statistical significance was observed for the smaller number of independent sites.

For the 2 time periods that had yielded significant results (Table 4-4), the results of the test with the re-combined sites were still significant, as shown in Table 4-5, with somewhat larger p-values ($p < 0.1$ for the 2013 to 2015, $p < 0.05$ for the 2011 to 2015 full project period).

Thus, we can conclude that the results are robust for the sites whether kept separate or combined.

Table 4-5: Test Results for Comparison of Control and Treatment Sites as Measured By Difference (Control – Treatment) of Δx midpoint With Split Sites Recombined. Yellow highlighting indicates statistically-significant result.

Change Measured As	Period	Mean	St. Dev.	N	St. Error	Df.	T Statistic	P Value
Difference in Midpoint averages (m)	2013 to 2015	0.28	0.20	4	0.18	3	2.77	0.07
Difference in Midpoint averages (m)	2011 to 2015	0.56	0.31	4	0.14	3	3.56	0.04
Notes: 1. Students one-sample t-test.								

4.4 Summary

In summary, analysis of the erosion pin and cross-section monitoring data indicate the following:

- Both treatment and control sites experienced erosion and deposition.
- Treatment sites experienced more consistent erosion over time, compared with the control sites.
- Treatment site erosion exceeded erosion at the control sites, although the difference was only statistically significant based on the cross-section data (and not the erosion pin data). Statistical significance of the cross-section results is robust whether sites are split or re-combined.

5. Discussion and Conclusions

As presented in Section 4, the bioengineering treatments applied to the CLBWORKS #35 sites have not yielded the desired result of reducing erosion when compared to untreated sites. While this may seem counterintuitive we present here important factors that affected the success of the bioengineering treatments.

It should be noted that the findings of this monitoring are based on four years (2011 to 2015) results to date. Typically, to be effective, plants used in bioengineering should establish and thrive within 1 to 3 years of planting; however, the site conditions experienced in this project were not ideal for plantings and may have delayed plant establishment (see discussion, below). Should the plants establish and begin to thrive in the future, it is possible that the observed trend may reduce or reverse.

5.1 Discussion

Why Do Treated Sites Erode More than Control Sites?

Both treated sites and control sites experienced both erosion and deposition during the study; however, the sites treated with bioengineering experienced more consistent erosion over the course of the study. Although this result is somewhat counterintuitive, it is a potential outcome of using 'soft' engineering techniques to mitigate bank erosion (in contrast to 'hard' engineering techniques such as riprap which can be more reliable immediately after installation).

How Does Bioengineering Work?

Bioengineering (biotechnical methods) for bank stabilization comprise temporary or short-term treatments offering initial stability (typically biodegradable man-made fabric mats), and natural materials (primarily willow cuttings) for long-term stability. Treatments made of inert materials are used to initially stabilize banks to allow the establishment of plants providing long-term stability. Once established, plants, in combination with wood and sediment elements, form systems that maintain the overall bank stability, with the short-term structural treatments contributing less. Where biodegradable treatments such as coconut matting are used in the initial stabilization, these elements degrade over time and only the natural (non-degrading) materials provide bank stabilization.

The establishment of plants following construction is a critical factor. Typically, the structural treatments providing initial stability are not designed to withstand exposure to long-term conditions, and therefore the bank stabilization relies on the successful establishment of vegetation in the first 1-3 years.

The ability of the bioengineering techniques applied on the CLBWORKS #35 sites to withstand erosion hinges on the strength imparted to the bank by the plants. The plants must become well-established in the bank for these techniques to be as effective as possible. If the plants do not grow well or the toe of slope is disturbed, causing failure of the treatment above, then the bioengineering treatment itself may function more akin to a disturbance to the bank, and may even temporarily reduce the bank strength in certain cases.

Factors that Affect Plant Survival

BC Hydro has been conducting re-vegetation projects within the Arrow Lakes Reservoir as part of the Columbia River WUP process. The Arrow Lakes Reservoir Revegetation Program (CLBWORKS-2)[3] focussed on revegetation of sites within drawdown zone of the Arrow Lakes Reservoir (<440 m elevation), including sites in the Revelstoke reach near the CLBWORKS #35 sites (Keefer, 2011). The results from CLBWORKS-2 were not available prior to the installation of the CLBWORKS #35 treatments; however, results from both projects can be used to discuss the plant survival observed in the bioengineering treatments.

Key findings from the CLBWORKS-2 program that are relevant to the CLBWORKS #35 treatments include:

- Planting in the mid and upper elevations (436 m to 440 m) maximizes plant survival;
- Do not plant in sites that are dominated by fine-textured soils as these are prone to erosion events;
- Plant on gentle slopes;
- Machine plant live stakes instead of hand staking wherever possible;
- Do not use fertilizer;
- For sedges, preferentially plant:
    - lenticular (*Carex lenticularis*) and Columbia sedge (*Carex aperta*) on upland sites,
    - water sedge (*Carex aquatilis*) and woolgrass (*Scirpus atrocinctus*) on wetter sites,
    - bluejoint reedgrass (*Calamagrostis canadensis*) only at upper elevations, and
    - do not plan small-fruited bulrush (*S. microcarpus*); and
- For live stake planting, preferentially plant black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) over Scouler's willow (*Salix scouleriana*) and red-osier dogwood (*Cornus stolonifera*).

With respect to the CLBWORKS-2 findings and implications for CLBWORKS #35, the following points may be made:

- CLBWORKS #35 bioengineering treatments were constructed at bank elevations between 437 m to 440 m (+/-): within the CLBWORKS-2 elevation band where plant survival is maximized.
- More willows were planted for CLBWORKS #35 than black cottonwood for a number of reasons: because willows were readily available for harvest at the treatment sites, willows are thought to be flood-tolerant, they have extensive root systems that are good for bank stabilization projects and willows have been applied successfully to bioengineering projects throughout BC. However, the results from CLBWORKS-2 suggest that willows do not have as high a survival rate in this system.
- Sites A1, A2 and C have a large proportion of fine material in the bank, while Site B is dominantly coarse-grained. The CLBWORKS-2 results would suggest that more erosion could be expected at Sites A1, A2 and C relative to B, which is consistent with the results of this study.

Additional factors that affect the ability of the plants to establish include:

- discharge and water-level conditions during initial years (including length of time of inundation),

[3] Keefer Ecological Services Ltd. (Keefer). 2011. *Arrow Lakes Reservoir Revegetation Program Physical Works Report (Phase 3).* Prepared for BC Hydro, October 2011.

- availability of water during the growing season; and
- the time of year when the plants are harvested and then re-planted (particularly willow cuttings).

Site discharge and water-level conditions are discussed in the following sections.

Effect of Water Level Variation

The CLBWORKS #35 sites are located about 9 km to 13 km downstream of Revelstoke Dam. The dam is a hydro-peaking facility, which means that flow releases are highly variable on a daily basis compared to an unregulated river. In addition, the downstream Arrow Lakes Reservoir sets an additional control on water levels at the site (backwatering). Arrow Lakes Reservoir is a managed reservoir with an annual cycle of low water in the winter and early spring, and high water level in the summer. The high water levels in the summer coincide with what is typically the growing season for plants.

The variation of water levels affected the construction timing of the works and the elevation at which treatments could be constructed 'in the dry', as well as the plants' ability to establish.

Water level monitoring data was obtained from LGL Ltd. who are currently managing the CLBMON15A[4] project, and these data are used below to illustrate the impacts of water level variation on the CLBWORKS #35 treatments (Elmar Plate, *pers. comm.*, 2015). Water levels shown are from Station 4 of CLBMON15A, located opposite the mouth of Illecillewaet River approximately midway between Sites A1/A2 and Sites B/C.

Construction

Water levels during the 2011 construction period are shown in Figure 5-1.

As indicated in that figure, water level during construction ranged from about 436.3 m to 437.3 m: mostly higher than the design elevation of the marsh bench treatment (top elevation of about 437 m, see Appendix A for record drawings, Drawing SW3). Daily water level fluctuations were in the order of 0.5 m to 0.7 m due to the fluctuation of dam releases. During this same period, Arrow Reservoir elevation ranged from 436.7 m to 436.3 m.

Typically, construction of in-stream works would be scheduled such that all or most of the work could be conducted with the site completely 'in the dry': this was not possible on CLBWORKS #35 due to the timing of permitting and tendering of the project.

As a result of the water levels during the initial construction period the lower portions of the banks were challenging to access. Construction of the lower treatments at Sites A1 and C was postponed until spring 2012.

Construction of the lower bioengineering treatments at Sites A1 and C resumed in May 2012 (see Figure 5-2). Despite overall lower water levels, there remained difficulties in accessing the local river gravel/cobble for use on the toe of the slope at Site A1, and also difficulties in getting proper compaction on the lower constructed bench surface. As a result, Site A1 could not be constructed as designed.

[4] 2015. Elmar Plate,Senior Fisheries Biologist,LGL Limited, Environmental Research Associates, *pers. comm.* Unpublished data from the *Mid-Columbia Physical Habitat Monitoring, Project Water Use Plan*, Years 1 through 9 (2007 to 2015).

Post-Construction Environment

Figure 5-2 shows the water level in the first year following the initial October 2011 construction. As indicated in this figure, from about mid-June 2012 through late August 2012, site water levels were largely controlled by Arrow Lakes Reservoir. As indicated in Figure 5-2, the sites were completely under water from about mid-June through to late August of 2012 (9 weeks). Inundation for 9 weeks is a significant portion of the growing season in this environment and is likely to have resulted in very poor seasonal growth.

Figure 5-3 compares Arrow Reservoir level in 2012, 2013 and 2014 to the long-term average and long-term maximum: as indicated, both 2012 and 2013 appear to have been above-average years. 2012 in particular saw a persistence of very high water levels for almost double the length of time as in the two subsequent years, which undoubtedly had negative effects on the plants' abilities to establish and grow in the first season following construction.

Impact of Elevation on the Results

The bioengineering treatments and plantings were installed within the active drawdown zone of the Arrow Lakes Reservoir, at elevations ranging from 437 m to 440 m. Although not separated into elevation bands for the statistical analysis, the erosion pin and cross-section survey results were assessed informally to consider to what extent elevation may have played a role in the observed changes. Stratifying the results into various elevation bands is not expected to change the overall result of the study, which is that the bioengineering sites experienced more consistent erosion than the control sites for the duration of the study.

Overall Significance of the Results

The management questions arising from the WUP review that this project has been designed to answer do not specify why shoreline erosion is of concern. The erosion-related "soft constraints" for Arrow Lakes identified in the Columbia River Water Use Plan are as follows:

> "*Minimize duration of full pool events and avoid sudden drawdown once full pool has been reached to avoid shoreline slumping. Reservoir water level of 438.9 metres (1440 feet) is ideal*."

However, there is no indication of the specific nature of the concern around erosion. Impacts of shoreline erosion on biological communities may be a driver for the management questions, or erosion concerns from property owners along the waterfront.

It is important to recall that this study is intended to evaluate the ability of bioengineering techniques to mitigate erosion. Given the cost of the bioengineering treatment, most river managers would likely expect to see a relatively large difference comparing treated and untreated sites, in terms of reduction of erosion. The conclusion drawn from CLBWORKS #35, which indicates an increase in erosion at the bioengineering treated sites compared to untreated sites, does not indicate support for the bioengineering techniques applied in this study.

It is also important to recall the constraints and goals associated with the project along with their potential impact on study results. These include factors such as:

- There was a desire to explore bioengineering techniques that would be cost-effective and therefore could be applied much more broadly in the area. Costly treatments including riprap and traditional "hard" engineering approaches, while potentially more robust, would be less feasible to apply over long stretches of channel.

- There was also a desire to avoid the use of synthetic materials as much as possible, given aesthetic, recreational and environmental concerns. The conceptual design included using gravel and cobble material at the lower elevations of the slope (where plants were not expected to grow at all) to stabilize the material at the toe of the treatments. This gravel and cobble material had been observed in the area during the initial site investigations. However, water levels during construction limited the availability of local, natural materials during construction (e.g. cobble material).
- Site selection was limited to the study reach (between the TransCanada Highway Bridge and Begbie Creek), and further limited by the practical constraint of access logistics for construction and monitoring. It may be possible to find sites at which bioengineering would be more successful if the study area were broadened; however, construction logistics will remain an important consideration.

5.2 Success Factors and Lessons Learned

The following points are presented as lessons learned that would improve the success of future bioengineering projects in this environment:

1. Plantings should be located at an elevation sufficiently high that the inundation due to hydropeaking (and reservoir operation) will not compromise their ability to establish and grow in the years immediately following construction. This places a limit on the area that is suitable for bioengineering, and likely excludes the portion of the bank where active erosion is occurring.
2. In the lower and mid elevations of the bank, ‘harder’ treatments (*e.g.,* riprap *etc*.) should be incorporated into the design to resist the forces generated by river current and waves. Treatments such as soil wraps and live staking in similar water level and soil conditions are unlikely to resist toe and lower slope erosion on their own.

5.3 Conclusions

In conclusion, to revisit the management question associated with CLBWORKS #35:

> **H_0**: Shoreline erosion does not differ significantly ($\alpha = 0.05$, $\beta = 0.8$) between sites with bioengineering works and sites without such measures,

our conclusion is that we reject the null hypothesis (based on the cross-section data collected): the bioengineering treatments resulted in overall <u>more erosion</u> than at the control sites for the observed 2011 to 2015 time period. The results of the erosion pin monitoring also suggest that more erosion occurred at treated sites but this difference was not statistically significant.

Based on our experience with CLBWORKS #35, we would suggest a modified approach to bioengineering in this reach of Columbia River that would include more robust lower bank features (such as a cobble or riprap toe), which could be better able to remain stable in the characteristic flow velocity and water level environment of these sites.

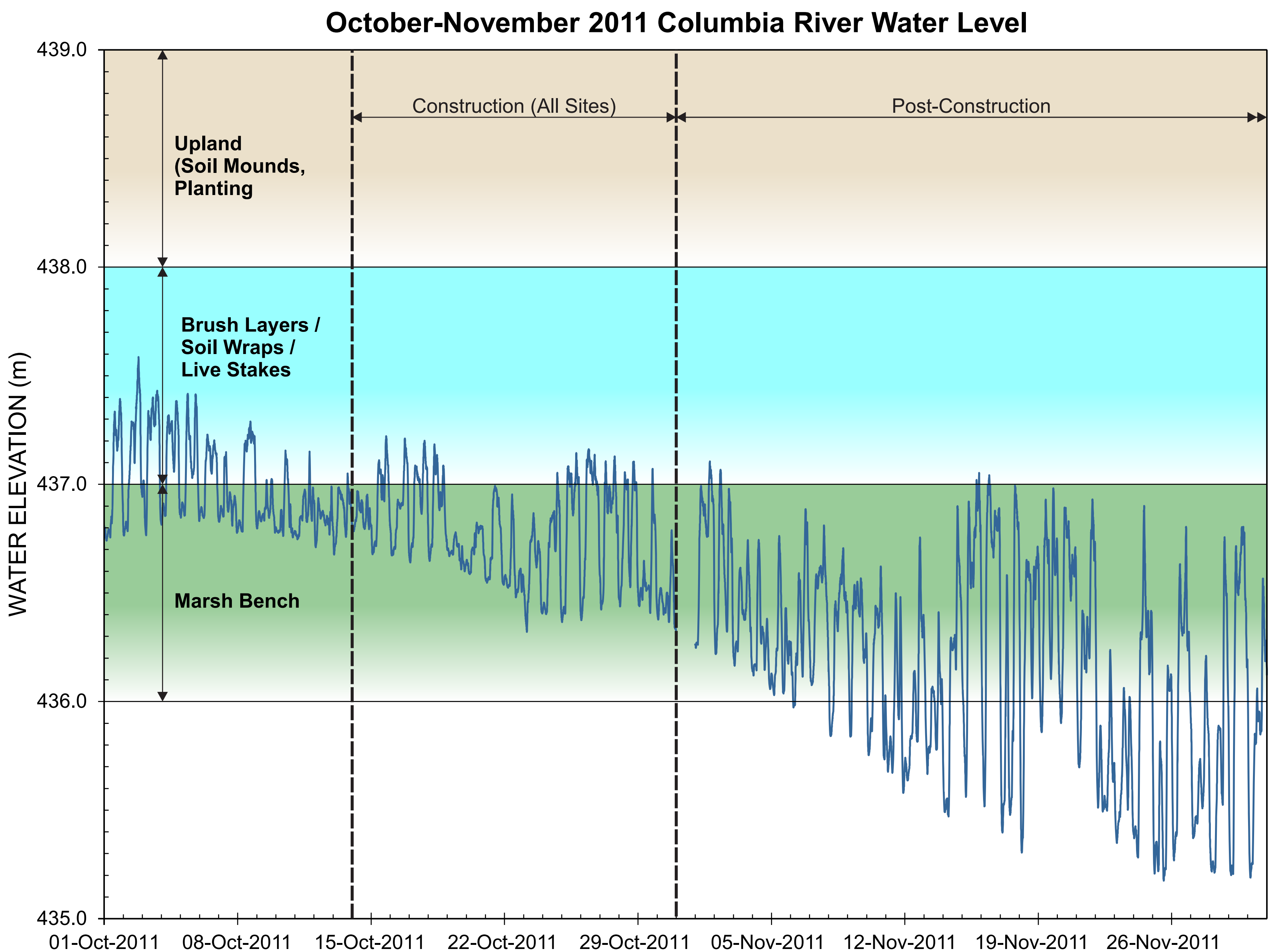

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Figure 5-1

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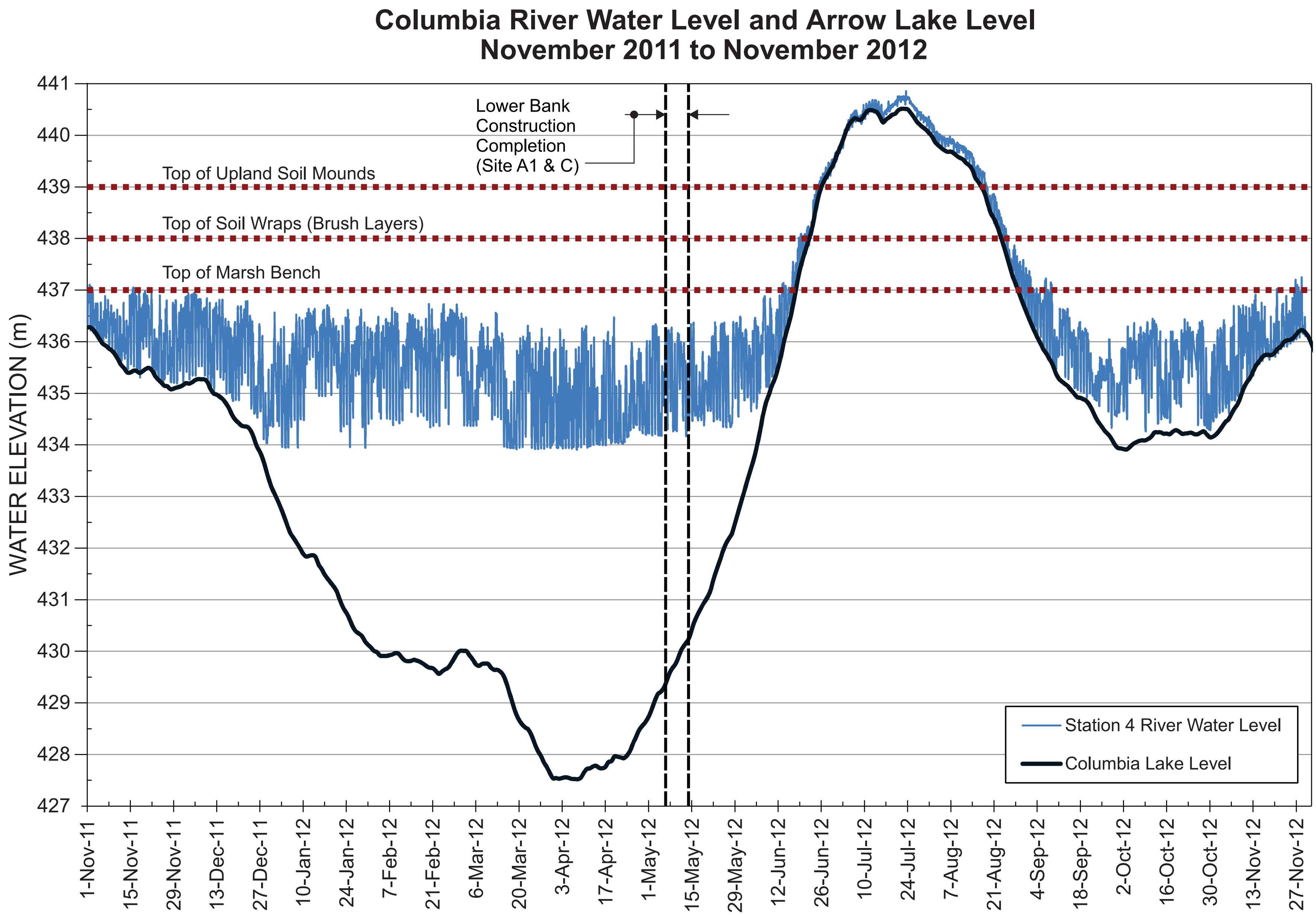

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Figure 5-2

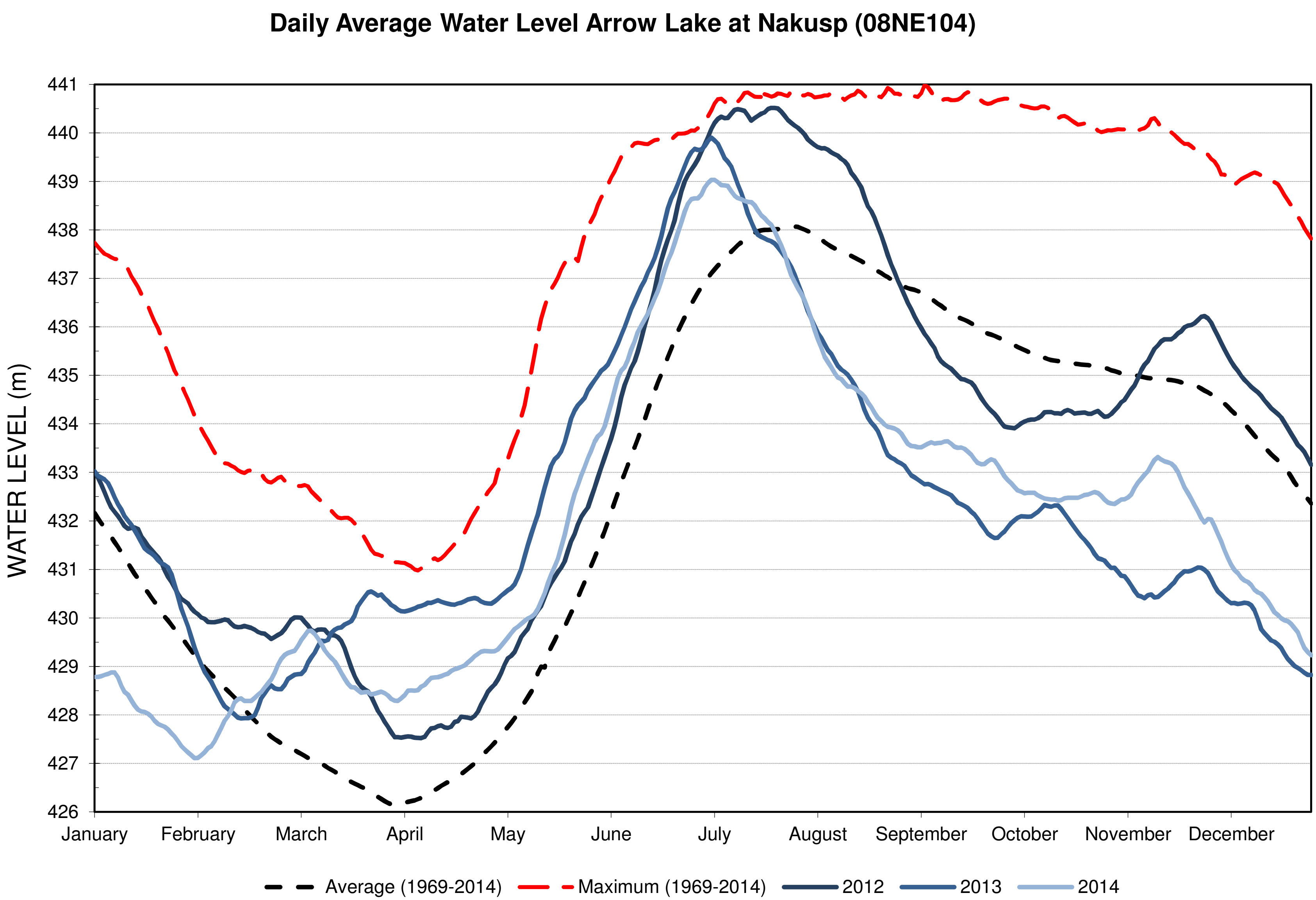

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Figure 5-3

5.4 Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

Erica Ellis, M.Sc., P.Geo.
Fluvial Geomorphologist

Sarah Lawrie, M.A.Sc., P.Eng
Water Resources Engineer

Reviewed by:

Dave Murray, A.Sc.T., P.Eng., CPESC
Senior Water Resources Engineer

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Revision History

Revision #	Date	Status	Revision	Author
1	Apr. 14, 2016	Final	Revised based on client review comments.	EE/SJL

OQM | Organizational Quality Management Program

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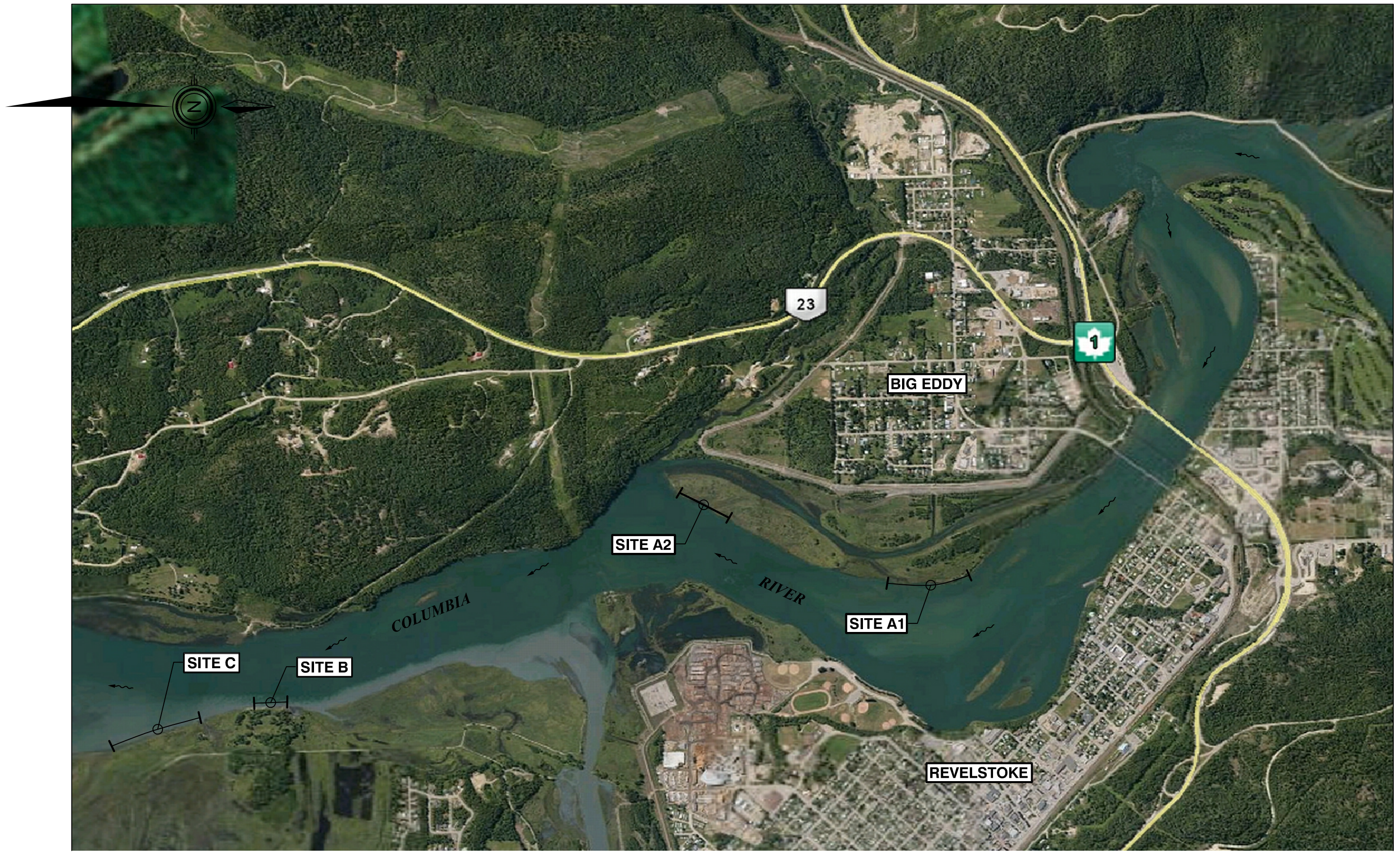
Appendix A

CLBWORKS #35 Drawings (Design of Engineering Works)



KEY PLAN
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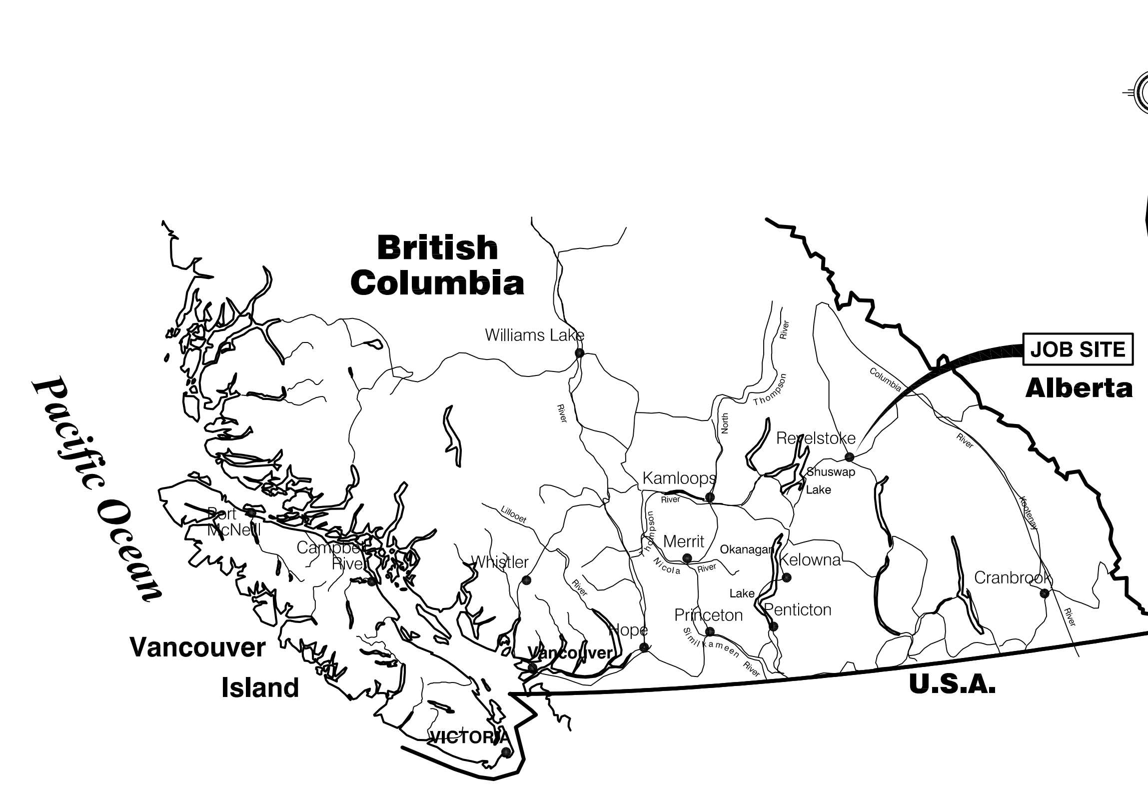

LOCATION PLAN
N.T.S.

		DRAWING LIST
SHT. NO.	DRAWING NO.	TITLE
1	G1	LOCATION PLAN, KEY PLAN AND DRAWING LIST
2	G2	OVERVIEW OF SITE ACCESS ROADS
3	SW1	SITE WORKS - SITES 'A1' & 'A2'
4	SW2	SITE WORKS - SITES 'B' & 'C'
5	SW3	SECTIONS - SITE 'A1'
6	SW4	SECTIONS - SITE 'A2'
7	SW5	SECTIONS - SITE 'B'
8	SW6	SECTIONS - SITE 'C'
9	SD1	STANDARD DETAILS

BC HYDRO
MID COLUMBIA RIVER BANK PROTECTION WORKS
PROJECT # 478.119

ISSUED INFORMATION

Issued for	Issue	Date	Issued By
Reference			
Approvals	A1	JUN.10/10	-
Tender			
Permits	P0	APR.15/11	-
Construction			
Record Drawings			

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	JAN.19/10	SJL	BVC	DTM	
1	JUN.10/10	SJL	MP	DTM	REVISED NOTES
2	APR.15/11	SJL	SC	DTM	ISSUED FOR PERMIT
3	DEC.23/10	SJL	BVC	DTM	ISSUED FOR 2011 PROGRESS REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

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MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
LOCATION PLAN, KEY PLAN & DRAWING LIST

KWL Project No. 478-119 Scale AS SHOWN
Sheet 01 of 9 Rev. No. 3
Client: BC HYDRO
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Drawing Number

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SITE ACCESS SITES 'A1' & 'A2'
N.T.S.

SITE ACCESS SITES 'B' & 'C'
N.T.S.

ISSUED INFORMATION: Issued for	Issue	Date	Issued By
Reference			
Approvals	A1	JUN.10/10	-
Tender			
Permits	P0	APR.15/11	-
Construction			
Record Drawings			

REVISION INFORMATION: Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	JAN.19/10	SJL	BVC	DTM	
1	JUN.10/10	SJL	MP	DTM	REVISED NOTES
2	APR.15/11	SJL	SC	DTM	ISSUED FOR PERMIT
3	DEC.23/10	SJL	BVC	DTM	ISSUED FOR 2011 PROGRESS REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

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MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
OVERVIEW OF SITE ACCESS ROADS

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Sheet 02 of 9	Rev. No. 3	Drawing Number
Client: BC HYDRO		

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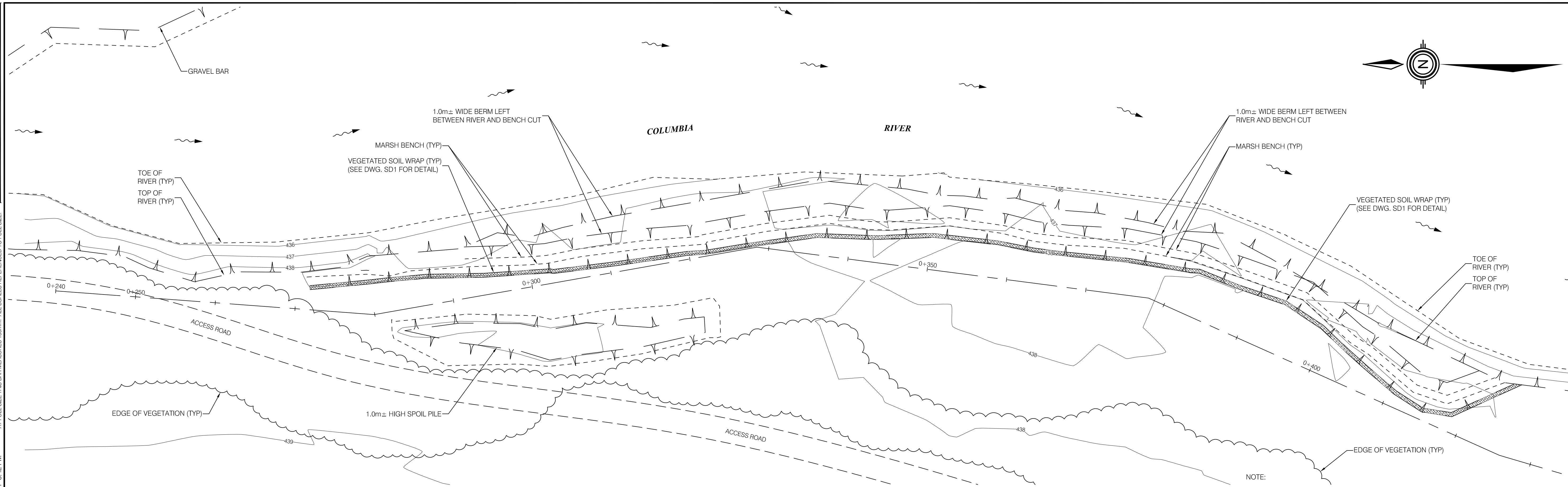

PLAN - SITE A1

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NOTE:

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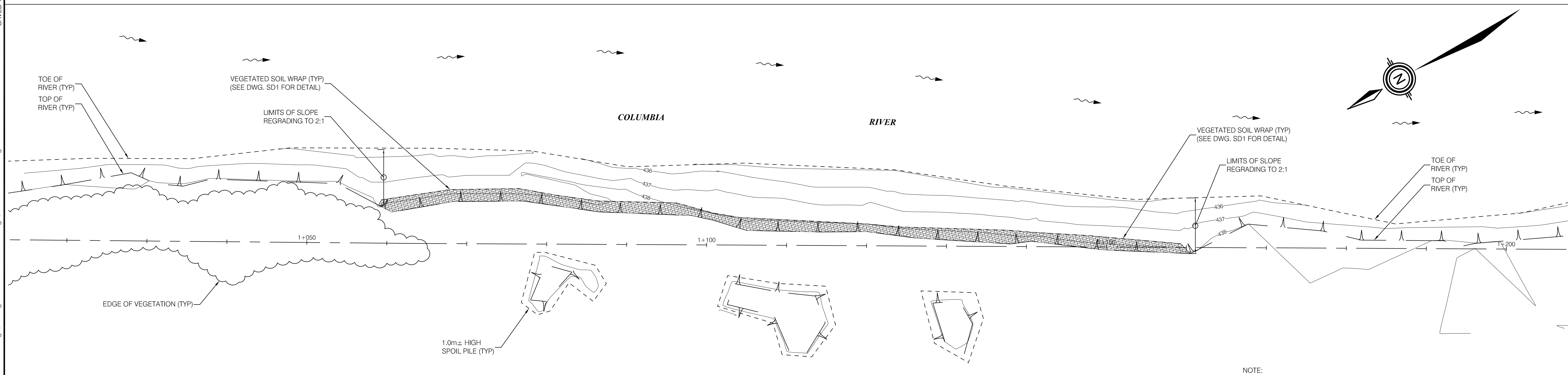

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NOTE:

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ISSUED INFORMATION

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Approvals	A1	JUN.10/10	-
Tender			
Permits	P0	APR.15/11	-
Construction			
Record Drawings			

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	JAN.19/10	SJL	BVC	DTM	
1	JUN.10/10	SJL	MP	DTM	REVISED NOTES
2	APR.15/11	SJL	SC	DTM	ISSUED FOR PERMIT
3	DEC.23/10	SJL	BVC	DTM	ISSUED FOR 2011 PROGRESS REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

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MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
SITE WORKS - SITES 'A1' & 'A2'

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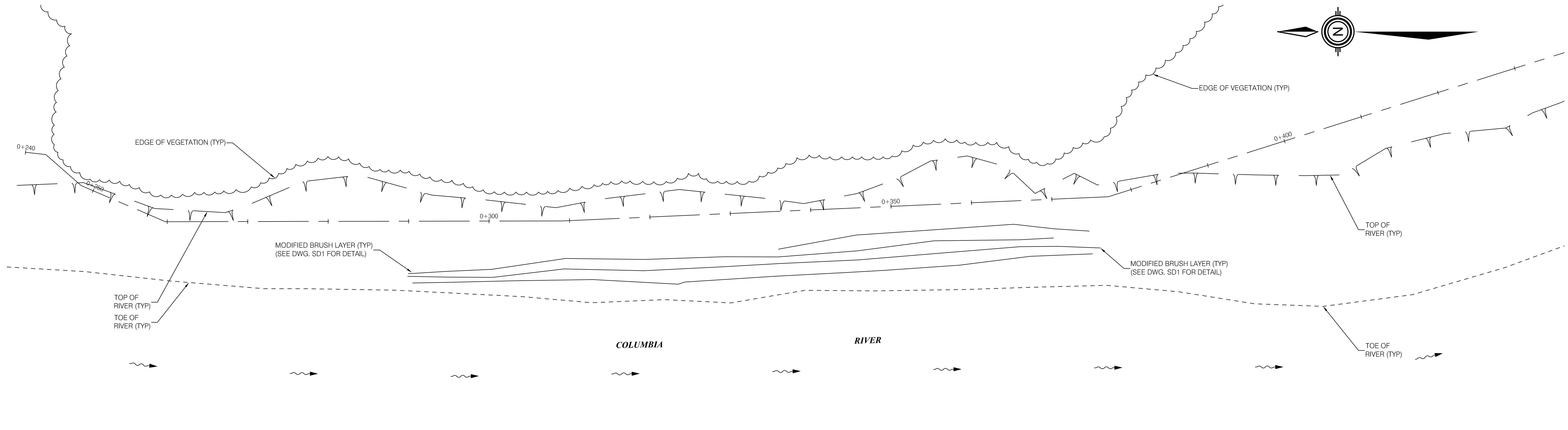

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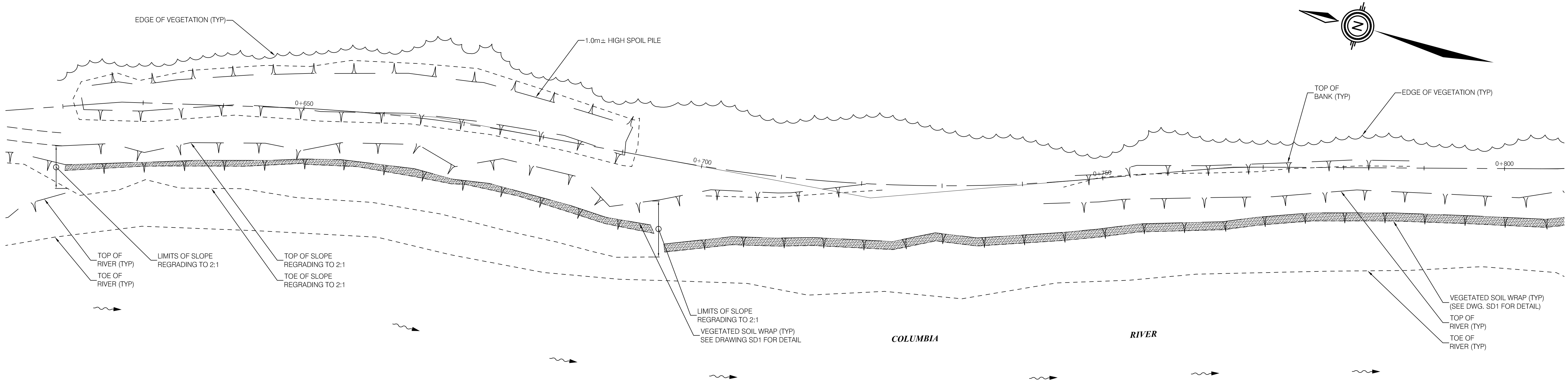

NOTE:

SITE C IS NOT YET COMPLETED. REVEGETATION OF SPOIL PILES TO BE COMPLETED IN THE SPRING OF 2012.

0 2 (1:250) 12m

PLAN - SITE C

SCALE 1:250

ISSUED INFORMATION

Issued for	Issue	Date	Issued By
Reference			
Approvals	A1	JUN.10/10	-
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Permits	P0	APR.15/11	-
Construction			
Record Drawings			

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	JAN.19/10	SJL	BVC	DTM	
1	JUN.10/10	SJL	MP	DTM	REVISED NOTES
2	APR.15/11	SJL	SC	DTM	ISSUED FOR PERMIT
3	DEC.23/10	SJL	BVC	DTM	ISSUED FOR 2011 PROGRESS REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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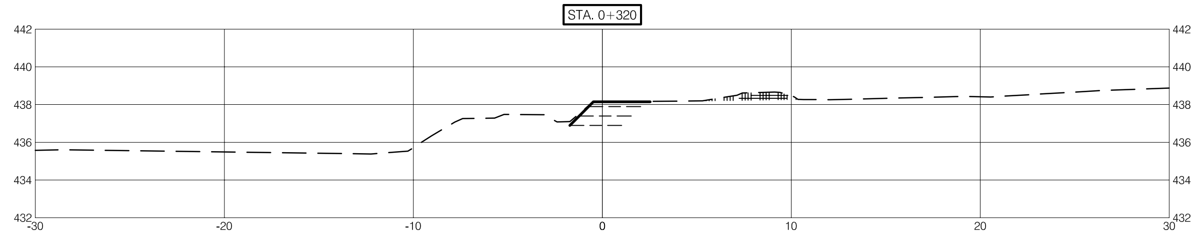
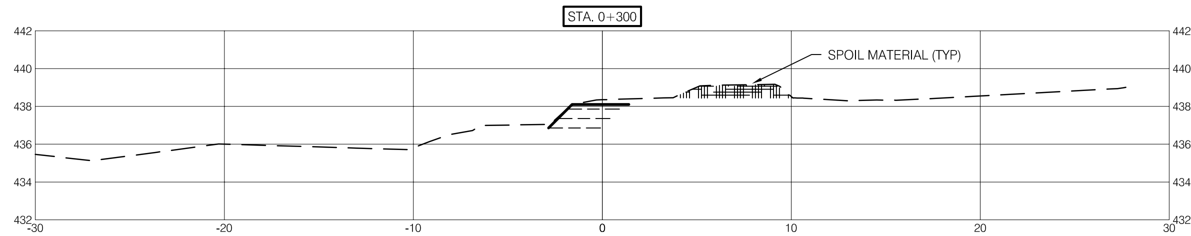
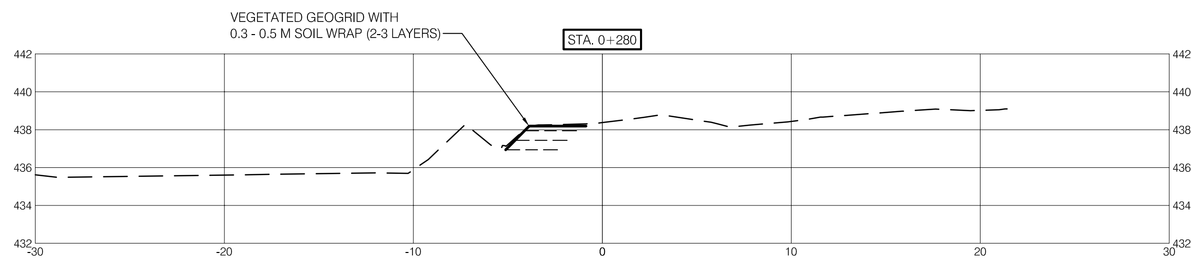
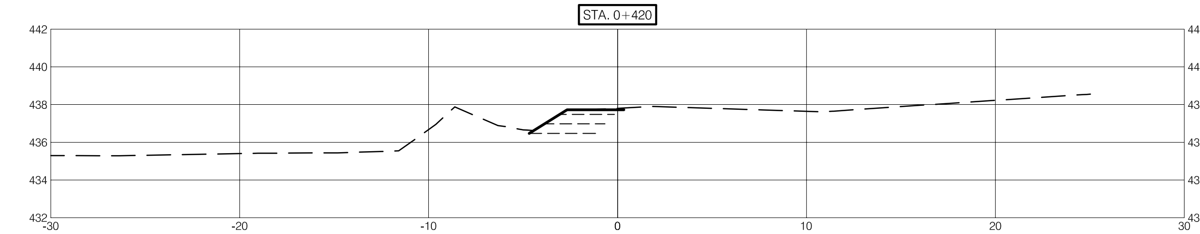
MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
SITE WORKS - SITES 'B' & 'C'

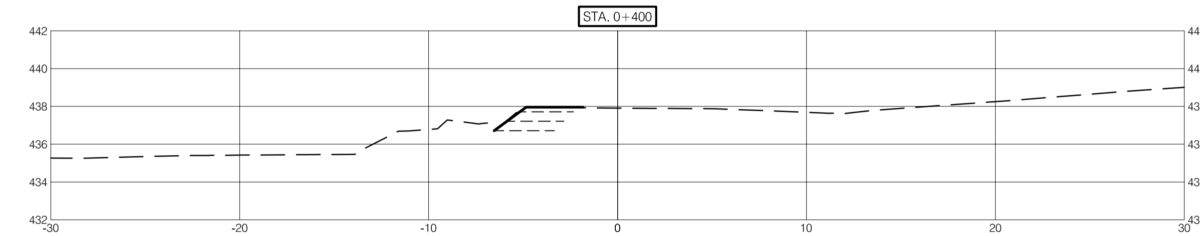
KWL Project No. 478-119	Scale 1:250	**SW2** Drawing Number	
Sheet 04 of	Rev. No. 3		
Client: BC HYDRO			

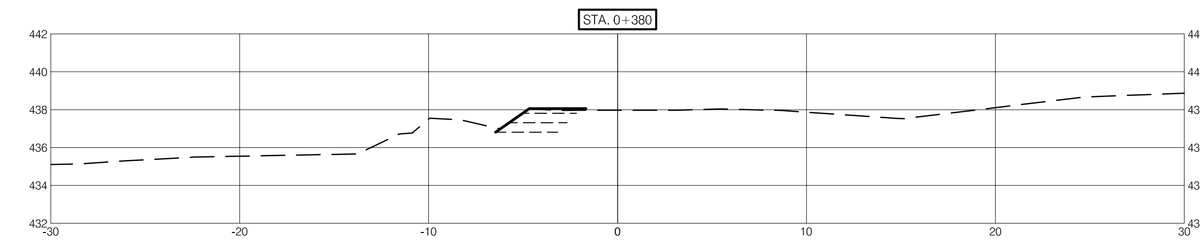


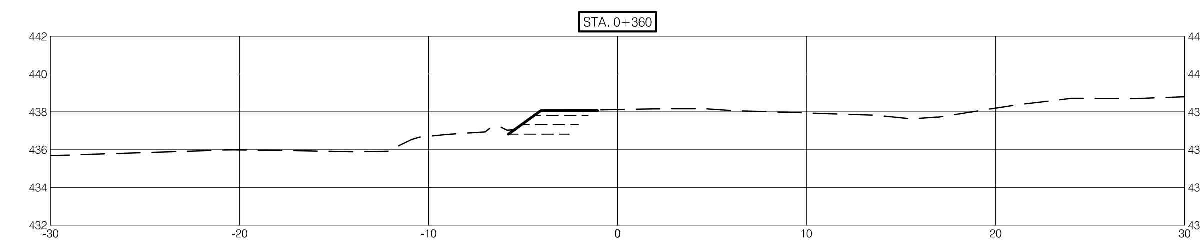


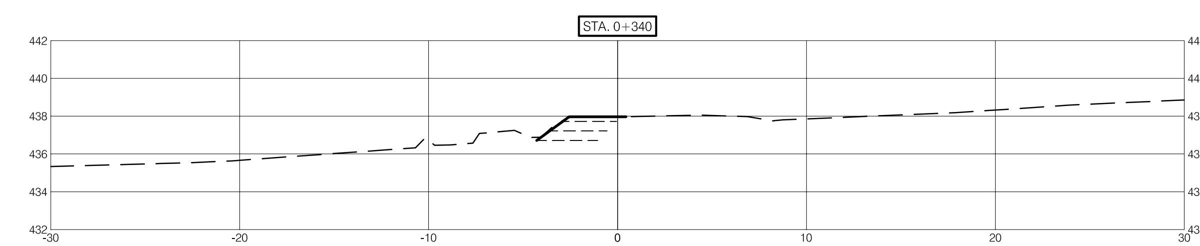


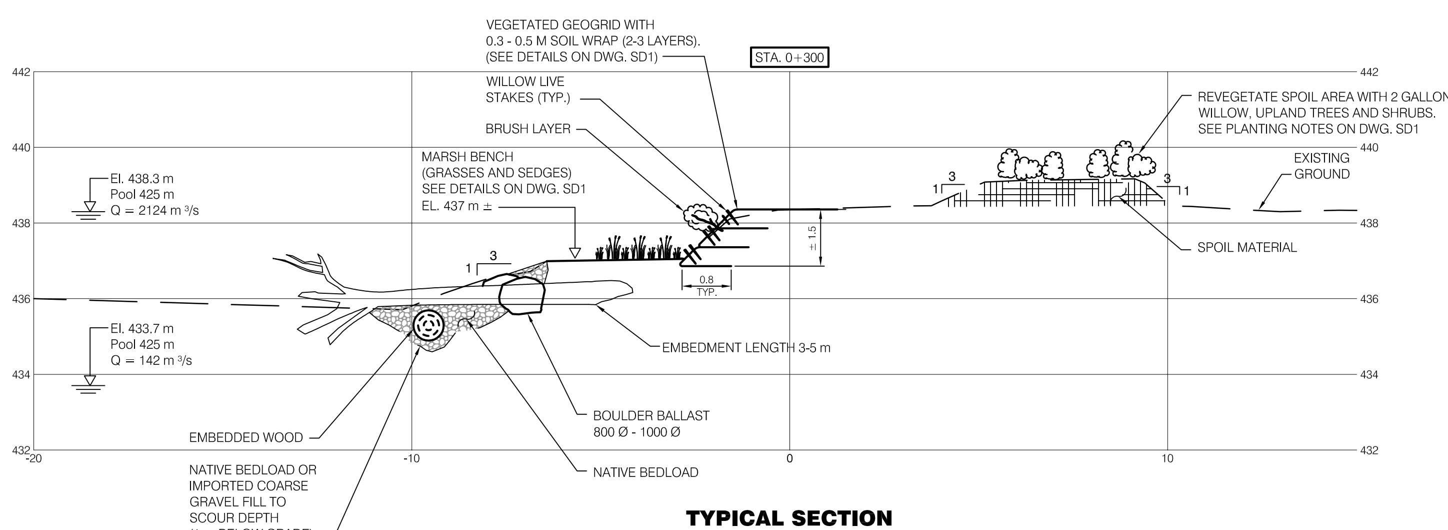












TYPICAL SECTION
SITE 'A1' STA 0+260 to STA 0+420
SCALE 1:100

NOTE:

SITE A1 IS NOT YET COMPLETED. INSTALLATION OF EMBEDDED WOOD, MARSH BENCH AND REVEGETATION OF SPOIL PILES TO BE COMPLETED IN THE SPRING OF 2012.

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AT FULL SIZE THIS BAR MEASURES 100mm. ALL SCALES REFERENCED TO FULL SIZE.

SAVED 9-Dec-2011 3:59 PM

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Reference			
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Tender			
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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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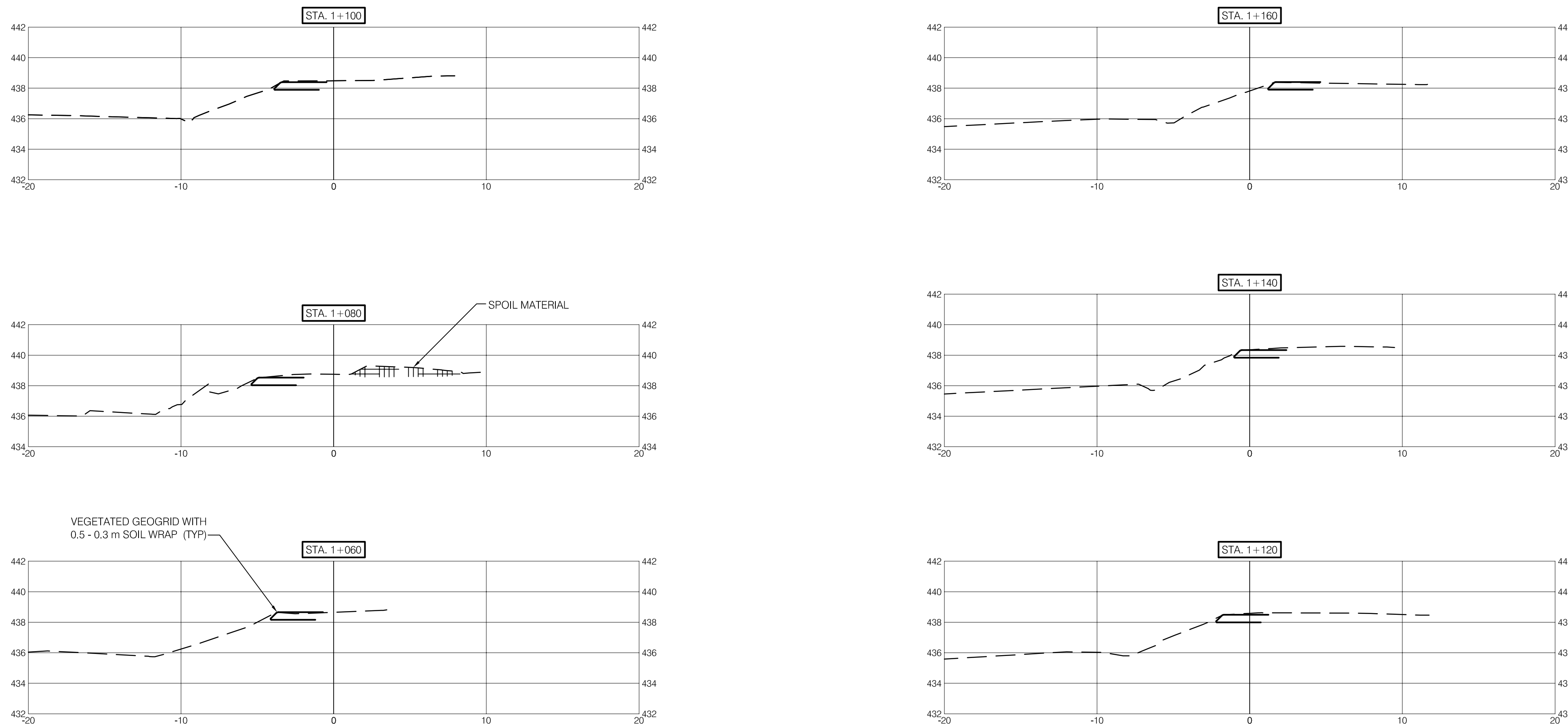
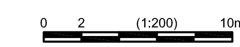
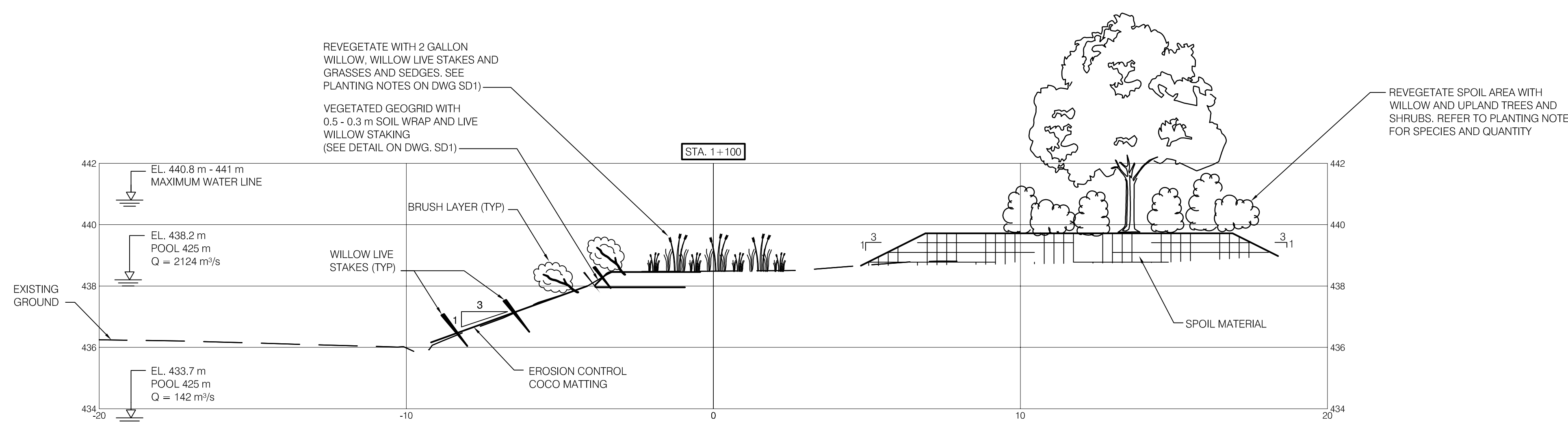
MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
SECTIONS - SITE 'A1'

KWL Project No.	478-119	Scale	1:200
Sheet	05 of	Rev. No.	3
Client: BC HYDRO			

SW3
Drawing Number







TYPICAL SECTION
SITE 'A2' STA 1+060 to STA 1+160
SCALE 1:100

Issued for	Issue	Date	Issued By
Reference			
Approvals	A1	JUN.10/10	-
Tender			
Permits	P0	APR.15/11	-
Construction			
Record Drawings			

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3	DEC.23/10	SJL	BVC	DTM	ISSUED FOR 2011 PROGRESS REPORTING

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
SECTIONS - SITE 'A2'

KWL Project No. 478-119 Scale 1:200
Sheet 06 of Rev. No. 3
Client: BC HYDRO

SW4
Drawing Number

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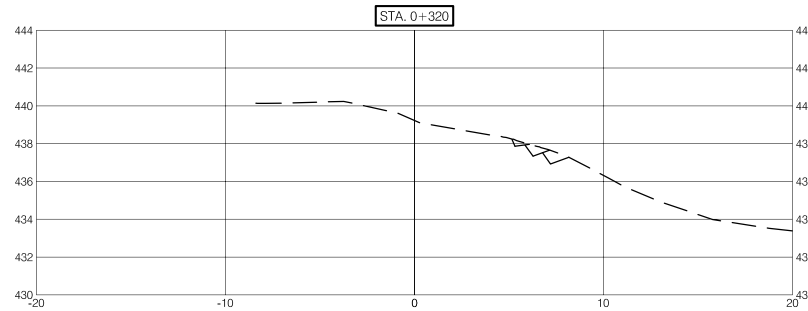

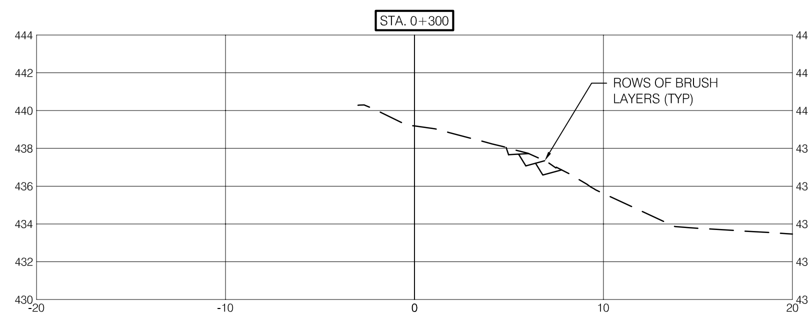

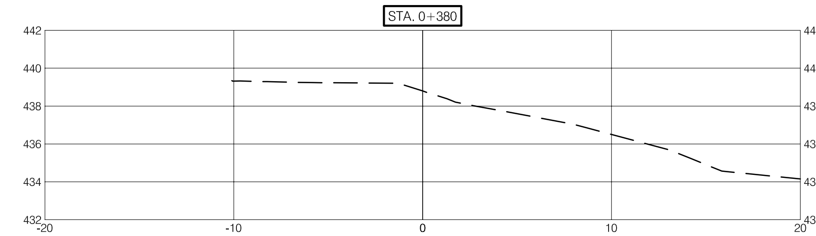

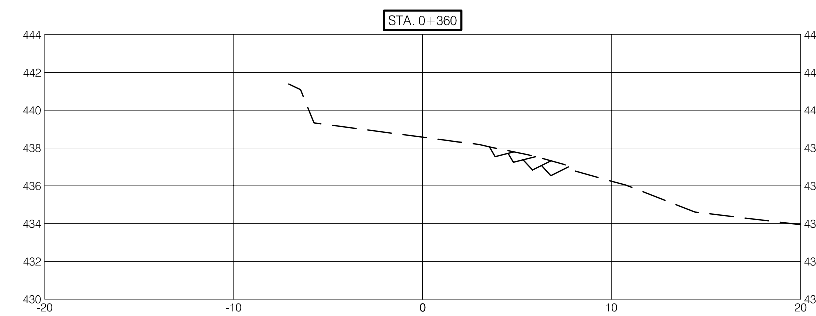

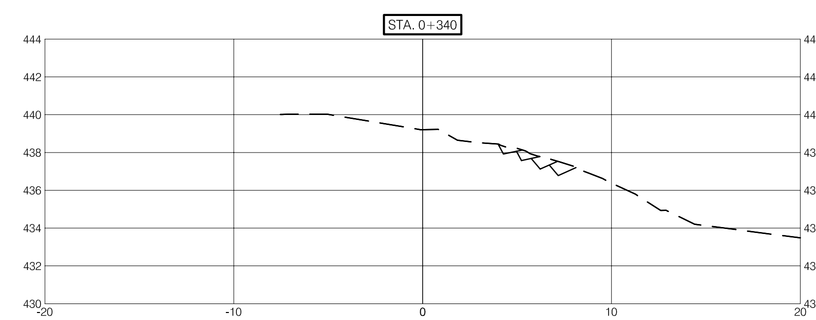

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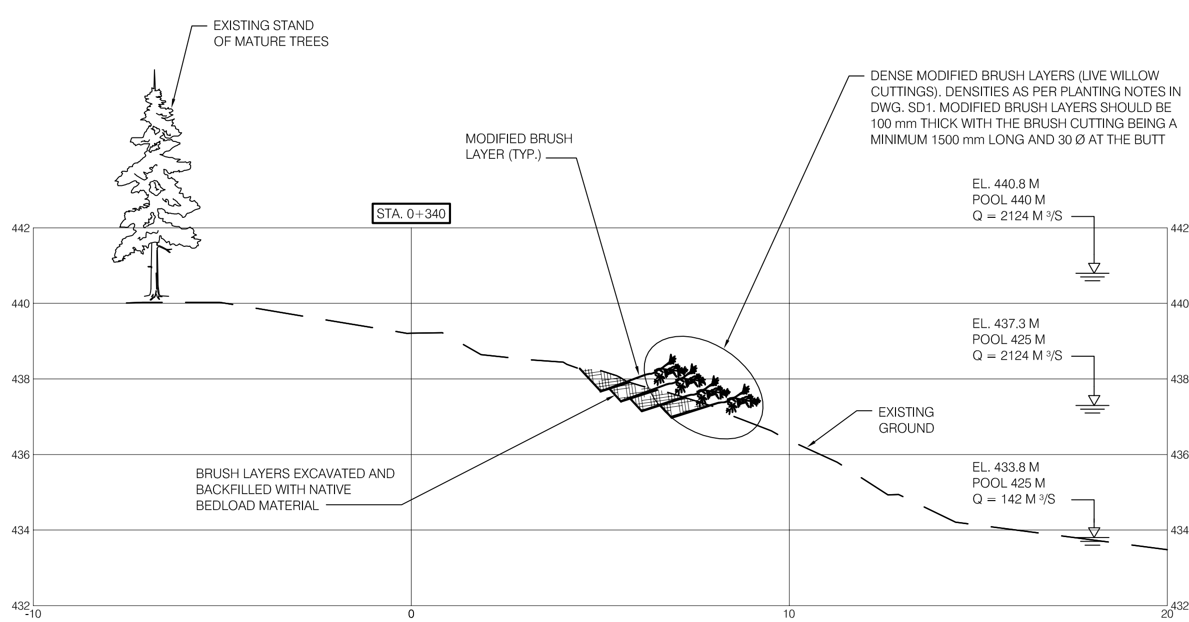
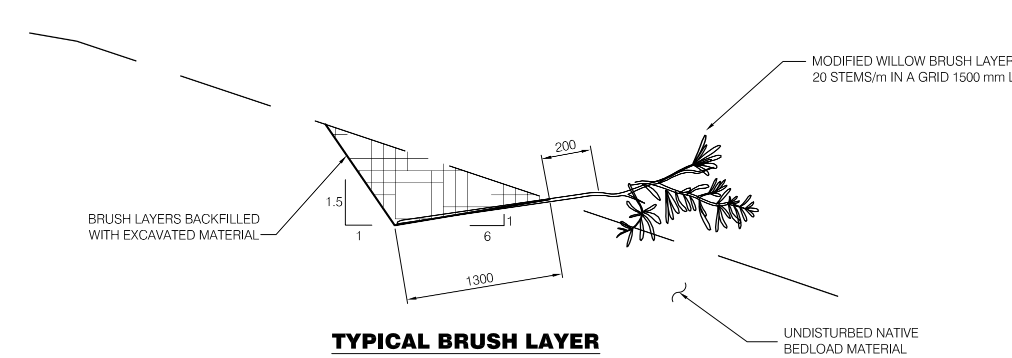


TYPICAL SECTION

SITE 'B' STA 0+300 to STA 0+380

SCALE 1:100



TYPICAL BRUSH LAYER

SCALE 1:50

ISSUED INFORMATION: Issued for	Issue	Date	Issued By
Reference			
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Tender			
Permits	P0	APR.15/11	-
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3	DEC.23/10	SJL	BVC	DTM	ISSUED FOR 2011 PROGRESS REPORTING						

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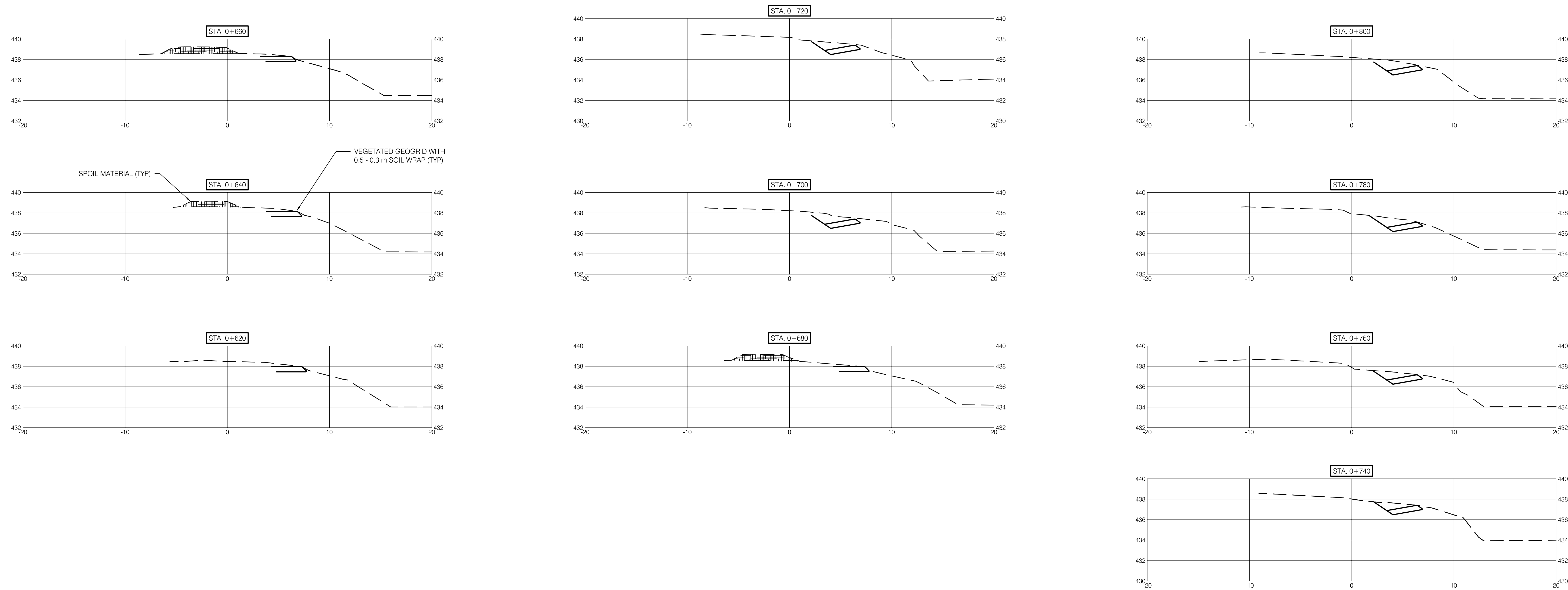
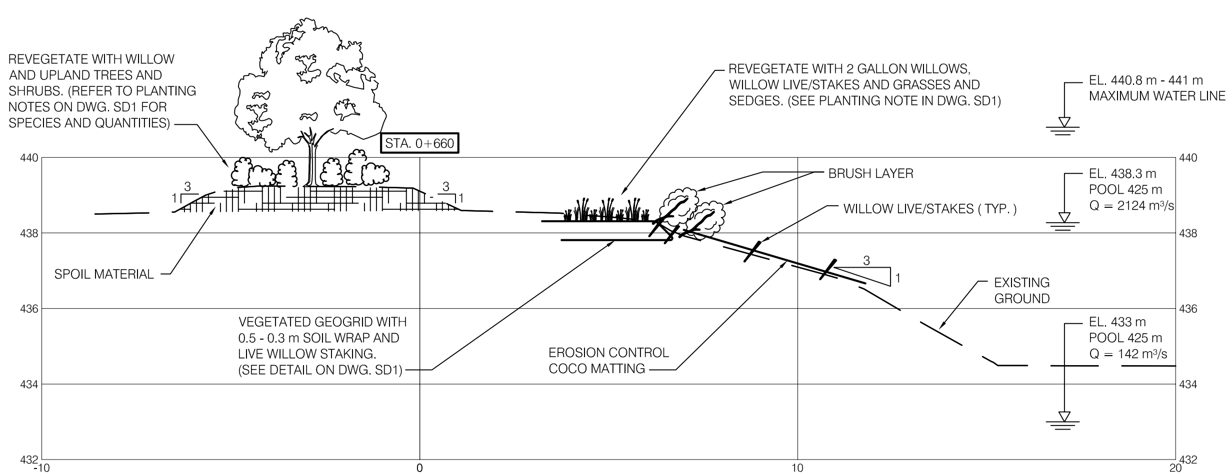
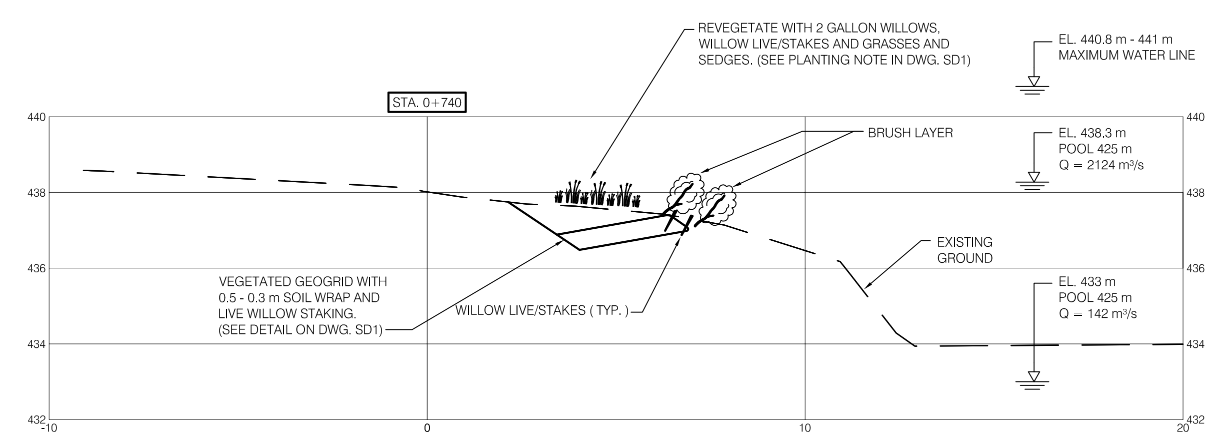
MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
SECTIONS - SITE 'B'

KWL Project No. 478-119	Scale 1:200	**SW5** Drawing Number	
Sheet 07 of	Rev. No. 3		
Client: BC HYDRO			





TYPICAL SECTION
SITE 'C' STA 0+620 to STA 0+695
SCALE 1:100



TYPICAL SECTION
SITE 'C' STA 0+695 to STA 0+810
SCALE 1:100

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AT FULL SIZE THIS BAR MEASURES 100mm. ALL SCALES REFERENCED TO FULL SIZE.

SAVED 14-Dec-2011 3:12 PM

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ISSUED INFORMATION

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Reference			
Approvals	A1	JUN.10/10	-
Tender			
Permits	P0	APR.15/11	-
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1	JUN.10/10	SJL	MP	DTM	REVISED NOTES						
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3	DEC.23/10	SJL	BVC	DTM	ISSUED FOR 2011 PROGRESS REPORTING						

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MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
SECTIONS - SITE 'C'

KWL Project No.	478-119	Scale	1:200
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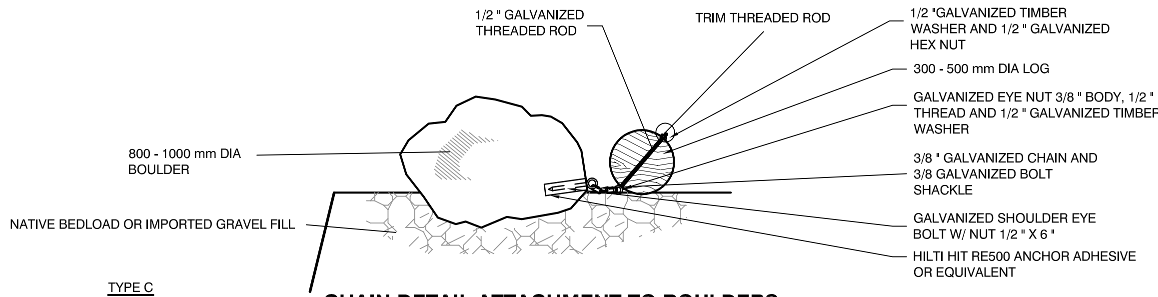
SW6
Drawing Number

Client: BC HYDRO

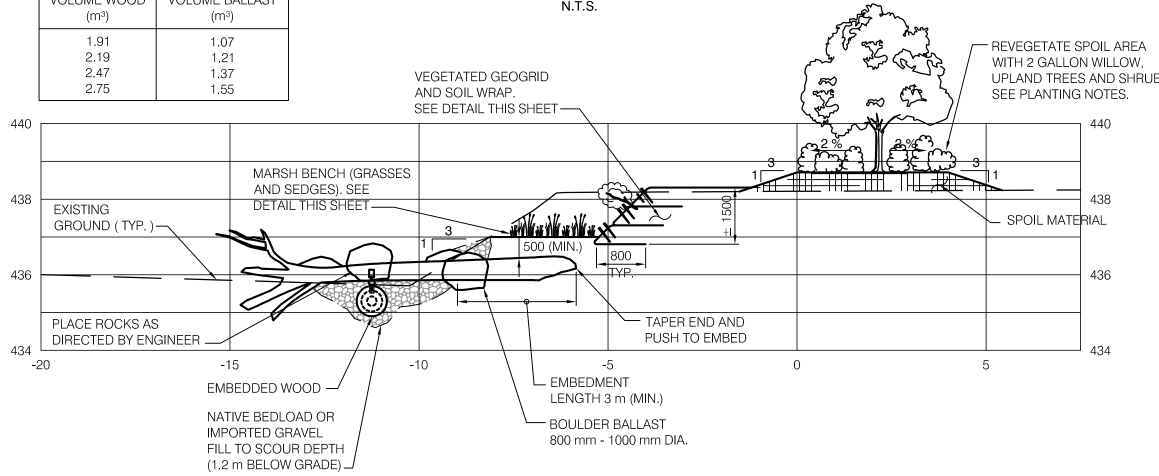


CHAIN DETAIL ATTACHMENT TO BOULDERS

N.T.S.

TYPE C

VOLUME WOOD (m^3)	VOLUME BALLAST (m^3)
1.91	1.07
2.19	1.21
2.47	1.37
2.75	1.55

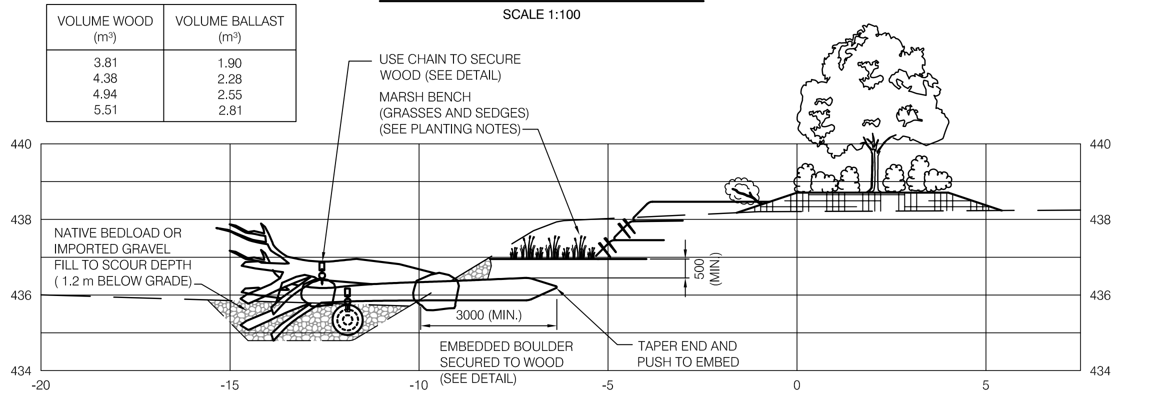


TYPE C - 2 LOG "T" STRUCTURE

SCALE 1:100

TYPE B

VOLUME WOOD (m^3)	VOLUME BALLAST (m^3)
3.81	1.90
4.38	2.28
4.94	2.55
5.51	2.81

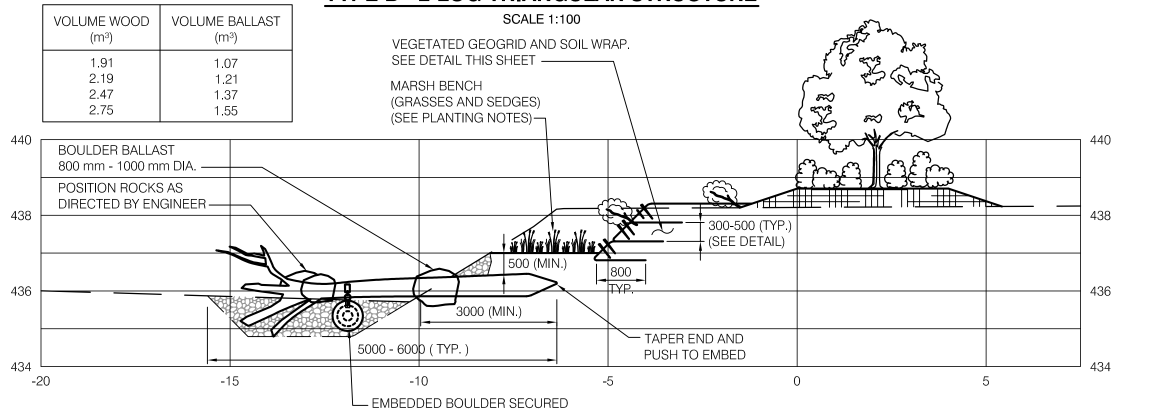


TYPE B - 2 LOG TRIANGULAR STRUCTURE

SCALE 1:100

TYPE A

VOLUME WOOD (m^3)	VOLUME BALLAST (m^3)
1.91	1.07
2.19	1.21
2.47	1.37
2.75	1.55



TYPE A - SINGLE LOG STRUCTURE

SCALE 1:100

0 1 (1:100) 5m

SUMMARY PLANT LIST

COMMON NAME	SPECIES NAME	BY AREA/LENGTH	STOCK SIZE	CALCULATE QUANTITY BASED ON
BIOENGINEERING PLANTINGS				
PACIFIC WILLOW	SALIX LUCIDA	30% BY BANK TREATMENT LENGTH	1.5 m CUTTING; 40 mm DIAMETER AT BUTT 0.65 m CUTTING; 40 mm DIAMETER AT BUTT	CALCULATE BASED ON 20 LIVESTAKES PER LINEAR METER OF BRUSH LAYER CALCULATE LIVESTAKES BY EITHER 30 cm OR 50 cm ON CENTRE SPACING BY AREA
SHRUB WILLOWS	SALIX BARCLAYI, SALIX BEBBIANA, SALIX DRUMMONDIANA	70% BY BANK TREATMENT LENGTH	1.5 m CUTTING; 40 mm DIAMETER AT BUTT 0.65 m CUTTING; 40 mm DIAMETER AT BUTT	CALCULATE BASED ON 20 LIVESTAKES PER LINEAR METER OF BRUSH LAYER CALCULATE LIVESTAKES BY EITHER 30 cm OR 50 cm ON CENTRE SPACING BY AREA
BLACK COTTONWOOD	POPULUS TRICHOCARPA	2 PLANTS PER 10 m OF BANK	1 GAL	THESE ARE ADDED TO THE FOUNDATION PLANTINGS OF WILLOW (NEED LINEAR METERS
MOUNTAIN ALDER	ALNUS INCANA	5 PLANTS PER 10 m OF BANK	1 GAL	THESE ARE ADDED TO THE FOUNDATION PLANTINGS OF WILLOW (NEED LINEAR METERS
RED-OSIER DOGWOOD	CORNUS SERICEA	5 PLANTS PER 10 m OF BANK	1 GAL	THESE ARE ADDED TO THE FOUNDATION PLANTINGS OF WILLOW (NEED LINEAR METERS
RIPARIAN (UPSLOPE) PLANTINGS				
SHRUB WILLOWS	SALIX BARCLAYI, SALIX BEBBIANA, SALIX DRUMMONDIANA	30% BY AREA	1 GAL	CALCULATE LIVESTAKES BY EITHER 30 cm OR 50 cm ON CENTRE SPACING BY AREA
MOUNTAIN ALDER	ALNUS INCANA	20% BY AREA	2 GAL	TREE SPACING IS 2.5 m ON CENTRE
PAPER BIRCH	BETULA PAPYRIFERA	15% BY AREA	2 GAL	TREE SPACING IS 2.5 m ON CENTRE
ENGLEMANN SPRUCE	PICEA ENGELMANNII	5% BY AREA	2 GAL	TREE SPACING IS 2.5 m ON CENTRE
WESTERN REDCEDAR	THUJA PLICATA	5% BY AREA	2 GAL	TREE SPACING IS 2.5 m ON CENTRE
RED-OSIER DOGWOOD	CORNUS SERICEA	10% BY AREA	1 GAL	TREE SPACING IS 1.5 m ON CENTRE
THIMBLEBERRY	RUBUS PARVIFLORUS	5% BY AREA	1 GAL	TREE SPACING IS 1.5 m ON CENTRE
SASKATOONBERRY	AMELANCHIER ALNIFOLIA	5% BY AREA	1 GAL	TREE SPACING IS 1.5 m ON CENTRE
BLACK TWINBERRY	LONICERA INVOLUCRATA	5% BY AREA	1 GAL	TREE SPACING IS 1.5 m ON CENTRE
MARSH BENCH PLANTINGS				
SEDGES	CAREX LENTICULARIS, CAREX UTICULATA, CAREX AQUATALIS	85% BY AREA	25 mm DIAMETER PLUG	SEDGE AND GRASS SPACING IS 30 CM ON CENTRE
COMMON SPIKE RUSH	ELEOCHARIS PALUSTRIS	5% BY AREA	25 mm DIAMETER PLUG	SEDGE AND GRASS SPACING IS 30 CM ON CENTRE
REDTOP	AGROSTIS GIGANTEA	10% BY AREA	25 mm DIAMETER PLUG	SEDGE AND GRASS SPACING IS 30 CM ON CENTRE

NOTES ON PLANTING:

GENERAL PLANTING
1. ALL PLANT MATERIALS SHALL CONFORM TO BCSLA / BCNTA LANDSCAPE STANDARD.
2. SUPPLIES OF WILLOW LIVE STAKES AND BRUSH LAYERS MUST BE APPROVED BY PROJECT BIOLOGIST PRIOR TO ON-SITE DELIVERY INCLUDING LOCATION AND TIMING OF HARVEST.
3. WILLOW BRUSH LAYERS AND LIVESTAKES MUST BE PROTECTED FROM DESSICATION DURING STORAGE AND INSTALLATION.
4. NO SUBSTITUTIONS WITHOUT APPROVAL FROM PROJECT BIOLOGIST.

VEGETATED GEOGRID - WILLOW BRUSH LAYERS
1. WILLOW FOR BRUSH LAYERS SHALL BE 1.5 m LONG AND 40 mm MINIMUM DIAMETER AT BUTT AND 20 mm MINIMUM DIAMETER AT TOP.
2. ALL WILLOW SHALL BE SALIX LUCIDA, SALIX BARCLAYI, SALIX BEBBIANA, SALIX DRUMMONDIANA OR SUBSTITUTE APPROVED BY PROJECT BIOLOGIST.
3. AVERAGE OF 20 STEMS PER METER.
4. BRUSH LAYERS TO BE STAGGERED BETWEEN WRAP LAYERS TO CREATE A CHECKERBOARD PATTERN.
5. INSTALL BRUSH LAYERS AT VARIABLE ANGLES (HORIZONTALLY WITHIN WRAP STRUCTURE) TO PROMOTE ROOT DEVELOPMENT.

VEGETATED GEOGRID - WILLOW LIVE STAKES
1. WILLOW FOR BRUSH LAYERS SHALL BE 0.65 m LONG AND 40 mm MINIMUM DIAMETER AT BUTT AND 20 mm MINIMUM DIAMETER AT TOP.
2. ALL WILLOW SHALL BE SALIX LUCIDA, SALIX BARCLAYI, SALIX BEBBIANA, SALIX DRUMMONDIANA OR SUBSTITUTE APPROVED BY PROJECT BIOLOGIST.
3. WILLOW LIVESTAKES SHALL BE DRIVEN AT ANGLES; DEPTH TO INTERSECT AT LEAST BRUSH LATER INTERFACE.
4. WILLOW LIVESTAKES SHALL BE DRIVEN AT 500 mm SPACINGS IN EACH WRAP AND SHALL BE STAGGERED BETWEEN SUCCESIVE LAYERS.

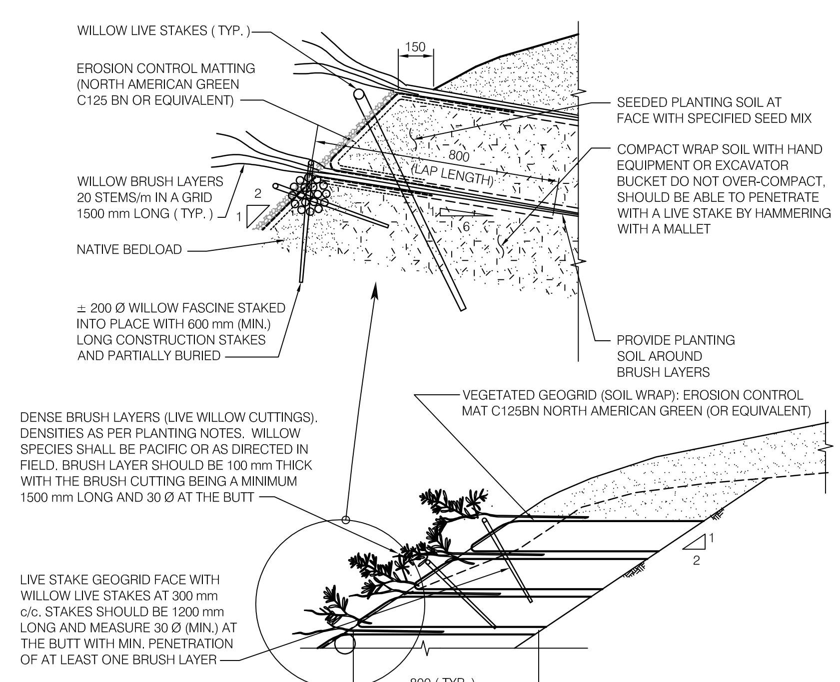
VEGETATED GEOGRID - WILLOW FASCINE
1. WILLOW FOR FASCINES SHALL BE A MINIMUM OF 1.0 m LONG AND 40 mm MINIMUM DIAMETER AT BUTT AND 15 mm MINIMUM DIAMETER AT TOP.
2. ALL WILLOW TO BE HOOKER'S WILLOW (SALIX HOOKERIANA) OR SUBSTITUTE APPROVED BY PROJECT BIOLOGIST.
3. FASCINES SHALL BE COMPOSED OF A OVERLAPPING WILLOW STEMS WITH A MINIMUM OF 10 STEMS AT ANY POINT.
4. FASCINES ARE TO BE TIED WITH JUTE CORD OR SIMILAR BIODEGRADABLE SUBSTITUTE EVERY 300 mm.

VEGETATED GEOGRID - SEEDING
1. SEED THE OUTER FACE OF EACH GEOGRID WRAP PRIOR TO CLOSURE WITH RICHARDSON'S COASTAL RECLAMATION MIX OR AN APPROVED SUBSTITUTE AT THE MANUFACTURES RECOMMENDED RATE OF APPLICATION.

MARSH BENCH
1. INSTALL 25 mm DIAMETER PLUGS OF SEDGES, RUSHES AND GRASSES.

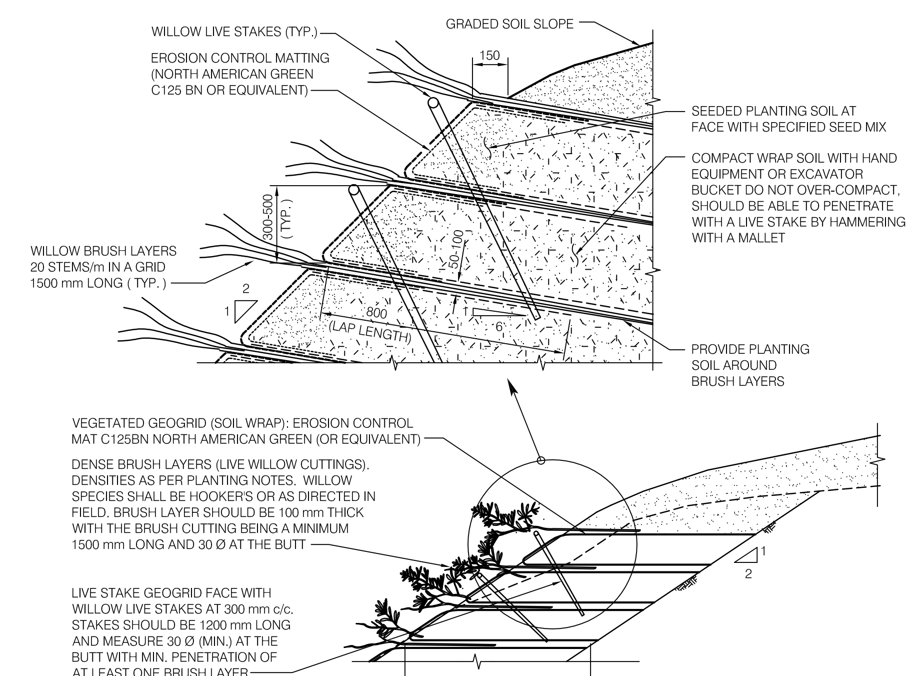
RIPRARIAN - SEEDING, SHRUBS AND TREE PLANTINGS
1. 1 AND 2 GALLON SHRUBS (SEE PLANTING LIST FOR LISTS OF SPECIES) ARE TO BE PLANTED AT SPACING GIVEN IN PLANT LIST.
2. BROADCAST SEED ALL EXPOSED SOIL IN THE RIPARIAN PLANTING ZONE WITH RICHARDSON'S INTERIOR REVEGETATION MIX, AT THE MANUFACTURER'S SPECIFIED RATES (OR APPROVED EQUAL).
3. CLUMP SHALL CONSIST OF 10 TO 15 PLANT IN IRREGULAR PATCHES OF SAME SPECIES.

MODIFIED BRUSH LAYERS
1. WILLOW FOR MODIFIED BRUSH LAYERS SHALL BE 1.5 m LONG AND 40 mm MINIMUM DIAMETER AT BUTT AND 20 mm MINIMUM DIAMETER AT TOP.
2. ALL WILLOW SHALL BE SALIX LUCIDA, SALIX BARCLAYI, SALIX BEBBIANA, SALIX DRUMMONDIANA OR SUBSTITUTE APPROVED BY PROJECT BIOLOGIST.
3. AVERAGE OF 20 STEMS PER METER.
4. MODIFIED BRUSH LAYERS TO BE STAGGERED TO CREATE A CHECKERBOARD PATTERN.
5. INSTALL MODIFIED BRUSH LAYERS AT VARIABLE ANGLES (HORIZONTALLY) TO PROMOTE ROOT DEVELOPMENT.



VEGETATED GEOGRID - SOIL WRAP WITH WILLOW FASCINE (SECTION) DETAIL

N.T.S.



VEGETATED GEOGRID - SOIL WRAP (SECTION) DETAIL

N.T.S.

ISSUED INFORMATION	Issue	Date	Issued By
Reference			
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Tender			
Permits	P0	APR.15/11	-
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Seal

KERR WOOD LEIDAL associates limited CONSULTING ENGINEERS

MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
STANDARD DETAILS

KWL Project No.	478-119	Scale	AS SHOWN
Sheet	09 of 9	Rev. No.	3
Client: BC HYDRO			

SD1
Drawing Number

KERR WOOD LEIDAL
consulting engineers

Appendix B

2015 Site Observations

Appendix B – 2015 Site Observations

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Appendix B – 2015 Site Observations

Introduction

Field measurements of the bioengineering treatment and control sites were conducted on April 21 to 23, 2015. Field conditions during 2015 monitoring were favourable. Dry weather and low river levels facilitated the location and measurement of erosion pins, and cross-section surveys.

The sites were evaluated for change (erosion or deposition) by two methods:

- measuring the length of exposed pins placed in the bank (and comparing to previous measurements on the same pin), and[1]
- surveying cross-section transects down the bank (and evaluating the distance to previous surveys of the same cross-section at specified elevations on the cross-section) (see Figure 4-3 in the main report).

The following section provides a brief description of each site, a summary of field observations and an overview of the 2015 measurements. Statistical analysis of the data for the most recent monitoring period (2013 to 2015) and the full project period (2011 to 2015) is presented in the main report (Section 4).

Negative measurement numbers indicates erosion and positive numbers indicates deposition. All bank references (left bank or right bank) are given looking downstream. For Sites A1, A2 and C the split treatment sites are described as one site to reduce redundancy in the description of the sites.

1. Site A1

1.1 Treatment

Location and Site Characteristics

Site A1 Treatment is located across from downtown Revelstoke on the right (west) bank of the Columbia River about 1.3 km downstream of the Highway 1 Bridge (Figure 2-1 in the main report). The site is approximately 160 m long and features the most complex bioengineering treatment works of all four sites (see Appendix A for detailed record drawings).

Treatment site characteristics are summarized in the following table.

[1] In most cases pins that are well exposed due to erosion of the surrounding bank) are pounded into the bank to be flush with the ground surface after being measured.

Appendix B – 2015 Site Observations

Table 1: Summary of A1 Treatment Site Characteristics

Characteristic	Site A1 Treatment
Bank Material	• lower bank: river gravel • mid and upper banks: silty sand
Treatment	• lower bank: regrading, large wood and boulder clusters, surfacing of bank with river gravel • mid bank: regrading, excavated 4.0 m wide aquatic bench, brush layers, soil wraps, willow staking • upper bank: regrading, brush layers, soil wraps, willow staking • upland areas: vegetated spoil piles
Plantings	• aquatic bench: sedges and grasses • spoil piles: willow staking and variety of planted shrubs and trees

Field Observations

The following observations were made during the 2015 field visit:

1. There was significant erosion of the (low-elevation) aquatic bench between 2012 and 2015. The erosion has exposed the previously-embedded large wood (and boulder ballasting) (Photo 1).
2. Gravel and cobble material placed in the aquatic bench remains (Photo 1) but much of the finer material (and plantings) were eroded (Photo 2).
3. The majority of the soil wrap and brush layer areas in the upper bank remain intact (Photo 2);
4. There is minimal new growth on the willow stakes and brush layers in the soil wraps (Photo 3); and
5. There is moderate survival of the planted potted trees and shrubs at the highest elevations.

The following photos illustrate the condition of Treatment Site A1 as observed during the 2015 field visit.

Appendix B – 2015 Site Observations

Photo 1: Site A1 Treatment Eroded Aquatic Bench, Exposed Woody Debris and Boulder Ballast (April 21, 2015)

Photo 2: Site A1 Treatment Eroded Aquatic Bench, Soil Wraps and Brush Layers (April 21, 2015)

Appendix B – 2015 Site Observations

Photo 3: Site A1 Treatment Minimal New Growth of Willow Stakes and Brush Layers (April 21, 2015)

Measurement Summary

The following is an overview of the 2015 measurements. 2013 to 2015 erosion pin measurements are presented in Figure 1, for Site A1 Treatment. 2013 to 2015 cross-section measurements for Site A1 Treatment are summarized in Table 2, below. Cross-section plots are presented in Figure 2 (Drawing SW1).

- On average, the erosion pin data indicate moderate erosion for Site A1 Treatment during the 2013 to 2015 period (-9 cm, including both the upstream and downstream treatments).
- Δx Midpoint means generally indicate erosion for the lower elevation band, which is supported by the field observations.[2]

[2] The horizontal distance between 2013 and 2015 cross-sections (and 2012 and 2015 cross-sections) evaluated at the mid-point of three elevation bands (upper, middle and lower). See Figure 4-3 in the main report for illustration.

Appendix B – 2015 Site Observations

Table 2: Mean Cross-section Δx Midpoint Values for Site A1 Treatment (Upstream & Downstream)

Elevation Band	2013 to 2015		TOTAL (2012 to 2015)	
	A1 U/S Treatment (m)	A1 D/S Treatment (m)	A1 U/S Treatment (m)	A1 D/S Treatment (m)
Upper	0.58	0.35	0.69	0.18
Middle	-0.15	-0.22	-0.20	-0.37
Lower	-0.70	-1.23	-1.65	-2.73

1.2 Control

Location and Site Characteristics

Site A1 control sites are located 150 m upstream and 210 m downstream from the ends of Site A1 (Figure 1). The control sites are both approximately 70 meters long.

Control site characteristics are summarized in the following table.

Table 3: Summary of A1 Control Site Characteristics

Characteristic	Site A1 Upstream Control	Site A1 Downstream Control
Bank Material	• lower bank: river gravel • mid bank: mix of river gravel and silty sand • upper bank: silty sand	• lower bank: silty sand over river gravels • mid and upper banks: silty sand
Riparian Vegetation	• brush large and large trees	• brush and grass

Appendix B – 2015 Site Observations

Field Observations

The following observations were made during the 2015 field visit:

1. Both control sites have experienced erosion and deposition; and
2. Undercutting of the bank leading to toppling of grassy blocks has occurred at both sites.

The following photos illustrate the condition of the control sites observed during the 2015 field visit.

Photo 4: Bank Condition at Site A1 Upstream Control (April 21, 2015).

Photo 5: Bank Condition at Site A1 Downstream Control (April 21, 2015).

Appendix B – 2015 Site Observations

Measurement Summary

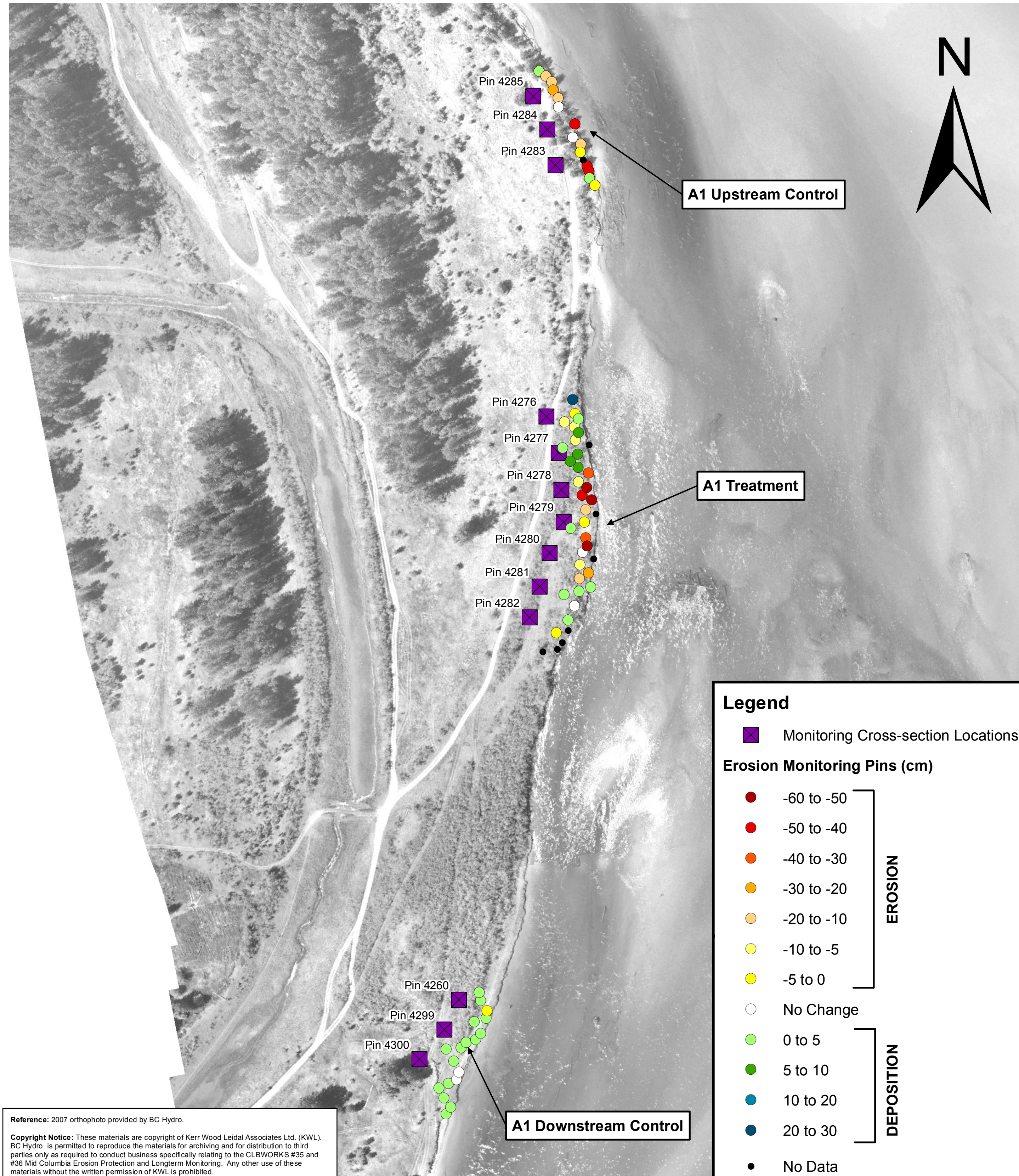
The following is an overview of the 2015 measurements. 2013 to 2015 erosion pin measurements are presented in Figure 1, for Site A1 Control (Upstream and Downstream). 2013 to 2015 and 2012 to 2015 cross-section measurements for Site A1 Control are summarized in Table 4, below. Cross-section plots are presented in Figure 2 (Drawing SW1).

Appendix B – 2015 Site Observations

- On average, the erosion pin data indicate moderate erosion for the upstream control site (-15 cm) and minor deposition for the downstream control site (1 cm) for the 2013 to 2015 period;
- Cross-section results are mixed for the 2013 to 2015 time period:
  - o Δx Midpoint means for the upstream control generally indicate erosion.
  - o Δx Midpoint means for the downstream control generally indicate deposition.
- The project-to-date period (2012 to 2015) shows a mix of deposition and erosion.
- Changes are largest in the middle elevation band.

Table 4: Mean Cross-section Δx Midpoint Values for Site A1 Control (Upstream and Downstream)

Elevation Band	2013 to 2015		2012 to 2015 (Total)	
	A1 U/S Control (m)	A1 D/S Control (m)	A1 U/S Control (m)	A1 D/S Control (m)
Upper	-0.07	0.05	-0.12	-0.08
Middle	-0.20	0.54	-0.16	0.34
Lower	-0.05	-0.06	-0.16	-0.19



Reference: 2007 orthophoto provided by BC Hydro.

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Project No. 478-081

Date December 2015

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2013 to 2015 Erosion Pin Data for Site A1 (Treatment and Control)

Figure 1

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Author: EEllis

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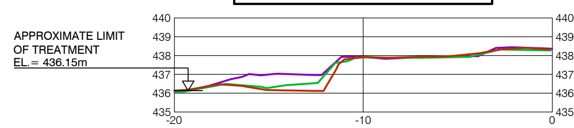
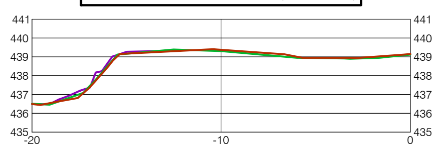


SITE A1 UPSTREAM CONTROL-3 (REBAR4283)



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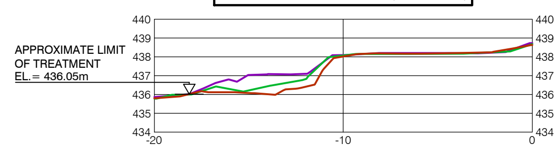

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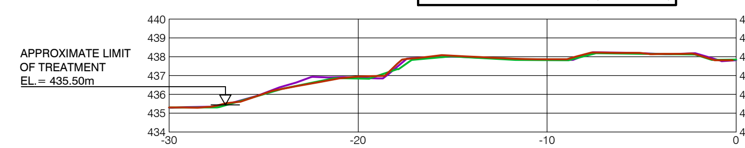

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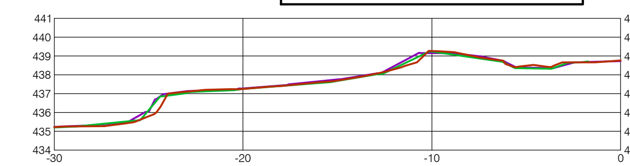

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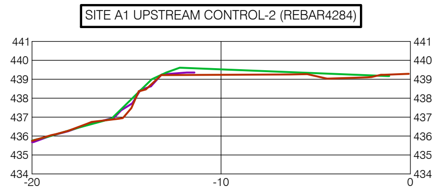

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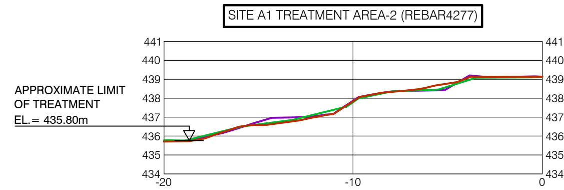

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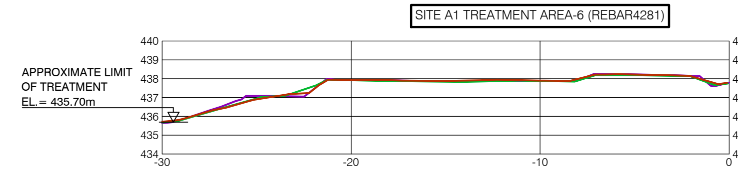
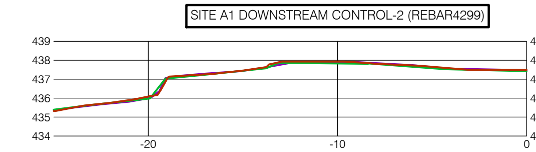


SITE A1 DOWNSTREAM CONTROL-2 (REBAR4299)



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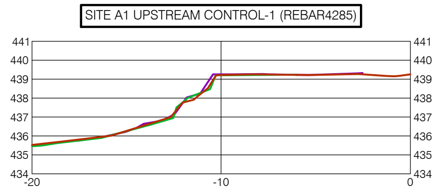

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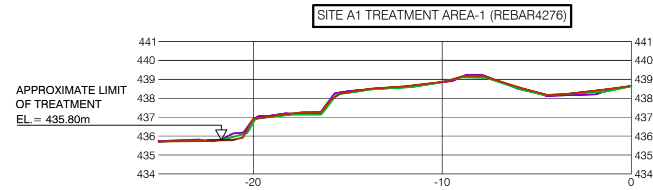

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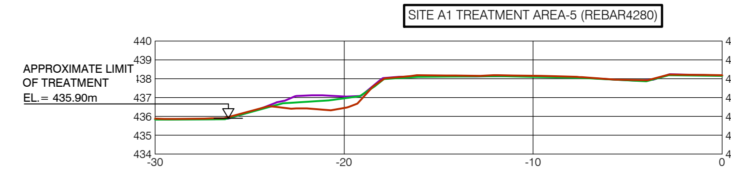
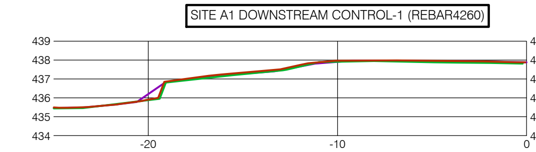


SITE A1 DOWNSTREAM CONTROL-1 (REBAR4260)



LEGEND

- TRANSECT GROUND JUNE, 2012
- TRANSECT GROUND APRIL, 2013
- TRANSECT GROUND APRIL, 2015

NOTE:

CONSTRUCTION OF THE SITE 'A1' BIO-ENG TREATMENT WORKS WAS PERFORMED IN OCTOBER 2011 AND MAY 2012. THEREFOR THERE IS NO TRANSECT GROUND MEASUREMENTS FOR NOVEMBER 2011 AS THE SITE WAS DISTURBED BY 2012 CONSTRUCTION.

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ISSUED INFORMATION

Issued for	Issue	Date	Issued By
Reference			
Approvals			
Tender			
Permits			
Construction			
Record Drawings			

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING
1	DEC.20/13	DTM	BVC		ISSUED FOR 2013 REPORTING
2	JUL.14/15		TMIN		ISSUED FOR 2015 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

KERR WOOD LEIDAL associates limited CONSULTING ENGINEERS

CLB#35
BIOENGINEERING EROSION MONITORING
SITE A1 SECTIONS

KWL Project No. 478.119 Scale 1:400
Sheet 1 of 4 Rev. No. 2
Client: BC HYDRO

SW1
Drawing Number

Appendix B – 2015 Site Observations

2. Site A2

2.1 Treatment

Location and Site Characteristics

Site A2 Treatment is located across from the Downie Timber Mill log yard in Revelstoke, on the right (west) bank of the Columbia River about 2.2 km downstream of the Highway 1 Bridge (Figure 2-1, main report). The site is approximately 100 meters long. See Appendix A for detailed record drawings.

Treatment site characteristics are summarized in the following table.

Table 5: Summary of A2 Treatment Site Characteristics

Characteristic	Site A2
Bank Material	• lower bank: river gravel • mid and upper banks: silty sand
Treatment	• lower bank: re-grading • mid bank: re-grading, temporary erosion control blanket, willow staking • upper bank: re-grading, temporary erosion control blanket, brush layers, soil wraps, willow staking • upland areas: vegetated spoil piles
Plantings	• spoil piles: variety of planted native shrubs and trees

Field Observations

The following observations were made during the 2015 field visit:

1. Substantial erosion has occurred along the toe and mid-bank of the site. The majority of the erosion control blanket / willow stake treatment has been washed away (Photos 6 and 7);
2. The soil wrap and brush layers in the upper bank are largely intact (Photo 8);
3. New growth on the willow stakes and brush layers in the soil wraps is moderate (Photo 9); and
4. The survival rate of the planted potted trees and shrubs is moderate.

The following photos illustrate the conditions of Site A2 Treatment observed during the 2015 field visit.

Appendix B – 2015 Site Observations

Photo 6: Site A2 Treatment Erosion of Erosion Control Blanket and Willow Stakes (Treatment Remnants Visible Mid-Photo) (April 21, 2015)

Photo 7: Site A2 Treatment Complete Erosion of Erosion Control Blanket and Willow Stakes (April 21, 2015)

Appendix B – 2015 Site Observations

Photo 8: Site A2 Treatment Erosion of Toe and Mid-Bank, Upper Soil Wraps and Brush Layers Intact (April 21, 2015)

Photo 9: Site A2 Treatment New Growth on Willow and Brush Layers (April 21, 2015)

Appendix B – 2015 Site Observations

Measurement Summary

The following is an overview of the 2015 measurements. 2013 to 2015 erosion pin measurements are presented in Figure 3. 2013 to 2015 and 2011 to 2015 cross-section measurements for Site A2 Treatment are summarized in Table 6 below. Cross-section plots are presented in Figure 4.

- On average, the 2013 to 2015 erosion pin data indicate moderate erosion for both treatment sites (-12 cm for the upstream and -30 cm for the downstream treatment);
- Δx Midpoint means[3] indicate erosion, generally, for both the more recent and the project-to-date timeline. For the most part, the erosion has been progressive: the project-to-date erosion is larger than the more recent period. Erosion in the middle elevation band is consistently larger than in the upper band. The lower elevation band data are more variable.

Table 6: Mean Cross-section Δx Midpoint Values for Site A2 Treatment (Upstream & Downstream)

Elevation Band	2013 to 2015		2011 to 2015 (Total)	
	A2 U/S Treatment (m)	A2 D/S Treatment (m)	A2 U/S Treatment (m)	A2 D/S Treatment (m)
Upper	0.20	-0.44	-0.06	-0.90
Middle	-1.01	-0.68	-1.60	-1.93
Lower	-0.85	-0.56	-0.76	-2.52

2.2 Control

Location and Site Characteristics

Site A2 control sites are located about 75 m upstream and downstream from the ends of Site A2 (Figure 2-1, main report). Both sites are approximately 60 m long.

Control site characteristics are summarized in the following table.

Table 7: Summary of A2 Control Site Characteristics

Characteristic	Site A2 Upstream Control	Site A2 Downstream Control
Bank Material	• lower bank: river gravel • mid and upper banks: silty sand	• lower bank: river gravels • mid and upper banks: silty sand
Riparian Vegetation	• brush with grassy mid bank	• grass

[3] The horizontal distance between 2013 and 2015 cross-sections (and 2011 and 2015 cross-sections) evaluated at the mid-point of three elevation bands (upper, middle and lower). See Figure 4-3 for illustration.

Appendix B – 2015 Site Observations

Field Observations

The following observations were made during the 2015 field visit:

1. Both control sites have experienced erosion; and
2. Undercutting of the bank leading to toppling of grassy blocks has occurred at both sites.

The following photos illustrate the conditions of the site as observed during the 2015 field visit.

Photo 10: Bank Condition at Site A2 Upstream Control (April 21, 2015).

Photo 11: Bank Condition Site A2 Downstream Control (April 21, 2015).

Appendix B – 2015 Site Observations

Measurement Summary

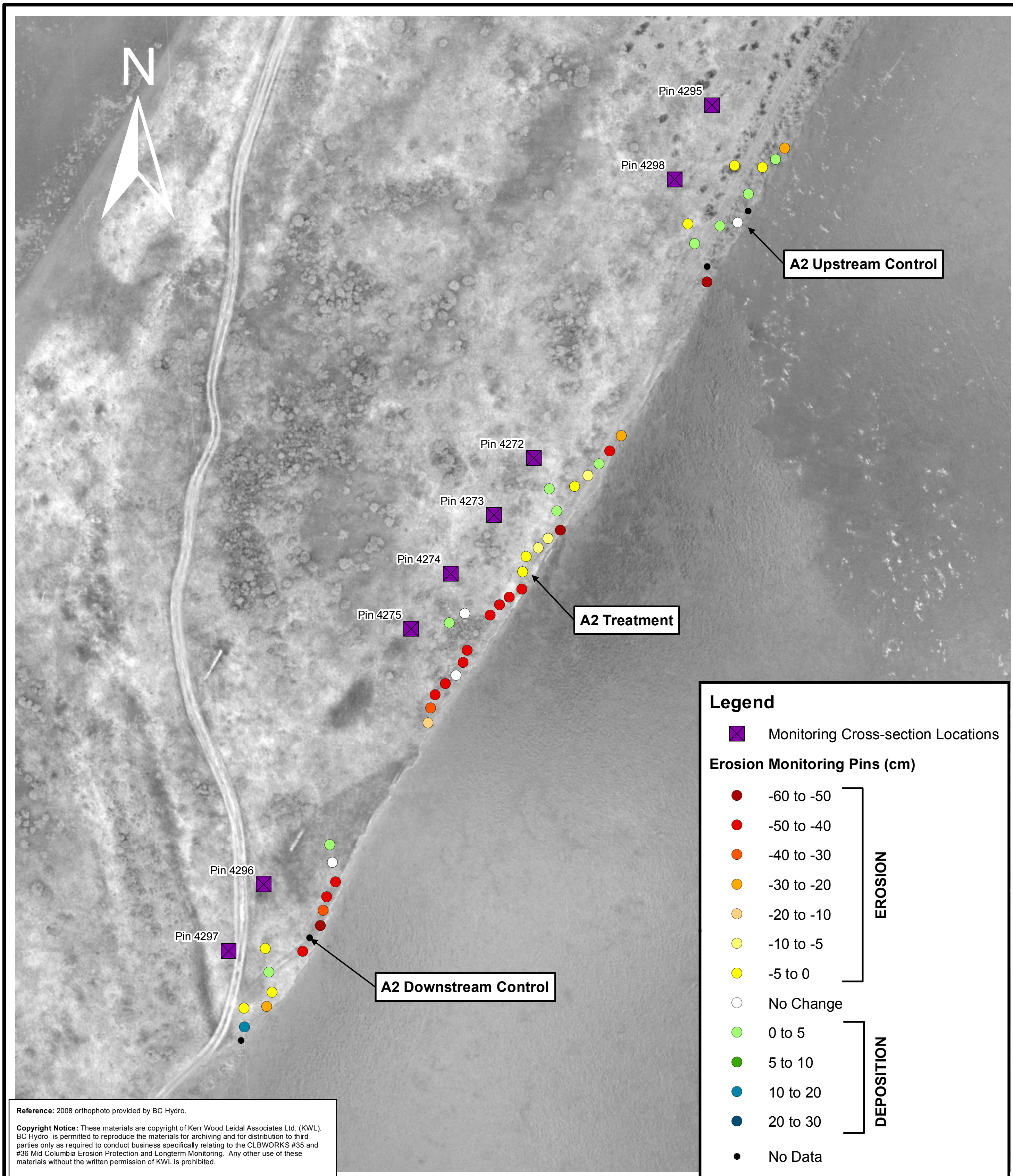
The following is an overview of the 2015 measurements. 2013 to 2015 erosion pin measurements are presented in Figure 3. 2013 to 2015 and 2011 to 2015 cross-section measurements for Site A2 Control are summarized in Table 8 below. Cross-section plots are presented in Figure 4.

- On average, the 2013 to 2015 erosion pin data indicate minor to moderate erosion for both control sites (-7 cm for the upstream control and -18 cm for the downstream control site);
- Δx Midpoint means[4] indicate erosion, generally, for both the more recent and the project-to-date timeline (Table 8). For the most part, the erosion has been progressive: the project-to-date erosion is larger than the more recent period. Erosion in the middle elevation band is consistently larger than in the upper band.

Table 8: Mean Cross-section Δx Midpoint Values for Site A2 Control (Upstream & Downstream)

Elevation Band	2013 to 2015		2011 to 2015 (Total)	
	A2 U/S Control (m)	A2 D/S Control (m)	A2 U/S Control (m)	A2 D/S Control (m)
Upper	1.25	-0.75	0.61	-0.14
Middle	-0.26	-0.35	-0.77	-1.17
Lower	-0.14	-0.46	0.24	-0.67

[4] The horizontal distance between 2013 and 2015 cross-sections (and 2011 and 2015 cross-sections) evaluated at the mid-point of three elevation bands (upper, middle and lower). See Figure 4-3 for illustration.



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Project No.	Date
478-081	December 2015

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2013 to 2015 Erosion Pin Data for Site A2 (Treatment and Control)

Figure 3

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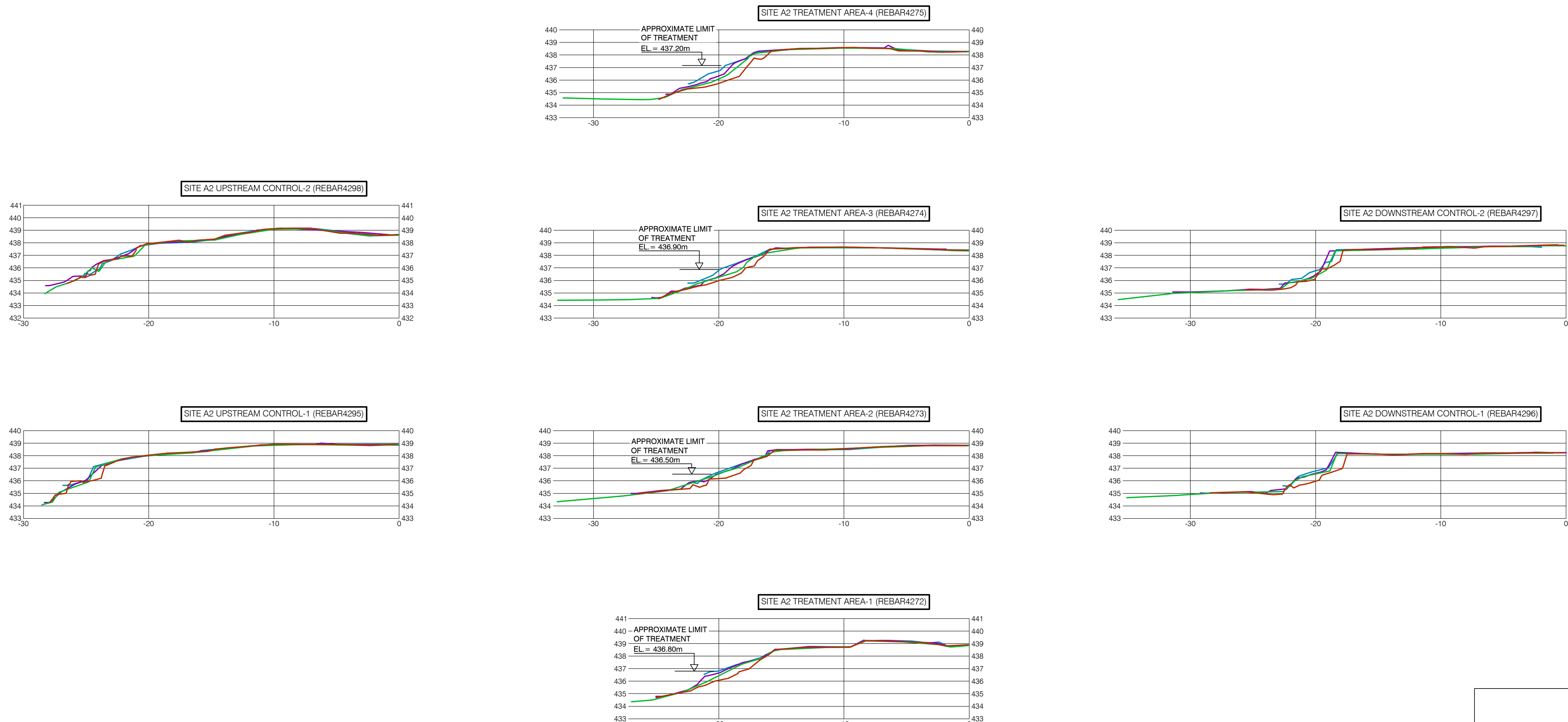

LEGEND

- TRANSECT GROUND NOVEMBER, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2013
- TRANSECT GROUND APRIL, 2015

NOTE:

AVERAGE WATER LEVELS DURING THE 1 WEEK CONSTRUCTION OF THE SITE 'A2' BIO-ENG TREATMENT WORKS VARIED BETWEEN ELEVATIONS 437.2m AND 436.5m

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ISSUED INFORMATION

Issued for	Issue	Date	Issued By
Reference			
Approvals			
Tender			
Permits			
Construction			
Record Drawings			

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING
1	DEC.20/13	DTM	BVC		ISSUED FOR 2013 REPORTING
2	JUL.14/15		TMIN		ISSUED FOR 2015 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

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CONSULTING ENGINEERS

CLB#35
BIOENGINEERING EROSION MONITORING
SITE A2 SECTIONS

KWL Project No. 478.119	Scale 1:400	**SW2** Drawing Number	
Sheet 2 of 4	Rev. No. 2		
Client: BC HYDRO			

Appendix B – 2015 Site Observations

3. Site B

3.1 Treatment

Location and Site Characteristics

Site B Treatment is located near the upstream end of the Revelstoke Airport runway, on the left (east) bank of the Columbia River, about 1.4 km downstream of the confluence of the Illecillewaet River (Figure 2-1). The site is approximately 85 meters long (see Appendix A for detailed record drawings).

Treatment site characteristics are summarized in the following table.

Table 9: Summary of Treatment Site B Characteristics

Characteristic	Site B
Bank Material	• lower and mid bank: river gravel • upper bank: river gravel and sand
Treatment	• lower bank: no treatment • mid bank: modified brush layers • upper bank: no treatment
Plantings	• disturbed upland slopes: variety of planted native shrubs and trees

Field Observations

The following observations were made during the 2015 field visit:

1. Brush layers appear stable.
2. New growth on brush layers is evident (Photo 12);

Photo 12: Site B Treatment New Growth on Brush Layers (April 21, 2015).

Appendix B – 2015 Site Observations

Measurement Summary

The following is an overview of the 2015 measurements. 2013 to 2015 erosion pin measurements are presented in Figure 5. 2013 to 2015 and 2011 to 2015 cross-section measurements for Treatment Site B are summarized in Table 10 below. Cross-section plots are presented in Figure 6.

- On average, the 2013 to 2015 erosion pin data indicate minor net deposition for this treatment site (about 4 cm);
- Δx Midpoint means[5] indicate minor erosion in the upper and lower elevation bands and deposition in the middle elevation band, for both the more recent and the project-to-date timeline. For the most part, the erosion and deposition has been progressive: the project-to-date erosion is larger than the more recent period.

[5] The horizontal distance between 2012 and 2013 cross-sections (and 2011 and 2013 cross-sections) evaluated at the mid-point of three elevation bands (upper, middle and lower). See Figure 4-3 for illustration.

Appendix B – 2015 Site Observations

Table 10: Mean Cross-section Δx Midpoint Values for Site B Treatment

Elevation Band	2013 to 2015 B Treatment (m)	2011 to 2015 B Treatment (m)
Upper	-0.04	-0.05
Middle	0.13	0.20
Lower	-0.04	-0.15

3.2 Control

Location and Site Characteristics

Site B control site is located about 100 m upstream from the end of Site B (Figure 2-1, main report). The site is approximately 80 meters long.

Control site characteristics are summarized in the following table.

Table 11: Summary of B Control Site Characteristics

Characteristic	Site B Control
Bank Material	• lower and mid bank: river gravel • upper bank: silty sand over river gravel
Riparian Vegetation	• clusters of grass in mid bank • grass and brush on upper bank • brush and large trees in upland area

Field Observations

The following observations were made during the 2015 field visit:

1. Erosion has occurred on the mid bank: some grassy blocks have broken off the upper bank and migrated down the mid bank slope (Photo 13).
2. Deposition is more common in the upper bank.

The following photo illustrates the conditions of the site as observed during the 2015 field visit.

Appendix B – 2015 Site Observations

Photo 13: Site B Control, Grassy Blocks Migrating Down Mid Bank Slope, Erosion Pin in Foreground (April 20, 2015)

Measurement Summary

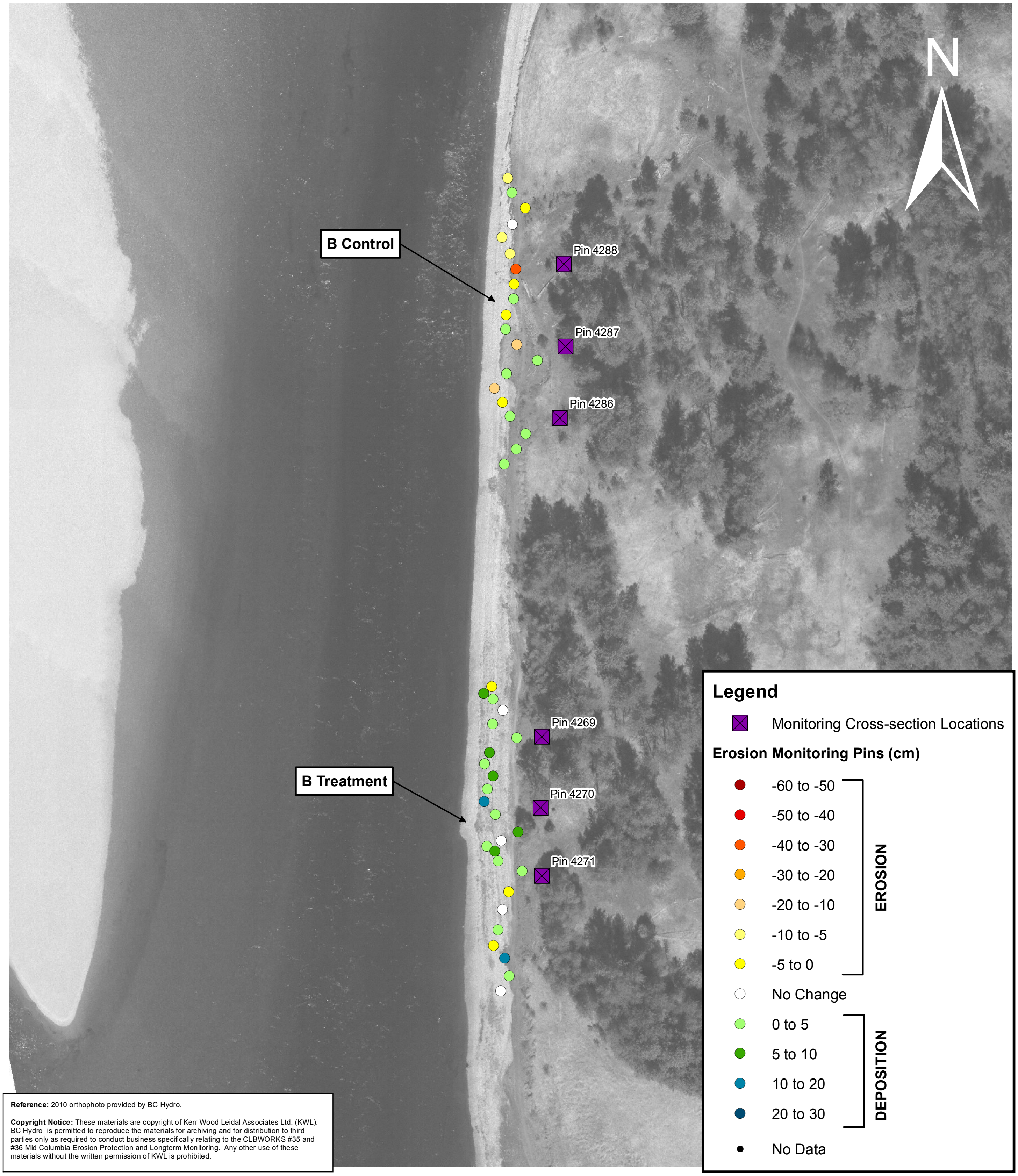
The following is an overview of the 2015 measurements. 2013 to 2015 erosion pin measurements are presented in Figure 5. 2013 to 2015 and 2011 to 2015 cross-section measurements for Control Site B are summarized in Table 12, below. Cross-section plots are presented in Figure 6.

- On average, the 2013 to 2015 erosion pin data indicate minor erosion for this control site (-3 cm);
- Δx Midpoint means[6] for the current period and the total project period indicate deposition for the upper and middle elevation bands, and erosion in the lower elevation band (Table 12).

Table 12: Mean Cross-section Δx Midpoint Values for Site B Control

Elevation Band	2013 to 2015 B Control (m)	2011 to 2015 B Control (m)
Upper	0.10	0.29
Middle	0.07	0.18
Lower	-0.13	-0.38

[6] The horizontal distance between 2012 and 2013 cross-sections (and 2011 and 2013 cross-sections) evaluated at the mid-point of three elevation bands (upper, middle and lower). See Figure 4-3 for illustration.



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Project No.	Date
478-081	December 2015

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2013 to 2015 Erosion Pin Data for Site B (Treatment and Control)

Figure 5

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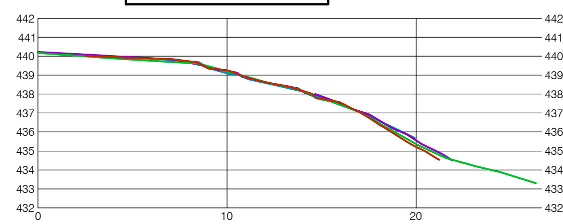
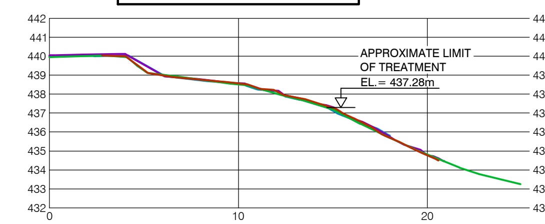
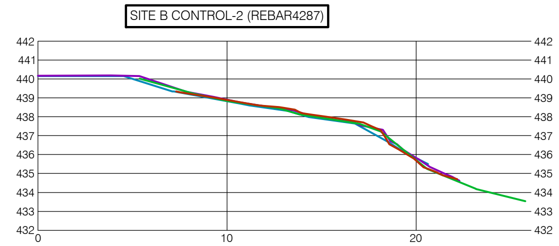


SITE B TREATMENTSITE-3 (REBAR4271)



SITE B CONTROL-2 (REBAR4287)



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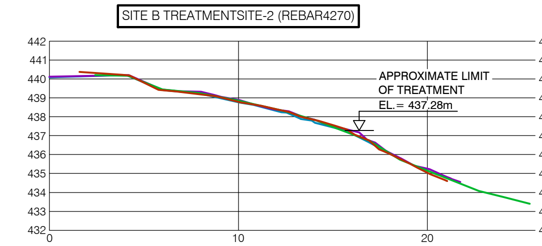

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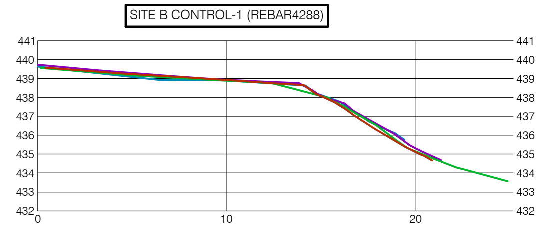

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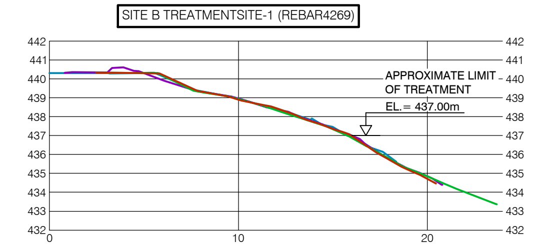

LEGEND

- TRANSECT GROUND NOVEMBER, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2013
- TRANSECT GROUND Q.A. APRIL, 2013
- TRANSECT GROUND APRIL, 2015

0 2 (1:400) 10m

ISSUED INFORMATION Issued for	Issue	Date	Issued By
Reference			
Approvals			
Tender			
Permits			
Construction			
Record Drawings			

REVISION INFORMATION Rev. No.	Date	Designed	Drawn	Checked	Description of Revision	Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING						
1	DEC.20/13	DTM	BVC		ISSUED FOR 2013 REPORTING						
2	JUL.14/15		TMIN		ISSUED FOR 2015 REPORTING						

Seal

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CLB#35
BIOENGINEERING EROSION MONITORING
SITE B SECTIONS

KWL Project No.	478.119	Scale	1:400	**SW3**
Sheet	3 of 4	Rev. No.	2	Drawing Number
Client: BC HYDRO				

Appendix B – 2015 Site Observations

4. Site C

4.1 Treatment

Location and Site Characteristics

Site C Treatment is located near the upstream end of the Revelstoke Airport runway, on the left (east) bank of the Columbia River, about 1.8 km downstream of the confluence of the Illecillewaet River (Figure 2-1, main report). The site is approximately 190 m long. See Appendix A for detailed record drawings.

Treatment site characteristics are summarized in the following table.

Table 13: Summary of Treatment C Site Characteristics

Characteristic	Site C
Bank Material	• lower bank: river gravel • mid bank: silty sand over river gravel • upper bank: silty sand • note: a 30 m section (Sta. 0+710 to 0+740) of mid and upper banks have a thick layer of organics, mostly tree bark, under the grassy vegetative mat, thought to be waste from old wood processing operations in the area.
Treatment – Upstream	• lower bank: no treatment • mid bank: regrading, temporary erosion control blanket, willow staking • upper bank: regrading, temporary erosion control blanket brush layers, soil wraps, willow staking • upland areas: vegetated spoil piles
Treatment – Downstream	• lower bank: 2012 regrading (Sta. 0+715 to 0+725 and Sta. 0+750 to 0+765) • mid bank: 2012 regrading, temporary erosion control blanket, willow staking (Sta. 0+715 to 0+725 and Sta. 0+750 to 0+765) • upper bank: brush layers, soil wraps, willow staking • upland areas: vegetated spoil piles
Plantings	• spoil piles: variety of planted native shrubs and trees

Appendix B – 2015 Site Observations

Field Observations

The following observations were made during the 2015 field visit:

1. Erosion is occurring in the (steeper) lower to mid bank areas, and undermining the treatment at higher elevations (Photo 14). As indicated in the cross-section surveys (Figure 8), the erosion is initiating at elevations below where the bank was treated.
2. The undermining effect is less evident toward the upstream end of the site (Photo 15).
3. Deposition is common in upland areas of the site; and
4. New growth on the willow stakes and brush layers in the soil wraps is evident (Photos 16).

The following photos illustrate the condition of the site as observed during the 2015 field visit.

Photo 14: Site C Treatment Erosion in Mid Bank (April 21, 2015)

Appendix B – 2015 Site Observations

Photo 15: Erosion Control Blanket and Willow Stakes in Place Mid-Bank Toward Upstream End of Site (April 21, 2015)

Photo 16: Growth on Willow Stakes and Brush Layers (April 21, 2015)

Appendix B – 2015 Site Observations

Measurement Summary

The following is an overview of the 2015 measurements. 2013 to 2015 erosion pin measurements are presented in Figure 7. 2013 to 2015 and 2011 to 2015 cross-section measurements for Site C Treatment are summarized in Table 14 below.

Cross-section plots are presented in Figure 8 (Drawing SW4). (Note that a limited amount of construction occurred in 2012, affecting 3 of the 8 cross-sections: for these cross-sections, the "post-construction" period starts with the 2013 survey).

- On average, the erosion pin data indicate minor erosion for upstream treatment site (-5 cm) and minor deposition for the downstream treatment (+1 cm) for the 2013 to 2015 period;
- Δx Midpoint means[7] in the middle and lower elevation bands indicate erosion, with the upper elevation band indicating deposition.

Table 14: Mean Cross-section Δx Midpoint Values for Site C Treatment (Upstream & Downstream)

Elevation Band	2013 to 2015		2011 to 2015	
	C U/S Treatment (m)	C D/S Treatment (m)	C U/S Treatment (m)	C D/S Treatment (m)
Upper	0.36	0.30	0.32	-0.10
Middle	-0.40	-0.64	-1.20	N/A
Lower	-0.44	0.07	N/A	N/A

4.2 Control

Location and Site Characteristics

Site C control sites are located approximately 150 m upstream and 110 m downstream from the ends of Site C (Figure 2-1, main report). Both sites are approximately 80 m long.

Control site characteristics are summarized in the following table.

[7] The horizontal distance between 2012 and 2013 cross-sections (and 2011 and 2013 cross-sections) evaluated at the mid-point of three elevation bands (upper, middle and lower). See Figure 4-10 for illustration.

Appendix B – 2015 Site Observations

Table 15: Summary of C Control Site Characteristics

Characteristic	Site C Upstream Control	Site C Downstream Control
Bank Material	• lower bank: silty sand over river gravel • mid bank and upper banks: silty sand • note: some woody debris is scattered at the toe and embedded in the lower bank	• lower, mid and upper banks: silty sand • note: some woody debris is scattered at the toe and embedded in the lower bank
Riparian Vegetation	• grass with brush clusters	• grass with brush clusters

Field Observations

The following photos illustrate the condition of the site as observed during the 2015 field visit.

Photo 17: Site C Upstream Control Bank Condition (April 20, 2015).

Appendix B – 2015 Site Observations

Photo 18: Site C Downstream Control Bank Condition

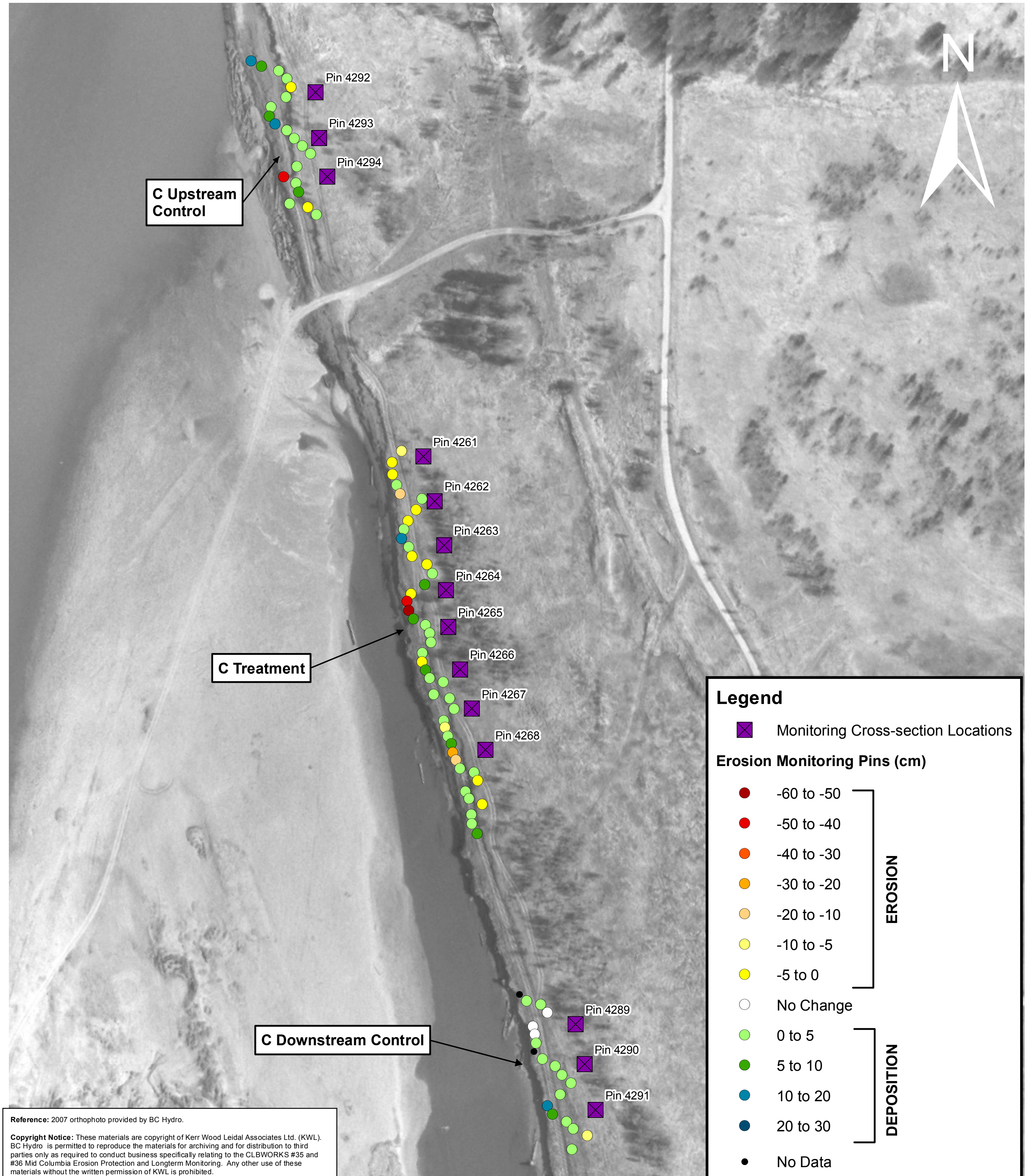
Measurement Summary

The following is an overview of the 2015 measurements. 2013 to 2015 erosion pin measurements are presented in Figure 7. 2013 to 2015 and 2011 to 2015 cross-section measurements for Site C Control are summarized in Table 16 below. Cross-section plots are presented in Figure 8.

- On average, the erosion pin data indicate minor deposition for both control sites (about 1 cm and 3 cm) for the 2013 to 2015 period;
- ∆x Midpoint means indicate erosion, generally, for both the more recent and the project-to-date timeline, except in the middle elevation band of the upstream control section. Both erosion and deposition trends appear to be mostly progressive (larger values in the project-to-date period).

Table 16: Mean Cross-section ∆x Midpoint Values for Site C Control (Upstream & Downstream)

Elevation Band	2013 to 2015		2011 to 2015	
	C U/S Control (m)	C D/S Control (m)	C U/S Control (m)	C D/S Control (m)
Upper	0.23	0.63	0.43	0.87
Middle	0.17	0.42	0.99	-0.44
Lower	0.37	-0.10	-1.16	N/A



Reference: 2007 orthophoto provided by BC Hydro.

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BC Hydro
CLBWORKS #35

Project No.	Date
478-081	December 2015

50 0 50 (m)
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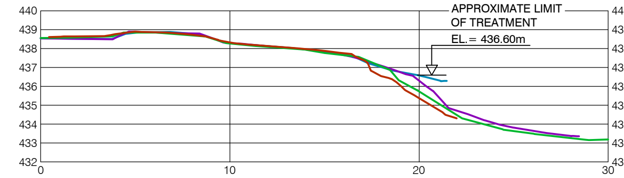
2013 to 2015 Erosion Pin Data Site C (Treatment and Control)

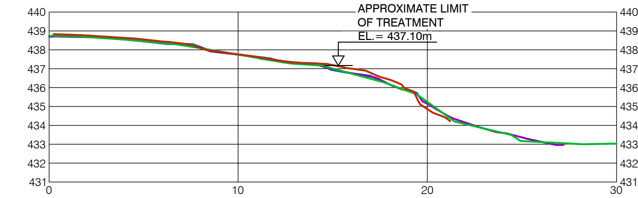
Figure 7

Path: O:\0400-0499\478-081\430-GIS\MXD-Rpt\2015\478081BioEngC_2015.mxd Date Saved: 12/14/2015 3:20:08 PM
Author: EEllis

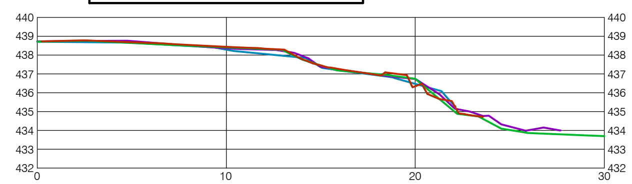
SITE C TREATMENT AREA-4 (REBAR4264)



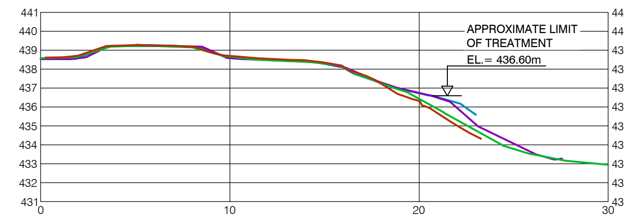
SITE C TREATMENT AREA-8 (REBAR4268)



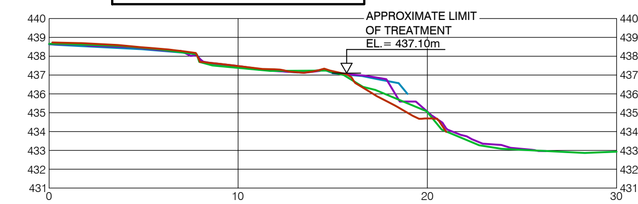
SITE C UPSTREAM CONTROL-3 (REBAR4294)



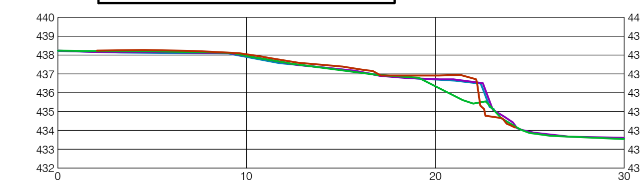
SITE C TREATMENT AREA-3 (REBAR4263)



SITE C TREATMENT AREA-7 (REBAR4267)



SITE C DOWNSTREAM CONTROL-3 (REBAR4291)



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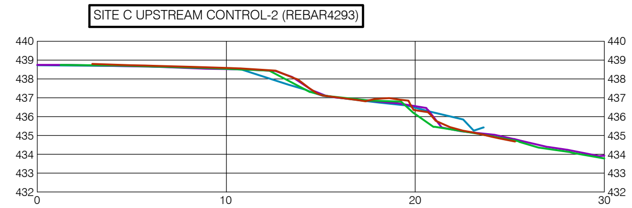

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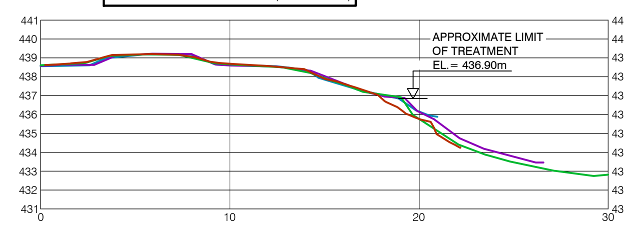

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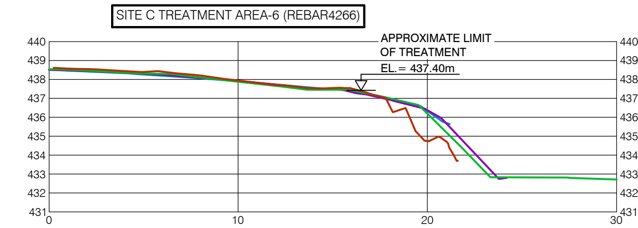

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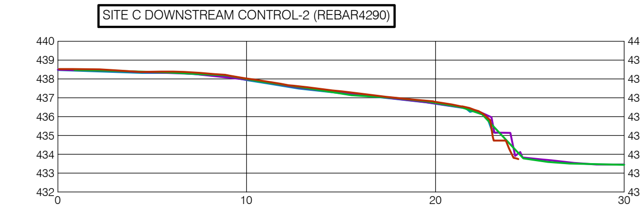

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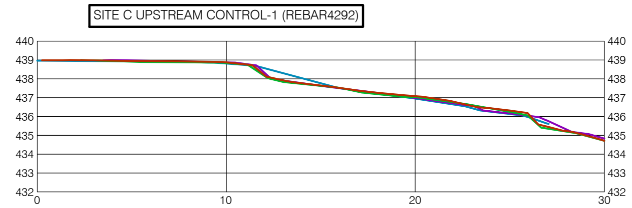

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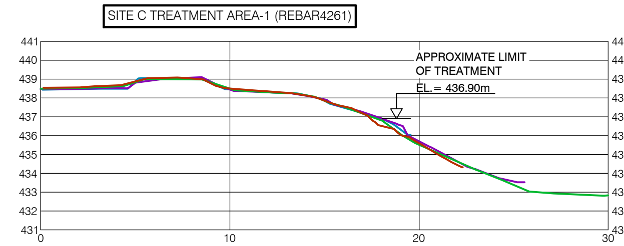

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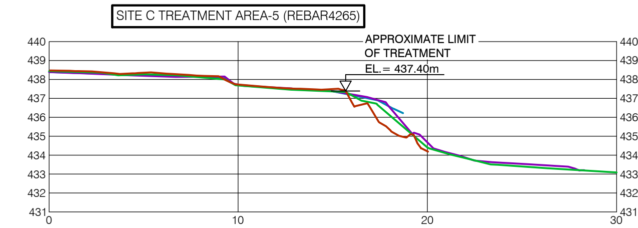

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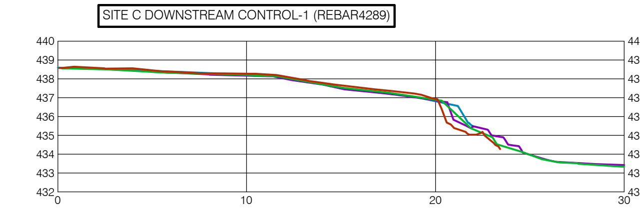

LEGEND

- TRANSECT GROUND NOVEMBER, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2013
- TRANSECT GROUND APRIL, 2015

NOTE:

AVERAGE WATER LEVELS DURING THE 2 WEEK CONSTRUCTION OF THE SITE 'C' BIO-ENG TREATMENT WORKS VARIED BETWEEN ELEVATIONS 437.4m AND 436.5m

0 2 (1:400) 10m

ISSUED INFORMATION: Issued for	Issue	Date	Issued By
Reference			
Approvals			
Tender			
Permits			
Construction			
Record Drawings			

REVISION INFORMATION: Rev. No.	Date	Designed	Drawn	Checked	Description of Revision	Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING						
1	DEC.20/13	DTM	BVC		ISSUED FOR 2013 REPORTING						
2	JUL.14/15		TMIN		ISSUED FOR 2015 REPORTING						

Seal

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BIOENGINEERING EROSION MONITORING
SITE C SECTIONS

KWL Project No. 478.119	Scale 1:400	SW4 Drawing Number	
Sheet 4 of 4	Rev. No. 2		
Client: BC HYDRO			

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Appendix C

Supplemental Statistical Tables

Appendix C – Supplementary Statistical Tables

Erosion Pins

Table 1: Erosion Pins Sample Size (N), Mean and Standard Deviation (SD) (2011 to 2012)

	Control			Treatment		
Site name	N	Mean (cm)	SD (cm)	N	Mean (cm)	SD (cm)
A1_DS	18	-0.1	0.4	9	0.8	1.5
A1_US	15	-0.9	2.3	11	0.2	3.0
A2_DS	15	-3.3	5.9	13	-4.8	9.7
A2_US	12	-2.0	6.7	12	-0.6	0.4
B	20	0.0	1.2	25	-0.1	1.8
C_DS	20	-0.1	0.9	19	0.4	0.7
C_US	19	-0.7	2.8	18	-0.1	0.7

Table 2: Erosion Pins Sample Size (N), Mean and Standard Deviation (SD) (2012 to 2013)

	Control			Treatment		
Site name	N	Mean (cm)	SD (cm)	N	Mean (cm)	SD (cm)
A1_DS	18	1.1	1.0	21	-3.3	11.7
A1_US	15	-2.2	7.6	19	-9.3	15.8
A2_DS	15	-1.7	8.2	13	-3.7	10.1
A2_US	12	-1.4	5.0	12	-2.3	7.5
B	20	-0.3	5.5	25	-1.1	5.5
C_DS	20	9.2	4.1	27	5.8	9.3
C_US	20	5.2	4.7	18	3.8	5.9

Table 3: Erosion Pins Sample Size (N), Mean and Standard Deviation (SD) (2013 to 2015)

	Control			Treatment		
Site name	N	Mean (cm)	SD (cm)	N	Mean (cm)	SD (cm)
A1_DS	18	0.5	0.5	21	-8.9	18.8
A1_US	15	-15.1	17.4	19	-9.4	4.8
A2_DS	15	-17.7	15.9	13	-30.2	8.8
A2_US	12	-7.3	21.9	12	-11.8	5.0
B	20	-3.4	23.6	25	3.9	10.4
C_DS	20	3.2	17.6	27	1.0	6.6
C_US	20	1.4	20.0	18	-5.2	15.6

Appendix C – Supplementary Statistical Tables

Table 4: Erosion Pins Sample Size (N), Mean and Standard Deviation (SD) (2011 to 2015)

	Control			Treatment		
Site name	N	Mean (cm)	SD (cm)	N	Mean (cm)	SD (cm)
A1_DS	18	1.6	1.1	21	-12.3	27.4
A1_US	15	-18.2	20.2	19	-15.4	36.0
A2_DS	15	-24.4	26.8	13	-42.0	21.5
A2_US	12	-11.2	26.5	12	-14.7	21.5
B	20	-3.7	11.2	25	2.8	3.6
C_DS	20	4.6	20.3	27	6.8	3.0
C_US	20	6.6	13.5	18	-1.4	17.2

Table 5: Mean Change in Pin Length at Control (C) and Treatment (T) sites, and Differences (C – T) (Test Statistic)

	2011 to 2012 (cm)			2012 to 2013 (cm)			2013 to 2015 (cm)			2011 to 2015 (cm)		
Site name	C	T	CmT	C	T	CmT	C	T	CmT	C	T	CmT
A1_DS	-0.06	0.83	-0.89	1.14	-3.32	4.46	0.50	-8.93	9.43	1.58	-12.29	13.87
A1_US	-0.90	0.15	-1.05	-2.18	-9.29	7.12	-15.07	-9.38	-5.69	-18.21	-15.41	-2.80
A2_DS	-3.32	-4.77	1.45	-1.65	-3.71	2.05	-17.73	-30.23	12.50	-24.39	-42.04	17.65
A2_US	-2.04	-0.58	-1.46	-1.35	-2.33	0.98	-7.25	-11.79	4.54	-11.21	-14.71	3.50
B	0.03	-0.06	0.09	-0.33	-1.08	0.76	-3.35	3.86	-7.21	-3.65	2.84	-6.49
C_DS	-0.10	0.45	-0.55	9.16	5.84	3.31	3.18	1.04	2.14	4.55	6.81	-2.26
C_US	0.03	-0.06	0.08	5.23	3.83	1.39	1.38	-5.19	6.57	6.63	-1.42	8.04

Table 6: Test Results for Comparison of Control and Treatment Sites as Measured By Difference (Control – Treatment) of Changes in Pin Length

Change measured as	Time Period	Mean (cm)	St. Dev. (cm)	N	St. Error (cm)	df	T stat	p value
Difference in change in pin length (cm)	**2011 to 2012**	-0.33	0.97	7	0.37	6	-0.96	0.40
Difference in change in pin length (cm)	**2012 to 2013**	2.87	2.30	7	0.87	6	3.30	0.02
Difference in change in pin length (cm)	**2013 to 2015**	3.18	7.38	7	2.79	6	1.14	0.30
Difference in change in pin length (cm)	**2011 to 2015**	4.50	9.07	7	3.43	6	1.31	0.24

Appendix C – Supplementary Statistical Tables

Cross-Sections

Table 7: Cross-Sections Sample Size (N), Mean Δx Midpoint and Standard Deviation (SD) (2011 to 2012)

	Control			Treatment		
Site name	N	Mean (m)	SD (m)	N	Mean (m)	SD (m)
A1_US	9	0.0	0.3	0		
A1_DS	9	0.1	0.3	0		
A2_US	5	-0.1	0.4	5	0.1	0.4
A2_DS	6	-0.1	0.5	5	-0.4	0.4
B	7	0.2	0.3	8	0.0	0.2
C_US	5	-0.4	0.8	4	0.1	0.1
C_DS	4	-0.2	0.3	3	0.0	0.0

Table 8: Cross-Sections Sample Size (N), Mean Δx Midpoint and Standard Deviation (SD) (2012 to 2013)

	Control			Treatment		
Site name	N	Mean (m)	SD (m)	N	Mean (m)	SD (m)
A1_US	9	0.0	0.2	9	-0.3	1.0
A1_DS	9	-0.1	0.2	12	-0.6	1.4
A2_US	6	-0.2	0.4	6	-0.3	0.1
A2_DS	6	-0.2	0.3	6	-0.4	0.3
B	9	-0.1	0.1	9	-0.1	0.2
C_US	9	-0.4	0.4	6	-0.3	0.3
C_DS	9	-0.4	0.7	9	-0.2	0.2

Table 9: Cross-Sections Sample Size (N), Mean Δx Midpoint and Standard Deviation (SD) (2013 to 2015)

	Control			Treatment		
Site name	N	Mean (m)	SD (m)	N	Mean (m)	SD (m)
A1_US	9	-0.1	0.2	9	-0.1	0.9
A1_DS	9	0.2	0.6	12	-0.4	1.3
A2_US	6	0.3	0.9	6	-0.6	0.7
A2_DS	6	-0.5	0.3	6	-0.6	0.3
B	9	0.0	0.3	9	0.0	0.2
C_US	9	0.3	0.4	12	-0.2	0.5
C_DS	9	0.3	0.7	12	-0.1	0.7

Appendix C – Supplementary Statistical Tables

Table 10: Cross-Sections Sample Size (N), Mean Δx Midpoint and Standard Deviation (SD) (2011 to 2015)

	Control			Treatment		
Site name	N	Mean (m)	SD (m)	N	Mean (m)	SD (m)
A1_US	9	-0.1	0.2	9	-0.4	1.8
A1_DS	9	0.0	0.6	12	-1.0	2.0
A2_US	5	0.0	0.8	5	-0.8	0.8
A2_DS	6	-0.7	0.7	5	-1.6	0.7
B	7	0.1	0.4	8	0.0	0.3
C_US	7	0.4	1.3	8	-0.4	1.0
C_DS	6	0.2	0.8	4	-0.1	0.4

Table 11: Mean Change (Δx midpoint) at Control (C) and Treatment (T) Sites And Differences (C – T) (Test Statistic)

	2011 to 2012 (m)			2012 to 2013 (m)			2013 to 2015 (m)			2011 to 2015 (m)		
Site name	C	T	CmT	C	T	CmT	C	T	CmT	C	T	CmT
A1_DS	0.10			-0.11	-0.61	0.50	0.18	-0.37	0.55	0.02	-0.97	1.00
A1_US	0.05			-0.04	-0.32	0.28	-0.11	-0.09	-0.02	-0.15	-0.39	0.24
A2_DS	-0.13	-0.44	0.31	-0.21	-0.45	0.24	-0.52	-0.56	0.04	-0.66	-1.63	0.98
A2_US	-0.07	0.09	-0.16	-0.22	-0.28	0.05	0.29	-0.55	0.84	-0.02	-0.81	0.79
B	0.21	0.04	0.17	-0.14	-0.10	-0.05	0.01	0.02	0.00	0.15	0.02	0.13
C_DS	-0.15	0.00	-0.15	-0.35	-0.19	-0.16	0.32	-0.09	0.41	0.22	-0.10	0.32
C_US	-0.35	0.13	-0.48	-0.37	-0.34	-0.03	0.26	-0.16	0.42	0.44	-0.44	0.88

Table 12: Test Results for Comparison of Control and Treatment Sites as Measured By Difference (Control – Treatment) of Δx midpoint

Change measured as	Time Period	Mean (m)	St. Dev. (m)	N	St. Error (m)	df	T stat	p value
Difference in Midpoint averages (m)	2011 to 2012	-0.06	0.31	5	0.14	4	-0.44	0.68
Difference in Midpoint averages (m)	2012 to 2013	0.12	0.23	7	0.09	6	1.35	0.23
Difference in Midpoint averages (m)	2013 to 2015	0.32	0.32	7	0.12	6	2.58	0.04
Difference in Midpoint averages (m)	2011 to 2015	0.62	0.38	7	0.14	6	4.36	0.01