Columbia River Project Water Use Plan

Kinbasket and Arrow Lakes Reservoir Recreation Management Plan

Mid Columbia River Long Term Erosion Monitoring Program

Implementation Year 5

Reference: CLBWORKS #36

Final Report

Study Period: 2009 to 2016

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Contents

Figures

Tables

Appendices

Executive Summary

Status of Objectives, Management Questions and Hypotheses After Year 5 (Final Year)

Objectives	Management Questions	Management Hypotheses
From CLBWORKS #36 ToR: "The primary objective of this program is to monitor shoreline erosion along the Columbia River in the region of influence of Revelstoke Dam, including operation of the fifth unit. This is to ensure that any incremental flows due to the five-unit operations do not impact the river banks in the area of influence. Specifically, the study will: • Identify shoreline areas susceptible to erosion (areas of concern) within the area, • Assess whether there are changes in the spatial extent of these areas of concern over the monitoring period, and • Assess whether any observed change in spatial extent is attributable to the operating regime of the fifth unit of Revelstoke Dam."	**From** CLBWORKS #36 ToR: "The key management question addressed by this Terms of Reference is: Will the addition and operation of a fifth unit at Revelstoke Dam increase, decrease or not affect erosion rates in the mid Columbia River from Revelstoke Dam downstream to Shelter Bay?"	**From** CLBWORKS #36 ToR: "Two management hypotheses will be considered: **$H1_0$**: Shoreline erosion does not differ significantly before and after start of operation of the fifth unit at Revelstoke Dam. **$H2_0$:** Shoreline erosion does not increase significantly through the duration of the Project."

Year 5 (2016, Final Year) Status

We do not have causal certainty between the implementation of a fifth unit at Revelstoke Dam and an impact on bank erosion. We conclude that (a) bank erosion is occurring, and (b) there is no increasing trend in erosion over the period of the study.

$H1_0$ cannot be addressed by this study as there were an insufficient number of years of baseline data collected prior to the start of operation of the fifth unit at Revelstoke Dam. This was identified at the beginning of the project. However post-Rev5 bank erosion rates are comparable or lower to pre-Rev5 bank erosion rates documented in another study (Table 4-3).

$H2_0$: Although erosion is occurring, there has been no consistent increase in erosion over the duration of the project (2010 to 2016) (Figure 3-3, Figure 3-6, Figure 3-7, Figure 3-8): **we therefore accept $H2_0$.** This is based on:

Erosion pin data:

- Of the 14 active sites:
  - 1 site showed statistically significant deposition,
  - 9 sites showed statistically significant erosion, and
  - 4 sites showed no statistically significant change.
- Erosion rates (2010 to 2016) ranged from about 1.5 cm/year to about 8.5 cm/year (Table 3-2).
- Deposition rate (2010 to 2016) was about 0.4 cm/year (Table 3-2).
- Average rate of change over <u>all sites</u> (2010 to 2016) was 3.1 cm/year (erosion).

River cross-section data:

- Of the 14 actives sites:
  - Upper elevation band: 7 sites out of 14 showed statistically significant erosion, and 1 showed deposition (Table 3-5).
  - Middle elevation band: 6 sites out of 14 showed statistically significant erosion, and none showed deposition (Table 3-6).
  - Lower elevation band: 4 sites out of 14 showed statistically significant erosion and 2 showed deposition (Table 3-7).
- Erosion rates (2010 to 2016) ranged from about 0.1 m/year to about 1.6 m/year (Table 3-5, Table 3-6, Table 3-7).
- Deposition rates (2010 to 2016) ranged from about 0.03 m/year to about 0.1 m/year.
- Average rate of change over <u>all sites</u> (2010 to 2016) was -0.21 m/year (erosion).

1. Introduction and Background

This report is a final summary of work conducted by Kerr Wood Leidal Associates Ltd. (KWL) on BC Hydro program CLBWORKS #36. 2016 is the final year of this project, which was initiated in 2009 (Table 1-1).

1.1 Water Use Plan

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. The fifth generating unit was put in service in December 2010.

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.

Each program is conducted separately. The final year for CLBWORKS #35 was 2015 (KWL 2016)[1].

The remainder of this report focuses on CLBWORKS #36.

1.2 Project Objectives, Management Question and Hypotheses

1.2.1 Project Objectives

As stated in the CLBWORKS #36 Terms of Reference (BC Hydro 2008):

> "*The primary objective of this program is to monitor shoreline erosion along the Columbia River in the region of influence of Revelstoke Dam, including operation of the fifth unit. This is to ensure that any incremental flows due to the five-unit operations do not impact the river banks in the area of influence.*
>
> *Specifically, the study will:*
>
> - *Identify shoreline areas susceptible to erosion (areas of concern) within the area,*
> - *Assess whether there are changes in the spatial extent of these areas of concern over the monitoring period, and*
> - *Assess whether any observed change in spatial extent is attributable to the operating regime of the fifth unit of Revelstoke Dam.*"

[1] The CLBWORKS-35 final report is accessible at https://www.bchydro.com/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/kinbasket-recreation.html

1.2.2 Management Question

As stated in the CLBWORKS #36 ToR (BC Hydro 2008) :

"*The key management question addressed by this Terms of Reference is:*

Will the addition and operation of a fifth unit at Revelstoke Dam increase, decrease or not affect erosion rates in the mid Columbia River from Revelstoke Dam downstream to Shelter Bay?"

1.2.3 Management Hypotheses

As stated in the CLBWORKS #36 ToR:

"*Two management hypotheses will be considered:*

- *$H1_0$: Shoreline erosion does not differ significantly before and after start of operation of the fifth unit at Revelstoke Dam.*
- *$H2_0$: Shoreline erosion does not increase significantly through the duration of the Project.*"

1.3 Project Schedule

The ToR project schedule called for a 5-year program (2009, 2010, 2012, 2014 and 2016). Year 1 was to include an information review, sites selection, design of study, and the first ground site erosion assessment if conditions permitted. Subsequent erosion assessments were to be scheduled once per two years in Years 2, 3, 4 and 5 of the project.

As referenced above, the first management hypothesis ($H1_0$) is specifically focused on quantification and comparison of shoreline erosion before and after the start of operation of the fifth unit at Revelstoke Dam. However, the project schedule did not support an evaluation of $H1_0$ for the following reasons:

- The ToR schedule did not include a period of baseline (pre- fifth unit) data collection equivalent or greater than the post-commissioning monitoring. Due to the timing of project award and water levels in early stages of the project, it was not possible to collect even one full year of baseline (pre- fifth unit) data.
- The lack of baseline data from before the fifth unit was activated makes it impossible to perform a statistical comparison between pre- and post-unit in service.

As a result, it was not possible to detect changes in erosion prior to and following the installation of the fifth generating unit ($H1_0$). However, the project schedule does permit monitoring of erosion rates over time ($H2_0$).

2016 is Year 5, the final year of the project. The schedule for CLBWORKS #36 is summarized in the following table.

Table 1-1: Project Schedule for CLBWORKS #36.

Year	CLBWORKS#36	MONTH (FIELD WORK)
2009	Y1 – Site Selection	August-September
2010	Y1 – Site Monitoring Set-Up (Erosion Pins & Cross-Sections) / Monitoring	April-May
2010	Entry in operation, REV5	December
2011	Y2 – Monitoring	May-June
2012	Y3 – Monitoring	April
2013		
2014	Y4 – Monitoring	April
2015		
2016	Y5 – Monitoring	May

1.4 Project Sites

The geographic area of influence of the dam includes the Mid Columbia River reach from immediately below the dam downstream to Shelter Bay (Figure 1-1). Fifteen[2] long-term erosion monitoring sites were established on the Columbia River banks between Revelstoke Dam and Shelter Bay (Figure 1-2). The sites were selected to represent the range of substrates observed in the study reach, as well as to represent the most common erosion and failure mechanisms that had been documented and observed in the reach. For a description of the physical characteristics of the monitoring sites, the reader is referred to KWL (2012).

1.4.1 Discontinuation of Measurements (Site MON14)

All sites were measured in Project Year 1 during baseline monitoring (2010). In 2011, the upland property owner at Site 14 expressed a preference for no erosion pins in the reservoir area adjacent to the upland property, and removed the majority of the erosion pins. Measurements were discontinued at Site 14 to avoid conflict with the property owner.

1.5 2016 Tasks

Major tasks undertaken in 2016 are summarized in Table 1-2.

Note that because both CLBWORKS #35 and #36 have now ended, additional work was conducted this year to remove the erosion pins from the monitoring sites established of both programs. Benchmarks were left in place (flush with the ground, or slightly below the surface), so that cross-sections could be re-surveyed at some future date, if desired.

[2] Note that data collection at one site (MON14) was discontinued during the course of the project (see Section 1.4.1).

Table 1-2: 2016 Work Program

Task	Description
Erosion Assessment (CLBWORKS #36 Y5)	• Safety Plan • Site Visit • Measure Bank Change Using Pins • Re-survey Monitoring Cross-Sections
Erosion Pin Removal	• Remove Erosion Pins at CLBWORKS #36 Sites. • Locate And Remove Erosion Pins at CLBWORKS #35 Sites.
2016 Data Entry and Analysis	• Enter Data Into Spreadsheet Databases • Data Analysis (CLBWORKS #36 Y5)
2016 Final Report	• Final Report for CLBWORKS #36

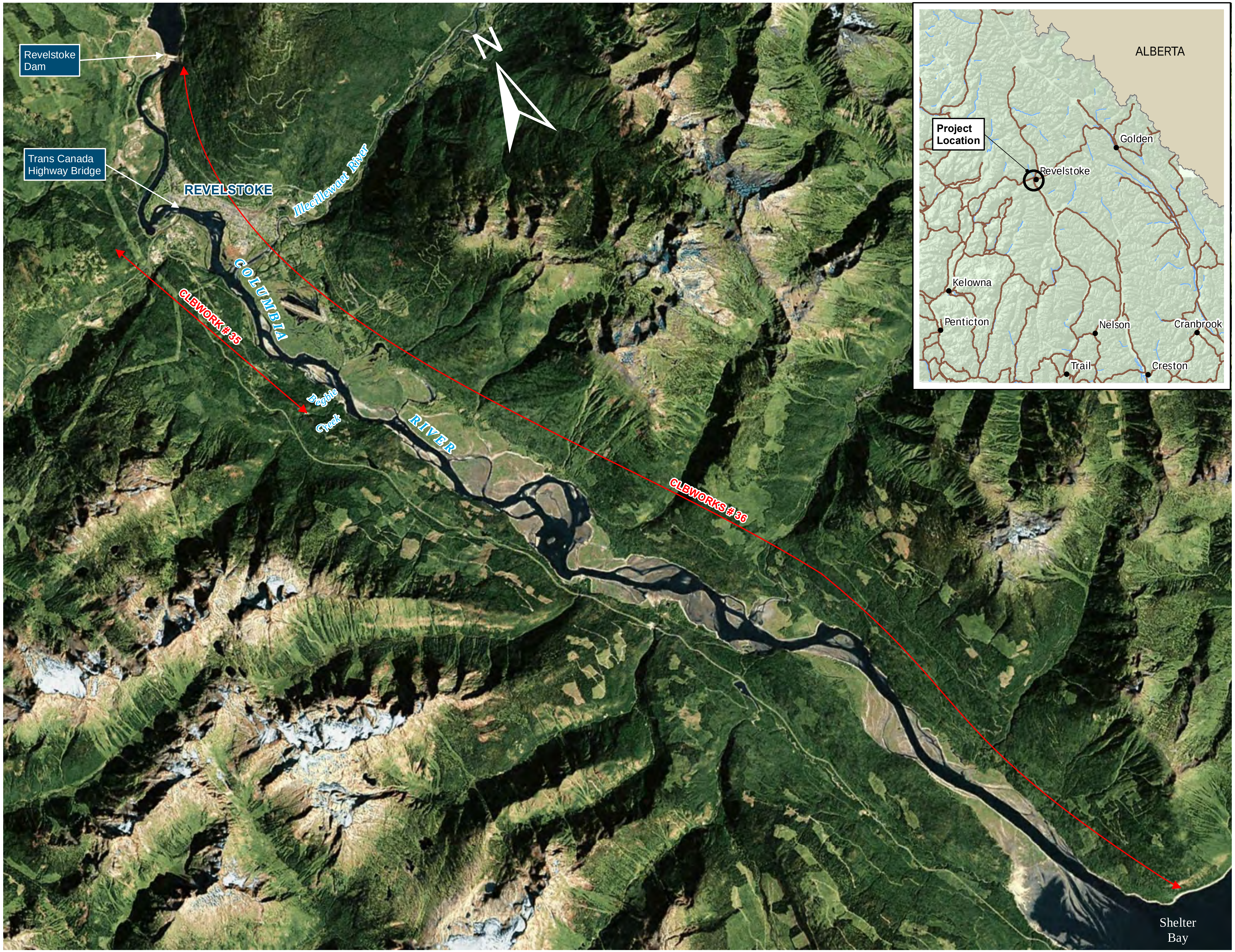
1.6 Project Team

Table 1-3: **Key Project Personnel For CLBWORKS-36**

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	Erosion Assessment
Jack Lau – KWL	GIS Specialist	GIS
Peter Tapp, Civil Technologist – KWL	Survey Coordinator	Survey Oversight and Coordination
Bruce VanCalsteren – KWL	Survey Technologist	Topographic Survey and Field Data Collection
Tony Minchenko – KWL	Technologist	Topographic Survey and Field Data Collection
Leska S. Fore, M.S., M.A. Leska, S. Fore, Statistical Design	Statistician	Statistical Design Statistical Analysis of Erosion Monitoring Data
David Matsubara, M.Eng., P.Eng. Run of the River Boat Charters	Boat Operator	Boat Operator (Formerly KWL Project Manager)
Peter Bernacki NuTrend Construction	Field Assistant	Boat Owner, Field Data Collection
John Creighton	Field Assistant	Field Data Collection

BC Hydro staff who have been part of the CLBWORKS #36 project team include:

- Jason Watson (former Contract Manager),
- Trish Joyce (current Contract Manager), and
- Guy Martel (Subject Matter Expert).



BC Hydro
CLBWORKS #36 Mid-Columbia River Long-term Erosion Monitoring Program

Reference: Orthophoto from Bing aerial image map.

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

Date November 2011

Location Plan

Figure 1-1

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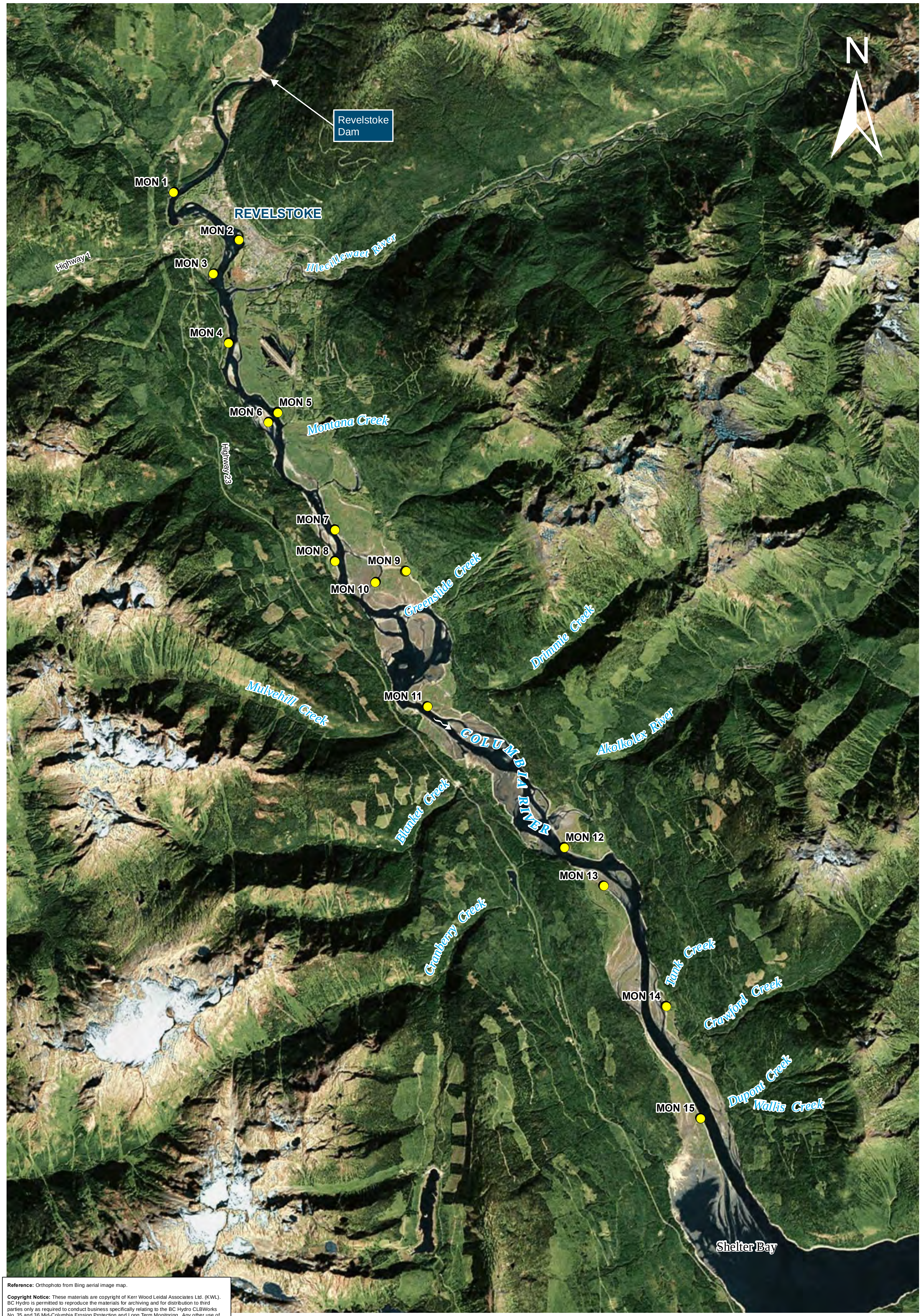

Reference: Orthophoto from Bing aerial image map.

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BC Hydro
CLBWORKS #36 Mid-Columbia River Long-term Erosion Monitoring

Project No.	Date
478-081	November 2011

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Bank Erosion Monitoring Sites (CLBWORKS #36)

Figure 1-2

2. 2016 Monitoring

2016 monitoring work was conducted between May 2 and May 5, 2016. Site access was by vehicle, where practical, and by boat for some sites.

Monitoring work was conducted at the same time as erosion pin removal: erosion pins were located, measured (cf. Section 2.1) and then removed from the bank for later disposal.

Water level and discharge conditions during the CLBWORKS #36 erosion monitoring work are summarized in Table 3-1.

Table 2-1: Water Level and Discharge Conditions During CLBWORKS #36 Fieldwork

Task	Dates	Daily Average Arrow Lake Water Level (m)	Daily Average Revelstoke Dam Flow Release (3) (m^3/s)
Year 1 Site Installation	Apr. 28 to May 1, 2010	432.6 – 432.8 (1)	534 – 586
Year 2 Erosion Measurements	May 31 to Jun. 2, 2011 Jun. 13 to Jun. 14, 2011	433.3 – 433.5 (2) 435.4 – 435.6 (2)	292 – 815 841 – 1087
Year 3 Erosion Measurements	Apr. 11 to Apr. 25, 2012	427.7 – 428.1 (1)	178 – 949
Year 4 Erosion Measurements	Apr. 23-24, 26-27, 2014	429.1 – 429.3 (1)	267 – 615
Year 5 Erosion Measurements	May 2-5, 2016	430.9 – 431.9 (1)	513 – 1098

Notes:
1. Water Survey of Canada: WSC 08NE104 (Arrow Reservoir at Nakusp).
2. BC Hydro (Arrow Reservoir at Fauquier).
3. Revelstoke Dam Flow Release data obtained from BC Hydro.

2.1 Field Methods and Measurements

Each site was evaluated for change (erosion or deposition) by two field methods:

- measuring the length of exposed pins placed in the bank (and comparing to previous measurements), and
- surveying cross-section transects perpendicular to the bankline (and comparing to previous surveys).

Field methods for both the erosion pins and the cross-sections are discussed in more detail, below.

2.1.1 Erosion Pins

At each site, during the 2010 installation 60 pins were placed into the bank so as to cover an area representative of the sediments between the waterline (at the time of installation) and the top of the bank. Pins were then measured. Each pin had a unique identifier so that it could be re-located and re-measured in subsequent years. Re-location was accomplished by maps, which showed the locations of the pins relative to each other at the site, and a metal detector (to locate pins that had been buried through deposition of sediment).

Once pins were located, the exposed (or buried) pin length was measured. This measurement was conducted in 2011, 2012, 2014 and 2016.

Erosion is measured as the length of exposed pin protruding from the bank. Deposition is measured by locating the buried pin (using a metal detector and maps) and measuring the depth of deposited sediment from the ground level to the top of the excavated pin (the hole is subsequently re-filled).

If erosion exposed a substantial length of pin at the time of field visit, the pin was measured, re-set into the bank and re-measured. Occasionally rapid erosion resulted in the pin 'toppling', in which case no measurement could be made and the pin was re-set (but noted to be toppled).

2.1.2 Cross-Sections

For each site, five cross-sections were also established and surveyed at each monitoring interval. The surveyed cross-sections documented distance and corresponding elevation (i.e., X,Y) from the top of the bank to the river's edge. The cross-sections were distributed over the same bank area as covered by the erosion pins.

Field work involved locating the benchmarks that defined the ends of the cross-section lines and then surveying each cross-section with a survey instrument. The orientation of the line was replicated year over year, so that cross-sections from different years could be compared (Figure 2-1).

2.2 Development of Project Datasets

2.2.1 Erosion Pins

Bank erosion exposes a greater length of a given pin compared to when it was last measured, whereas deposition covers the pin so that a shorter length is exposed (or completely buries it).

Steady erosion would result in a steadily-increasing pin length over time; however, since the pins are only about 0.6 m long, they need to be re-set into the bank once a certain proportion of the pin is exposed, or they may topple out of the bank. In the field, the pin length data is recorded relative to the bank position at that time: data reduction is required to evaluate the overall change in the bank over a number of years.

To support the statistical analysis, the measured pin length data from all years was converted into cumulative pin length over time. This process takes into account any re-setting of the pins back into the bank for pins that were experiencing erosion.

For the final year of CLBWORKS #36 we assumed a nominal erosion of 50 cm for toppled pins and incorporated the toppled pin results into the analysis. The erosion allowance for toppled pins is based on evaluating the exposed length data from all pins at all sites through all sampling events. Based on our observed data, the longest length of exposed pin for un-toppled pins was 50 cm (total pin length is 60 cm). Therefore, it was decided that toppling was more likely once the exposed length of pin is greater than 50 cm. Assuming a nominal erosion value of 50 cm for toppled pins appears to be reasonable in light of the observed pin length data.

The resulting erosion pin dataset was provided to the project statistician for analysis.

2.2.2 Cross-Sections

To make comparisons of the cross-sections through time, survey data were reduced and plotted on drawings. Measurements were made between cross-sections surveyed in different years, at three points on each cross section. The points for measurement 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), to define a “lower”, “middle” and “upper” portion of the bank.

Figure 2-1 presents a theoretical bank section to illustrate the cross-section measurements. In this example, 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 varied between cross-sections and sites.

To support the statistical analysis, the distance from a set point on the bank to the surveyed cross-section line from each year was measured. The distance was measured for each elevation band (lower, middle and upper) at the midpoint elevation of each band (Figure 2-1).

Steady erosion would result in decreasing distance over time, while steady deposition would result in increasing distance over time.

The resulting cross-section dataset was provided to the project statistician for analysis.

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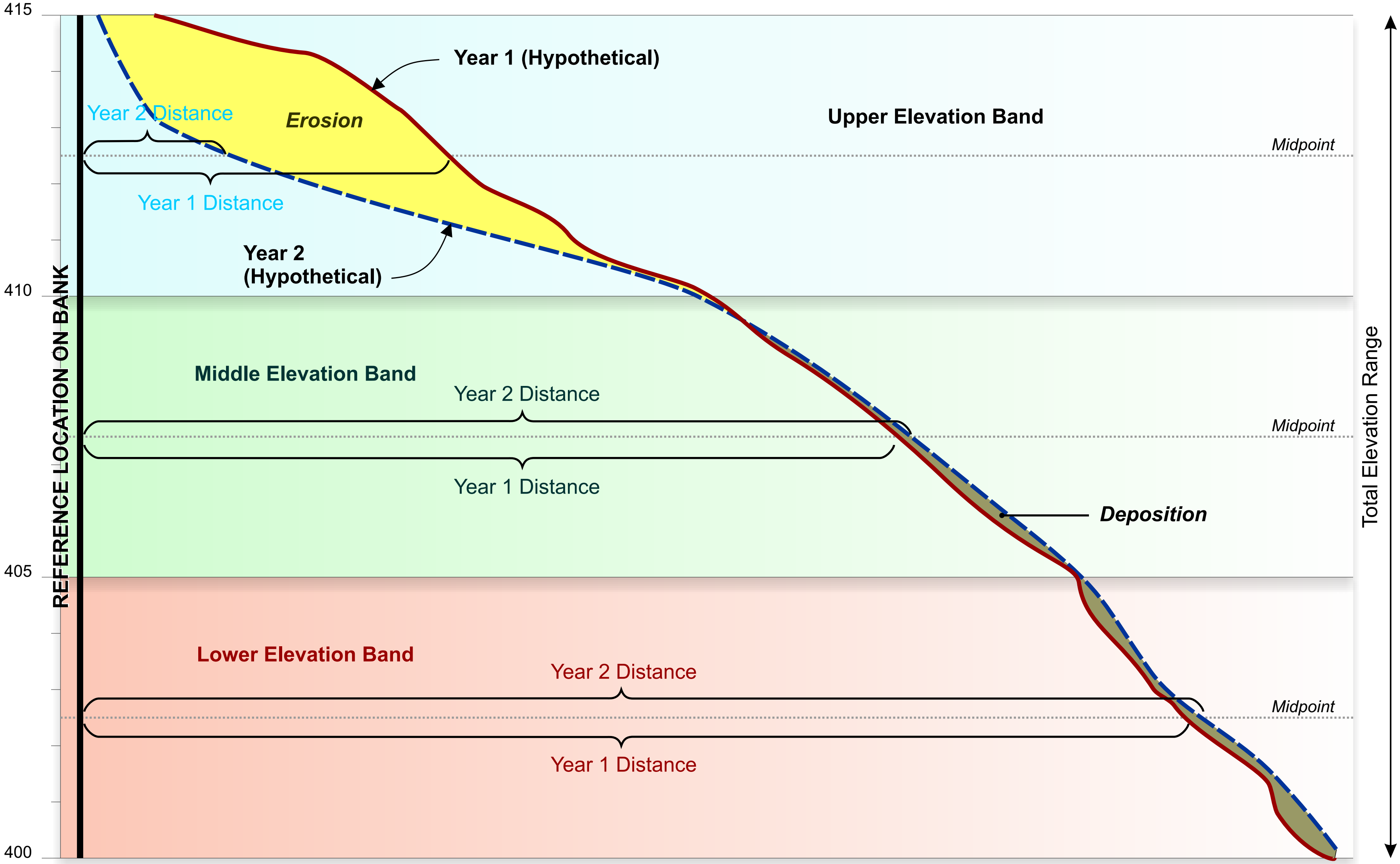

Demonstration of Cross-Section Comparison to Evaluate Erosion/Deposition

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Figure 2-1

3. Statistical Analysis

The statistical analysis tests whether erosion (or deposition) is occurring over time, using a regression analysis.

Based on the results presented herein, three conclusions are possible:

1. the bank change that is measured over time is not statistically significant,
2. statistically significant bank erosion has occurred over the 2010 to 2016 period, or
3. statistically significant bank deposition has occurred over the 2010 to 2016 period.

The Management Hypothesis asks a slightly different and more specific question, which is whether the rate of erosion is increasing over time. No mention is made of deposition in the Management Hypothesis although it is evident that sites that show statistically significant deposition are ones in which the null hypothesis would be rejected.

Results of the statistical analysis for the erosion pins and cross-sections are presented below.

3.1 Erosion Pins

Table 3-1 summarizes the number of pins measured at each site, in each measurement year. This includes pins that experienced toppling and were given an assumed erosion allowance (see Section 2.2). Records from pins that were not located in a given year but found in later years were also included in the analysis (with missing years).

In particular, re-locating the pins in 2011 was challenging due to the higher water levels during the measurement period: during the June portion of the fieldwork the Arrow Lake water level was about 3 m higher than it had been during the 2010 pin installation (Table 2-1). In subsequent years, additional effort has been expended to carefully time fieldwork for the relatively short window following snowmelt (so that the ground is not obscured) but prior to a large increase in reservoir levels. However, regardless of reservoir level the Revelstoke Dam releases are highly variable and these also influence the water level at the monitoring sites: this effect could not be controlled except by working at night, which was not practical.

Table 3-1: Number of Pins Measured Each Year

Site	2010	2011[1]	2012	2014	2016	2016 Pin Re-location Rate (Relative to 2010) (%)
MON1	60	57	60	60	60	100
MON2	60	40	41	39	36	60
MON3	61	9	35	17	28	46
MON4	60	33	56	52	55	92
MON5	60	4	46	43	52	87
MON6	60	5	46	43	45	75
MON7	60		25	25	19	32
MON8	60	22	48	47	60	100
MON9	60	58	57	57	54	90
MON10	60	53	59	59	58	97
MON11	59		14	15	44	75
MON12	60	45	58	59	60	100
MON13	60	56	59	57	58	97
MON14	60	7	N/A[2]	N/A[2]	N/A[2]	N/A[2]
MON15	60	28	51	48	59	98

Notes:
1. Many pins could not be relocated in 2011 due to the higher water levels during part of the fieldwork (see Table 2-1).
2. MON14 data collection discontinued at request of upland property owner.

3.1.1 Test for Erosion or Deposition

To evaluate change over time at each site, the change in pin length was evaluated for each pin by calculating a rate of change over years for pins that had two or more recorded measurements. The slope of the regression line for pin length by year was calculated and plotted for each pin at each site (Figure 3-1 and Figure 3-2). In these figures, the slope of the line indicates the change over time:

- An upward-sloping line (pin length *increasing* over time) indicates **erosion**.
- A downward-sloping line (pin length *decreasing* over time) indicates **deposition**.
- A line with little or no slope (pin length remains more or less constant over time) indicates little or no change.

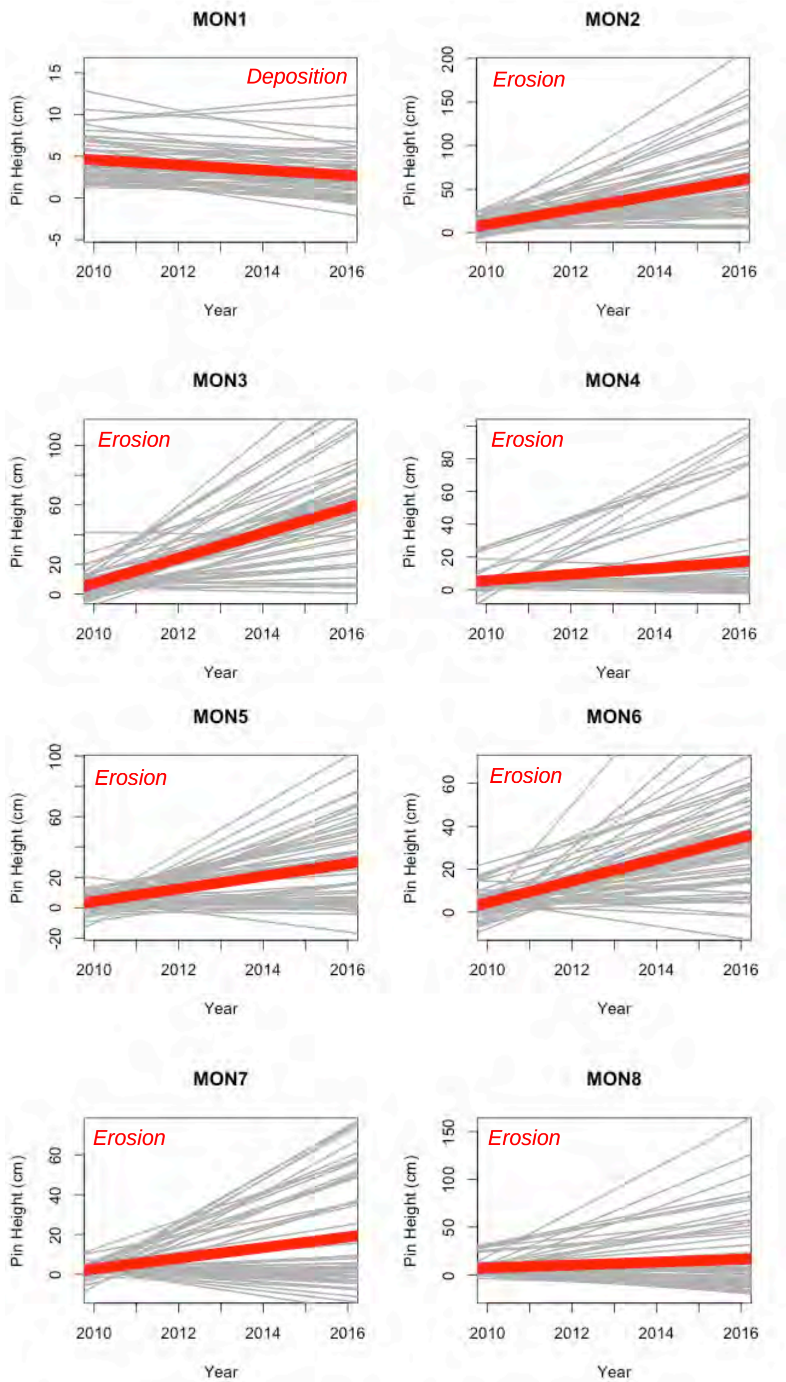

Figure 3-1: Erosion Pin Lengths (cm) Over Time Sites MON 1 through MON 8 for Individual Pins (Grey lines) And Site Average (Red line). Erosion Indicated By Increasing Pin Length, Deposition Indicated By Decreasing Pin Length.

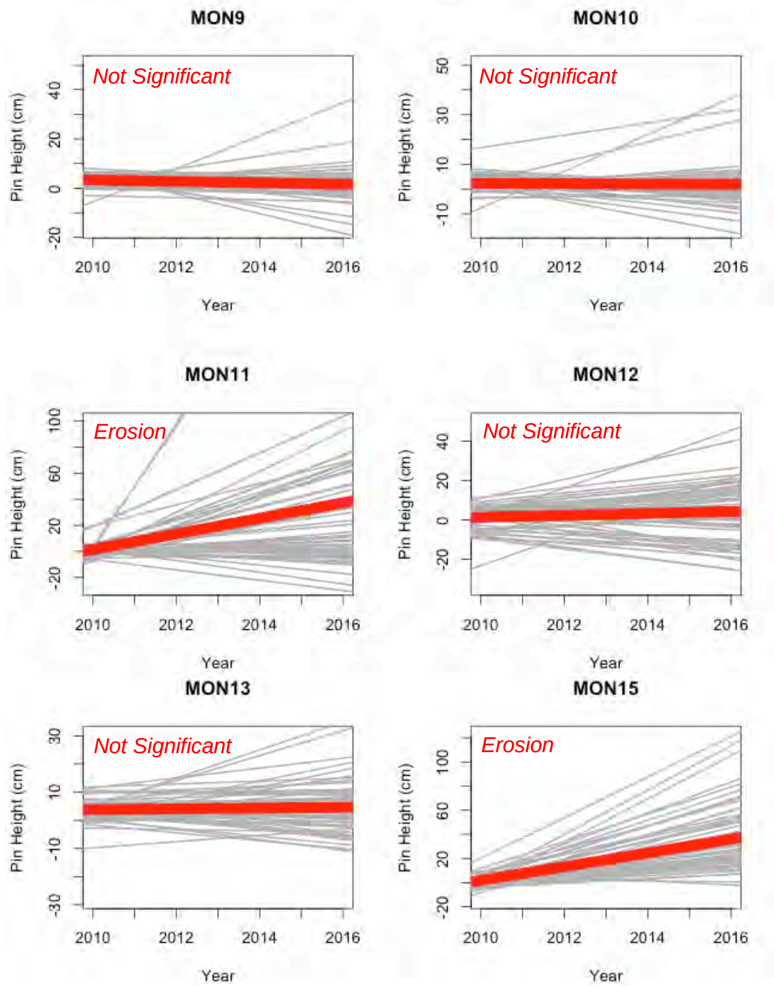

Figure 3-2: Erosion Pin Lengths (cm) Over Time Sites MON 9 through MON 15 for Individual Pins (Grey lines) And Site Average (Red line). Erosion Indicated By Increasing Pin Length, Deposition Indicated By Decreasing Pin Length.

The average slope was calculated for each site and evaluated to determine if it was significantly different from 0 (one-sample t-test, two-sided test).

Out of the 14 monitoring sites:

- 9 sites showed statistically significant erosion,
- 1 site showed statistically significant deposition, and
- 4 sites showed no statistically significant change.

Overall, the average change across all sites was 3.1 cm/year (positive values indicate erosion for erosion pin results).

Table 3-2 summarizes the results of the erosion pin regression analysis.

Table 3-2: Summary of Erosion Pin Regression Analysis By Site (2010 to 2016)

Site	Average Slope [1, 2] (cm/yr)	SD (cm/yr)	# Pins	P-value	Significance [3]	Type of Change	Approx. Distance From Dam [4] (km)
MON1	-0.31	0.34	60	0.00	**	Deposition	5.9
MON2	8.54	6.79	60	0.00	**	Erosion	9.3
MON3	8.44	5.53	54	0.00	**	Erosion	10.7
MON4	1.91	4.35	60	0.00	**	Erosion	13.1
MON5	4.16	4.47	55	0.00	**	Erosion	16.3
MON6	5.06	4.79	58	0.00	**	Erosion	16.5
MON7	2.67	4.64	55	0.00	**	Erosion	21.0
MON8	1.52	5.43	60	0.03	*	Erosion	22.1
MON9	-0.29	1.33	59	0.10	NS		22.5
MON10	-0.07	1.47	60	0.70	NS		22.9
MON11	5.99	9.41	57	0.00	**	Erosion	30.7
MON12	0.49	2.23	60	0.09	NS		37.8
MON13	0.13	1.40	60	0.47	NS		40.2
MON14	N/A [5]	N/A [5]	N/A [5]	N/A [5]	N/A [5]	N/A [5]	N/A [5]
MON15	5.67	4.24	60	0.00	**	Erosion	49.1

Notes:
1. Positive slopes indicate erosion, negative slopes indicate deposition.
2. Individual pin slopes calculated for pins with two or more recorded measurements over the period of record. Average slope is the average of all calculated pin slopes for a given site.
3. Significance of change indicated as follows: * $p < 0.05$, ** $p < 0.01$, NS = Not significant, one-sample t-test, two-sided test.
4. Distance measured along channel in GIS based on 2007 orthophotos.
5. MON14 data collection discontinued at request of upland property owner.

Appendix A includes site maps that display the location of the pins on the bank, as well as the regression slope for each pin.

3.1.1 Test for a Change in the Rate of Erosion (or Deposition)

The rate of erosion was tested by comparing the changes observed in pin height during each of the four time periods (one-way ANOVA to compare 4 time periods), as follows:

- 2010 to 2011,
- 2011 to 2012,
- 2012 to 2014, and
- 2014 to 2016.

As indicated, the first two time periods represent a single year and the second two time periods represent 2 years. To make the change in height comparable, changes from the last two times periods were divided by 2 so they represented cm change per year.

As indicated in Table 3-1, some sites saw relatively few pins located in 2011 due to high water levels at the time of the field measurements (see Table 2-1). This affects both the 2010 to 2011, and 2011 to 2012 time period calculations. For the purposes of the time period analysis, 4 sites had too few pin height measurements and were excluded from the analysis:

- MON 5,
- MON 6,
- MON 7, and
- MON 11.

Changes in pin length for each time period are presented in Table 3-4.

Table 3-3: Mean Change in Pin Length For Each Time Period

Site	2010 to 2011 [1] (cm)	2011 to 2012 [1] (cm)	2012 to 2014 [1, 2] (cm)	2014 to 2016 [1, 2] (cm)	Approx. Distance From Dam [3] (km)
MON1	-0.10	-0.56	-0.38	-0.14	5.9
MON2	18.09	10.95	5.10	11.51	9.3
MON3	25.31	8.50	10.92	2.77	10.7
MON4	3.71	0.35	1.97	1.66	13.1
MON5	N/A[3]	N/A[3]	N/A[3]	N/A[3]	16.3
MON6	N/A[3]	N/A[3]	N/A[3]	N/A[3]	16.5
MON7	N/A[3]	N/A[3]	N/A[3]	N/A[3]	21.0
MON8	20.28	4.98	-3.06	4.39	22.1
MON9	-0.84	-0.51	-0.52	0.45	22.5
MON10	-0.21	0.13	-0.69	0.67	22.9
MON11	N/A[4]	N/A[4]	N/A[4]	N/A[4]	30.7
MON12	-1.54	0.60	-0.23	3.25	37.8
MON13	-0.81	0.25	-0.21	0.88	40.2
MON14	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A [5]
MON15	8.26	3.33	6.88	7.40	49.1

Notes:
1. Positive values indicate erosion, negative values indicate deposition.
2. The values in the 2012-2014 and 2014-2016 time periods were divided by two in order to show the change in height per year.
3. Distance measured along channel in GIS based on 2007 orthophotos.
4. Insufficient pin measurements to be included in the time period analysis.
5. MON14 data collection discontinued at request of upland property owner.

To test for an increase in the rate of erosion (or deposition), the amount of change in pin height for all remaining sites during the 4 time periods was tested for differences in change between the time periods. No consistent increase in erosion was detected (one-way ANOVA, $p > 0.05$).

Figure 3-3 displays the erosion pin length change for each time period. The figure highlights three main findings from the pin data:

- Erosion is occurring in all time periods.
- In the year following entry in service of REV5 the erosion was quite variable.
- Since then, the erosion has remained fairly consistent.

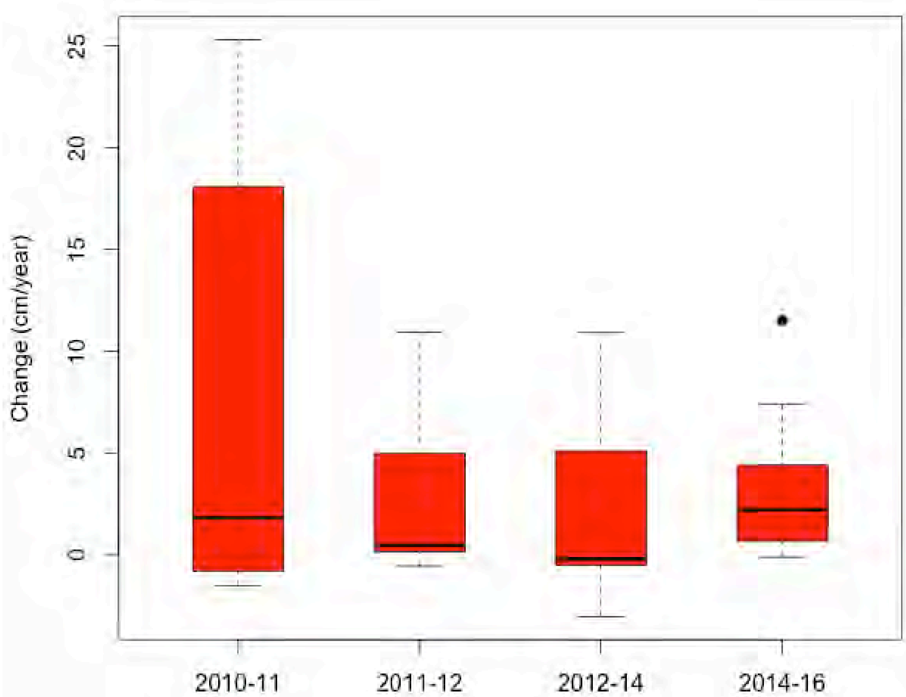

Figure 3-3: Pin Length Change (cm/year) For Each Time Period. Positive values indicate erosion, negative values indicate deposition. Shown in box plots are the median (solid line), 25th and 75th percentiles (edges of box), range of values (whiskers) and outlier (dot).

3.2 Cross-Section Data

At each of the 14 active sites, measurements were made from the 5 cross-sections at each of the three elevation bands (upper, middle and lower).

Measurements were made from cross-sections surveyed in 2010, 2011, 2012, 2014 and 2016 (Table 3-4). In 2011, high water prevented measurements at several sites. These sites were included in the analysis with these data points treated as missing.

Table 3-4: Number of Cross-Section Measurements In Each Elevation Band By Year

Site	Upper [1]					Middle [1]					Lower [1]				
	'10	'11	'12	'14	'16	'10	'11	'12	'14	'16	'10	'11	'12	'14	'16
MON1	5	5	5	5		5	5	5	5	5	5	5	5	5	4
MON2	5	5	5	5	5	5	5	5	5	5	5	3	5	5	
MON3	5	5	5	5	5	5	5	5	5	5	5	3	5	5	5
MON4	5	5	5	5	5	5	5	5	5	5	5		5	5	
MON5	5	5	5	5	5	5	5	5	5	5	5		5	5	5
MON6	5	5	5	5	5	5	5	5	5	5	5	2	5	5	5
MON7	5	5	5	5	5	5		5	5	5	5		5	5	5
MON8	5	5	5	5	5	5	5	5	5	5	5		5	5	5
MON9	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5
MON10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MON11	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MON12	5	5	5	5	5	5	5	5	5	5	5	1	5	5	5
MON13	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MON14	N/A[2]					N/A[2]					N/A[2]				
MON15	5	5	5	5	5	5	5	5	5	5	5		5	5	5

Notes:
1. A blank indicates no data. Missing cross-section measurements in the middle and lower elevation bands are due to high water levels at the time of survey, which limited the extent of the bank that could be surveyed. In the upper elevation band, 2016 cross-section measurements were not extended up the vegetated bank at MON1 in the interests of time, since the bank is heavily treed (making survey challenging) and has shown no change over time in the preceding years.
2. MON14 data collection discontinued at request of upland property owner.

3.2.1 Test for Erosion or Deposition

For each site, change over time was measured as the change in the distance measured on each cross-section for each of the three elevation bands. A regression line was calculated for the resulting dataset (five cross-sections per site, and three elevation bands: 15 slope values).

The resulting regression lines are plotted for each site in Figure 3-4 and Figure 3-5. Note that in these figures a consistently decreasing distance (negative slope) would imply consistent erosion over time, while a consistently increasing distance (positive slope) would imply consistent deposition over time (i.e. *opposite* to how the erosion pin data are interpreted).

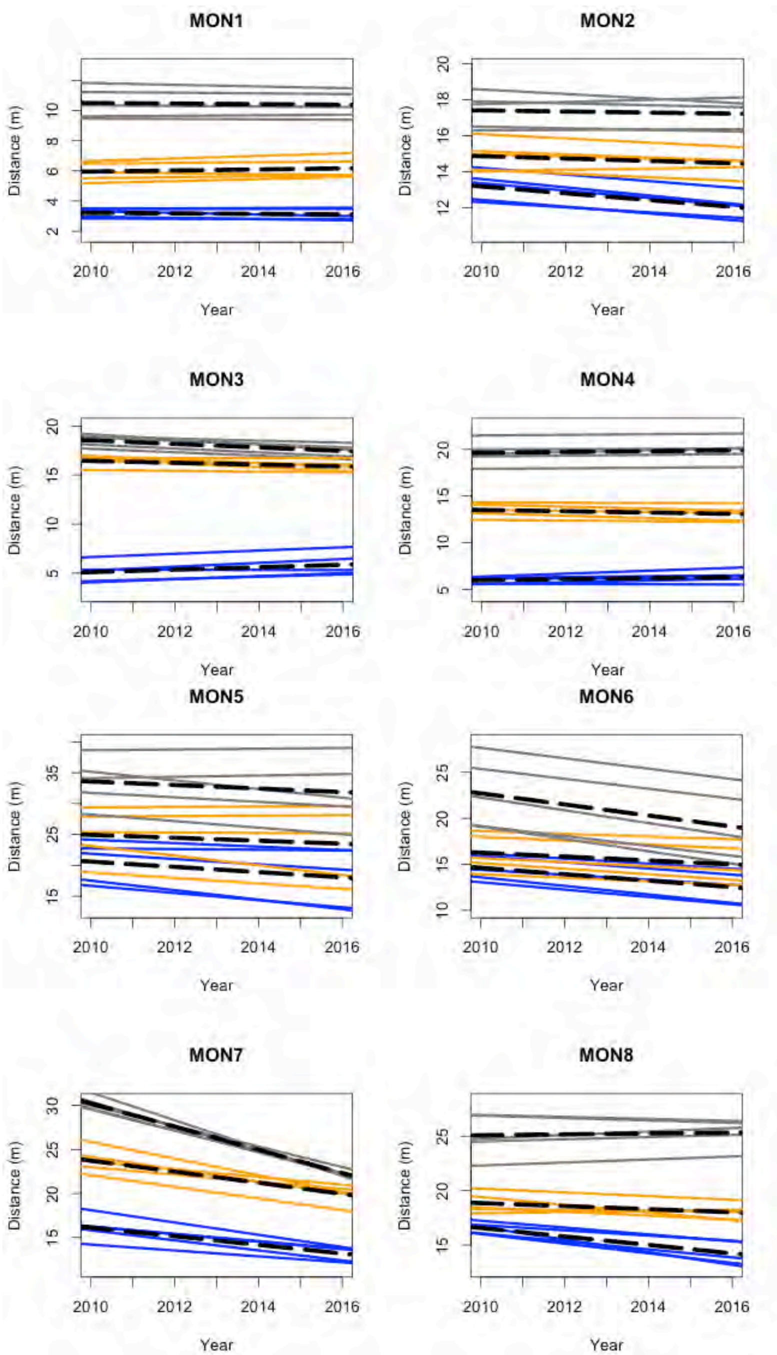

Figure 3-4: Distance To Cross-section (XS) Line (m) For Individual XS in Elevation Band (Upper: Blue, Middle: Orange and Lower: Grey), and Average (Black Dash), Sites MON 1 Through MON 8. Erosion Indicated By Negative Slope, Deposition Indicated By Positive Slope.

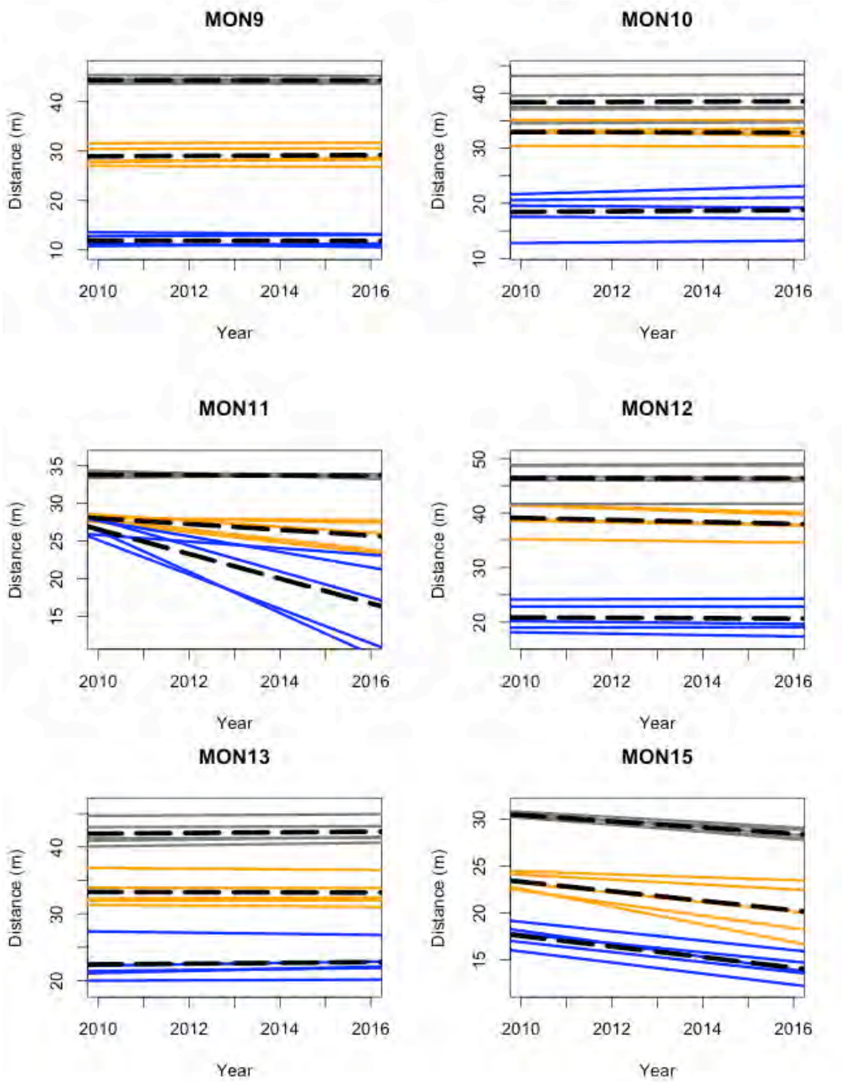

Figure 3-5: Distance To Cross-section (XS) Line For Individual XS In Elevation Band (Upper: Blue, Middle: Orange, Lower: Grey), And Average (Black Dash), Sites MON 9 Through MON 15. Erosion Indicated By Negative Slope, Deposition Indicated By Positive Slope.

Within each site and elevation band, slopes were tested to determine if they were significantly different from 0 (i.e. no change over time; one-sample t-test, two-sided test). Results for each site are summarized by elevation band and presented in Table 3-4 (Upper), Table 3-5 (Middle) and Table 3-6 (Lower).

In general, the following trends are noted:

- Changes in the upper elevation band, if statistically significant, are erosion: 7 sites out of 14 showed statistically significant erosion (Table 3-5).
- Similarly, changes in the middle elevation band, if statistically significant, are erosion: 6 sites out of 14 showed statistically significant erosion (Table 3-6).

Statistically significant lower elevation band changes are dominantly erosion also: 4 sites out of 14 showed statistically significant erosion, while only 2 showed deposition (Table 3-7).

The overall change for all sites and all elevation bands was -0.21 m/year (negative values indicate erosion for cross-section results).

Appendix B includes drawings that display the surveyed cross-sections in each year.

Table 3-5: Summary of Cross-Section Regression Analysis By Site For Upper Elevation Band

Site	Avg. Slope [1, 2] (m/yr)	SD (m/yr)	# of XS	P-value	Significance[3]	Type of Change	Approx. Distance From Dam [4] (km)
MON1	-0.02	0.03	5	0.23			5.9
MON2	-0.19	0.03	5	0.00	**	Erosion	9.3
MON3	0.12	0.08	5	0.03	*	Deposition	10.7
MON4	0.05	0.07	5	0.17			13.1
MON5	-0.42	0.28	5	0.03	*	Erosion	16.3
MON6	-0.35	0.08	5	0.00	**	Erosion	16.5
MON7	-0.49	0.14	5	0.00	**	Erosion	21.0
MON8	-0.39	0.13	5	0.00	**	Erosion	22.1
MON9	-0.01	0.08	5	0.85			22.5
MON10	0.05	0.12	5	0.38			22.9
MON11	-1.64	0.92	5	0.02	*	Erosion	30.7
MON12	-0.03	0.07	5	0.33			37.8
MON13	0.05	0.09	5	0.25			40.2
MON14	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]
MON15	-0.56	0.08	5	0.00	**	Erosion	49.1

Notes:
1. Negative slopes indicate erosion, positive slopes indicate deposition.
2. Average slope is the average of all calculated cross-section slopes for a given elevation band and site.
3. Significance of change indicated as follows: * $p < 0.05$, ** $p < 0.01$, blank = Not significant, one-sample t-test, two-sided test.
4. Distance measured along channel in GIS based on 2007 orthophotos.
5. MON14 data collection discontinued at request of upland property owner.

Table 3-6: Summary of Cross-Section Regression Analysis By Site For Middle Elevation Band

Site	Avg. Slope[1,2] (m/yr)	SD (m/yr)	# of XS	P-value	Significance[3]	Type of Change	Approx. Distance From Dam [4] (km)
MON1	0.03	0.05	5	0.16			5.9
MON2	-0.07	0.06	5	0.07			9.3
MON3	-0.09	0.08	5	0.07			10.7
MON4	-0.07	0.05	5	0.03	*	Erosion	13.1
MON5	-0.24	0.36	5	0.22			16.3
MON6	-0.21	0.06	5	0.00	**	Erosion	16.5
MON7	-0.63	0.22	5	0.00	**	Erosion	21.0
MON8	-0.14	0.15	5	0.11			22.1
MON9	0.04	0.07	5	0.24			22.5
MON10	-0.02	0.08	5	0.65			22.9
MON11	-0.38	0.30	5	0.05	*	Erosion	30.7
MON12	-0.18	0.07	5	0.00	**	Erosion	37.8
MON13	-0.01	0.03	5	0.43			40.2
MON14	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]
MON15	-0.51	0.32	5	0.02	*	Erosion	49.1

Notes:
1. Negative slopes indicate erosion, positive slopes indicate deposition.
2. Average slope is the average of all calculated cross-section slopes for a given elevation band and site.
3. Significance of change indicated as follows: * $p < 0.05$, ** $p < 0.01$, blank = Not significant, one-sample t-test, two-sided test.
4. Distance measured along channel in GIS based on 2007 orthophotos.
5. MON14 data collection discontinued at request of upland property owner.

Table 3-7: Summary of Cross-Section Regression Analysis By Site For Lower Elevation Band

Site	Avg. Slope[1,2] (m/yr)	SD (m/yr)	# of XS	P-value	Significance[3]	Type of Change	Approx. Distance From Dam [4] (km)
MON1	-0.02	0.03	5	0.19			5.9
MON2	-0.03	0.07	5	0.39			9.3
MON3	-0.18	0.06	5	0.00	**	Erosion	10.7
MON4	0.04	0.04	5	0.05			13.1
MON5	-0.29	0.36	5	0.15			16.3
MON6	-0.60	0.07	5	0.00	**	Erosion	16.5
MON7	-1.32	0.17	5	0.00	**	Erosion	21.0
MON8	0.04	0.13	5	0.53			22.1
MON9	-0.01	0.01	5	0.14			22.5
MON10	0.03	0.02	5	0.03	*	Deposition	22.9
MON11	-0.02	0.10	5	0.61			30.7
MON12	0.00	0.03	5	0.89			37.8
MON13	0.05	0.04	5	0.03	*	Deposition	40.2
MON14	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]	N/A[5]
MON15	-0.33	0.07	5	0.00	**	Erosion	49.1

Notes:
1. Negative slopes indicate erosion, positive slopes indicate deposition.
2. Average slope is the average of all calculated cross-section slopes for a given elevation band and site.
3. Significance of change indicated as follows: * $p < 0.05$, ** $p < 0.01$, blank = Not significant, one-sample t-test, two-sided test.
4. Distance measured along channel in GIS based on 2007 orthophotos.
5. MON14 data collection discontinued at request of upland property owner.

3.2.1 Test for Change in Rate of Erosion or Deposition

The rate of erosion was tested by comparing the changes observed in distance within cross-sections during each of the four time periods (one-way ANOVA to compare 4 time periods).

Table 3-8, Table 3-9 and Table 3-10 present the changes in distance to cross-sections for each period, in the upper, middle and lower elevation bands, respectively.

Table 3-8: Change in Distance to Cross-Section For Each Time Period, Upper Elevation Band

Site	2010 to 2011 [1] (m)	2011 to 2012 [1] (m)	2012 to 2014 [1, 2] (m)	2014 to 2016 [1, 2] (m)
MON1	-0.1	0.1	0.0	N/A[3]
MON2	-0.3	-0.4	-0.1	-0.1
MON3	0.3	-0.2	0.1	0.2
MON4	0.0	0.2	0.0	0.0
MON5	-0.4	-0.8	-0.4	-0.2
MON6	-0.9	-0.8	-0.2	0.0
MON7	-1.7	0.3	-0.6	-0.3
MON8	-1.3	-0.3	-0.4	-0.1
MON9	0.3	-0.1	0.0	-0.1
MON10	1.1	-1.0	0.1	0.3
MON11	-1.9	-3.0	-1.8	-0.5
MON12	0.6	-0.4	-0.1	0.0
MON13	0.0	0.1	0.1	-0.1
MON14	N/A[4]	N/A[4]	N/A[4]	N/A[4]
MON15	-3.0	0.3	-0.3	-0.6

Notes:
1. Negative values indicate erosion, positive values indicate deposition.
2. The values in the 2012-2014 and 2014-2016 time periods were divided by two in order to show the change in distance to cross-section per year.
3. Data not available: see Table 3-4 for cross-sections measured in each year.
4. MON14 data collection discontinued at request of upland property owner.

Table 3-9: Change in Distance to Cross-Section For Each Time Period, Middle Elevation Band

Site	2010 to 2011 [1] (m)	2011 to 2012 [1] (m)	2012 to 2014 [1, 2] (m)	2014 to 2016 [1, 2] (m)
MON1	-0.2	0.4	-0.1	N/A[3]
MON2	-0.2	0.0	-0.1	0.0
MON3	-0.7	0.1	0.0	-0.1
MON4	-0.3	-0.1	0.0	-0.1
MON5	-1.4	-0.1	-0.5	0.5
MON6	-0.2	-0.2	-0.3	-0.2
MON7	N/A[3]	N/A[3]	-0.6	-1.2
MON8	-0.3	-0.8	0.4	-0.4
MON9	1.0	-0.2	0.0	-0.1
MON10	-0.3	0.2	-0.1	0.1
MON11	-3.1	-0.3	0.2	-0.3
MON12	-0.8	0.2	0.0	-0.4
MON13	0.4	-0.1	0.0	-0.1
MON14	N/A[4]	N/A[4]	N/A[4]	N/A[4]
MON15	-0.3	-0.3	-0.9	-0.2

Notes:
1. Negative values indicate erosion, positive values indicate deposition.
2. The values in the 2012-2014 and 2014-2016 time periods were divided by two in order to show the change in distance to cross-section per year.
3. Data not available: see Table 3-4 for cross-sections measured in each year.
4. MON14 data collection discontinued at request of upland property owner.

Table 3-10: Change in Distance to Cross-Section For Each Time Period, Lower Elevation Band

Site	2010 to 2011 [1] (m)	2011 to 2012 [1] (m)	2012 to 2014 [1, 2] (m)	2014 to 2016 [1, 2] (m)
MON1	0.1	-0.2	0.0	0.0
MON2	-0.6	0.2	0.1	N/A[3]
MON3	-0.6	0.0	-0.3	-0.1
MON4	N/A[3]	N/A[3]	0.1	N/A[3]
MON5	N/A[3]	N/A[3]	-0.6	-0.4
MON6	-0.6	-0.5	-0.4	-0.9
MON7	N/A[3]	N/A[3]	-0.4	-3.8
MON8	N/A[3]	N/A[3]	-0.1	-0.2
MON9	0.6	-0.4	0.0	0.0
MON10	0.0	0.0	0.0	0.1
MON11	1.5	-0.4	-0.3	0.0
MON12	0.4	0.0	0.1	-0.2

Site	2010 to 2011 [1] (m)	2011 to 2012 [1] (m)	2012 to 2014 [1, 2] (m)	2014 to 2016 [1, 2] (m)
MON13	-0.3	0.5	0.1	-0.2
MON14	N/A[4]	N/A[4]	N/A[4]	N/A[4]
MON15			0.0	-1.2

Notes:
1. Negative values indicate erosion, positive values indicate deposition.
2. The values in the 2012-2014 and 2014-2016 time periods were divided by two in order to show the change in distance to cross-section per year.
3. Data not available: see Table 3-4 for cross-sections measured in each year.
4. MON14 data collection discontinued at request of upland property owner.

To test for an increase in the rate of erosion, the amount of change in distance for cross-sections was averaged for each site and level. Three statistical test were performed: one for each elevation band.

No consistent differences were observed for the change in distance to cross-section: the rate of erosion did not increase or decrease during the 4 time periods observed (one-way ANOVA, $p > 0.05$).

The lack of a consistent trend over time is also evident in Figure 3-6, Figure 3-7, and Figure 3-8, which present the changes over time graphically. As indicated in these figures, the average erosion rate is fairly constant between the different time periods, and erosion occurs in all elevation bands (although it appears to be somewhat less in the lower elevation bands).

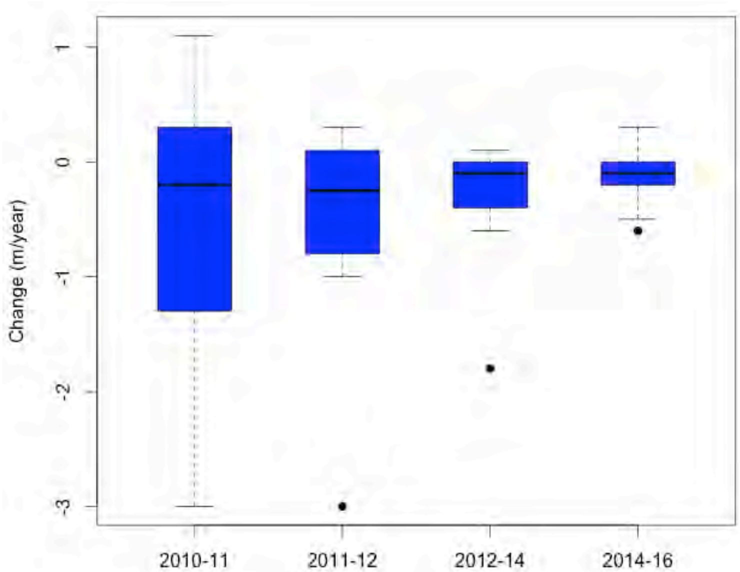

Figure 3-6: Change in Distance to Cross-section for Upper Elevation Band For Each Time Period. Negative values indicate erosion, positive values indicate deposition. Shown in box plots are the median (solid line), 25th and 75th percentiles (edges of box), range of values (whiskers) and outlier (dot).

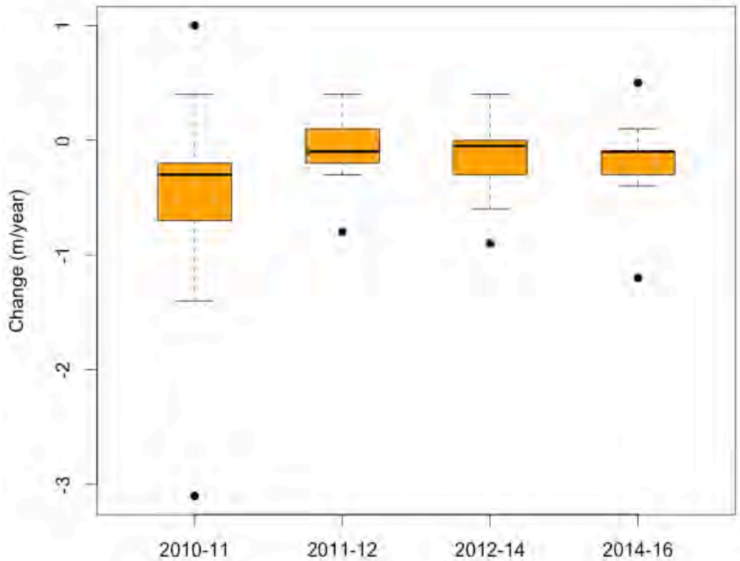

Figure 3-7: Change in Distance to Cross-section for Middle Elevation Band For Each Time Period. Negative values indicate erosion, positive values indicate deposition. Shown in box plots are the median (solid line), 25th and 75th percentiles (edges of box), range of values (whiskers) and outlier (dot).

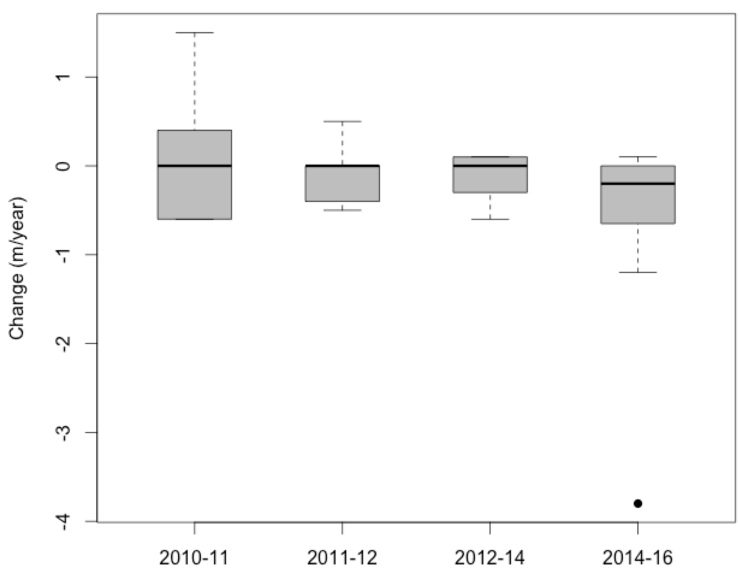

Figure 3-8: Change in Distance to Cross-section for Lower Elevation Band For Each Time Period. Negative values indicate erosion, positive values indicate deposition. Shown in box plots are the median (solid line), 25th and 75th percentiles (edges of box), range of values (whiskers) and outlier (dot).

4. Discussion of Results

4.1 Comparison of Observed Trends Between Methods

4.1.1 Direction of Trends

Table 3-7 (below) presents the statistically significant trends for each site based on the results for the erosion pins, and the cross-sections at each elevation band. Coloured shading has been used to indicate all sites where there was no disagreement in trend.

The following summary points may be made regarding trend direction:

- Statistically significant trends were detected in 13 of14 sites by one or more measures: in 9 sites the trend was significant in more than one measurement method.
- Of those 9 sites with a significant trend, almost all showed consistency in the direction of the trend (i.e., either erosion or deposition).
- Only at one site, MON 3, do the results indicate that statistically significant erosion and deposition are both occurring.
- Sites at which deposition is occurring are distributed through the reach.

Table 4-1: Summary of Statistically Significant Trends by Site and Measurement Method

Site	Erosion Pins	XS Upper	XS Middle	XS Lower
MON1	Deposition			
MON2	Erosion	Erosion		
MON3	Erosion	Deposition		Erosion
MON4	Erosion		Erosion	
MON5	Erosion	Erosion		
MON6	Erosion	Erosion	Erosion	Erosion
MON7	Erosion	Erosion	Erosion	Erosion
MON8	Erosion	Erosion		
MON9				
MON10				Deposition
MON11	Erosion	Erosion	Erosion	
MON12			Erosion	
MON13				Deposition
MON15	Erosion	Erosion	Erosion	Erosion

Notes:
1. Shading indicates that there was no disagreement in trend (either agreement, or only one significant trend). Deposition = blue, Erosion = brown.

4.1.2 Magnitude of Trend

In general, regardless of measurement method, the dominant trend in the dataset is erosion (Table 4-1).

The average change measured by erosion pins was 3.1 cm/year, or 0.031 m/year, (erosion) when calculated across all active sites. The change measured by cross-sections was -0.21 m/year (erosion) when calculated as an average across all active sites and elevation bands[3]. The average rates differ by an order of magnitude, with the cross-sections yielding the higher rate of erosion.

These differences can be expected given the orientation of the measurements:

- the erosion pins are measuring erosion and deposition (quasi-) perpendicular to the bank surface,
- the cross-sections are measuring erosion and deposition along a horizontal line intersecting the bank profile.

As the bank angle approaches 90° (a vertical cut bank), the difference in the resulting measurement (by pin or by cross-section) approaches zero. However, for shallowly-sloping banks the difference would be magnified and the dimension measured by the cross-sections would be larger than what is being measured by the erosion pins. Both measures are 'correct', but with a different frame of reference. Therefore, it is important to note the different orientation of the measurement when considering the overall rates of change.

Another factor is the degree to which rapid erosion may be contributing to bias in the erosion pin results: erosion that is sufficiently rapid can cause pin toppling between site visits. Toppled pins have been included in the analysis by making an assumed allowance of 50 cm to represent the erosion that may have occurred (but could not be measured). This allowance represents an estimate of the erosion that would have to occur for the pin to fall from the bank due to gravity.

However, the amount of erosion that actually occurred is unknown: the erosion that occurred prior to toppling, as well as the erosion (or deposition) that may have occurred while the pin was toppled. As well, it is possible for toppling to occur as a result of human or animal intervention, although this is only likely to occur at certain sites (i.e., where vehicle access is possible and where there is evidence of human or vehicle impact at the site).

For sites at which rapid (natural) erosion is likely to have resulted in pin toppling, rates of erosion based on pins will have a bias which will yield lower rates of erosion than the "true" rate, while the cross-section results should provide an unbiased result. Therefore, the actual erosion rate is likely to be closer to that indicated by the cross-section data, rather than the erosion pin data.

4.2 Historical Bank Erosion Rates

Previous work by NHC (2006) has documented the maximum local rate of bank erosion in the study reach for 5 time periods between 1949 and 2000, from historical air photographs. Photo coverage varied by time period but generally covered sections of the river from the Golf Course (Revelstoke) to near Greenslide Creek (about 24 km downstream). The range of measured maximum local bank erosion is presented in Table 4-2 for the different time periods.

[3]Note that both measures indicate erosion although one measure is negative and the other is positive.

Table 4-2: Maximum Local Rates of Bank Erosion From Air Photographs

Time Period	Bank Erosion (m/year)	Notes
1949 to 1961	1.5 – 1.9	Pre-regulation. Photo coverage ends at airstrip.
1961 to 1968	2.1 – 2.7	Arrow Lake impoundment starts in 1967. Photo coverage ends at air strip.
1968 to 1977	2.5 – 5.6	Mica Dam flow regulation starts in 1973. Photo coverage starts at Illecillewaet River.
1977 to 1985	0	Revelstoke Dam flow regulation starts in 1973. Photo coverage starts at Illecillewaet River.
1985 to 2000	0.5 – 6.0	

Notes:
1. Bank erosion rates from NHC (2006).
2. Rates of erosion from actively eroding areas only: average rates for the entire reach would be lower because there are many lengths of bank that do not experience any erosion.

Of note, the 1985 to 2000 range in bank erosion rates is large, and encompasses the rates documented for previous time periods under different regulation scenarios (including pre-regulation). It should be noted that the rates are indicative of localized rates of erosion at specific sites rather than indicating the general state of bank erosion along the entire reach.

The 1985 to 2000 period documents the rates of erosion experienced prior to the fifth generating unit at Revelstoke Dam, but following the major period of adjustment that was experienced following the impoundment of Arrow Lake. A comparison of pre-fifth generating unit bank erosion rates and rates from the current study is presented in Table 4-3. In an effort to improve the comparability between the NHC (2006) maximum local rates of bank erosion and this study, rates are presented from consistently eroding CLBWORKS #36 sites.

Table 4-3: Comparison of Bank Erosion Rates Prior To and Following Operation of Rev5

Air Photo Reach Location (CLBWORKS #36 Site)	1985 to 2000 [1, 2] (pre-Rev5) (m/year)	2010 to 2016 [3] (post-Rev5) (m/year)
Golf Course to Airstrip (MON5, MON2)	0.5 to 0.8	0.2 to 0.5
Airstrip to Begbie Creek (MON6)	1.2	0.5
Loopcut to Near Greenslide Creek (no CLB36 sites in this reach)	6.0	3.1 [4]

Notes:
1. Bank erosion rates from NHC (2006).
2. Rates of erosion from actively eroding areas only: average rates for the entire reach would be lower because there are many lengths of bank that do not experience any erosion.
3. Average of annual rates presented in Table 3-8.
4. No CLBWORKS #36 site in this reach. Value presented is the maximum annual rate of erosion documented at any site and any time period.

Based on the comparison presented above, post-Rev5 bank erosion rates are comparable to pre-Rev5 bank erosion rates documented in NHC (2006), or lower.

5. Erosion Mechanisms and Operational Implications

As presented in Section 3 and 4, this project has concluded that shoreline erosion is occurring in the study reach. Measured rates of erosion are comparable or lower to historic rates of bank erosion, and there is no evidence that the rate of erosion has increased during the current study.

In this section we briefly explore potential links between bank erosion and operations and provide suggestions on possible future work.

5.1 Erosion Mechanisms

Various bank erosion mechanisms have previously been identified in the study reach (NHC, 2006):

- scour and undermining of coarse-grained banks,
- slumping of fine-grained banks due to oversteepening and loss of basal support, and
- channel shifting and avulsion.

The main style of erosion observed during CLBWORKS #36 is slumping of fine-grained banks. A combination of factors is indicated by NHC (2006) to contribute to this slumping process, including:

- scour of sands overlying basal gravels by river flows and wave action (at higher water levels),
- effect of periodic wetting and drying due to daily cycling of discharge releases from Revelstoke Dam, which could contribute to loss of bank strength, and
- removal of slumped bank materials by peak release flows.

5.2 Operational Implications

The Columbia River hydrograph is substantially altered by regulation: average annual peak flows near Revelstoke have decreased by about one half and regulation has also decreased the typical seasonal variation in flow (e.g. see Figure 5-1 in Bray (2017)). In addition, backwatering by the Arrow Lakes Reservoir gives the study reach characteristics of a river for some part of the year, but also characteristics more like a lake for another part of the year.

As indicated in Section 5.1, it seems likely that observed bank erosion can be linked both to the releases from Revelstoke Dam (the daily fluctuation, as well as the peaks) as well as the downstream Arrow Lakes reservoir level. The way in which these two operational conditions interact with each other and with other factors such as the wind-wave climate, and bank composition and geometry, likely dictates the pattern of bank erosion that will occur. Currently there is insufficient information to identify whether one operational factor dominates over the other (i.e. Revelstoke dam releases vs. Arrow Lakes reservoir level) in terms of its contribution to the observed bank erosion.

The hydraulic assessment of adding a fifth and sixth unit to Revelstoke Dam concluded that the incremental increase in peak shear stresses still would be insufficient to mobilize and transport gravel-sized (or coarser) material (NHC 2006). However, the increased shear stresses were expected to be able to mobilize and transport sand and fine gravel. As a result, the fifth unit was anticipated to increase the transport of slumped fine material at the base of unstable banks, resulting in a rate of bank retreat in the order of 1 to 2 m per year at actively eroding sites (NHC 2006). This is generally consistent with the erosion rates measured during this study (e.g. see rates in Table 3-8).

As bank erosion progresses the shape of the channel cross-section will change. In most locations that have an eroding fine sediment 'cap', the gravel is at shallow depth and will not be mobilized under the current dam releases. As such, over time the eroded nearshore zone will remain shallow. As the cross-section widens with further erosion, the widening shallow zone might be expected to reduce wave forces onshore, so the process would be expected to decelerate. It is not known how long it might take for this deceleration to occur. Although the literature was reviewed to seek out similar systems, this combination of river erosion processes and quasi-lake shore erosion processes was not found in the literature: studies present rates of erosion for either rivers regulated by dams or reservoirs with shoreline erosion, but not a system that combines both processes.

A more direct link between operations and bank erosion could be made by designing a targeted study to determine the mechanisms most responsible for the observed bank retreat. For example, seasonal measurements of bank retreat might permit some inference of when most erosion occurs, hence the dominant mechanism. Technologies such as drone-based measurements may facilitate these kinds of more frequent, but detailed, surveys.

5.3 Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

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

May 8, 2017

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

Reviewed by:

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

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Statement of Limitations

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This document represents KWL's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

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Revision History

Revision #	Date	Status	Revision	Author
1	May 8, 2017	Final	Revised based on additional client review.	EE
0	Apr. 19, 2017	Final	Revised based on client review.	EE
B	Dec. 1, 2016	Draft	Revised based on internal review.	EE
A	Nov. 10, 2016	Draft	Original	EE

Appendix A:
Monitoring Site Erosion Pin Maps

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Author: JLau

Reference: 2010, 2008, and 2007 orthophotos supplied by BC Hydro. Orthophoto for inset map from Bing aerial image map.

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BC Hydro
CLBWORKS #36: Mid-Columbia River Long-term Erosion Monitoring Program

Project No.	Date
478-081	December 2016

10 0 10 (m)
1:500

MON 1 Erosion Pin Average Change (2010 to 2016)

Figure A1

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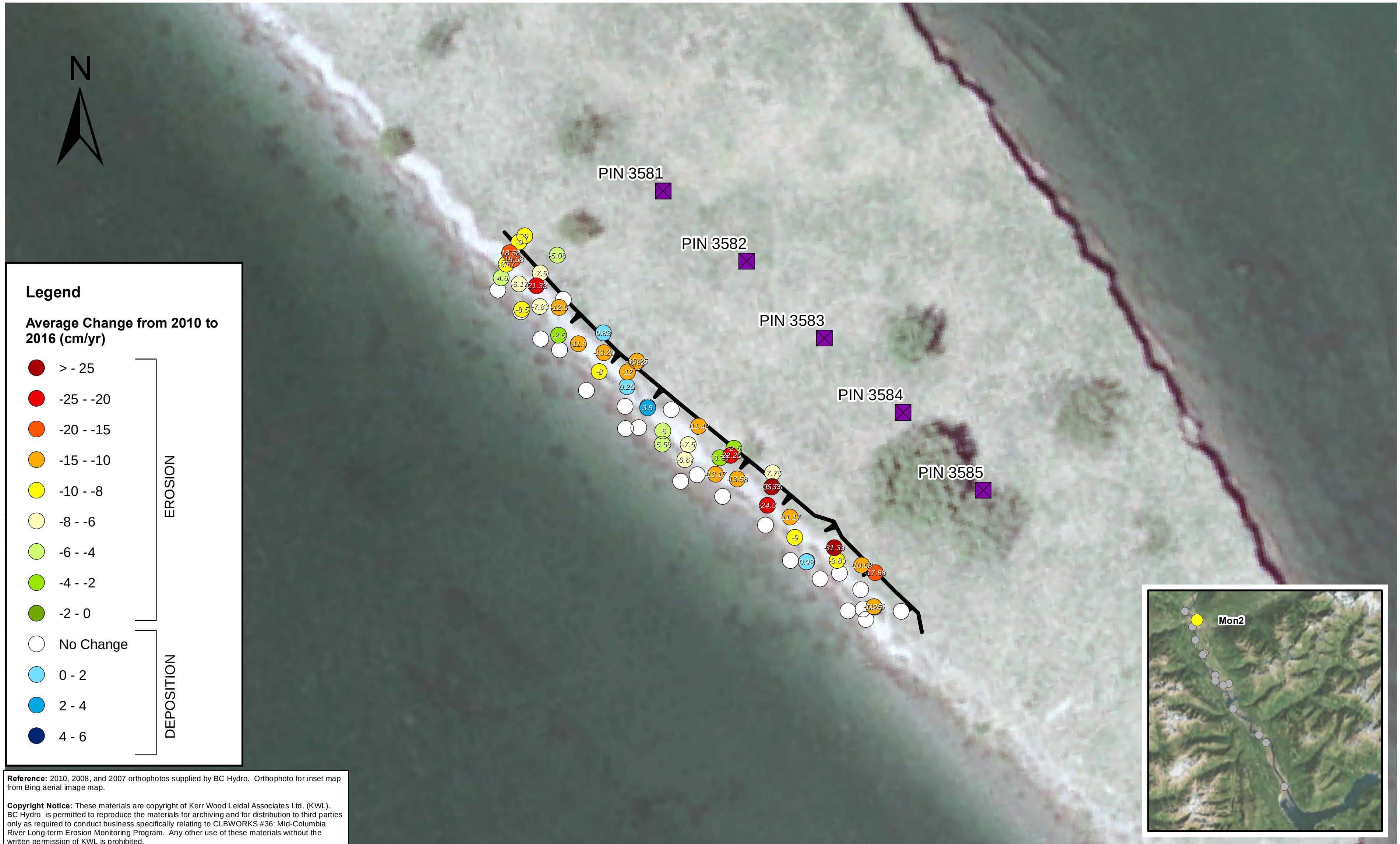

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Project No. 478-081

Date December 2016

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1:500

MON 2 Erosion Pin Average Change (2010 to 2016)

Figure A2

Path: O:\0400-0499\478-081\430-GIS\MXD-Rp\2016\478081_2016_MonSites.mxd Date Saved: 12/1/2016 4:01:36 PM
Author: JLau

Reference: 2010, 2008, and 2007 orthophotos supplied by BC Hydro. Orthophoto for inset map from Bing aerial image map.

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Project No.	Date
478-081	December 2016

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MON 3 Erosion Pin Average Change (2010 to 2016)

Figure A3

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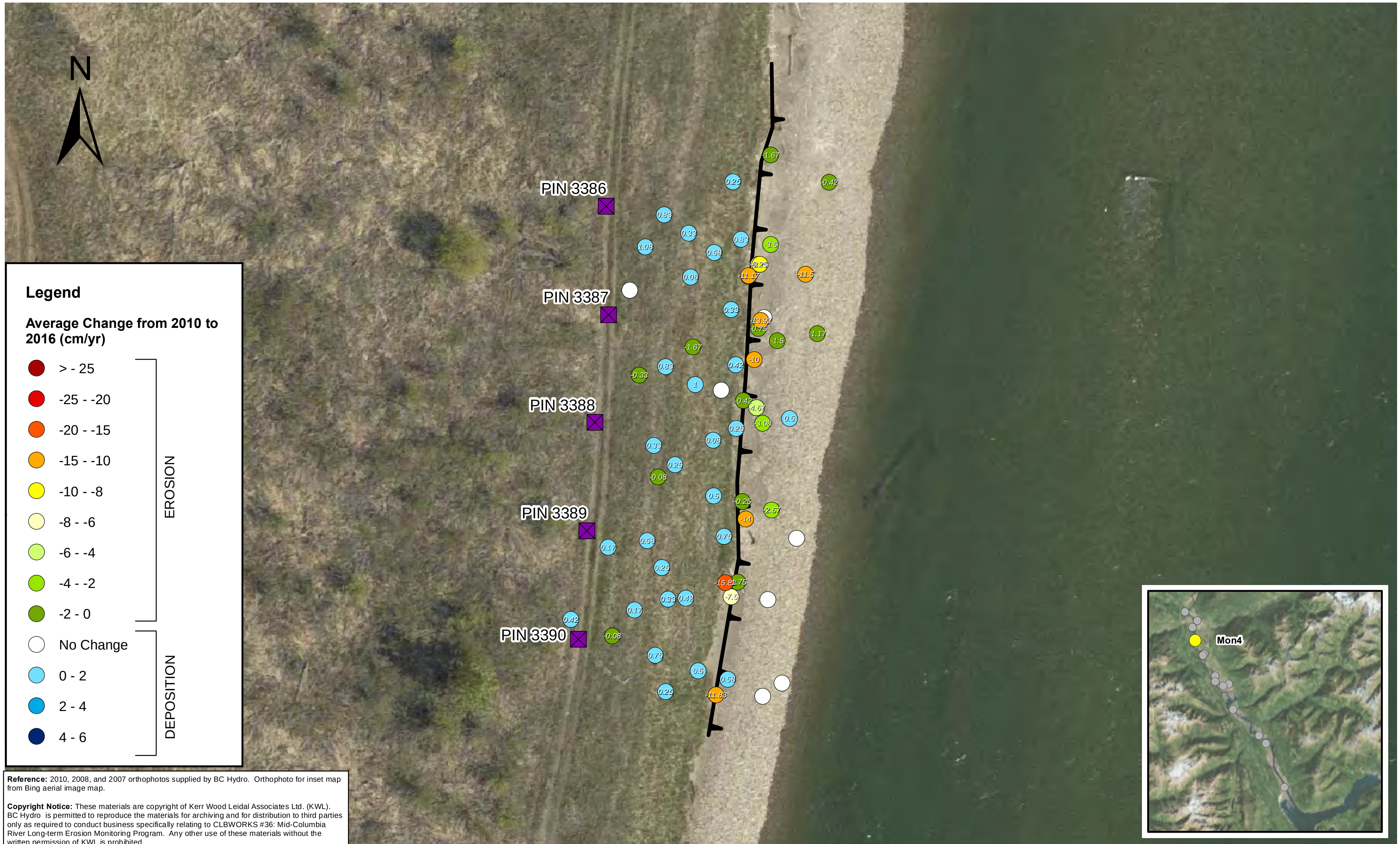

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CLBWORKS #36: Mid-Columbia River Long-term Erosion Monitoring Program

Project No.	Date
478-081	December 2016

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MON 4 Erosion Pin Average Change (2010 to 2016)

Figure A4

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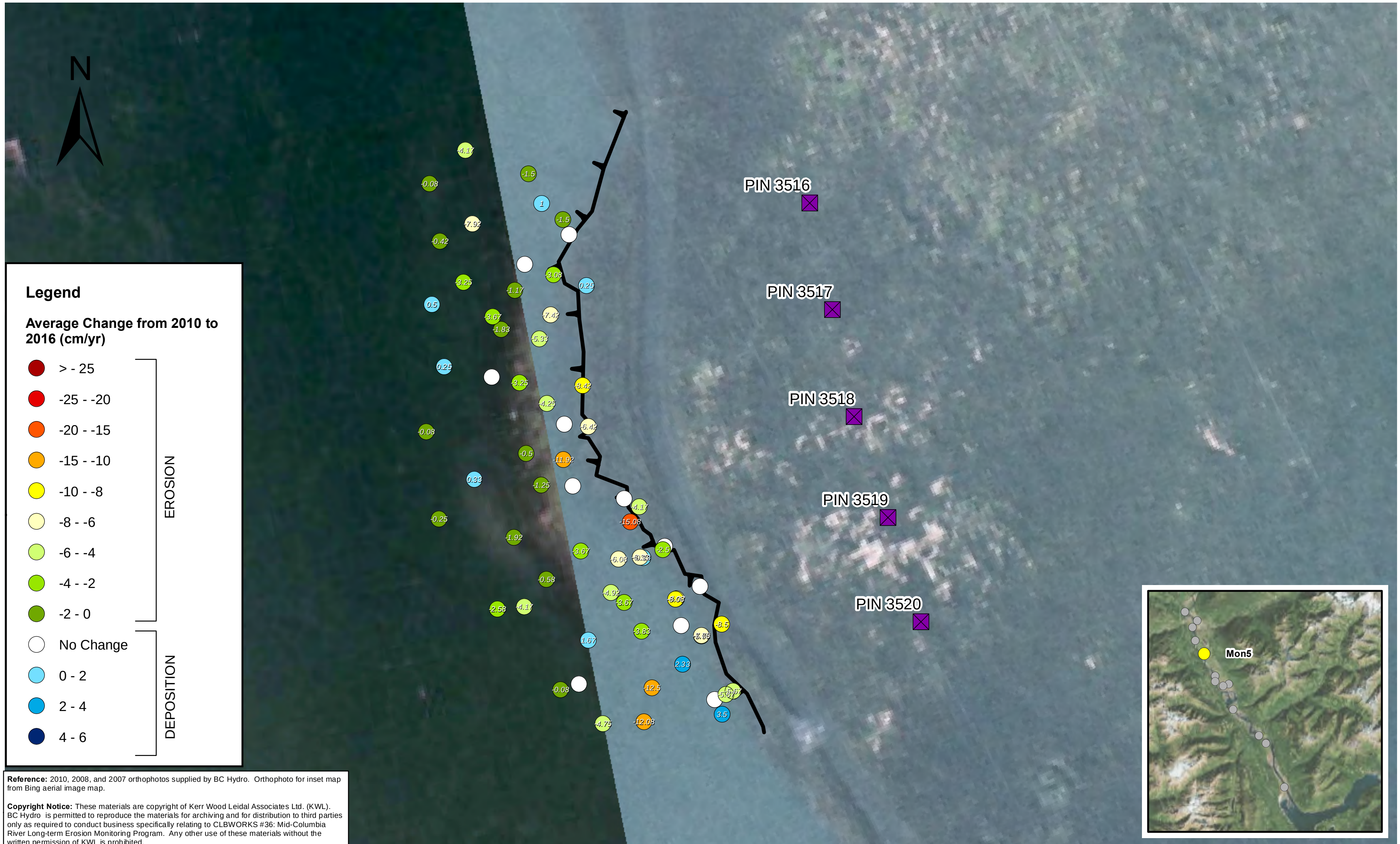

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Project No. 478-081

Date December 2016

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MON 5 Erosion Pin Average Change (2010 to 2016)

Figure A5

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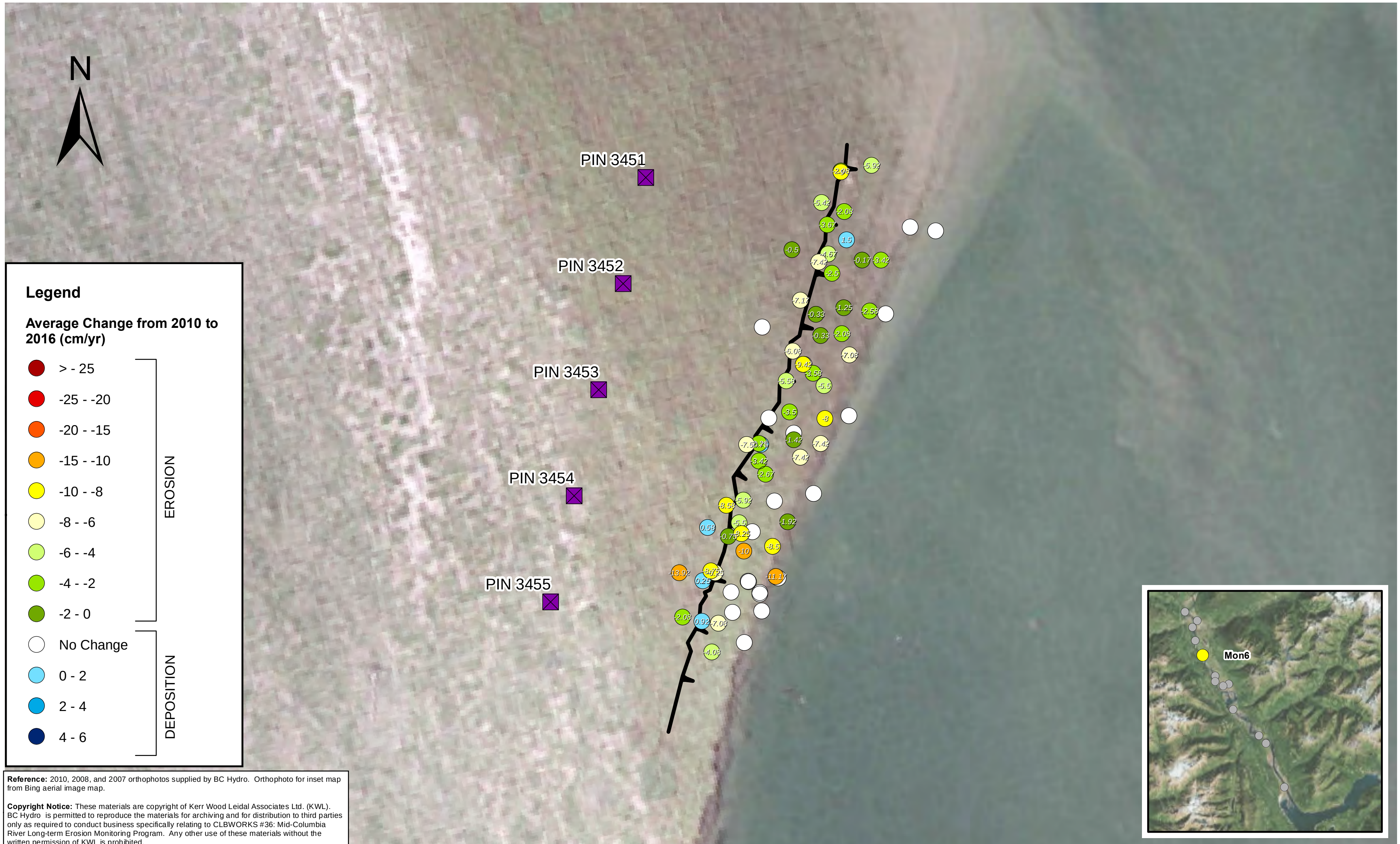

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Project No. 478-081

Date December 2016

10 0 10 (m)
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MON 6 Erosion Pin Average Change (2010 to 2016)

Figure A6

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Author: JLau

Reference: 2010, 2008, and 2007 orthophotos supplied by BC Hydro. Orthophoto for inset map from Bing aerial image map.

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Project No. 478-081

Date December 2016

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MON 7 Erosion Pin Average Change (2010 to 2016)

Figure A7

Path: O:\0400-0499\478-081\430-GIS\MXD-Rp\2016\478081_2016_MonSites.mxd Date Saved: 12/1/2016 4:01:36 PM
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10 0 10 (m)
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MON 8 Erosion Pin Average Change (2010 to 2016)

Figure A8

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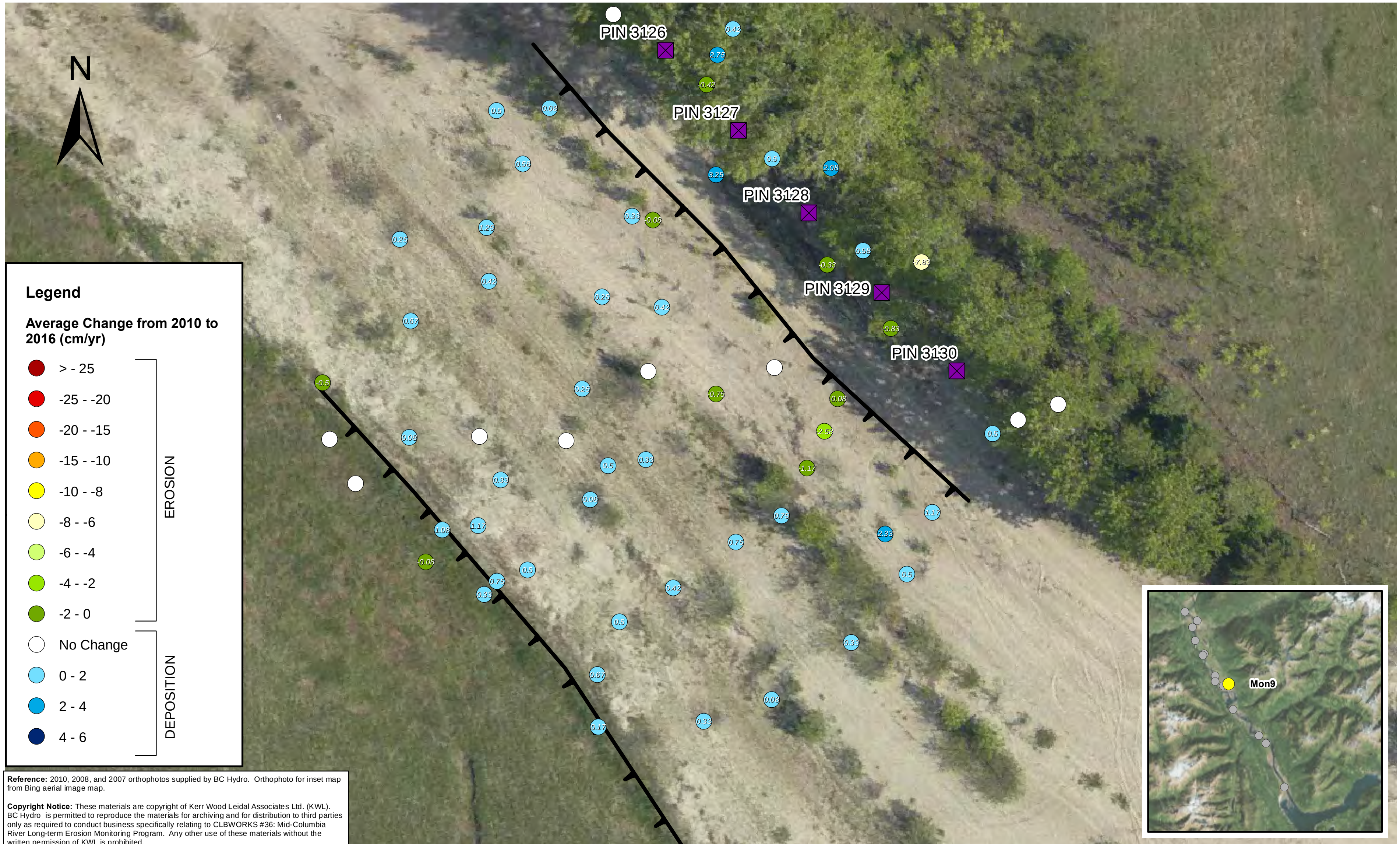

Reference: 2010, 2008, and 2007 orthophotos supplied by BC Hydro. Orthophoto for inset map from Bing aerial image map.

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Project No.	Date
478-081	December 2016

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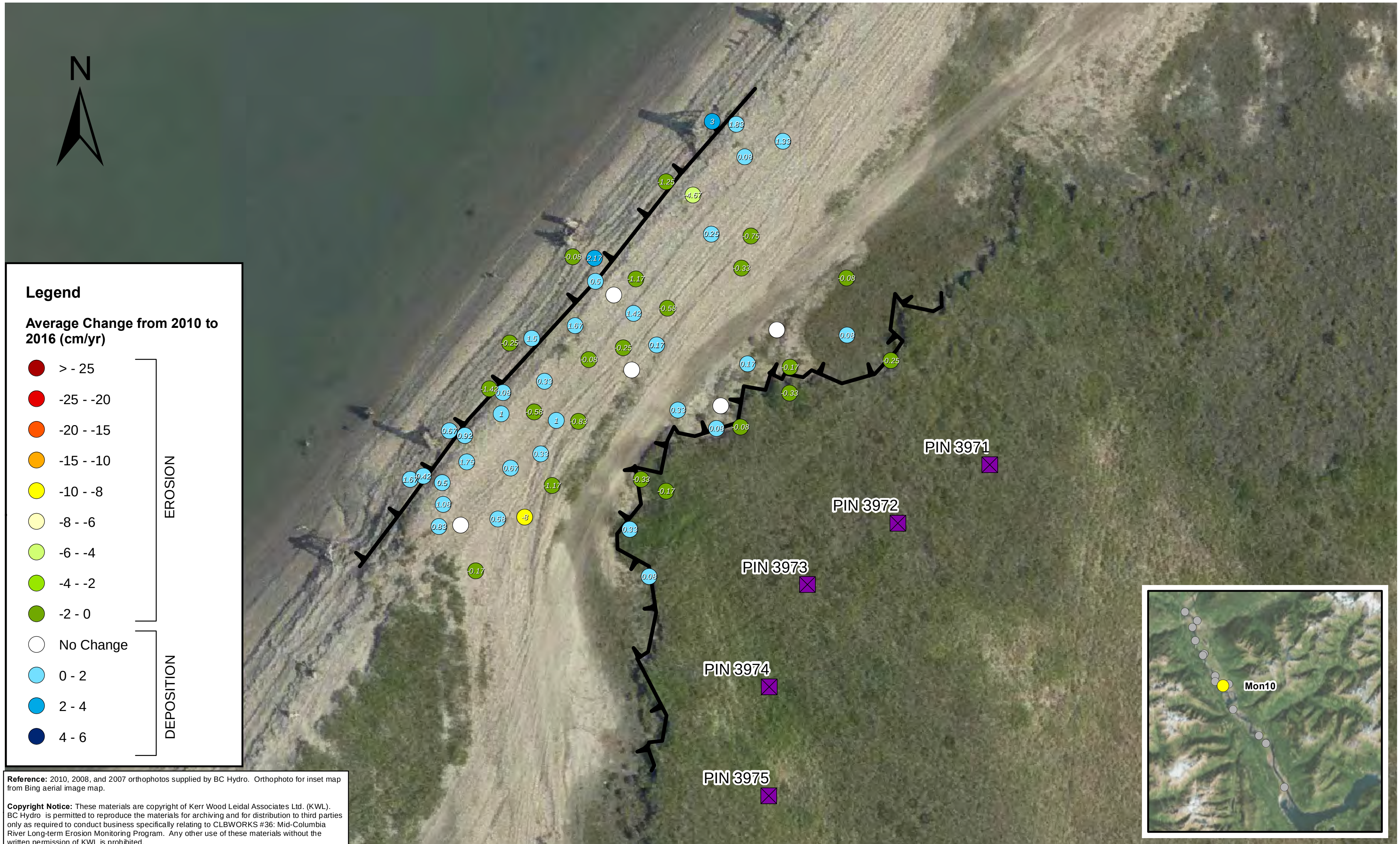
MON 9 Erosion Pin Average Change (2010 to 2016)

Figure A9



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MON 10 Erosion Pin Average Change (2010 to 2016)

Figure A10

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Author: JLau

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Project No.	Date
478-081	December 2016

10 0 10 (m)
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MON 11 Erosion Pin Average Change (2010 to 2016)

Figure A11

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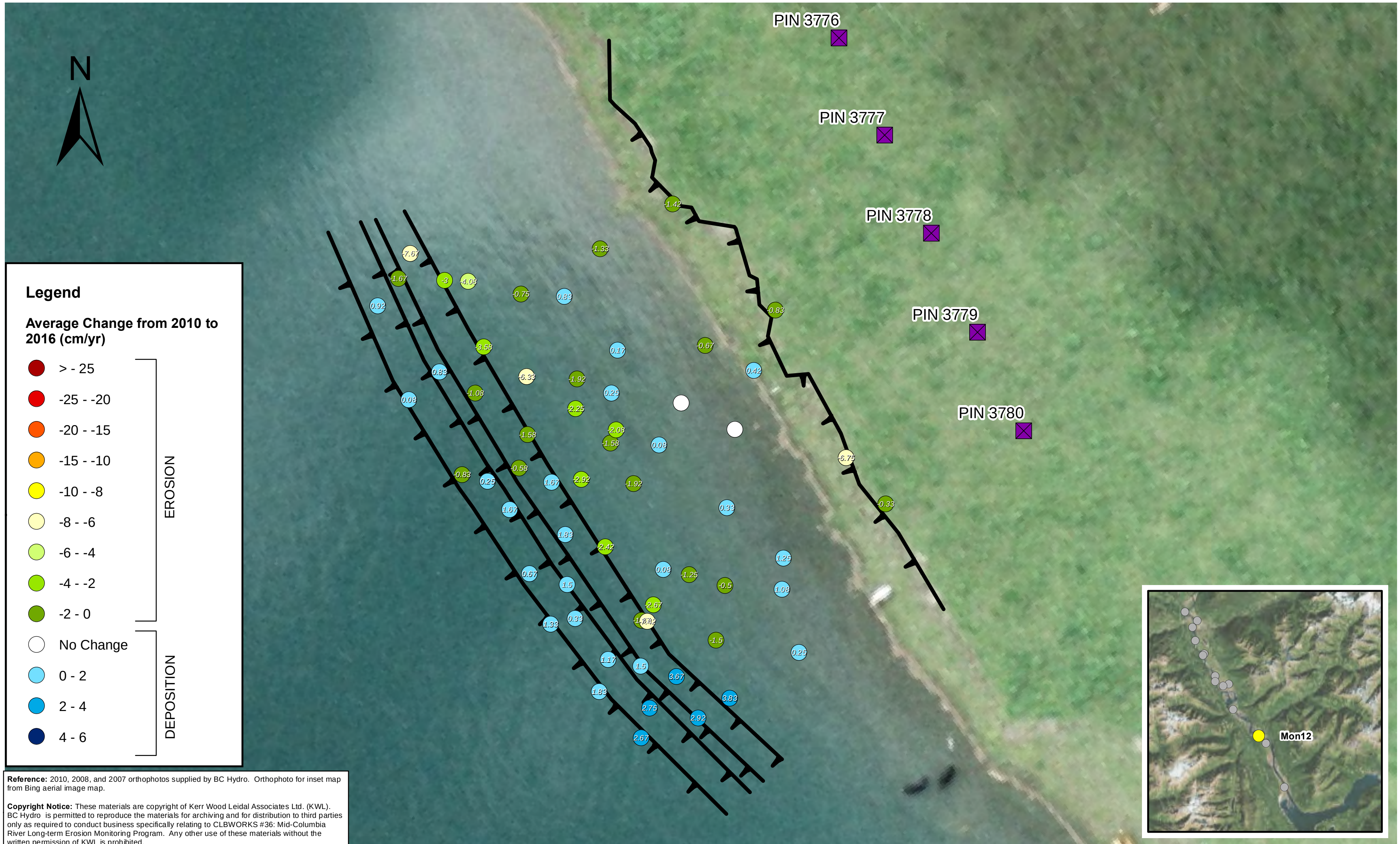

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Project No.	Date
478-081	December 2016

10 0 10 (m)
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MON 12 Erosion Pin Average Change (2010 to 2016)

Figure A12

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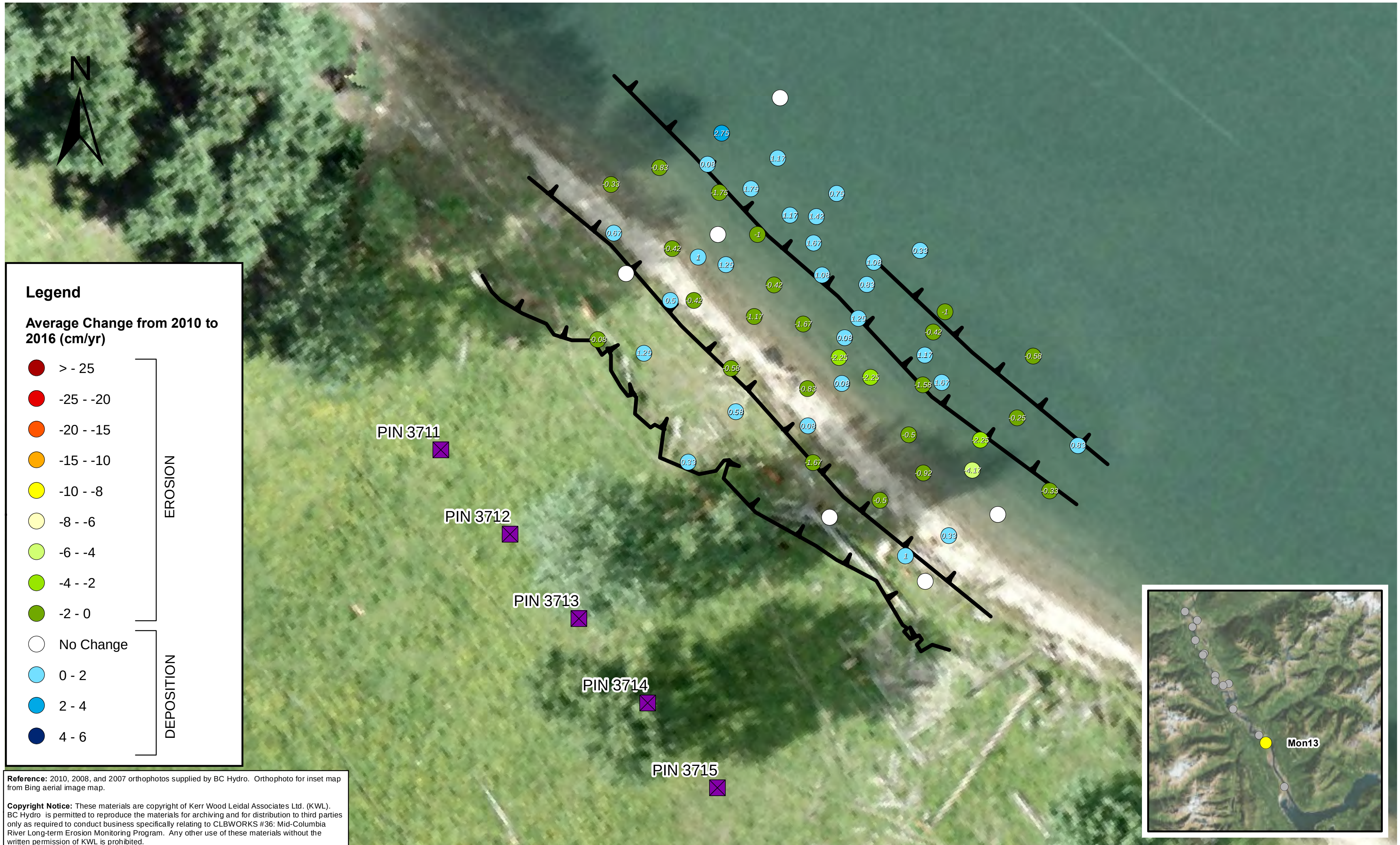

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Project No.	Date
478-081	December 2016

10 0 10 (m)
1:500

MON 13 Erosion Pin Average Change (2010 to 2016)

Figure A13

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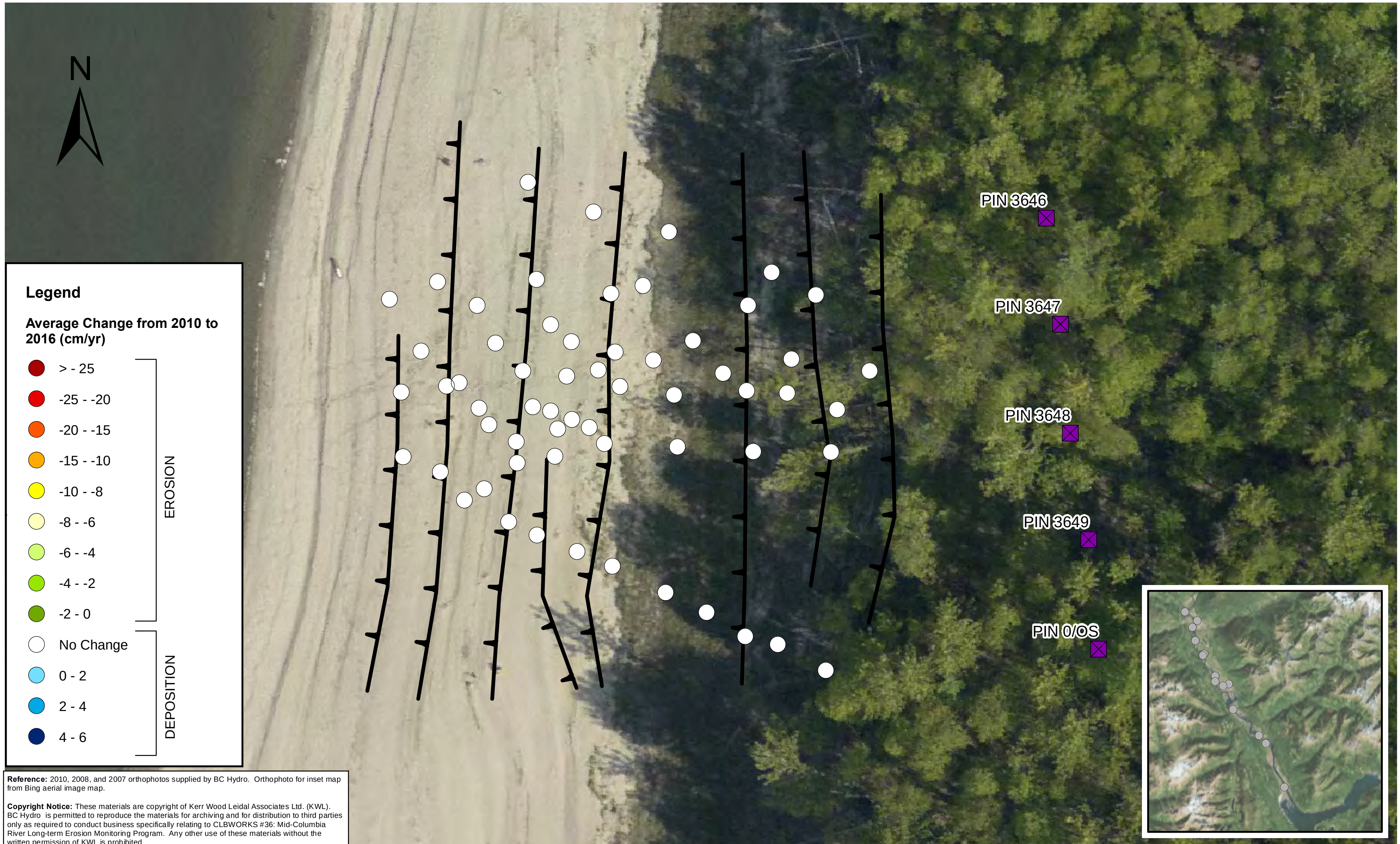

Legend

Average Change from 2010 to 2016 (cm/yr)

EROSION
- > - 25
- -25 - -20
- -20 - -15
- -15 - -10
- -10 - -8
- -8 - -6
- -6 - -4
- -4 - -2
- -2 - 0
- No Change

DEPOSITION
- 0 - 2
- 2 - 4
- 4 - 6

Reference: 2010, 2008, and 2007 orthophotos supplied by BC Hydro. Orthophoto for inset map from Bing aerial image map.

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Project No.	Date
478-081	December 2016

10 0 10 (m)
1:500

MON 14 Erosion Pin Average Change (2010 to 2016)

Figure A14

Path: O:\0400-0499\478-081\430-GIS\MXD-Rp\2016\478081_2016_MonSites.mxd Date Saved: 12/1/2016 4:01:36 PM
Author: JLau

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Project No.	Date
478-081	December 2016

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MON 15 Erosion Pin Average Change (2010 to 2016)

Figure A15

Appendix B:
Monitoring Site Cross-Section Plots

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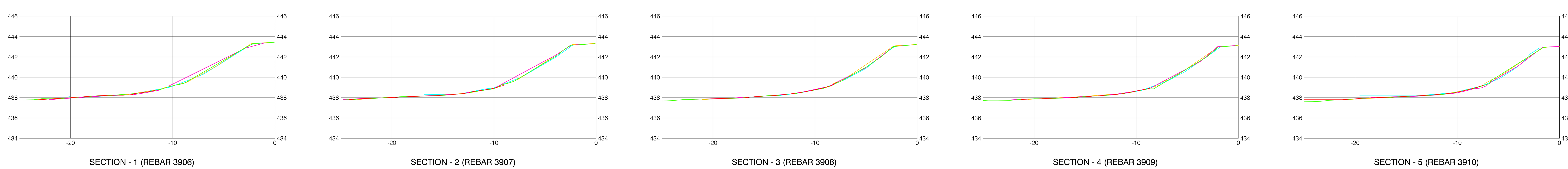

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Reference			
Approvals			
Tender			
Permits			
Construction			
Record Drawings			

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1	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING
2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Seal

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EROSION MONITORING SITE #1

KWL Project No.	478.120	Scale	AS SHOWN
Sheet	01 of 27	Rev. No.	3
Client: BC HYDRO		Drawing Number	MON 1

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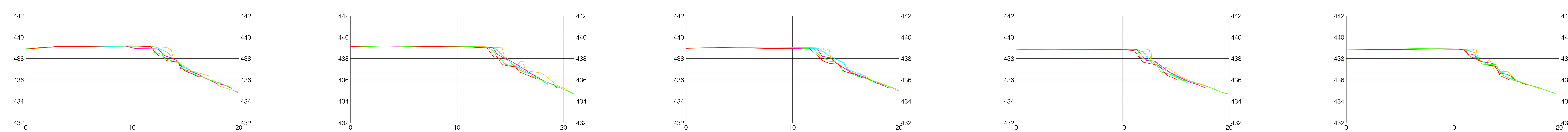

MONITORING SITE 2 - SECTIONS

1:200H, 1:200V

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Reference			
Approvals			
Tender			
Permits			
Construction			
Record Drawings			

REVISION INFORMATION: Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
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EROSION MONITORING SITE #2

KWL Project No. 478.120 | Scale AS SHOWN | **MON 2** Drawing Number

Sheet 02 of 27 | Rev. No. 3

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MONITORING SITE 3 - PLAN

1:100

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Approvals			
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REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
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3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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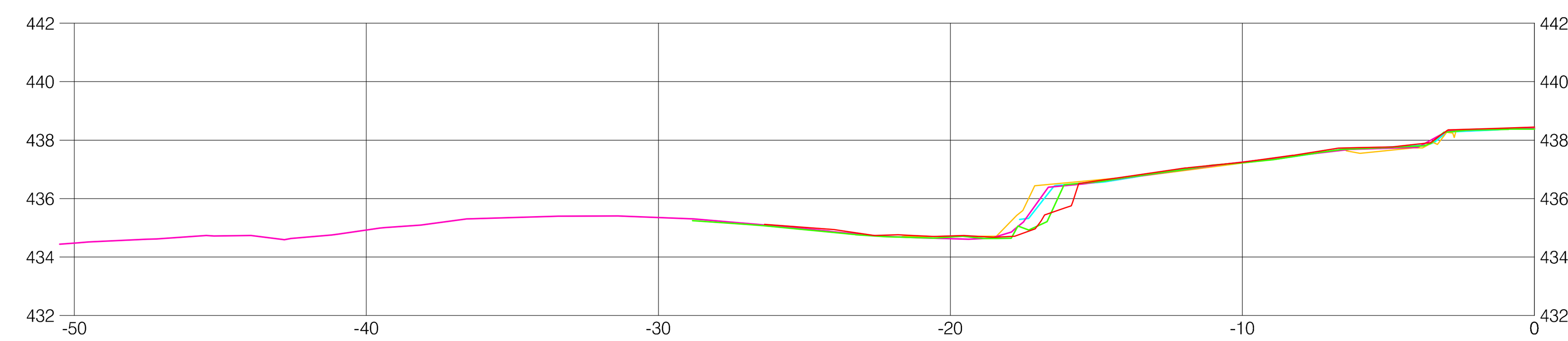
EROSION MONITORING SITE #3

KWL Project No.	478.120	Scale	1:100
Sheet	03 of 27	Rev. No.	3
Client: BC HYDRO			

MON 3
Drawing Number



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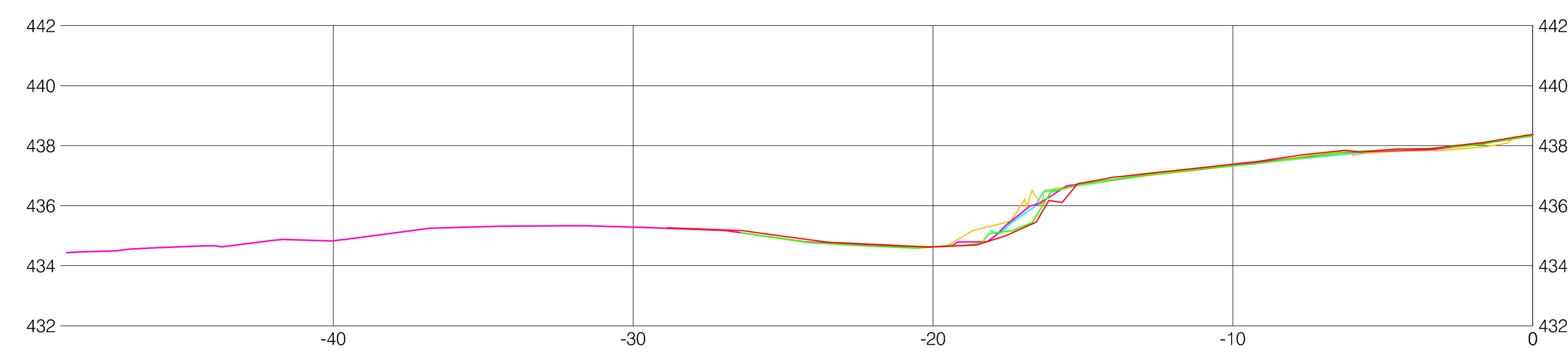

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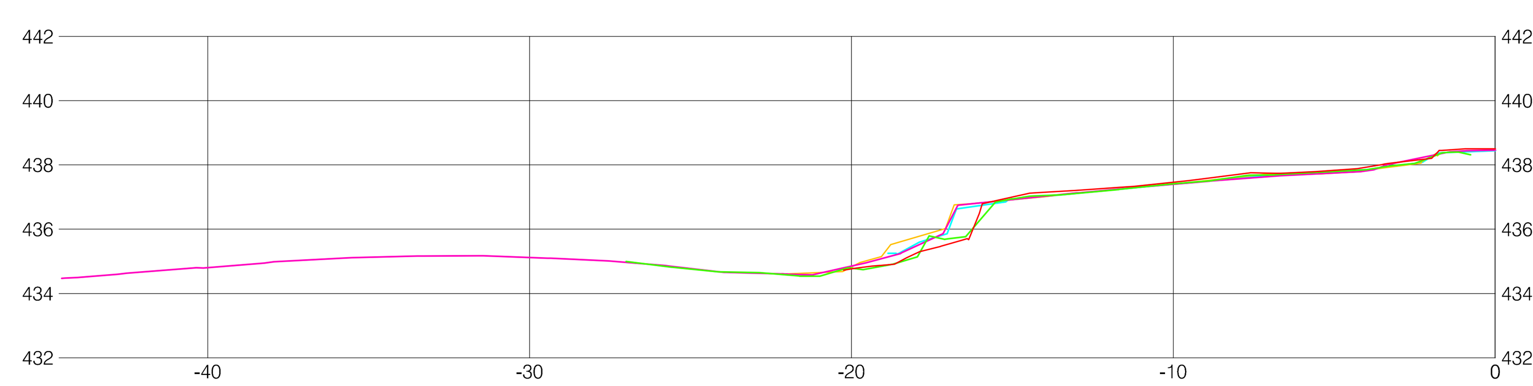

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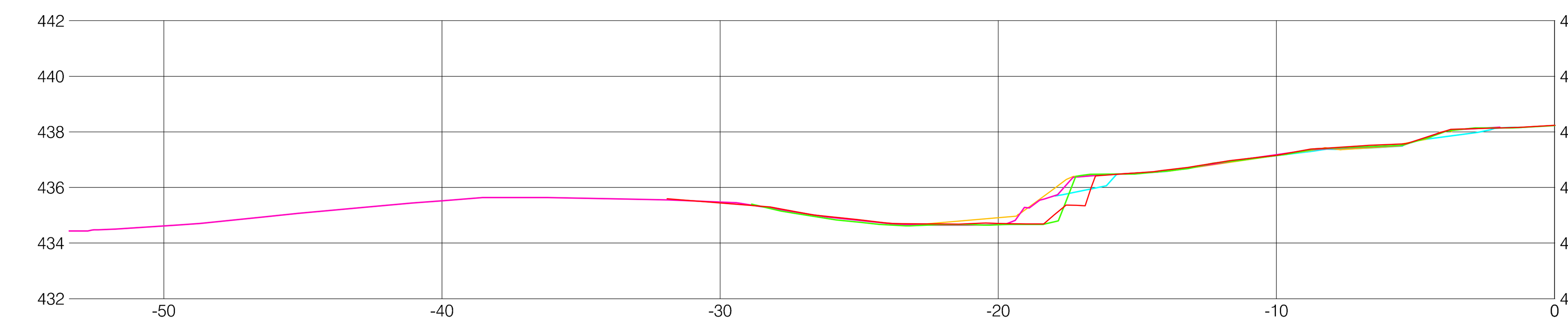

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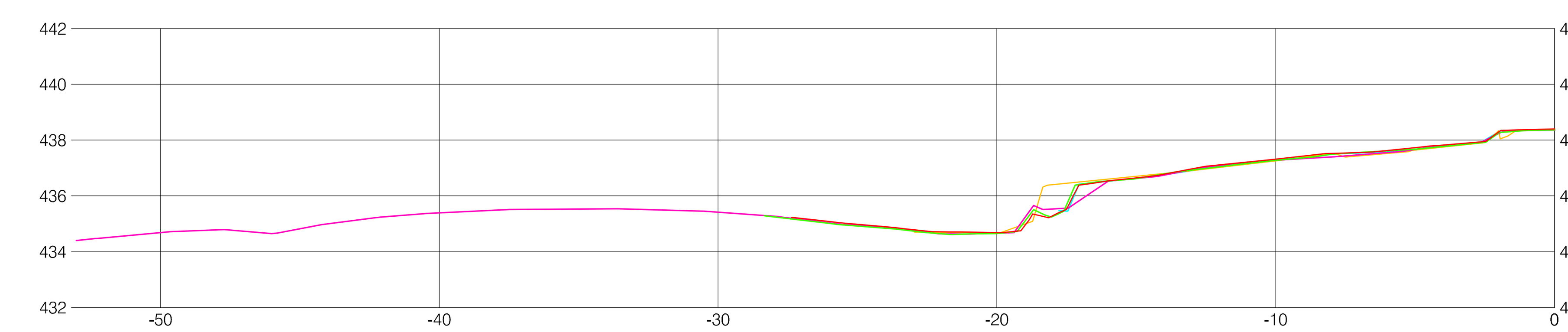

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- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

MONITORING SITE 3 - SECTIONS

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REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision	Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
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3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING						

Seal

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EROSION MONITORING SITE #3 - SECTIONS

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Sheet 04 of 27 | Rev. No. 3
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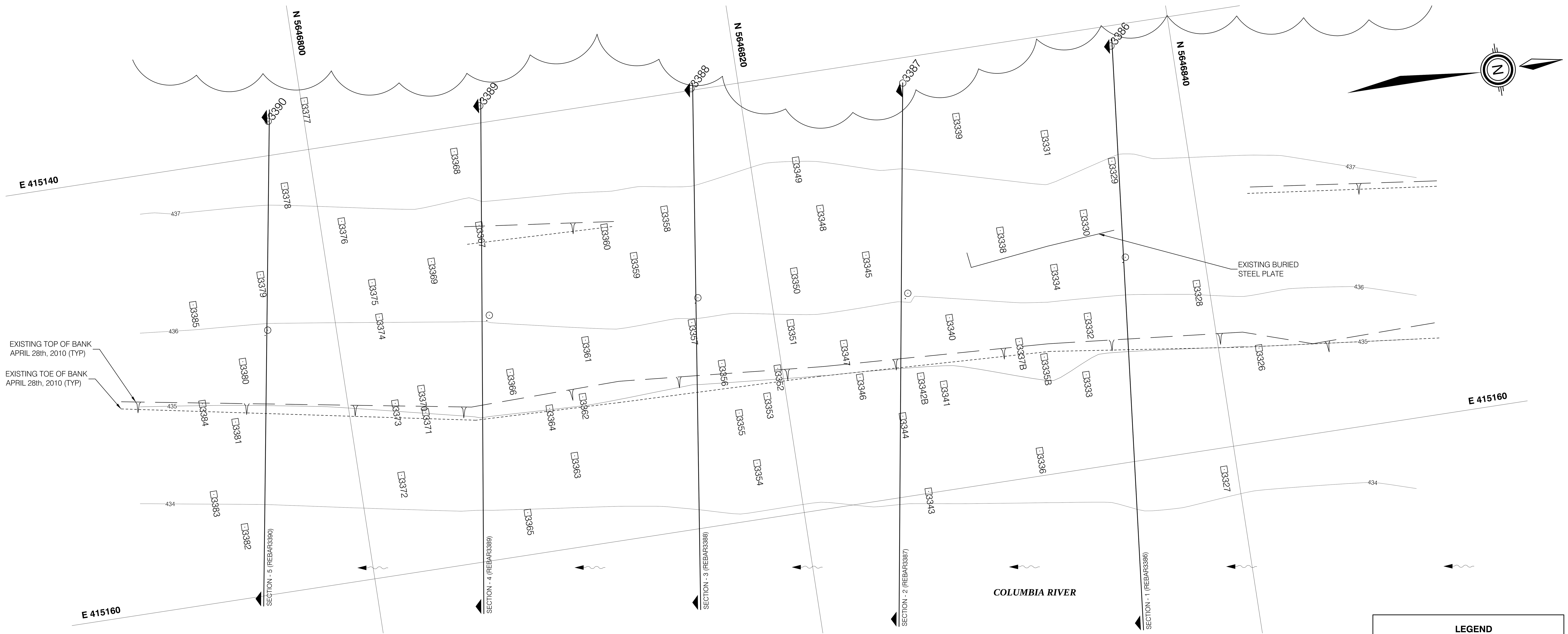

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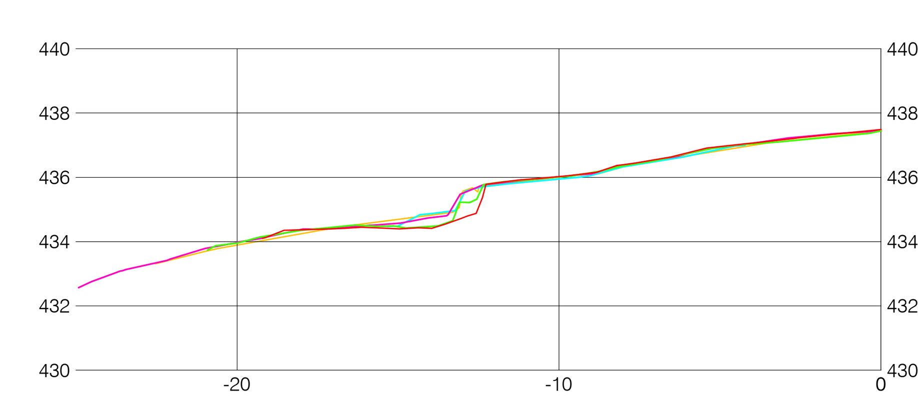
MONITORING SITE 4 - PLAN

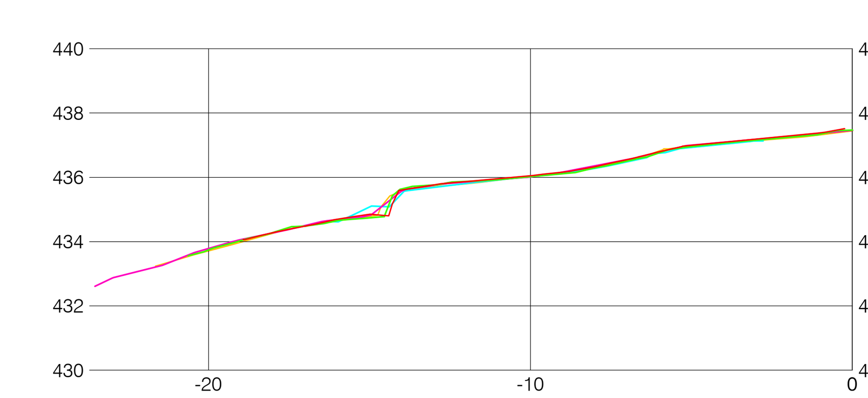
1:100

LEGEND

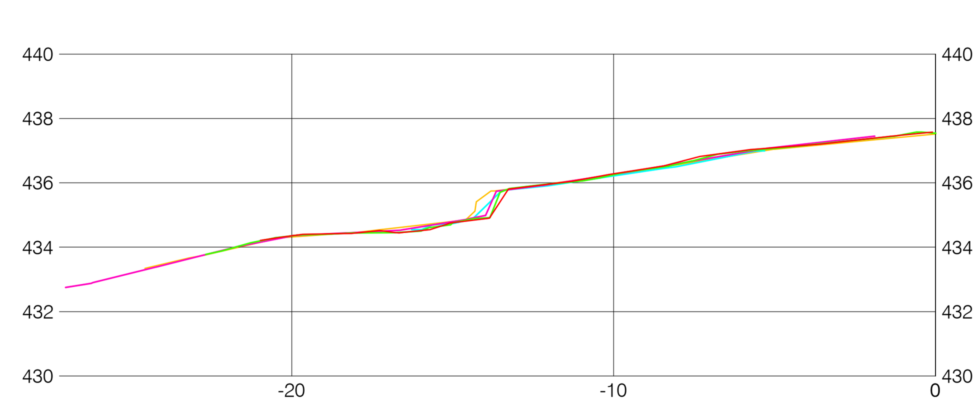
○1234	TRANSECT CONTROL REBAR
□1234	EROSION MONITORING REBAR
	TRANSECT GROUND APRIL, 2010
	TRANSECT GROUND JUNE, 2011
	TRANSECT GROUND APRIL, 2012
	TRANSECT GROUND APRIL, 2014
	TRANSECT GROUND MAY, 2016



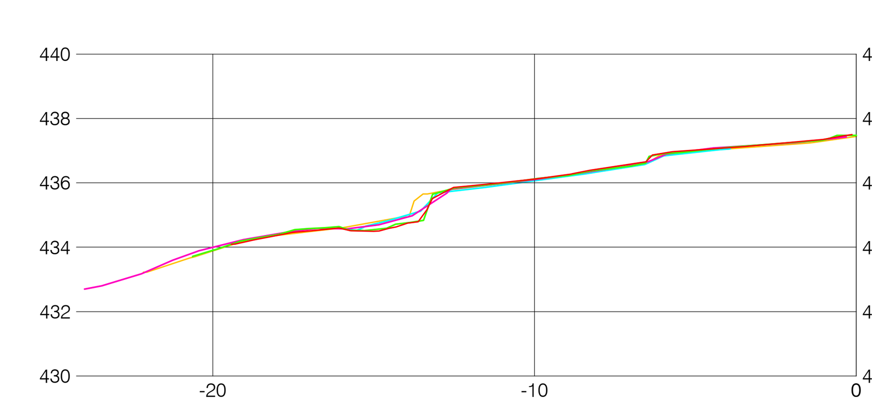
SECTION - 2 (REBAR3387)



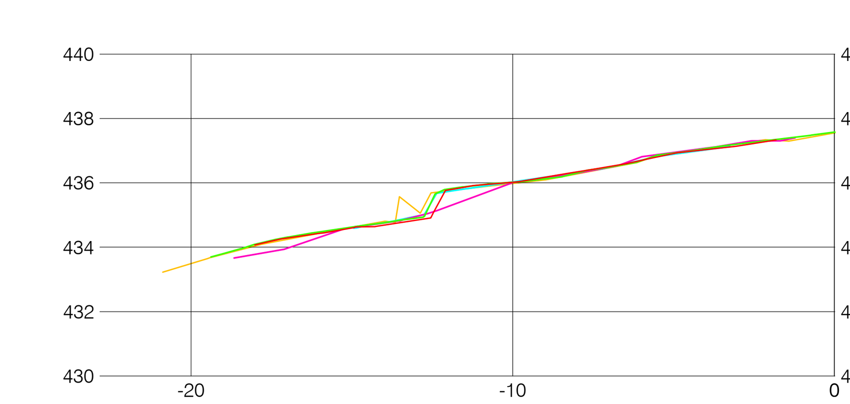
SECTION - 4 (REBAR3389)



SECTION - 1 (REBAR3386)



SECTION - 3 (REBAR3388)



SECTION - 5 (REBAR3390)

0 2 (1:200) 10m

MONITORING SITE 4 - SECTIONS

1:200H, 1:200V

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

REVISION INFORMATION: Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	DEC.16/11	DTM	BVC		ISSUED FOR 2011 REPORTING
1	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING
2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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BC HYDRO
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #4

KWL Project No. 478.120 | Scale AS SHOWN | **MON 4** Drawing Number
Sheet 05 of 27 | Rev. No. 3
Client: BC HYDRO

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MONITORING SITE 5 - PLAN

1:100

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

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	DEC.16/11	DTM	BVC		ISSUED FOR 2011 REPORTING
1	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING
2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Seal

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BC HYDRO
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #5

KWL Project No. 478.120 | Scale 1:100
Sheet 06 of 27 | Rev. No. 3
Client: BC HYDRO

MON 5
Drawing Number

SAVED 14-Nov-2016 3:47 PM AT FULL SIZE THIS BAR MEASURES 100mm. ALL SCALES REFERENCED TO FULL SIZE

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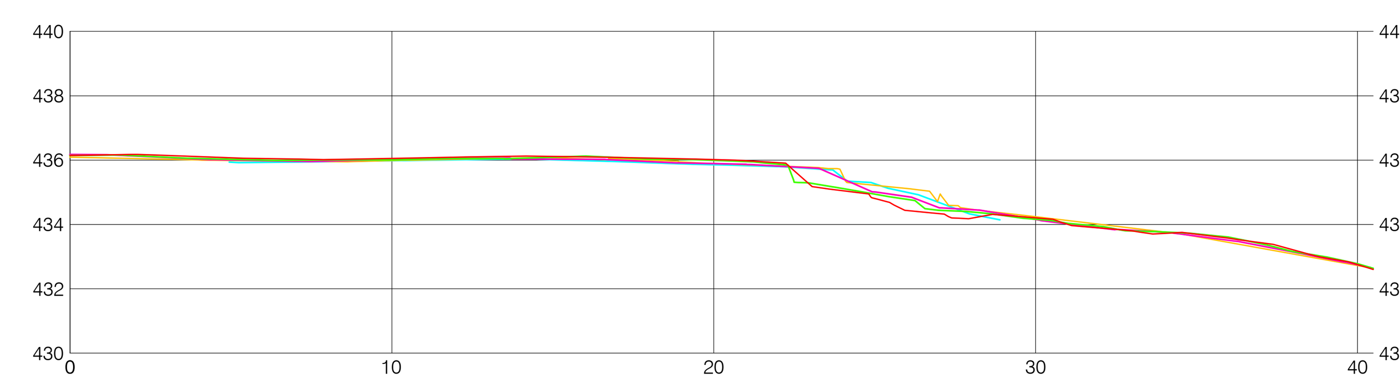
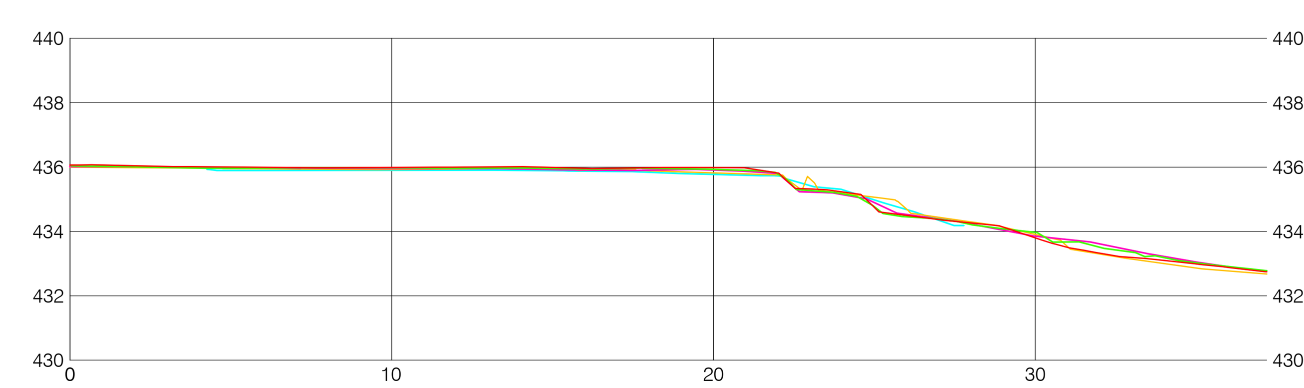
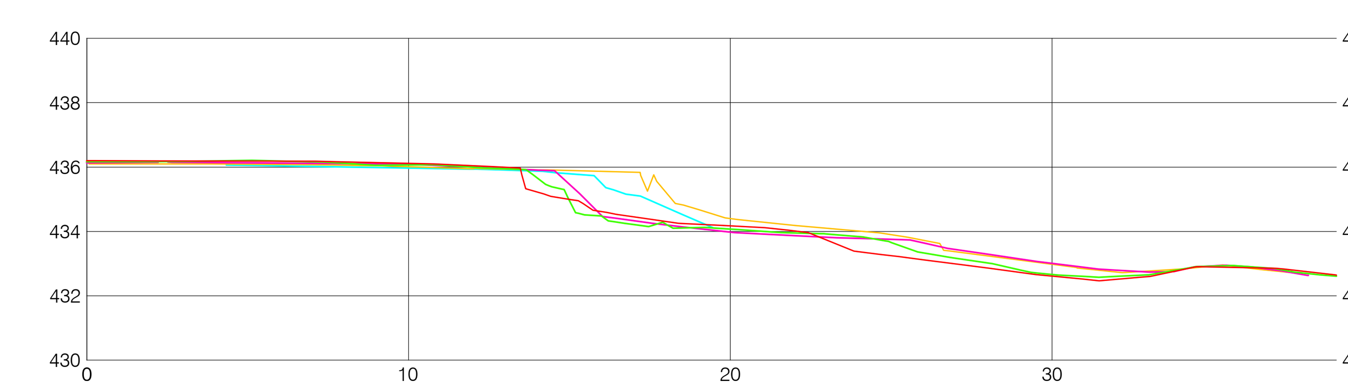


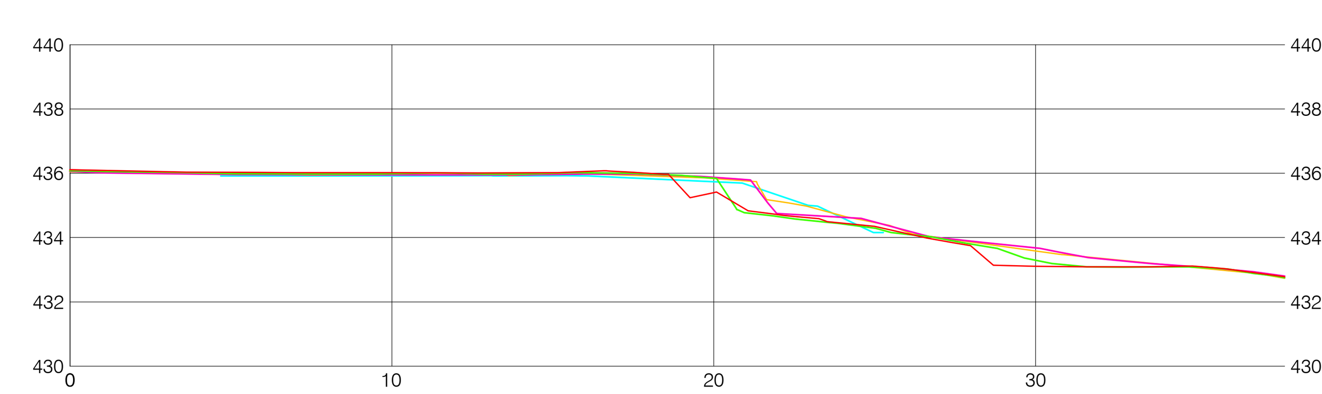
SECTION - 3 (REBAR3518)



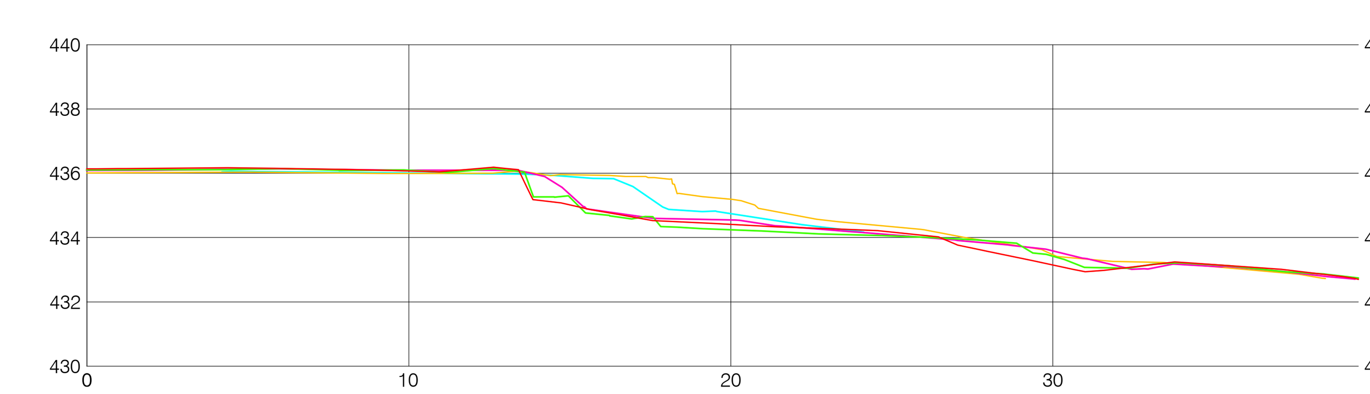
SECTION - 2 (REBAR3517)



SECTION - 5 (REBAR3520)



SECTION - 1 (REBAR3516)



SECTION -4 (REBAR3519)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

0 2 (1:200) 10m

MONITORING SITE 5 - SECTIONS

1:200H, 1:200V

SAVED 14-Nov-2016 4:41 PM AT FULL SIZE THIS BAR MEASURES 100mm. ALL SCALES REFERENCED TO FULL SIZE

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ISSUED INFORMATION

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0	DEC.16/11	DTM	BVC		ISSUED FOR 2011 REPORTING
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3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #5 - SECTIONS

KWL Project No.	478.120	Scale	1:200 H 1:200 V
Sheet	07 of 27	Rev. No.	3
Client: BC HYDRO			

MON 5A
Drawing Number

MONITORING SITE 6 - PLAN

1:100

ISSUED INFORMATION

Issued for	Issue	Date	Issued By
Reference			
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Record Drawings			

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
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3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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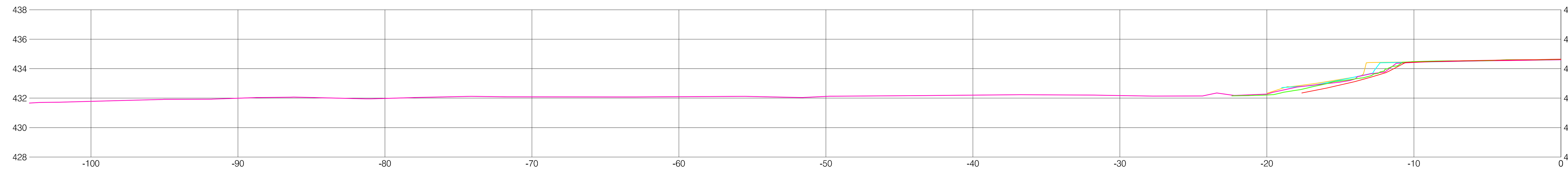
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #6

KWL Project No.	478.120	Scale	1:100
Sheet	08 of 27	Rev. No.	3

MON 6
Drawing Number

Client: BC HYDRO



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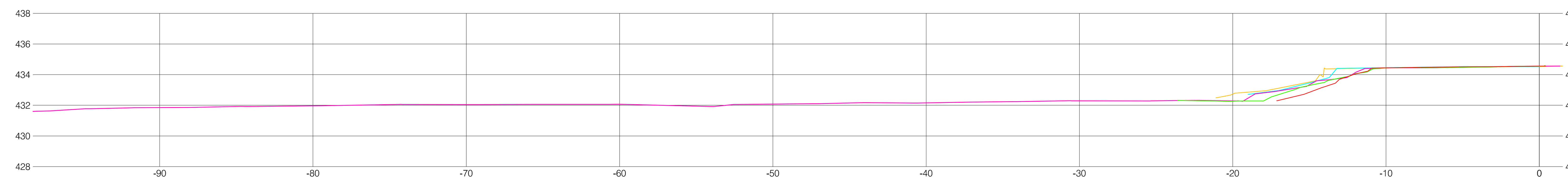
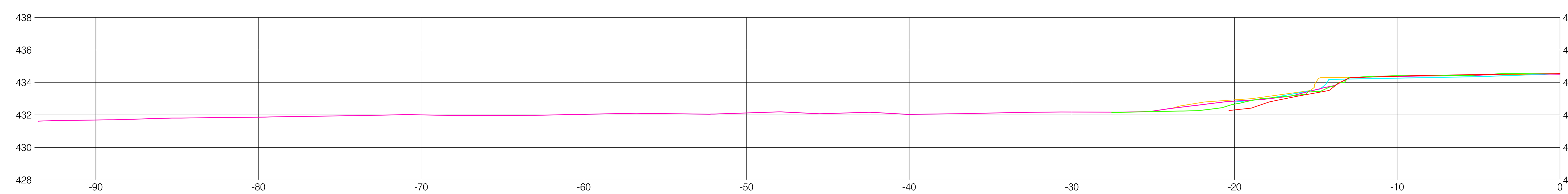


SECTION - 4 (REBAR3554)



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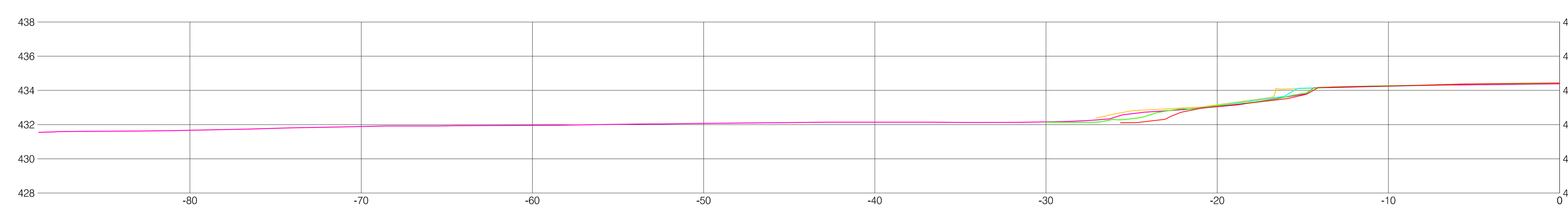
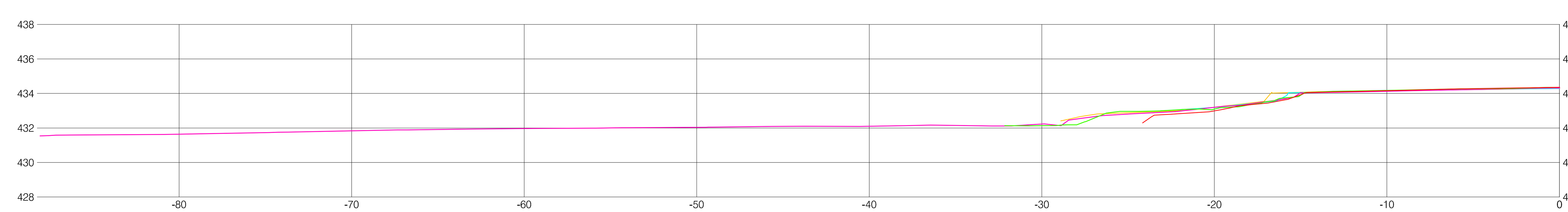


SECTION - 2 (REBAR3452)



SECTION - 1 (REBAR3451)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

0 2 (1:200) 10m

MONITORING SITE 6 - SECTIONS

1:200H, 1:200V

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Issued for	Issue	Date	Issued By
Reference			
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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
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1	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING
2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #6 - SECTIONS

KWL Project No. 478.120	Scale 1:200 H 1:200 V		**MON 6A**
Sheet 09 of 27	Rev. No. 3		Drawing Number
Client: BC HYDRO			

MONITORING SITE 7 - PLAN

1:100

0 1 (1:100) 5m

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Reference			
Approvals			
Tender			
Permits			
Construction			
Record Drawings			

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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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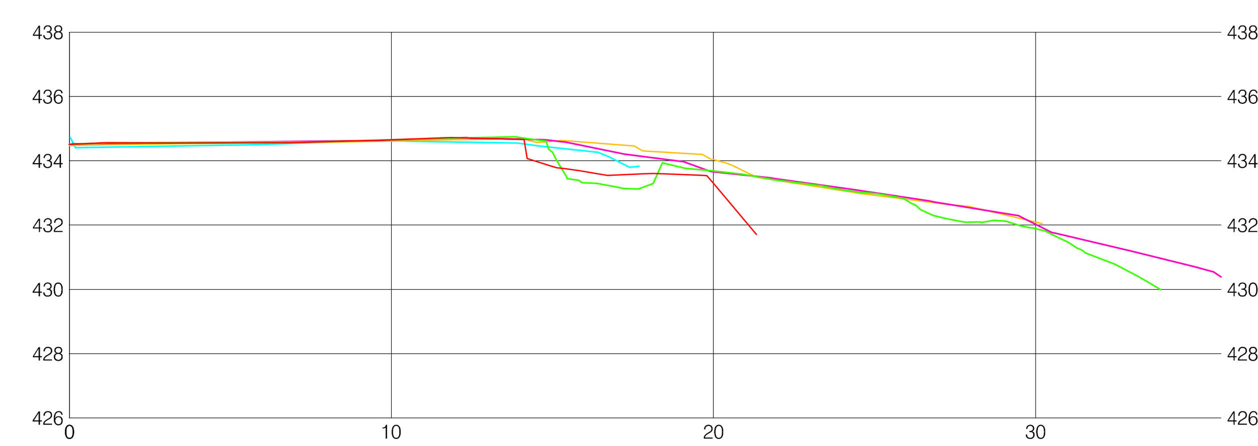
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #7

KWL Project No.	478.120	Scale	1:100
Sheet	10 of 27	Rev. No.	3
Client: BC HYDRO			

MON 7
Drawing Number



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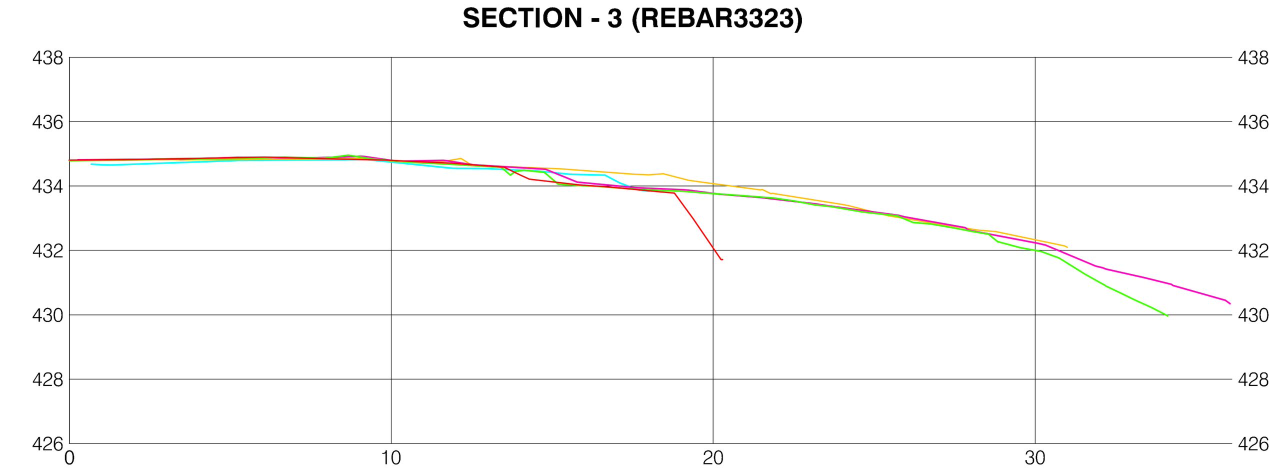

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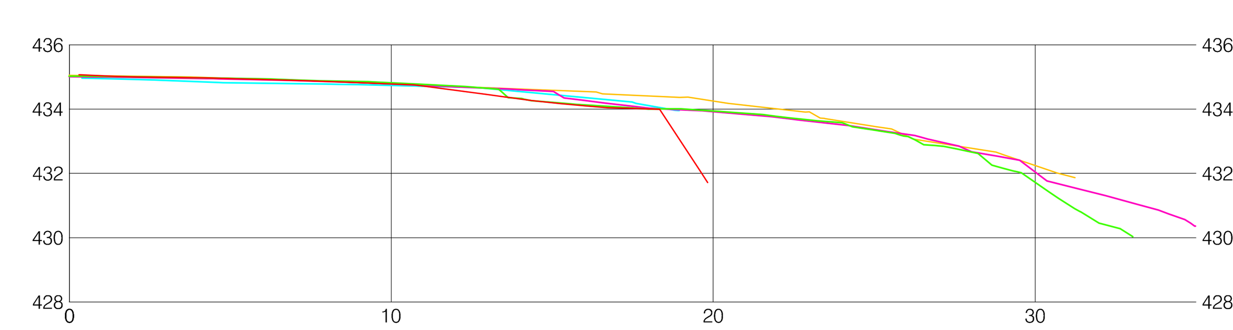
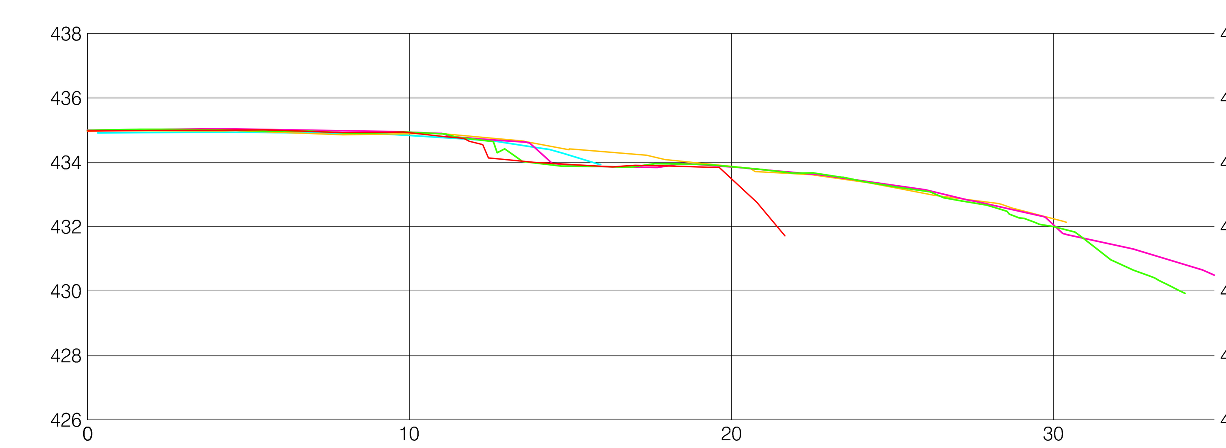
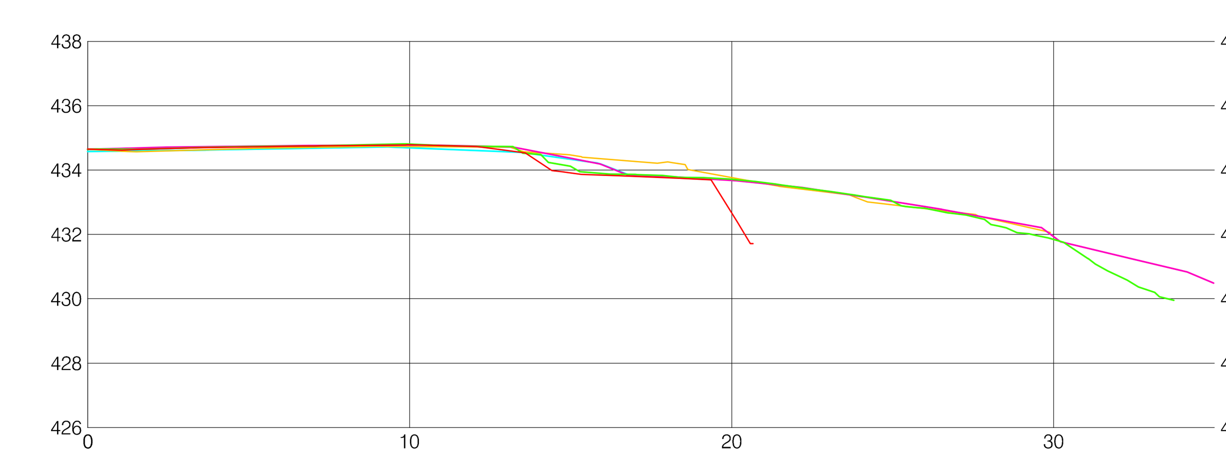


SECTION - 1 (REBAR3325)



SECTION - 5 (REBAR3321)



SECTION - 4 (REBAR3322)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

MONITORING SITE 7 - SECTIONS

1:200H, 1:200V

0 2 (1:200) 10m

ISSUED INFORMATION			
Issued for	Issue	Date	Issued By
Reference			
Approvals			
Tender			
Permits			
Construction			
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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
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2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #7 - SECTIONS

KWL Project No. 478.120	Scale 1:200 H 1:200 V		
Sheet 11 of 27	Rev. No. 3	**MON 7A** Drawing Number	
Client: BC HYDRO			

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

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MONITORING SITE 8 - PLAN

1:100

0 1 (1:100) 5m

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
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2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #8

KWL Project No.	478.120	Scale	1:100
Sheet	12 of 27	Rev. No.	3
Client: BC HYDRO			

MON 8
Drawing Number

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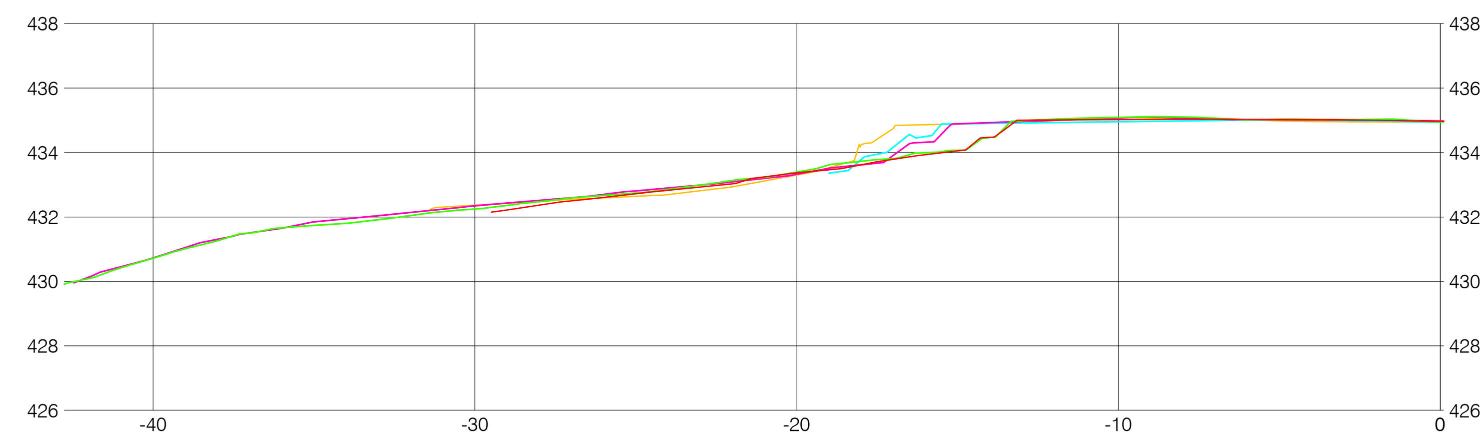

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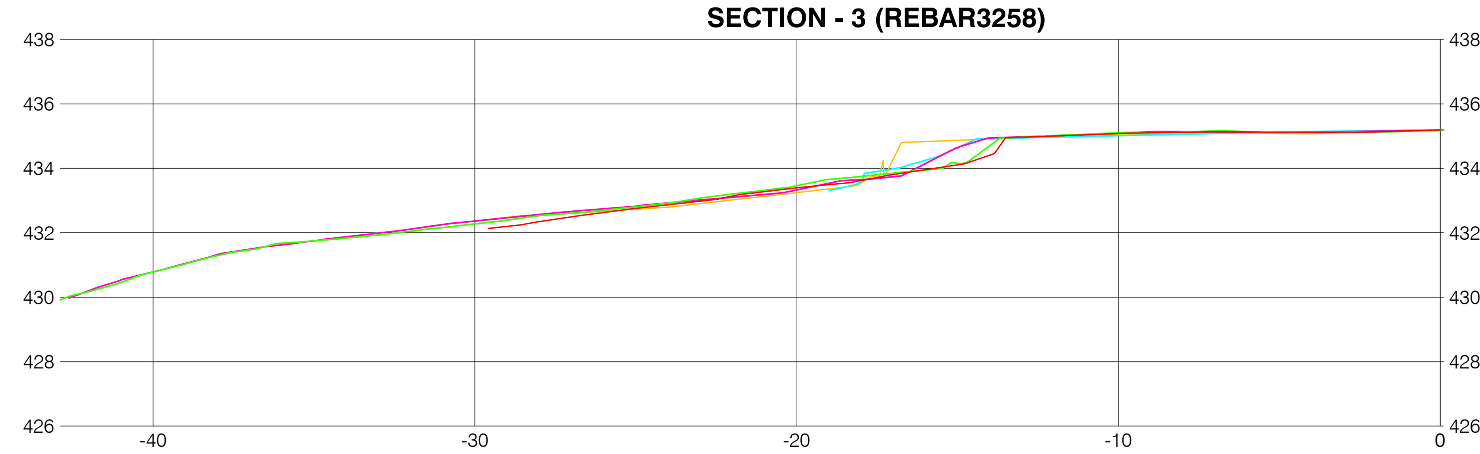
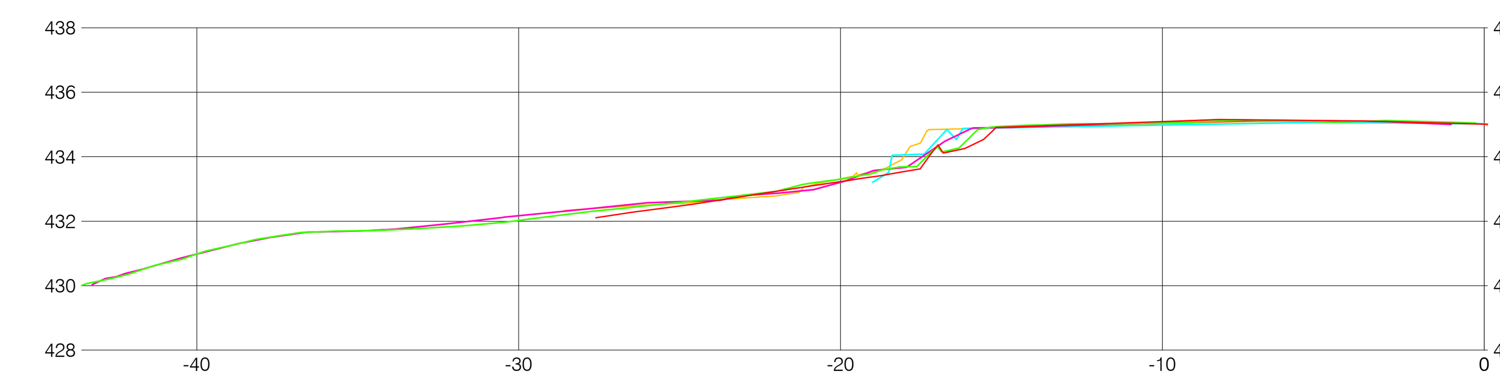


SECTION - 2 (REBAR3257)



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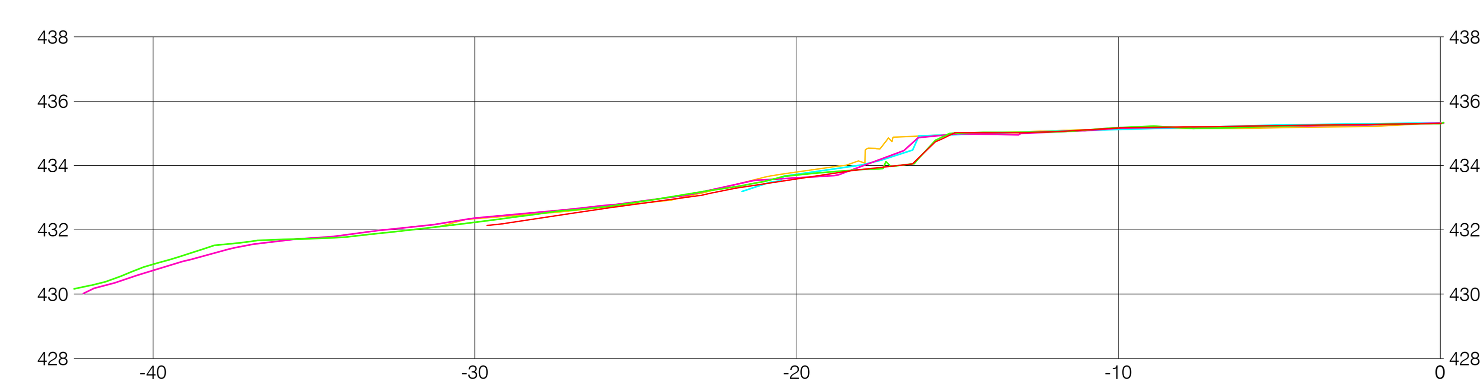
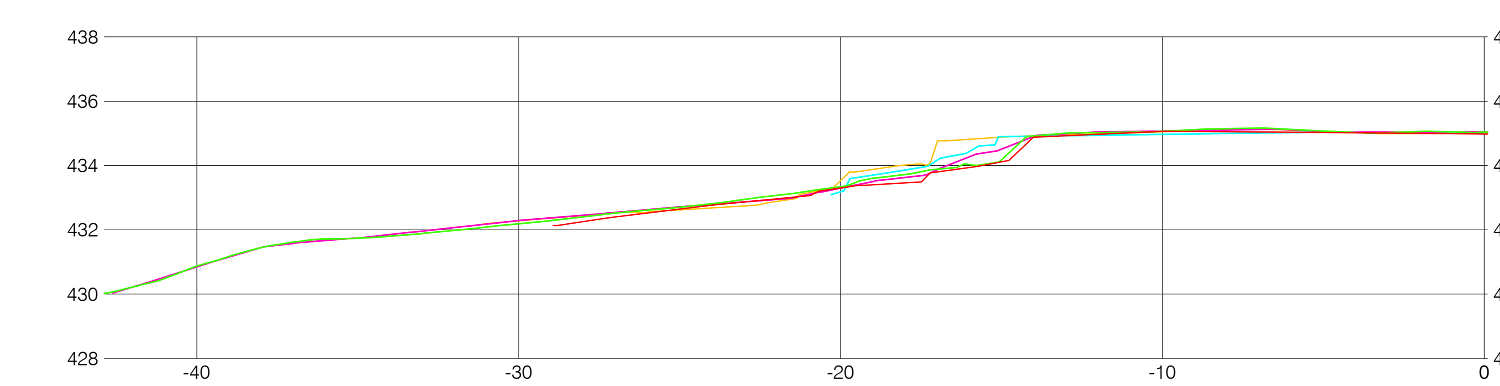


SECTION - 1 (REBAR3256)



SECTION - 4 (REBAR3259)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

0 2 (1:200) 10m

MONITORING SITE 8 - SECTIONS

1:100

ISSUED INFORMATION

Issued for	Issue	Date	Issued By
Reference			
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Construction			
Record Drawings			

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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
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2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #8 - SECTIONS

KWL Project No. 478.120	Scale 1:200 H 1:200 V	**MON 8A**	
Sheet 13 of 27	Rev. No. 3	Drawing Number	
Client: BC HYDRO			

MONITORING SITE 9 - PLAN

1:100

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
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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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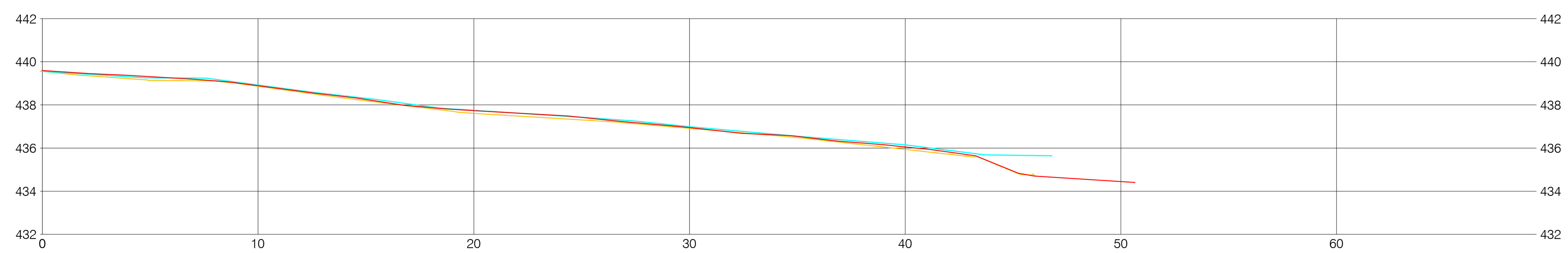
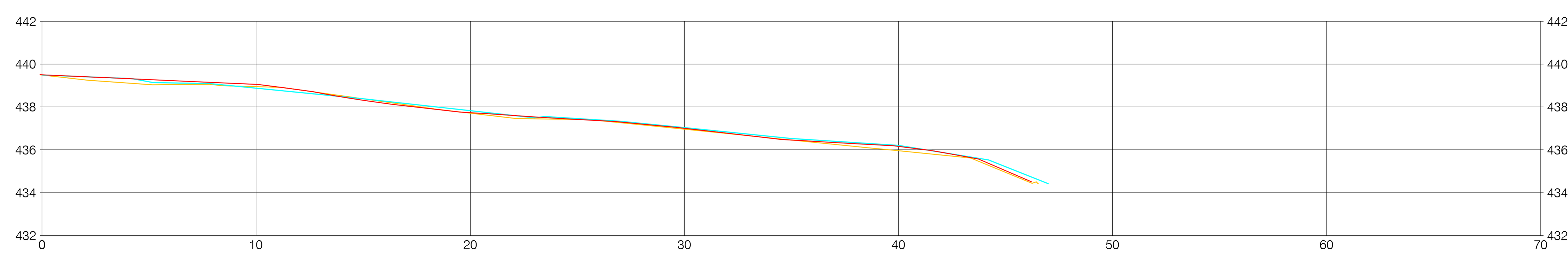
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #9

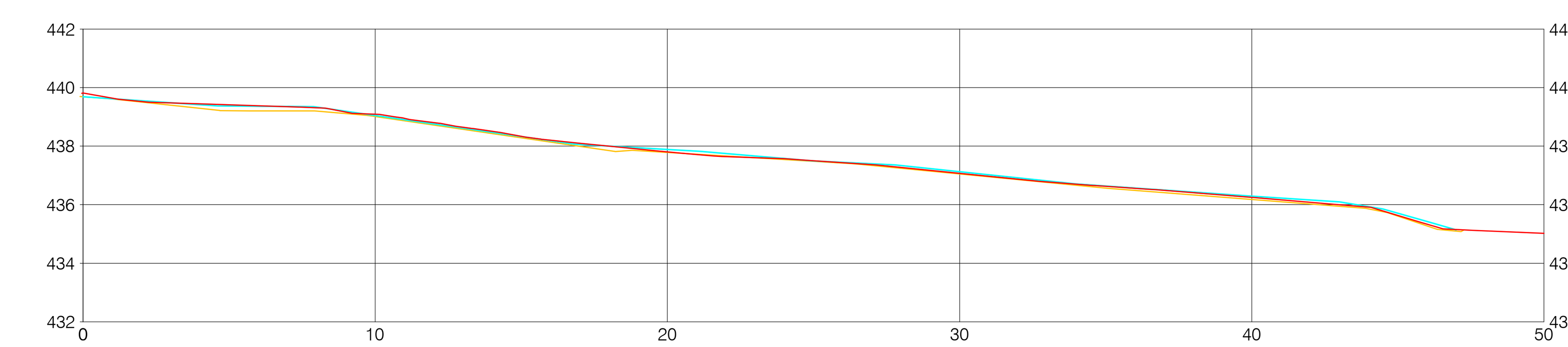
KWL Project No. 478.120		Scale 1:100	MON 9
Sheet 14 of 27		Rev. No. 3	Drawing Number
Client: BC HYDRO			



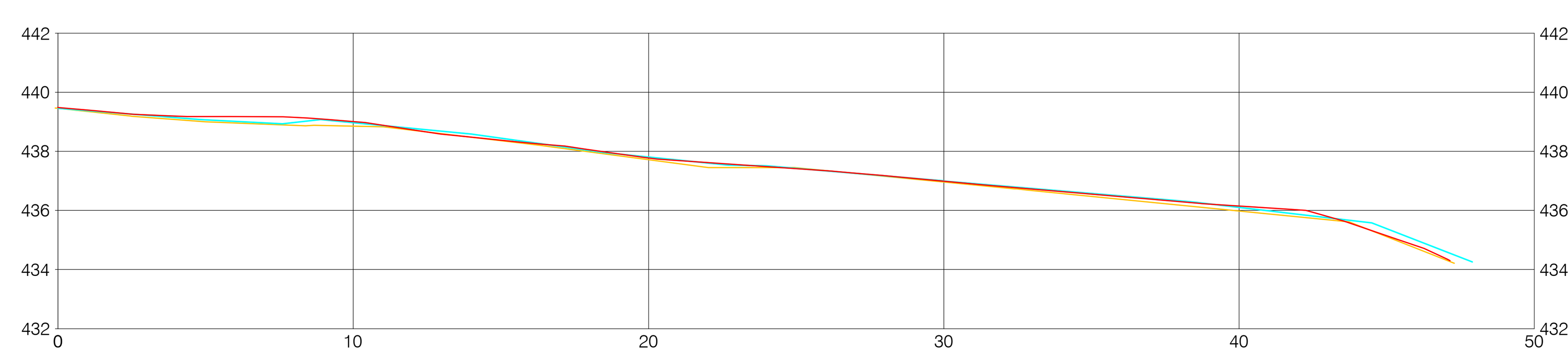
SECTION - 3 (REBAR3128)



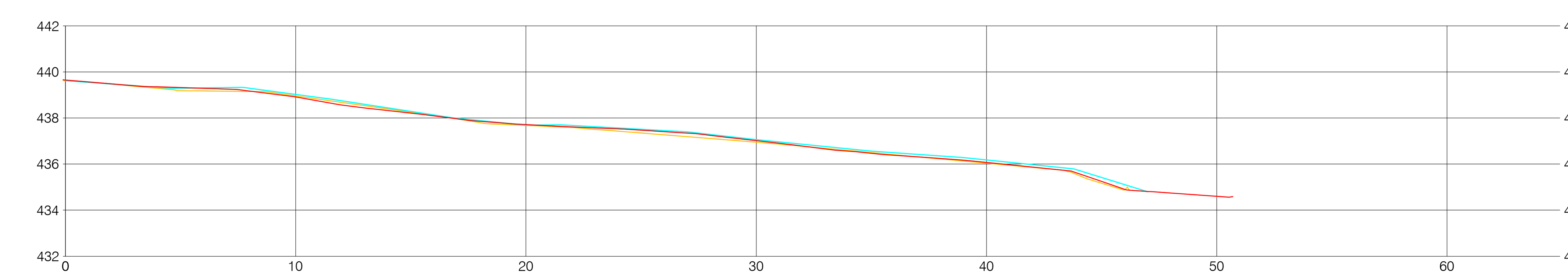
SECTION - 2 (REBAR3127)



SECTION - 5 (REBAR3130)



SECTION - 1 (REBAR3126)



SECTION - 4 (REBAR3129)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

0 2 (1:200) 10m

MONITORING SITE 9 - SECTIONS

1:200H, 1:200V

ISSUED INFORMATION

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

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2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #9 - SECTIONS

KWL Project No.	478.120	Scale	1:200 H 1:200 V
Sheet	15 of 27	Rev. No.	3

Client: BC HYDRO

MON 9A
Drawing Number

MONITORING SITE 10 - PLAN

1:100

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SAVED 14-Nov-2016 3:49 PM

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

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Construction			
Record Drawings			

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	DEC.16/11	DTM	BVC		ISSUED FOR 2011 REPORTING
1	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING
2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

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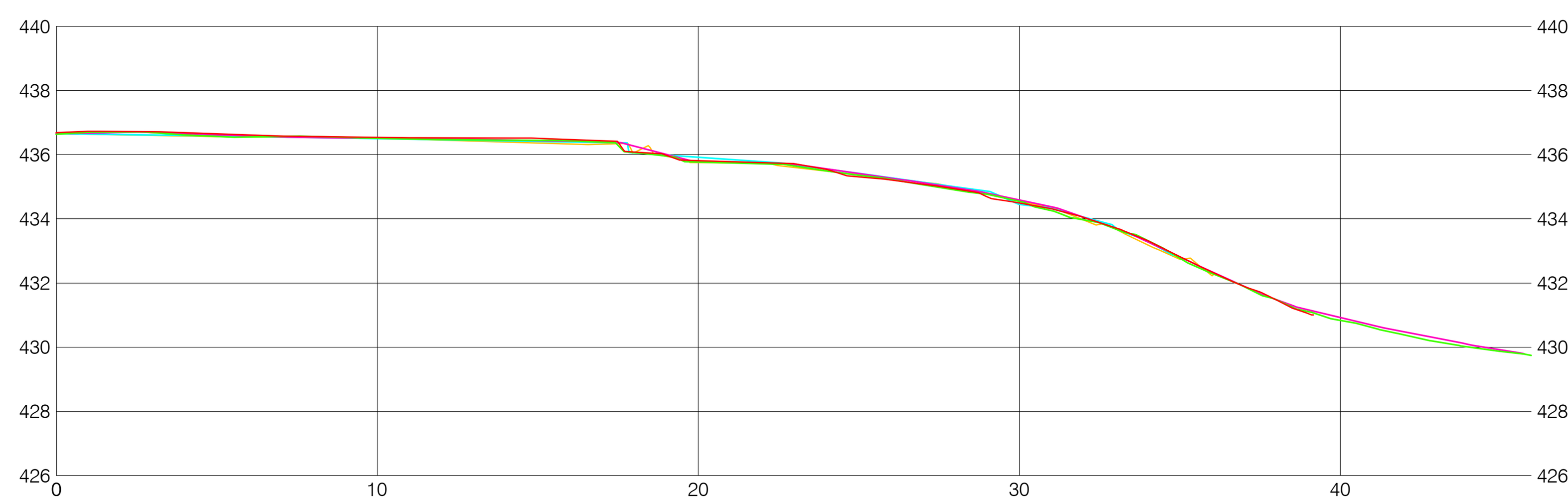
BC HYDRO
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #10

KWL Project No.	478.120	Scale	1:100	**MON 10**
Sheet	16 of 27	Rev. No.	3	Drawing Number
Client: BC HYDRO				

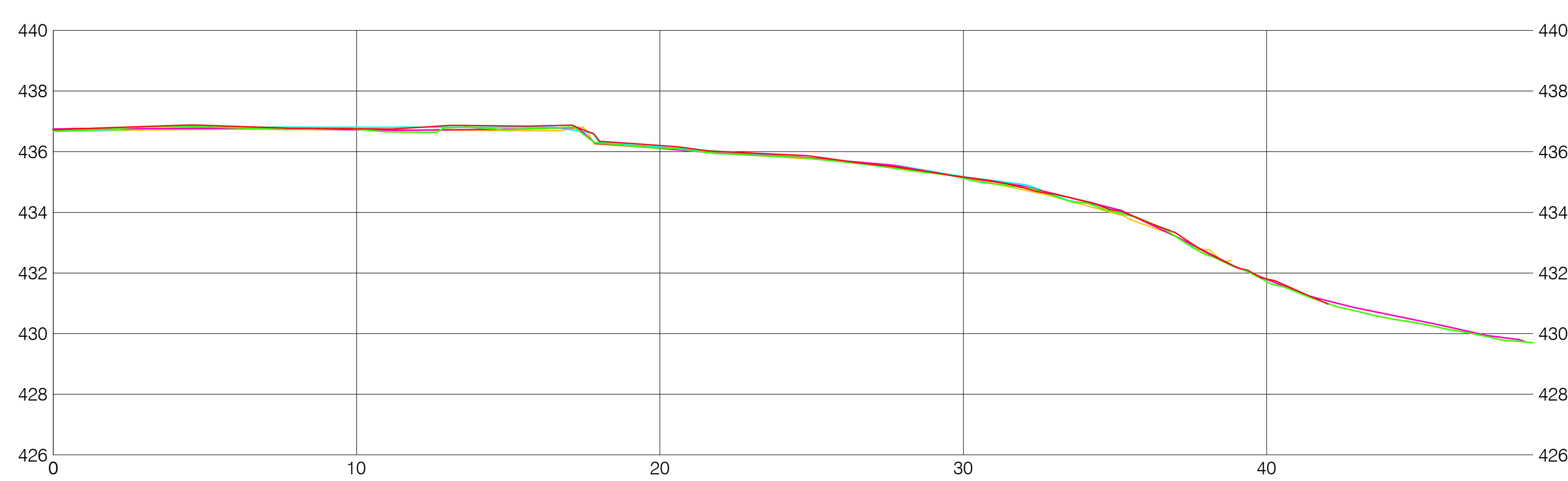
O:\0400-0499\478-120\500-Drawings\521-Production Drawings\EROSION MONITORING SITE #10.dwg   SAVED 14-Nov-2016 5:07 PM   AT FULL SIZE THIS BAR MEASURES 100mm. ALL SCALES REFERENCED TO FULL SIZE



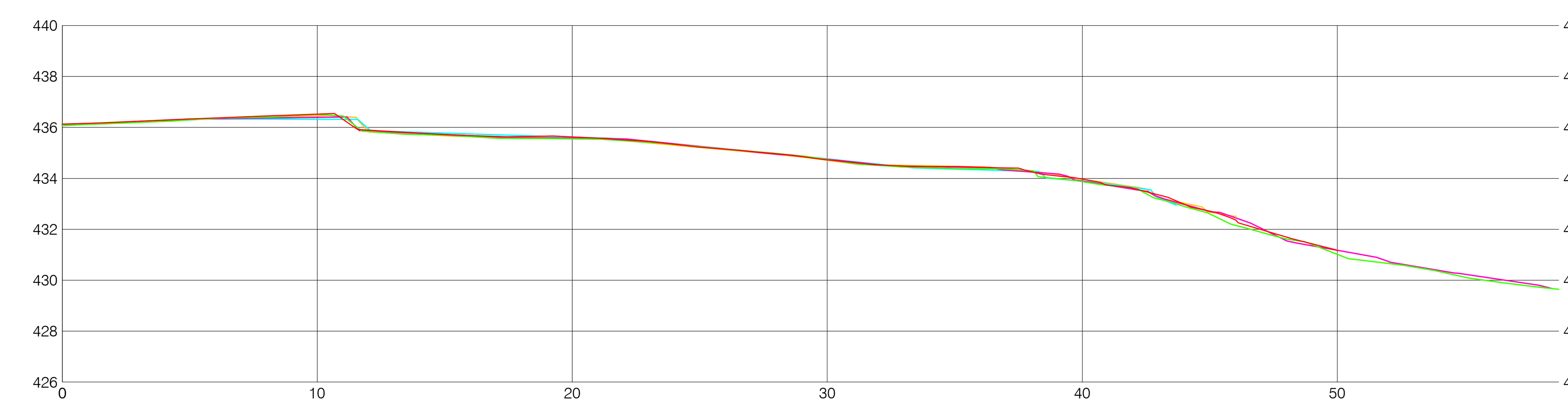
SECTION - 3 (REBAR3973)

LEGEND

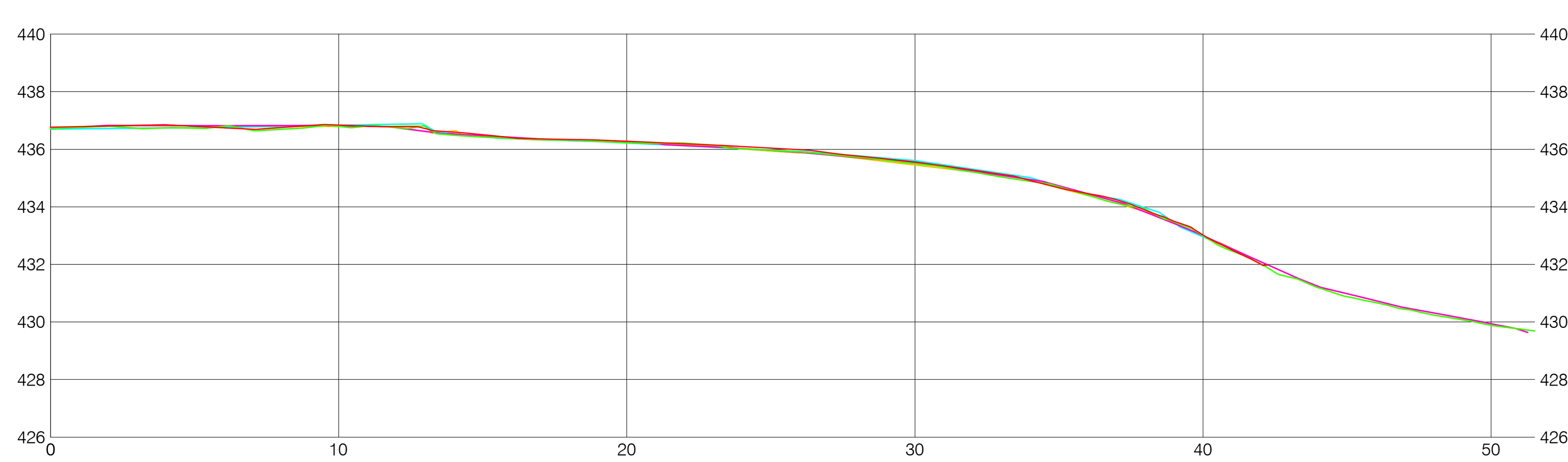
- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016



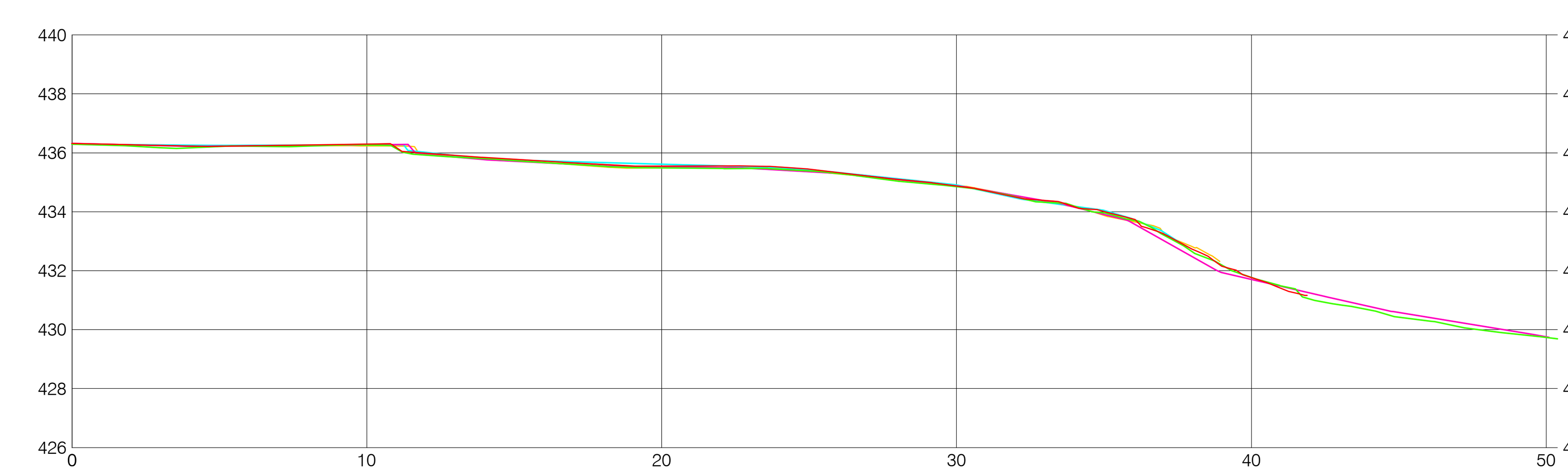
SECTION - 2 (REBAR3972)



SECTION - 5 (REBAR3975)



SECTION - 1 (REBAR3971)



SECTION - 4 (REBAR3974)

MONITORING SITE 10 - SECTIONS

1:200H, 1:200V

0 2 (1:200) 10m

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

REVISION INFORMATION: Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	DEC.16/11	DTM	BVC		ISSUED FOR 2011 REPORTING
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3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #10 - SECTIONS

KWL Project No. 478.120 | Scale 1:200 H 1:200 V
Sheet 17 of 27 | Rev. No. 3
Client: BC HYDRO

MON 10A
Drawing Number

MONITORING SITE 11 - PLAN

1:100

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

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
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3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #11

KWL Project No.	478.120	Scale	1:100
Sheet	18 of 27	Rev. No.	3
Client: BC HYDRO			

MON 11
Drawing Number

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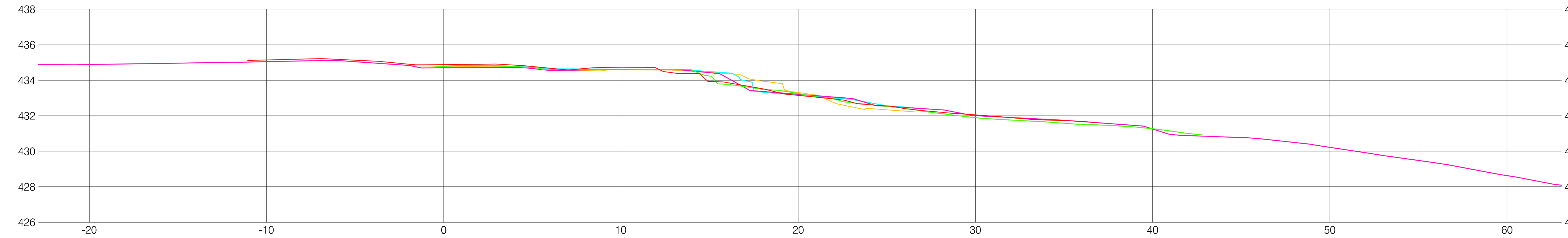

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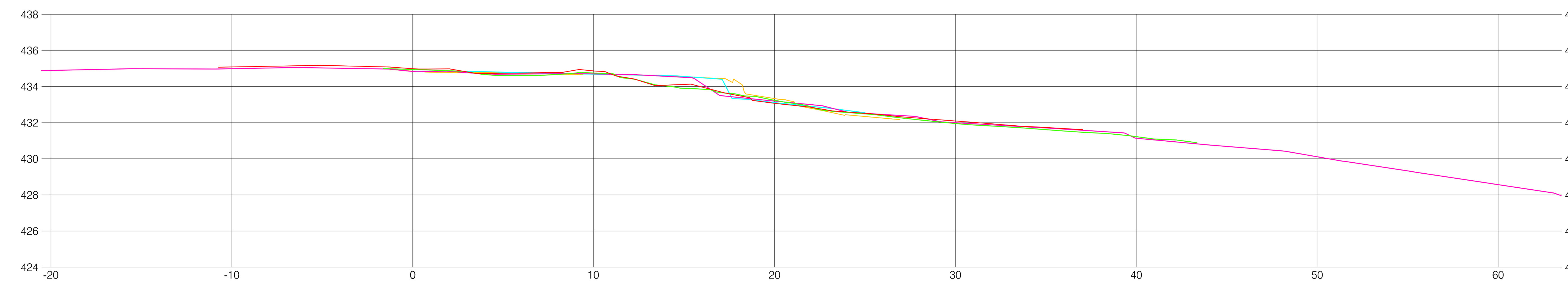
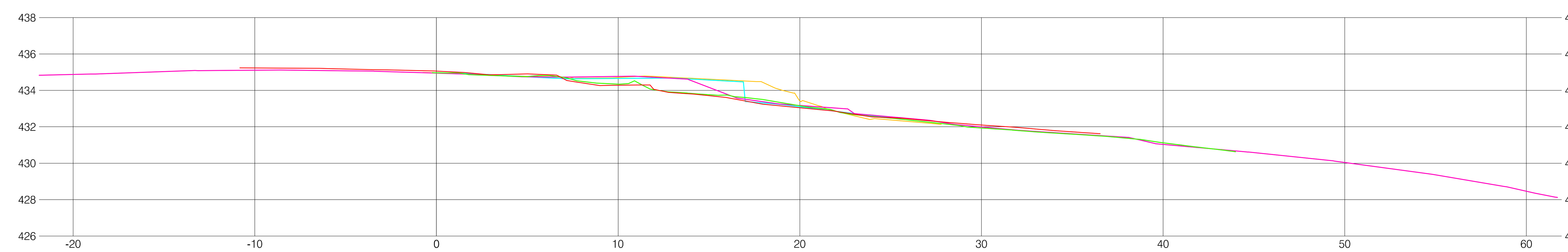


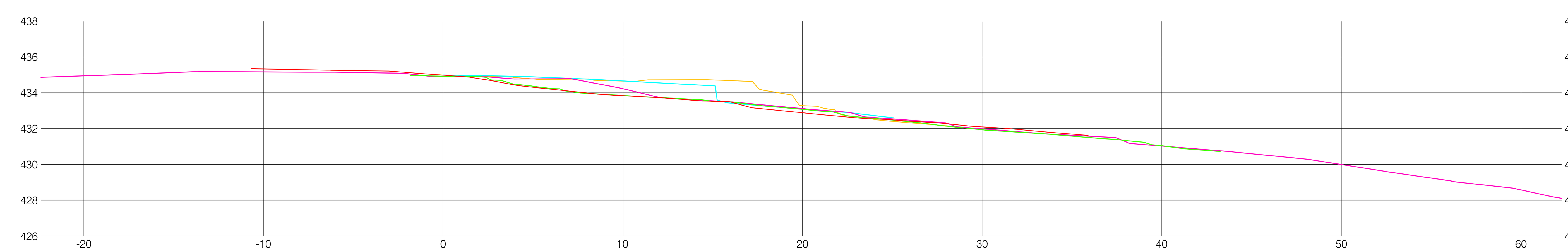
SECTION - 4 (REBAR3194)



SECTION - 3 (REBAR3193)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016



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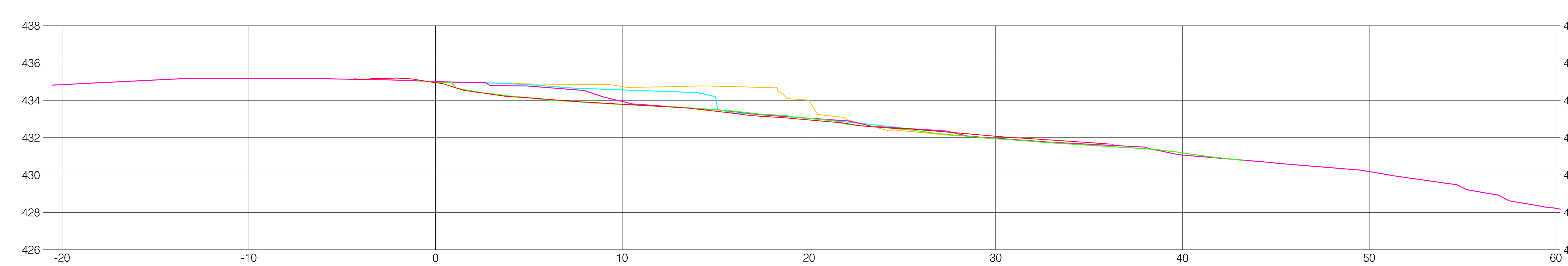

SECTION - 1 (REBAR3191)

MONITORING SITE 11 - SECTIONS

1:200H, 1:200V

0 2 (1:200) 10m

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

REVISION INFORMATION: Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	DEC.16/11	DTM	BVC		ISSUED FOR 2011 REPORTING
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3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #11 - SECTIONS

KWL Project No.	478.120	Scale	1:200 H 1:200 V
Sheet	19 of 27	Rev. No.	3
Client: BC HYDRO			

MON 11A
Drawing Number

MONITORING SITE 12 - PLAN

1:100

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

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

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #12

KWL Project No.	478.120	Scale	1:100
Sheet	20 of 27	Rev. No.	3
Client: BC HYDRO			

MON 12
Drawing Number

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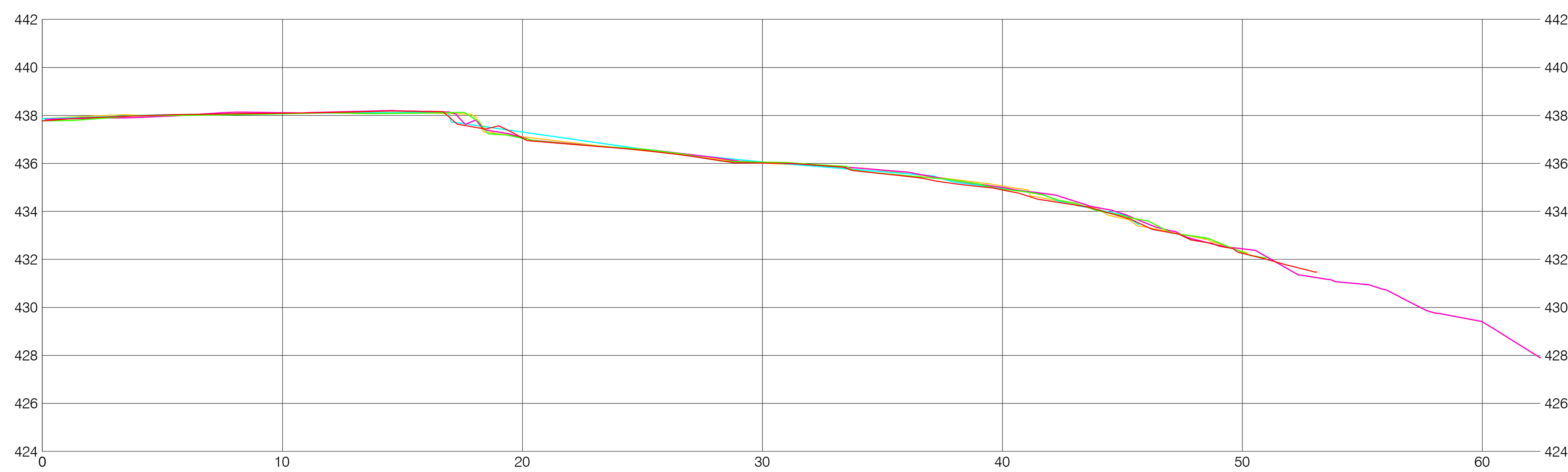
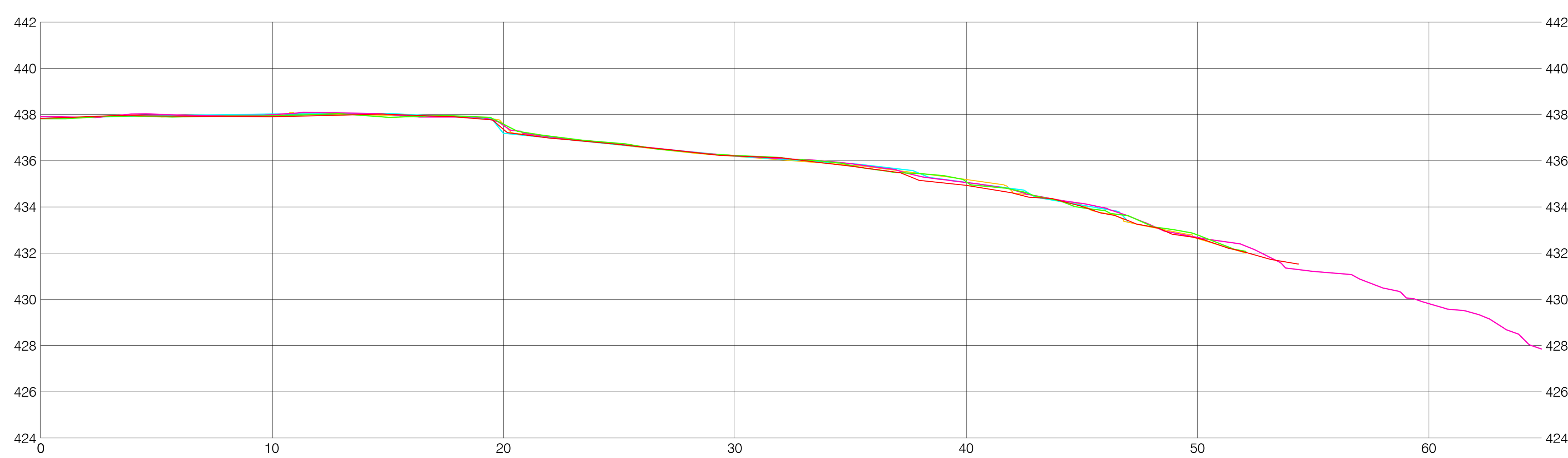
SAVED 14-Nov-2016 3:50 PM
AT FULL SIZE THIS BAR MEASURES 100mm. ALL SCALES REFERENCED TO FULL SIZE



SECTION -3 (REBAR3778)



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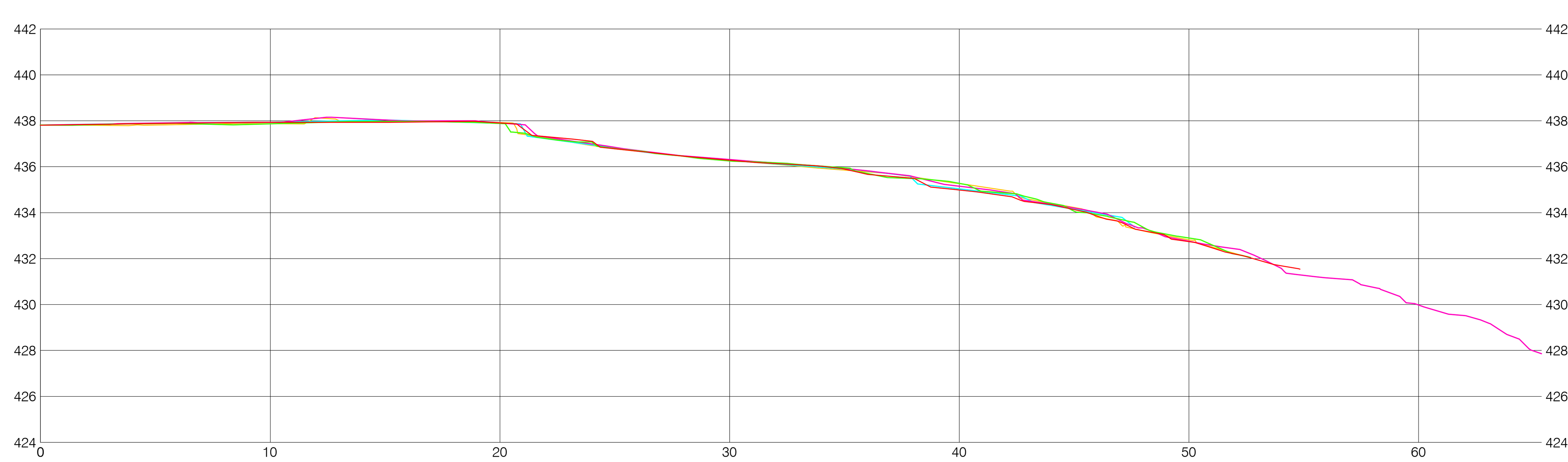

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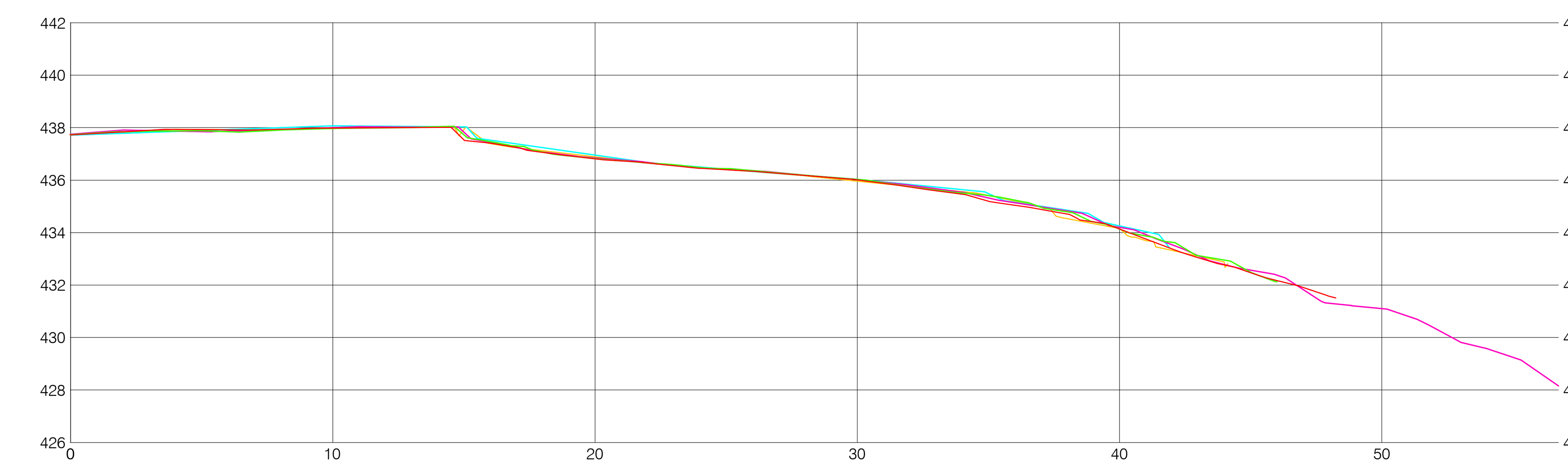

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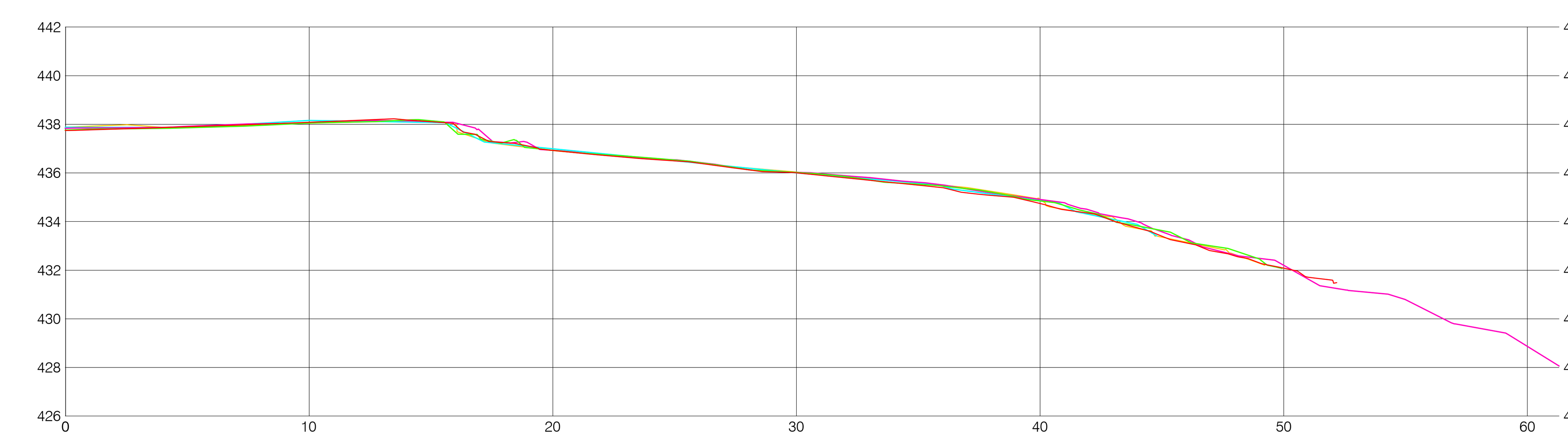

SECTION -4 (REBAR3779)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

0 2 (1:200) 10m

MONITORING SITE 12 - SECTIONS

1:200H, 1:200V

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

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	DEC.16/11	DTM	BVC		ISSUED FOR 2011 REPORTING
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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #12 - SECTIONS

KWL Project No.	478.120	Scale	1:200 H 1:200 V
Sheet	21 of 27	Rev. No.	3
Client: BC HYDRO			

MON 12A
Drawing Number

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

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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
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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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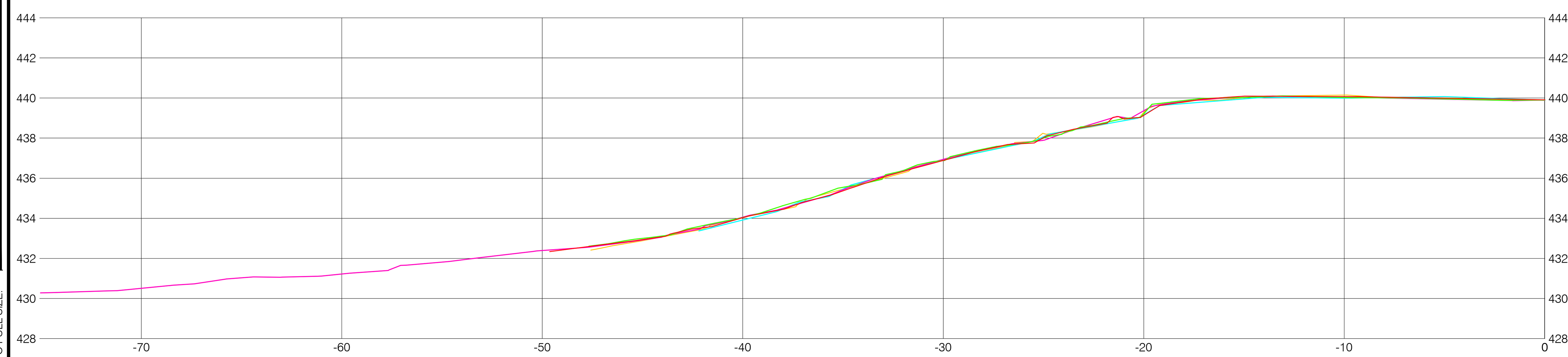
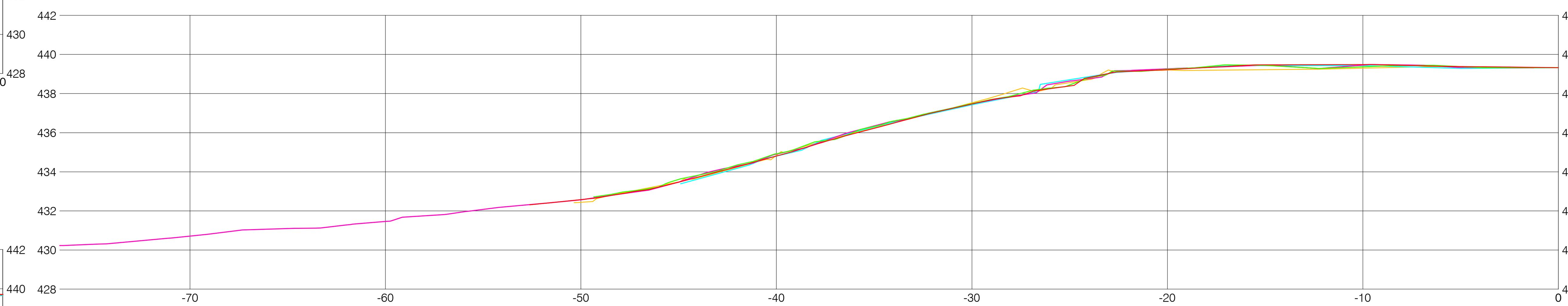
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #13

KWL Project No.	478.120	Scale	1:100
Sheet	22 of 27	Rev. No.	3
Client: BC HYDRO			

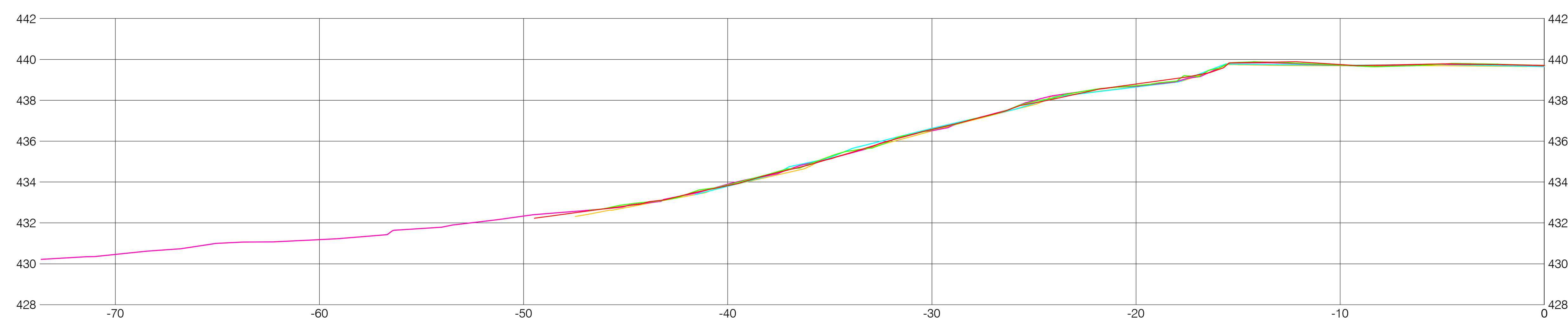
MON 13
Drawing Number



SECTION - 3 (REBAR3713)



SECTION - 5 (REBAR3715)



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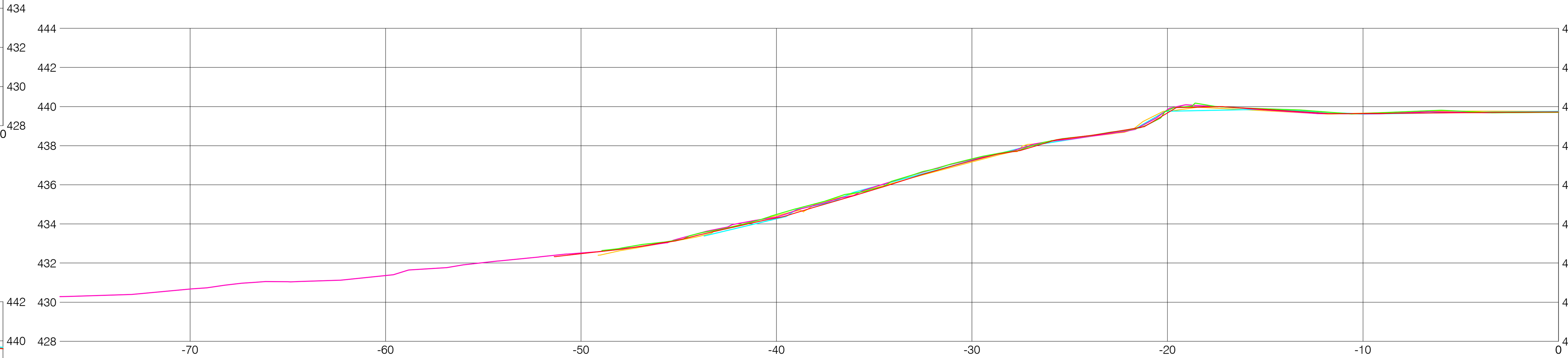
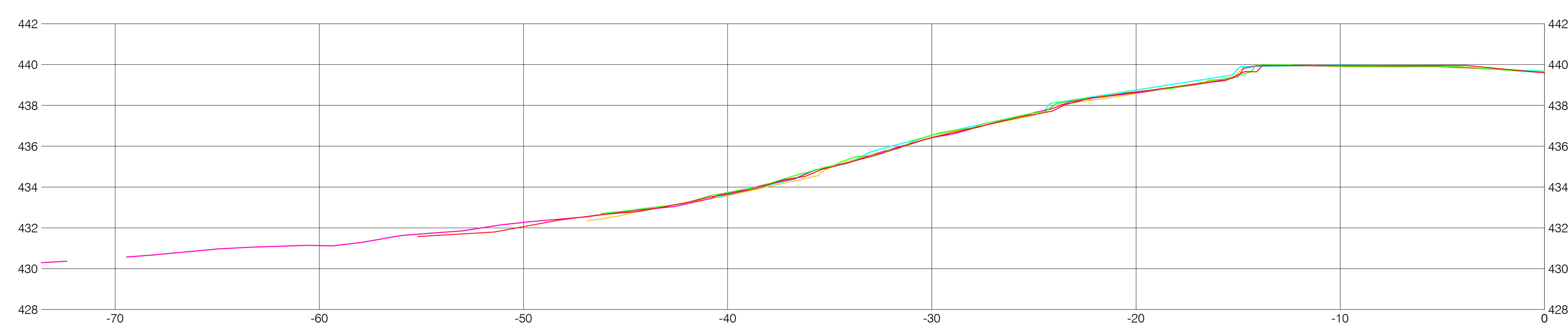


SECTION - 4 (REBAR3714)



SECTION - 1 (REBAR3711)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

MONITORING SITE 13 - SECTIONS

1:200H, 1:200V

0 2 (1:200) 10m

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

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Issued for	Issue	Date	Issued By
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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #13 - SECTIONS

KWL Project No.	478.120	Scale	1:200 H 1:200 V
Sheet	23 of 27	Rev. No.	3
Client: BC HYDRO			

MON 13A
Drawing Number

MONITORING SITE 14 - PLAN

1:100

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Issued for	Issue	Date	Issued By
Reference			
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Construction			
Record Drawings			

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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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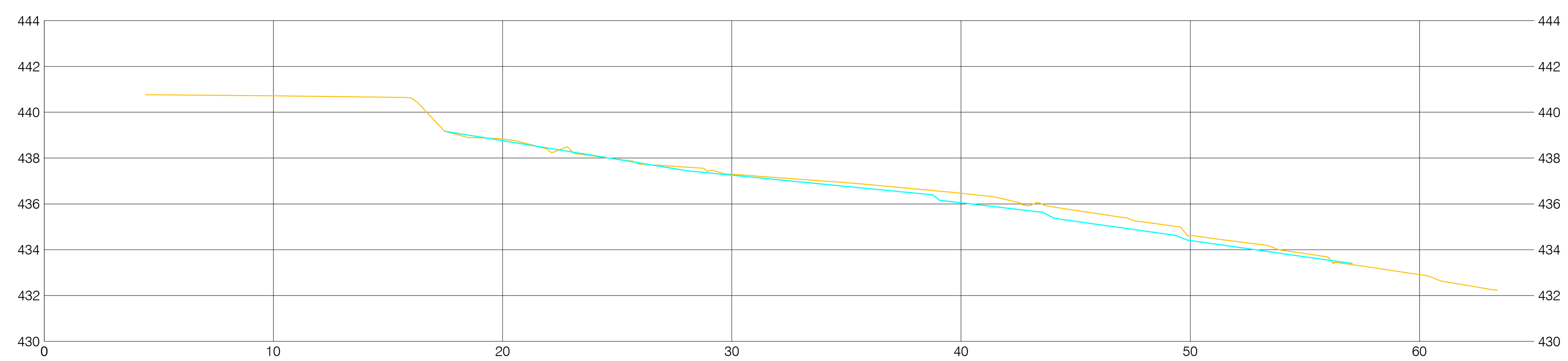
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #14

KWL Project No.	478.120	Scale	1:100
Sheet	24 of 27	Rev. No.	3
Client: BC HYDRO			

MON 14
Drawing Number



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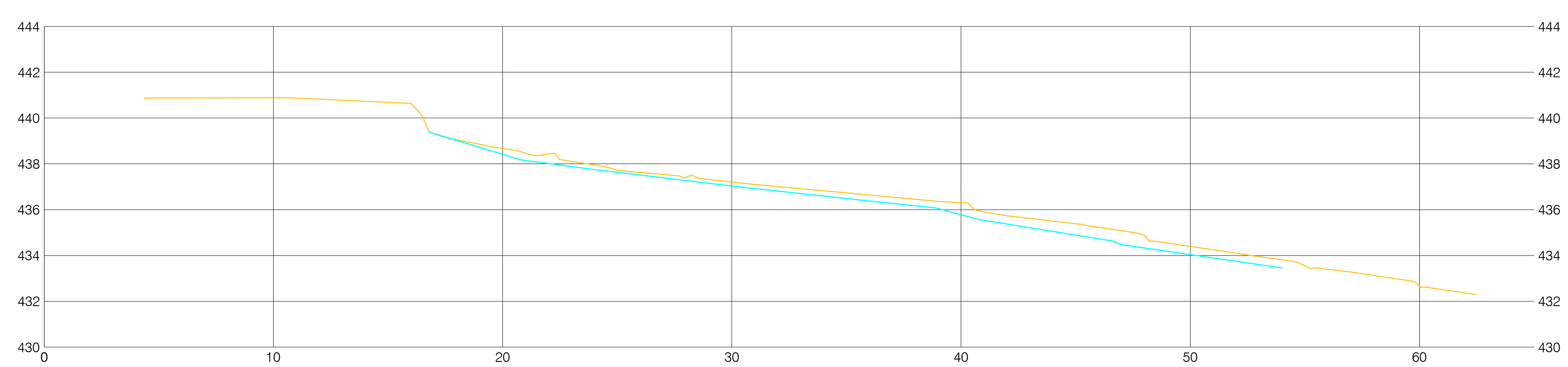

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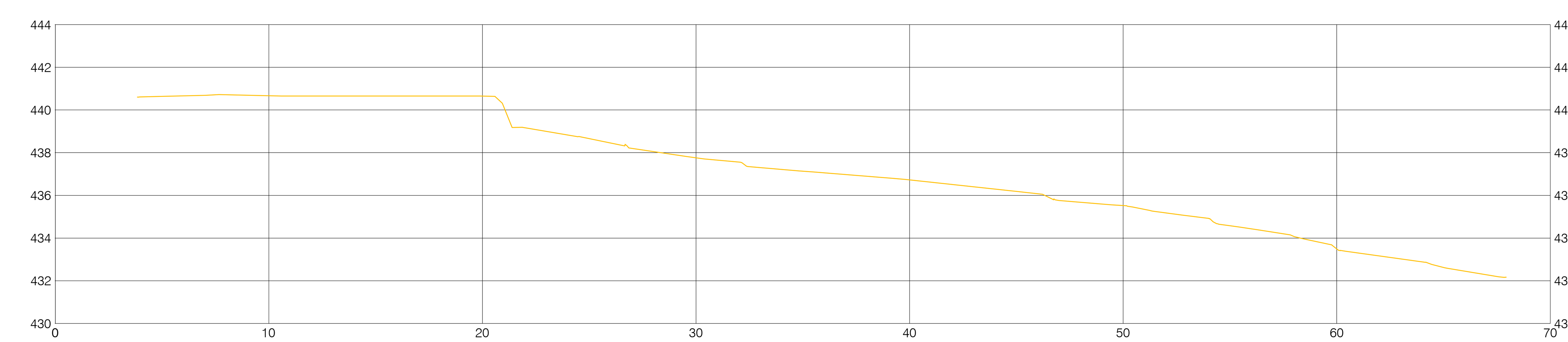

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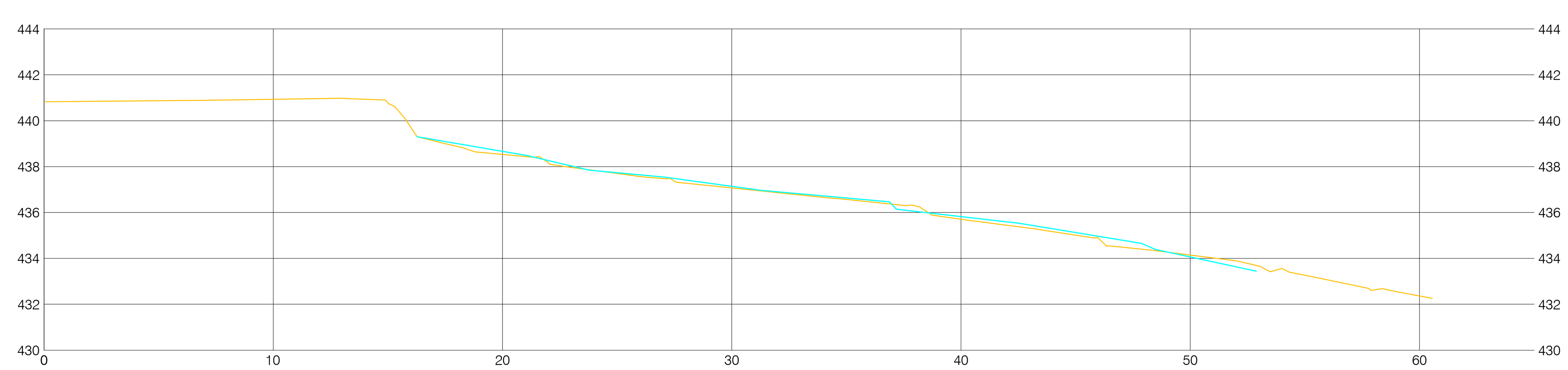

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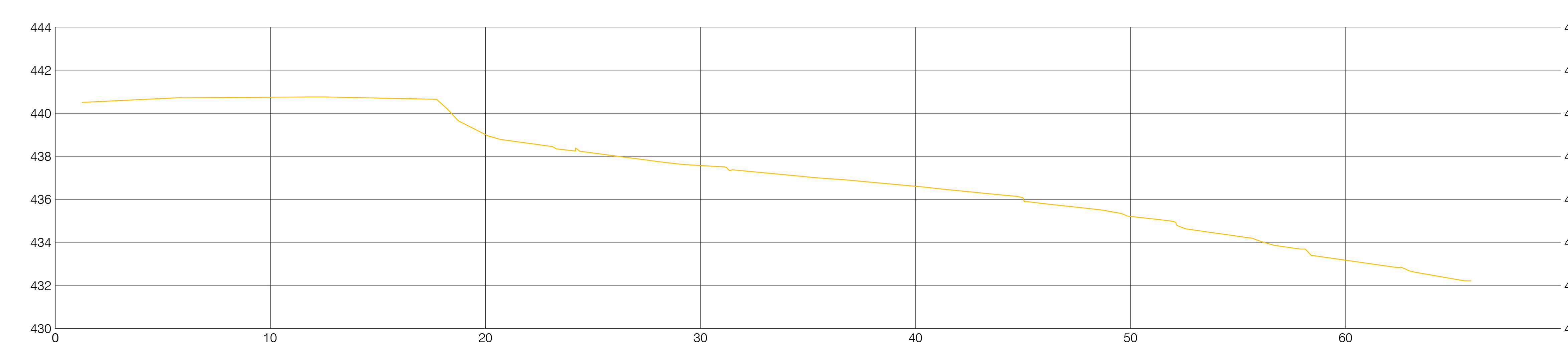

SECTION -4 (REBAR3649)

LEGEND

TRANSECT GROUND APRIL, 2010

TRANSECT GROUND OCTOBER, 2010

NOTE:

MONITORING SITE #14 NOT SURVEYED IN 2012/2014.

0 2 (1:200) 10m

MONITORING SITE 14 - SECTIONS

1:200H, 1:200V

ISSUED INFORMATION

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

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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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COLUMBIA RIVER EROSION MONITORING - CLB#36

EROSION MONITORING SITE #14 - SECTIONS

KWL Project No.	478.120	Scale	1:200 H 1:200 V
Sheet	25 of 27	Rev. No.	3

MON 14A Drawing Number

Client: BC HYDRO

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MONITORING SITE 15 - PLAN

1:100

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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
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3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

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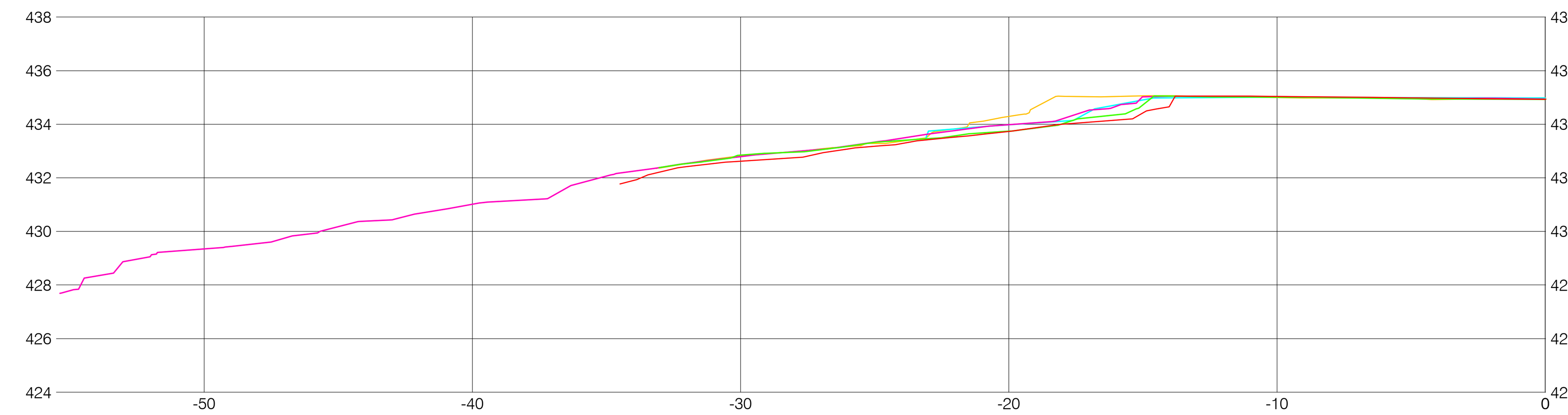
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #15

KWL Project No.	478.120	Scale	1:100
Sheet	26 of 27	Rev. No.	3
Client: BC HYDRO			

MON 15
Drawing Number



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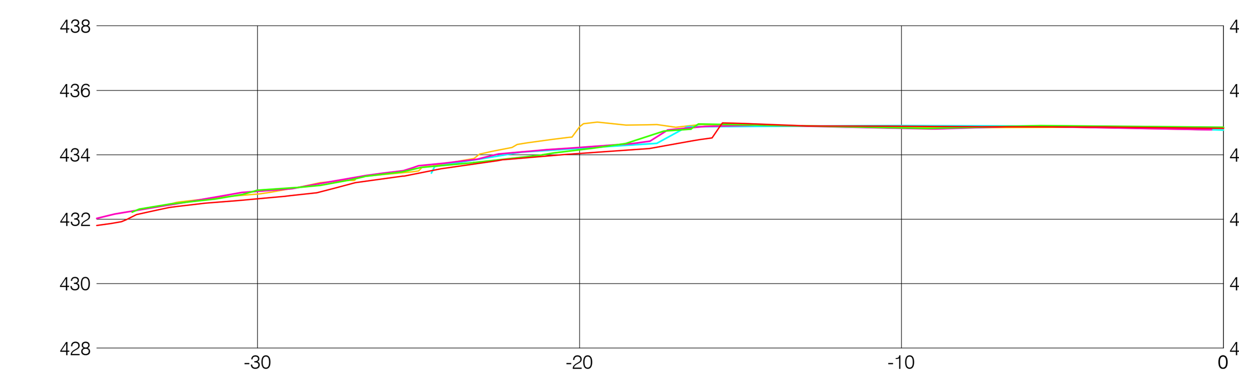
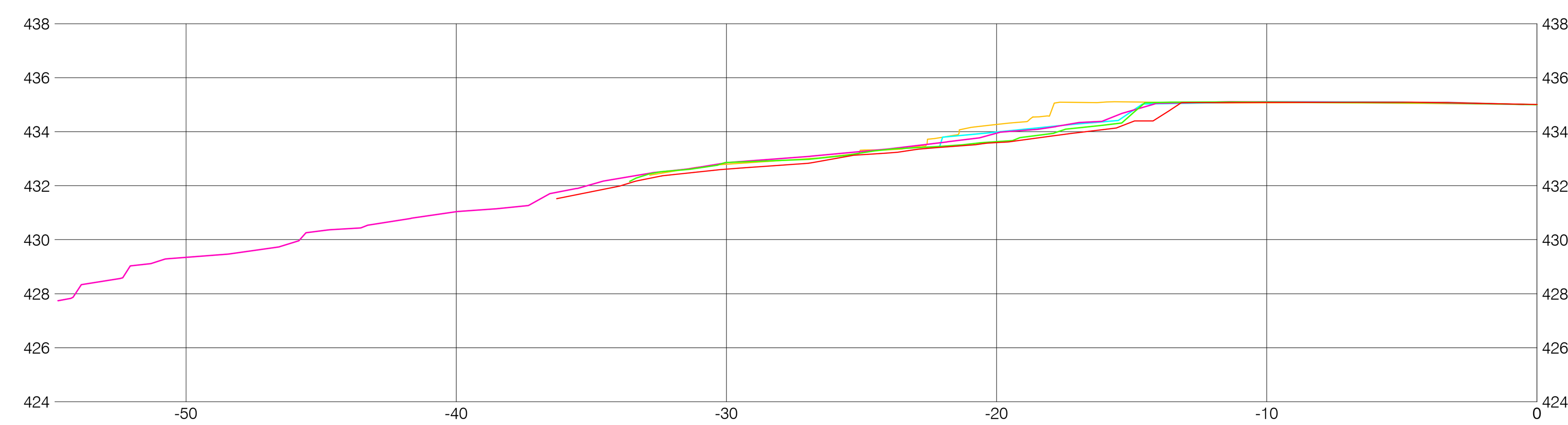


SECTION - 5 (REBAR3845)



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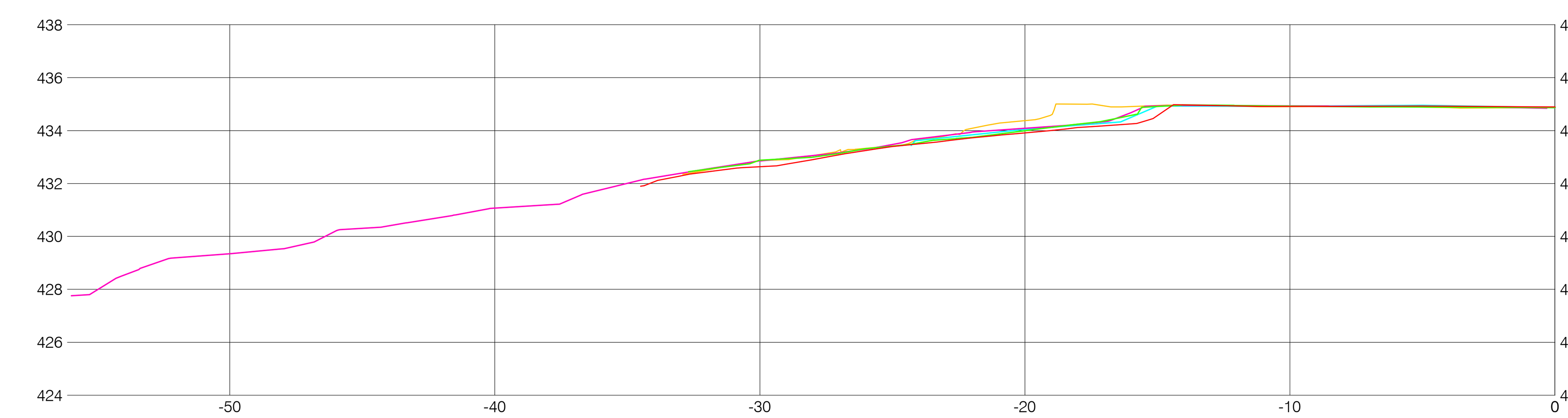
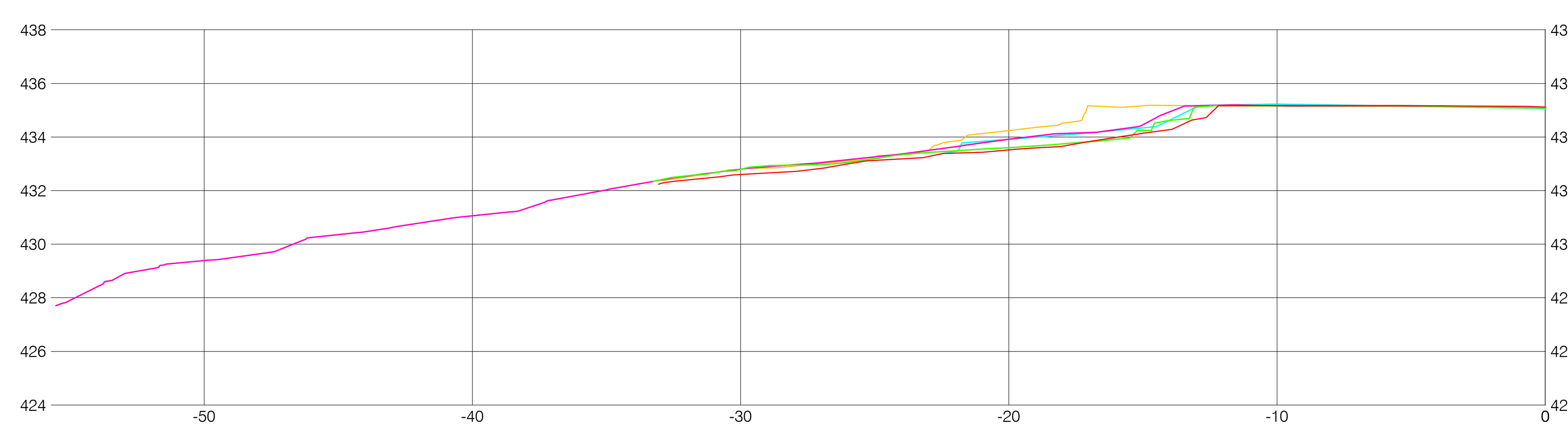


SECTION - 4 (REBAR3844)



SECTION - 1 (REBAR3841)

LEGEND

- TRANSECT GROUND APRIL, 2010
- TRANSECT GROUND JUNE, 2011
- TRANSECT GROUND APRIL, 2012
- TRANSECT GROUND APRIL, 2014
- TRANSECT GROUND MAY, 2016

0 2 (1:200) 10m

MONITORING SITE 15 - SECTIONS

1:200H, 1:200V

ISSUED INFORMATION

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

REVISION INFORMATION

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	DEC.16/11	DTM	BVC		ISSUED FOR 2011 REPORTING
1	JUL.27/12	DTM	BVC		ISSUED FOR 2012 REPORTING
2	NOV.17/14	DTM	BVC		ISSUED FOR 2014 REPORTING
3	NOV.15/16	EE	BVC		ISSUED FOR 2016 REPORTING

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision

Seal

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

BC HYDRO
COLUMBIA RIVER EROSION MONITORING - CLB#36
EROSION MONITORING SITE #15 - SECTIONS

KWL Project No.	478.120	Scale	1:200 H 1:200 V
Sheet	27 of 27	Rev. No.	3
Client: BC HYDRO			

MON 15A
Drawing Number