Columbia River Project Water Use Plan

Kinbasket and Arrow Recreation Management Plan

Mid Columbia Erosion Protection and Monitoring

Implementation Year 4

Reference: CLBWORKS-35

2013 Progress Report

Study Period: 2009 to 2013

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Kerr Wood Leidal Associates Limited
Consulting Engineers

May 2014

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Revision History

Revision #	Date	Status	Revision	Author
1	May 29, 2014	Final	Revised based on BC Hydro review.	EE/BVC
0	Dec. 28, 2013	Final	Revised based on internal review.	EE/BVC
A	Dec. 19, 2013	Draft	Draft for internal review.	EE/BVC

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Executive Summary

This report summarizes progress made by Kerr Wood Leidal Associates Ltd. (KWL) during 2013 on BC Hydro programs CLBWORKS #35 and #36. These two programs were 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 and CLBWORKS #36 are part of a large suite of physical works and monitoring projects developed under the WUP for the Columbia River system.

In 2013, the following work was conducted:

- **CLBWORKS #35**: erosion monitoring (Year 3); and
- **CLBWORKS #36**: no work scheduled or performed.

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, with three of the sites being further split to increase the total number of samples in the statistical analysis (N = 7). Construction of the bioengineering works was completed in 2012.

CLBWORKS #35: Status of Objectives, Management Questions and Hypotheses after Year 3

Objectives	Management Questions	Management Hypotheses	Year 3 (2013) 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 observed at treatment and control sites (Figure 4-9, p. 4-34) • **H_0 is rejected** for the 2012 to 2013 period (Table 4-18, p. 4-35): erosion at treatment sites modestly exceeds that at control sites (a 2.3 cm difference). • Results indicate that the erosion pin study design is capable of detecting small differences. However, statistical significance may not translate to 'significance' from a management perspective (p. 4-39). **Cross-section data**: • Cross-section data indicate erosion at both treatment and control sites (Figure 4-11, p. 4-37) • **H_0 cannot be rejected** (Table 4-20, p.4-38). Interim results are counterintuitive but may arise from the ability of the plantings (which impart strength to the bank) to survive and thrive. The final analysis will examine the success of the bioengineering techniques in more detail (Year 4 / 2015 / Final Year).

CLBWORKS #36

CLBWORKS #36 is a long-term erosion monitoring program of fifteen sites on Columbia River between Revelstoke Dam and Shelter Bay. No work was scheduled or performed on CLBWORKS #36 for 2013. Year 4 monitoring is scheduled for spring of 2014. Year 5 (2016) will be the final year of the project.

1. Introduction

This report summarizes progress made by Kerr Wood Leidal Associates Ltd. (KWL) during 2013 on BC Hydro programs CLBWORKS #35 and #36.

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. According to pubic BC Hydro reports, the fifth generating unit was expected to be complete by late 2011.

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; Figure 1-1).
- **CLBWORKS #36**: Monitor long-term erosion rates along the mid-Columbia River from Revelstoke Dam downstream to Shelter Bay (Figure 1-1).

Given the complementary nature of the work, these two physical works programs were combined into one project, which was awarded to KWL in summer 2009.

No work was scheduled or performed on CLBWORKS #36 for 2013. As such, this report concerns CLBWORKS #35 only.

1.1 Project Overview

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 was:

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

The project schedule did not permit adequate baseline data (i.e., a period of time equivalent or greater than the post installation monitoring) to be collected before the fifth generating unit was installed at Revelstoke Dam; therefore, the second management question cannot be entirely addressed. Rather, the long-term erosion monitoring program will document rates of erosion at various sites over time, and will attempt to determine which mechanisms are responsible.

1.2 Project Schedule

The original intent of the erosion monitoring work was to have repeat baseline measurements at all sites prior to commissioning of Revelstoke Unit 5, and to assess erosion through several years of operation.

However, due to unusually high water levels in the system in 2010, no data could be collected in that year. In addition, higher than average water levels made installation of the bioengineering works for CLBWORKS #35 impractical in that year.

The schedule of both projects was shifted to accommodate this change. The general schedule for CLBWORKS #35 and #36 is summarized in the following table.

Table 1-1: Current Schedule for CLBWORKS #35 and #36 (Current Year in Red)

Year	CLBWORKS#35	CLBWORKS#36
2009	Y1 – Design	Y1 – Site Selection
2010	Y1 – Permitting	Y1 – Baseline Monitoring
2011	Y1 – Bioengineering Construction	Y2 – Monitoring
2012	Y2 – Monitoring	Y3 – Monitoring
2013	Y3 – Monitoring	
2014		Y4 – Monitoring
2015	Y4 – Monitoring	
2016		Y5 – Monitoring

No work is scheduled for CLBWORKS #36 for 2013: the next monitoring work will occur in 2014.

1.2.1 2013 Work

Project work completed during 2013 is summarized in the following table.

Table 1-2: 2013 Work Program (CLBWORKS #35)

Task	Description
Bioengineering Works (CLBWORKS #35 Y3)	• Monitoring of any repeat Erosion Monitoring Pins • Cross-section surveys
2013 Data Entry and Analysis	• Populate GIS Database • Data Analysis
2013 Progress Report	• Progress Report for CLBWORKS #35

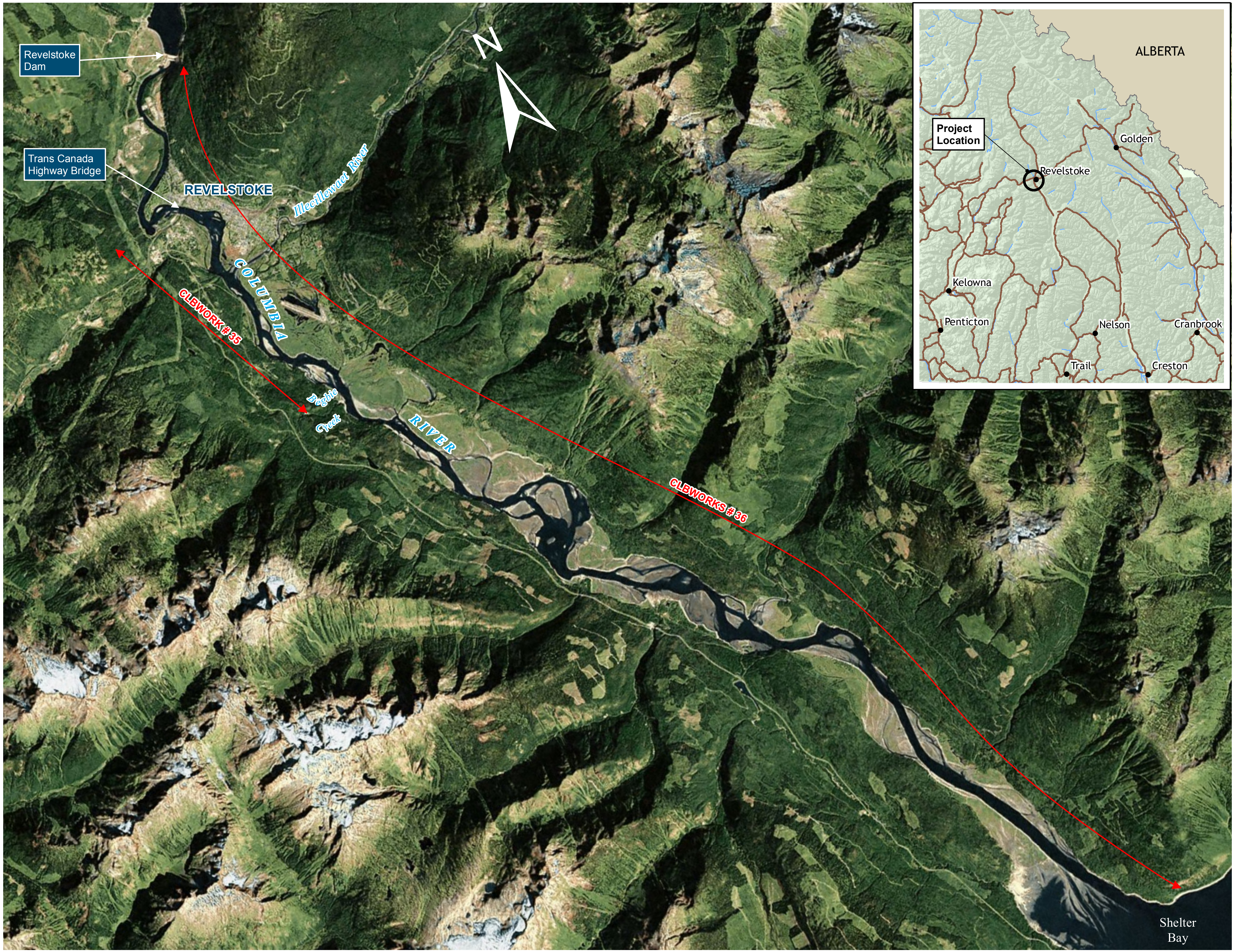
1.3 Project Team

Key project personnel for this project include KWL staff and sub-consultants listed in Table 1-3. Note that the following staff changes occurred in 2013:

- Erica Ellis took over the Project Manager role from David Matsubara, following David's departure from KWL at the beginning of December 2013; and
- David Murray has assumed the Senior Technical Review role from Mike Currie.

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
Mike Moody – KWL	Technologist	Topographic Survey and Field Data Collection
Nick Page, B.L.A., M.Sc., R.P.Bio. Raincoast Applied Ecology	Professional Biologist	Bioengineering 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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Project No.	Date
478-081	November 2011

Location Plan

Figure 1-1

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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:

- active erosion at the site;
- feasible construction (access and appropriate site conditions); and
- potential for treatment success.

Paired control sites also were identified based on similarity of hydraulics, location, and site conditions (e.g., bank angle, bank composition, 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 analogues of the treatment sites but differences were minimized through careful site selection.

2.1 Final Study Design

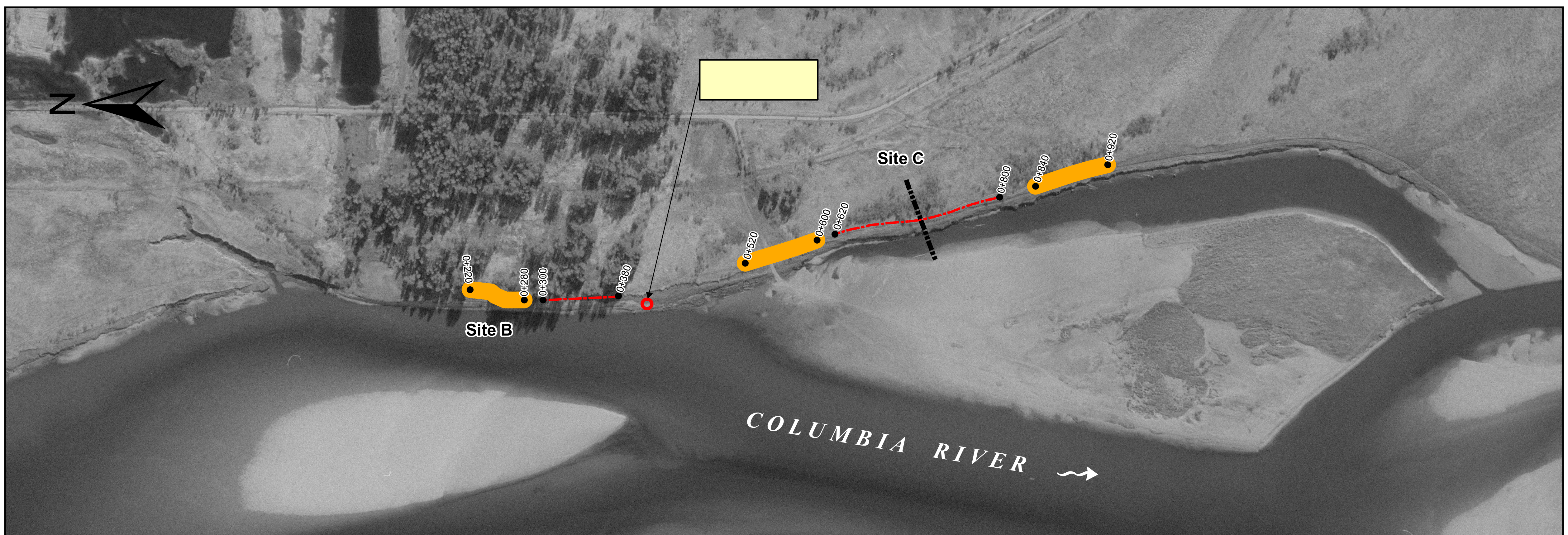
BCH Terms of Reference (ToR) specified a regulatory goal of a total of 500 m of constructed bioengineering works (paired design: 2 X 250 m treatment sites, 2 paired control sites). As this yields a sample size of N = 2, KWL initially proposed that the number of sites be increased to four in order to 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 4.9.

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.

Sites A1/A2



Sites B/C

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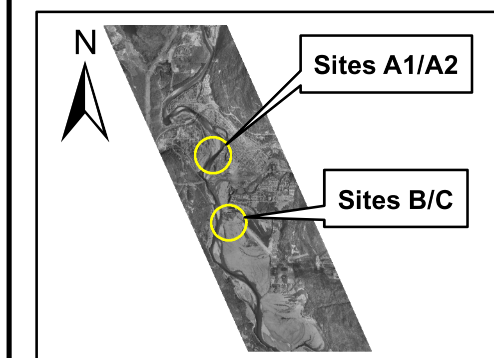
and Long Term Monitoring

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

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Author: EEllis

3. Bioengineering Treatment

The following sections summarize the design and construction timeline for CLBWORKS #35, and provide a summary of the bioengineering treatment.

3.1 Timeline

Detailed design of the bioengineering works and preparation of construction specifications was 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 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 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 for the bioengineering and control sites in November 2011 and measurements were 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 3-1: 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 3-2: Timing of Topographic Surveys At Each Site

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

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.

3.2 Treatment Summary

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.

The bioengineering treatment for each site is similar, although bank geometry and configuration result in some differences between sites, as summarized in the following table.

Table 3-3: Bioengineering Treatment Summary

Site	Treatment
Sites A1, A2 & C	• Re-grading of bank. • Willow staking • Vegetated soil wraps and 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

See Appendix A for detailed record drawings of the constructed bioengineering works. For a complete list of plant species (including Latin names) and planting distribution, refer to Drawing SD1 (“Mid-Columbia River Bank Protection Works BC Hydro Standard Details”, provided in Appendix A.

4. CLBWORKS #35 Erosion Monitoring Results

2013 field measurements of the bioengineering treatment and control sites were conducted on April 23 and 24 (Table 3-2). Field conditions during 2013 monitoring were favourable. Dry weather and low river levels allowed the field crew to locate all intact erosion pins and conduct accurate transect survey measurements in the dry.

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),[1] and
- 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 4-10).

The following section provides a brief description of each site, a summary of field observations and an overview of the 2013 measurements. Section 4.9 summarizes the statistical analysis of the data.

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.

4.1 Site A1 Treatment

4.1.1 Location and Site Characteristics

Site A1 Treatment is located across from downtown Revelstoke on the right (west) bank of the Columbia River approximately 1.3 km downstream of the Highway 1 Bridge (Figure 2-1). The site is approximately 160 meters 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.

Table 4-1: 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

[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.

4.1.2 Field Observations

The following observations were made during the 2013 field visit:

- Significant erosion of the aquatic bench has occurred between stations 0+320 and 0+360,[2] (about 25% of the entire treatment bank length), exposing the buried woody debris structure at station 0+340 and undermining the vegetated soil wraps/brush layers (Photo 4-1, Photo 4-2);
- A majority of the grasses and sedges planted in the entire aquatic bench did not establish themselves and have been washed away (Photo 4-3);
- The majority of the soil wrap and brush layer areas in the upper bank remain intact;
- There is only modest new growth on the willow stakes and brush layers in the soil wraps (Photo 4-4); and
- There is moderate survival of the planted potted trees and shrubs (Photo 4-5).

Upstream and downstream of the above-mentioned section, the bioengineering treatment has stayed intact, with moderate erosion occurring on the aquatic bench and at the toe of the slope. Some minor settlement of the soil mounds has also occurred.

The following photos illustrate the conditions of Treatment Site A1 as observed during the 2013 field visit.

Photo 4-1: Eroded aquatic bench, exposed woody debris and boulder cluster at station 0+340. (April 23, 2013)

[2] See Appendix A for drawings, including stationing.

Photo 4-2: Undermined soil wraps and brush layers at station 0+340. (April 23, 2013)

Photo 4-3: Aquatic bench at downstream end with planted grasses and sedges washed away. (April 23, 2013)

**Photo 4-4: Growth in willow stakes and brush layer.
(April 23, 2013)**

**Photo 4-5: Planted soil mound vegetation.
(April 23, 2013)**

4.1.3 Treatment Site A1 Measurement Summary

The following is an overview of the 2013 measurements. Statistical analysis of the erosion pin and cross-section data is presented in Section 4.9.

- 2012 to 2013 erosion pin measurements are presented in Figure 4-1, for Site A1 Treatment.
- On average, the erosion pin data indicate minor erosion for both treatment sites (-3 cm and -5 cm) for the 2012 to 2013 period.
- 2012 to 2013 cross-section measurements for Site A1 Treatment are summarized in Table 4-2, below. Note that due to timing of construction, post-construction data for Site A1 Treatment are only available starting in 2012. Cross-section plots are presented in Figure 4-2.
- Δx Midpoint[3] means indicate erosion, generally, with the lower elevation band exhibiting the largest changes, which is supported by the field observations.

Table 4-2: Mean Cross-section Δx Midpoint Values for Site A1 Treatment (Upstream and Downstream)

Elevation Band	2012 to 2013		2011 to 2013	
	A1 U/S Treatment (m)	A1 D/S Treatment (m)	A1 U/S Treatment (m)	A1 D/S Treatment (m)
Upper	0.04	-0.17	n/a	n/a
Middle	-0.05	-0.15	n/a	n/a
Lower	-0.94	-1.50	n/a	n/a

4.2 Site A1 Control

4.2.1 Location and Site Characteristics

Site A1 control sites are located 150 m upstream and 210 m downstream from the ends of Site A1 (Figure 2-1). The control sites are both approximately 70 meters long.

Control site characteristics are summarized in the following table.

Table 4-3: 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 & 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

[3] 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.

4.2.2 Field Observations

The following observations were made during the 2013 field visit:

- Minimal erosion/deposition has occurred on the bank at both control sites; and
- Some minor undercutting of the bank leading to toppling of grassy blocks has occurred at the downstream control site.

The following photos illustrate the conditions of the site as observed during the 2013 field visit.

Photo 4-6: Site A1 Upstream Control (April 23, 2013)

Photo 4-7: Site A1 Downstream Control (April 23, 2013)

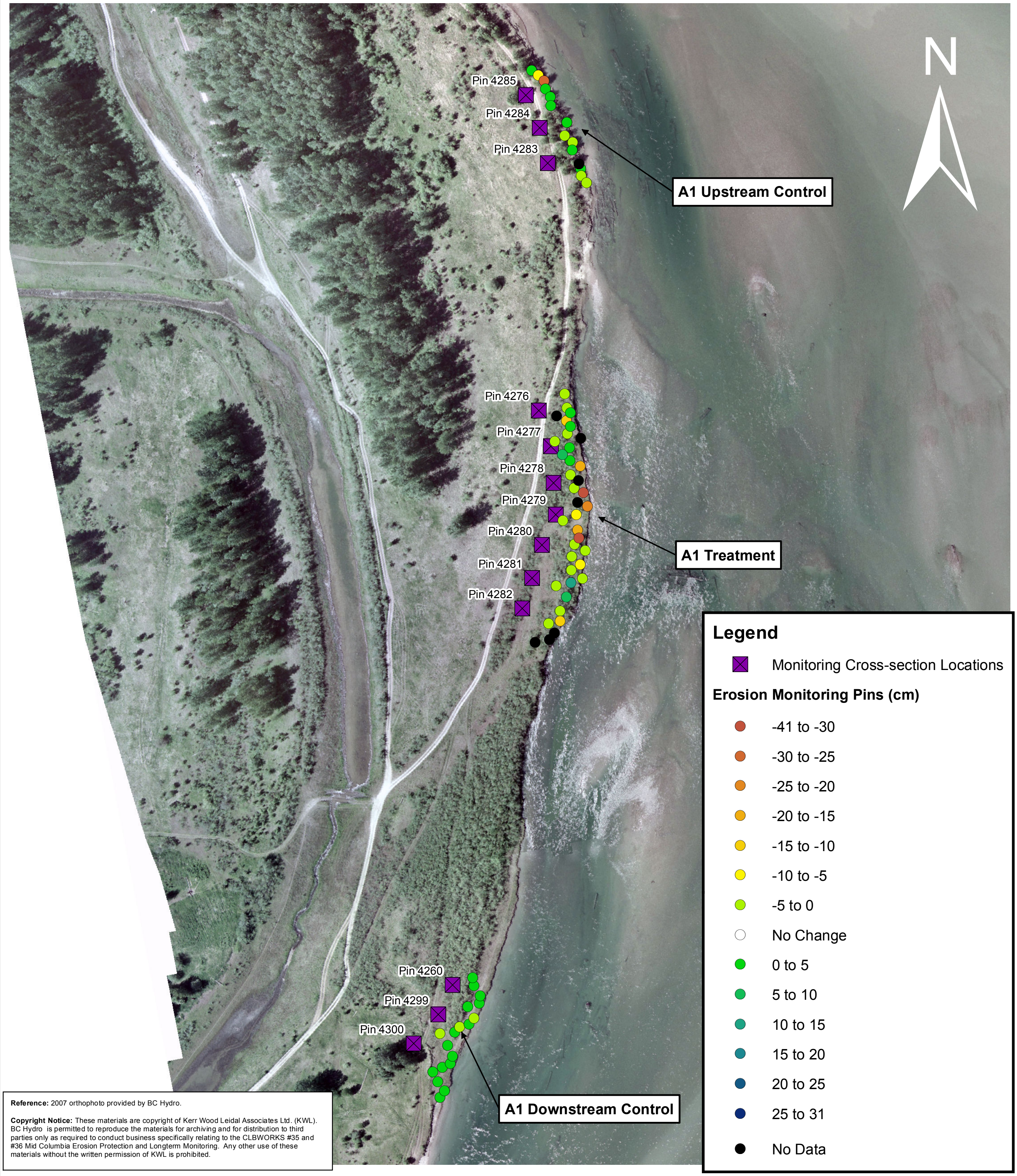
4.2.3 Control Site A1 Measurement Summary

The following is an overview of the 2013 measurements. Statistical analysis of the erosion pin and cross-section data is presented in Section 4.9.

- 2012 to 2013 erosion pin measurements are presented in Figure 4-1, for Site A1 Control;
- On average, the erosion pin data indicate minor erosion for the upstream control site (-2 cm) and minor deposition for the downstream control site (1 cm) for the 2012 to 2013 period;
- 2012 to 2013 and 2011 to 2013 cross-section measurements for Site A1 Control are summarized in Table 4-4, below. Cross-section plots are presented in Figure 4-2; and
- Δx Midpoint means for 2012 to 2013 generally indicate erosion, with the lower elevation band exhibiting larger changes. The project-to-date period (2011 to 2013) shows a mix of deposition and erosion, and generally smaller changes.

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

Elevation Band	2012 to 2013		2011 to 2013	
	A1 U/S Control (m)	A1 D/S Control (m)	A1 U/S Control (m)	A1 D/S Control (m)
Upper	-0.05	-0.08	0.02	-0.11
Middle	0.04	-0.01	0.09	-0.01
Lower	-0.11	-0.24	-0.10	0.08



Reference: 2007 orthophoto provided by BC Hydro.

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CLBWORKS #35 and #36

Project No.	Date
478-081	December 2013

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2012 to 2013 Erosion Pin Data for Site A1 (Treatment and Control)

Figure 4-1

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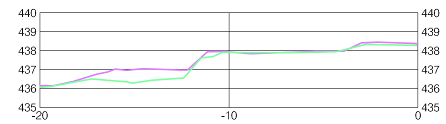
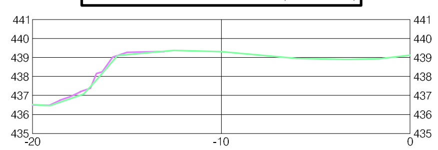
Author: EEllis

SITE A1 TREATMENT AREA-4 (REBAR4279)



SITE A1 UPSTREAM CONTROL-3 (REBAR4283)



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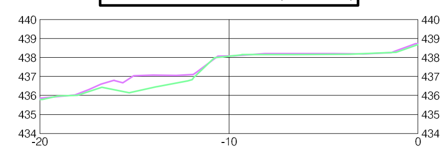

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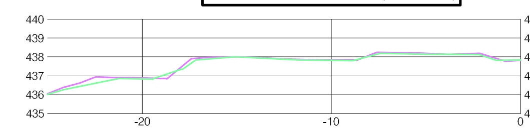
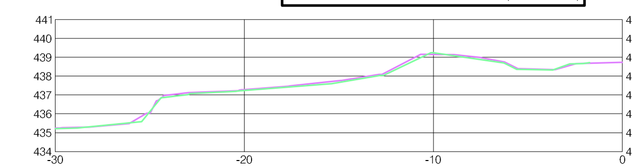
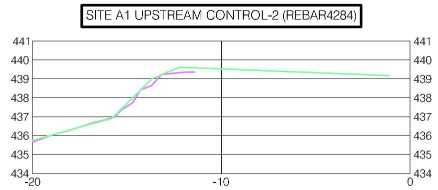


SITE A1 DOWNSTREAM CONTROL-3 (REBAR4300)



SITE A1 UPSTREAM CONTROL-2 (REBAR4284)



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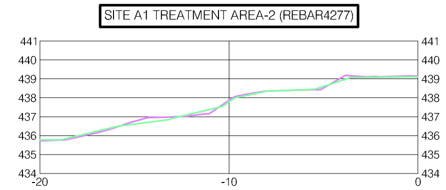

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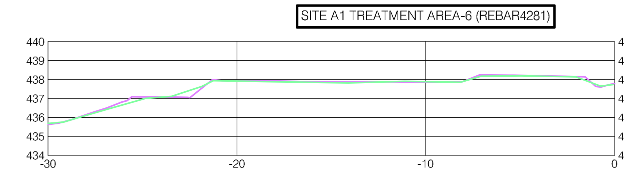

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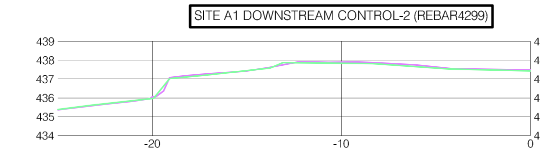

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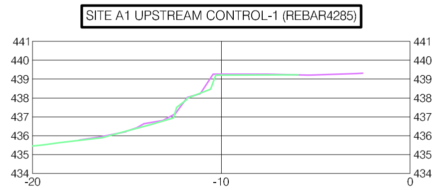
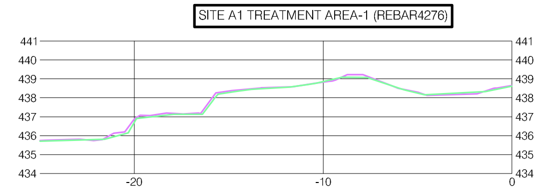


SITE A1 TREATMENT AREA-1 (REBAR4276)



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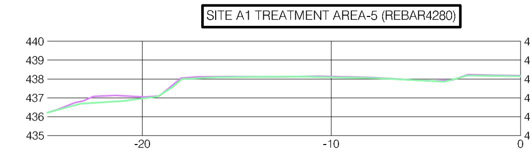

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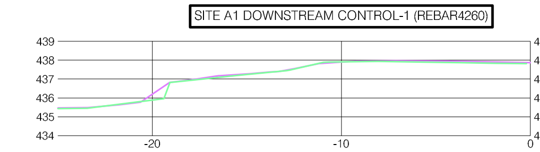

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ISSUED INFORMATION

Issued for	Issue	Date	Issued By
Reference			
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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						

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SITE A1 SECTIONS

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SW1 Drawing Number

Client: BC HYDRO

4.3 Site A2 Treatment

4.3.1 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 approximately 2.2 km downstream of the Highway 1 Bridge (Figure 2-1). The site is approximately 100 meters long (see Appendix A for detailed record drawings).

Treatment site characteristics are summarized in the following table.

Table 4-5: 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 cocomat erosion blanket, willow staking • upper bank: re-grading, temporary cocomat erosion blanket, brush layers, soil wraps, willow staking • upland areas: vegetated spoil piles
Plantings	• spoil piles: variety of planted native shrubs and trees

4.3.2 Field Observations

The following observations were made during the 2013 field visit:

1. Minor erosion has occurred at mid-bank and toe of the upstream half of the site. Half of the cocomat erosion control blanket and a majority of the willow stakes are in place in this half of the site (Photo 4-8);
2. Significant erosion has occurred at mid-bank and toe of the downstream half of the site. The majority of the cocomat erosion control blanket and willow stakes has been washed away in this half of the site (Photo 4-9);
3. The soil wrap and brush layers in the upper bank are intact;
4. New growth on the willow stakes and brush layers in the soil wraps is modest (Photo 4-10); and
5. The survival rate of the planted potted trees and shrubs is moderate (Photo 4-11).

The following photos illustrate the conditions of the site as observed during the 2013 field visit.

Photo 4-8: Upstream Half: mid bank with willow staking and cocomat in place. (April 23, 2013)

Photo 4-9: Downstream Half: mid bank with willow staking and cocomat washed away. (April 23, 2013)

Photo 4-10: Growth in brush layer. (April 23, 2013)

Photo 4-11: Planted soil mound vegetation. (April 23, 2013)

4.3.3 Treatment Site A2 Measurement Summary

The following is an overview of the 2013 measurements. Statistical analysis of the erosion pin and cross-section data is presented in Section 4.9.

- 2012 to 2013 erosion pin measurements are presented in Figure 4-3;
- On average, the erosion pin data indicate minor erosion for both treatment sites (-2 cm and -4 cm) for the 2012 to 2013 period;
- 2012 to 2013 and 2011 to 2013 cross-section measurements for Site A2 Treatment are summarized in Table 4-6, below. Cross-section plots are presented in Figure 4-4; and
- Δx Midpoint[4] means 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 4-6: Mean Cross-section Δx Midpoint Values for Site A2 Treatment (Upstream and Downstream)

Elevation Band	2012 to 2013		2011 to 2013	
	A2 U/S Treatment (m)	A2 D/S Treatment (m)	A2 U/S Treatment (m)	A2 D/S Treatment (m)
Upper	-0.39	-0.36	-0.25	-0.46
Middle	-0.30	-0.64	-0.59	-1.25
Lower	-0.15	-0.35	0.58	-1.39

[4] 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.

4.4 Site A2 Control

4.4.1 Location and Site Characteristics

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

Control site characteristics are summarized in the following table.

Table 4-7: 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

4.4.2 Field Observations, Upstream Control Site

The following observations were made during the 2013 field visit:

- Some undercutting leading to toppling of grassy blocks has occurred at the toe of the lower and upper banks in the upstream control site; and
- Some brush clusters have broken away from the top of bank and toppled onto the mid and lower banks.

4.4.3 Field Observations, Downstream Control Site

The following observations were made during the 2013 field visit:

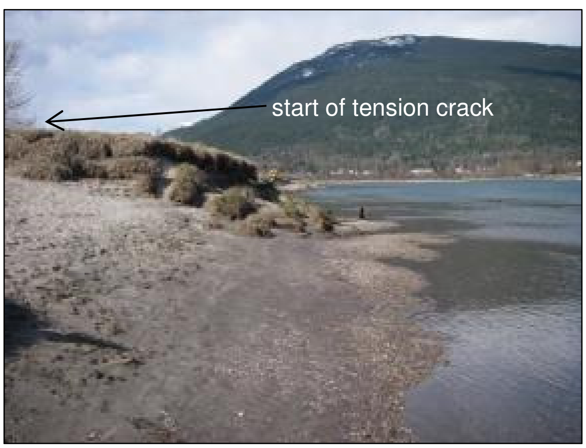
- Erosion at the toe of the lower bank has caused continuous migration of toppled grassy blocks down the mid and lower slopes (Photos 4-13 and 4-14);
- Steep (near vertical) upper bank continues to undercut top grassy layer leading to breaking off and toppling of grassy blocks (Photo 4-15); and
- A large tension crack has formed approximately three to five meters behind the top of bank in the downstream portion of the site (Photos 4-16 & 4-17).

The following photos illustrate the conditions of the site as observed during the 2013 field visit.

**Photo 4-12: Site A2 Upstream Control
(April 23, 2013)**

**Photos 4-13 & 14: Site A2 Downstream Control, migration of grassy blocks.
(April 23, 2013)**

Photo 4-15: Site A2 Downstream Control, steep (near vertical) upper bank. (April 23, 2013)



Photos 4-16 & 17: Site A2 Downstream Control, tension crack behind top of bank. (April 23, 2013)

4.4.4 Control Site A2 Measurement Summary

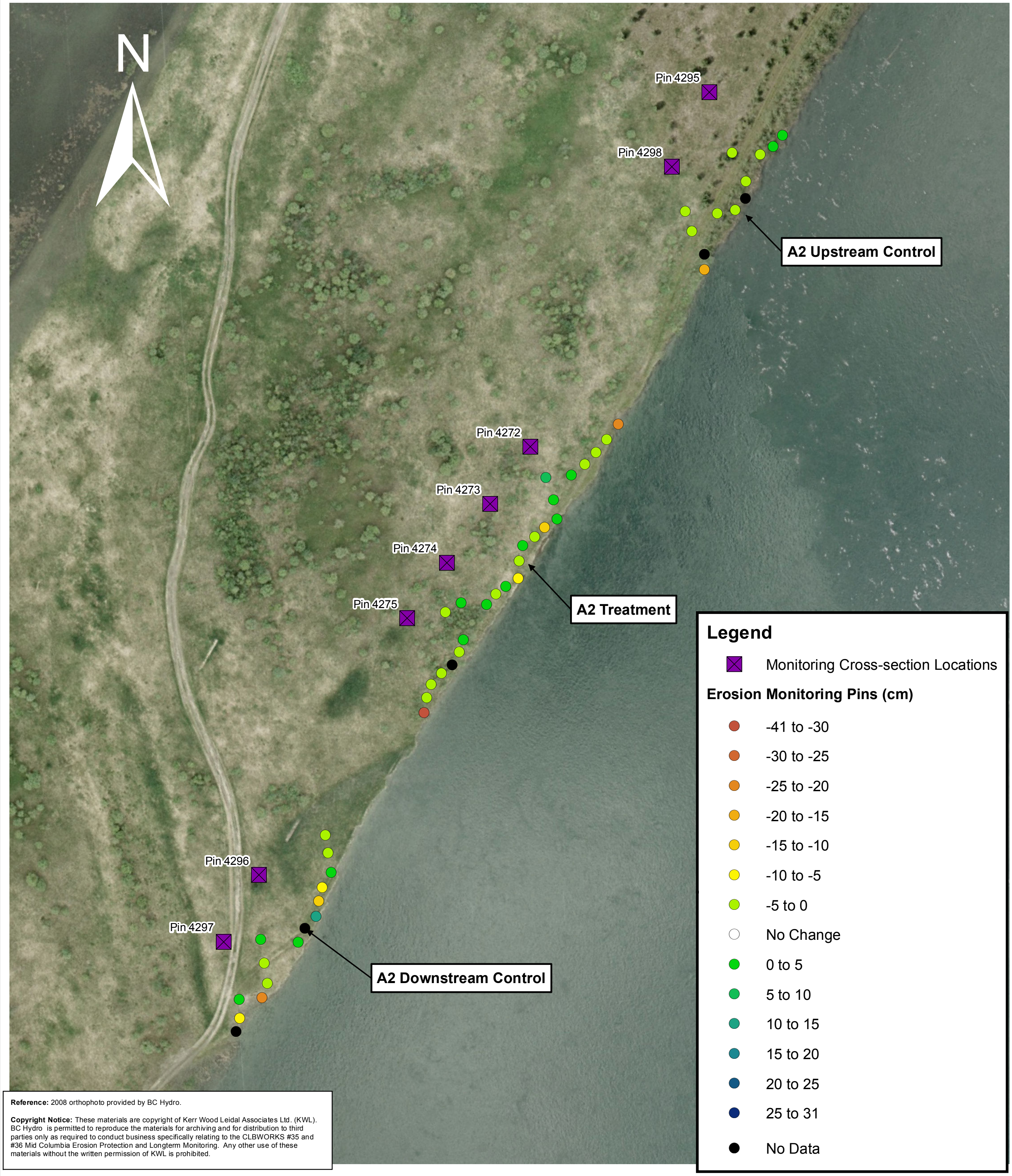
The following is an overview of the 2013 measurements. Statistical analysis of the erosion pin and cross-section data is presented in Section 4.9.

- 2012 to 2013 erosion pin measurements are presented in Figure 4-3;
- On average, the erosion pin data indicate minor erosion for both treatment sites (about -1 cm) for the 2012 to 2013 period;
- 2012 to 2013 and 2011 to 2013 cross-section measurements for Site A2 Control are summarized in Table 4-8, below. Cross-section plots are presented in Figure 4-4; and
- ∆x Midpoint[5] means 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 4-8: Mean Cross-section ∆x Midpoint Values for Site A2 Control (Upstream and Downstream)

Elevation Band	2012 to 2013		2011 to 2013	
	A2 U/S Control (m)	A2 D/S Control (m)	A2 U/S Control (m)	A2 D/S Control (m)
Upper	-0.13	-0.30	-0.34	0.00
Middle	-0.24	-0.42	-0.52	-0.82
Lower	-0.31	0.10	-0.13	-0.21

[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 4-10 for illustration.



Reference: 2008 orthophoto provided by BC Hydro.

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2012 to 2013 Erosion Pin Data for Site A2 (Treatment and Control)

Figure 4-3

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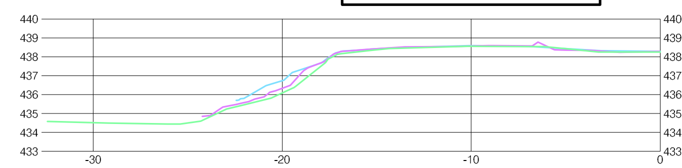
Author: EEllis

SITE A2 TREATMENT AREA-4 (REBAR4275)



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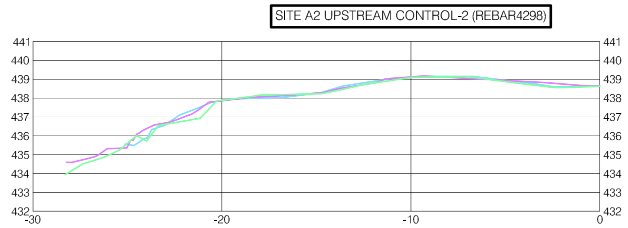

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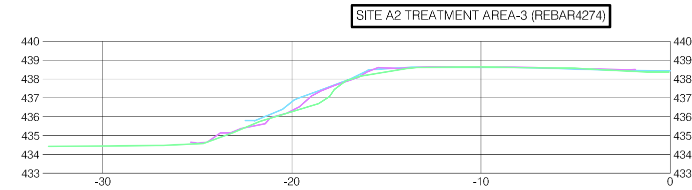

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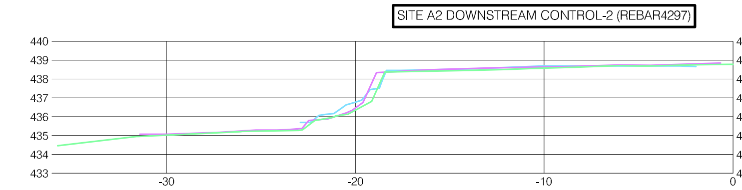

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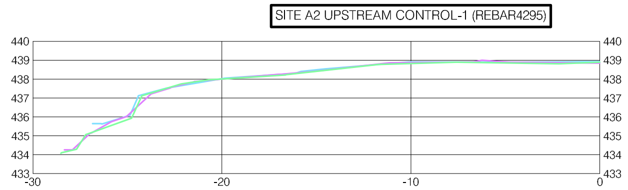

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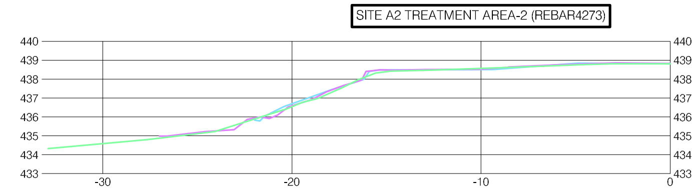

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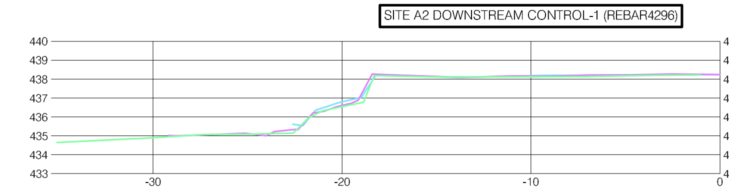

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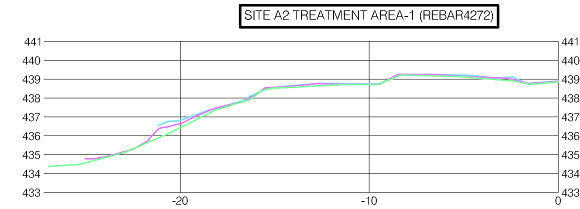

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ISSUED INFORMATION

Issued for	Issue	Date	Issued By
Reference			
Approvals			
Tender			
Permits			
Construction			
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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						

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SITE A2 SECTIONS

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4.5 Site B Treatment

4.5.1 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, approximately 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 4-9: 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

4.5.2 Field Observations

The following observations were made during the 2013 field visit:

- Minor erosion/deposition has occurred within the mid and lower banks around the brush layers;
- Minor erosion has occurred on the upland slope above the brush layers;
- New growth on the brush layers is moderate (Photo 4-19); and
- Survival rate of the planted potted trees and shrubs is moderate.

The following photos illustrate the conditions of the site as observed during the 2013 field visit.

Photo 4-18: Site B (April 24, 2013)

Photo 4-19: Brush layer growth (April 24, 2013)

4.5.3 Treatment Site B Measurement Summary

The following is an overview of the 2013 measurements. Statistical analysis of the erosion pin and cross-section data is presented in Section 4.9.

- 2012 to 2013 erosion pin measurements are presented in Figure 4-5;
- On average, the erosion pin data indicate minor erosion for this treatment site (about -1 cm) for the 2012 to 2013 period;
- 2012 to 2013 and 2011 to 2013 cross-section measurements for Treatment Site B are summarized in Table 4-10, below. Cross-section plots are presented in Figure 4-6; and
- Δx Midpoint[6] means indicate modest 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 is greatest in the upper elevation band, which is supported by field observations.

Table 4-10: Mean Cross-section Δx Midpoint Values for Site B Treatment

Elevation Band	2012 to 2013	2011 to 2013
	B Treatment (m)	B Treatment (m)
Upper	-0.19	-0.23
Middle	-0.07	0.11
Lower	-0.03	-0.08

[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 4-10 for illustration.

4.6 Site B Control

4.6.1 Location and Site Characteristics

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

Control site characteristics are summarized in the following table.

Table 4-11: 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

4.6.2 Field Observations

The following observations were made during the 2013 field visit:

- Minor erosion/deposition has occurred on the bank; and
- Some grassy blocks have broken off the upper bank and migrated down the mid bank slope (Photo 4-20).

The following photos illustrate the conditions of the site as observed during the 2013 field visit.

Photo 4-20: Site B Control, grassy blocks migrating down mid bank slope. (April 24, 2013)

4.6.3 Control Site B Measurement Summary

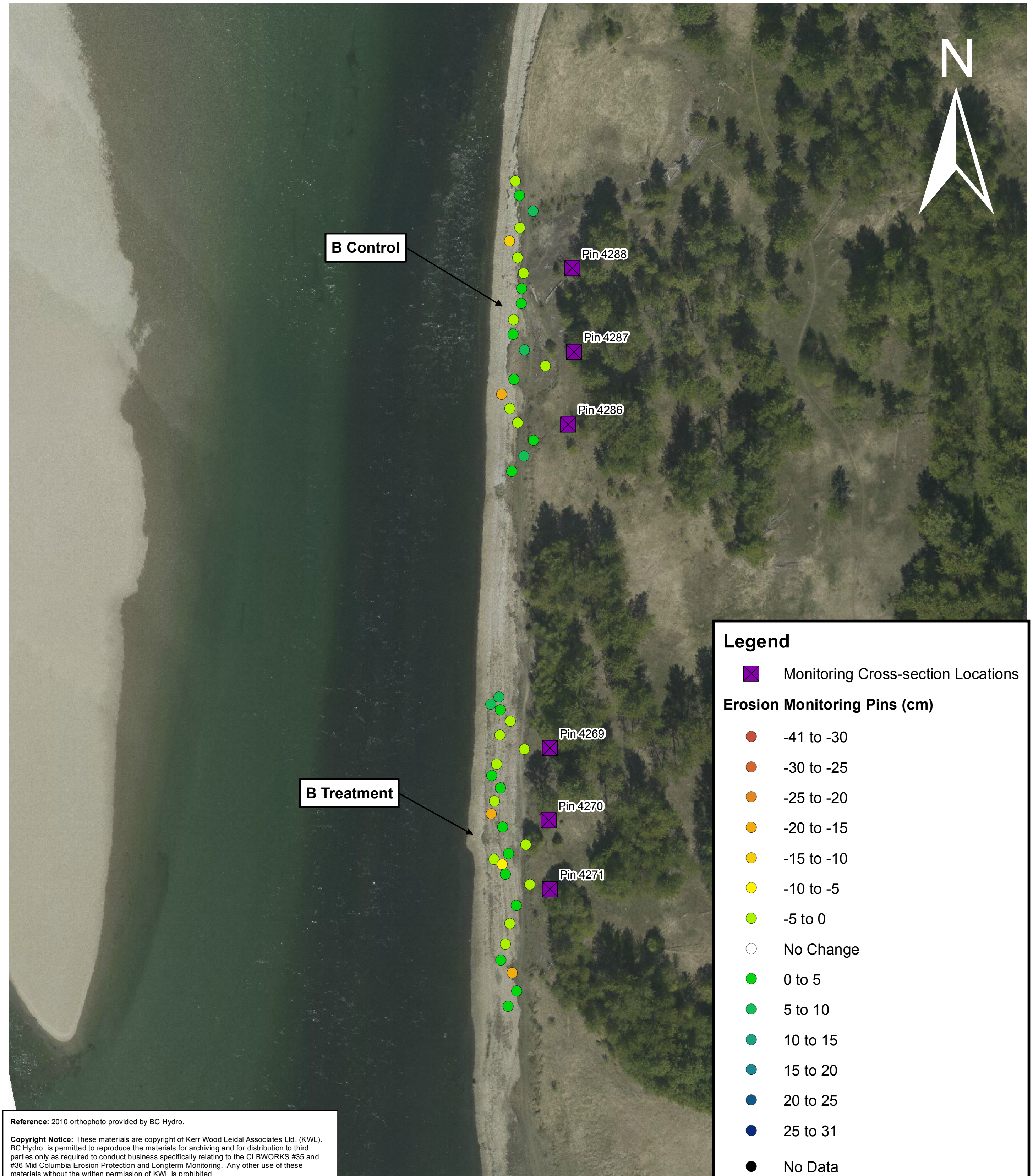
The following is an overview of the 2013 measurements. Statistical analysis of the erosion pin and cross-section data is presented in Section 4.9.

- 2012 to 2013 erosion pin measurements are presented in Figure 4-5;
- On average, the erosion pin data indicate very minor erosion for this treatment site (less than -1 cm) for the 2012 to 2013 period;
- 2012 to 2013 and 2011 to 2013 cross-section measurements for Control Site B are summarized in Table 4-12, below. Cross-section plots are presented in Figure 4-6; and
- Δx Midpoint[7] means indicate modest erosion for the more recent (2012 to 2013) period. In contrast, the project-to-date (2011 to 2013) period means indicate deposition for the upper and middle elevation bands.

Table 4-12: Mean Cross-section Δx Midpoint Values for Site B Control

Elevation Band	2012 to 2013 B Control (m)	2011 to 2013 B Control (m)
Upper	-0.19	0.28
Middle	-0.07	0.11
Lower	-0.03	-0.33

[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.



Reference: 2010 orthophoto provided by BC Hydro.

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2012 to 2013 Erosion Pin Data for Site B (Treatment and Control)

Figure 4-5

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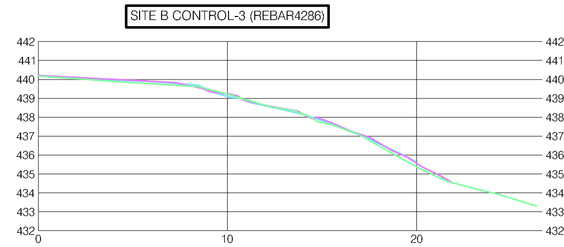

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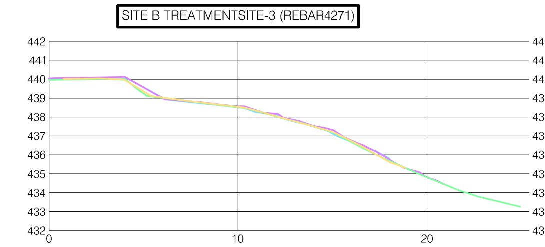
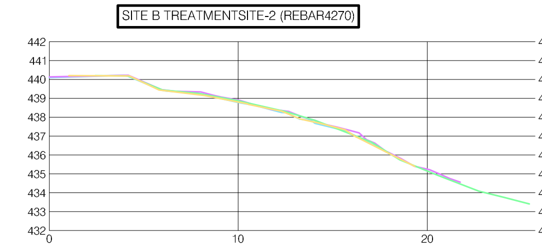


SITE B CONTROL-2 (REBAR4287)

SITE B TREATMENTSITE-2 (REBAR4270)



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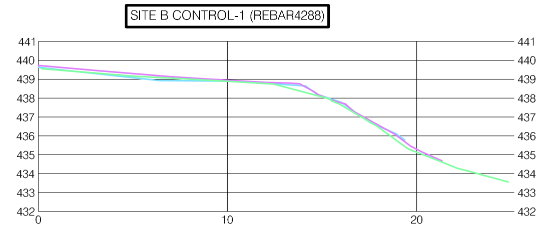

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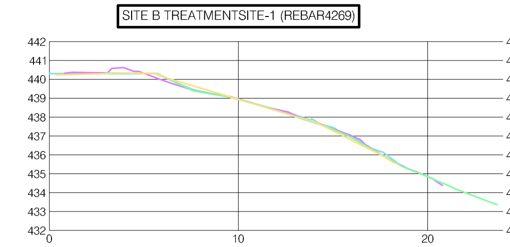

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ISSUED INFORMATION	Issue	Date	Issued By
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REVISION INFORMATION

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						
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SITE B SECTIONS

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Sheet 3 **of** 4	**Rev. No.** 1		Drawing Number
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4.7 Site C Treatment

4.7.1 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, approximately 1.8 km downstream of the confluence of the Illecillewaet River (Figure 2-1). The site is approximately 190 meters long (see Appendix A for detailed record drawings).

Treatment site characteristics are summarized in the following table.

Table 4-13: 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 cocomat erosion blanket, willow staking • upper bank: regrading, temporary cocomat erosion 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 cocomat erosion 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

4.7.2 Field Observations

The following observations were made during the 2013 field visit:

- Noticeable erosion has occurred at the lower and mid banks of the upstream half of the site with the silty sand layer washed away (Photo 4-21);
- Most (75%) of the cocomat erosion control blanket and a majority of the willow stakes are still in place at mid-bank on the upstream half of the site;
- Some erosion has occurred at the toe of the regraded sections in the downstream half of the site (Photo 4-22);
- A majority of the cocomat erosion control blanket and willow stakes are still in place at mid-bank of the regraded sections in the downstream half of the site;

- Significant undercutting and toppling has occurred at the untreated mid-bank below the soil wrap and brush layer in the downstream half of the site (Sta. 0+700 to 0+710 and 0+785 to 0+805) (Photos 4-23 and 4-24);
- The soil wrap and brush layers in the upper bank are intact;
- Noticeable amounts of silty sand deposition has occurred in the upland areas of the entire site (Photos 4-25 and 4-26);
- New growth on the willow stakes and brush layers in the soil wraps is moderate (Photos 4-27 and 4-28); and
- Survival rate of the planted potted trees and shrubs is moderate.

The following photos illustrate the conditions of the site as observed during the 2013 field visit.

Photo 4-21: Upstream half of site, erosion of silty sand at mid bank, cocomatting and willow stakes in place. (April 24, 2013)

Photo 4-22: Downstream half of site, erosion at the toe of the re-graded sections in the downstream half of the site with coco-matting and willow stakes in place. Photo also shows natural deposition of woody material near the waterline. (April 24, 2013)

Photo 4-23 & 24: Erosion and toppling of untreated bank below brush layer (Sta. 0+700 to 710 & 0+785 to 0+805). (April 24, 2013)


Photo 4-25 & 26: Silty sand deposition in upper bank and upland areas. (April 24, 2013)


Photo 4-27 & 28: Growth in willow stakes (downstream half) and brush layer (upstream half). (April 24, 2013)

4.7.3 Treatment Site C Measurement Summary

The following is an overview of the 2013 measurements. Statistical analysis of the erosion pin and cross-section data is presented in Section 4.9.

- 2012 to 2013 erosion pin measurements are presented in Figure 4-7;
- On average, the erosion pin data indicate deposition for both treatment sites (about 4 cm and 6 cm) for the 2012 to 2013 period;
- 2012 to 2013 and 2011 to 2013 cross-section measurements for Site C Treatment are summarized in Table 4-14, below. Cross-section plots are presented in Figure 4-8. (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); and

- ∆x Midpoint[8] means indicate erosion, generally, for both the more recent and the project-to-date timeline. Project-to-date erosion is somewhat less than the 2012 to 2013 erosion, suggesting a reversal in trend. The magnitude of mean erosion is generally similar between the three elevation bands.

Table 4-14: Mean Cross-section ∆x Midpoint Values for Site C Treatment (Upstream and Downstream)

Elevation Band	2012 to 2013		2011 to 2013	
	C U/S Treatment (m)	C D/S Treatment (m)	C U/S Treatment (m)	C D/S Treatment (m)
Upper	-0.29	0.00	-0.23	0.00
Middle	-0.42	-0.26	-0.22	N/A
Lower	-0.31	-0.30	N/A	N/A

4.8 Site C Control

4.8.1 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). Both sites are approximately 80 meters long.

Control site characteristics are summarized in the following table.

Table 4-15: 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

4.8.2 Field Observations, Upstream Control Site

The following observations were made during the 2013 field visit:

- Minor erosion has occurred at the toe and mid-bank leading to breaking off and toppling of grassy blocks; and
- Some minor deposition of silty sand has occurred on the upper bank and upland areas.

[8] 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.

4.8.3 Field Observations, Downstream Control Site

The following observations were made during the 2013 field visit:

- Steep (near vertical) mid and upper bank continues to undercut top grassy layer leading to breaking off and toppling of blocks.

Photo 4-29 Site C Upstream Control (April 24, 2013)

Photo 4-30 Site C Downstream Control (April 24, 2013)

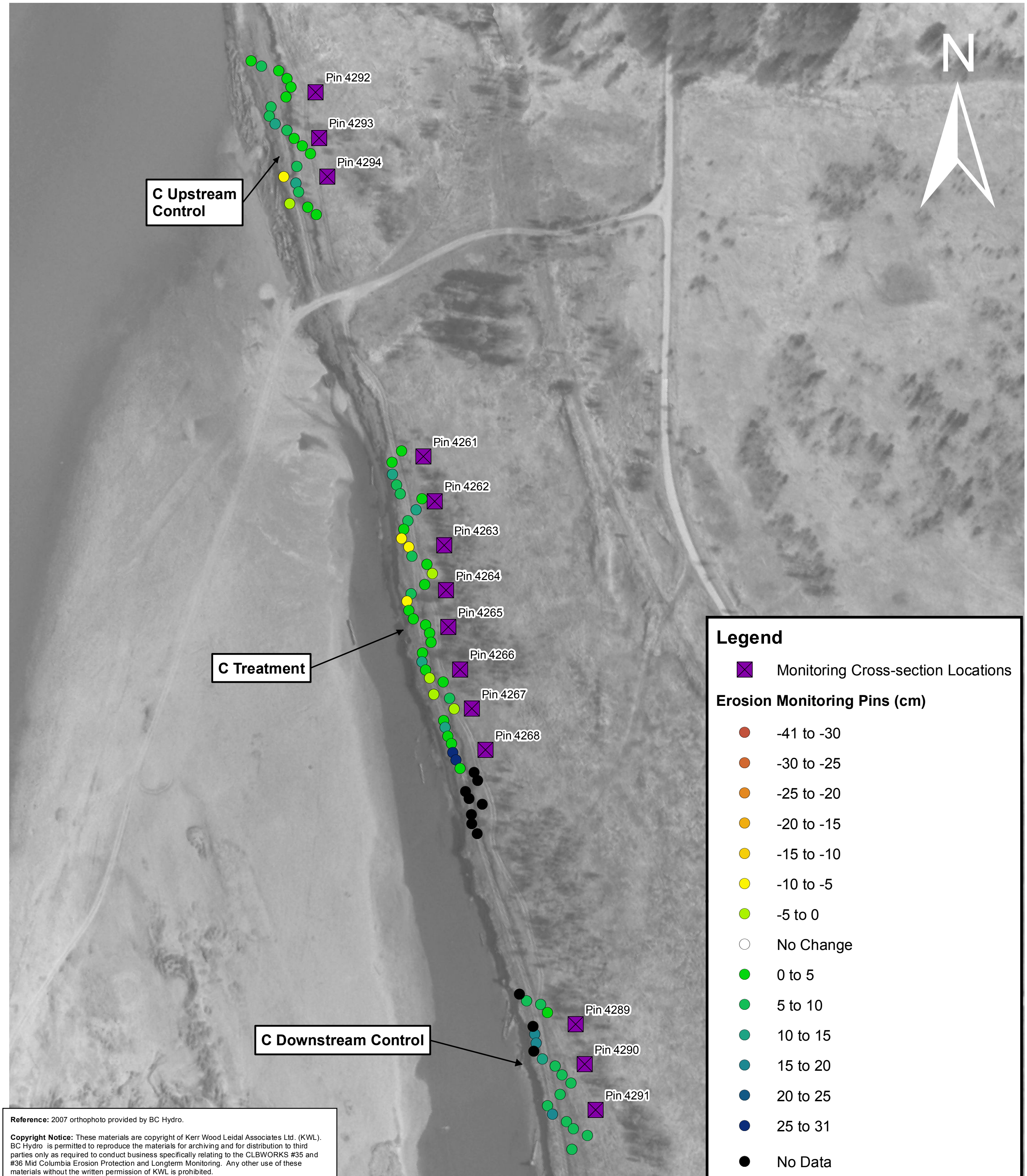
4.8.4 Control Site C Measurement Summary

The following is an overview of the 2013 measurements. Statistical analysis of the erosion pin and cross-section data is presented in Section 4.9.

- 2012 to 2013 erosion pin measurements are presented in Figure 4-7;
- On average, the erosion pin data indicate modest deposition for both control sites (about 5 cm and 9 cm) for the 2012 to 2013 period;
- 2012 to 2013 and 2011 to 2013 cross-section measurements for Site C Control are summarized in Table 4-16, below. Cross-section plots are presented in Figure 4-8; and
- Δx 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 4-16: Mean Cross-section Δx Midpoint Values for Site C Control (Upstream and Downstream)

Elevation Band	2012 to 2013		2011 to 2013	
	C U/S Control (m)	C D/S Control (m)	C U/S Control (m)	C D/S Control (m)
Upper	-0.40	0.00	-1.21	0.00
Middle	0.07	-0.71	0.32	-0.27
Lower	-0.78	-0.35	-1.95	N/A



Reference: 2007 orthophoto provided by BC Hydro.

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BC Hydro
CLBWORKS #35 and #36

Project No.	Date
478-081	December 2013

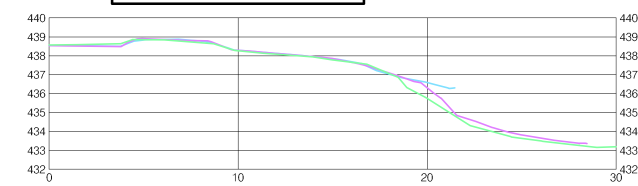
50 0 50 (m)
1:2,500

2012 to 2013 Erosion Pin Data Site C (Treatment and Control)

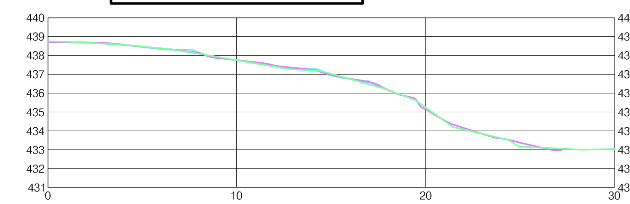
Figure 4-7

Path: O:\0400-0499\478-081\430-GIS\MXD-Rpt\2013\478081BioEngC1_2013.mxd Date Saved: 12/19/2013 1:39:55 PM
Author: EEllis

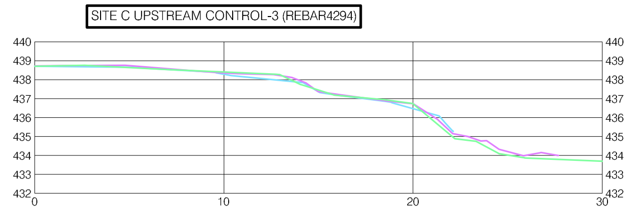
SITE C TREATMENT AREA-4 (REBAR4264)



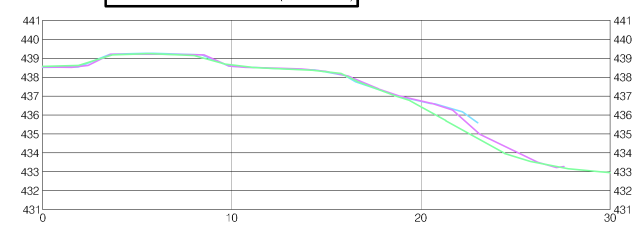
SITE C TREATMENT AREA-8 (REBAR4268)



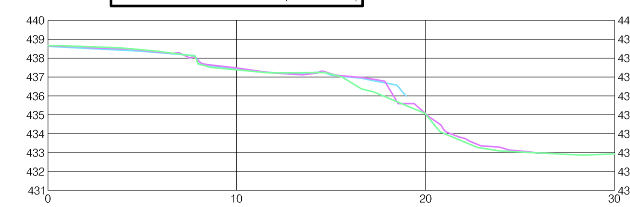
SITE C UPSTREAM CONTROL-3 (REBAR4294)



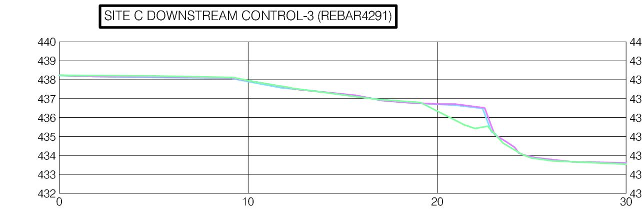
SITE C TREATMENT AREA-3 (REBAR4263)



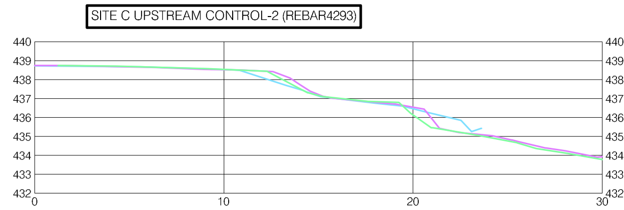
SITE C TREATMENT AREA-7 (REBAR4267)



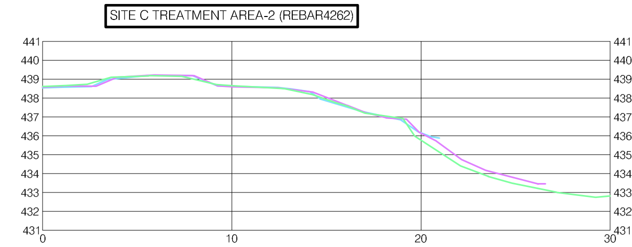
SITE C DOWNSTREAM CONTROL-3 (REBAR4291)



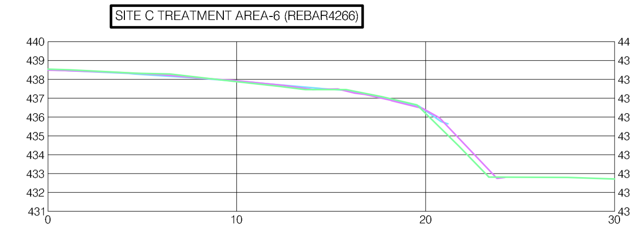
SITE C UPSTREAM CONTROL-2 (REBAR4293)



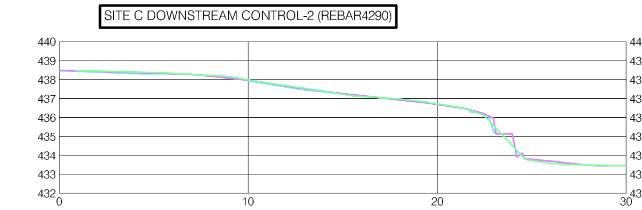
SITE C TREATMENT AREA-2 (REBAR4262)



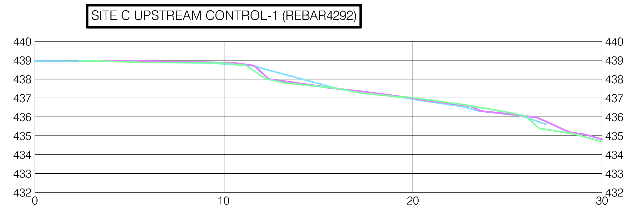
SITE C TREATMENT AREA-6 (REBAR4266)



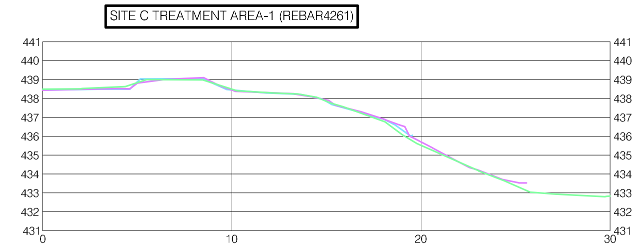
SITE C DOWNSTREAM CONTROL-2 (REBAR4290)



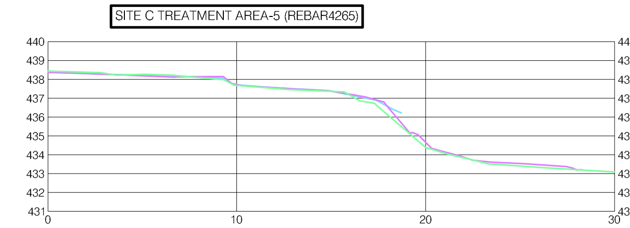
SITE C UPSTREAM CONTROL-1 (REBAR4292)



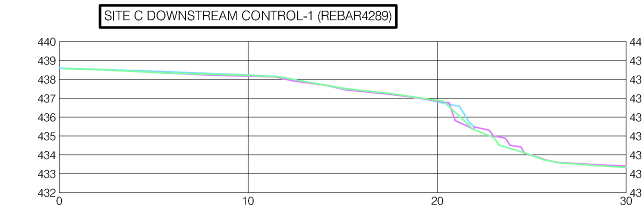
SITE C TREATMENT AREA-1 (REBAR4261)



SITE C TREATMENT AREA-5 (REBAR4265)



SITE C DOWNSTREAM CONTROL-1 (REBAR4289)



LEGEND

- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2013

0 2 (1:400) 10m

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

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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	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						

Seal

KERR WOOD LEIDAL associates limited
CONSULTING ENGINEERS

CLB#35
BIOENGINEERING EROSION MONITORING
SITE C SECTIONS

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

SW4
Drawing Number

4.9 Statistical Analysis

A total of seven sites were modified with bioengineering methods designed to reduce erosion. 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.

4.9.1 Measurement Methodology

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. 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 changes measured at each pin over the specified time period.

Cross-sections

For each treatment/control site pair, multiple cross-sections are 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 is marked by a survey benchmark placed on the bank so that the same location on the bank can be measured during each cross-section survey.

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 4-10.

As indicated in Figure 4-10, 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 is 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 4-10.

For each site, the mean Δx midpoint is calculated as the average of all the individual cross-section Δx midpoint values.

4.9.2 Erosion Pins

The statistical model used to evaluate change in site condition is a before/after control/impact design (BACI; Stewart-Oaten et al., 1992[9]; Stewart-Oaten and Bence, 2001[10]). 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), will influence both the control and treatment sites in similar ways and in this way the change in the treatment site can be benchmarked with the change observed at its paired control site. In this case, the impacted sites are those treated with bioengineering designs to minimize erosion. Control sites were not treated.

Changes in pin length were evaluated over the following time periods:

- 2011 to 2012,
- 2012 to 2013, and
- 2011 to 2013.

2011 to 2012 data have been presented previously in the 2012 Progress Report. The emphasis in this report will be on the 2012 to 2013 period and the overall project period (2011 to 2013).

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 subtracted difference for exposed pin lengths 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, e.g., climate. 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.

Thus, the 'difference of the differences' is the test statistic. A Student's one-sample t test was used to determine whether the test statistics are significantly greater than or less than 0.

The null hypothesis (H_o) being tested can be stated as:

> **H_o**: Erosion (as measured by change in pin length) does not differ significantly between sites with bioengineering works and sites without.

It should be noted that statistical significance is not equivalent to biological significance. Significant results must be considered within the larger context of what is biologically or otherwise meaningful for the sites (see Section 4.10 for further discussion).

Measured pin length changes are presented in Table 4-17, for all three time periods (Appendix B contains an expanded table which includes N and standard deviation corresponding to each mean).

The results are summarized graphically in Figure 4-9. No data transformation was needed.

The most recent measurement period (2012-2013) shows a relatively clear difference between the treatment and control sites, with treatment sites tending to show more erosion than control sites. However, evaluated over the longer project-to-date period (2011-2013), this result is not evident.

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[9] Stewart-Oaten, A., J. R. Bence, and C. W. Osenberg. 1992. Assessing effects of unreplicated perturbations: no simple solutions. Ecology 73:1396-1404.
[10] Stewart-Oaten, A. and Bence, J.R. 2001. Temporal and spatial variation in environmental assessment, Ecological Monographs 71: 305–339.

Table 4-17: 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: 2011 to 2012 (cm)			Mean Change in Pin Length: 2012 to 2013 (cm)			Mean Change in Pin Length: 2011 to 2013 (cm)		
	C	T	Test Statistic C - T	C	T	Test Statistic C - T	C	T	Test Statistic C - T
A1 Upstream	-0.90	0.15	-1.05	-2.18	-5.53	3.35	-3.14	1.05	-4.19
A1 Downstream	-0.06	0.83	-0.89	1.14	-3.32	4.46	1.08	0.00	1.08
A2 Upstream	-2.04	-0.58	-1.46	-1.35	-2.33	0.98	-3.65	-2.92	-0.73
A2 Downstream	-3.32	-4.77	1.45	-1.65	-3.71	2.05	-4.92	-8.88	3.95
B	0.03	-0.06	0.09	-0.33	-1.08	0.76	-0.30	-1.02	0.72
C Upstream	0.03	-0.06	0.08	5.23	3.83	1.39	5.25	3.78	1.47
C Downstream	-0.10	0.45	-0.55	9.16	5.84	3.31	9.22	6.29	2.93

Notes:
1. For all values except the test statistic (C-T), negative values indicate erosion and positive values indicate deposition.
2. Missing values were not estimated or included in any calculation.
3. Note expanded table including N and standard deviations is included in Appendix B (Table B-1).

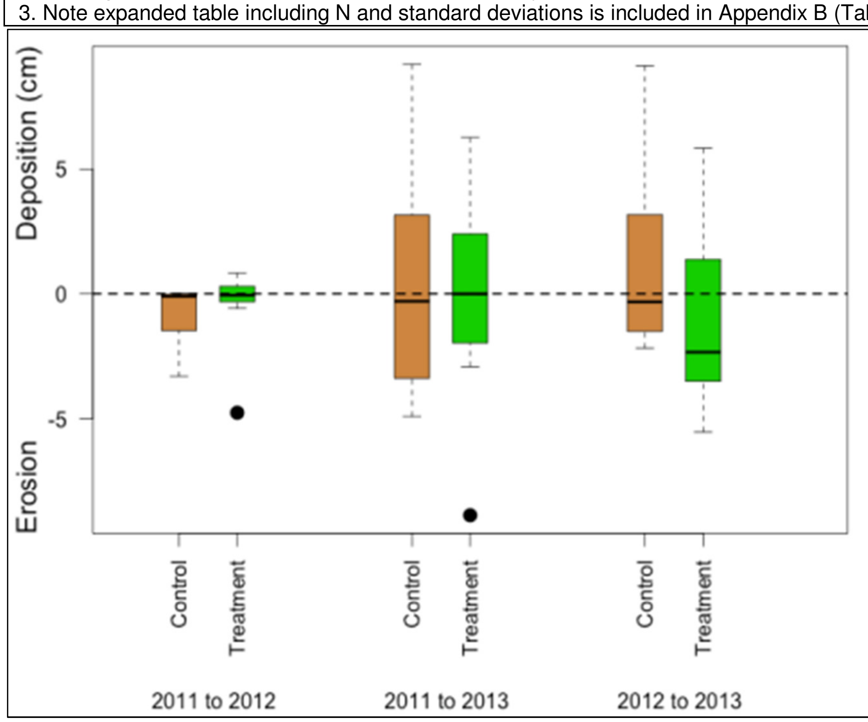


Figure 4-9: Change in Pin Length for Different Time Periods for All Sites

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 4-18. It should be noted that the sign of the test statistic (C – T) does not indicate erosion if negative, due to the effect of the algebraic expression.

As indicated in Table 4-18, the 2012 to 2013 period was the only period that yielded a statistically significant result ($p < 0.01$). Although both treatment and control sites exhibited erosion, the magnitude of erosion measured at treatment sites was greater than in control sites (mean difference of 2.3 cm).

Table 4-18: Test Results for Comparison of Control and Treatment Sites as Measured By Difference (Control – Treatment) of Changes in Pin Length.

Period	Mean (cm)	Std. Dev. (cm)	N	Std. Error	df	T statistic	p value
2011 to 2012	-0.33	0.97	7	0.37	6	-0.91	0.40
2012 to 2013	2.33	1.40	7	0.53	6	4.39	0.00
2011 to 2013	0.75	2.65	7	1.00	6	0.74	0.48

4.9.3 Cross-Sections

Cross-sections were measured at 12 out of 14 of the sites in 2011, and at all 14 sites in 2012 and 2013 (see Table 3-1 and Table 3-2 for a summary of construction and survey timing). The number of cross-sections per site varies from two to four.

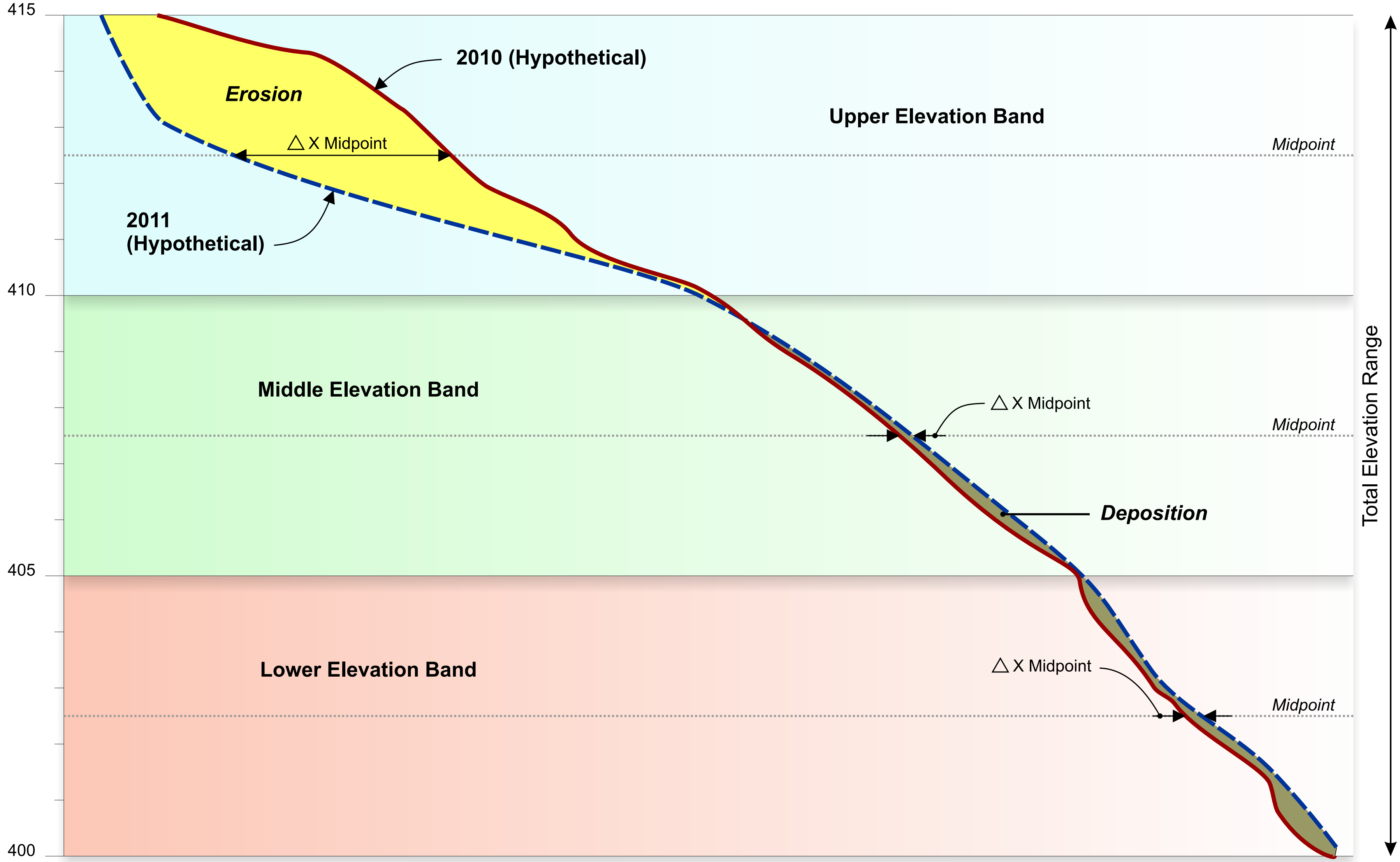
Treatment and control sites were paired, and a similar BACI statistical model was used to test for a difference in the amount of change in erosion (or deposition) for each pair of sites.

The null hypothesis being tested can be stated as:

> **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 4-19 presents a summary of mean change (Δx midpoint) for each site and time period. The same data are presented graphically, in Figure 4-11. As indicated, for the 2012 to 2013 time period, all of the control and treatment sites experienced erosion. Over the longer 2011 to 2013 period, the majority of treatment and control sites experienced erosion (2 of 7 control sites and 1 of 5 treatment sites showed no change or deposition).



Demonstration of Cross-Section Analysis to Measure Erosion/Deposition

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Figure 4-10

Table 4-19: Mean Change (∆x midpoint) at Control (C) and Treatment (T) Sites And Differences (C – T) (Test Statistic).

Site Name	Change: 2011 to 2012 (m)			Change: 2012 to 2013 (m)			Change: 2011 to 2013 (m)		
	C	T	C - T	C	T	C - T	C	T	C - T
A1 Upstream	0.05			-0.04	-0.32	0.28	0.00		
A1 Downstream	0.10			-0.11	-0.61	0.50	-0.01		
A2 Upstream	-0.07	0.09	-0.16	-0.22	-0.28	0.05	-0.37	-0.22	-0.15
A2 Downstream	-0.13	-0.44	0.31	-0.21	-0.45	0.24	-0.34	-0.96	0.62
B	0.21	0.04	0.17	-0.14	-0.10	-0.05	0.12	-0.07	0.19
C Upstream	-0.35	0.13	-0.48	-0.37	-0.34	-0.03	-0.44	-0.22	-0.22
C Downstream	-0.15	0.00	-0.15	-0.35	-0.19	-0.16	-0.13	0.00	-0.13

Notes:
1. Negative values indicate erosion and positive values indicate deposition.
2. Missing values are indicated by the grey shaded cells. Missing values were not estimated or included in any calculation.

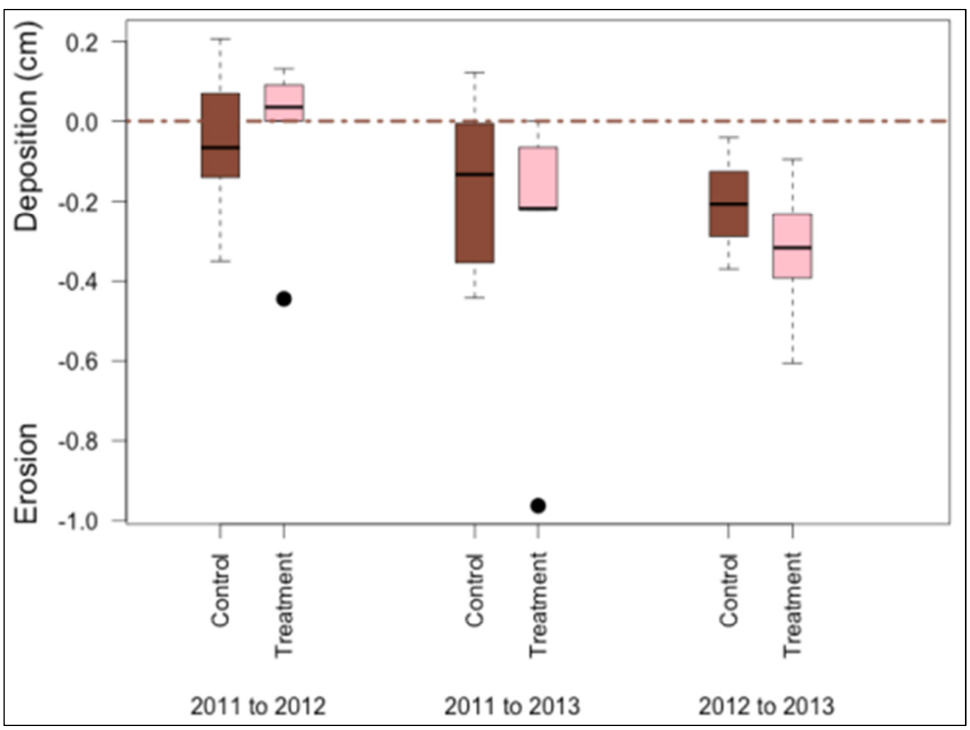


Figure 4-11: Bank Change (∆x midpoint) Measured over Three Time Periods

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 4-20. As indicated below, none of the time periods yielded a statistically significant difference.

Table 4-20: Test Results for Comparison of Control and Treatment Sites as Measured By Difference (Control – Treatment) of Δx midpoint.

Period	Mean (m)	Std. Dev. (m)	N	Std. Error	df	t statistic	p value
2011 to 2012	-0.06	0.31	5	0.14	4	-0.44	0.68
2011 to 2013	0.06	0.35	5	0.16	4	0.39	0.72
2012 to 2013	0.12	0.23	7	0.09	6	1.35	0.23

4.10 Summary and Discussion

4.10.1 Summary

A significant difference in erosion pin length was detected for control and treatment sites for the 2012 to 2013 period. Counter to what might be expected the pin data showed that erosion at the treatment sites exceeded that at the control sites. However, the overall difference was 2.3 cm: a modest difference that would be difficult to identify if simply visually comparing two sites. The significance of the results is discussed further, below.

Differences in cross-section measurements (Δx midpoint) at control and treatment sites were not statistically significant.

4.10.2 Discussion

Independence of Sites

In general, the independence of the treatment sites should be considered when interpreting any statistically significant results. If values at the split treatment sites are highly similar, and differences are significant, it may be appropriate to test for significance based on four site pairs rather than seven. To address these concerns, we can compare the changes in pin length at the upstream and downstream treatment sites for A1, A2, and C (Table 4-17):

- The upstream and downstream sites at A1 tended to show deposition during the earlier time period (2011-2012), erode during the later (2012-2013), and change only slightly overall;
- The upstream and downstream A2 treatment sites showed erosion for all time periods; during the second time period the amount of erosion at the treatment sites was similar and more variable during the first and overall time periods; and
- For C, during the first period one site had erosion and the other deposition, while in the later time period and overall, both sites had deposition.

Thus, in overall patterns of deposition or erosion, the split sites show similar general patterns. However the sites are not very similar in terms of observed amount of change in pin length.

Overall Significance of the Results

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*.”

CLBWORKS #35 is a monitoring program that is linked to the Arrow Lakes soft constraints around erosion, and designed to test whether bioengineering may be an effective means of reducing erosion.

The study’s terms of reference do not specify the nature of the concern around erosion. We have assumed that property owners along the river may have concerns around erosion. Impacts of shoreline erosion (and/or associated downstream sedimentation) on biological communities may be another driver for the management questions.

In both of these cases, the minimum erosion that is “significant” (i.e. important) may not be the same as the minimum erosion that is statistically significant. For instance, many property owners (but not all) likely would not be concerned about 2 cm of bank erosion over one year. That sentiment might change if the erosion were sustained at a constant annual rate for a number of decades. And some biological species may be affected by a relatively modest amount of bank retreat. It is assumed that the results of this work will be interpreted by different interested parties, based on their respective concerns.

It is important to recall that this study is intended to evaluate the ability of bioengineering techniques to mitigate erosion. Therefore the approximately 2 cm difference is the difference in erosion/deposition between sites left untreated, and sites treated with bioengineering. Given the cost of the bioengineering treatment, most river managers likely would hope to see a relatively large difference comparing treated and untreated sites, and a difference that indicates a reduction in erosion: the interim results from this study are not in line with these expectations. A final study result that indicates no difference, or even suggests modestly increased erosion, would not indicate support for the bioengineering techniques applied in the study.

Erosion Mechanisms

Three main processes influence bank changes in the CLBWORKS #35 reach:

1. Fluvial erosion, related to the force of the river current acting on the bank;
2. Wave erosion, related to backwatering from the Arrow Lakes Reservoir; and
3. Erosion related to the fluctuation in discharge due to the operation of the Revelstoke Dam, upstream.

Water levels at the CLBWORKS #35 sites vary greatly during the year, as does the force of the river current, due to the timing of and combination of backwater effect, dam operation, and natural hydrograph. Water level changes at a given site are in the range of 1 m to 4 m annually but can fluctuate relatively rapidly during a given day depending on the operation of the dam.

Although the CLBWORKS #35 sites technically are located within the Arrow Lakes Reservoir, they are about 220 km upstream of the Hugh Keenleyside Dam (which regulates flow in the Arrow Lakes Reservoir). In comparison, the Revelstoke Dam is about 11 km upstream of the sites. It is believed that the effect of the Revelstoke Dam discharge is likely more important than the backwater. Therefore, it is assumed that minor erosion occurring at the top of bank may be caused by wave action at full backwater while a majority of the erosion occurring at the sites is the fluvial process undermining the lower and mid bank leading to toppling as the discharge from Revelstoke dam fluctuates.

Bioengineering Success Factors

Interim results to date suggest that erosion is occurring at all sites, and that erosion is occurring somewhat faster at the sites treated with bioengineering techniques than in those that were not treated. The difference, although statistically significant, is small.

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). The ability of the bioengineering techniques applied on the CLBWORKS #35 sites to withstand erosion hinges, to a certain extent, on the strength imparted to the bank by the plants. Therefore, 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 the 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 the ability of the plants to establish include:

- time of year when planted;
- availability of water during the growing season; and
- flow and water-level conditions during initial years.

The success of the bioengineering treatments applied to the CLBWORKS #35 sites will be evaluated more completely as part of the final analysis, to be conducted in 2015 (Year 4 / Final Year). It should also be noted that only certain bioengineering techniques have been applied in this study, and that the results should not necessarily be generalized to all bioengineering.

4.11 Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

PROFESSIONAL
PROVINCE
OF
E. R. ELLIS
#32982
BRITISH
COLUMBIA
GEOSCIENTIST

May 29, 2014

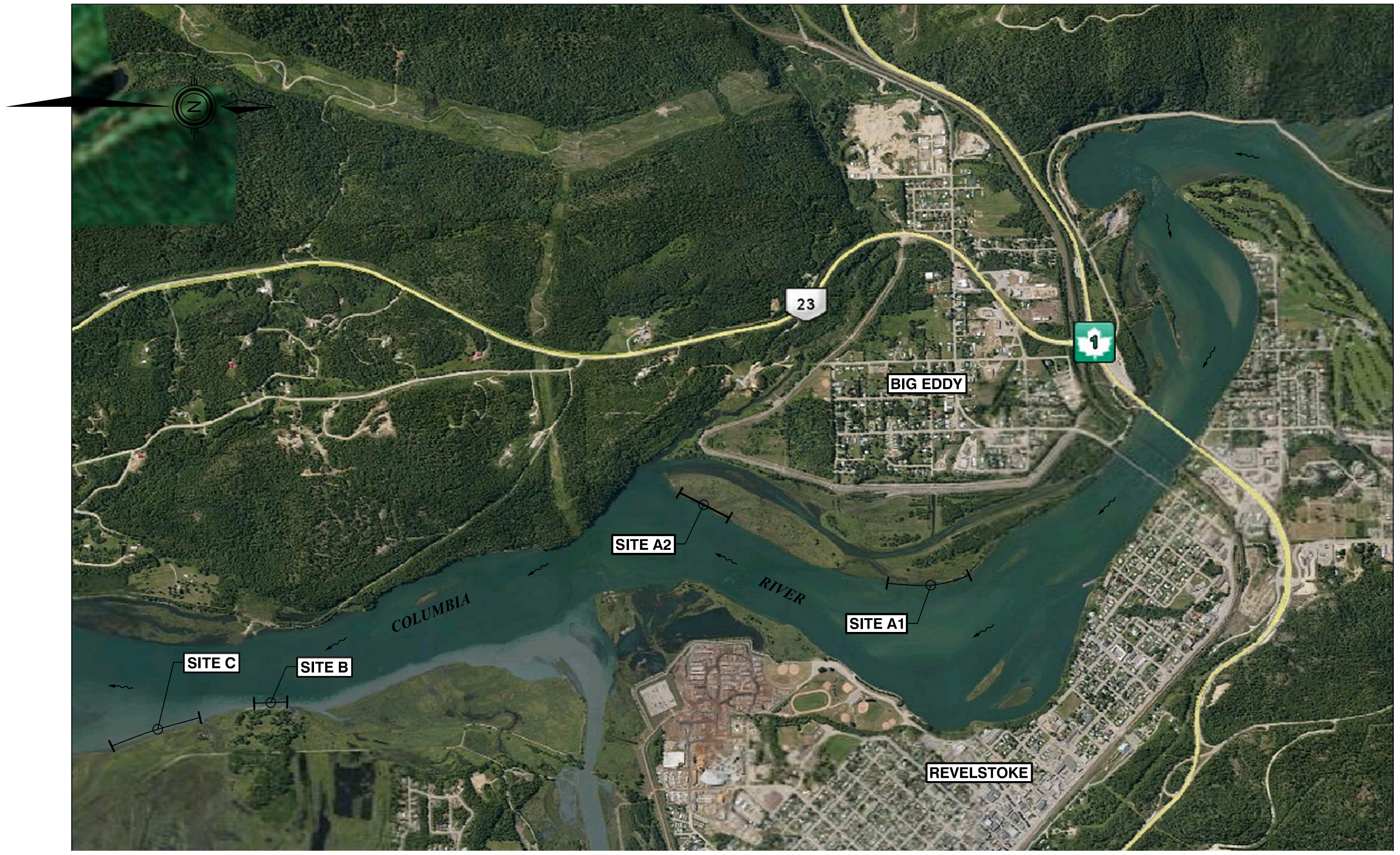
Erica Ellis, M.Sc., P.Geo.
Fluvial Geomorphologist

Reviewed by:

David Murray, AScT, CPESC, P.Eng.
Senior Water Resources Engineer

Appendix A

CLBWORKS #35 Drawings
(Design of Engineering Works)



KEY PLAN
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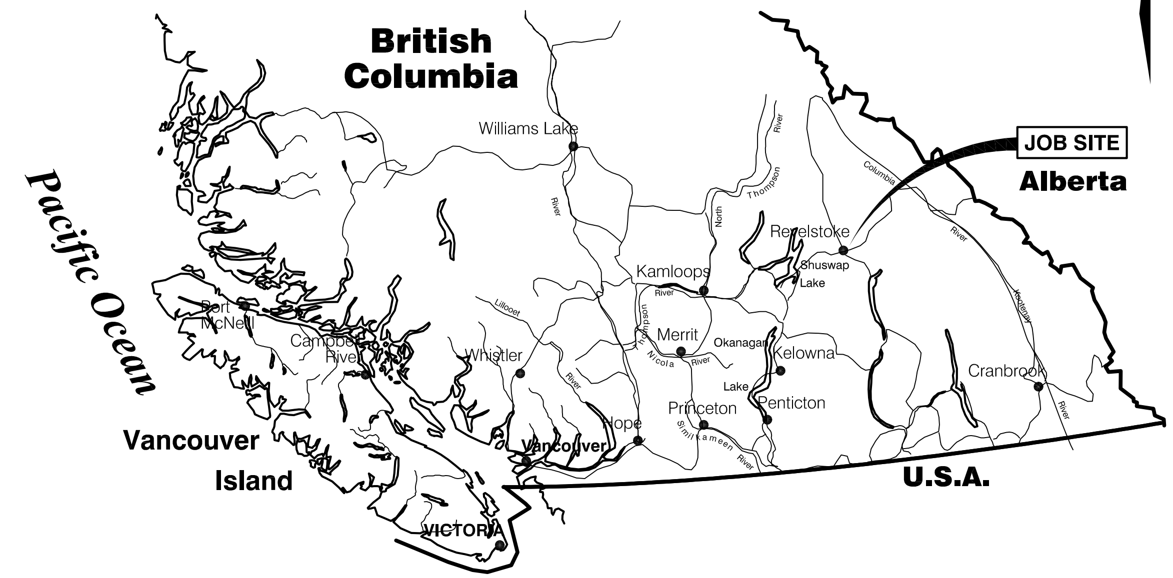

LOCATION PLAN
N.T.S.

SHT. NO.	DRAWING NO.	DRAWING LIST 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

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Construction			
Record Drawings			

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2	APR.15/11	SJL	SC	DTM	ISSUED FOR PERMIT						
3	DEC.23/10	SJL	BVC	DTM	ISSUED FOR 2011 PROGRESS REPORTING						

Seal

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CONSULTING ENGINEERS

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
Drawing Number 1
Client: BC HYDRO

SITE ACCESS SITES 'A1' & 'A2'

N.T.S.

SITE ACCESS SITES 'B' & 'C'

N.T.S.

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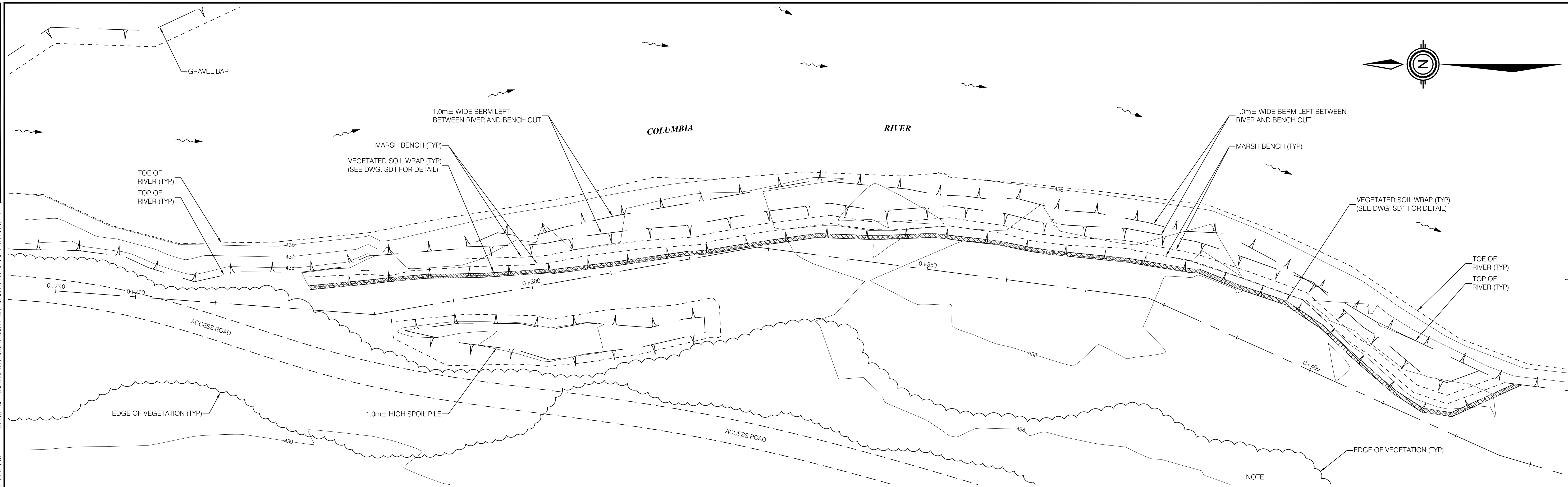
CONSULTING ENGINEERS

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

KWL Project No. 478-119	Scale AS SHOWN		G2
Sheet 02 of 9	Rev. No. 3		Drawing Number
Client: BC HYDRO			

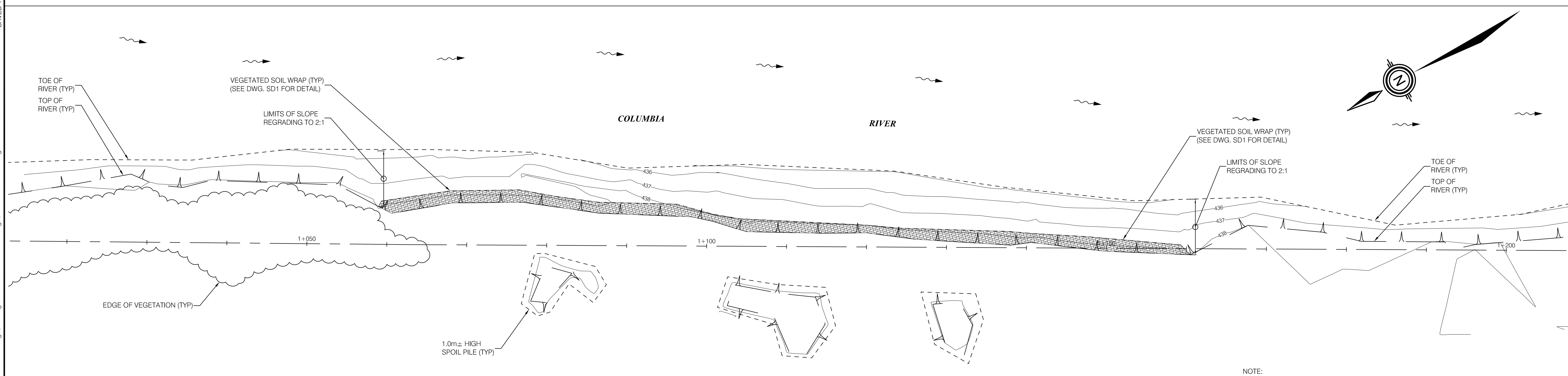


PLAN - SITE A1

SCALE 1:250

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.



PLAN - SITE A2

SCALE 1:250

NOTE:

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Record Drawings			

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

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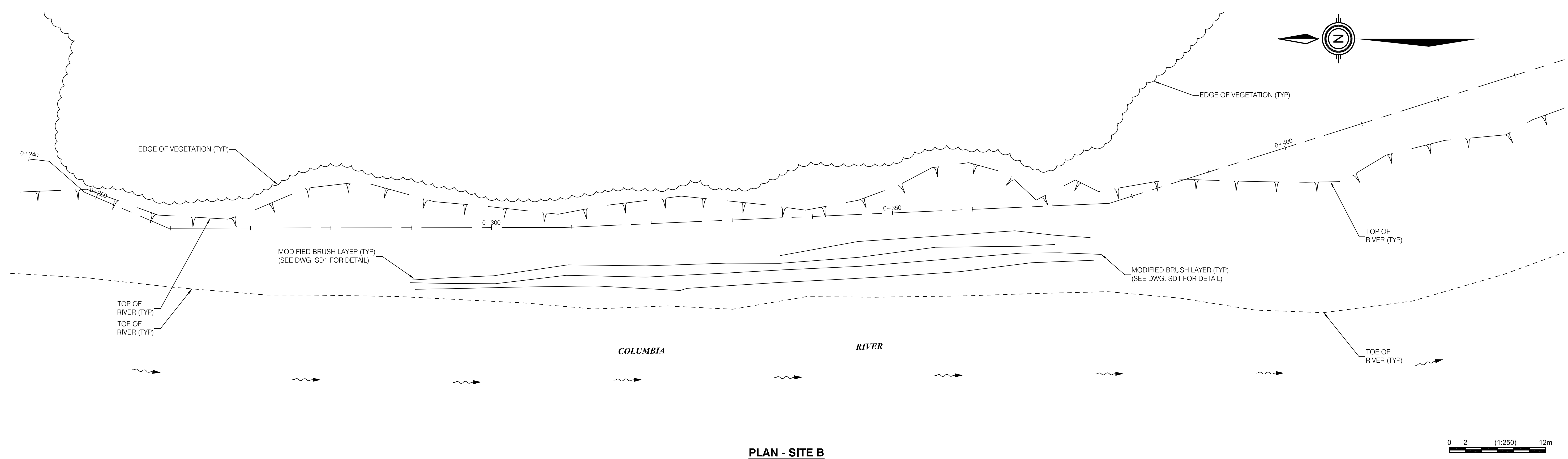
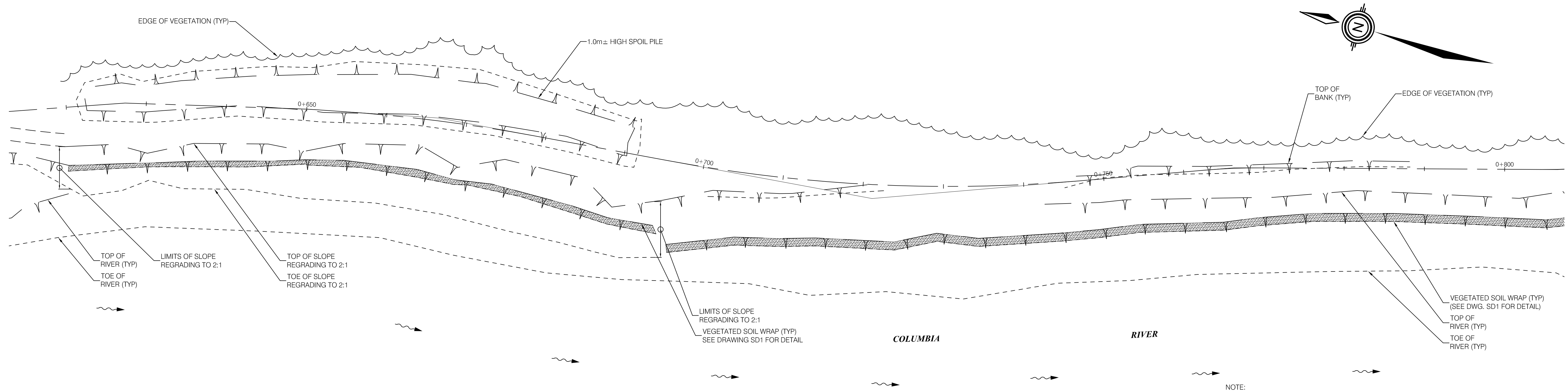
Sheet	03 of	Rev. No.	3
Client: BC HYDRO			

SW1
Drawing Number



PLAN - SITE B

SCALE 1:250



PLAN - SITE C

SCALE 1:250

NOTE:

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

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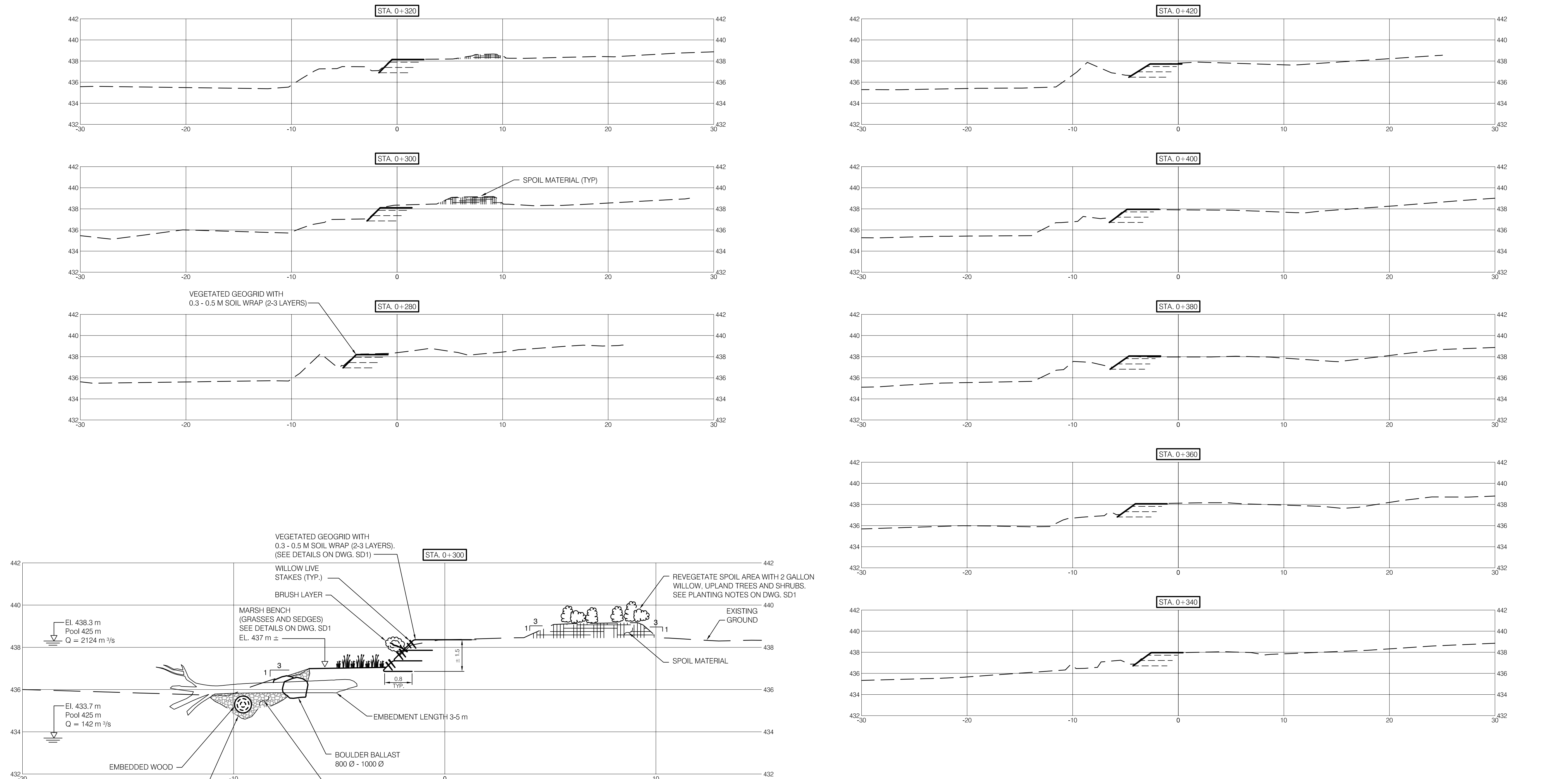

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SCALE 1:100

NOTE:

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Permits	P0	APR.15/11	-
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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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BC HYDRO
SECTIONS - SITE 'A1'

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Sheet 05 of | Rev. No. 3
Client: BC HYDRO

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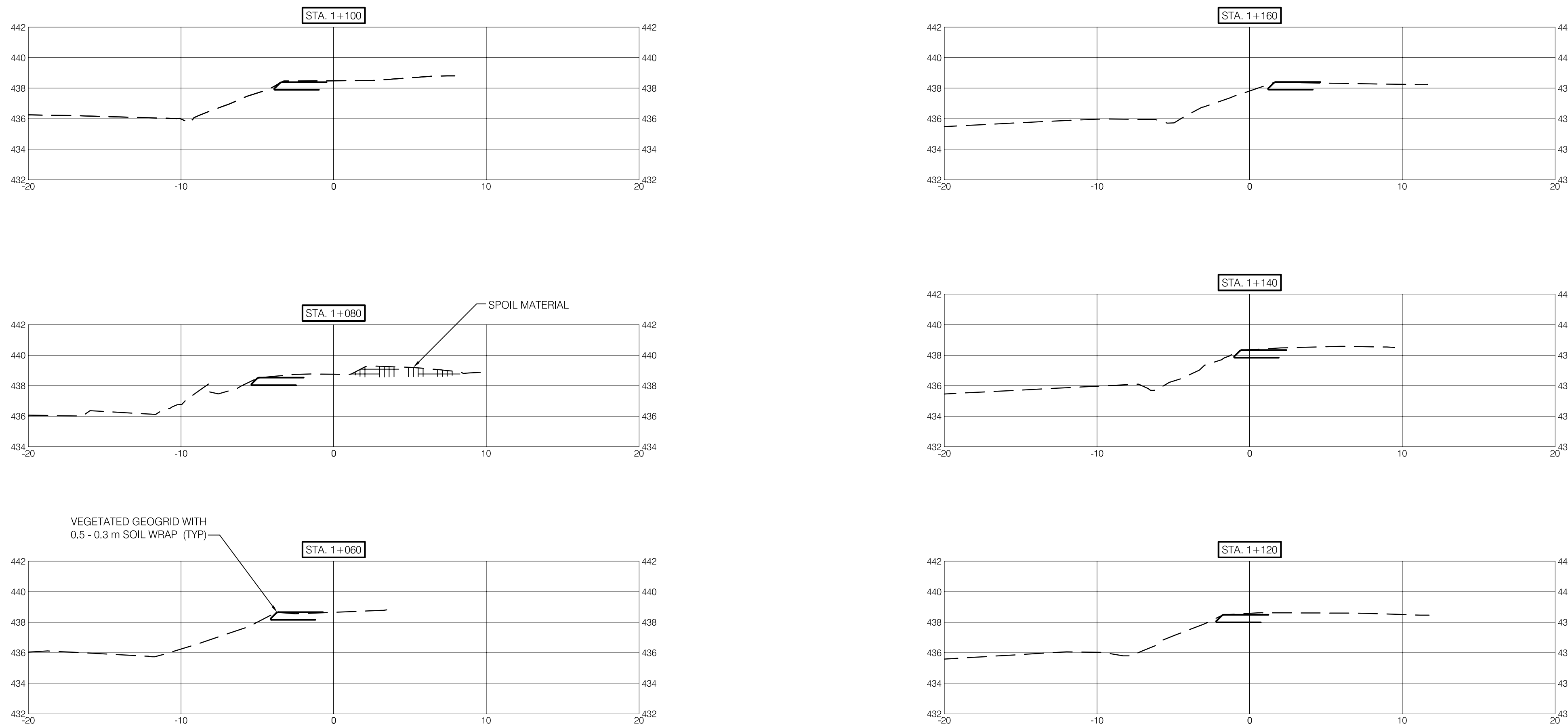

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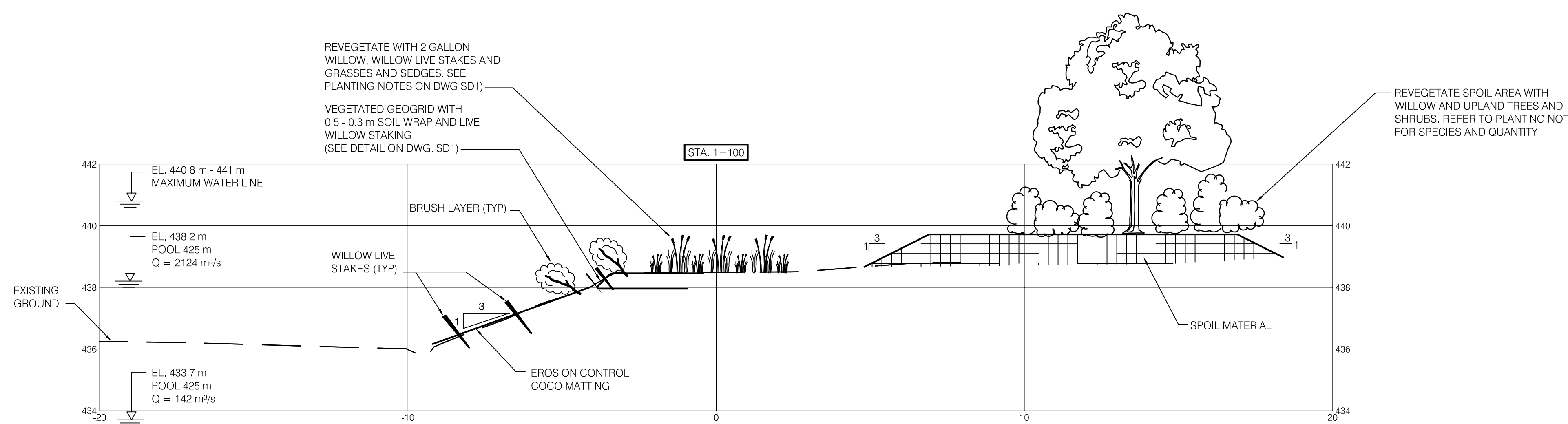

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SCALE 1:100

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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 'A2'

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Sheet 06 of	Rev. No. 3	
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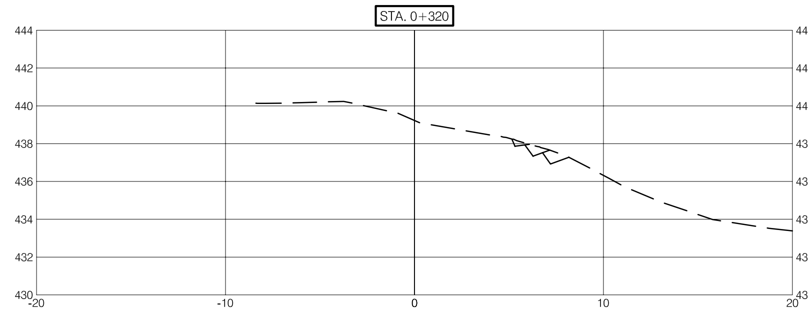

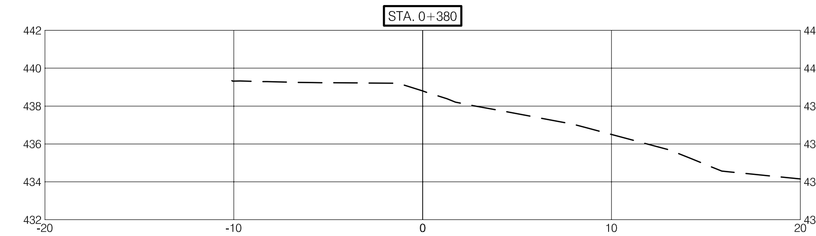

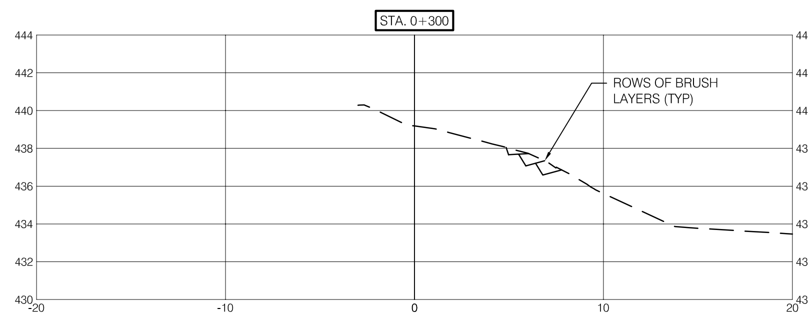

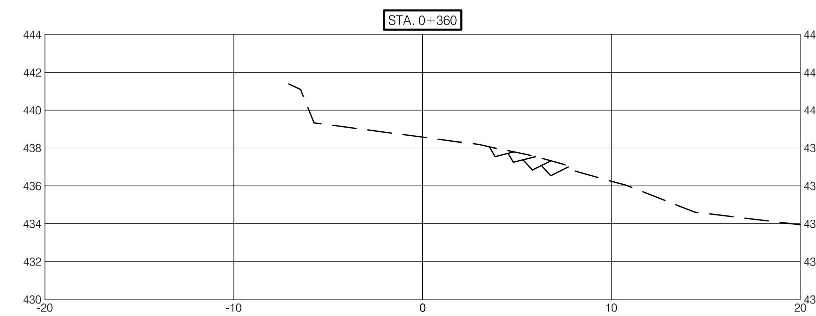

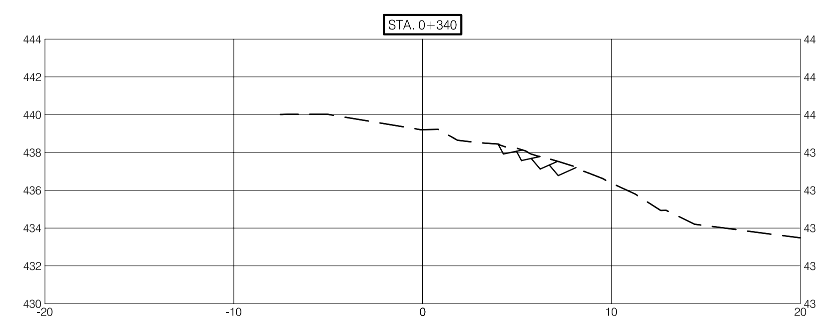

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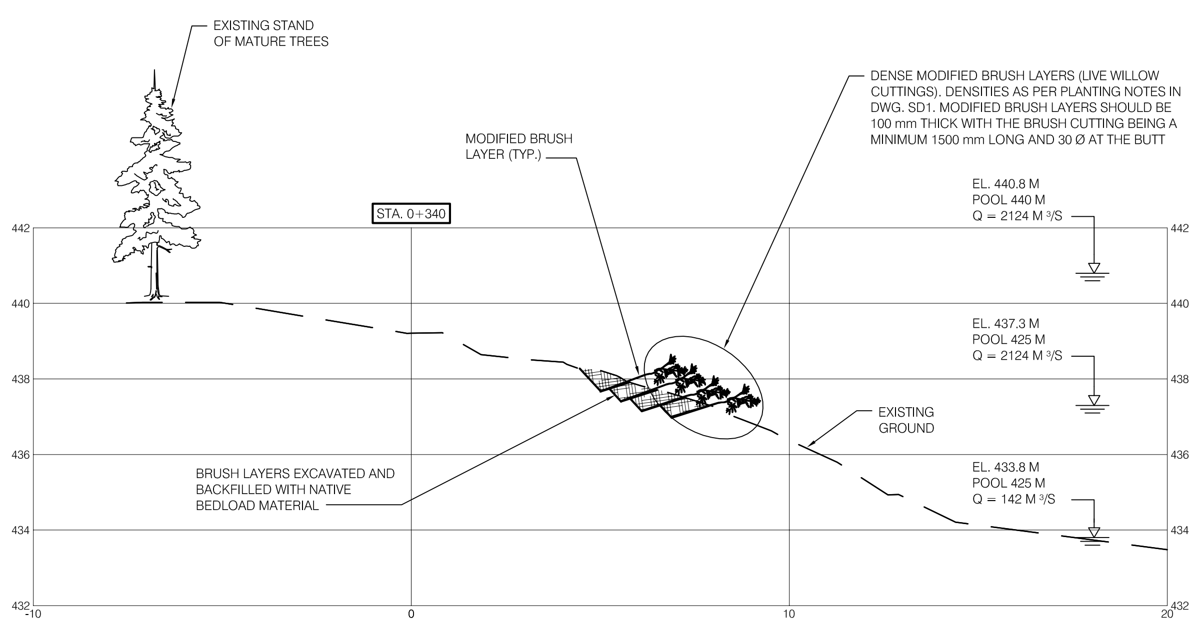
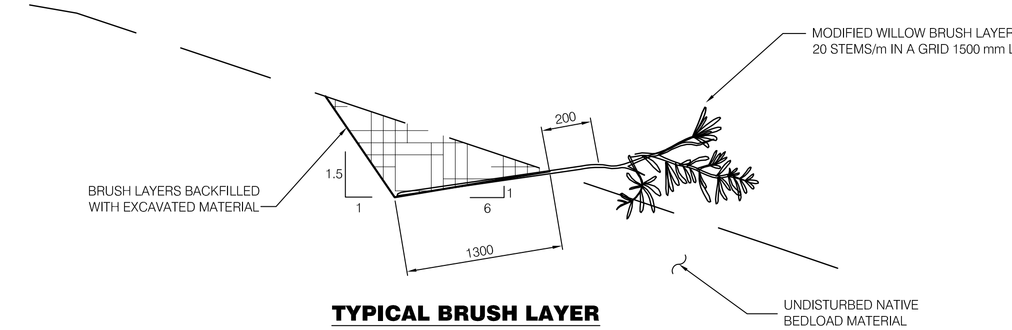


TYPICAL SECTION
SITE 'B' STA 0+300 to STA 0+380
SCALE 1:100



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

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Sheet 07 of	Rev. No. 3	Drawing Number
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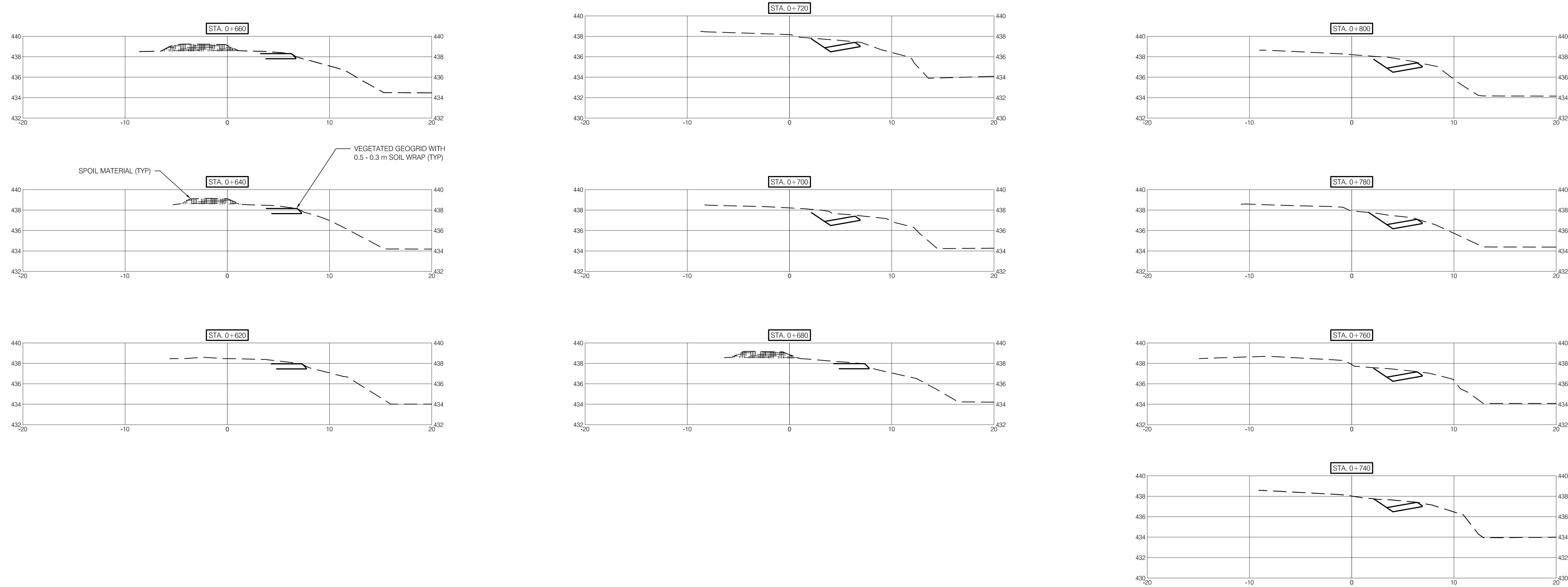

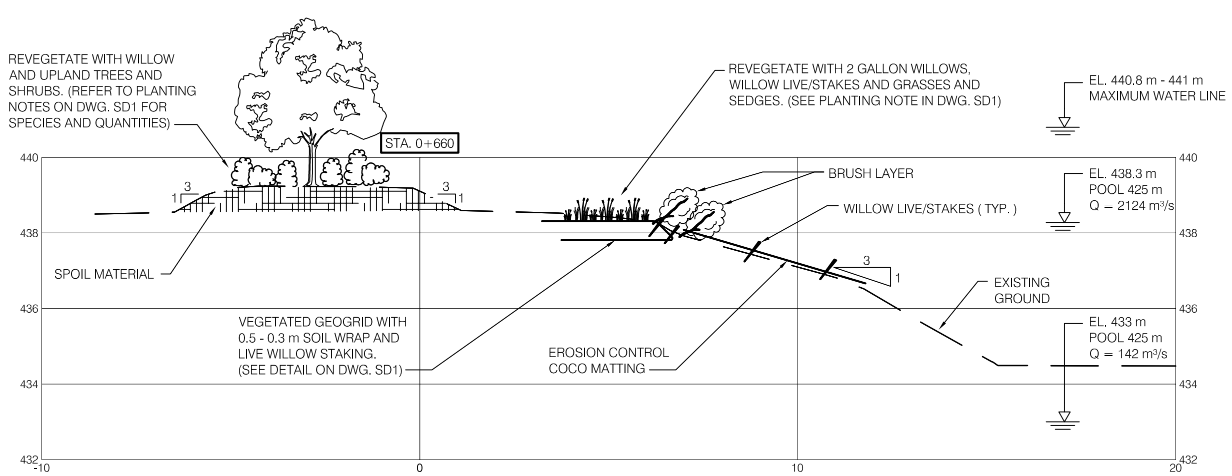

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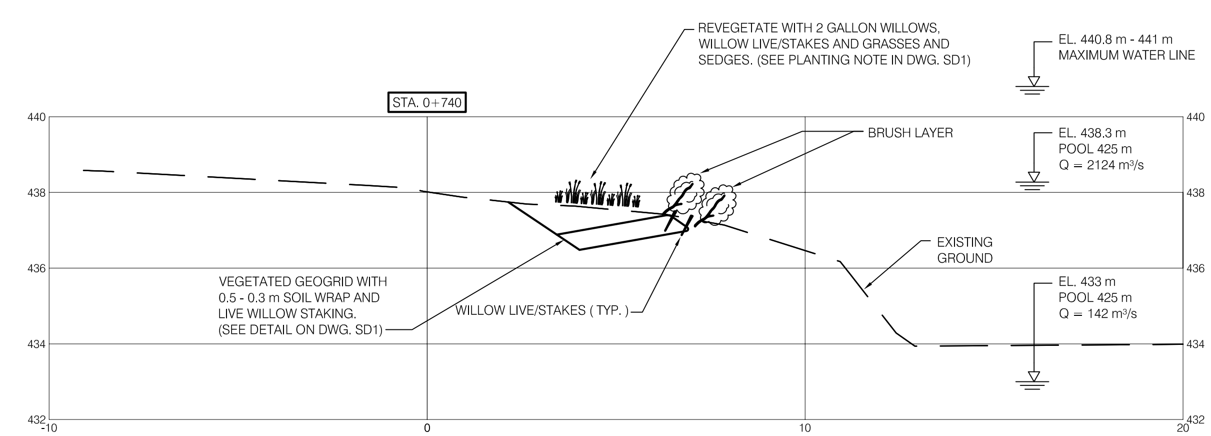
SITE 'C' STA 0+620 to STA 0+695

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.

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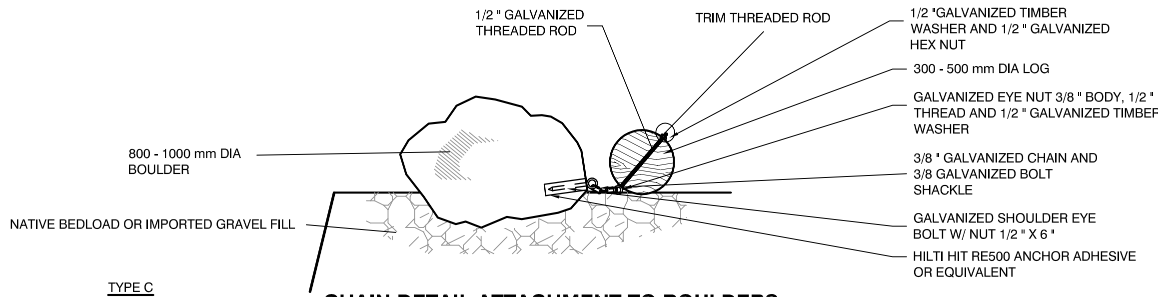
MID COLUMBIA RIVER BANK PROTECTION WORKS
BC HYDRO
SECTIONS - SITE 'C'

KWL Project No. 478-119 Scale 1:200
Sheet 08 of Rev. No. 3
Client: BC HYDRO

SW6
Drawing Number

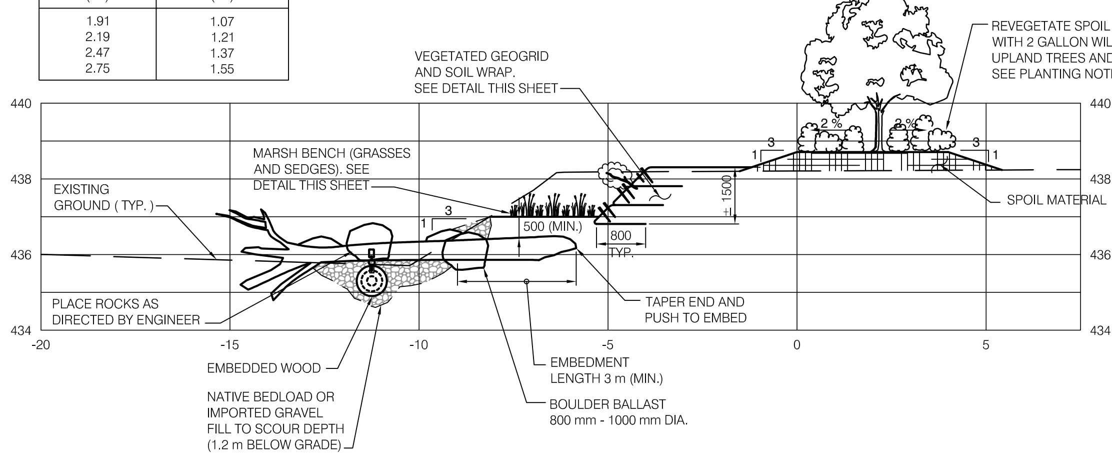


CHAIN DETAIL ATTACHMENT TO BOULDERS

N.T.S.

TYPE C

VOLUME WOOD (m³)	VOLUME BALLAST (m³)
1.91	1.07
2.19	1.21
2.47	1.37
2.75	1.55

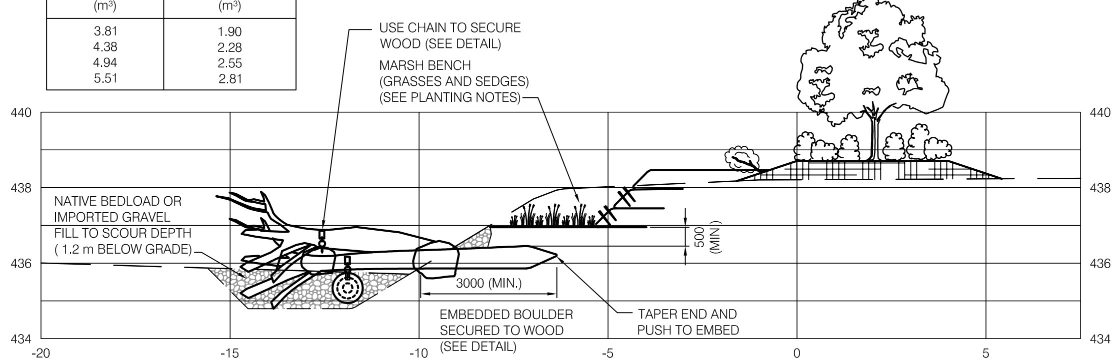


TYPE C - 2 LOG "T" STRUCTURE

SCALE 1:100

TYPE B

VOLUME WOOD (m³)	VOLUME BALLAST (m³)
3.81	1.90
4.38	2.28
4.94	2.55
5.51	2.81

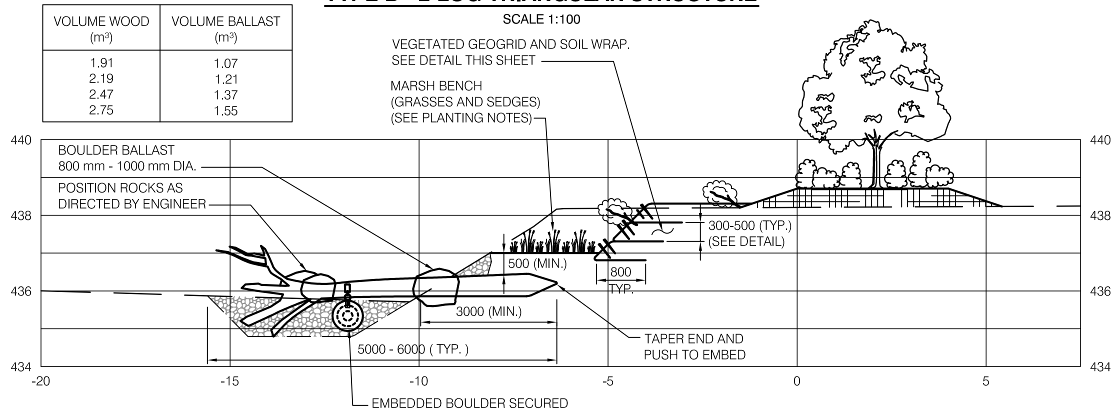


TYPE B - 2 LOG TRIANGULAR STRUCTURE

SCALE 1:100

TYPE A

VOLUME WOOD (m³)	VOLUME BALLAST (m³)
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.

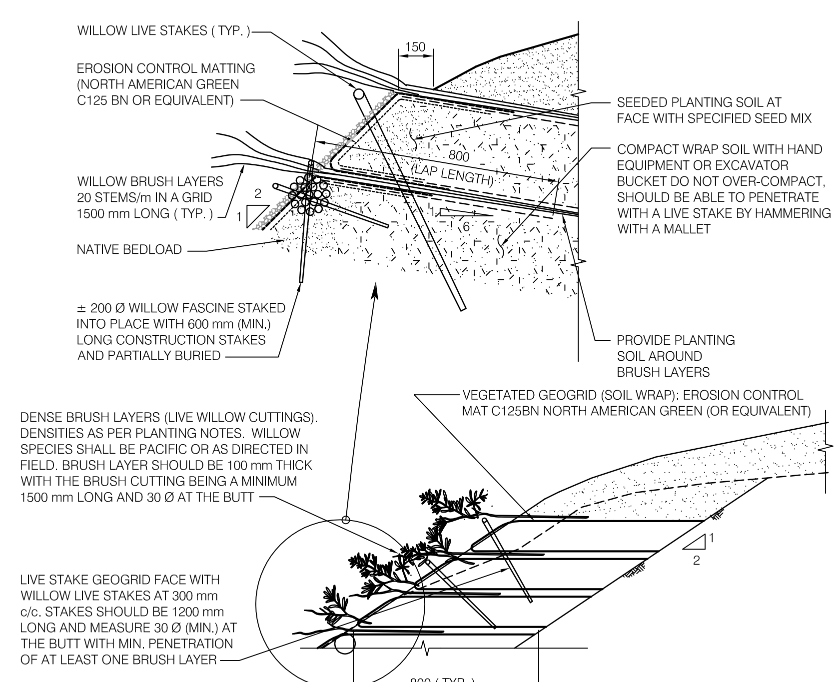
VEGETATED GEOGRID - WILLOW FASCINE
1. WILLOW FOR FASCINES SHALL BE A MINIMUM OF 1.0 m LONG AND 40 mm MINIMUM DIAMETER AT BUTT AND 15 mm MINIMUM DIAMETER AT TOP.
2. ALL WILLOW TO BE HOOKER'S WILLOW (SALIX HOOKERIANA) OR SUBSTITUTE APPROVED BY PROJECT BIOLOGIST.
3. FASCINES SHALL BE COMPOSED OF A OVERLAPPING 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.

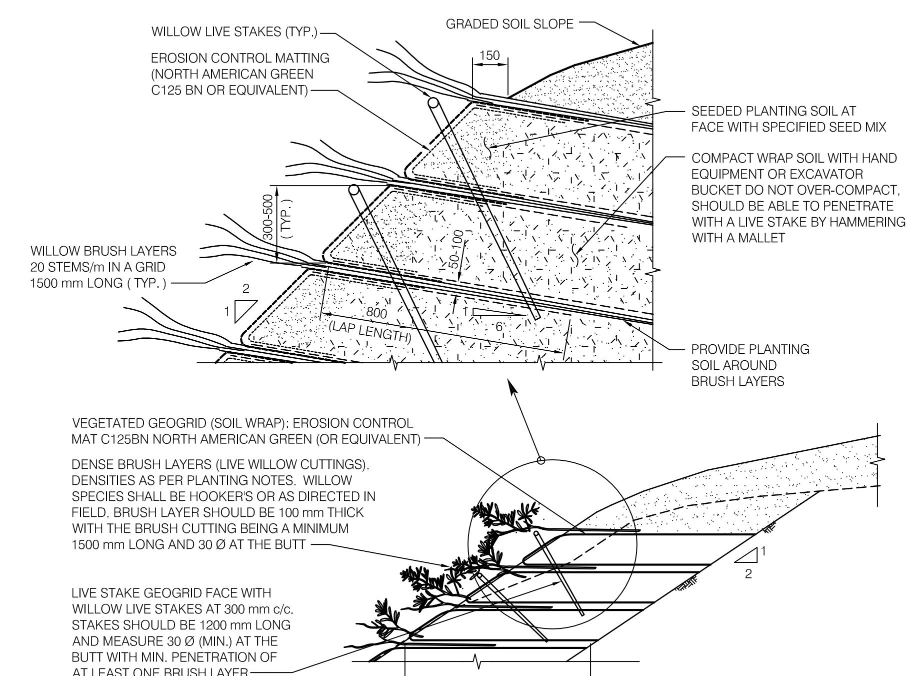
RIPRARIAN - SEEDING, SHRUBS AND TREE PLANTINGS
1. 1 AND 2 GALLON SHRUBS (SEE PLANTING LIST FOR LISTS OF SPECIES) ARE TO BE PLANTED AT SPACING GIVEN IN PLANT LIST.
2. BROADCAST SEED ALL EXPOSED SOIL IN THE RIPARIAN PLANTING ZONE WITH RICHARDSON'S INTERIOR REVEGETATION MIX, AT THE MANUFACTURER'S SPECIFIED 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

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

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

O:\0400-0499\478-119\500-Drawings\521-Production Drawings\Bio Eng Treatment Record Drawings\478081-SD1-Rcd.dwg
SAVED 15-Dec-2011 9:06 AM
AT FULL SIZE THIS BAR MEASURES 100mm. ALL SCALES REFERENCED TO FULL SIZE.

KERR WOOD LEIDAL
consulting engineers

Appendix B

Supplemental Statistical Tables

Table B-1. Erosion Pin Site Data: N, Mean Change in Pin Length and Standard Deviation.

2011 - 2012

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

2012 - 2013

Site	Control Sites (cm)			Treatment Sites (cm)		
	N	Mean	SD	N	Mean	SD
A1_US	15	-2.2	7.6	19	-5.5	11.9
A1_DS	18	1.1	1.0	21	-3.3	11.7
A2_US	12	-1.4	5.0	12	-2.3	7.5
A2_DS	15	-1.7	8.2	13	-3.7	10.1
B	20	-0.3	5.5	25	-1.1	5.5
C_US	20	5.2	4.7	18	3.8	5.9
C_DS	20	9.2	4.1	27	5.8	9.3

2011 - 2013

Site	Control Sites (cm)			Treatment Sites (cm)		
	N	Mean	SD	N	Mean	SD
A1_US	15	-3.1	8.5	11	1.1	10.8
A1_DS	18	1.1	1.1	9	0.0	8.0
A2_US	12	-3.7	12.3	12	-2.9	7.7
A2_DS	15	-4.9	7.2	13	-8.9	18.7
B	20	-0.3	5.4	25	-1.0	5.3
C_US	20	5.3	4.6	18	3.8	6.2
C_DS	20	9.2	4.2	19	6.3	9.4

Table B-2. Cross-Section Site Data: N, Mean ∆x midpoint and Standard Deviation.

2011 - 2012

Site	Control Sites (m)			Treatment Sites (m)		
	N	Mean	SD	N	Mean	SD
A1_US	9	0.05	0.30	0	-	-
A1_DS	9	0.10	0.26	0	-	-
A2_US	5	-0.07	0.44	4	0.09	0.44
A2_DS	6	-0.13	0.49	5	-0.44	0.35
B	7	0.21	0.27	8	0.04	0.18
C_US	5	-0.35	0.85	4	0.13	0.10
C_DS	4	-0.15	0.30	3	0.00	0.00

2012 - 2013

Site	Control Sites (m)			Treatment Sites (m)		
	N	Mean	SD	N	Mean	SD
A1_US	9	-0.04	0.22	9	-0.32	1.00
A1_DS	9	-0.11	0.18	12	-0.61	1.42
A2_US	6	-0.22	0.38	6	-0.28	0.12
A2_DS	6	-0.21	0.26	5	-0.45	0.35
B	9	-0.14	0.13	9	-0.10	0.19
C_US	9	-0.37	0.42	6	-0.34	0.29
C_DS	9	-0.35	0.71	9	-0.19	0.19

2011 - 2013

Site	Control Sites (m)			Treatment Sites (m)		
	N	Mean	SD	N	Mean	SD
A1_US	9	0.003	0.20	0	-	-
A1_DS	9	-0.01	0.24	0	-	-
A2_US	5	-0.37	0.38	4	-0.22	0.48
A2_DS	6	-0.34	0.48	3	-0.96	0.54
B	7	0.12	0.31	8	-0.07	0.26
C_US	5	-0.44	1.09	4	-0.22	0.20
C_DS	4	-0.13	0.18	3	0.00	0.00