Columbia River Project Water Use Plan

Lower Columbia River Fish Management Plan

Implementation Year 3

Reference: CLBMON-47

Lower Columbia River: Whitefish Spawning Ground Topographic Survey: Year 3 Summary Report

Study Period: January 2011 to January 2014

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CLBMON - 47: YEAR 3

Lower Columbia River Whitefish Spawning Ground Topographic Survey

Submitted to:
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REPORT

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Cover Photo: Conducting ADCP surveys along selected channel cross sections at the confluence of the lower Columbia and Kootenay rivers, April 23, 2013.

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Glossary

BRD	Brilliant Dam
CPR	Canadian Pacific Railway
ELM	Egg Loss Model
GPS	Global Positioning System
GRTS	Generalized Random Tessellation Stratified
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HLK	Hugh L. Keenleyside Dam
LCR	Lower Columbia River
LDB	Left Downstream Bank
RDB	Right Downstream Bank
RTK	Real Time Kinematic
SEL	Sproulers’ Enterprises
TOR	Terms of Reference
UTM	Universal Transverse Mercator
WFM	Whitefish Flow Management
WUP	Water Use Plan

Executive Summary

Mountain whitefish (*Prosopium williamsoni*) are the most abundant sportfish in the Keenleyside Reach of the lower Columbia River [defined as the Columbia River from Hugh L. Keenleyside Dam (HLK) to the Canada-US Border and including the lower Kootenay River below Brilliant Dam (BRD)]. This species uses this area for all life history functions. Results of studies conducted by BC Hydro in the early 1990s raised concerns by the environmental regulatory agencies (BC Ministry of Environment, Lands and Parks; Department of Fisheries and Oceans Canada) about the effects of river regulation on Mountain Whitefish reproductive success in the lower Columbia River. Water level fluctuations associated with dam operations on both the Columbia (HLK) and Kootenay (BRD) rivers can negatively impact whitefish spawning success by exposing incubating embryos when water levels recede. These concerns led to the development and initiation of BC Hydro's Whitefish Flow Management (WFM) program in the winter of 1994/95. A series of intensive studies on Mountain Whitefish life history characteristics were subsequently conducted annually between 1995 and 1999. Additional annual studies were initiated in 2008 as a component of BC Hydro's Water Use Planning program and are scheduled to continue until 2013 (CLBMON 48: Lower Columbia River Whitefish Life History and Egg Mat Monitoring Program).

The present study was developed to provide data to support the refinement of the Mountain Whitefish Egg Loss Model (ELM) that is currently used to project the proportion of the deposited eggs within defined study areas that are dewatered during HLK and BRD operations. Refined hydraulic modelling was chosen as the primary tool to both assess habitat use by spawning Mountain Whitefish and determine project areas being dewatered during regulated flow changes in the Kootenay and Columbia rivers. Golder updated the existing HEC-RAS model for the Columbia River below HLK and the Kootenay River below BRD using the topographic survey data collected in 2011. The original Mountain Whitefish ELM includes HEC-RAS transects from Kinnaird and Tin Cup Rapids. These areas were not selected for topographic or ADCP surveys based on the relatively low numbers of stranded eggs found in these areas during previous studies. The updated HEC-RAS model adequately represented the river hydraulic situations of the key Mountain Whitefish spawning areas at CPR Island and the lower Kootenay River where spawning is prevalent.

In total, 40 cross sections were surveyed at the CPR Island key Mountain Whitefish spawning area. Eleven of the 40 cross sections characterized the spawning area near CPR Island. Topographical features of interest included steep-gradient areas along the right downstream bank, a channel between the left downstream bank and CPR Island that remained wetted at higher water elevations, shallow depths in the downstream portion of the spawning area, and relatively gentle nearshore gradients along the mainstem side of CPR Island. In the Kootenay River spawning area, 30 cross sections were surveyed for inclusion into the River2D hydraulic model. The Kootenay spawning area was divided into three separate sections based on topography and documented egg depositional rates. The downstream section of the Kootenay River spawning area is dominated by Kootenay Eddy and a large shallow bar that deflects and constricts the Kootenay River flow, creating a deep channel adjacent to the eddy, and a ridge between the eddy and the channel. The middle section is dominated by low gradient banks, a relatively wide thalweg with consistent depth, and a large backwater area downstream of two islands along the southern shore. The upstream section exhibits greater thalweg depths, and steep shorelines. Topographical features of interest in this portion include a shallow shoal and a bedrock outcrop along the north bank, as well as an island off the south bank.

Individual River2D hydraulic models were calibrated for the two key Mountain Whitefish spawning areas. The developed Columbia Reach River2D Hydraulic Model adequately represents the river hydraulic situations of the CPR Island spawning area. The results of the sensitivity analysis for this reach showed that the simulated water levels are not sensitive to variations in *Ks* (the effective roughness height, a bed resistance parameter). In the Kootenay Reach, the hydraulic situation is influenced by the water levels in the Columbia River at its confluence. High water levels in the Columbia River will cause backwater effects in the Kootenay River. During development and testing of the Kootenay River2D model, inconsistencies were found that were related to the hydraulic effects of the confluence. To address these inconsistencies, the model was expanded to incorporate the confluence in addition to the Kootenay River area. To facilitate the expansion of the Kootenay spawning area River2D model, a total of 30 cross sections were conducted in the confluence area of the Columbia and Kootenay rivers. The Kootenay River expansion area was divided into three separate sections based on documented topography; the area upstream of the confluence, the confluence, and downstream of the confluence. Topographical features of interest in the expansion area are a boulder garden and multiple benches and ridges in the upstream section and a trend of increasing depth in an upstream to downstream direction. After expansion, sensitivity analysis testing was conducted on the roughness height *Ks*. As in the Columbia Reach, it was shown that the simulated water levels are not sensitive to *Ks* variations along the Kootenay River Reach.

The River2D models allowed quantification of the fluctuations in river stage (water elevation) in the key spawning areas as a function of BRD and HLK discharges. River stage within these spawning areas was also shown to depend on the particular discharge levels of HLK and BRD that comprised the total discharge. At CPR Island, predicted water elevations and wetted area were higher if discharge from HLK made up the larger portion of combined discharge. This pattern was also observed in the Kootenay River if BRD discharge accounted for the larger portion of the combined discharge. As HLK discharge increased, the influence of BRD on wetted area at CPR Island decreased dramatically. On the other hand, HLK discharge had a large effect on Kootenay River wetted area under all examined BRD discharges, albeit this effect was somewhat smaller at high BRD discharge. Increases in water elevation resulted in a nonlinear increase in wetted area at both areas. Over the range of discharge documented in this study, the wetted area in the Kootenay River spawning area was typically 3 to 5 times higher than at CPR Island. As it is the larger of two spawning areas, the range of wetted area in relation to water elevation was substantially larger in the Kootenay River.

Under the current operating regime for both the HLK and BRD facilities during the Mountain Whitefish spawning period, daily flow changes are most likely to occur at BRD as load factoring. The extent of wetted area loss at both spawning sites due to load factoring at BRD decreased with increasing HLK discharge, although Kootenay River lost wetted area was greatest at intermediate HLK discharges. HLK discharge not only affects the amount of channel dewatering during load factoring, but also dictates specific habitat dewatering. If HLK discharge remains stable, the area dewatered during load factoring at BRD is consistent. Therefore, altering HLK discharge during load factoring will result in the daily dewatering of differing habitats. The timing of daily flow fluctuations also affects risk to eggs deposited during the load factoring period. As Mountain Whitefish are crepuscular spawners, the majority of newly spawned eggs will be deposited near dusk or dawn. Hence, if load-factored discharges are at their lowest during these periods, the majority of newly spawned eggs will be deposited below the daily dewatered zone, reducing potential stranding impacts.

Results from this work will provide updated models as tools for BC Hydro to reduce the uncertainty related to overall reliability of egg loss estimates and will help guide future management of this population. The progress made to address the study objectives and management questions is summarized in Table EI.

Table EI: CLBMON-47 Year 3, STATUS of OBJECTIVES and MANAGEMENT QUESTIONS

Management Question	Study Objective	Current Status
What are the topographic characteristics of the key spawning locations for Mountain Whitefish in the lower Columbia and Kootenay rivers?	To design and implement controlled topographical surveys to describe the characteristics of representative whitefish spawning locations in the lower Columbia and Kootenay rivers.	At the CPR Island spawning area, topographic features include steep gradient banks along the RDB, a channel between the LDB and CPR Island that remains wetted at higher water elevations, and shallow depths in the downstream portion of the spawning area. In the downstream portions of the Kootenay River, topographic features include Kootenay Eddy along the RDB, a large point bar that deflects and constricts the Kootenay River flow creating a deep channel along the LDB adjacent to the eddy, and a ridge between the eddy and the channel. The middle section is dominated by low gradient banks, a relatively wide thalweg with consistent depth, and a large backwater area downstream of two islands along the LDB. Topographic features of interest in the upstream portion include a shallow shoal and a bedrock outcrop along the RDB. The upstream section of the Kootenay expansion area is dominated by a large boulder garden in the mid-channel and along the LDB. Downstream of the boulder garden, multiple benches and ridges are present. In the mid-channel portion of the confluence section of the expansion area, the river bottom is relatively uniform. Along the LDB, the gradient gradually decreases, while along the RDB, gradients were typically steeper. The downstream section of the expansion area consists of steep gradients along both banks, while the mid-channel portion of the river bottom is relatively uniform.
What is the hydraulic response of the river to discharge fluctuations at these key spawning locations? How do changes in river discharge influence river stage, and how does river stage relate to wetted channel area at these key spawning locations?	Assemble, verify, analyze, and input new topographic data of the representative whitefish spawning locations into an existing 1-dimensional steady state hydraulic model (HEC-RAS model).	Updated topographic data were collected for the Kootenay River and Upper Reach of the Columbia River. The original HEC-RAS model was then updated and calibrated. The River2D models allowed quantification of changes in river stage (water elevation) with changes in combined discharge of BRD and HLK. River stage within these spawning areas also depended on the particular discharge levels of HLK and BRD that comprised the total discharge. At CPR Island, predicted water elevations and wetted area were higher if discharge from HLK made up the larger portion of combined discharge. At Kootenay, this pattern was observed if BRD discharge accounted for the larger portion of the combined discharge. As HLK discharge increased, the influence of BRD on wetted area at CPR Island decreased dramatically. Increases in water elevation resulted in a nonlinear increase in wetted area at both areas. Over the range of discharge documented in this study, the wetted area in the Kootenay River spawning area was typically 3 to 5 times higher than at CPR Island. As it is the larger of two spawning areas, the range of wetted area in relation to water elevation was substantially larger in the Kootenay River.
	Test and calibrate the HEC-RAS model to improve the accuracy of the model.	
	Assess the impact of the increased number of cross-sections and survey detail from the previous HEC-RAS model, and comment on the accuracy and reliability of the previous model.	
How do daily flow changes contribute to cumulative channel dewatering in key spawning areas over the whitefish reproductive period?	Refine and redevelop the Egg Loss Model, as appropriate, to enhance the reliability of outputs from the model.	The ELM was updated and redesigned as an R-based model. The updated version includes modeling of stranding across the entire River2D surface, rather than individual transects, and incorporates time, depth, and temperature effects on egg deposition and incubation. In addition, the model incorporates uncertainty of these effects and yields confidence intervals around the stranding estimates. The model is undergoing further refining, and will be included in its final form with the finalized version of this document.
	Document changes to the model and compare inter-annual egg loss estimates in relation to the flow stabilization index.	Egg loss estimates for CPR Island were slightly higher and less variable than estimates for the Kootenay River. At CPR Island, egg loss estimates were above 20% in all years examined (2007 to 2012), while the Kootenay River estimates were below 20% in all years. Inter-annual egg loss estimates did not appear to be correlated to the flow stabilization index.
N/A	Make recommendations for further refinement of both the topographic survey and ELM.	Recommendations to refine the River2D and Egg Loss models include: calibration of the River2D models at high flows, incorporating BC Hydro's substrate mapping data (when completed) into the ELM, field tests of the ELM's accuracy, and conduct more egg developmental experiments to refine ATU-to-hatch estimates. Recommended adjustments to how the flow stability index is calculated in the future were also presented.

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1.0 INTRODUCTION

1.1 Background

Mountain Whitefish (*Prosopium williamsoni*) are the most abundant sportfish in the Keenleyside Reach of the lower Columbia River [LCR - defined as the Columbia River from Hugh L. Keenleyside Dam (HLK) to the Canada-US Border and including the lower Kootenay River below Brilliant Dam (BRD)]. This species uses this area for all life history functions (Hildebrand and English 1991; R.L. & L. 1995). Although Mountain Whitefish do not support a recreational fishery in the lower Columbia River, they do represent an important indicator species in this ecosystem. Results of studies conducted by BC Hydro in the early 1990s raised concerns by the environmental regulatory agencies (i.e., BC Ministry of Environment, Lands and Parks; Department of Fisheries and Oceans Canada) about the effects of river regulation on Mountain Whitefish reproductive success in the lower Columbia River. Water level fluctuations associated with dam operations on both the Columbia (HLK) and Kootenay (BRD) rivers can negatively impact whitefish spawning success by exposing incubating embryos when water levels recede. In addition, armoured substrates found in regulated systems like the lower Columbia River have been identified as potentially detrimental to whitefish egg survival by decreasing the egg retention capabilities of incubation habitat. Flow regulation of the lower Columbia River may also affect whitefish spawning behaviour, hatch periodicity, and hatch success through the modification of flows that may provide essential spawning and hatching cues. Finally, flow fluctuations may also affect larval and juvenile Mountain Whitefish, which prefer near-shore rearing habitats with relatively low velocities and gradients (R.L. & L. 2001).

These concerns led to the development and initiation of BC Hydro's Whitefish Flow Management (WFM) program in the winter of 1994 and 1995. A series of intensive studies on Mountain Whitefish spawning and life history characteristics were subsequently conducted annually between 1995 and 1999 (R.L. & L. 1997, 1997a, 1998, 1998a, 1999, 2000, 2001, 2001a). These monitoring programs identified that whitefish eggs are dewatered by flow changes in the lower Columbia River (Golder 2003). A more recent Columbia River Water Use Plan (WUP) study, CLBMON-48 LCR: Whitefish Life History and Egg Mat Monitoring Program, was initiated by BC Hydro in 2008 to expand knowledge on Mountain Whitefish spawning and life history (Golder 2009, 2010, 2011, 2012a, 2014 in prep.).

In 2003, BC Hydro commissioned Golder Associates Ltd. (Golder) to develop the Mountain Whitefish Egg Loss Model (ELM), a tool that estimates the risk of egg loss under alternative WFM flow scenarios (Golder 2003). The Columbia River Water Use Planning Consultative Committee expressed concern about the reliability of the ELM for quantifying egg loss resulting from regulated flow changes (BC Hydro 2007). Currently the ELM estimates egg loss in four previously identified spawning areas during flow reductions from HLK and BRD. In each area, egg deposition along one HEC RAS transect is predicted. To update the ELM, the model will incorporate current topographical and hydraulic data from multiple transects in the key spawning areas, as well as current egg deposition and developmental rates from CLBMON-48.

The low quality and quantity of topographic data was also identified by the WUP Consultative Committee as a key data gap. Updated topographic information within identified Mountain Whitefish spawning areas will allow the ELM to provide more accurate estimates of egg loss by providing more precise information on egg deposition in relation to the velocities and depths used by spawning whitefish and to more accurately depict spawning areas that are subsequently dewatered. To address these uncertainties and data gaps, the Consultative Committee recommended the implementation of a monitoring program to study the topographic characteristics of representative whitefish spawning locations and to update the existing ELM (BC Hydro 2007).

In-depth topographic surveys had not been conducted previously in identified Mountain Whitefish spawning areas. The present study's site selection, approach, and design were based on the results of previous study programs on Mountain Whitefish distribution, movements, spawning behaviour, habitat selection, and early life stage biology in the lower Columbia River, plus the primary literature reviewed during and subsequent to these studies. This program represents knowledge gained by the study team from over eight years of study, including three years as part of BC Hydro's LCR WUP study program. Results from this work will provide updated models as tools for BC Hydro to reduce the uncertainty related to overall reliability of egg loss estimates and will help guide future management of this population.

1.2 Management Questions, Study Hypotheses and Objectives

As stated in the CLBMON#47 Lower Columbia River Whitefish Spawning Ground Topographic Survey Terms of Reference (TOR; BC Hydro 2007), the specific management questions for this study are:

1. *What are the topographic characteristics of the key spawning locations for Mountain Whitefish in the lower Columbia and Kootenay rivers?*
2. *What is the hydraulic response of the river to discharge fluctuations at these key spawning locations? How do changes in river discharge influence river stage, and how does river stage relate to wetted channel area at these key spawning locations?*
3. *How do daily flow changes contribute to cumulative channel dewatering in key spawning areas over the whitefish reproductive period?*

There are no management hypotheses with the above management questions, as this program has been designed to fill data gaps associated with uncertainties about the effects of flow fluctuations on key Mountain Whitefish spawning areas. This monitoring program has also been designed to update or replace and enhance the existing 1D HEC RAS Hydraulic Model and ELM as primary impact analysis tools required for the adaptive management program.

The specific objectives of the Lower Columbia River Whitefish Spawning Ground Topographic Survey Program (the Program) are as follows:

1. *To design and implement controlled topographic surveys to describe the characteristics of representative whitefish spawning locations in the lower Columbia and Kootenay rivers.*
2. *Assemble, verify, analyze and input new topographic data of the representative whitefish spawning locations into an existing 1-dimensional steady state hydraulic model.*
3. *Test and calibrate the model to improve the accuracy of the model.*
4. *Refine and redevelop the Egg Loss Model, as appropriate, to enhance the reliability of outputs from the model.*
5. *Document changes to the model and compare inter-annual egg loss estimates in relation to the flow stabilization index.*
6. *Assess the impact of the increased number of cross-sections and survey detail from the previous model, and comment on the accuracy and reliability of the previous model.*
7. *Make recommendations for further refinement of both the topographic survey and ELM.*

1.3 Study Design and Rationale

1.3.1 Key Spawning Area Selection

Sampling effort and analysis for this program were concentrated in the two key Mountain Whitefish spawning areas:

- CPR Island on the Columbia River (Appendix A, Sheet 4 between transects 10 and 18); and,
- The lower Kootenay River (Appendix A, Sheet 1 between transects 6 and 30).

Based on data from previous studies, these two areas are used consistently and extensively for Mountain Whitefish spawning, and exhibit the range of depths, substrate, and velocity characteristics utilized by the majority of spawning whitefish (R.L. & L. 2001, Golder 2010, 2011 and 2012a). Egg catch rates indicate a substantially lesser degree of use of other spawning areas compared to the key spawning areas at the CPR Island and Kootenay River sites (Golder 2010). The physical habitat characteristics at these spawning areas are similar to those found at other areas in the LCR; the reasons why Mountain Whitefish spawn in some specific areas but not in other apparently similar areas is unknown, but could be related to site fidelity or microhabitat conditions in the vicinity of spawning habitats. The main purpose of this program is to study those habitat conditions to determine which conditions are preferred by spawning whitefish, and how flow manipulation changes these conditions.

1.3.2 Topography Surveys

To collect the required topographic data to upgrade the existing HEC RAS model, boat- and land-based topographic surveys were conducted at the selected cross sections. This sampling methodology provided the field crew with the flexibility needed to accurately survey each cross section up to the high water mark of each river bank with sufficient detail to meet the objective of developing bathymetric contours with 0.25 m resolution.

1.3.3 Velocity Measurements for River2D Hydraulic Model Development

Depth, substrate, and velocity are the three physical factors that appear to have the most influence on the selection of the specific river bed location where Mountain Whitefish release their eggs (R.L.&L. 2001). Of these, velocity is the most difficult to measure and consequently, is the least understood in terms of possible effects on egg deposition and subsequent downstream dispersion. Flow regulation alters both depth and velocity, and both are usually highly correlated with spawning site selection in salmonids. Therefore, the use of depth as the only variable in the hydraulic model precludes the examination of velocity as a covariate with depth in the prediction of egg deposition location. This could potentially constrain the predictive ability of the ELM that is presently based solely on predicting the depth at which eggs are deposited. To identify the effects of velocity on egg deposition location, velocity was measured in the CPR Island and Kootenay spawning areas along the same transects sampled during the topographic surveys. The data set collected was sufficient to allow for the development of the River2D hydraulic model (Section 1.3.5).

The use of an Acoustic Doppler Current Profiler (ADCP) to collect velocity data reduced the challenge of maintaining position in fast flowing water to obtain point velocity data. This allowed a more accurate characterization of the velocity throughout the water column and along the channel transect.

1.3.4 Velocity Measurements during CLBMON-48 Egg Collection Mat Monitoring

Additional ADCP sampling was conducted in conjunction with the ongoing Mountain Whitefish spawning assessment program (CLBMON-48). This provided a dataset of velocity measurements during the actual Mountain Whitefish spawning period that can be used to validate the model while also providing important information that can be used by the spawn monitoring program. During peak spawning, the GPS coordinates, depth, and the water column velocity profile were recorded at all deployed paired egg collection mat sets. As the exact location where the substrate mat is situated on the river bottom is not always known, the ADCP was used to obtain velocity data along several selected transects at each sample area to more accurately characterize flow conditions within each site. These data were used to supplement the dataset used in developing the River2D hydraulic model and ELM.

1.3.5 River2D Hydraulic Development

The main objective of the CLBMON-47 program was the creation and calibration of the River2D Hydraulic Models for the Canadian Pacific Railway Island (CPR; Figure 1) and Kootenay River (Figure 2) key Mountain Whitefish spawning areas selected in Year 1 (Golder 2012). River2D is a two dimensional depth averaged finite element hydrodynamic model that has been specially customized for fish habitat evaluation studies. The River2D Model, which was developed by the University of Alberta (Steffler and Blackburn 2002), was proposed for use in this study. To develop the models, the BC Hydro Hydrological Engineering Centers River Analysis System (HEC-RAS) Model, which was updated in Year 1 of this study, was used to establish boundary conditions for the models within each spawning area. The River2D models were then created using the assembled data during the Year 1 topographic survey and the ADCP measurements (Golder 2012).

The 2D Model can be used for predicting water surface elevations, depths, and velocities at multiple cross sections collected within each of the two key spawning areas that are the major contributors to the spawning population. As requested by the TOR (BC Hydro 2007), the 2D Hydraulic Model will also provide 25 cm vertical resolution at each of the cross sections, and would be sensitive to water levels in both the Kootenay and Columbia rivers.

1.3.6 River2D Model Calibration

After the creation of the River2D Hydraulic Models, field activities were conducted to calibrate the models. This calibration involved conducting additional Acoustic Doppler Current Profiler (ADCP) surveys to augment those conducted in Year 1. These additional surveys were conducted at the sampling transects (Figure 1 and Figure 2) established in Year 1 at lower Columbia River discharges. Lower discharges were selected for the calibration process as these would be the most representative of conditions in the spawning areas during egg deposition and incubation. High flows in the summer of 2012 delayed the Year 2 calibration sampling until late fall 2012 and submission of 2012 reporting. Calibration of the expanded Kootenay River2D Model occurred in Year 3 of this study.

1.3.7 Expansion of the Kootenay River Spawning Area River2D Hydraulic Model

Initially, the Kootenay River Model ended at the confluence of Columbia and Kootenay rivers (Figure 2). Inconsistencies were found in the Kootenay River2D Hydraulic Model during development, which were related to the confluence of the Columbia and Kootenay rivers. To address these inconsistencies, the model was expanded to incorporate the confluence, as well as a 1 km section of the Columbia River extending 500 m upstream and downstream from the confluence as well (Figure 2).

1.3.7.1 Selection of Cross Sections in Expanded Kootenay River Model Area

The selection of cross sections within the expanded Kootenay River area was consistent with the methodology used in Year 1. In total, 30 cross sections in each spawning area were selected for sampling. These included 20 main sample transects and 10 over-sample transects that may be sampled if some of the main transects could not be sampled due to logistical constraints (Figure 2).

1.3.7.2 Topographic Surveys

To collect the required topographic data to expand the existing Kootenay River Hydraulic Model, boat- and land-based topographic surveys were conducted at the selected cross sections (Section 2.5). As in Year 1, this sampling methodology provided the field crew with the flexibility needed to accurately survey each cross section up to the high water mark of each river bank with sufficient detail to meet the objective of developing bathymetric contours with 0.25 m resolution.

1.3.7.3 ADCP Transects

To remain consistent with Year 1 methodology, an Acoustic Doppler Current Profiler (ADCP) was used to collect velocity data in the study area. This reduced the challenge of maintaining position in fast flowing water to obtain point surface velocity data and allowed for a more accurate characterization of the velocity throughout the water column and along the channel transect.

To allow for expansion of the Kootenay River2D Model, water velocity was measured along the same transects sampled during the topographic surveys in the expanded area. The dataset collected was sufficient to allow for the development and calibration of the River2D Hydraulic Models.

1.3.8 Water Elevation Measurements

After the incorporation of the expanded area into the existing Kootenay River hydraulic model, inconsistencies in the predicted water elevations downstream of the Columbia/Kootenay confluence occurred during test runs of the model. To calibrate the model to remove these inconsistencies, additional water elevation measurements were conducted (Figure 3 and Section 2.5.1). These measurements were conducted throughout the study area to allow for additional calibration of both CPR Island and Kootenay River2D hydraulic models.

1.3.9 Mountain Whitefish Egg Loss Model (ELM) Updating/Development

Work on updating the current ELM was not conducted in Years 1 and 2 of this program. The model was updated in Year 3 after both River2D Hydraulic Models were completed and calibrated. The updated ELM includes data from the River2D Models, as well as data collected during Mountain Whitefish spawn monitoring as part of the CLBMON-48: Whitefish Life History and Egg Mat Monitoring program.

2.0 METHODS

2.1 Study Area

The geographical scope of the CLBMON-47 study area was the approximately 2.5 km section of the mainstem Columbia River from the ferry landing in Robson, BC to the upstream end of Tin Cup Rapids (Figure 1). The study area also included the 1.8 km section of the lower Kootenay River from the Highway 3A Bridge to the confluence with the Columbia River. The expanded Kootenay River2D Model encompasses the 1 km section of the Columbia River extending 500 m upstream and downstream from the confluence (Figure 2). The cross sections selected for sampling in each spawning area are also presented in Figure 1 and Figure 2.

2.2 Study Period

Sampling activities in Year 1 consisted of ADCP and topographic surveys to update the existing HEC-RAS model and to develop both River2D hydraulic models (Table 1). In Year 2, the ADCP and topographic surveys were conducted to calibrate both River-2D models and expand the Kootenay Model. Year 3 sampling was conducted solely to collect data for model calibration. The chronology of all field sampling activities during the CLBMON-47 program is outlined in Table 1.

Table 1: Chronology of sampling activities for the CLBMON-47 Lower Columbia River Whitefish Spawning Ground Topography Survey Program.

Date(s)	Year 1 Sampling Activities
January 13 and 14, 2011	ADCP surveys in Kootenay River spawning area
April 11 and 18, 2011; May 6, 2011	Topographic ground surveys and control
April 19, 25 and 29, 2011; May 3 2011	Topographic surveys in Kootenay River spawning area
April 26 and 28, 2011; May 4 and 5, 2011	Topographic surveys in CPR Island spawning area
August 12 and 13, 2011	ADCP surveys in CPR Island spawning area

Date(s)	Year 2 Sampling Activities
November 20, 2012	ADCP surveys in CPR Island and Kootenay River spawning areas to calibrate existing models
November 21, 2012	ADCP surveys in Kootenay River expanded area
November 27 and 28, 2012; and, December 12 and 13; 2012	Topographic surveys in Kootenay River expanded area

Date(s)	Year 3 Sampling Activities
April 23 and 24, 2013	ADCP surveys in Expanded Kootenay model area to calibrate the model
May 3, 2013	Water level elevation measurements in entire study area

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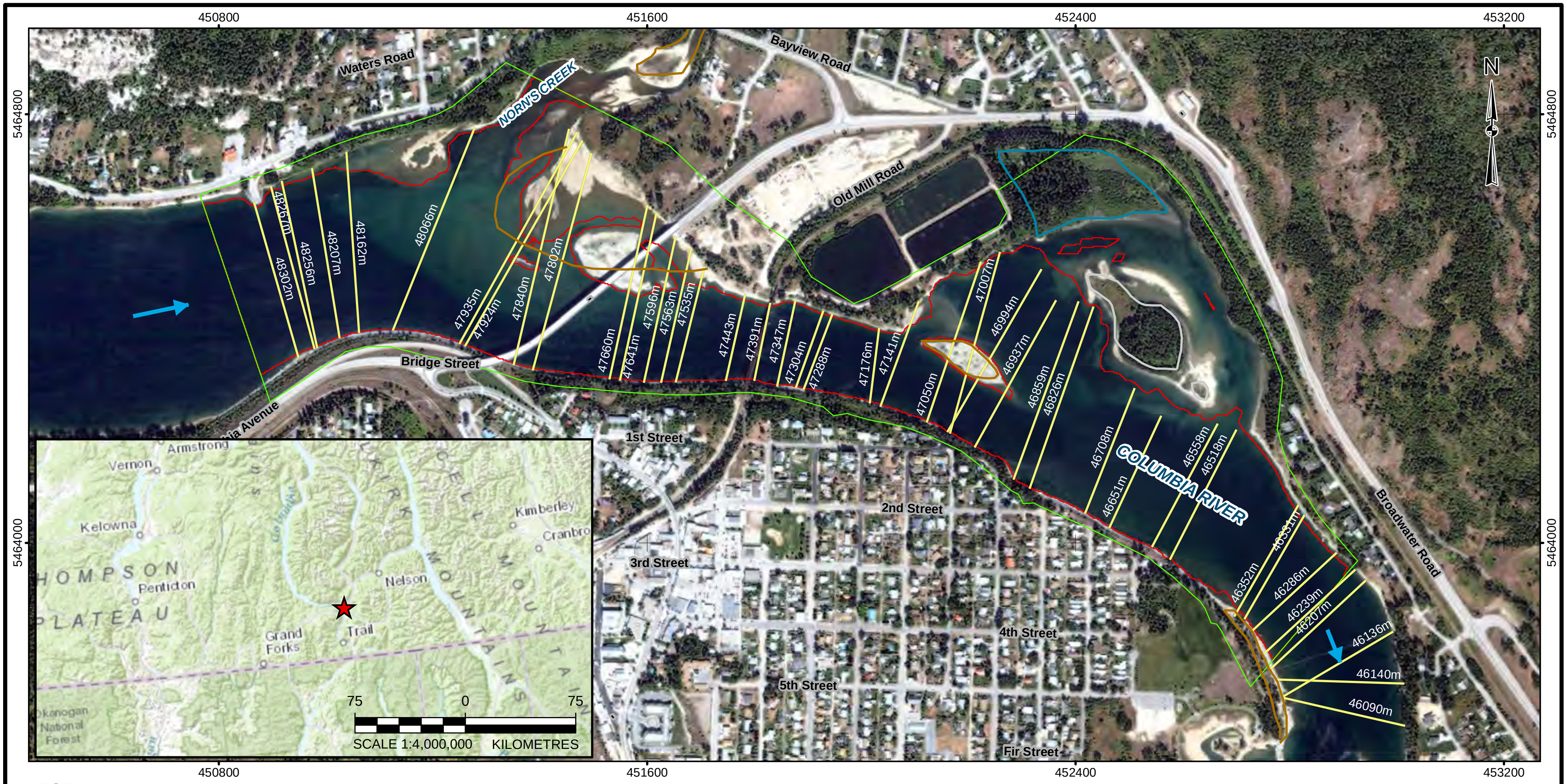

LEGEND

WATER FEATURE

— ISLAND	— COLUMBIA RIVER CROSS SECTION
— SAND OR GRAVEL BAR	➡ FLOW DIRECTION
— SWAMP	☐ SURVEY AREA
	☐ WETTED AREA

400 0 400

SCALE 1:11,000 METRES

REFERENCE

SERVICE LAYER CREDITS: SOURCES: ESRI, DELORME, NAVTEQ, TOMTOM, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), AND THE GIS USER COMMUNITY
SOURCE: ESRI, DIGITALGLOBE, GEOEYE, I-CUBED, USDA, USGS, AEX, GETMAPPING, AEROGRID, IGN, IGP, SWISSTOPO, AND THE GIS USER COMMUNITY.
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PROJECT

CLBMON-47: LOWER COLUMBIA RIVER WHITEFISH SPAWNING GROUND TOPOGRAPHIC SURVEY

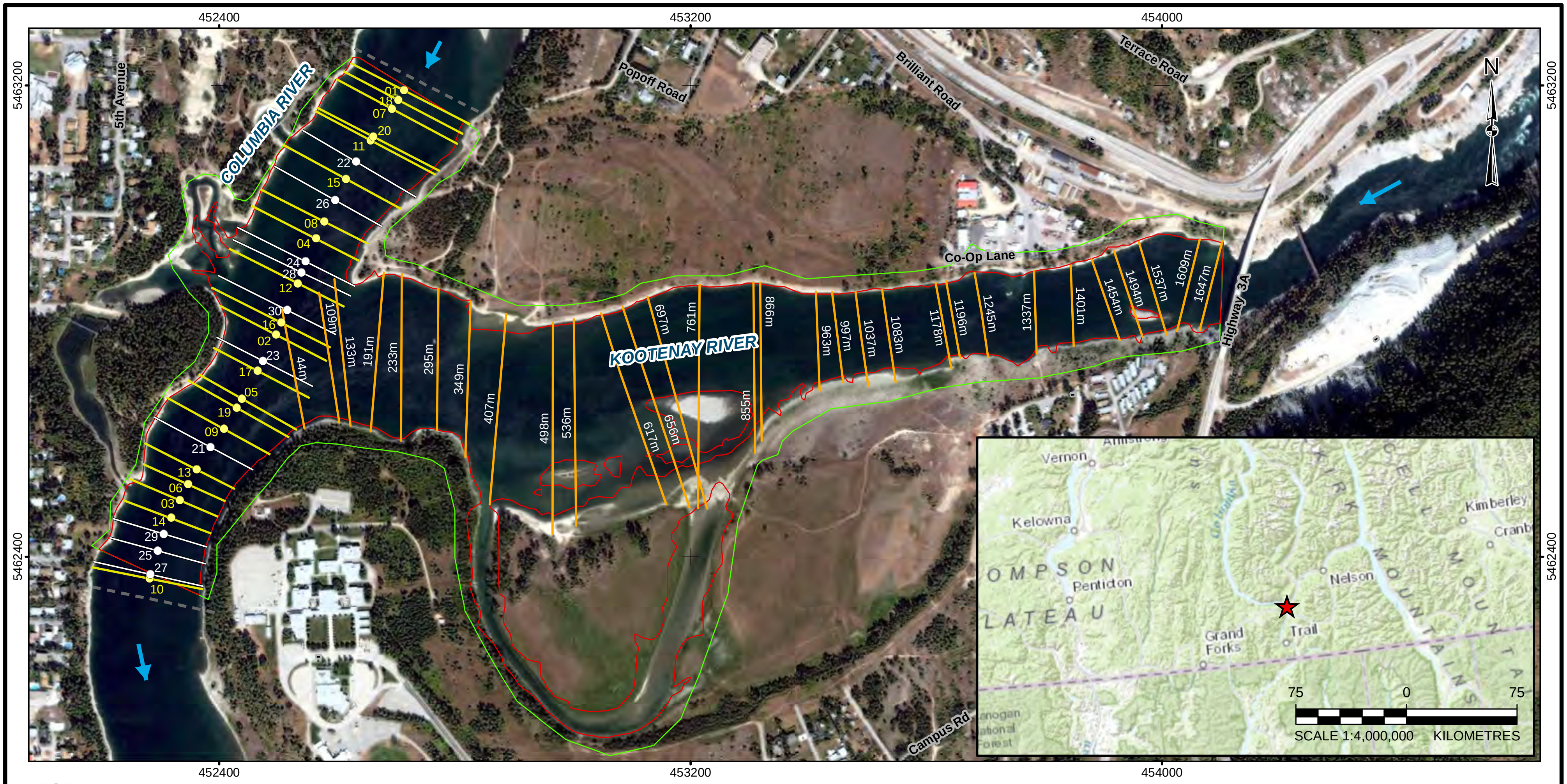
TITLE

COLUMBIA RIVER MODEL LOCATION

Golder Associates

PROJECT		10-1422-0072	FILE No.
DESIGN	WP	15 Feb. 2012	SCALE AS SHOWN — REV. 0
GIS	KLN	03 Apr. 2013	
CHECK	WP	13 Jan. 2014	**FIGURE: 1**
REVIEW	BH	13 Jan. 2014	

I:\2010\10-1492\10-1492-0142\Mapping\MXD\Hydrology\FIG2_KeyPlan_Kootenay_FINAL.mxd



LEGEND

KOOTENAY RIVER CONFLUENCE

- ● MAIN SAMPLE SITE
- ○ OVER SAMPLE SITE
- — MAIN SAMPLE TRANSECT (SURVEYED IN NOVEMBER 2012)
- ═ OVER SAMPLE TRANSECT (SURVEYED IN NOVEMBER 2012)
- - - 1 km FOR EXPANDED TRANSECT AREA
- → FLOW DIRECTION
- — KOOTENAY RIVER CROSS SECTION (SURVEYED IN MAY 2011)
- 🟩 SURVEY AREA
- 🟥 WETTED AREA

400 0 400

SCALE 1:10,000 METRES

REFERENCE

DRAFT

SERVICE LAYER CREDITS: SOURCES: ESRI, DELORME, NAVTEQ, TOMTOM, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), AND THE GIS USER COMMUNITY
SOURCE: ESRI, DIGITALGLOBE, GEOEYE, I-CUBED, USDA, USGS, AEX, GETMAPPING, AEROGRID, IGN, IGP, SWISSTOPO, AND THE GIS USER COMMUNITY.
SURVEY WAS COMPLETED IN LOCAL COORDINATE SYSTEM, RECTIFIED BASED ON AIR PHOTO.
DATUM: NAD83 PROJECTION: UTM ZONE 11

PROJECT

CLBMON-47: LOWER COLUMBIA RIVER WHITEFISH SPAWNING GROUND TOPOGRAPHIC SURVEY

TITLE

KOOTENAY RIVER MODEL LOCATION

Golder Associates

PROJECT		10-1422-0072	FILE No.
DESIGN	WP	15 Feb. 2012	SCALE AS SHOWN · REV. 0
GIS	KLN	03 Apr. 2013	
CHECK	WP	13 Jan. 2014	FIGURE: 2
REVIEW	BH	13 Jan. 2014	

2.3 Physical Parameters – All Study Years

2.3.1 Discharge

All discharge data from the Columbia River were provided by BC Hydro Power Records from HLK. Kootenay River discharge during the study period was provided by the operators of BRD (Fortis BC Ltd.) in the form of hourly spill and generation discharges from BRD.

2.4 Topographic and ADCP Transect Selection

The selection of cross sections within each of the key areas followed the advice of Williams (2010) to ensure that both spatial coverage and randomness are achieved, and used Generalized Random Tessellation Stratified Design (GRTS) for linear sampling studies (Steven and Olsen 2004). GRTS allows the use of standard statistical methods to generate confidence intervals on areas dewatered following flow reductions when developing the hydraulic models. In addition, the reaches of interest can be re-sampled following changes in channel morphology related to flood events or mechanical changes in channel structure designed to mitigate fish stranding. Initially, 20 cross-sections in each spawning area were proposed for sampling. Oversample transects were selected using GRTS to allow field crews to collect additional data if sampling of the original transects was completed ahead of schedule. To achieve the desired level of precision as stated in the TOR, individual transects were surveyed to obtain sufficient precision to develop bathymetric contours with 0.25 m resolution.

2.5 Topographic Surveys – Years 1 and 2

The topographic surveys conducted in the River2D model areas were designed to obtain accurate contours (0.25 m resolution), requiring a very dense cloud of sounding data points. Topographic surveys were conducted by SEL and Golder. Boat-based topography was conducted using a jet boat equipped with a TOPCON Real Time Kinematic (RTK) Global Positioning System (GPS) to provide accurate three dimensional (3D) positions, coupled with a Lowrance single-beam sounding system. This system allowed for the field crew to log one point a second and get maximum coverage as they drove transects slowly along each selected cross section. Gaps between cross sections were opportunistically sampled as well to provide adequate data for spawning area contour maps. As a component of the topography surveys, land-based surveys were conducted in the expanded Kootenay Model area to measure the dewatered portion of each cross-section up to the high water mark.

The software used to perform the topographic survey was HYPACK Hydrographic Survey and Processing Software from HYPACK, Inc. The software was used for survey planning, navigation, and topographic data collection. The output data included Northing, Easting, and Elevation (UTM, NAD 83) coordinates in ASCI format. Quicksurf running in AutoCAD was used to produce contour maps at the required 0.25 m vertical strata resolution (Appendix A).

Gaps between each cross section were also sampled to provide adequate data to produce contour maps of each spawning area. Data were collected with the use of survey equipment and a TOPCON RTK GPS, and a GPS base station.

2.5.1 Water Elevation Measurements – Year 3

To obtain the water elevation measurements for the final calibration of the hydraulic models, a jet boat was used to travel to each of the 56 pre-selected locations (Figure 3). The locations were selected by hand to provide an even spatial distribution to ensure adequate coverage of both hydraulic model areas. Once at the pre-selected location, the field crew took a measurement of the current water elevation using a TOPCON RTK GPS, and a GPS base station. The software used to perform the water elevation measurements was the same utilized during the boat and land based topographic surveys (Section 2.5).

2.6 ADCP Surveys – Years 1 to 3

2.6.1 HEC-RAS Update and Original Columbia and Kootenay River2D Model Development

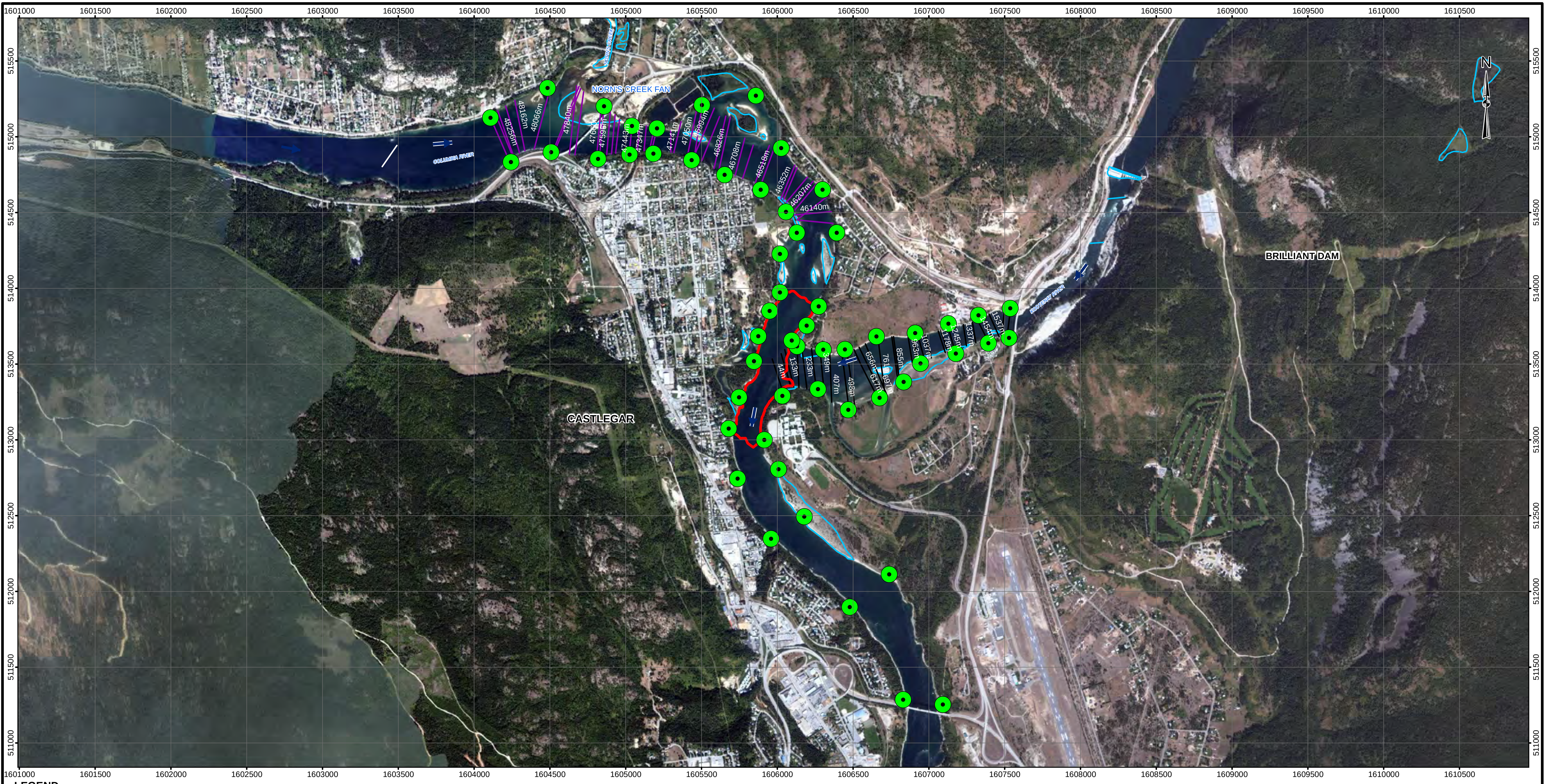
Velocity measurements were obtained using a jet boat equipped with an ADCP and RTK GPS to provide velocity profile data. Similar to the topographic surveys, the boat operator drove transects slowly along each selected cross section while the ADCP collected data. The horizontal resolution of the RD Instruments Rio Grande 1200 kHz ADCP velocity profile data was 20-25 m along each cross section (calibrated to 5% or better of the measured velocities and vertical resolution of 0.5 m or better). The ADCP provided the velocity data and the single beam sounder provided the high degree of resolution necessary to achieve the 0.25 m vertical contour intervals.

In addition to sampling each cross section, ADCP sampling was conducted in conjunction with the ongoing egg collection mat sampling program (CLBMON-48, Golder 2011). The boat was positioned over all deployed egg collection mat sets, and the GPS coordinates, depth, and water column velocity profile were recorded. These velocity measurements during the actual Mountain Whitefish spawning period can be used to validate the model while also providing important information to characterize velocity parameters in known spawning habitats, which can be used by the Mountain Whitefish spawn monitoring program.

Velocity data were collected in the Kootenay River spawning area during the peak spawning period. However, as egg captures at CPR Island were consistently low through the spawning period and developmental staging of collected eggs was conducted after the cessation of the egg mat program, a peak in spawning could not be identified during the winter sample period (Golder 2011). Therefore, the peak in spawning activity (early January 2011) had to be identified in the subsequent egg developmental staging, and the velocity data collection at CPR Island was postponed until August 12, 2011, when HLK discharges were similar to those recorded during the identified peak.

2.6.2 Original Columbia and Kootenay River2D Model Calibrations – Year 2

Velocity measurements conducted in the Columbia and Kootenay River spawning areas to calibrate the River2D models followed the methodology utilized in Year 1 (Section 2.6). All velocity data for the calibration of the original River2D model areas were collected during the low flow period prior to the onset of the winter season, which allowed for the calibration of the River2D models for low flow conditions. Currently, both River2D models have not been calibrated under high flow and freshet conditions.



LEGEND

- ● WATER LEVEL SURVEY APR 2013
- ― COLUMBIA RIVER CROSS SECTIONS
- ― KOOTENAY RIVER CROSS SECTIONS
- ― WATER FEATURES

500 0 500

SCALE 1:25,000 KILOMETRES

REFERENCE

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DATUM: NAD 83 PROJECTION: 11

PROJECT

CLBMON-47 LOWER COLUMBIA RIVER
WHITEFISH SPAWNING GROUND TOPOGRAPHIC SURVEY

TITLE

PROJECT STUDY AREA

Golder Associates
Calgary, Alberta

PROJECT		10-1492-0142	FILE No.	
DESIGN	WP	26 Apr. 2013	SCALE AS SHOWN	REV. 0
WREG	WP	26 Apr. 2013	FIGURE: 3	
CHECK	WP	13 Jan. 2014		
REVIEW	BH	13 Jan. 2014		

I:\2010\10-1492\10-1492-0142\Mapping\MXD\Hydrology\Overview_SurveyRequest_20130426_FINAL.mxd

2.6.3 Expanded Kootenay River2D Model Development and Calibration – Years 2 and 3

As in sampling for the original Kootenay River2D model, sampling within the expanded Kootenay River model area consisted of ADCP transects along cross-sections selected using Generalized Random Tessellation Stratified (GRTS) survey design. Of the 20 main sample cross-sections selected for sampling, 19 were sampled. Also, ten over-sample cross-sections were selected for sampling in the event that some of the main transects could not be sampled due to logistical constraints (Figure 2). During the ADCP surveys, the field crew was able to sample transects along all over-sample cross-sections. This allowed for the inclusion of these transects into the expanded model as well.

The methodology used for the ADCP surveys in the expanded area followed the methodology used during ADCP sampling in Year 1 (Section 2.6). In Year 3, model calibration of the expanded area also involved ADCP surveys that followed the methodology used during ADCP surveys completed in Years 1 and 2 (Golder 2012 and 2013).

2.7 HEC-RAS 1D Model Update – Year 1

The hydraulic modelling analysis was conducted using a one-dimensional model (HEC-RAS) to predict water levels and flow velocities. The hydraulic model was set up based on survey data collected in April and May 2011 by Sproulers' Enterprises Limited (SEL) Survey & Design. During Year 1 sampling, a total of 30 cross sections were surveyed at the Kootenay River and 40 cross sections were surveyed at the Columbia River (Figure 1 and Figure 2).

2.7.1 Manning's *n* Value – River Bottom Roughness

Manning's *n* value is an empirical coefficient used to determine the roughness of river and stream bottoms. This value is used in water velocity and stream discharge calculations, as well as hydraulic modeling. The Manning's *n* value of major natural rivers ranges between 0.030 (clean and straight) and 0.040 (sluggish with deep pools) with an average value of 0.035 (Chow 1959 and Barnes 1967).

2.7.2 Hydraulic Model Setup

The HEC-RAS model was updated (vers. 4.1, January 2010) by modifying the existing HEC-RAS model. Existing cross-sections were deleted from the model, and the cross sections surveyed in the present study were then imported according to their locations (river station). During the process of importing the surveyed cross-sections into HEC-RAS, each cross-section was checked for consistency and outliers. Also, each cross-section was divided into three parts: left overbank flow, main channel, and right overbank flow.

There are five model sub-reaches (three on the Columbia River, one on the Kootenay River and one on the Pend d'Oreille River) in the integrated HEC-RAS model (Table 2). The middle and lower reaches of the Columbia River and the river section of the Pend d'Oreille River were not changed within the scope of this study.

2.7.3 Model Calibration

The river reaches of the Kootenay and Upper Columbia were calibrated separately, and then combined into one integrated model. The boundary conditions used for calibration are listed in Table 3.

Table 2: River Sub-sections in the HEC-RAS Model.

Sub-reach ID	River	Reach description	Downstream Boundary	River station (m upstream of downstream boundary)[a]		Length (m)
				From	To	
1	Columbia	Upper Reach (below HLK Dam to Kootenay River confluence)	Columbia/Kootenay River confluence	45 055	55 375	10 320
2	Columbia	Middle Reach (Kootenay to Pend d'Oreille River)	Columbia/Pend d'Oreille River confluence	695	45 055	44 360
3	Columbia	Lower Reach (below Pend d'Oreille River confluence)	Canada US/Border	0	695	695
4	Kootenay	Kootenay River confluence to Brilliant Dam	Columbia/Kootenay River confluence	0	2 805	2 805
5	Pend d'Oreille River	Pend d'Oreille River confluence to Waneta Dam	Columbia/Pend d'Oreille River confluence	0	425	425

[a] River Station: Canada/US Border was the downstream boundary of the entire study area, and therefore is assigned River station of 0 m.

Table 3: Boundary Conditions for Model Calibration.

River	Date	Discharge (upstream boundary)	Measured water level (downstream boundary)
Kootenay	May 3, 2011	825 m^3/s	417.62 m (1)
Columbia	May 4, 2011	707 m^3/s - 834 m^3/s	418.08 m (2)

(1) Mainly influenced by water levels in the Columbia River.

(2) Corresponding discharge at time of measurement was 707 m^3/s.

2.7.3.1 Kootenay River Model Calibration and Sensitivity Analysis

The boundary conditions for calibration of the Kootenay River model reach were the surveyed water level at the downstream boundary at the confluence on May 3, 2011, and the river discharge at the upstream boundary (Table 3). During the model calibration, modelling results were compared to the measured water levels at each cross section. The river bottom roughness parameters (Manning's *n* values) were adjusted to minimize the water level differences between the simulated and surveyed water levels (Table 4).

Table 4: Calibrated and assumed Manning's roughness values for Kootenay River reach.

Description	Manning's *n* value
Main channel	0.038
Overbank areas	0.07 (1)

(1) Overbank areas are mostly above the measured water level and were therefore not calibrated. A typical roughness value for vegetated floodplains was applied based on experience.

2.7.3.2 Columbia River Model Calibration and Sensitivity Analysis

The downstream boundary condition for calibration of the Columbia River model reach was defined by the surveyed water level at the downstream end of the study reach on May 4, 2011. On May 4, 2011, the discharge in the Columbia River ranged from 707 m^3/s to 830 m^3/s. Therefore, the calibration of the model was completed using three different discharges along three river sections (Table 5).

Table 5: Discharge data for calibration of the Columbia River reach, May 04, 2011.

River Station (m upstream of Canada/US border)		Discharge (m^3/s)
From	To	
45 055	47 391	707
47 443	47 935	830
48 066	55 375	793

During the model calibration, the modelling results were compared to the measured water levels at the cross sections. The roughness parameters (Manning's *n* values) were adjusted to minimize the water level differences between the simulated and surveyed water levels (Table 6). During the calibration process, the following changes were made in the model:

- Update of railway bridge geometry; and,
- Ineffective flow area added at cross-sections 46 859 to 47 050 to limit the flow conveyance to the main channel.

Table 6: Calibrated and Assumed Manning's Roughness Values for upper Columbia River Reach.

Description	Roughness Parameter (Manning's *n*)
Main channel	0.034
Overbank areas	0.07 (1)

(1) Overbank areas are mostly above the measured water level and were therefore not calibrated. A typical roughness value was applied based on experience

2.8 River2D Hydraulic Modeling – Year 2

In this study, the calibration of water surface elevations was conducted using the River2D Model. The study reaches of the Columbia and Kootenay rivers were calibrated separately. The Columbia River reach was about 2.5 km long whereas the Kootenay River was about 1.7 km long. The hydrodynamic component of the River2D Model is based on the two-dimensional, depth-averaged St. Venant equations expressing the conservation of water mass and momentum components in two directions. River2D are based on the finite element method. The implicit method is used to solve non-linear equations resulting from finite element discretization. The main advantage of the model is that it can easily handle a computation region with irregular boundaries characterized by diversified flow conditions, including subcritical, supercritical, and transcritical flows.

The River2D modelling tasks in this study involved the following:

- create a bathymetric model and generate a finite element mesh;
- setup model boundary conditions;
- calibrate the model; and,
- conduct model sensitivity analysis.

2.9 Columbia River Modelling

2.9.1 Bathymetric Model

The bathymetric survey on May 4, 2011 was used to setup the River2D Model for the Columbia River reach.

2.9.2 Model Boundary Conditions

The range of measured discharges on May 4, 2011 (Table 3) was used as upstream boundary conditions. This range was also used to calibrate the HEC-RAS model in this spawning area during Year 1 project activities (Golder 2012), and therefore, was the range used for the River2D calibration. The model calibration was conducted based on four different discharges within that range for the selected river segments (stations; Table 7). The updated HEC-RAS model was used to establish downstream boundary conditions for discharges where surveyed water levels at the downstream boundary were not available. The HEC-RAS model was calibrated using the assembled data of the topographic survey and the ADCP measurements (Golder 2012).

Table 7: Hourly Discharge Data for River2D Calibration of the Columbia River Reach.

River Station (m, upstream of Canada/US Border)		Discharge (m^3/s)
From	To	
48 302	48 066	793
47 935	47 924	811
47 802	47 443	830
47 391	46 239	707

2.10 Kootenay River

The model calibration of the Kootenay River spawning area was conducted by incorporating a section of the Columbia River and the Kootenay River (Section 3.6.2, Figure 20). Recirculating low velocity flow areas were recorded just upstream of the Kootenay River confluence with the Columbia River, which may be essential for Mountain Whitefish holding and feeding during the spawning season.

2.10.1 Bathymetric Model

The model was setup based on the bathymetric data collected on May 3, 2011 in the Kootenay River, and data collected at the Kootenay River confluence with the Columbia River on November 28, 2012 (Golder 2013).

2.10.2 Model Boundary Conditions

The model upstream boundary conditions were discharges at the Columbia and Kootenay rivers. The downstream boundary condition was water surface elevation at the Columbia River confluence with the Kootenay River. Mean daily discharges recorded on May 3, 2011 for the Columbia and Kootenay rivers were 708 m^3/s and 825 m^3/s, respectively (Table 3). These discharges were used for the model calibration. There were no survey water level data available in the Columbia River immediately downstream of the Kootenay River confluence for the model calibration. An initial adjustment of the model's downstream boundary condition was made to relate the simulated water level on the Columbia River to the surveyed water level (417.62 m) at the most downstream survey cross-section on the Kootenay River. Accordingly, the downstream boundary condition for the River2D Model calibration was estimated to be 417.60 m at the Columbia River.

2.11 River2D Interpolation

The results of the 99 runs of the River2D models were interpolated to provide a continuous description of changes in depth and velocity at the two spawning sites as a function of HLK and BRD discharge. The interpolation was performed separately for each node, which resulted in individual functions of depth and velocity changes. The functions used were selected to best fit each node. For depth interpolation at CPR Island spawning site, the following equation was used:

Equation 1 $$depth_i = c + e^{-b*HLK-d*BRD},$$

where $depth_i$ is the River2D-derived depth (in m), at node *i*, *HLK* and *BRD* are discharges from the respective dams (m^3/s), and *c*, *b*, and *d* are regression coefficients,

For depth interpolation at Kootenay spawning site, the following equation was used:

Equation 2 $$depth_i = a * BRD + b * HLK + c,$$

where *depth*$_i$ is the River2D-derived depth (in m) at node *i*, *HLK* and *BRD* are discharges from the respective dams (m³/s), and *c*, *b*, and a are regression coefficients,

Velocity interpolation utilized three different equations at CPR Island, due to the variability of velocity response to changes in discharge. The choice of interpolating function was made based on node-specific plots of velocity as a function of discharge:

Equation 3

$$velocity_i = \frac{a}{1 + e^{c-b*HLK-d*BRD}},$$

Equation 4

$$velocity_i = c + d * BRD + a * e^{-b*HLK},$$

Equation 5

$$velocity_i = a + b * HLK + c * HLK^2 + d * HLK * BRD,$$

where *velocity*$_i$ is the River2D-derived velocity (in m/s) at node *i*, *HLK* and *BRD* are discharges (m³/s) from the respective dams, and *a*, *b*, *c*, and *d* are regression coefficients.

At the Kootenay River key spawning area, velocity interpolation was more straightforward, with only one equation needed to describe all nodes:

Equation 6

$$velocity_i = a + b * BRD + c * HLK + d * BRD * HLK,$$

where *velocity*$_i$ is the River2D-derived velocity (m/s) at node *i*, *HLK* and *BRD* are discharges from the respective dams (m³/s), and *a*, *b*, *c*, and *d* are regression coefficients.

2.12 Egg Loss Model

2.12.1 Data Sources

Several data sources were used in the construction of the ELM and subsequent simulations. Columbia River discharge data were provided by BC Hydro Power Records from HLK (total discharge from HLK and Arrow Lakes Generating Station [ALGS] combined). Kootenay River discharge during the study was provided by the operators of BRD (Fortis BC) in the form of hourly spill and generation plant discharges from BRD.

Data Collection Platforms (DCPs) equipped with Lakewood^{TM} Universal temperature probes (accurate to ± 0.5°C) were used to obtain water temperatures in the Columbia River at the BC Hydro monitoring station adjacent to Norn's Creek Fan. Water temperatures in the Kootenay River were collected using paired Vemco™ Minilog12 temperature data loggers (accurate to ± 0.5°C) that were deployed on a cobble island downstream of BRD (RKm 1.0).

The ELM includes a component that predicts the timing of egg deposition. The data for this sub-model included water temperature (see above) and the total daily corrected CPUE (number of freshly-deposited eggs/mat-day) recorded in previous sampling years. Corrected CPUE was estimated based on the number of deposited fresh eggs; i.e., developmental stages 1-3, using Rajagopal (1979), or developmental stages 1-12, using Vernier (1969). Only a subsample of all captured eggs was staged at each sampling. Therefore, to estimate the total daily count of fresh eggs, we estimated the ratio of fresh to old eggs in the staged subsample, and multiplied by the total number of eggs collected in the sample.

Another sub-model included in the egg loss model was the development of eggs as a function of accumulated thermal units (ATU). The data used for the construction of this model were the results of the egg incubation experiment in 1995-1996 (R.L.&L. 1997). As part of the experiment, site-specific temperature values were collected using temperature loggers deployed at the sites of egg incubation (Kootenay mid-channel and near shore, and Columbia mid-channel).

The probability of fresh egg deposition as a function of velocity was estimated using the estimated corrected CPUE at each sampling (as above), and the recorded surface velocity at each mat deployment using a Marsh McBirney Flo-Mate™ velocity meter.

River bed elevation, water depth, and water velocity throughout the study area were estimated using the output of the River2D model, calibrated for the Columbia and Kootenay spawning sites. A total of 51 modeling runs were performed, spanning the majority of discharge ranges observed at HLK and BRD during December-March 1995-2012 (Appendix A, Table A1). The output was a matrix of 6,206 and 3,873 nodes in Columbia and Kootenay, respectively, with coordinates, water elevation, depth, and water velocity data associated with each node.

For the purpose of egg loss analysis, the area modeled using the River2D model was restricted to the extent of the Mountain Whitefish spawning areas (Figure 4). This was performed to reduce computational time of the egg loss model. Since every point in the modeled area is propagated throughout the entire study period (Nov 1 to May 1), the reduction of sampled points dramatically streamlined the analysis and trimmed the processing time.

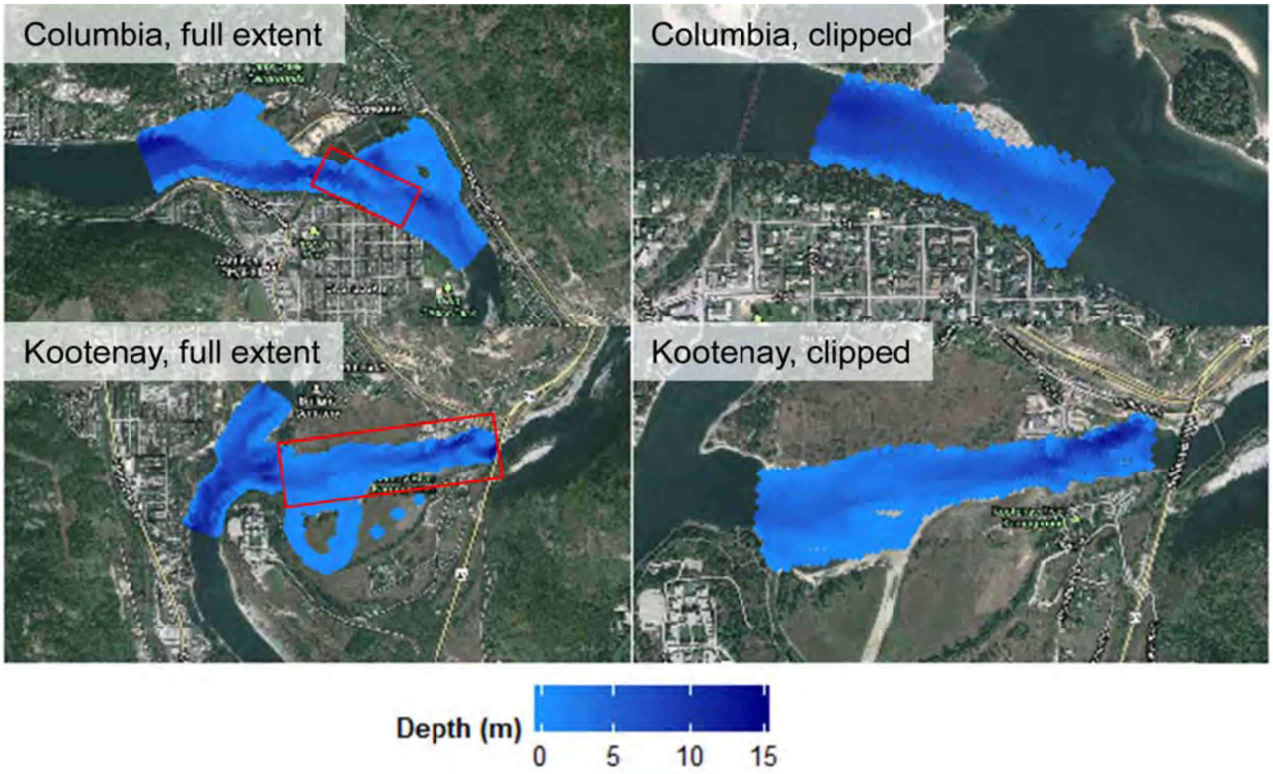


Figure 4: Full extent of River2D model (left panels) and the areas used for egg loss modeling (right panels); depth values are based on one model run. The red rectangles designate the extent of area used for modeling.

2.12.2 Analysis

All statistical analyses were performed in R v. 3.0.1 (R Development Core Team, 2013). Data were imported from Access databases using the package RODBC (Ripley and Lapsley 2012), and processed for analysis using the packages plyr (Wickham 2011), data.table (Dowle et al 2013), and reshape2 (Wickham 2007). Plotting was performed using the packages ggplot2 (Wickham 2007), gridExtra (Auguie 2012), scales (Wickham 2012), RColorBrewer (Neuwirth 2011), and ggmap (Kahle and H. Wickham 2013). All non-linear regressions were performed using 'nls', a non-linear least squares function in R.

2.12.2.1 Timing of Egg Deposition

For each sampling, the ratio between fresh eggs [stages 1-3, using Rajagopal (1979), or developmental stages 1-12, using Vernier (1969)] and the total number of staged eggs was calculated. The ratio was multiplied by the total number of eggs captured in the sampling to estimate the total number of captured fresh eggs. The daily totals of mat days and the corrected number of captured eggs were used to calculate fresh egg CPUE value for each sampling day. The array of CPUE estimates was used to calculate a cumulative proportion of daily fresh egg CPUE out of the total fresh egg CPUE for the study year. The models were constructed using egg capture and development data from 1996-1997, and 2009-2012. This estimation assumes that all spawning activity took place during the sampling period. Non-linear models of cumulative probability of fresh egg deposition as a function of time (where 1-Nov is day 1, 2-Nov is day 2, etc.) were developed in R using Equation 7:

Equation 7 $$\mathit{Cumulative\ CPUE}_{Time,temp} = \frac{1}{1+e^{b*Time+c}} \quad ,$$

where ‘Cumulative $\mathrm{CPUE}_{\mathrm{Time,temp}}$’ is a cumulative proportion of daily fresh egg CPUE out of the total fresh egg CPUE, ‘Time’ is day of study period, ranging from 1 to 183, and *b*, and *c* are regression coefficients.

A separate curve was developed for every sampling year. The coefficients were used to generate among-year mean and standard deviations of every regression coefficients. These values were used in the following bootstrap to incorporate variability in egg deposition with temperature and time.

2.12.2.2 Development vs. ATU – Model

During the 1995-1996 incubation study, water temperature was recorded at the experimental sites (Columbia and Kootenay rivers, shallow and deep deployment locations). The ATU values of the developing eggs were estimated, and the developmental stages (Vernier 1969) were plotted against the ATU values. Nonlinear regression (Equation 8) was used to estimate the relationship between developmental stage and ATU:

Equation 8 $$Stage = a\left(1 - e^{-b*ATU+c}\right),$$

where ‘Stage’ is egg developmental stage (ranging from 1 to 30), ‘ATU’ is accumulated thermal units, and *a*, *b*, and *c* are regression coefficients. Once the model was constructed, this equation was used to inversely predict the ATU value at which eggs reach stage 30 of development (hatching).

To estimate the 95% prediction intervals around the ATU values, we used the following equation, as given in Seber and Wild (2003), p. 247:

Equation 9 $$Stage_{ATU} \pm z_{\gamma/2}\left(\frac{n-p}{c}\right)^{1/2},$$

where *“Stage”* is egg developmental stage (ranging from 1 to 30), ‘ATU’ is accumulated thermal units, Once the upper and lower prediction bands (which comprise the prediction interval) were found, they were solved for x (ATU) using Equation 8, thereby providing the lower and upper confidence intervals for $\mathrm{ATU}_{\mathrm{Stage\ =\ 30}}$, the stage at hatching.

2.12.2.3 Egg Deposition with Depth – Model

Corrected CPUE values were used to construct relationships between water depth and cumulative corrected CPUE values. CPUE values were used in this analysis, rather than egg counts, to ensure accounting for differences in effort between sampling years. Cumulative CPUE values were estimated to describe egg deposition with depth (at a resolution of 0.1 m), where no eggs are deposited at zero depth, and all eggs have been deposited by maximum river depth. The model was constructed as a logistic regression:

Equation 10 $$Cumulative\ CPUE_{Depth} = \frac{1}{1+ e^{b*Depth+c}} \ ,$$

where 'Cumulative CPUE$_{Depth}$' is a cumulative proportion of fresh egg CPUE out of the total fresh egg CPUE, estimated by depth, 'Depth' is river depth as measured during egg collections, and *b* and *c* are regression coefficients.

A separate curve was developed for every sampling year. The coefficients were used to generate among-year mean and standard deviations of every regression coefficients. These values were used in the following bootstrap to incorporate variability in egg deposition with depth.

2.12.2.4 Egg Deposition at Node/Day

The curves describing egg deposition as a function of: 1) time; and, 2) depth were combined to express the probability of egg deposition at each node on each day. To provide this combined probability for each node, the two probabilities were multiplied to express the probability of egg deposition on each day at each depth value. At each day of egg deposition, the number of nodes assigned a value of depth were counted, and the combined probability of egg deposition on a certain day at the given depth was then divided by the number of nodes with that depth, yielding the specific probability of egg deposition on that day at that node.

2.12.2.5 Development of Stranding Estimate Confidence Intervals

The incorporation of uncertainty into the estimates of stranding was performed using bootstrapping, a resampling technique widely used to assess uncertainty (Efron and Tibshirani 1993). Bootstrapping allows empirical assessment of confidence intervals based on the resampling distributions of the data at hand, rather than assumed theoretical distributions.

In this study, bootstrapping was used to provide confidence intervals around the final estimate of total egg stranding, as well as for propagating the different sources of error throughout the model. These sources include:

1) variability of ATU required for hatching;
2) variability of egg deposition levels with time; and,
3) variability of egg deposition levels with depth..

Bootstrapping was performed in R, and included 300 iterations of stranding estimates. At each iteration, the program randomly chose values from the following parameters:

1) a value of ATU-to-hatch, based on the distribution of ATU values at hatching stage;
2) a value of egg deposition probability on a given day, using the among-years mean and standard deviations of regression coefficients (Equation 7); and,
3) a value of egg deposition probability at a given depth, using the among-years mean and standard deviations of regression coefficients (Equation 10).

The high interannual variability in coefficients of egg deposition probability curves with time and depth resulted in unrealistic estimates of deposition (e.g., egg deposition in April). Hence, the variability in these curve coefficients was restricted to lie between the 20th and the 80th quantiles of a normal distribution created using the mean and standard deviation of year-specific egg deposition curves with time and depth. A similar restriction was applied to the distribution of ATU values at hatch.

Once the values were picked, the program estimated the resulting stranding value. The 300 stranding values based on the bootstrapping procedure were then used to create a 95% confidence interval around the median daily estimate of the proportion of stranded eggs out of eggs deposited each day.

2.12.2.6 Model Output and Future Use

Maps of the spatial extent of egg deposition and stranding will be saved as pdf files. The total stranding probability (and its uncertainty), encompassing the entire study period, will be printed directly on the screen and saved to a csv file in the chosen folder.

The model's R script is provided in Appendix C. The code is provided as a script, which will reduce the required amount of interaction for the end user. The user will have to provide input files of temperature and discharge data for both Brilliant Dam and HLK Dam, and the software will estimate stranding using the regressions and maps developed in this study (Figure 5). The detailed requirements for input files (naming, format, layout, and content) are provided in Appendix B1.

The output table and maps will be saved into a working directory, which will be selected by the user (see Appendix B2). The output values of total (± 95% CI) egg stranding (expressed as a proportion of total eggs deposited) at both CPR Island and Kootenay will be displayed on the screen for immediate reference. The step-by-step instructions on the input and use of the model are provided in Appendices B1 and B2.

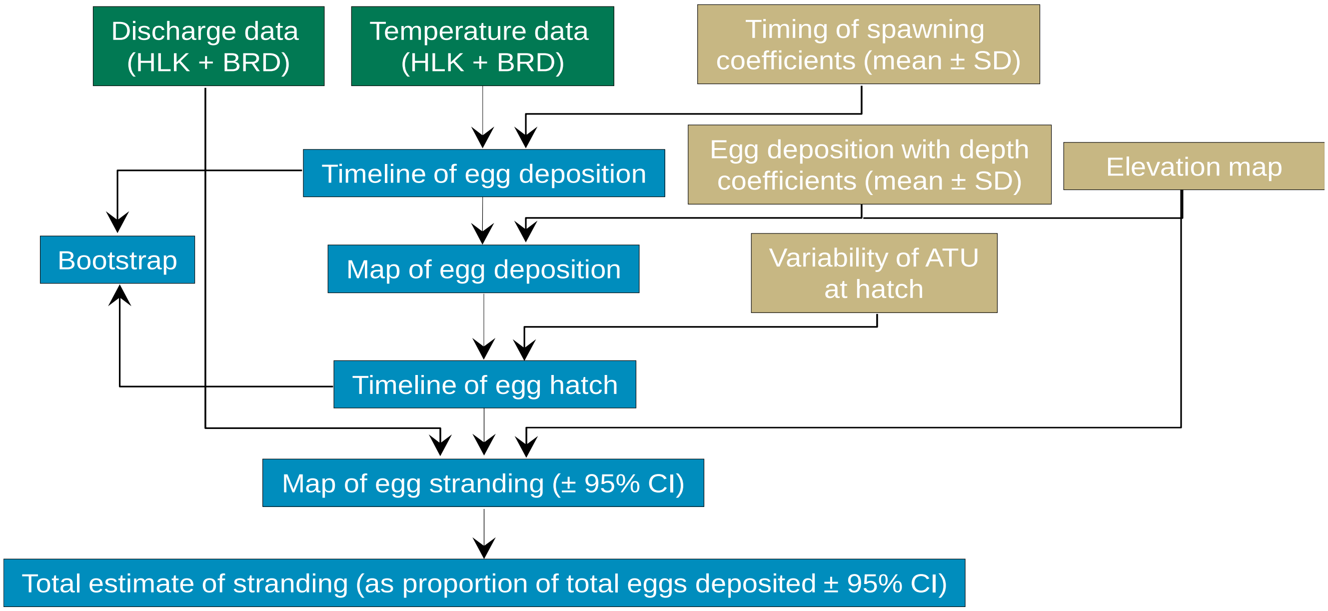


Figure 5: Flow chart of the components used in modeling egg loss. Green boxes designate input data required for every run, brown boxes designate model components developed for this study, and blue boxes designate steps in the model computation.

2.12.3 Egg Loss in Relation to Flow Stabilization

To compare egg loss among several years, discharge and temperature data for the period between November 1, 2007 and May 1, 2013 were compiled from the same sources as in Section 2.12.1. The model requires a full dataset, with no missing data. When missing data were encountered in the compiled dataset, they were either computed as a mean of the data points immediately before and after the missing data period. If the missing period was at the beginning or the end of the dataset (i.e., missing data included November 1 or May 1), the missing data were replaced with values collected in the adjacent year. If the adjacent year was 2012, when exceedingly high flows were recorded in both Columbia and Kootenay, the data were replaced with values collected in 2011. Once the datasets were complete, the ELM model was run for each year and the yearly estimates of total stranding were plotted. The ELM was performed using 300 iterations, the highest possible on the available computers.

The flow stabilization index calculation, as stated by the TOR (BC Hydro 2007) is as follows:

"*the difference between the maximum flow during the peak spawning period (January 1 -21,* Q_{Smax}*) and the minimum flow prior to egg hatch (January 22 – Apr 1,* Q_{Imin}*). The relative degree of flow stabilization (and risk of egg loss) is indexed by a simple hydrologic metric,* Q_{Smax}-Q_{Imin}".

This index was calculated by using the summed hourly discharge from both HLK and BRD for the 2007 to 2012 spawning seasons and compared to updated ELM results.

3.0 RESULTS

3.1 Discharge

The hydrographs for HLK and BRD in the study area for all years of this program are provided in Figure 6 and Figure 7. Mean daily discharge of the Columbia River below HLK exhibited a bi-modal pattern with peaks between December and March, as well as June and August in most sampling years. In Year 2 (2012), high flows in the summer season precluded ADCP and bathymetric surveys, and therefore all field work was delayed until the low water period in the fall season. Discharge patterns in the Kootenay River at BRD were unimodal with peak discharge in May to August in all years (Figure 7).

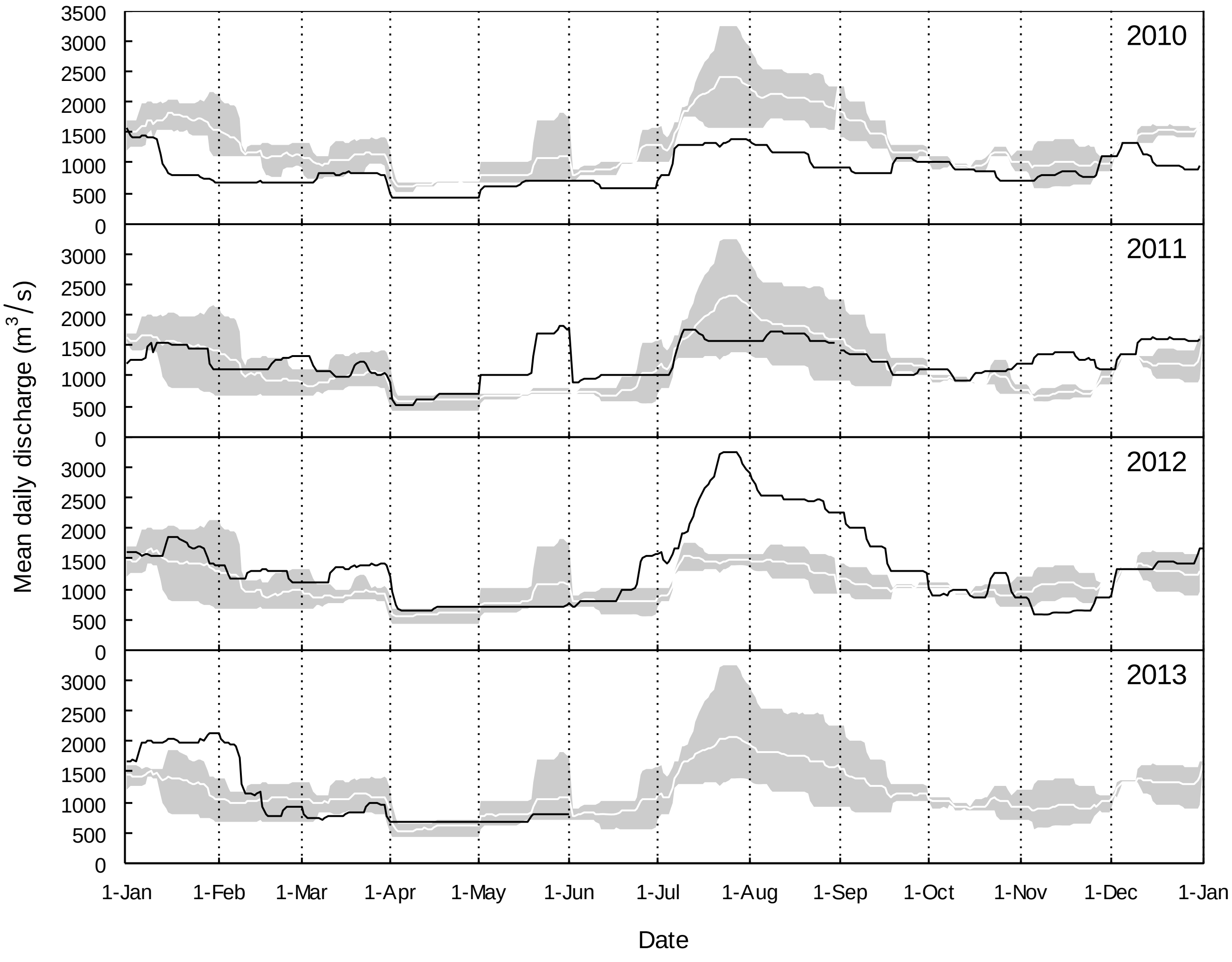


Figure 6: Mean daily discharge (m³/s) for the Columbia River at Hugh L. Keenleyside Dam (black line), 2010-2013. The shaded area represents minimum and maximum mean daily discharge values recorded during other study years (between 2008 and 2013). The white lines represent average mean daily discharge values over the same time period.

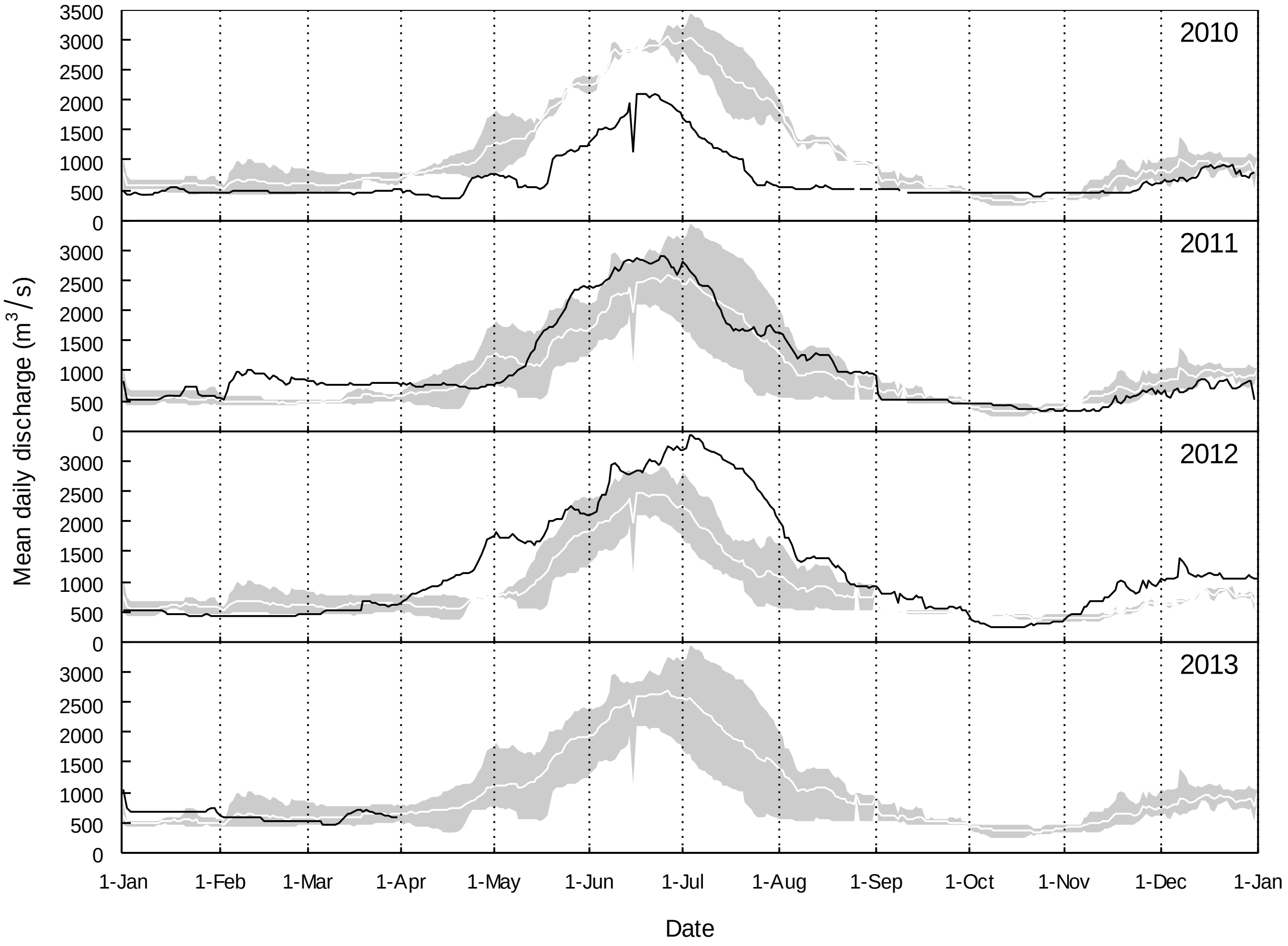


Figure 7: Mean daily discharge (m³/s) for the Kootenay River at Brilliant Dam (black line), 2008-2012. The shaded area represents minimum and maximum mean daily discharge values recorded at Brilliant Dam during other study years (between 2008 and 2012). The white lines represent average mean daily discharge values over the same time period.

3.1.1 Topographic, ADCP, and Elevation Surveys

Discharges for the Columbia and Kootenay rivers on the survey dates were provided by BC Hydro. Table 8 presents the mean daily discharges during the ADCP and topographic surveys.

Table 8: Mean daily discharges during CLBMON-47 survey dates (provided by BC Hydro).

Date	Survey activity	Mean Columbia River daily discharge (m^3/s)	Mean Kootenay River daily discharge (m^3/s)
13-Jan-11	Year 1 – ADCP Survey of Kootenay River	1529	556
14-Jan-11	Year 1 – ADCP Survey of Kootenay River	1529	580
19-Apr-11	Year 1 – Bathymetric Survey of Kootenay River	714	752
25-Apr-11	Year 1 – Bathymetric Survey of Kootenay River	707	714
26-Apr-11	Year 1 – Bathymetric Survey of CPR Island	709	748
28-Apr-11	Year 1 – Bathymetric Survey of CPR Island	709	758
29-Apr-11	Year 1 – Bathymetric Survey of Kootenay River	710	756
3-May-11	Year 1 – Bathymetric Survey of Kootenay River	708	825
4-May-11	Year 1 – Bathymetric Survey of CPR Island	777	852
5-May-11	Year 1 – Bathymetric Survey of CPR Island	849	912
12-Aug-11	Year 1 – ADCP Survey of Columbia River	1711	1283
13-Aug-11	Year 1 – ADCP Survey of Columbia River	1695	1272
20-Nov-12	Year 2 – ADCP Survey CPR Island and Kootenay River spawning areas to calibrate existing models	654	873
21-Nov-12	Year 2 – ADCP surveys in Kootenay River expanded area	654	831
27-Nov-12	Year 2 – Bathymetric Survey of Columbia/Kootenay Confluence	847	933
28-Nov-12	Year 2 – Bathymetric Survey of Columbia/Kootenay Confluence	847	947
12-Dec-12	Year 2 – Bathymetric Survey of Columbia/Kootenay Confluence	1330	1094
13-Dec-12	Year 2 – Bathymetric Survey of Columbia/Kootenay Confluence	1332	1092
23-Apr-13	Year 3 – ADCP surveys in Expanded Kootenay model area to calibrate the model	682	Not available at this time
24-Apr-13	Year 3 – ADCP surveys in Expanded Kootenay model area to calibrate the model	691	Not available at this time
3-May-13	Year 3 – Water Level Measurements over entire study area	682	756

An initial modeling exercise on the Kootenay River section based on the Year 1 (2011) survey information suggested that some areas near the Kootenay River confluence were not be adequately surveyed. Therefore, additional field sampling was performed in Year 2 (2012) to survey the portion of the Columbia River at the Kootenay River confluence.

3.2 Topography Surveys

3.2.1 CPR Island (Columbia River) Spawning Area

Topographic surveys in the CPR Island Mountain Whitefish spawning area occurred from April 25 to May 5, 2011 (Table 1). As these cross-sections were selected at random using GRTS (Section 2.4), they are not in numerical order from upstream to downstream on the figure presented in Appendix A.

At the request of BC Hydro, the area sampled during the topographic and ADCP surveys was expanded to encompass Norn's Creek Fan (Figure 1). Therefore, not all of the cross-sections sampled represent the CPR Island spawning area. The 11 cross-sections of interest that encompass the CPR Island spawning area cross-sections no. 11-18 (Appendix A, Sheets 4, 6 and 7). The spawning area consists of steep gradients along the right downstream bank (RDB). Along the left downstream bank (LDB), a channel between the river bank and CPR Island (cross section no. 26) allows water to flow through at higher water elevations. In the upstream portions of the spawning area, depths are greater in the thalweg, and the contours of the river bottom are relatively uniform. Water levels are shallower in the downstream portion of the spawning area, where the thalweg exhibits the characteristics of a deep riffle. Mountain Whitefish egg deposition during previous studies was greatest along the LDB and the mainstem side of CPR Island (Golder 2010 and 2011), which consists of relatively gentle gradients (cross sections no. 38 to no. 34). A back eddy in the downstream portion of the spawning area along RDB is another topographical feature present within the spawning area (cross sections no. 2 and no. 18).

3.2.2 Original Kootenay River Spawning Area

Topographic surveys in the Kootenay River Mountain Whitefish spawning area were performed from April 19 to May 3, 2011 (Table 1). As these cross sections were selected at random using GRTS (Section 2.4), they are not in numerical order when viewed from the confluence with the Columbia River upstream to the Highway 3A bridge on the figure presented in Appendix A.

The Kootenay River spawning area can be divided into three separate sections based on topography and documented egg depositional rates (Golder 2011). The downstream section of the Kootenay River spawning area is characterized by the five cross-sections (no. 26 to 30; Appendix A, Sheet 1 and 2). This section is dominated by Kootenay Eddy (cross-sections 8, 24 and 26) along RDB, which consists of a large and deep backwater area. Immediately upstream of Kootenay Eddy, a large bench (cross-sections no. 12 and no. 22) deflects and constricts the Kootenay River flow, creating a deep channel along LDB adjacent to the eddy. Also, a ridge has formed between the eddy and the channel, as shown by cross sections no. 24 and no. 26. This section also exhibits the greatest depth within the Kootenay spawning area.

The highest rates of Mountain Whitefish egg deposition during the 2010-2011 spawning season were documented in the middle section of the Kootenay area (Golder 2011). This section was characterized by the 10 cross sections from no. 12 to no. 18 (inclusive; Appendix A, Sheets 1 to 3). This section is dominated by low gradient banks, a relatively broad deep section encompassing the thalweg with consistent depth, and a large backwater area downstream of two islands along LDB.

The upstream section of the Kootenay spawning area is the longest and narrowest of the three sections, and is represented by the 14 cross sections from no. 11 to no. 25 (inclusive; Appendix A, Sheets 1 and 3). The eight upstream cross sections (cross sections no. 25 to no. 2 inclusive) exhibit greater thalweg depths and steep shorelines. A shallow shoal along RDB (cross sections no. 25 and no. 23), an island along LDB (cross sections no. 9 and no. 6), and a bedrock outcrop along RDB (immediately downstream of cross section no. 13) are also prominent topographical features in this section. At cross-section 1, shoreline gradients and thalweg depth decrease. During CLBMON-48 egg mat sampling, egg deposition rates in the upper section of the Kootenay River were lower than in the middle section (Golder 2010, 2011).

3.2.3 Expanded Kootenay River Model Area

Topographic surveys were conducted in the Columbia/Kootenay River confluence area to expand the Kootenay River2D model occurred from November 27 to December 13, 2012 (Table 1). In total, 30 cross-sections were conducted and included in the Kootenay River2D hydraulic model expansion (Appendix A, Sheets 9 to 12). As these cross-sections were selected at random using GRTS (Section 2.6.3), they are not in numerical order when viewed on the figure presented in Appendix A.

The Kootenay River2D expansion area can be divided into three separate sections based on topography: the area upstream of the confluence, the confluence itself and downstream of the confluence. The upstream section of the expansion area is characterized by the ten cross-sections (starting with no. 1 and ending with no. 4-not in sequence; Appendix A, Sheet 9 and 10). This section is dominated a large boulder garden (cross sections 1, 18, 7, 20 and 11) mid-channel and the boulder garden extending along the left downstream bank (LDB). Downstream of the boulder garden, multiple benches and ridges are present (cross sections no. 22, 15, 26, 8, and 4).

The confluence section of the expansion area is represented by the 8 cross sections (starting with no. 24 and ending with no. 17; Appendix A, Sheets 9 to 11). Along LDB in the upstream portion of the confluence section, gradient gradually decreases (cross sections 24, 28, 12, 30, and 16). Farther downstream, the channel constricts and gradients along LDB steepen (cross sections 2, 23, and 17). The river bottom is relatively uniform in the mid-channel portion of the confluence section (cross sections 30, 16, and 2). Along RDB, gradients were typically steep (cross sections 24, 28, 12, 23 and 17).

The downstream section of the expansion area is represented by 12 cross sections starting with no. 5 and ending with no. 10 (Appendix A, Sheets 9, 11 and 12). The section consists of steep gradients along both LDB and RDB. The mid-channel portion of the river bottom is relatively uniform, with one large ridge observed at cross sections 9 and 21. The greatest depths within the expansion area occur in this section.

3.3 HEC-RAS Model – Columbia River Simulations

The calibrated and surveyed water level elevations are shown in Figure 8. The differences between surveyed and calibrated water levels are shown in Figure 9. The simulation results of the calibrated model were within -0.2 m to 0.1 m of the surveyed water levels. The largest deviation was observed in the area where there is a wide opening on the left downstream side of the Columbia River. At this location the flow is mainly conveyed in the main channel. The geometry at this river section would require a two-dimensional modelling approach to provide a better estimate on the flow separation between the main channel and the widening on the left side (north) of the Columbia River.

A sensitivity analysis was conducted to test the influence of varying roughness parameters on the calculated water levels. The initial Manning's *n* value of 0.034 was varied by approximately 10% for both channel and floodplains. The model results for a discharge of 793 m^3/s yielded water level variations of approximately ±0.2 m within the study reach when the roughness was changed by ±10% of 0.034 for the main channel roughness (Figure 10). These variations in mean elevation are insignificant in comparison to the variation in actual river bottom elevation along the thalweg, as shown in Figure 8. This sensitivity analysis provided an estimate of the model accuracy for open water flows and indicated that the updated HEC RAS model adequately represents the river hydraulic parameters of the upper Columbia River reach where Mountain Whitefish spawning is prevalent.

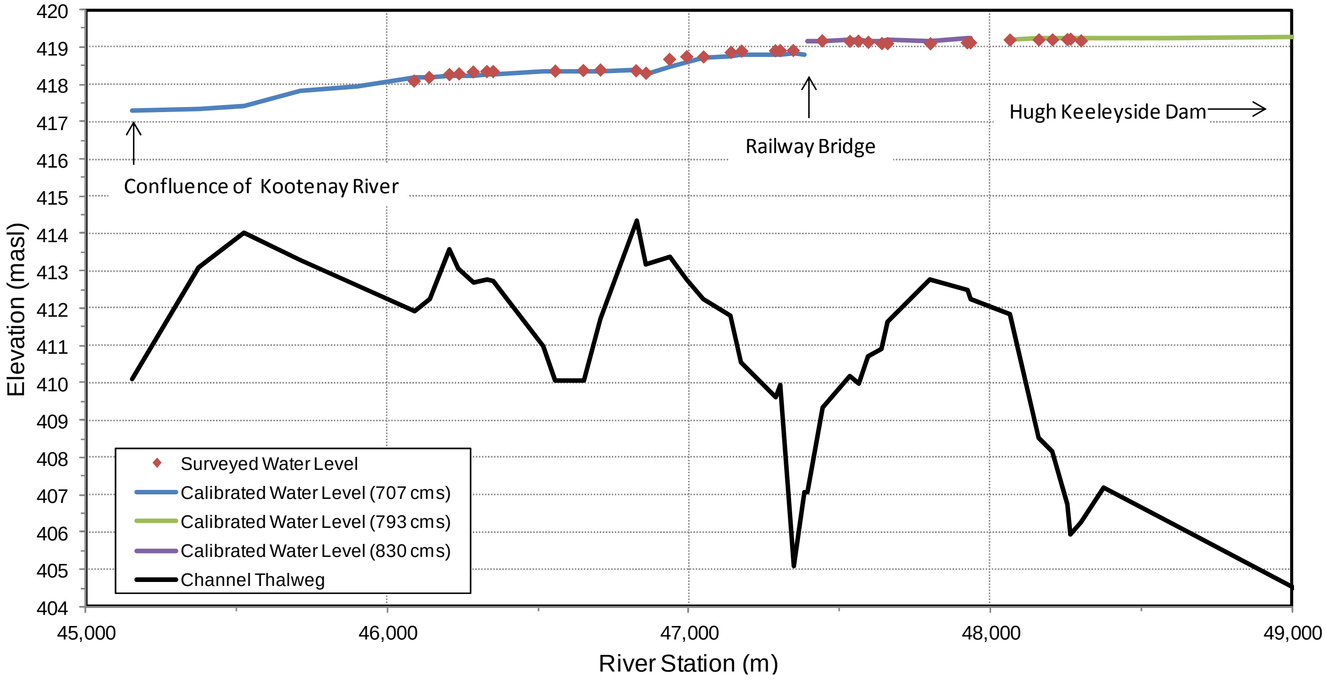


Figure 8: Columbia River HEC-RAS model: surveyed and calibrated water levels.

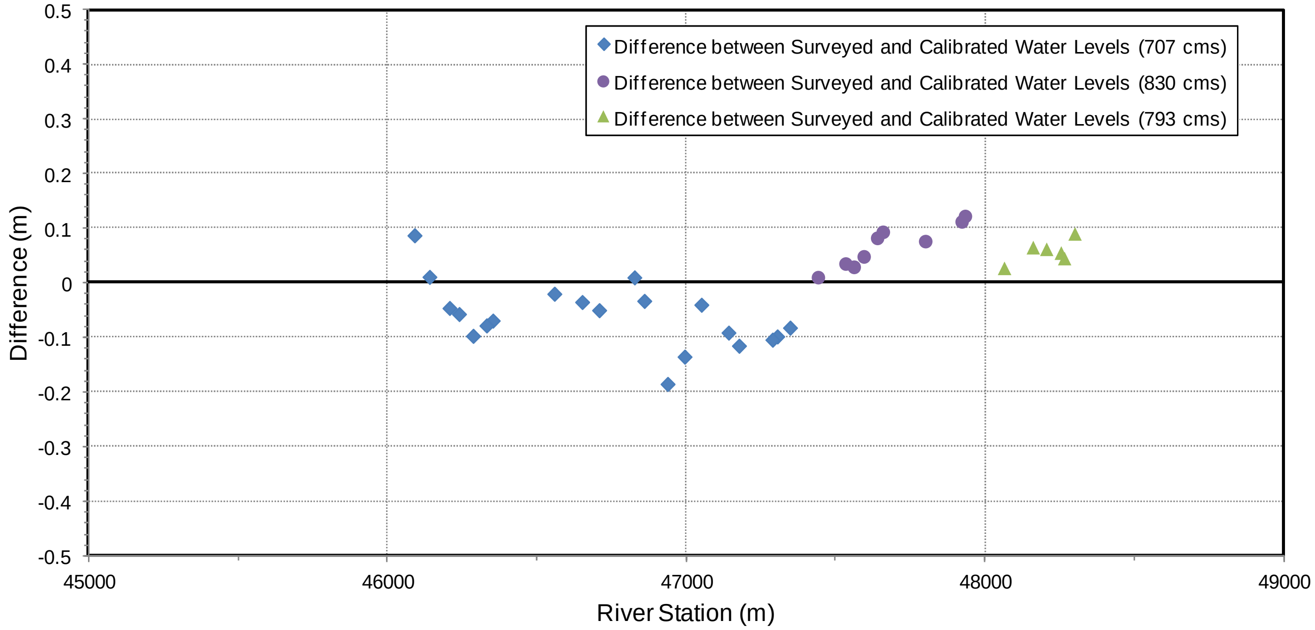


Figure 9: Columbia River HEC-RAS model: difference between surveyed and calibrated water levels.

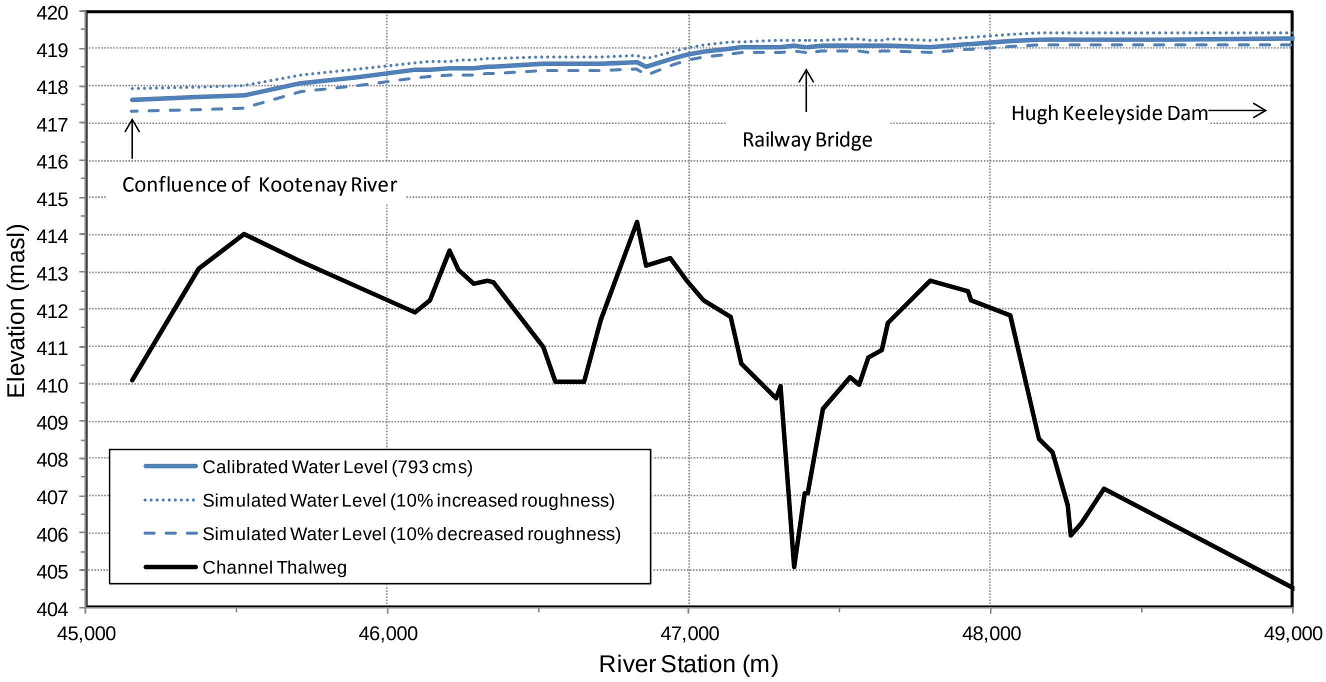


Figure 10: Columbia River HEC-RAS model: sensitivity analysis.

3.4 HEC-RAS Model – Kootenay River Simulations

The simulation results of the calibrated model were consistently within ±0.1 m of the surveyed water levels (Figure 11). A difference of approximately 0.4 m between measured and simulated water levels was found at one cross section (Figure 12). This is considered to be an outlier as the surveyed water level appeared to be too high when compared to the water levels measured upstream and downstream of that location.

A sensitivity analysis was conducted to test the influence of varying roughness parameters on the calculated water levels for the flow during the survey. The initial Manning's *n* value of 0.038 was varied by approximately 10% for both the channel and floodplains. Water levels varied approximately 0.4 m within the study reach when the roughness was changed by ±10% of 0.038 for the main channel roughness (Figure 11). As with the Columbia River HEC-RAS model, these variations in mean elevation are insignificant in comparison to the variation in actual river bottom elevation along the thalweg, as shown in Figure 11. This sensitivity analysis provided an estimate of the model accuracy for open water flows and indicated that the updated HEC RAS model adequately represents the river hydraulic situations of the Kootenay River key spawning area.

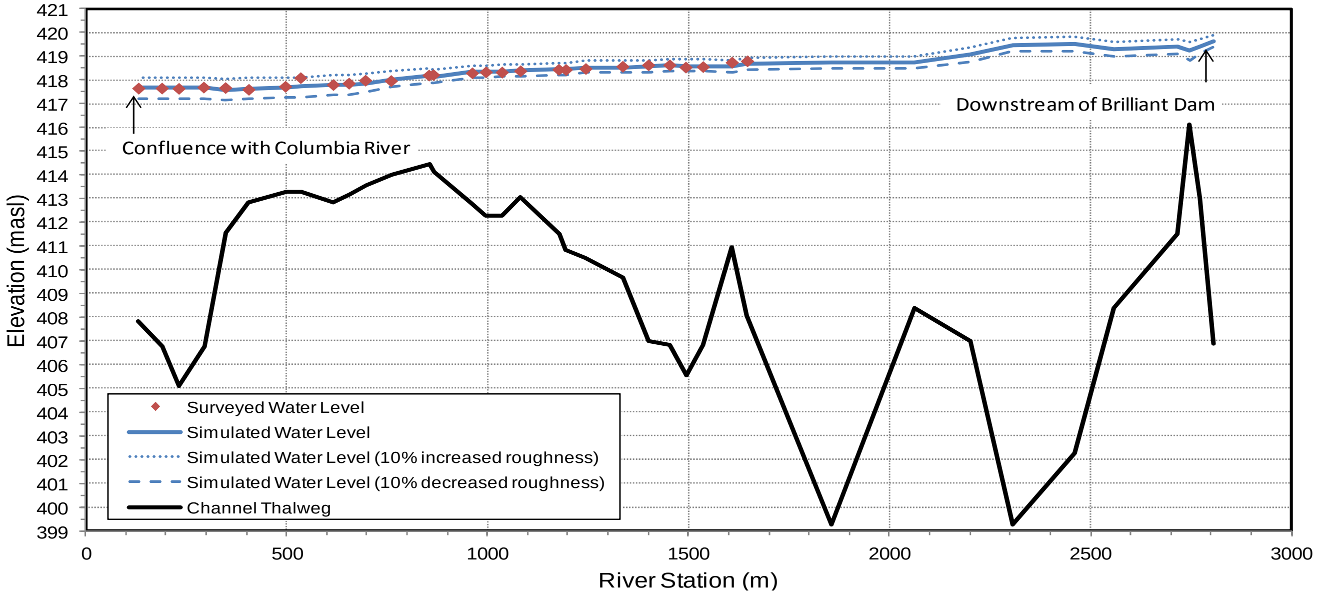


Figure 11: Kootenay River HEC-RAS model: surveyed and simulated water levels.

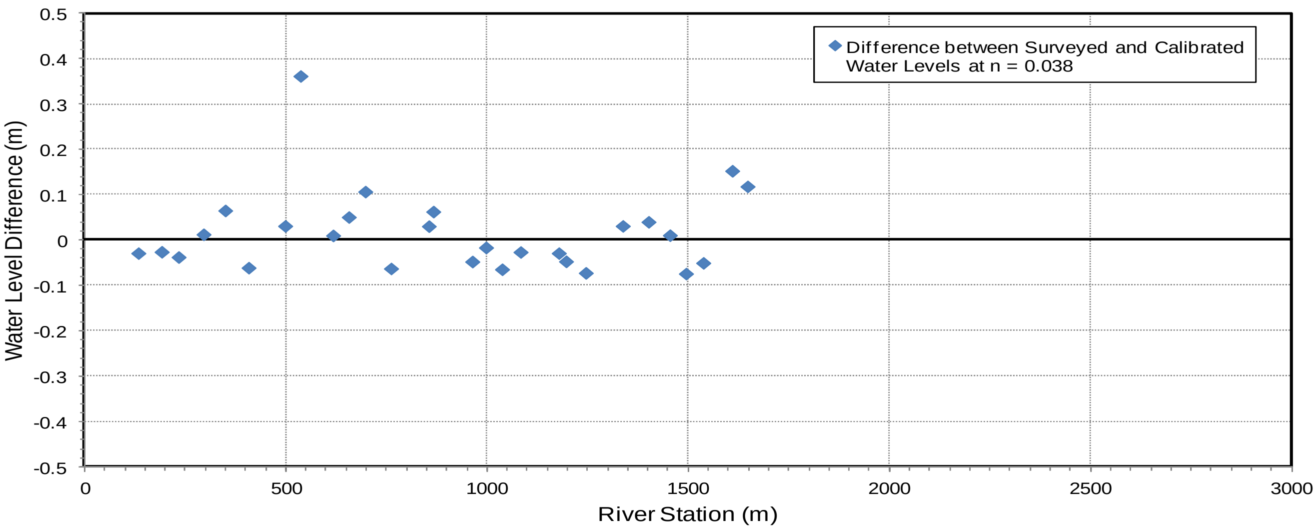


Figure 12: Kootenay River HEC-RAS model: difference between surveyed and calibrated water levels.

3.5 Columbia River Hydraulic Modelling

3.5.1 Columbia River2D Model Calibration

The Columbia River bed consists mainly of coarse materials (gravels and cobbles). The effective roughness height, *Ks*, is a bed resistance parameter. Bed roughness, in the form of a roughness height or Manning's *n* value, is an input parameter to any river modelling. Compared to traditional one-dimensional models, where most two-dimensional effects are abstracted into the resistance parameter, the two-dimensional resistance term accounts only for the direct bed shear stress (Steffler and Blackburn 2002). There is no standard range of initial *Ks* values that are typical of major rivers; and observations of bed material and bed form size are required and usually sufficient to establish reasonable initial roughness estimates. Calibration to observed water surface elevations yields the final *Ks* values.

A roughness height (*Ks*) of 0.20 m was initially assigned for the River2D model. During model calibration, the modelling results were compared to the measured water levels. It was found that the initially set roughness height of 0.2 m was the best fit for this model reach and no further adjustments were necessary. The surveyed and simulated water surface elevations along the right and left banks for the calibration model run are presented in Figure 13 and Figure 14. Water level difference between surveyed and simulated water levels along the right bank ranged between -0.08 m and 0.05 m (mean of -0.01 m). Along the left bank, difference between surveyed and simulated water levels ranged between -0.06 m and 0.13 m (mean of 0.05 m; Figure 15).

The deviations observed in Figure 13 to Figure 15 suggest that there is no strong systematic bias in the results. However, these figures show that the differences between surveyed and simulated water levels were the highest along both riverbanks from 600 m to 1400 m downstream of the model's upstream boundary. This 800 m section of the Columba River 2D model encompasses CPR and Waldies islands where the Columba River widens and shallows. Several back eddies are also present in this area. These habitat features in this section are believed to be the source of this variation in the River2D model.

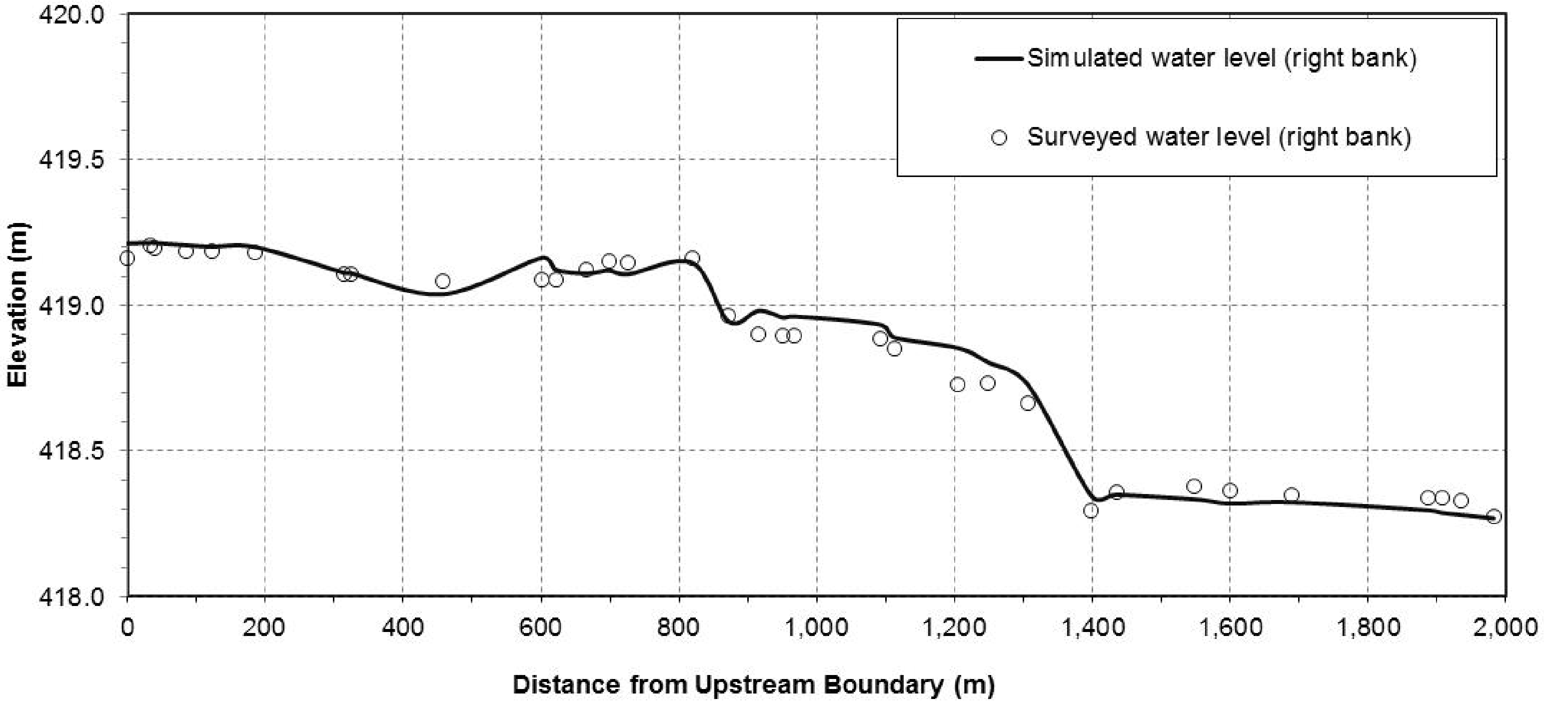


Figure 13: Comparison of simulated and surveyed water levels along the right bank of the Columbia River study reach.

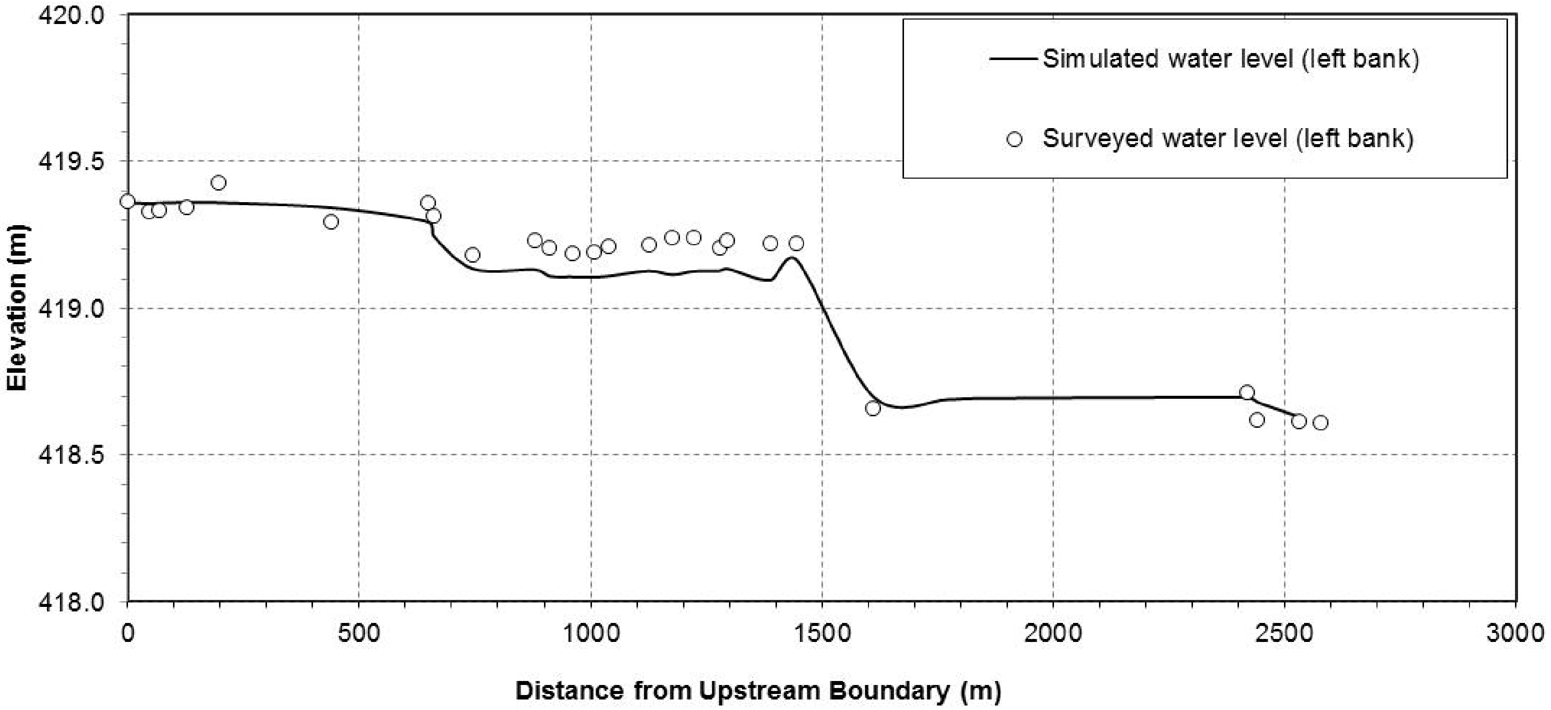


Figure 14: Comparison of simulated and surveyed water levels along left bank of the Columbia River reach.

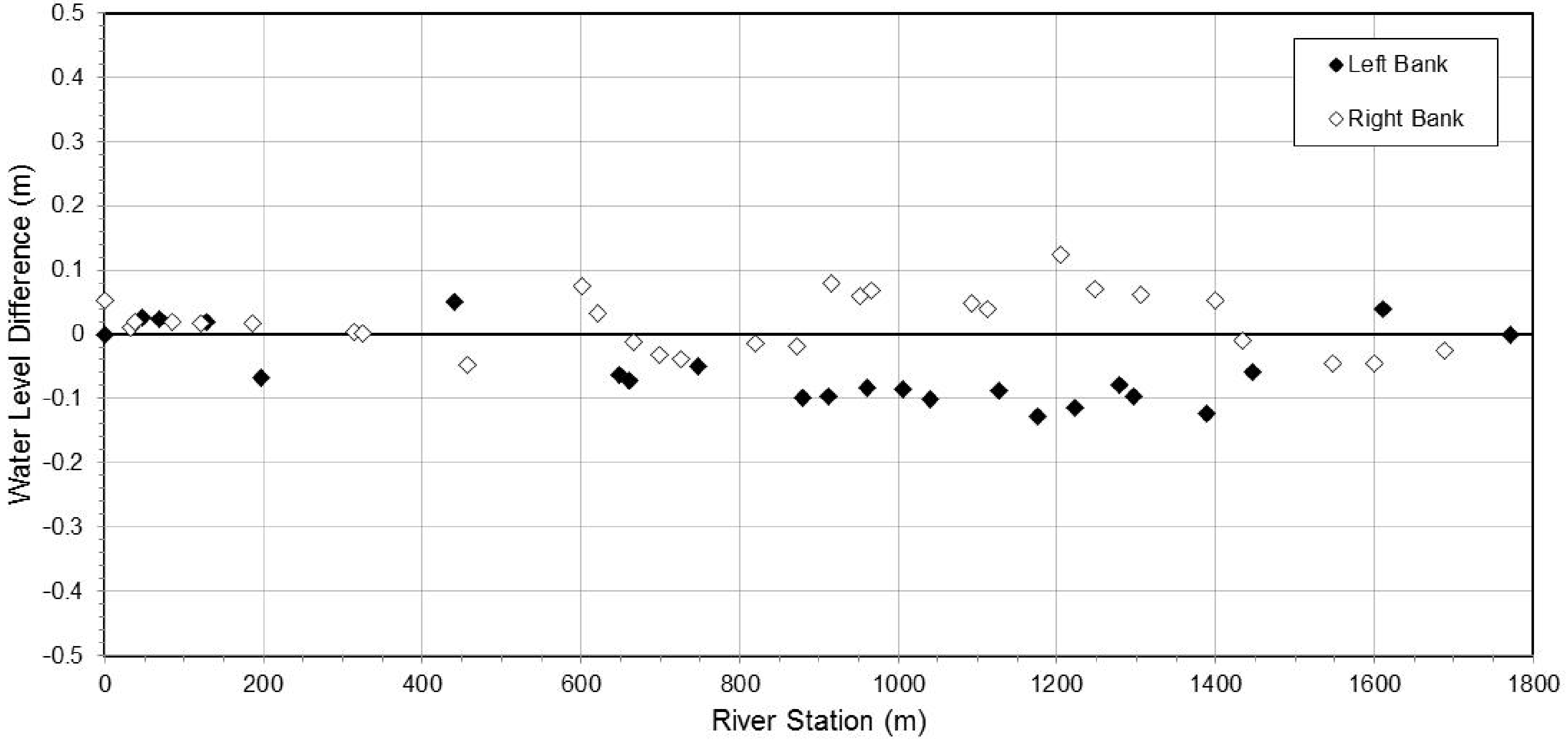


Figure 15: Differences between the surveyed and simulated water levels along right and left banks of the Columbia River reach. Note: the solid line represents the surveyed water levels, and the data points represent simulated water levels at certain points along each riverbank.

3.5.2 Columbia River2D Model Sensitivity Analysis

A sensitivity analysis was conducted on the roughness height *Ks*. The *Ks* values were varied by ±25% (0.05 m) from the calibrated values: the simulated water levels were not sensitive to *Ks* variations (Figure 16). The water levels along the shoreline vary by up to ± 0.05 m if the roughness is varied by 25%, for both the right and left banks. These results show that the 2D model water levels are only slightly sensitive to a change in the roughness height. This also indicated that the direct bed shear only produces minor effects on the water levels, with bed topography and boundary conditions contributing a more substantive effect.

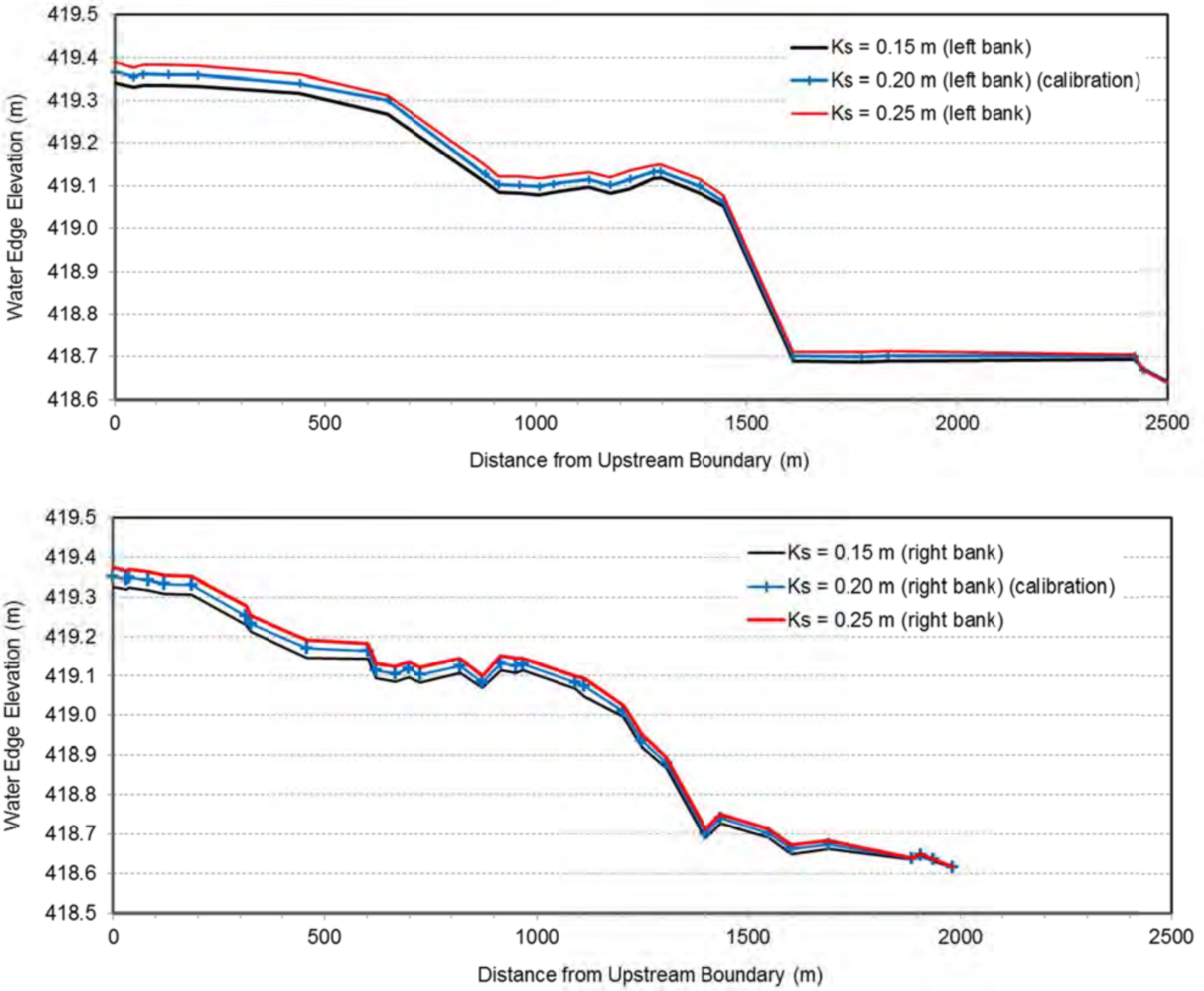


Figure 16: River2D model sensitivity analysis results along the Columbia River reach.

3.6 Kootenay River Hydraulic Modeling

3.6.1 Kootenay River2D Model Calibration

The river bed materials along the Kootenay River consist of coarse materials (mainly gravels and cobbles). A roughness height (*Ks*) of 0.25 m was assigned for the River2D Model. During the model calibration, the simulated water levels were compared to the measured water levels. The surveyed and simulated water levels along the left and right banks of the Kootenay River for the model calibration are presented in Figure 17 and Figure 18. Figure 19 compares the differences between simulated and surveyed water levels along the 1.7 km study reach of the Kootenay River. The difference between the surveyed and simulated water levels ranged from -0.15 m to 0.20 m (mean of -0.006 m) along the right bank. Along the left bank, the difference between the surveyed and simulated water levels ranged from -0.23 m to 0.35 m (mean of 0.013 m).

The deviations observed in Figure 18 and Figure 19 suggest that there is no strong systematic bias in the results. However, Figure 19 shows some skew at the downstream end and a weak tendency of the simulation to underestimate water levels towards the downstream end and to slightly overestimate towards the upstream boundary. Possible sources of error may include downstream boundary condition adjustment, as well as field survey, such as operator blunders, equipment problems, and variation of discharges during the survey.

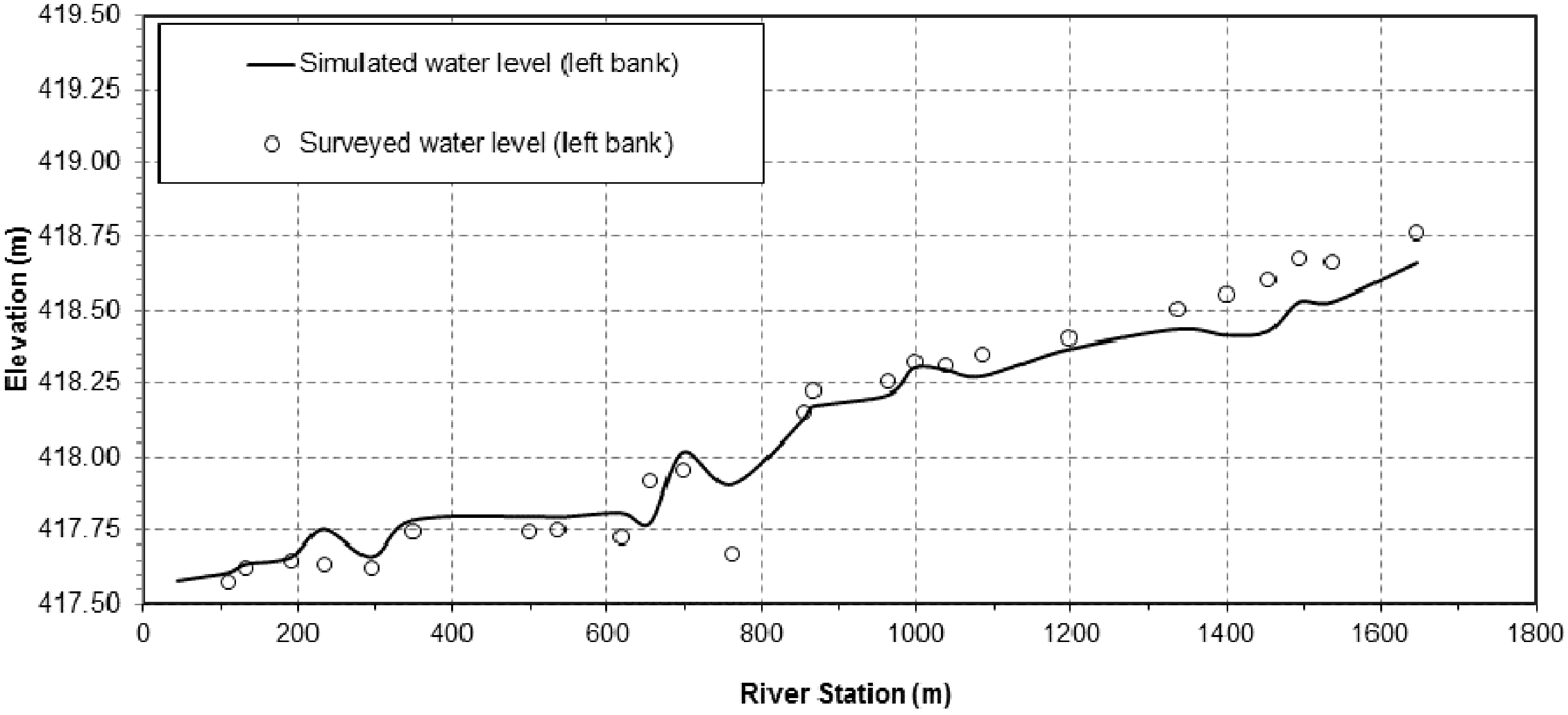


Figure 17: Comparison of simulated and surveyed water levels along the left bank of the Kootenay River reach.

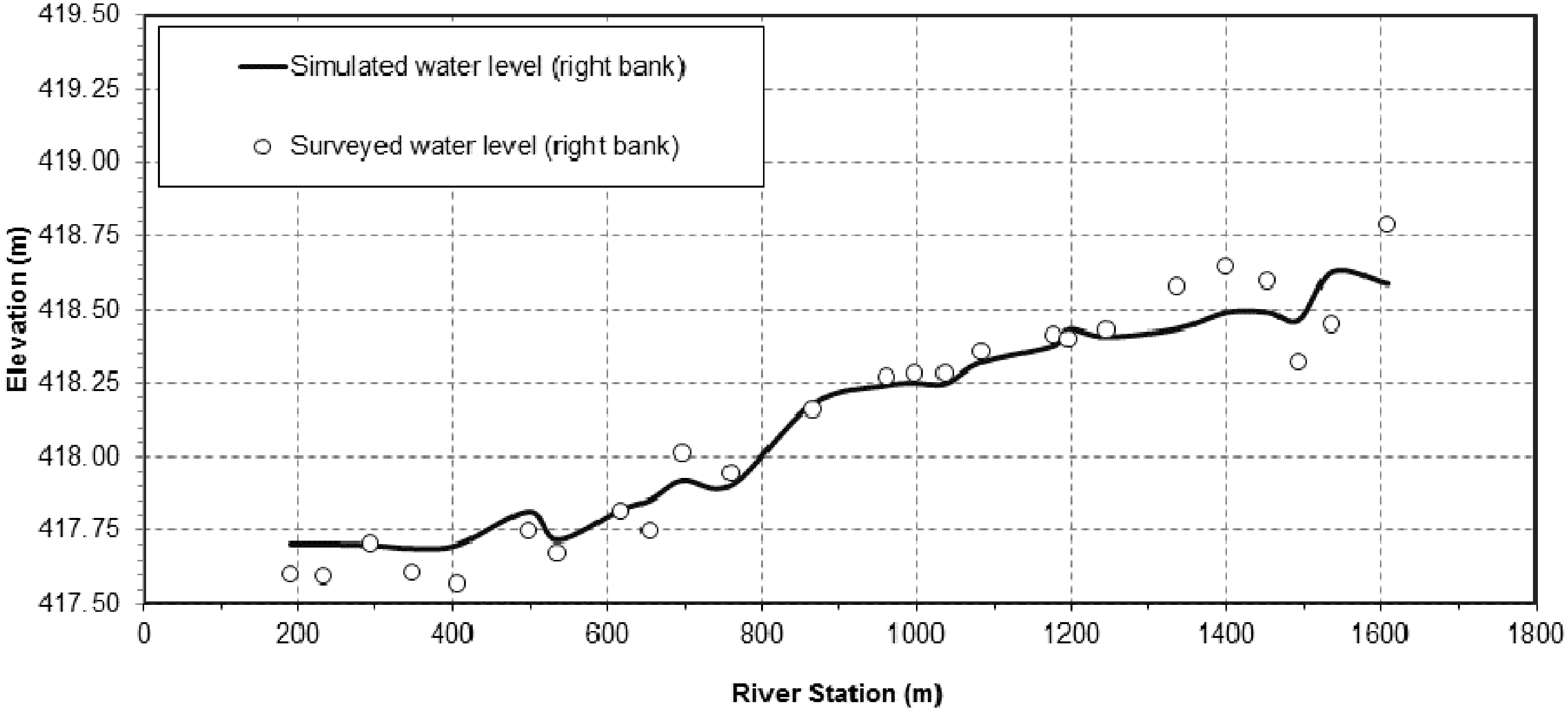


Figure 18: Comparison of simulated and surveyed water levels along the right bank of the Kootenay River reach.

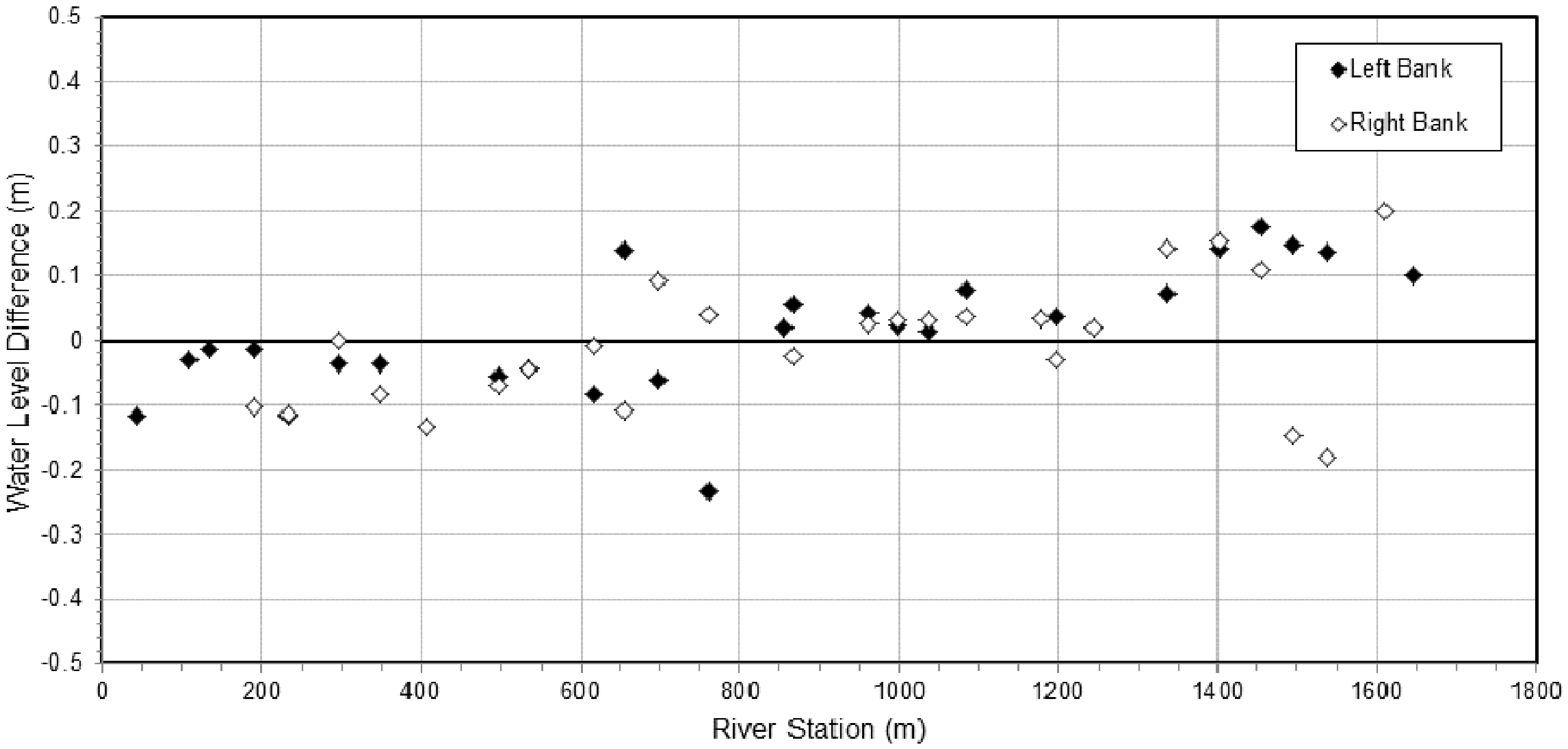


Figure 19: Differences between the surveyed and simulated water levels along the left and right banks of the Kootenay River reach. Note: the solid line represents the surveyed water levels, and the data points represent simulated water levels at certain points along each riverbank.

3.6.2 Kootenay River2D Sensitivity Analysis

A sensitivity analysis of simulated water levels was conducted by varying roughness heights *Ks*. The *Ks* values were varied by ±20% from the calibrated values (Figure 20). The simulated water levels were not sensitive to the *Ks* variations, fluctuating on average ±0.02 m. Similar to the results of the sensitivity analysis on the Columbia River2D model, these results show a minor effect of bed shear on water levels.

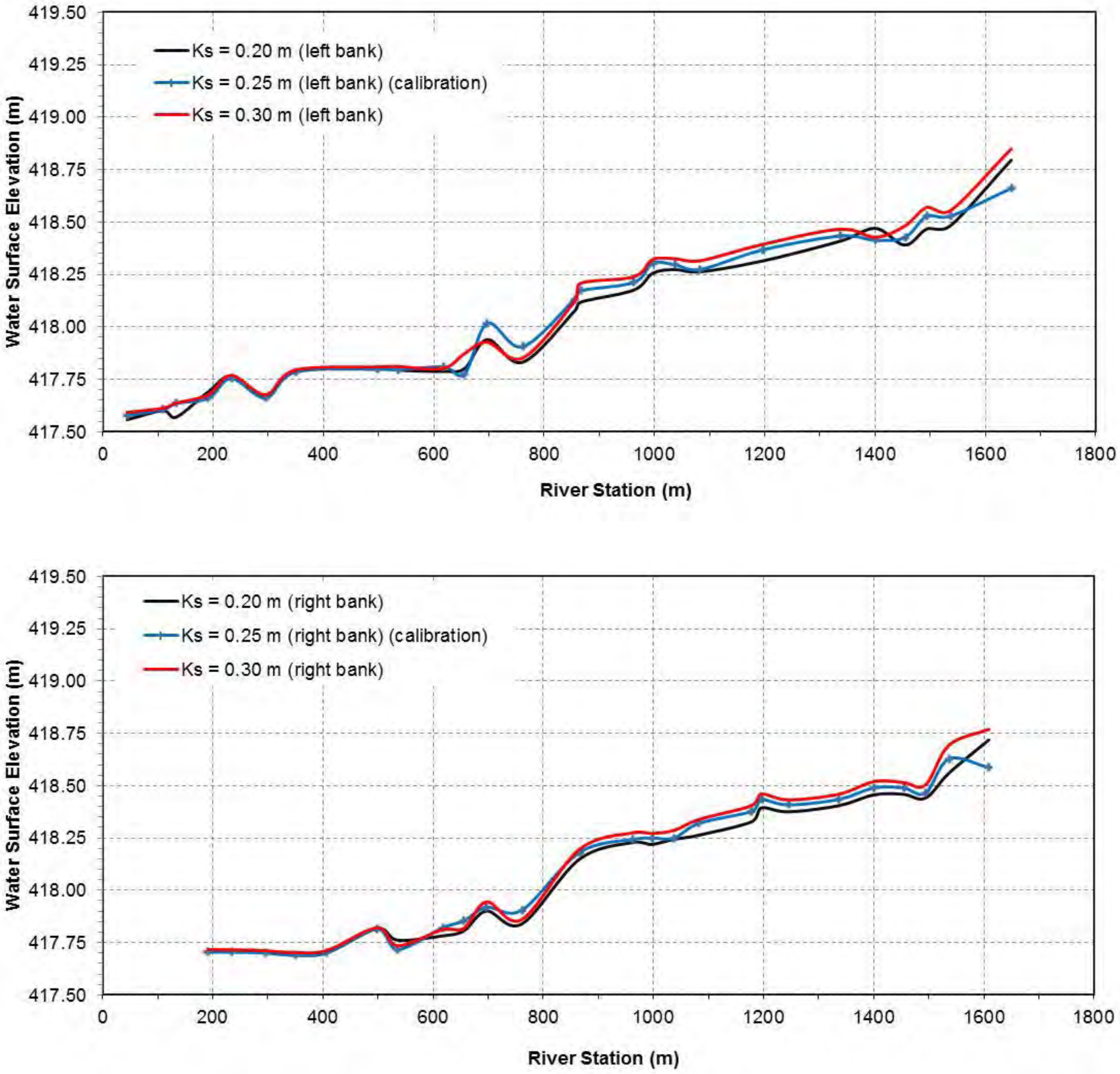


Figure 20: River2D Model Sensitivity Analysis Results along the Kootenay River Reach.

3.7 River2D Interpolation

The equations chosen for depth interpolations described the systems well, since the plot of fitted values vs. River2D values fell on the 1:1 line. Outliers and non-linear patterns were not observed, and the points exhibited very little scatter (Figure 21).

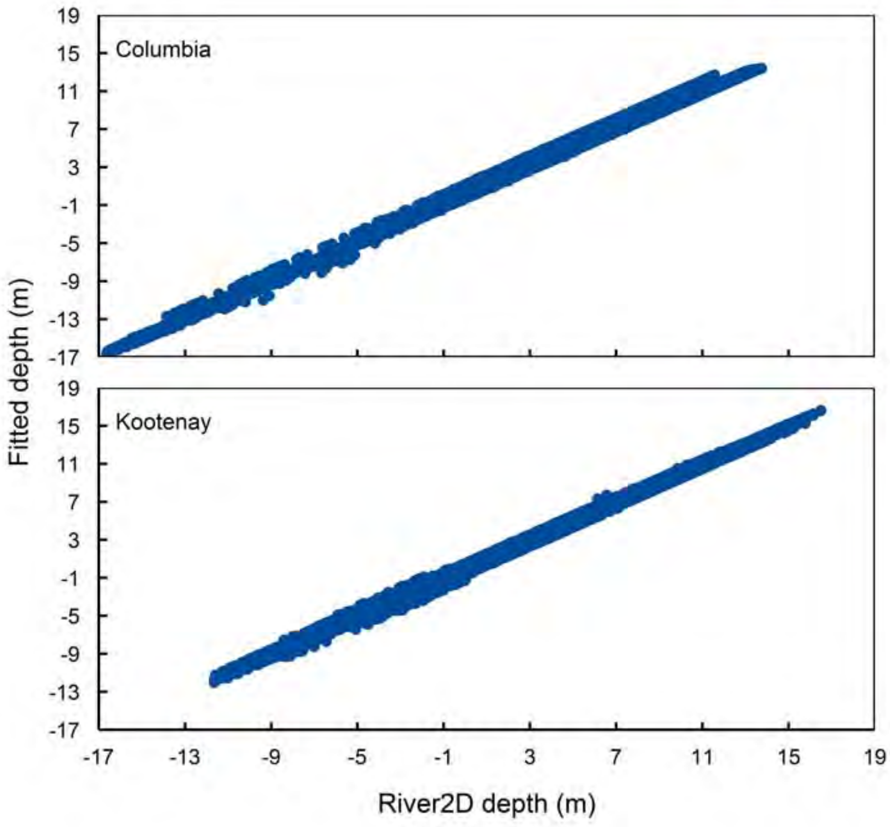


Figure 21: Interpolation of depth at CPR Island and Kootenay spawning grounds, plotted as interpolation-fitted values of depth (m) vs. depth values. Data derived from 99 River2D runs.

As opposed to the depth interpolations, velocity interpolations had a considerably wider scatter, indicating that discharge did not account for all of the velocity variability at the two spawning sites (Figure 22). A subset of the modeled nodes (94 nodes out of 475 in CPR Island [20%] and 223 nodes out of 1211 in Kootenay [18%]) were too shallow to be successfully modeled, with few, if any, values above 0 m/s. These were modeled as having no flow throughout the used range of discharges. In addition, 50 nodes in the CPR section (11%) and 64 nodes in the Kootenay (5%) had irregular relationships between velocity and discharge. This precluded their interpolation in this study, and these nodes were modeled as zeroes throughout the utilized range of discharges.

The linearity of the plots of interpolated vs. River2D-derived velocities (Figure 22) indicated that the chosen functions were likely appropriate despite not accounting for a considerable extent of the variability associated with the modeled velocities.

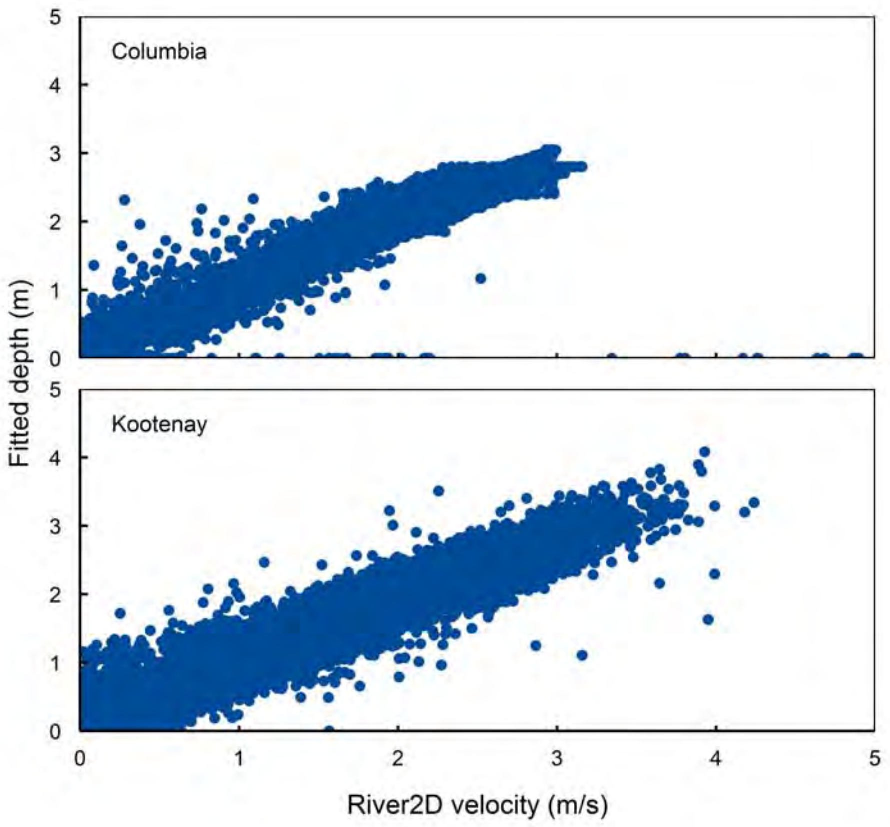


Figure 22: Interpolation of velocity at CPR Island and Kootenay spawning grounds, plotted as interpolation-fitted values of velocity (m/s) vs. depth values. Data derived from 99 River2D runs.

The scatter of interpolated velocity values suggested that velocity interpolation was less precise than depth interpolation. Hence, velocity was not utilised in the development of the ELM, as it could introduce a large source of error. Instead, only River2D depths were used to predict egg deposition and stranding.

3.8 River Stage versus Wetted Area

As predicted by the River2D models, when the combined discharge of BRD and HLK increased, the river stage (water surface elevation) increased as well (Figure 23). HLK discharge had the highest influence on CPR Island river stage, although BRD discharge had a considerable effect on river stage as well at the CPR Island site. Similarly, Kootenay River water stage was most affected by BRD discharge, with a lesser, albeit still pronounced, effect of HLK discharge. Considerable variability in water stage was observed throughout the Kootenay spawning grounds as a result of variability in the proportion of the flows from the Columbia or the Kootenay rivers. This was particularly pronounced at lower discharges, where variability in water levels of > 1m was projected from the model, at sites 0.25KM/0.25KR and sites 0.8KM/0.8KR as a result of variable composition of the combined flows. The pattern was similar at CPR Island sites, although considerably more attenuated.

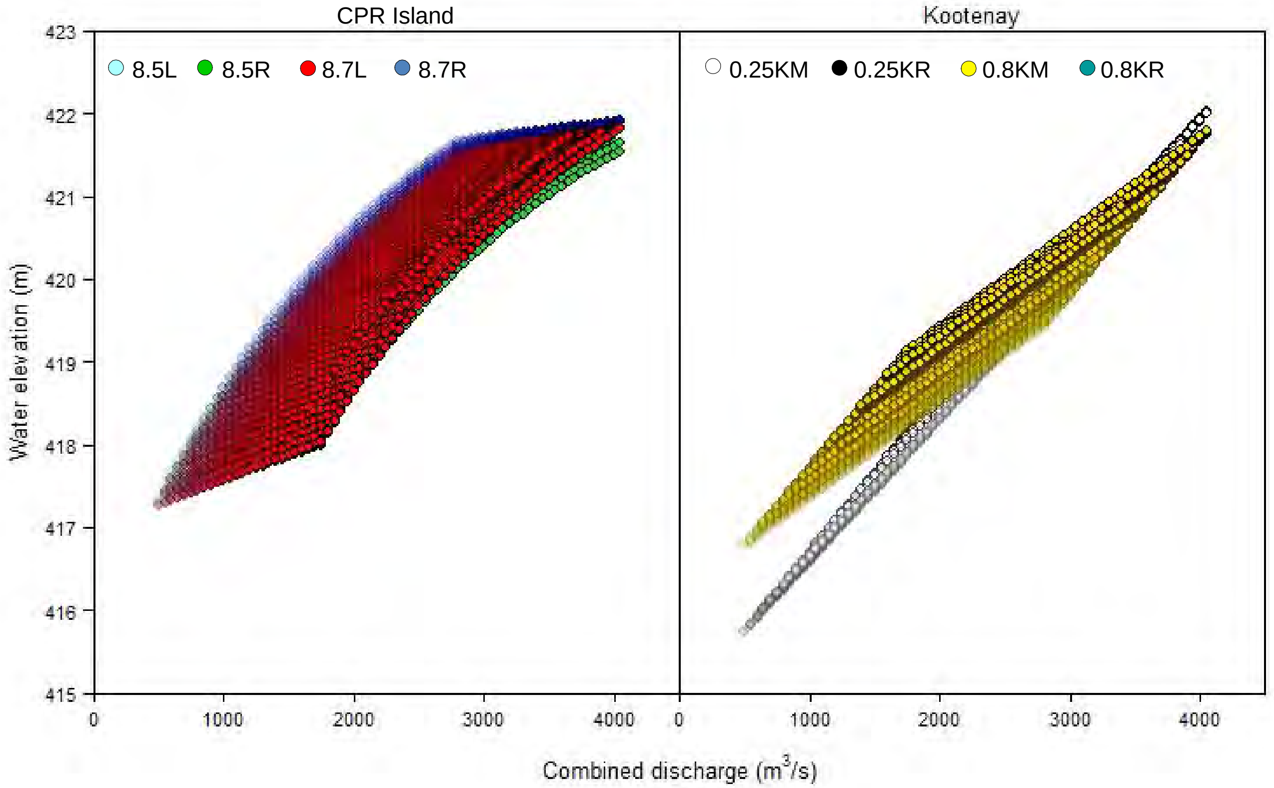


Figure 23: Water elevation (m) at select sites at CPR Island on the Columbia River and sites from the Kootenay River, plotted against combined (HLK + BRD) discharge. Transparency level is related to BRD discharge – transparent points represent low BRD discharge, while solid points represent high BRD discharge.

An increase in water elevation was accompanied by a nonlinear increase in wetted area (Figure 24). At CPR Island (Columbia River), under the modeled discharge conditions, water elevation ranged between 417 and 422 m, while wetted area ranged between approximately 50,000 and 67,000 m². In the Kootenay spawning grounds, elevation range was similar to CPR Island, while the range of wetted area was substantially larger, spanning 150,000-350,000 m². This difference in wetted areas was due to difference in modeled areas – while CPR modeled area was approximately 73,000 m², the Kootenay modeled area was approximately 380,000 m². The curvilinear relationship between CPR Island water elevation and combined discharge is due to the channel morphology in the area. While the Kootenay rivers' relative steady channel gradient results in a linear relationship with discharge, at CPR Island the channel slope varies, resulting in faster water elevation change under low discharge conditions.

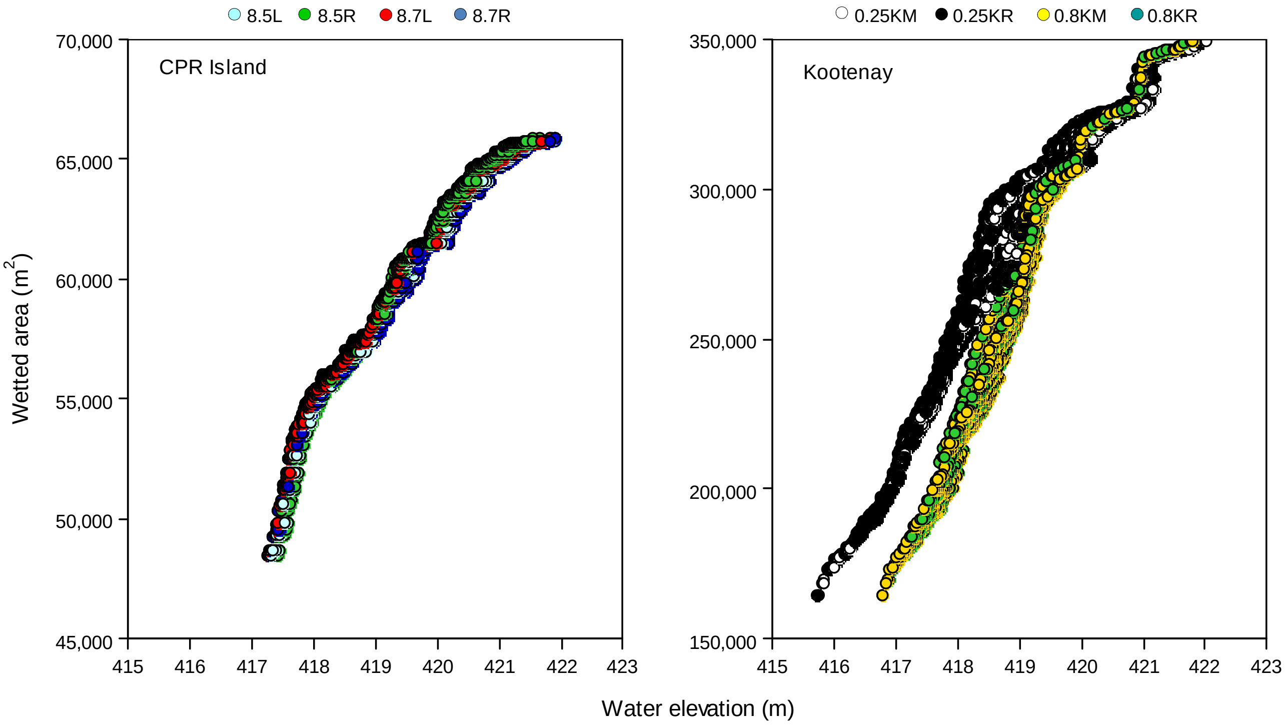


Figure 24: Wetted area (m²) vs. water elevation (m) at selected sampling sites at CPR Island and Kootenay spawning grounds.

With an increase in combined (HLK + BRD) discharge, the estimated wetted area increased in both spawning sites (Figure 25). At CPR Island, the highest wetted area values (within each combined discharge bin) were associated with low BRD discharge, as it implied a high HLK discharge. At Kootenay, the opposite pattern was seen, as expected. Within each combined discharge bin, highest wetted area was estimated for higher BRD discharges. At both sites, as combined discharge increased, the variability of wetted area decreased, albeit the trend was more apparent at CPR Island than Kootenay. This decrease in variability of wetted areas is due to channel morphology – the amount and slope of exposed substrate determine the extent of influence of either dam on inundation of potential spawning habitat represented by wetted area. At low discharge, an exposed area of low-slope substrate would be subjected to inundation from increased discharge from the secondary dam (BRD for CPR Island and HLK for Kootenay).

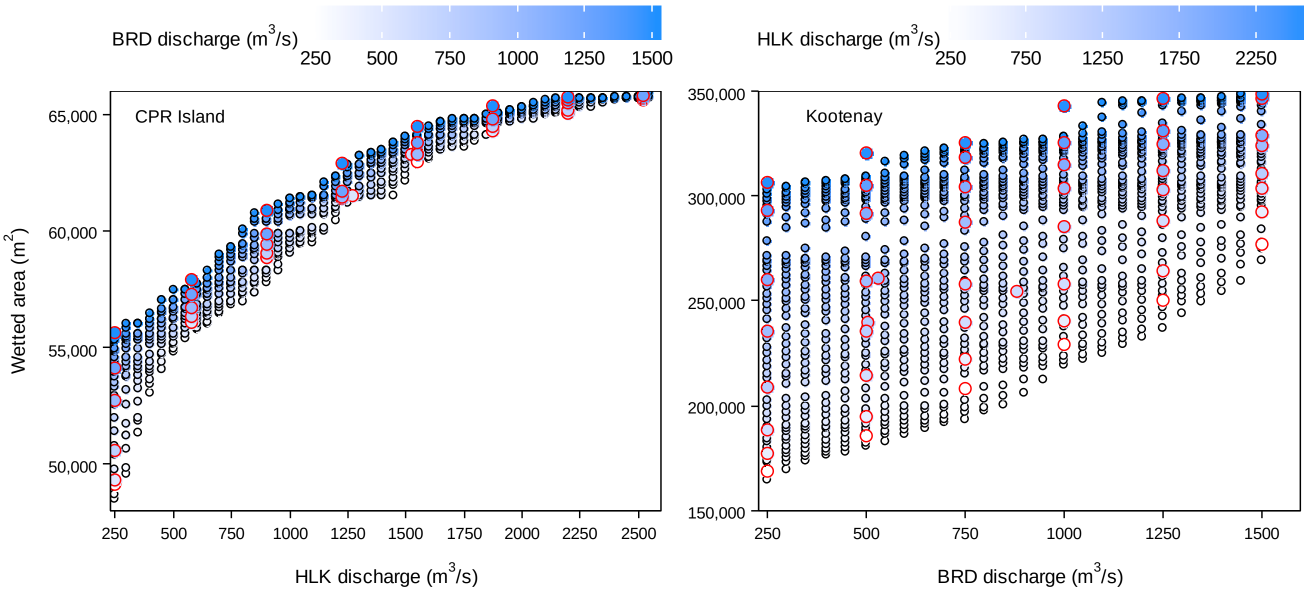


Figure 25: Wetted area (m²) at CPR Island and Kootenay River plotted against HLK and BRD discharge, respectively, with point fill as a function of BRD and HLK discharge, respectively. Graph points are interpolated wetted area values; red points are values from the original 51 model runs. Note that colour scales differ between the panels.

3.9 Cumulative dewatering of eggs due to daily flow fluctuations

The fluctuation in wetted area resulting from the BRD discharge reduction (1000 m³/s to 500 m³/s: range observed during CLBMON-48 spawning surveys, Golder 2014 in prep.) was evaluated at a range of HLK discharges (Figure 26). At each HLK discharge, we estimated the difference between wetted areas (defined as loss of wetted area) at BRD discharge of 1000 m³/s and 500 m³/s. At CPR Island, the largest loss of wetted area (approximately 3,500 m²) as a result of declined BRD discharge was at a HLK discharge of 250 m³/s. As HLK discharge increased, lost area from BRD reduction in flows was reduced below 1,000 m². At the Kootenay spawning area reach, lost wetted area as the BRD discharge declined from 1,000 m³/s and 500 m³/s, was approximately 45,000 to 55,000 m² at HLK discharges of 250 to 1,500 m³/s, and decreased to approximately 20,000 m² at HLK discharges above 1,500 m³/s.

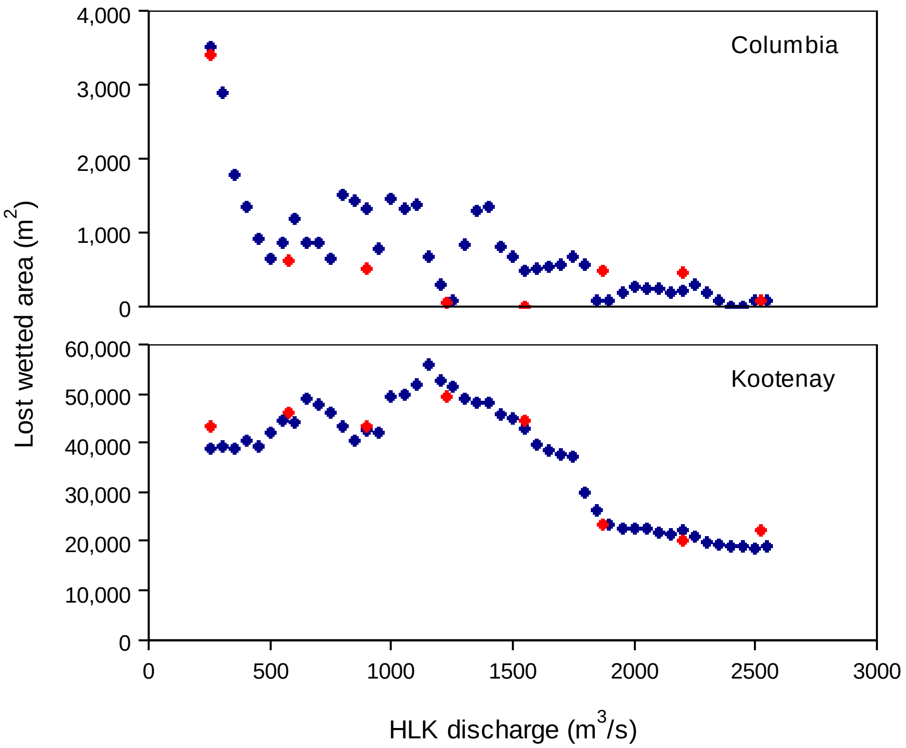


Figure 26: Lost wetted area (m²) resulting from decreasing BRD flows from 1000 m³/s to 500 m³/s, plotted against HLK discharge. Graph points are interpolated wetted area values; red points are values from the original 51 model runs.

3.10 Egg Loss Model

3.10.1 Analysis

3.10.1.1 Timing of Egg Deposition

New egg deposition at both the CPR Island and Kootenay River key spawning areas was modeled as a function of time. At Kootenay, the timing at which 50% of cumulative corrected CPUE and the beginning of spawning were slightly less variable than at CPR Island (Figure 27).

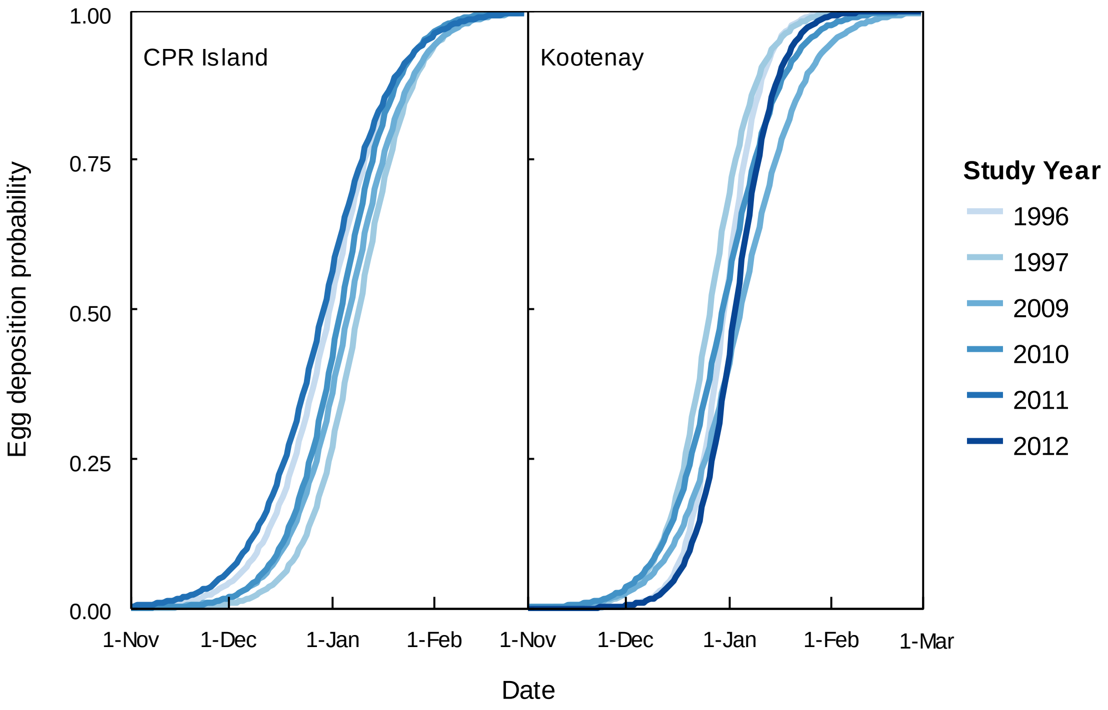


Figure 27: Year- and site-specific predicted cumulative probability of egg deposition.

3.10.1.2 Development vs. ATU – Model

The relationship between egg developmental stage and ATU was described using an asymptotic exponential curve (Figure 28). At hatch (stage 30), predicted mean ATU (°C) value was 267 ATUs (95% confidence interval of 219-337 ATUs; R.L.&L. 2001). The distribution of ATU-at-hatch values, generated using the standard deviation of the residuals, was skewed Figure 28, as expected for inverse prediction confidence intervals (Seber and Wild 2003).

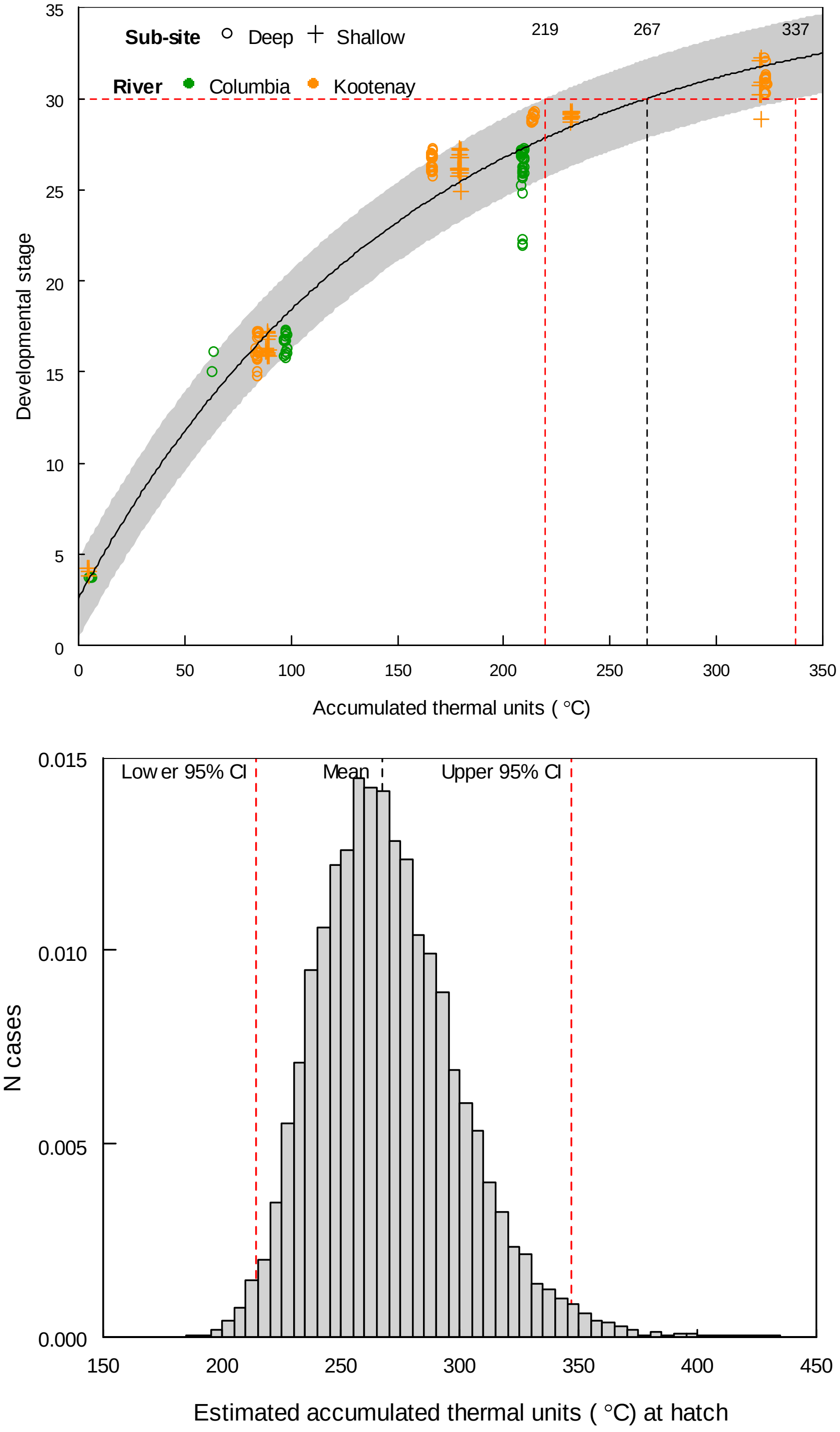


Figure 28: Developmental stages plotted against accumulated thermal units (ATU; top panel); an estimated distribution of ATU values at hatching stage (stage = 30). Data used are the results of 1995-1996 Mountain Whitefish incubation study (R.L.&L. 2001). The dashed lines on the bottom panel correspond to the 95% confidence intervals plotted on the top panel (red lines) and the mean estimate of ATU at hatch (black).

3.10.1.3 Egg Deposition with Depth/Velocity – Model

The distribution of cumulative new egg CPUE was variable when plotted against either water velocity or depth (Figure 29), although the cumulative distribution of Kootenay CPUE vs. velocity was less variable than that of CPUE vs. depth. Due to the high variability in River2D velocity interpolation (Section 3.7), only depth was used in subsequent egg loss modeling.

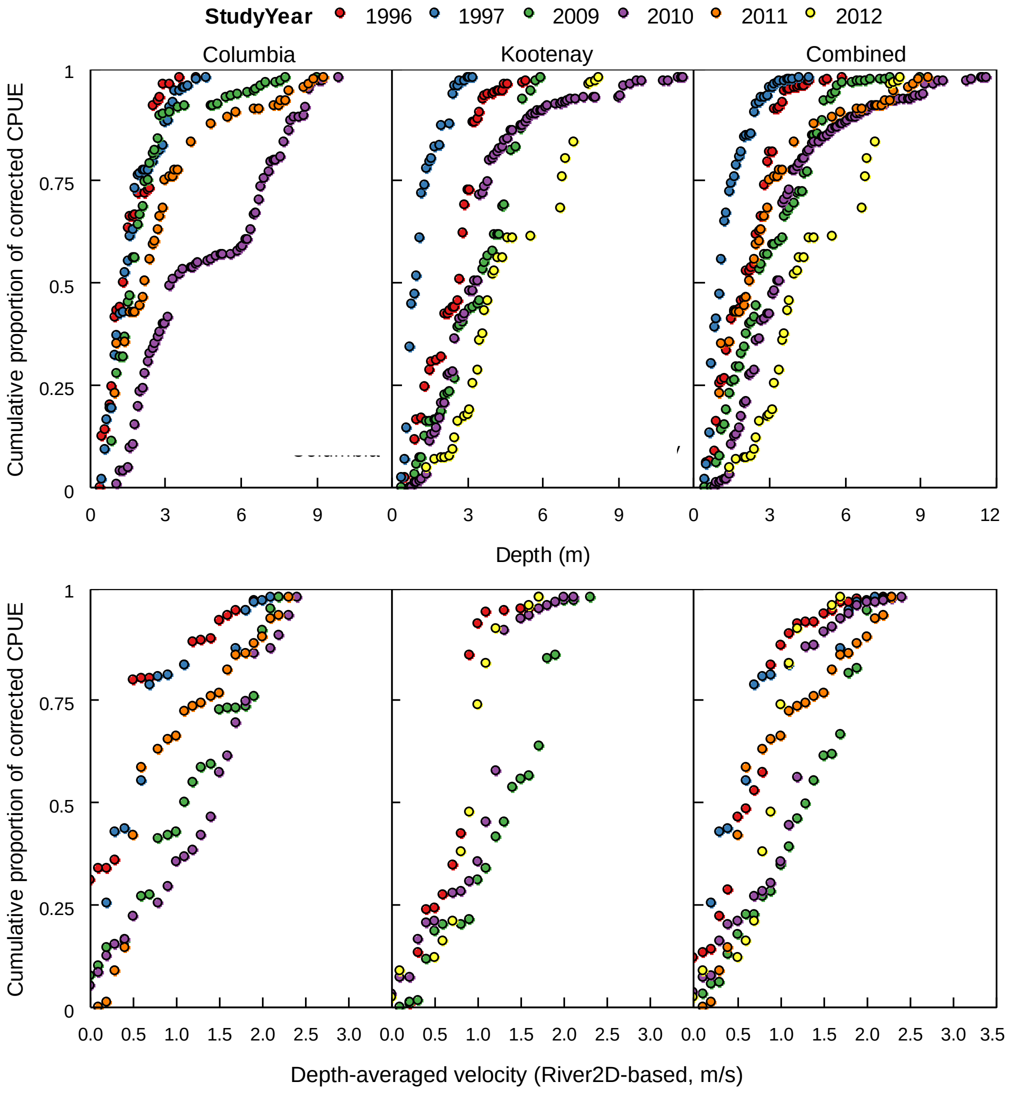


Figure 29: Cumulative proportion of corrected CPUE (fresh eggs only) throughout the sampling years (1996, 1997, 2009-2012), plotted against depth and River2D-based, depth-averaged velocity at deployment locations (top and bottom panels, respectively). The cumulative distributions are shown for Columbia and Kootenay sampling sites separately, as well as in a combined plot.

3.10.2 Model Output

For each model run, the model will create maps of egg deposition and stranding, separately for each spawning site (Figure 30, Figure 31). These maps describe the total deposition and stranding levels throughout the entire spawning and incubation periods (November 1 to May 1). The maps will be colour-coded based on level of egg deposition and stranding proportion, respectively. The maps will be saved in the working directory supplied to the program (see Appendix B2 for details).

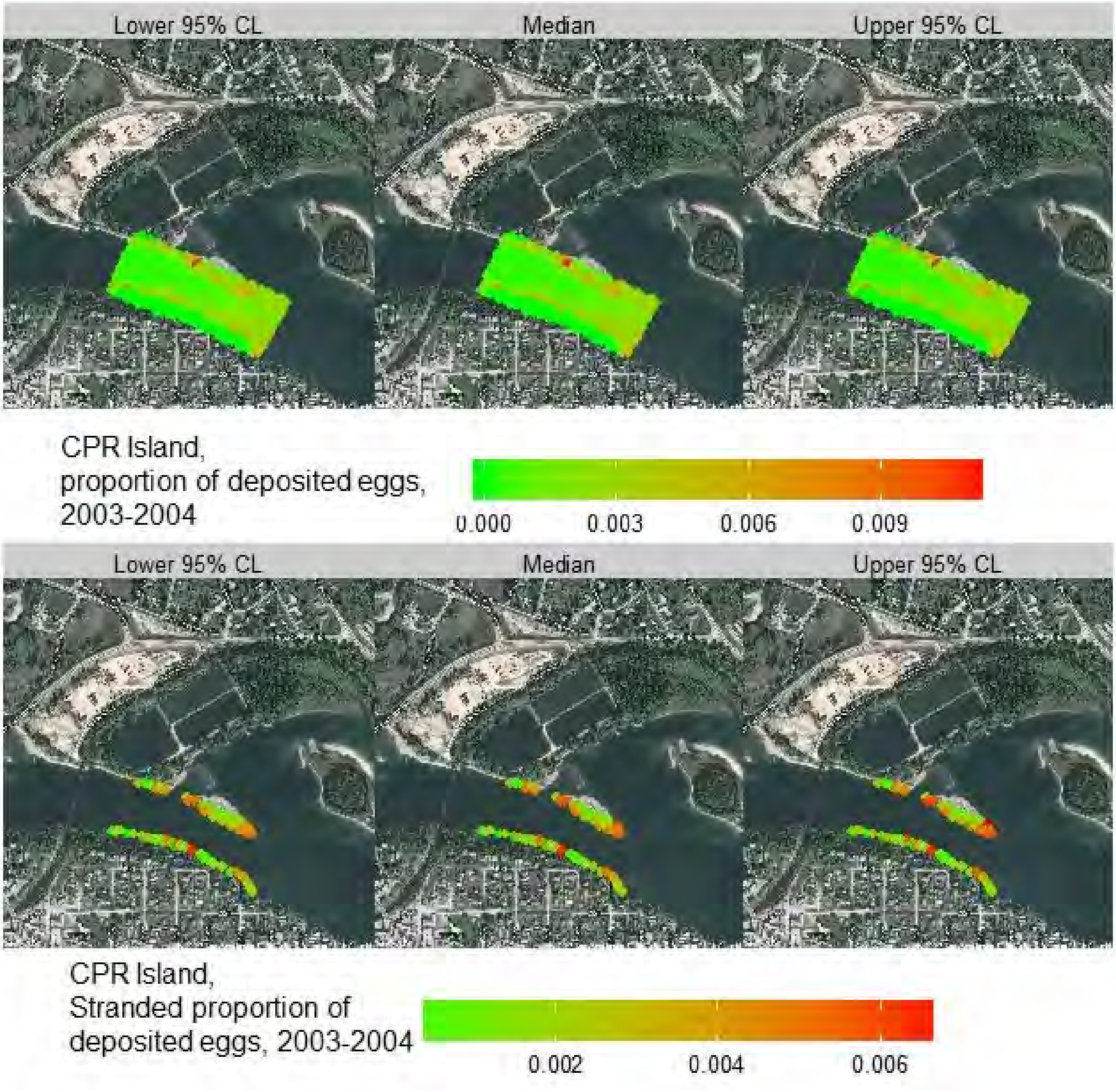


Figure 30: Maps of total egg deposition (upper panel) and proportion of stranded eggs out of those deposited (lower panel) at CPR Island throughout the entire spawning and incubation periods (November 1 to May 1). The maps are colour-coded based on deposition and stranding levels, respectively.

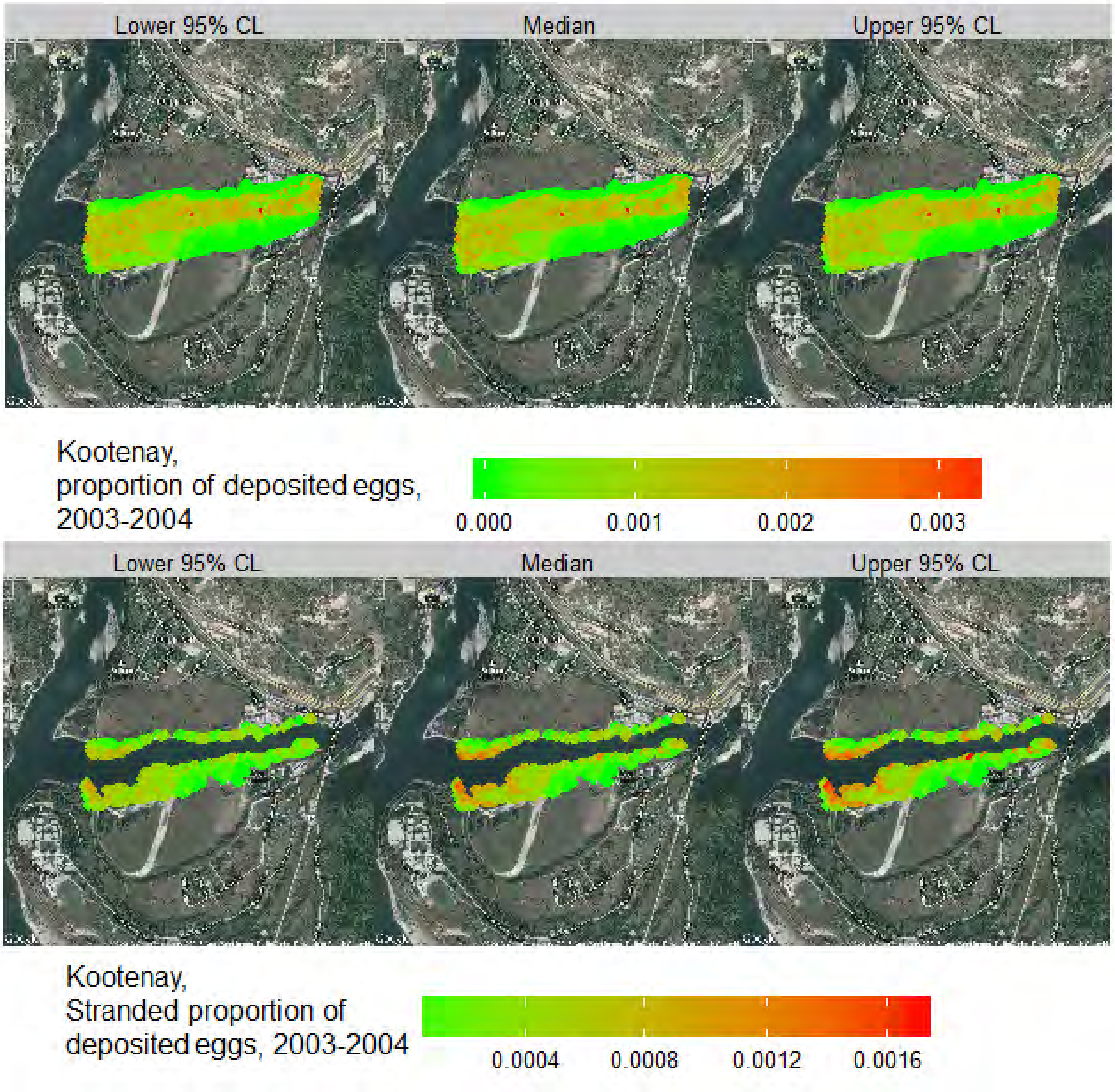
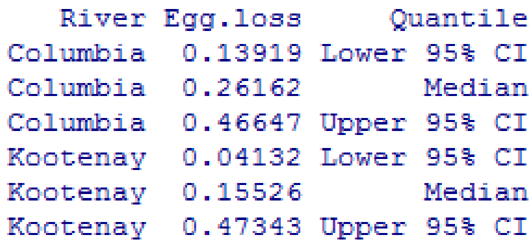


Figure 31: Maps of total egg deposition (upper panel) and proportion of stranded eggs out of those deposited (lower panel) at Kootenay throughout the entire spawning and incubation periods (November 1 to May 1). The maps are colour-coded based on deposition and stranding levels, respectively.

Lastly, the model will print the total estimates of stranding directly on the screen, for immediate use (see examples in Figure 32). These describe the proportion of total eggs deposited throughout the spawning season that get stranded before May 1.



```
   River Egg.loss     Quantile
Columbia  0.13919 Lower 95% CI
Columbia  0.26162       Median
Columbia  0.46647 Upper 95% CI
Kootenay  0.04132 Lower 95% CI
Kootenay  0.15526       Median
Kootenay  0.47343 Upper 95% CI
```

Figure 32: An example output of total stranding estimates using 2003-2004 HLK and BRD discharge data.

The choice of length of bootstrap will influence the repeatability of the model's results. Fewer bootstraps will result in less stable estimates of stranding; i.e., if the model is re-run several times, results will vary among runs. An increase in bootstrap iteration will result in more stable estimates and higher repeatability (Figure 33). Kootenay stranding results were generally more variable than those for CPR Island, although the reduction in variability of both median values and 95% confidence limits was observed for both spawning grounds.

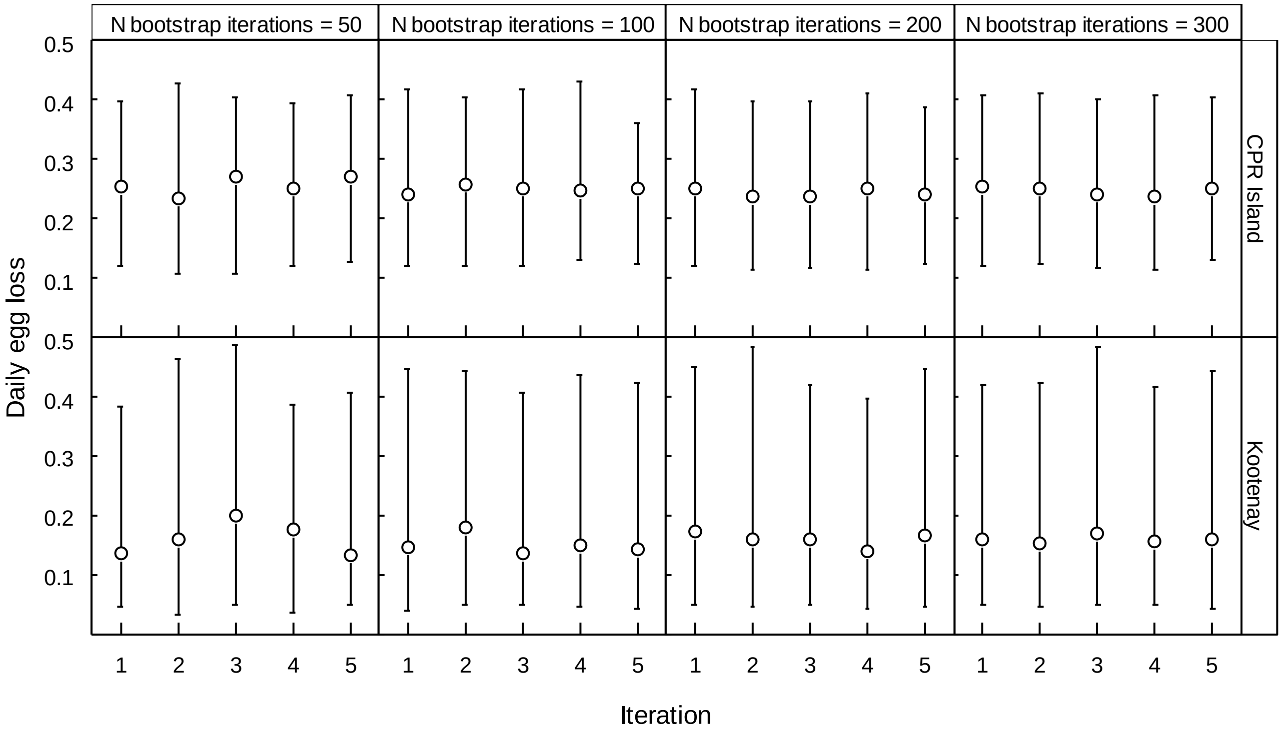


Figure 33: Example of repeatability of ELM total stranding estimates as a function of the number of bootstrap iterations conducted; data used: 2003-2004 HLK and BRD discharge records. X axis indicates a sequence of repeated identical trials using the number of iterations in the column headings. Points are median stranding estimates; error bars are 2.5th and 97.5th quantiles.

3.10.3 Changes to the Previous Egg Loss Model

The current version of the ELM differs in many aspects from the previous version (Table 9). These updates increased the resolution of the model, now providing a spatially-explicit map of deposition and stranding areas. In addition to change in spatial scale, the addition of variability around deposition estimates allowed the estimation of uncertainty associated with the total stranding estimate provided by the model.

Table 9: Differences between previous and current ELMs.

	Previous model	**Current model**
Hydraulic data (depth)	Based on 4 HEC-RAS transects	Based on 99 ADCP and topographic transects, and interpolation of 99 River2D model runs
Spatial scale	One-dimensional (depth)	Two-dimensional (depth and mean column velocity), spatially explicit, with egg deposition and stranding probabilities associated with each River2D node
Variability in egg deposition time	None; deterministic deposition curve with separate curves for Kootenay and Columbia River spawning areas	Based on six years of egg collections
Variability in egg deposition with depth	None; deterministic deposition curve	Based on six years of egg collections
Variability in egg hatching time	None; deterministic ATU to development	Based on distribution of developmental stages at different ATUs
Total stranding variability estimates	None; deterministic stranding estimates	Incorporation of bootstrapping allows estimation of variability around stranding estimates

3.10.4 Egg Loss in Relation to Flow Stabilization

Comparisons between total egg stranding estimates suggested a high degree of inter-annual variability in stranding, as well as differences in stranding estimates between the two spawning sites. However, all 95% confidence intervals overlapped, indicating no statistically significant differences among the years (Figure 34).

Overall, CPR Island egg stranding estimates were slightly higher and less variable among years than those from Kootenay River. At CPR Island, all generated lower confidence limits ranged from 0.109 to 0.239 (in 2010 and 2012, respectively), while all upper confidence limits ranged between 0.440 and 0.701 (in 2010 and 2012, respectively). In comparison, while all lower confidence limits in the Kootenay river were similar (range of 0.016 to 0.096), upper confidence limits varied greatly, ranging 0.120 to 0.738 (2010 and 2009, respectively).

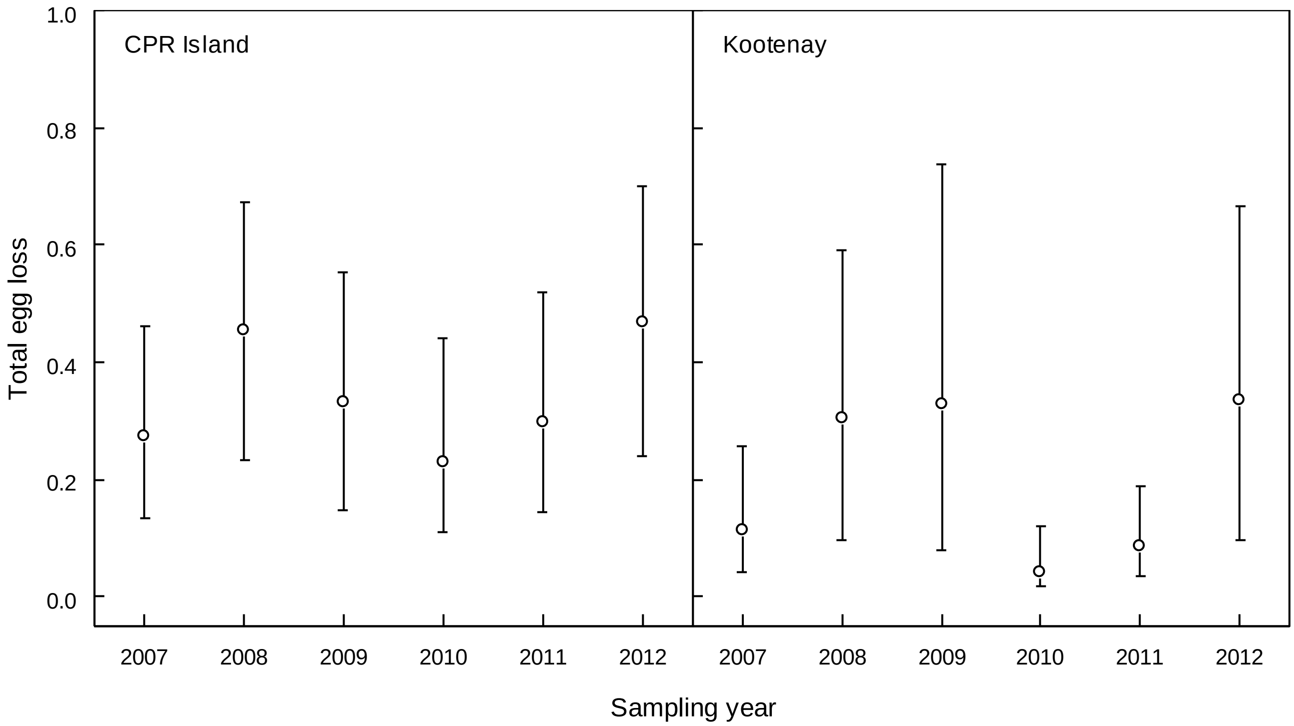


Figure 34: Comparison of yearly total stranding estimates in both key Mountain Whitefish spawning areas from 2007 to 2012. Each year represents a spawning/hatching period between November 1 of that year to May 1 of the next year. Egg loss represents the proportion of the total amount of deposited eggs that strands throughout the period of interest (November 1 to May 1).

In order to relate the egg loss estimates from the ELM to the flow stabilization index, two separate calculations for the flow stabilization were made. During the first calculation, the flow stabilization index ranged between 1111 in 2011 to 1426 in 2010 (Table 10). Upon inspection of the hourly discharge from both HLK and BRD, a BRD flow increase that was five hours (08:00 to 13:00) in duration on January 21, 2010 was identified. This short term flow increase introduced a potential bias to the initial flow stabilization index calculation, as it occurred on the last day of the Q_{Smax} period. Therefore, this flow increase was removed from the dataset and a second calculation was conducted. This second calculation resulted in a reduction in the 2010 flow stabilization index from 1426 to 1334 (Table 10).

When compared to the flow stabilization index, the ELM mean egg loss estimates between years did not follow an identifiable pattern, especially at CPR Island. Both high and low median egg loss estimates were associated with the lowest flow stabilization index values (2010 to 2012: Table 10). The median egg loss estimates associated with the high flow stabilization index values (2007 to 2009) was also highly variable (Table 10).

Table 10: Maximum flow during the peak spawning period (January 1-21, Q_{Smax}), minimum flow prior to egg hatch (January 22 – Apr 1, Q_{Imin}), flow stabilization index (Q_{Smax}- Q_{Imin}), and egg loss estimates (median and upper and lower 95% confidence limits) in 2007-2012. Note, a second calculation for 2009 was conducted after a 5 hour flow increase from BRD at the end of the peak spawning period was removed from the dataset.

Year	Q_{Smax}	Q_{Imin}	Flow Stabilization Index	CPR Island			Kootenay River		
				Lower CL	Median	Upper CL	Lower CL	Median	Upper CL
2007	2329	1085	1244	0.133	0.272	0.461	0.043	0.114	0.258
2008	2266	891	1375	0.231	0.454	0.675	0.096	0.305	0.592
2009	2317	890	1426	0.146	0.33	0.553	0.078	0.327	0.738
2009 - second calculation	2224	890	1334						
2010	1981	868	1113	0.109	0.231	0.44	0.016	0.043	0.12
2011	2341	1231	1111	0.146	0.298	0.521	0.034	0.087	0.187
2012	2404	1257	1148	0.239	0.468	0.701	0.096	0.337	0.665

4.0 DISCUSSION

4.1 Topographic Characteristics of the Key Spawning Areas

Management Question 1: *What are the topographic characteristics of the key spawning locations for Mountain Whitefish in the lower Columbia and Kootenay rivers?*

In Year 1, a total of 40 cross sections were conducted in the Columbia River at the CPR Island area, and 30 cross sections were surveyed in the Kootenay River, all of which were included in the RIVER-2D hydraulic model when it was developed in Year 2. Originally, the upstream hydraulic control selected for the CPR Island River2D hydraulic model was established at the downstream end of Norn's Creek Fan. The downstream hydraulic control was set at the upstream end of Tin Cup Rapids. The area between these two controls was the original study area for CPR Island. At the request of BC Hydro, the area sampled during the topographic and ADCP surveys was expanded upstream to encompass all of Norn's Creek Fan. Eleven of the 40 bathymetric cross sections surveyed for this model characterized the spawning area near CPR Island. Topographical features of the spawning area include steep gradient banks along RDB (Appendix A, Sheets 4, 6 and 7), a channel between LDB and CPR Island that remains wetted at higher water elevations (Figure 1, transect 47 141 m), and shallow depths in the downstream portion of the spawning area (Figure 1, transects 46 826 m to 46 518 m). At this spawning area, the highest rates of egg deposition have been documented along the mainstem bank of CPR Island, which is dominated by relatively gentle gradients (Figure 1, transects 47 007 m to 46 937 m). Consistent lower use of the thalweg and right downstream bank has also been documented, with sporadic increases in egg deposition (Golder 2014 in prep.).

The Kootenay River key spawning area was divided into three separate sections based on documented egg depositional rates and topography (Golder 2011). The downstream section of the Kootenay River spawning area is dominated by Kootenay Eddy along RDB (Figure 2, transects 191 m to 295 m), a large point bar (Figure 2, transects 349 m and 470 m) that deflects and constricts the Kootenay River flow, creating a deep channel along LDB adjacent to the eddy (Figure 2, transects 295 m to 109 m), and a ridge between the eddy and the channel (Figure 2, transects 295 m to 109 m). This section also exhibits the greatest depth within the Kootenay spawning area. This portion is not considered favourable for whitefish spawning, and the majority of eggs collected in this area are believed to have drifted from upstream (Golder 2011). The highest rates of Mountain Whitefish egg deposition during the 2009/2010 and 2010/2011 spawning seasons were documented in the middle section of the Kootenay spawning area (Golder 2011). This section is dominated by low gradient banks, a relatively wide thalweg with consistent depth, and a large backwater area downstream of two islands along the LDB (Figure 2, transects 349 m to 866 m). The upstream section of the Kootenay spawning area (Figure 2, transects 963 m to 1647 m) is the longest and narrowest of the three sections. The upstream portion of this section exhibits greater thalweg depths and steep shorelines (Figure 2, transects 1337 m to 1647 m). Topographical features of interest in this portion include a shallow shoal (Figure 2, transect 1647 m) and a bedrock outcrop along RDB (Figure 2, between transects 1245 m and 1337 m), as well as an island along LDB (Figure 2, transects 1494 m and 1537 m). Upstream of the transition between the upstream and middle sections of the Kootenay spawning area (Figure 2, transects 963 m to 1178 m), shoreline gradients and thalweg depth decrease. During CLBMON-48 egg mat sampling, egg depositional rates in the upper section of the Kootenay River were lower than in the middle section (Golder 2010 and 2011).

To facilitate the expansion of the Kootenay spawning area River2D Model, bathymetric surveys along a total of 30 cross sections were conducted in the confluence area of the Columbia and Kootenay rivers. These cross sections were included in the River2D Hydraulic Model. Similar to the original Kootenay River model, the expansion area was divided into three separate sections based on documented topography; the area upstream of the confluence, the confluence itself and downstream of the confluence. Although this area is not considered part of the Kootenay River key spawning area, its inclusion in the Kootenay River2D model is crucial to accurately predict the hydraulic conditions at the confluence. The upstream section of the expansion area is dominated by a large boulder garden in the mid-channel and along LDB. Downstream of the boulder garden, multiple benches and ridges are present. In the mid-channel portion of the confluence section of the expansion area, the river bottom is relatively uniform. The river bed gradient gradually decreases along LDB, while along RDB gradients were typically steeper. The downstream section of the expansion area consists of steep gradients along both banks, while the mid-channel portion of the river bottom is relatively uniform. Over the entire expansion area, depth increased in an upstream to downstream direction (Appendix A, Sheet 9).

Several sections of both key spawning areas have similar habitat characteristics. The mainstem bank of CPR Island and the Kootenay River’s LDB have similar gentle gradient habitats and substrate characteristics. On the other hand, the RDBs in both key spawning areas consist of steep gradient banks (Golder 2014 in prep). Differences between the key spawning areas in relation to habitat characteristics were documented in the mid-channel areas. Depth was variable and greatest at mid-channel sites at CPR Island, while in the Kootenay River the wider mid-channel area exhibited slightly shallower, more consistent depths.

4.2 Effect of Operations on River Stage and Wetted Area

Management Question 2: *What is the hydraulic response of the river to discharge fluctuations at these key spawning locations? How do changes in river discharge influence river stage, and how does river stage relate to wetted channel area at these key spawning locations?*

As expected, the River2D models predicted an increase in river stage (water elevation) in the key spawning areas when the combined discharge of BRD and HLK increased. River stage within these spawning areas also depended on the particular discharge levels of HLK and BRD that comprised the total discharge. In both spawning areas, downstream sites had lower elevations than more upstream sites. This reduction in water elevation in a downstream direction was more pronounced in the Kootenay River. At CPR Island, predicted water elevations and wetted area were higher if discharge from HLK made up the larger portion of combined discharge. This pattern was also observed in the Kootenay River if BRD discharge was the larger portion of the combined discharge. As HLK discharge increased, the influence of BRD on wetted area at CPR Island decreased dramatically. On the other hand, HLK discharge had a large effect on Kootenay River wetted area under all examined BRD discharges, albeit this effect was somewhat smaller at high BRD discharge.

Consistent with the findings of the bathymetric surveys of differing gradients over various elevations, increases in water elevation resulted in a nonlinear increase in wetted area at both areas. Over the range of discharge documented in this study, the wetted area in the Kootenay River spawning area was typically 3 to 5 times higher than at CPR Island. As it is the larger of two spawning areas, the range of wetted area in relation to water elevation was substantially larger in the Kootenay River.

Management Question 3: *How do daily flow changes contribute to cumulative channel dewatering in key spawning areas over the whitefish reproductive period?*

Under the current operating regime for both the HLK and BRD facilities during the Mountain Whitefish spawning period, daily flow changes in the study area are most likely to occur as load factoring at BRD. The largest risk to Mountain Whitefish recruitment success that results from load factoring is the continual dewatering of deposited eggs. An egg exposure study conducted in 1995 suggested that as long as ambient air temperatures remain above freezing, eight hours of daily exposure did not result in substantial or significant mortality (R.L.&L. 2001).

The largest amount of area dewatered during load factoring was in the Kootenay River spawning area, due to its large size and proximity to BRD. At Kootenay, lost wetted area during BRD load factoring was attenuated by HLK discharge. The greatest loss of wetted area occurred under intermediate HLK flows (approximately 1100-1200 m^3/s); as HLK discharge increased, the loss of wetted area decreased, reaching approximately 20,000 m^2 (about a third of maximum estimated loss in this report). In comparison, substantially less dewatering occurred at CPR Island. The greatest loss of wetted area at CPR Island as a result of BRD load factoring was at low HLK discharges. As HLK discharge increased, dewatered area decreased, reaching zero loss at highest modeled HLK discharges. Overall, higher HLK discharges substantially decreased the amount of dewatered area in both key spawning areas during load factoring.

HLK discharge not only affects the amount of channel dewatering during BRD load factoring, but also dictates specific habitat dewatering. If HLK discharge remains stable, the area dewatered during load factoring at BRD is consistent. Therefore, altering HLK discharge during load factoring will result in the daily dewatering of differing habitats. The largest risk to deposited eggs in this scenario is if HLK decreases by an amount that results in the shifting of the daily dewatered zone to lower elevations. This will permanently dewater eggs deposited in the highest elevations of the previous daily dewatered zone, as well as dewater additional eggs in the newly dewatered area. If HLK flow decreases are unavoidable during the BRD load factoring period, it is recommended that the magnitude of these decrease are as small as possible. If HLK increases, the daily dewatered zone will shift to higher elevations, thereby reducing the amount of previously deposited eggs in the dewatered zone.

The timing of daily flow fluctuations also affects the risk to eggs deposited during the load factoring period. As Mountain Whitefish are crepuscular spawners (R.L.&L. 2001), the majority of newly spawned eggs will be deposited at dusk and at dawn. If load-factored discharges are at their lowest during these periods, the majority of newly spawned eggs will be deposited below the daily dewatered zone. Alternatively, if flows are at their highest during this period, eggs will be continually deposited in the daily dewatered zone over the load factoring period.

The original ELM conducted a weighted average of the egg loss estimates it presented for each individual spawning area, which was based on data collected in the 1990's on spawning abundance. Based on our current state of knowledge in relation to spawn timing, spawning intensity and the effects of operations on wetted area in the key spawning areas, the spawners at CPR Island and Kootenay represent two distinct sub populations within the study area (Golder 2014 in prep.). Therefore, it is recommended that the egg loss estimates provided from the updated ELM for each area should be considered separately so decisions on flow do not adversely affect either of these apparently separate populations.

Inter-annual comparisons between mean total egg stranding estimates from the updated ELM suggested a high degree of variability in stranding between years, although statistically significant differences among years were not found. The high degree of uncertainty in egg loss projections is related to all of the parameters, but the predictability of the depth and velocity where spawning occurs, based on the multiple years of sampling data, is very low (Figure 29). A wide range of depths among years, in particular, was observed being used for spawning. Overall, CPR Island egg stranding estimates were slightly higher than those from Kootenay River. Mean total egg loss estimates at CPR Island were above 20% in all years (2007 to 2012), while in the Kootenay River estimates of egg loss were below 20% in all years. This is supported by the findings of the spawning studies conducted in these areas, as the majority of documented egg deposition at CPR Island occurred in shoreline habitats, which are associated with higher risks of stranding. Conversely, the majority of egg deposition in the Kootenay River was in mid-channel channel areas (R.L. &L. 2001 and Golder 2014 in prep.).

Both high and low mean egg loss estimates were associated with the lowest flow stabilization index values (2010 to 2012), and mean egg loss estimates associated with the high flow stabilization index values (2007 to 2009) were also highly variable. Therefore, the ELM mean egg loss estimates did not appear to be related to flow stabilization index values. This may be a result of the uncertainty related to the egg loss estimates, or how the current flow stabilization index is calculated. The flow stabilization index sums discharges from both HLK and BRD, which masks the effect of varying discharge levels from individual facilities on water levels within in the study area. Also, the CLBMON-48 program documented that peak spawning in the Kootenay River occurred mid to late December in most study years (Golder 2014 in prep.). That program also documented that peak emergence of larval Mountain Whitefish in 2013 occurred in early April. Also, in 2010 and 2011, flows in the Kootenay River were the lowest in mid to late April, which is outside of the period represented in the current flow stabilization index calculation. Therefore, based on these results, the current flow stabilization index does not adequately represent conditions over the entire peak spawning and egg incubation periods. Recommendations to alter the current flow stabilization index to ensure it adequately represents flow conditions during critical Mountain whitefish recruitment periods is presented in Section 5.0.

The current version of the ELM model depicts high levels of uncertainty in stranding estimates. Although the reasons for this uncertainty have not been thoroughly investigated, the most likely cause is the high degree of empirically observed interannual variability in egg deposition as a function of depth and velocity. The basis for the model is the assumption inherent in most instream flow assessments, that the hydraulic parameters of depth and velocity are reasonable predictors of egg deposition. The high degree of variability observed in depth of observed egg deposition suggests that other factors may also contribute to the habitat selected by spawners to deposit their eggs, and the subsequent risk of stranding in any given year. These may include schooling behavior, substrate preference, or homing to previous spawning sites, regardless of the changes in depth (or velocity) that may have occurred. Examination of the site fidelity of spawning over multiple years of spawning data may provide insight into predicting spawning locations in any given year.

4.3 Updated Egg Loss Model (ELM)

The original Mountain Whitefish ELM solely predicted the depth at which eggs are deposited, which could potentially constrain the predictive ability of the ELM as flow regulation alters both depth and velocity, and both have been shown to be highly correlated with spawning site selection in salmonids. The updated ELM includes data from the River2D models, updated bathymetry data, as well as data collected during Mountain Whitefish spawn monitoring as part of the CLBMON-48.

The use of the statistical environment R for developing the updated version of the ELM allows for great flexibility in the resulting model. The updated version includes the entire River2D-modeled surface of both spawning areas, rather than individual transects, which allows incorporation of a variety of environmental effects on the timing and location of egg deposition and the timing of egg hatching. R also supports error propagation to provide confidence intervals around the final estimate of stranding levels, and provides a flexible and powerful graphic platform, allowing the inclusion of a variety of plots as the output from the model. Such plots include time series of discharge, temperature, and stranding, and maps of egg deposition and stranding at both spawning sites. In addition, the modular nature of the R scripts allows straightforward incorporation of future findings related to Mountain Whitefish spawning and incubation ecology, as well as modifications to desired output.

This document presents the structure of the updated ELM (Figure 5), and provides step by step instruction on its operation and detailed descriptions of the required data layout and format for each model run (Appendix B).

4.4 Summary

Water depth, velocity patterns, and substrate type availability are all important determinants of spawning site selection by Mountain Whitefish (Golder 2014 in prep.). Also, the CLBMON-48 program identified that the component of flow management that likely poses the greatest risk to Mountain Whitefish recruitment success is egg mortality related to stranding. Typically, load factoring at BRD occurs during the mountain whitefish peak spawning period in both the CPR Island and Kootenay River key spawning areas. Although highly variable, documented egg stranding rates also have shown that flow reductions during the incubation period and the implementation of Rainbow Protection flows have the potential to dewater substantial numbers of eggs (Golder 2014, in prep.). Recommended operations to mitigate these egg stranding risks are presented below in Section 5.0.

The River2D hydraulic models allowed us to quantify the changes in river stage and wetted channel area in the key spawning areas for various dam operations, while the updated ELM used this data to produce improved egg loss estimates. These models provide BC Hydro with tools to better understand how operations effect the key Mountain Whitefish spawning areas, how egg stranding risk is related to those operations, and to examine possible operational strategies to mitigate that risk.

As this study concludes, some uncertainty within the data set remains. To date, the River2D models have not been validated under high flow conditions. Also, the updated ELM model has high levels of uncertainty related to stranding estimates as a result of large inter-annual variation in depth of egg deposition. Lastly, the current flow stability index calculation does not adequately represent conditions during key periods in early Mountain Whitefish recruitment. Recommendations to strengthen these models, to further reduce uncertainty related to estimated egg stranding, and to better understand the relationship between operations and egg mortality are presented below in Section 5.0.

5.0 RECOMMENDATIONS

Based on the available dataset, the following recommendations for the operations of HLK and BRD are presented to reduce the risk of egg stranding:

- The most effective operations to mitigate egg stranding is to maintain stable flows during peak spawning that are below the forecasted flows for the remainder of the recruitment period.
- HLK discharge should remain as stable as possible during load factoring operations at BRD to reduce the amount of egg dewatering.
- Discharges during load factoring should be kept at their lowest during the dusk and the dawn period, to reduce the number of newly deposited eggs in the daily dewatered zone. If ambient air temperatures are below freezing, it is likely that load factoring will increase the risk of mortality of the dewatered eggs.

With the conclusion of this study, the following tasks have been identified that will strengthen both the River2D and Egg Loss models and increase their usefulness in regards to Mountain Whitefish management and other studies:

- Validate the calibrated River2D models under high flow conditions so that the models developed in this study can be used for both high and low flow predictions. This would make the hydraulic models more useful for other programs and studies as well.
- Validate the updated HEC-RAS model if additional water level data for high flow conditions become available to supplement the low-flow data available from the surveys conducted in the present study. This would increase the accuracy of the River2D models at predicting hydraulic conditions under high flow scenarios.
- Once completed, examine the substrate mapping data collected by BC Hydro within the key spawning areas to create a spawning suitability curve. Also, incorporate the data into the ELM to allow for substrate preference during egg deposition.
- To further understand egg deposition, examine site fidelity among years, using existing or future spawning location data.
- Conduct egg stranding surveys to test the predictions of the updated ELM. This would involve predicting egg stranding under a certain flow reduction scenario, and then developing and implementing an in-depth field program to sample the dewatered areas of the key spawning areas.
- Conduct systematic lab/field experiments to assess egg developmental rates. Currently, there is a substantial difference between literature-based ATU values required for Mountain Whitefish egg hatching and ATU values derived from studies conducted on the Columbia River in the 1990’s. As the 1990’s incubation experiments were not entirely systematic (typically monthly checks of incubating eggs), the interpolated developmental curve used for the ELM may be biased. An egg developmental study conducted with regular weekly checks to assess incubating eggs would reduce the uncertainty related to ATU-to-hatch estimates.

- Separate the flow stability index calculations for HLK and BRD. This would provide more representative indexes and allow for better understanding of how operations of individual facilities relate to egg loss estimates. Also, short duration operations that would influence the flow stabilization index value but have little to no effect on spawning activities should be identified and removed from the dataset prior to conducting the calculation.

- Adjust the date range of the current flow stabilization index calculations to coincide with the peak Mountain Whitefish spawning and egg incubation period documented during the CLBMON-48 program. The following flow stabilization index calculation for each facility would better represent flows during the Mountain Whitefish spawning and incubation periods:

  - Q_{Smax} (December 15 to January 21) – Q_{Imin} (22 January to 1 May)

6.0 LITERATURE CITED

Auguie. B. 2012. gridExtra: functions in grid graphics. R package version 0.9.1. http://CRAN.R-project.org/package=gridExtra

Barnes, H.H., Jr., 1967. Roughness characteristics of natural channels. U.S. Geological Survey Water-Supply Paper 1849, 213p.

BC Hydro. 2007. CLBMON-47 Lower Columbia River Whitefish Spawning Ground Topographic Survey. Monitoring Program Terms of Reference, Columbia River Project Water Use Plan.

Chow, V.T., 1959. Open-channel hydraulics. New York, Mc Graw-Hill Book Co., 680p.

Dowle, M., T. Short, and S. Lianoglou. 2013. data.table: Extension of data.frame for fast indexing, fast ordered joins, fast assignment, fast grouping and list columns.. R package version 1.8.8. http://CRAN.R-project.org/package=data.table.

Efron, B., and R. J. Tibshirani. 1993. An introduction to the bootstrap. Chapman & Hall, New York.

Golder Associates Ltd. 2003. Estimates of Mountain Whitefish Egg Stranding Mortality for potential Columbia River Flow Reductions in 2002 - 2003. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 02-28-057D: 12 p.

Golder Associates Ltd. 2009. Lower Columbia River whitefish life history and egg mat monitoring program: 2008 - 2009 investigations data report. Report prepared for BC Hydro, Castlegar, BC Golder Report No. 08-1480-0054F: 42 p. + 6 app.

Golder Associates Ltd. 2010. Lower Columbia River whitefish life history and egg mat monitoring program: 2009 - 2010 investigations data report. Report prepared for BC Hydro, Castlegar, BC Golder Report No. 08-1480-0054F: 59 p. + 7 app.

Golder Associates Ltd. 2011. Lower Columbia River whitefish life history and egg mat monitoring program: Year 3 data report. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 10-1492-0111F: 50 p. + 5 app.

Golder Associates Ltd. 2012. Lower Columbia River whitefish spawning ground topography survey: Year 1 data report. Report prepared for BC Hydro, Castlegar, BC Golder Report No. 10-1492-0142F: 23 p. + 1 app.

Golder Associates Ltd. 2012a. Lower Columbia River whitefish life history and egg mat monitoring program: Year 4 data report. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 11-1492-0111F: 48 p. + 3 app.

Golder Associates Ltd. 2013. Lower Columbia River whitefish spawning ground topography survey: Year 2 data report. Report prepared for BC Hydro, Castlegar, BC Golder Report No. 10-1492-0142: 33 p. + 1 app.

Golder Associates Ltd. 2014. Lower Columbia River whitefish life history and egg mat monitoring program: Year 5 interpretive report. Draft report prepared for BC Hydro, Castlegar, BC Golder Report No. 11-1492-0111D: 86 p. + 5 app.

Hildebrand, L., and K. English. 1991. Lower Columbia Development. Lower Columbia River fisheries inventory. 1990 Studies. Volume I Main Report. Prepared for BC Hydro, Environmental Resources by R.L. & L. Environmental Services Ltd., in association with L.G.L. Ltd., Sydney, B.C. 166 p. + app.

Kahle, D., and H. Wickham. 2013. ggmap: A package for spatial visualization with Google Maps and OpenStreetMap. R package version 2.3. http://CRAN.R-project.org/package=ggmap.

Neuwirth, E. 2011. RColorBrewer: ColorBrewer palettes. R package version 1.0-5. http://CRAN.R-project.org/package=RColorBrewer.

Rajagopal, P.K. 1979. The embryonic development and the thermal effects on the development of the Mountain Whitefish, *Prosopium williamsoni* (Girard). Journal of Fish Biology 15: 153-158.

Ripley, B., and M. Lapsley. 2012. RODBC: ODBC database access. R package version 1.3-6. URL: http://CRAN.R-project.org/package=RODBC

R.L. & L. Environmental Services Ltd. 1995. Columbia Basin Developments - Lower Columbia River. Fisheries Inventory Program 1990 to 1994. Prepared for BC Hydro, Environmental Affairs. R.L. & L. Report No. 381-95D: 156 p. + 7 app.

R.L. & L. Environmental Services Ltd. 1997. Lower Columbia River whitefish monitoring program, 1994 1996 investigations. Draft report prepared for BC Hydro, Kootenay PS/PF. R.L. & L. Report No. 514D: 101 p + 8 app.

R.L. & L. Environmental Services Ltd. 1997a. Lower Columbia River whitefish monitoring program, 1996-1997 investigations, Data Report. Draft report prepared for BC Hydro. R.L. & L. Report No. 574D: 21 p. + 6 app.

R.L. & L. Environmental Services Ltd. 1998. Brilliant Redevelopment Mountain Whitefish studies, 1996-1997 investigations. Report prepared for Columbia Power Corporation. R.L. & L. Report No. 546F: 48 p. + 7 app.

R.L. & L. Environmental Services Ltd. 1998a. Analysis of historical Mountain Whitefish data from the lower Columbia and Kootenay rivers, B.C. Report prepared for BC Hydro. R.L. & L. Report No. 603D-F: Report A: 30 p. + 3 app.; Report B: 36 p. + 1. app.

R.L. & L. Environmental Services Ltd. 1999. Lower Columbia River whitefish monitoring program. 1997-1998 investigations, data report. Report prepared for BC Hydro. R.L. & L. Report No. 608F: 21 p. + 5 app.

R.L. & L. Environmental Services Ltd. 2000. Lower Columbia River whitefish monitoring program, 1998-1999 investigations, data report. Report prepared for BC Hydro, Kootenay Power Supply/Power Facilities, Castlegar, B.C.. R.L. & L. Report No. 694F: 16 p. + 5 app.

R.L. & L. Environmental Services Ltd. 2001. Lower Columbia River Mountain Whitefish monitoring program: 1994-1996 investigations. Final Report prepared for BC Hydro, Kootenay PS/PF. R.L. & L. Report No. 514F: 101 p + 8 app.

R.L. & L. Environmental Services Ltd. 2001a. Evaluation of Keenleyside Projected Drawdown Impacts on Mountain Whitefish Spawning in the winter/spring of 2001. Memo report to BC Hydro, January 2001.

Seber, G.A.F., and C.J. Wild. 2003. Nonlinear Regression. John Wiley & Sons, Inc. Hoboken, New Jersey.

Steffler, P. and Blackburn, J. 2002. River2D Two-Dimensional Depth Averaged Model of River Hydrodynamics and Fish Habitat. University of Alberta, Canada, September 2002.

Steven, D.L. Jr. and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

Vernier, J.M. 1969. Chronological table of the embryonic development of rainbow trout, *Salmo gairdneri*. (Annal. D'Embryol. Morphogen., 2:495-520). Fisheries Management Services, Translation Series No. 3913, 1977.

Wickham, H. 2007. Reshaping data with the reshape package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/.

Wickham, H. 2011. The split-apply-combine strategy for data analysis. Journal of Statistical Software, 40(1), 1-29. URL http://www.jstatsoft.org/v40/i01/.

Wickham, H. 2012. scales: scale functions for graphics.. R package version 0.2.3. http://CRAN.R-project.org/package=scales

Williams, J.G. 2010. Sampling for environmental flow assessment. Fisheries 35(9):434-442.

7.0 CLOSURE

We trust that this report meets your current requirements. If you have any further questions, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

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APPENDIX A

Key Spawning Area and River2D Model Area Contour Maps

Attached as digital files.

LEGEND

⊗ SURVEY MONUMENT

MAJOR CONTOUR
MINOR CONTOUR
PRESENT WATER May 3-6 2011)
HIGH WATER MARK

COORDINATES ARE UTM BASED ON
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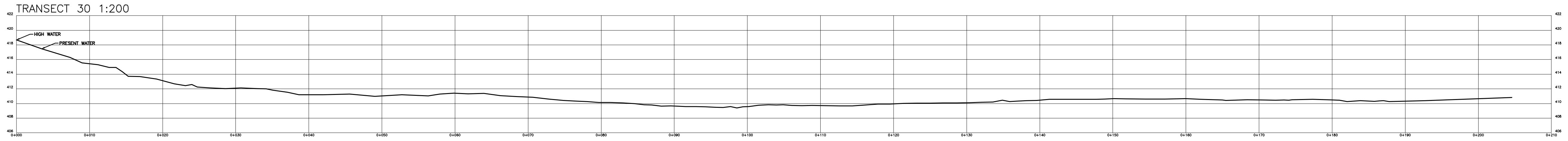

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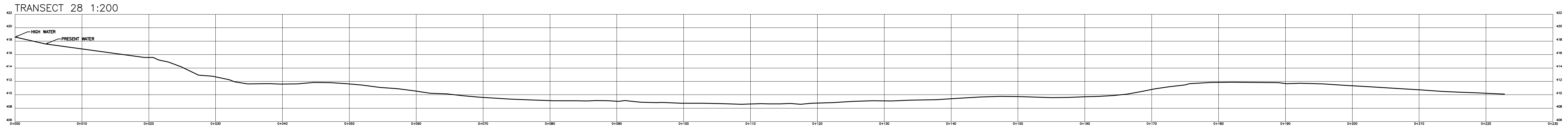

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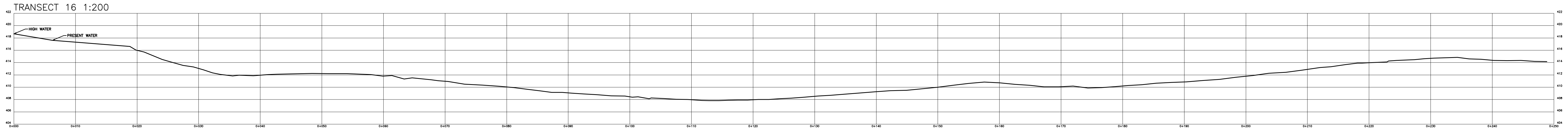

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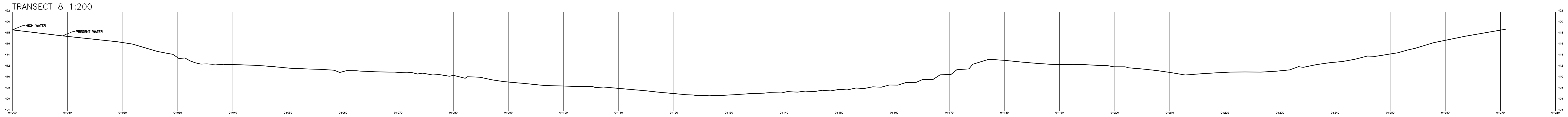

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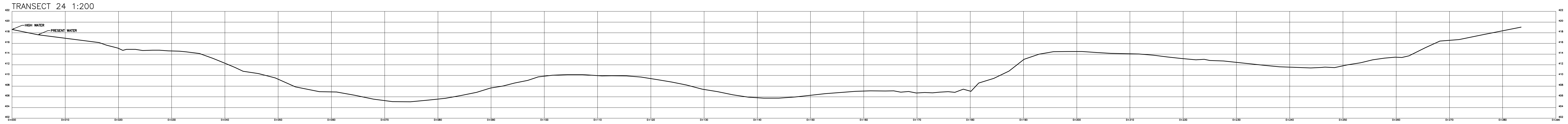

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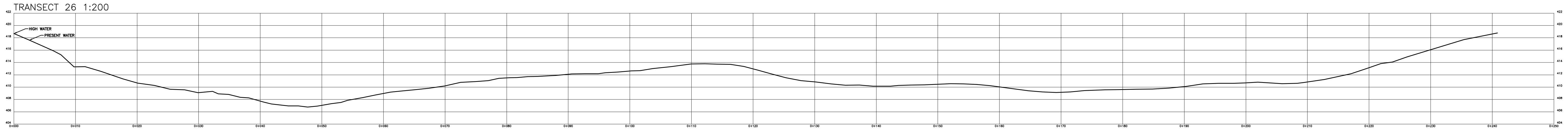

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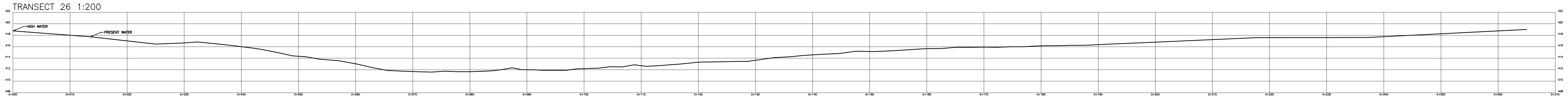

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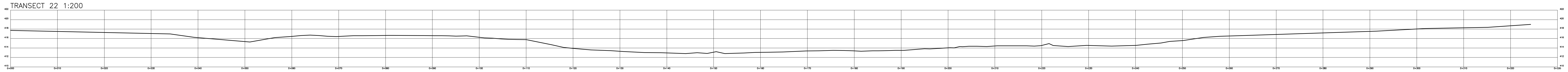

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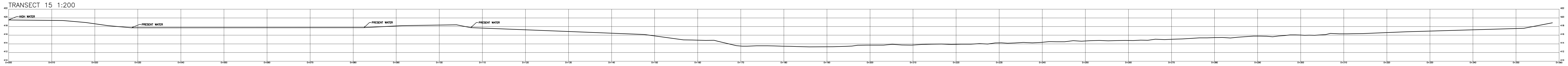

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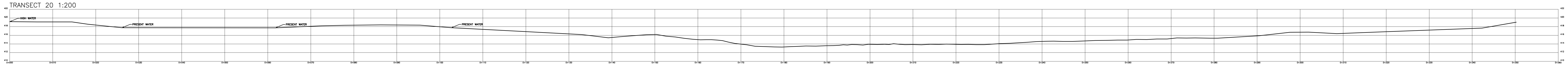

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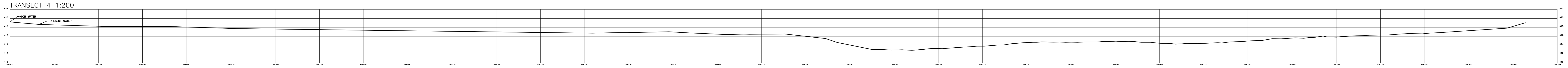

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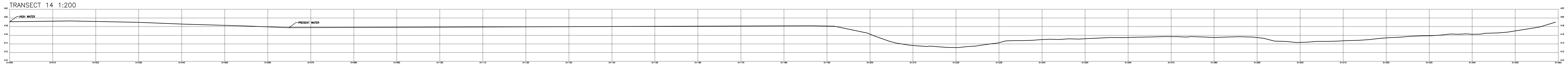

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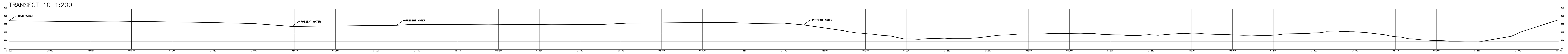

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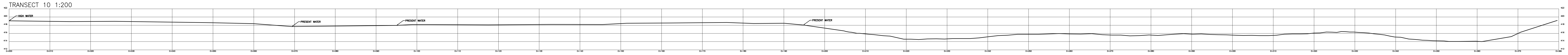

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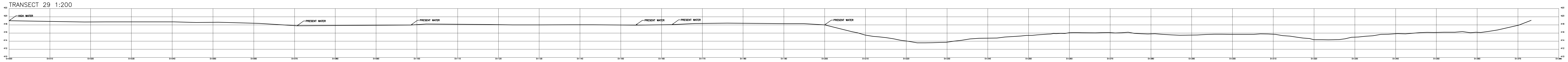

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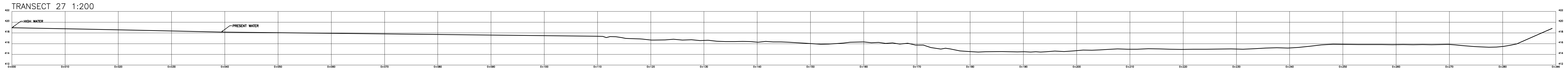

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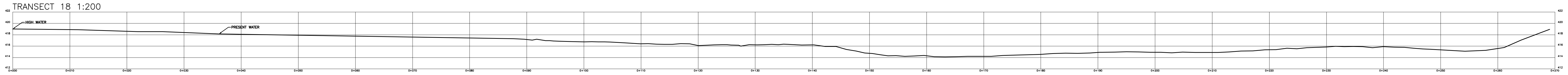

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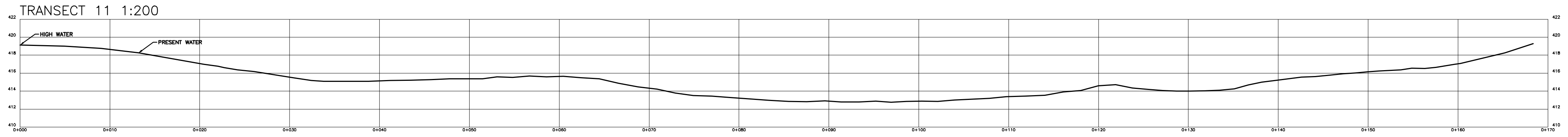

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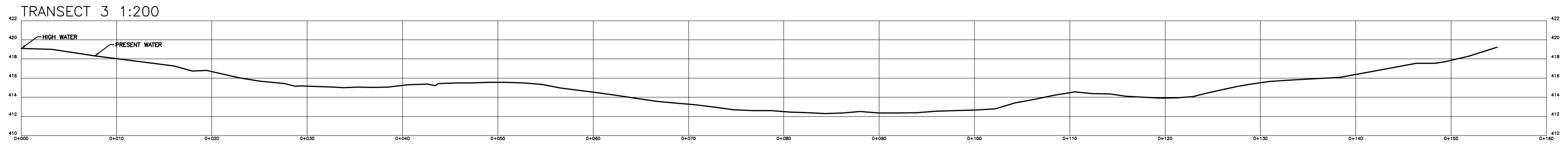

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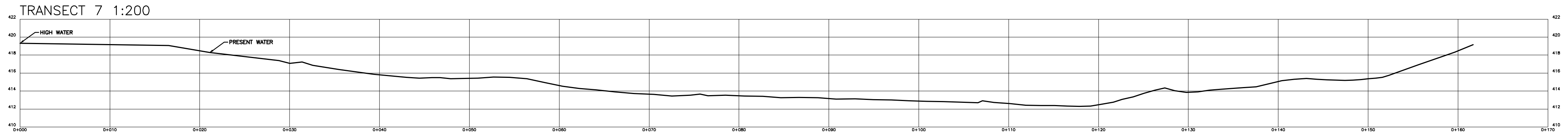

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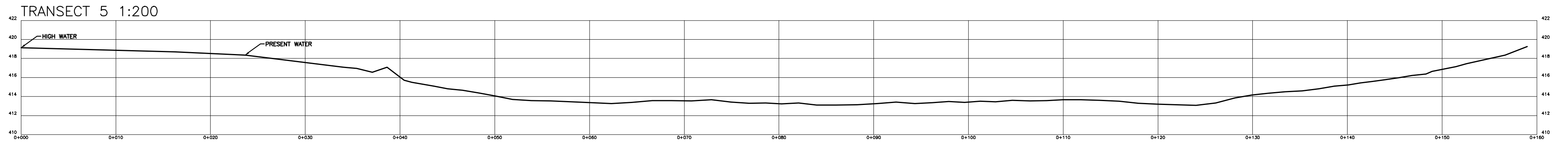

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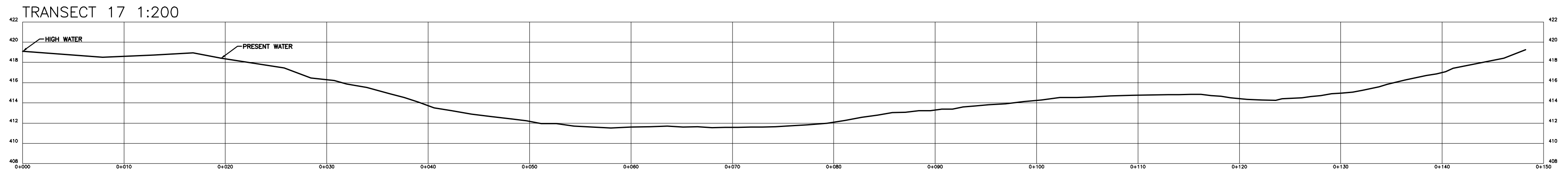

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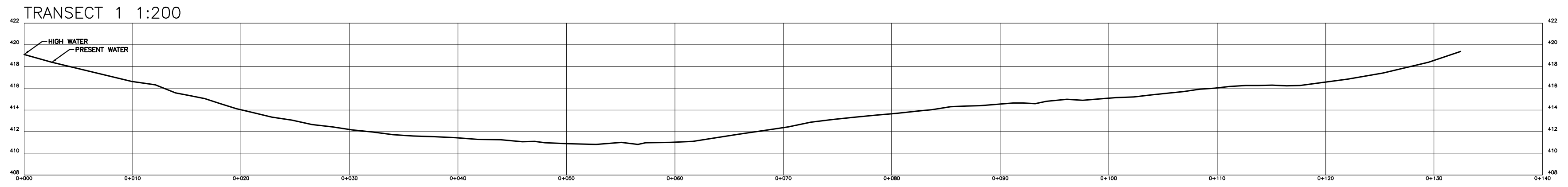

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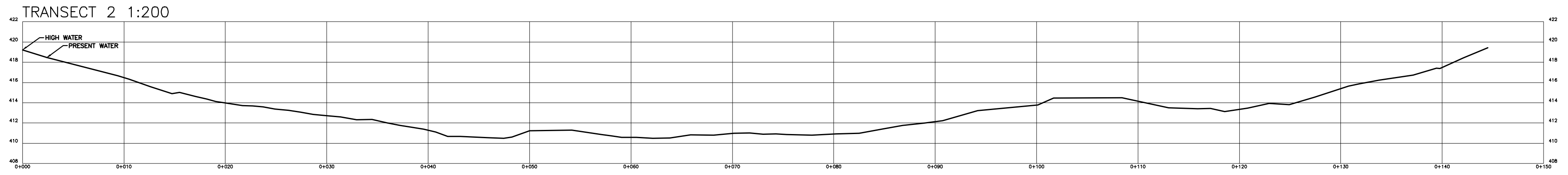

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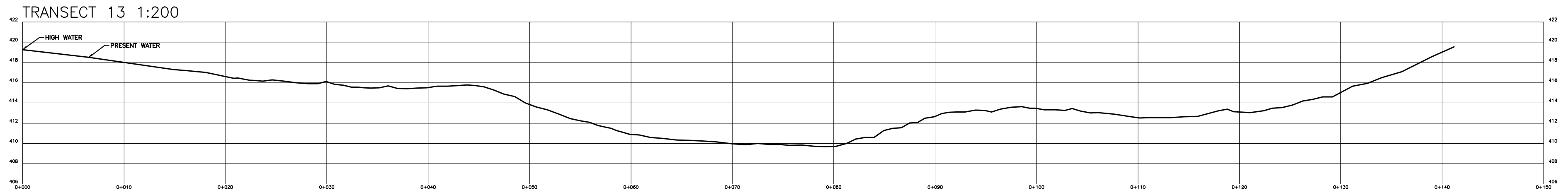

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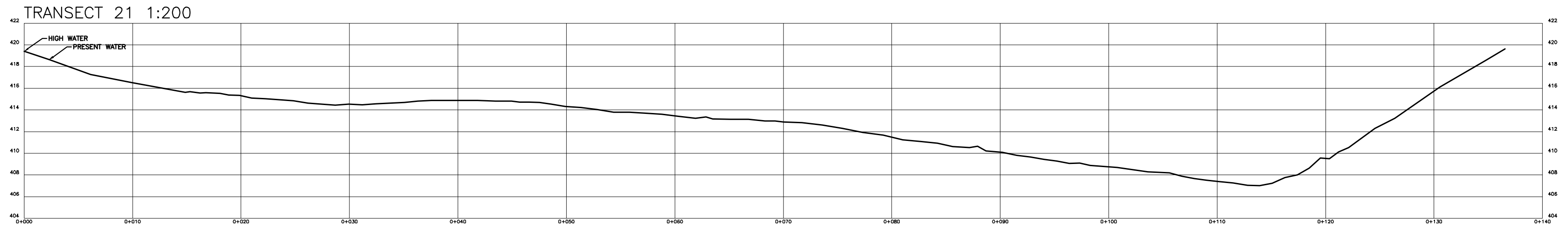

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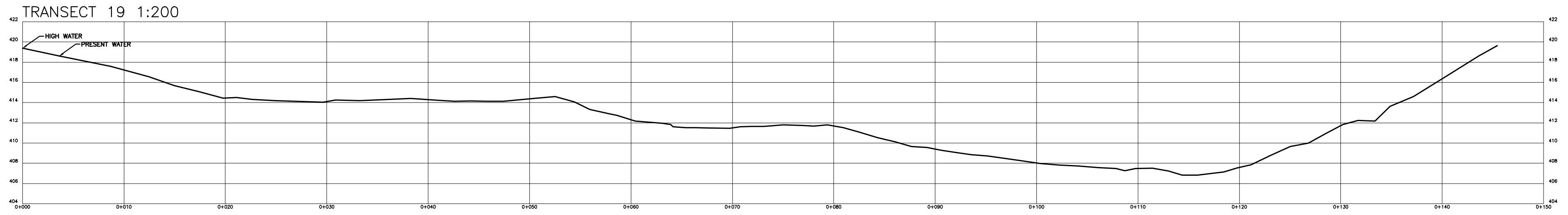

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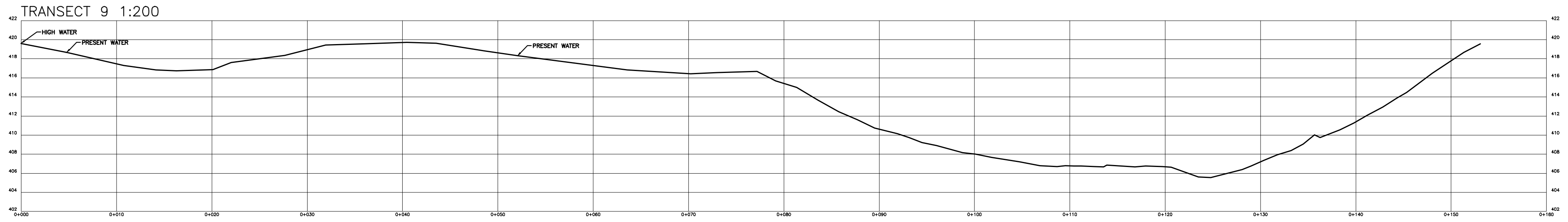

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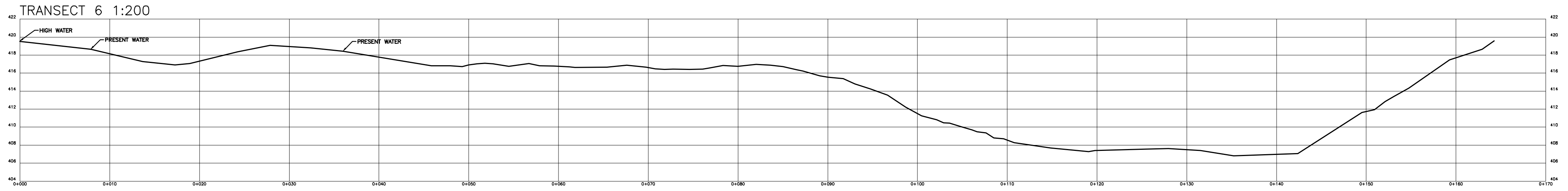

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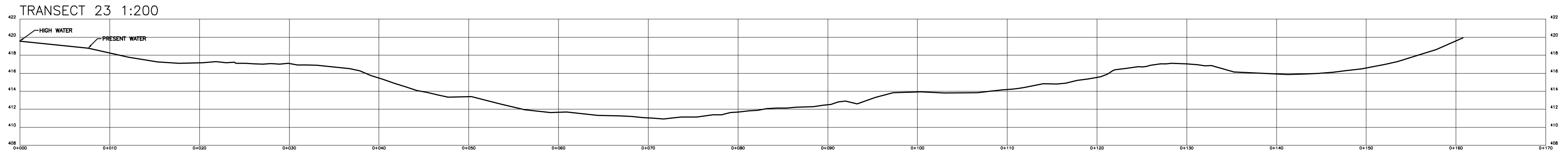

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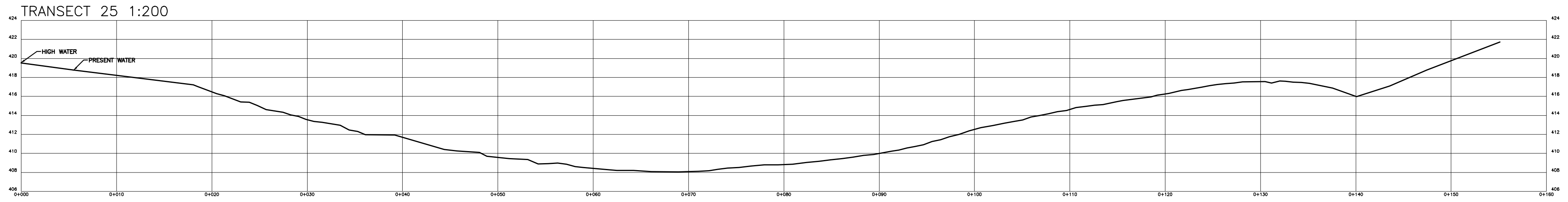

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LEGEND

⊗ SURVEY MONUMENT

— MAJOR CONTOUR

— MINOR CONTOUR

— PRESENT WATER May 3-6 2011)

— HIGH WATER MARK

COORDINATES ARE UTM BASED ON
GEODETIC CONTROL MONUMENT No.
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PROJECT NO.
TITLE: SITEPLAN MAP OF
COLUMBIA RIVER BATHYMETRY
AREA: ROBSON
REVISION
DWG.NO. CK4
SHEET 4 OF 8

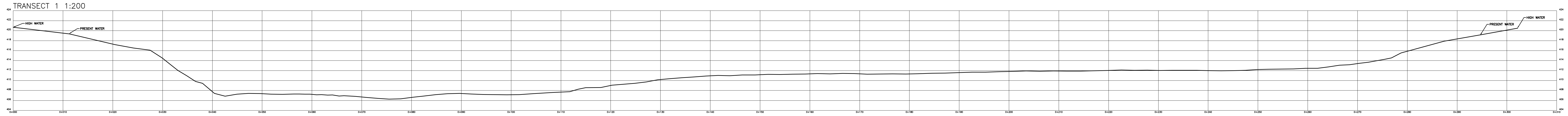
UTM

PLAN DETAILS		DATE
FILENAME:	2011 PROJECTS\Columbia Kootenay 2011.dwg	
SURVEY BY:		APRIL 19 – MAY 6 2011
DESIGN BY:		
DES. CHECK:		

REVISION	INTL	APPD	DATE
Ⓒ			
Ⓑ			
Ⓐ			
DRAWING BY: C STUBBE			JUNE 3 2011

P. ENG

TRANSECT 1 1:200



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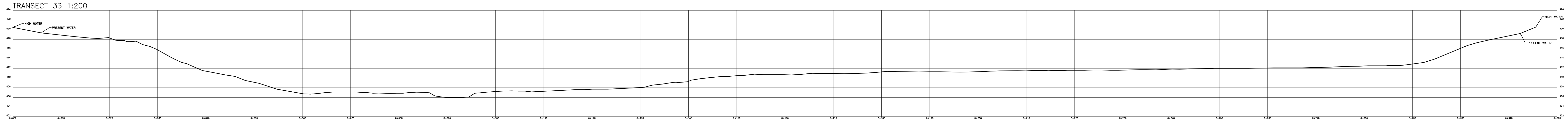
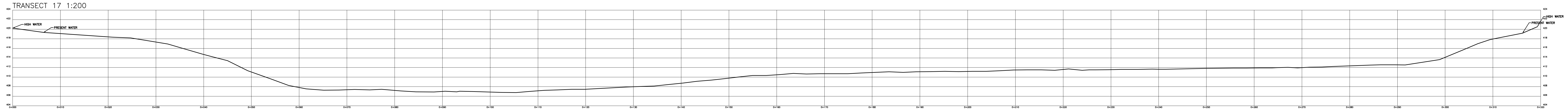


TRANSECT 17 1:200



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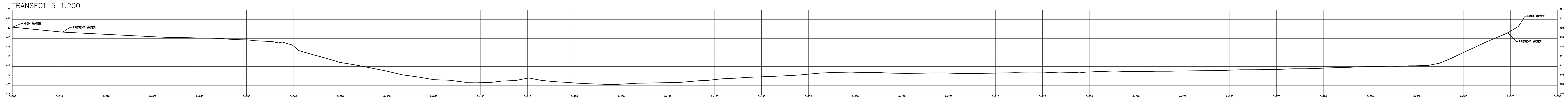

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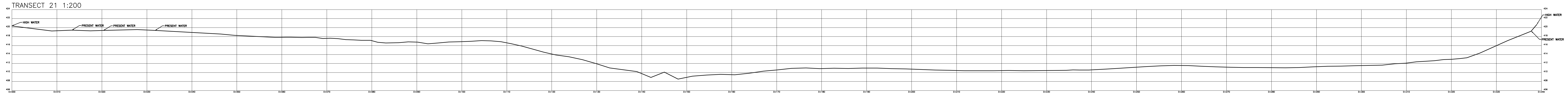


TRANSECT 37 1:200

TRANSECT 25 1:200

TRANSECT 9 1:200

TRANSECT 30 1:200

SPROULERS' ENTERPRISES LIMITED
SURVEY AND DESIGN
509-A LAKE ST. NELSON B.C. Ph:(250)352-7900

SCALE: 1:2500

TITLE: COLUMBIA RIVER
ADCP TRANSECTS

AREA: ROBSON

REVISION

DWG.NO. CK5

SHEET 5 OF 8

FILE NO.

PROJECT NO.

UTM

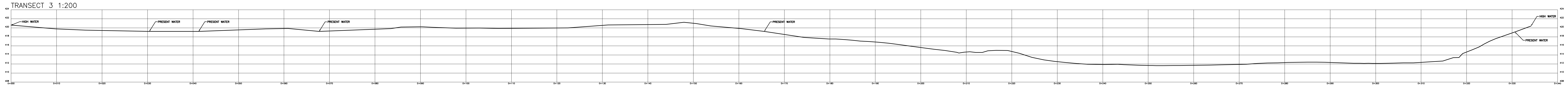
PLAN DETAILS		DATE
FILENAME:	2011 PROJECTS\Columbia Kootenay 2011.dwg	
SURVEY BY:		APRIL 19 – MAY 6 2011
DESIGN BY:		
DES. CHECK:		

	REVISION	INTL	APPD	DATE
C				
B				
A				
DRAWING BY:	C STUBBE			JUNE 3 2011

P. ENG

TRANSECT 14 1:200

TRANSECT 3 1:200



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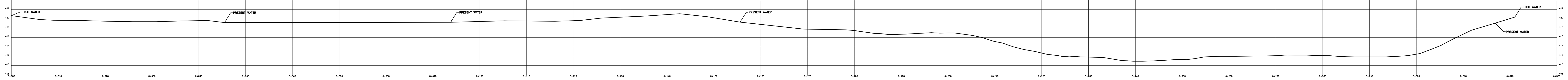
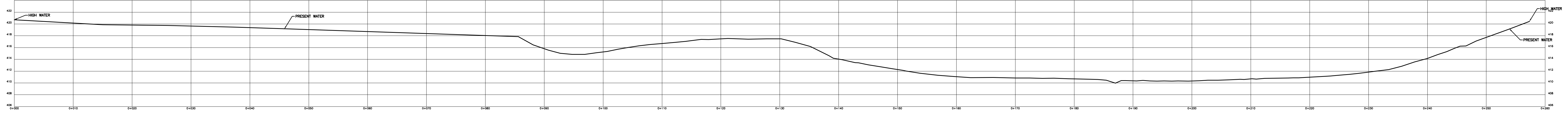


TRANSECT 7 1:200

TRANSECT 23 1:200



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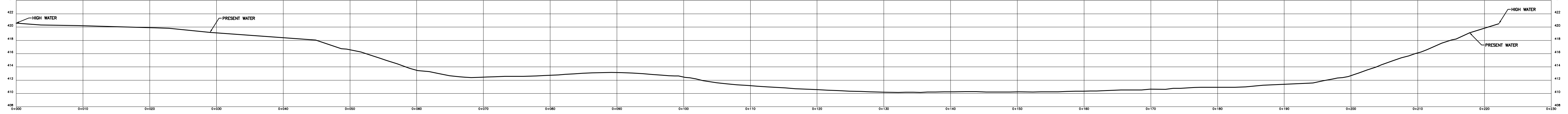

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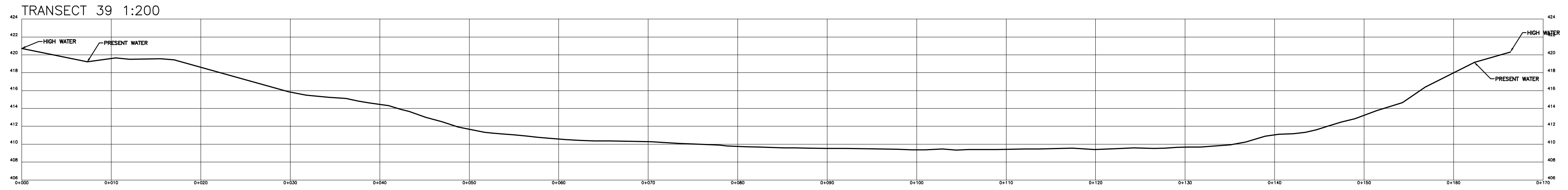

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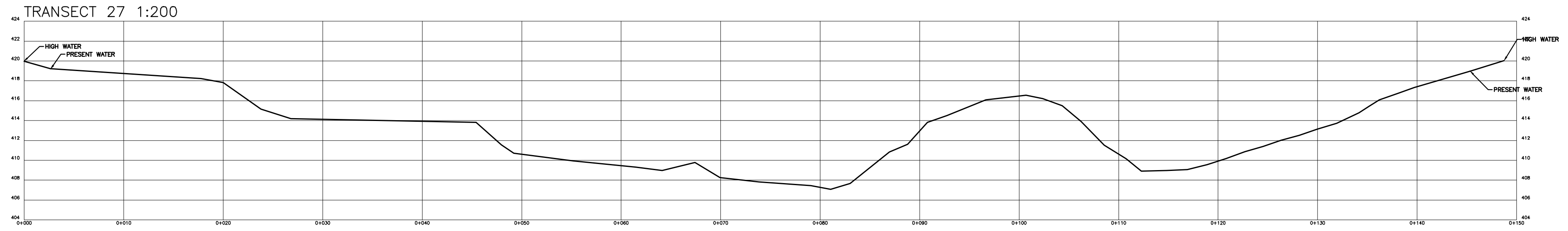

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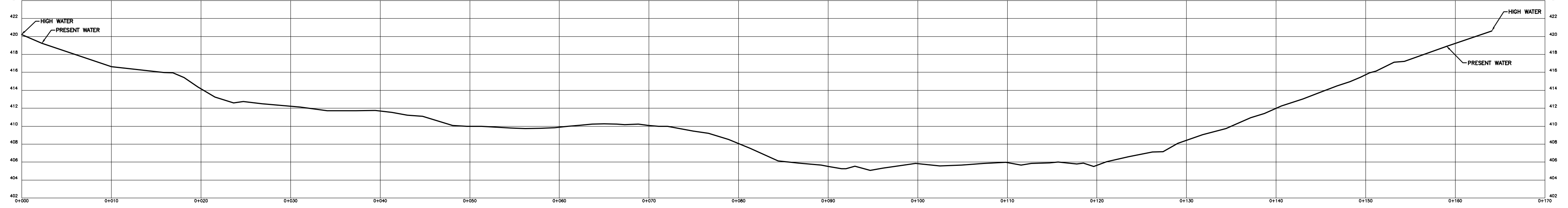

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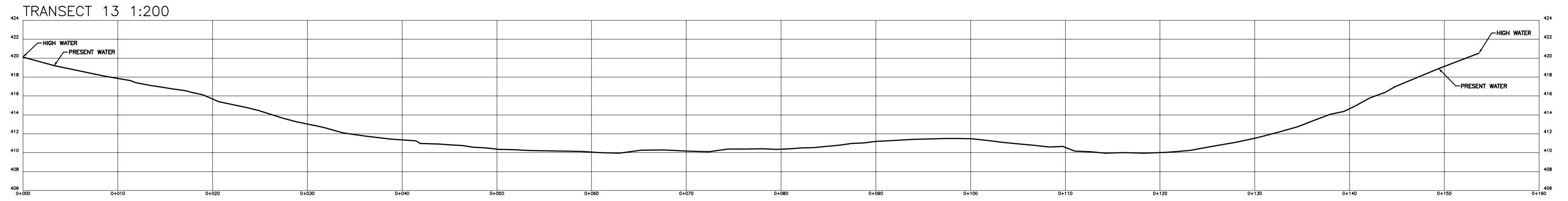

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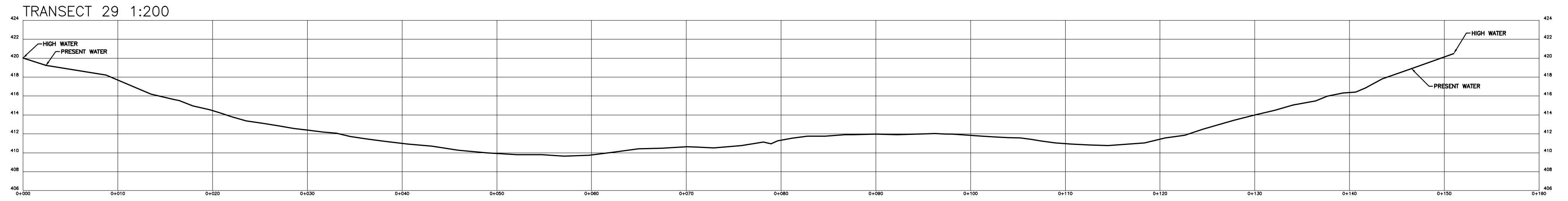

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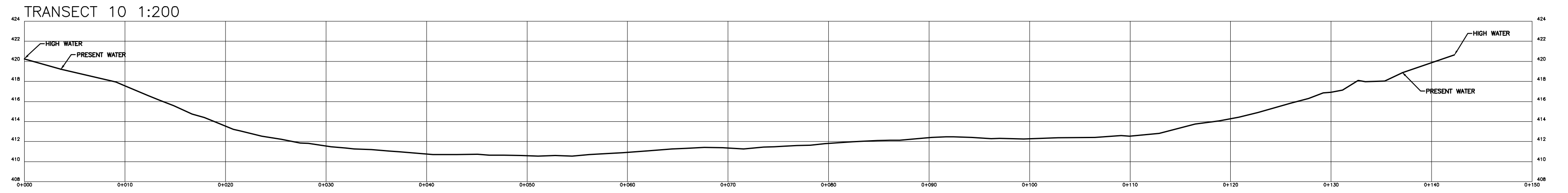


SPROULERS' ENTERPRISES LIMITED
SURVEY AND DESIGN
509-A LAKE ST. NELSON B.C. Ph:(250)352-7900

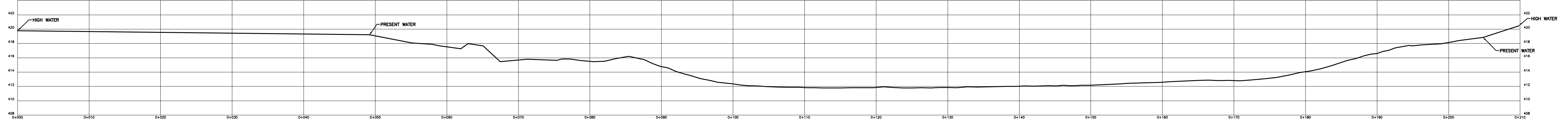
SCALE: 1:500
FILE NO.
PROJECT NO.
TITLE: COLUMBIA RIVER
ADCP TRANSECTS
AREA: ROBSON
REVISION
DWG.NO. CK6
SHEET 6 OF 8

UTM

PLAN DETAILS		DATE	REVISION		INTL	APPD	DATE
FILENAME:	2011 PROJECTS\Columbia Kootenay 2011.dwg		C				
SURVEY BY:		APRIL 19 – MAY 6 2011	B				
DESIGN BY:			A				
DES. CHECK:			DRAWING BY:	C STUBBE			JUNE 3 2011

P. ENG

TRANSECT 26 1:200



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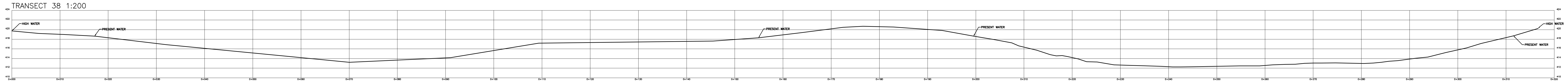

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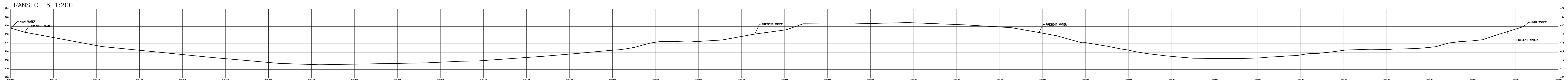

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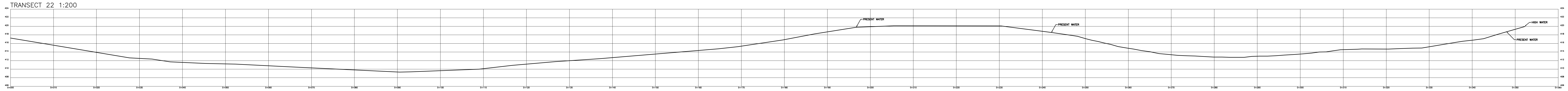

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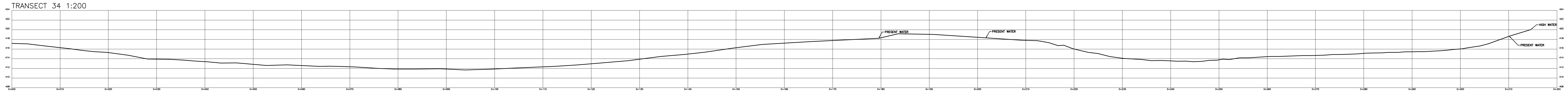

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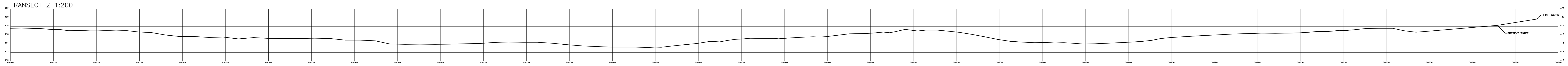

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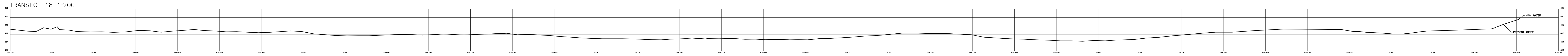

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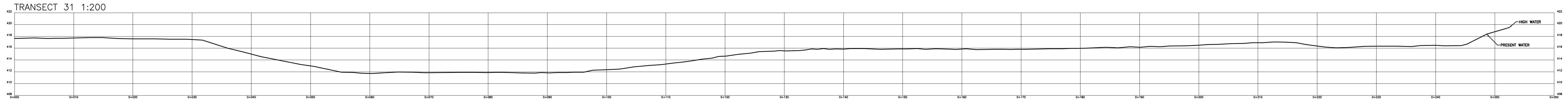

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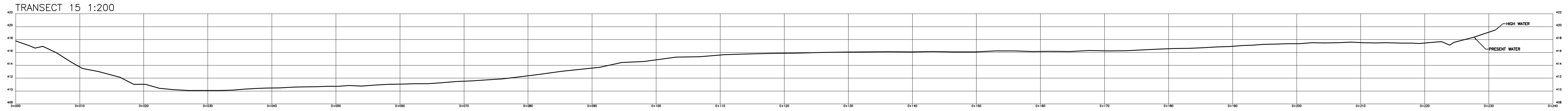

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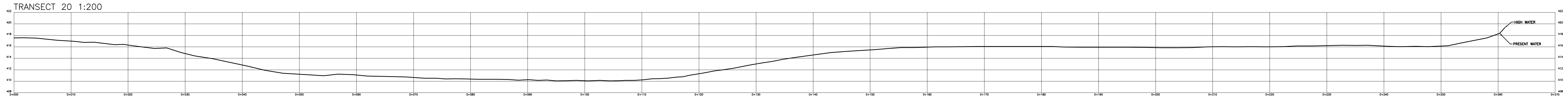

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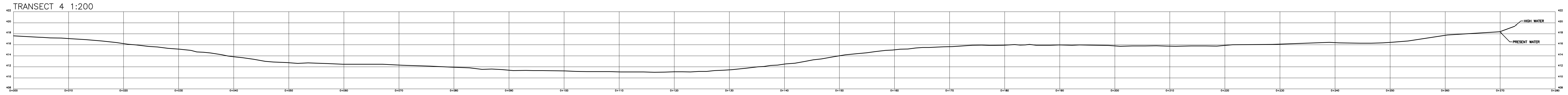

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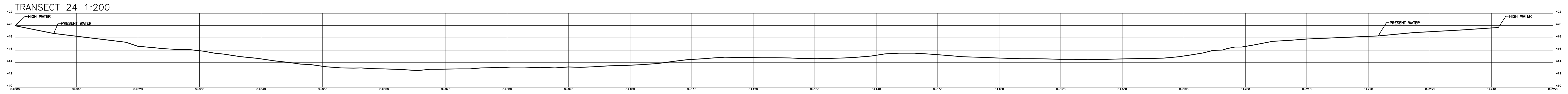

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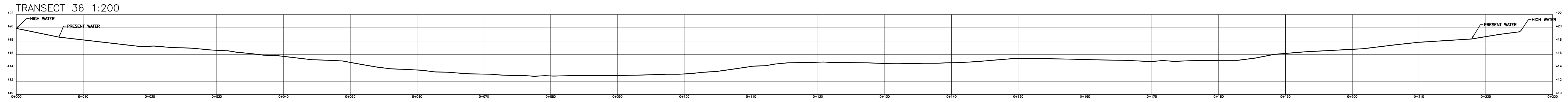

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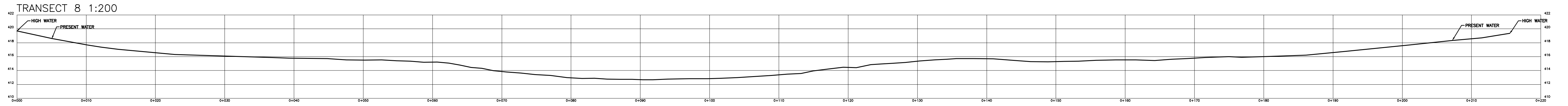


SPROULERS' ENTERPRISES LIMITED
SURVEY AND DESIGN
509-A LAKE ST. NELSON B.C. Ph:(250)352-7900

SCALE: 1:500

FILE NO.

PROJECT NO.

TITLE: COLUMBIA RIVER ADCP TRANSECTS

AREA: ROBSON

REVISION

DWG.NO. CK7

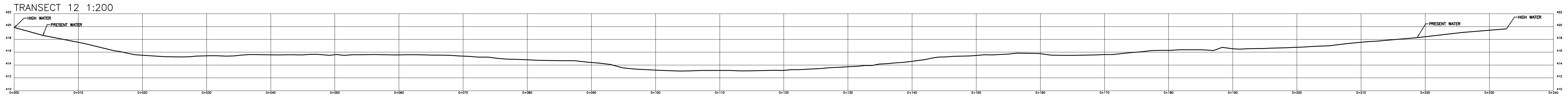
SHEET 7 OF 8

UTM

PLAN DETAILS		DATE	REVISION	INTL	APPD	DATE
FILENAME:	2011 PROJECTS\Columbia Kootenay 2011.dwg		Ⓒ			
SURVEY BY:		APRIL 19 – MAY 6 2011	Ⓑ			
DESIGN BY:			Ⓐ			
DES. CHECK:			DRAWING BY: C STUBBE			JUNE 3 2011

P. ENG

TRANSECT 12 1:200



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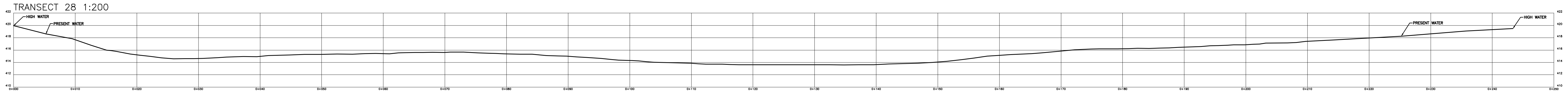

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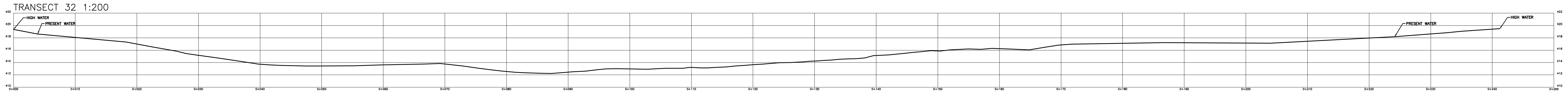
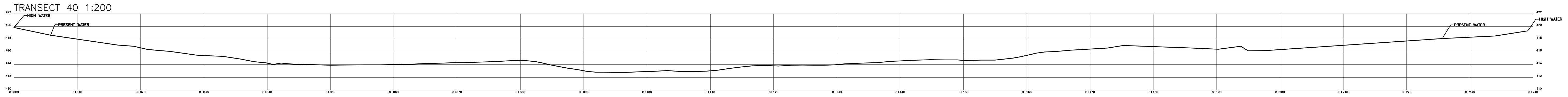
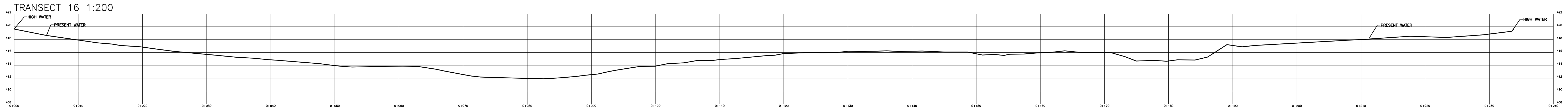


TRANSECT 40 1:200



TRANSECT 16 1:200



SPROULERS'
ENTERPRISES
LIMITED
SURVEY AND DESIGN
509-A LAKE ST. NELSON B.C. Ph:(250)352-7900

SCALE: 1:500
FILE NO.
PROJECT NO.
TITLE: COLUMBIA RIVER
ADCP TRANSECTS
AREA: ROBSON
REVISION
DWG.NO. CK8
SHEET 8 OF 8

UTM

PLAN DETAILS		DATE	REVISION	INTL	APPD	DATE
FILENAME:	2011 PROJECTS\Columbia Kootenay 2011.dwg		C			
SURVEY BY:		APRIL 19 – MAY 6 2011	B			
DESIGN BY:			A			
DES. CHECK:			DRAWING BY: C STUBBE			JUNE 3 2011

P. ENG

COORDINATES ARE UTM BASED ON
GEODETIC CONTROL MONUMENT No.
918243, DATUM NAD83

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SPROULERS' ENTERPRISES LIMITED
SURVEY AND DESIGN
509–A LAKE ST. NELSON B.C. Ph:(250)352–7900

SCALE: 1:2000

FILE NO.

PROJECT NO.

TITLE: SITEPLAN MAP OF
COLUMBIA RIVER BATHYMETRY

AREA: BRILLIANT

REVISION

DWG.NO. CT1

SHEET 1 OF 4

UTM 5462750 N, 452470 E, ZONE 11

PLAN DETAILS		DATE	REVISION	INTL	APPD	DATE
FILENAME:	2012 PROJECTS\Columbia 2012.dwg		C			
SURVEY BY:		NOV 27– NOV 28 2012	B			
DESIGN BY:			A			
DES. CHECK:			DRAWING BY: C STUBBE			NOV 30 2012

P. ENG

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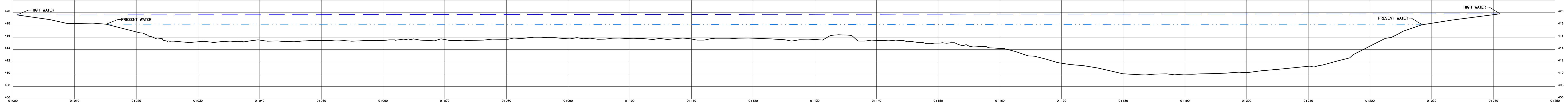

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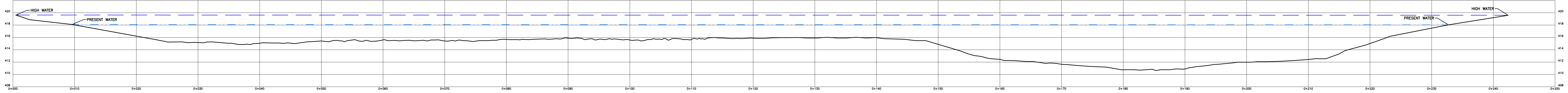

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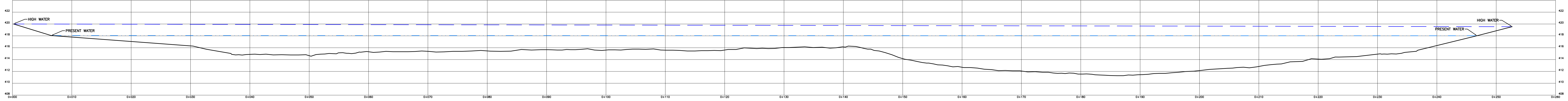

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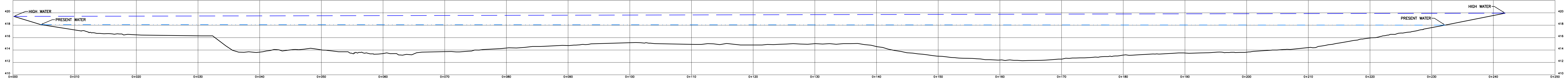

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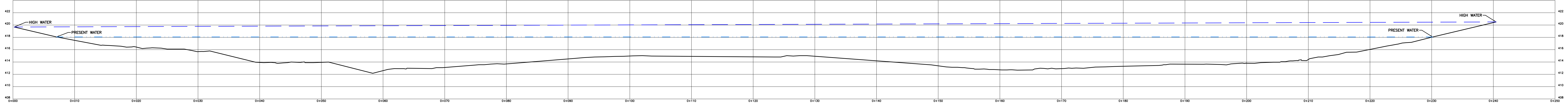

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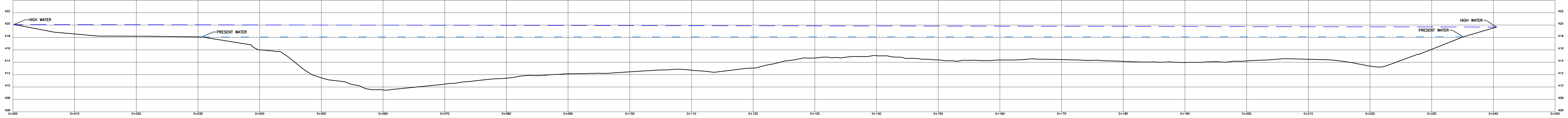

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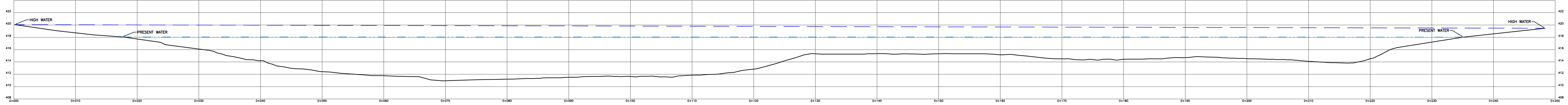

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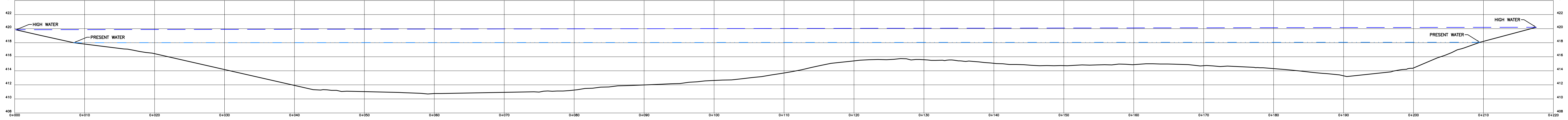

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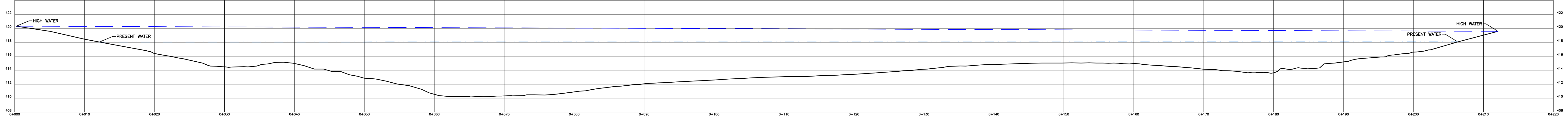

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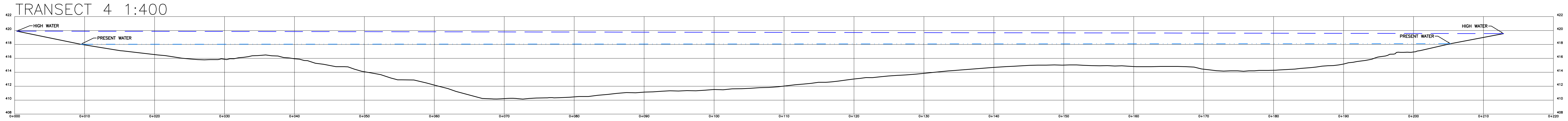

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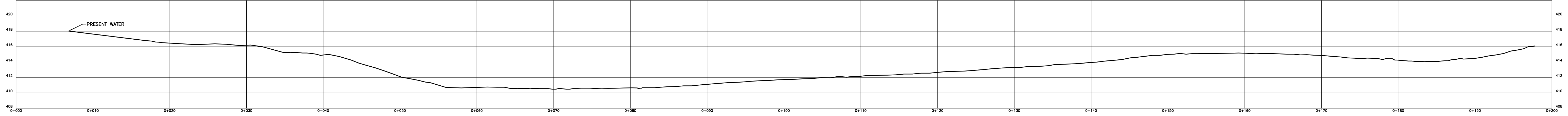

Golder Associates

SPROULERS'
ENTERPRISES
LIMITED
SURVEY AND DESIGN
509-A LAKE ST. NELSON B.C. Ph:(250)352-7900

SCALE: 1:400
FILE NO.
PROJECT NO.
TITLE: SECTION VIEW OF COLUMBIA RIVER TRANSECTS
AREA: BRILLIANT
REVISION
DWG.NO. CT2
SHEET 2 OF 4

UTM 5462750 N, 452470 E, ZONE 11

PLAN DETAILS		DATE	REVISION	INTL	APPD	DATE
FILENAME:	2012 PROJECTS\Columbia tRANSECTS.dwg		Ⓒ			
SURVEY BY:		NOV 27– NOV 28 2012	Ⓑ			
DESIGN BY:			Ⓐ			
DES. CHECK:			DRAWING BY: C STUBBE			NOV 30 2012

P. ENG

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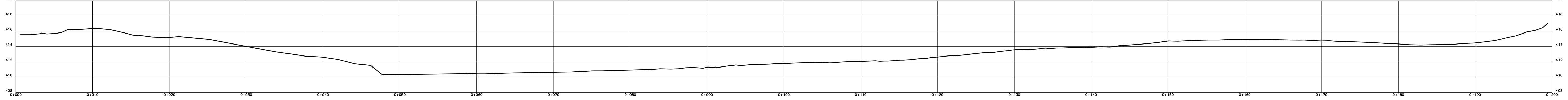
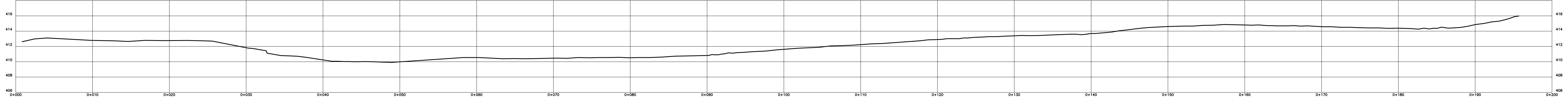


TRANSECT 12 1:400



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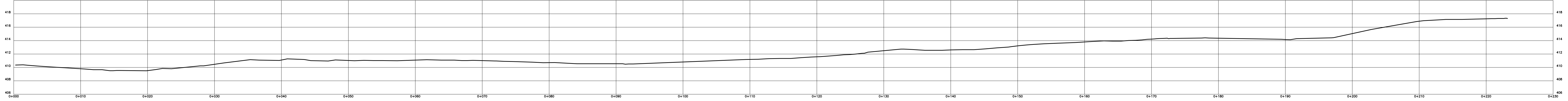

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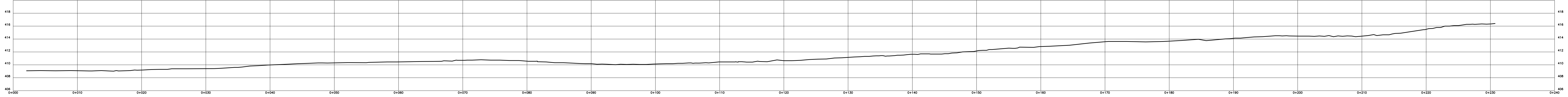

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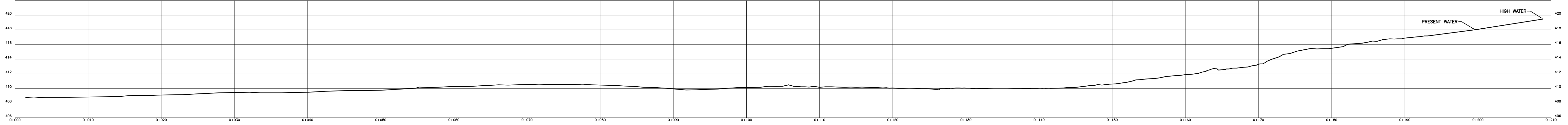
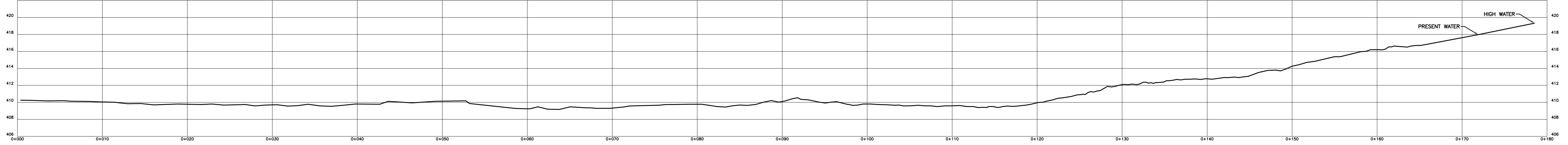


TRANSECT 23 1:400



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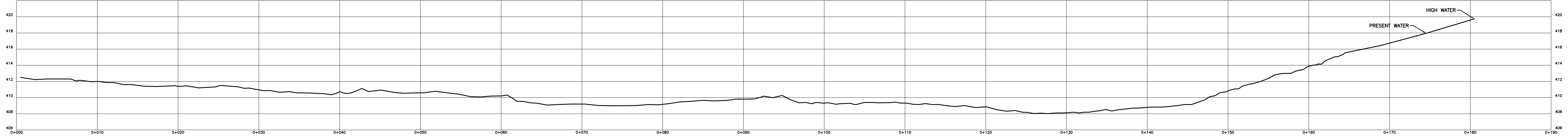

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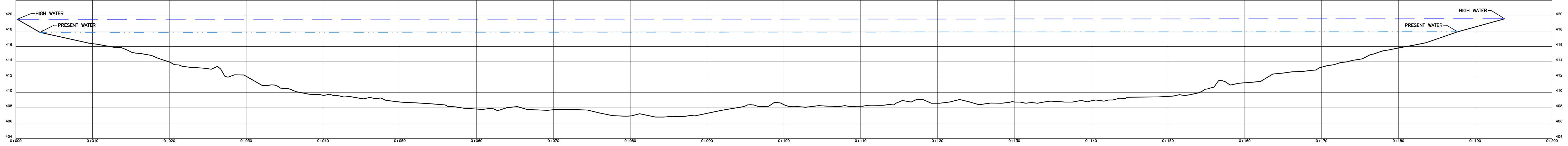

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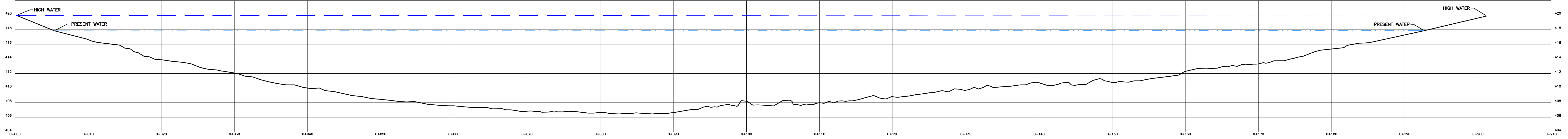

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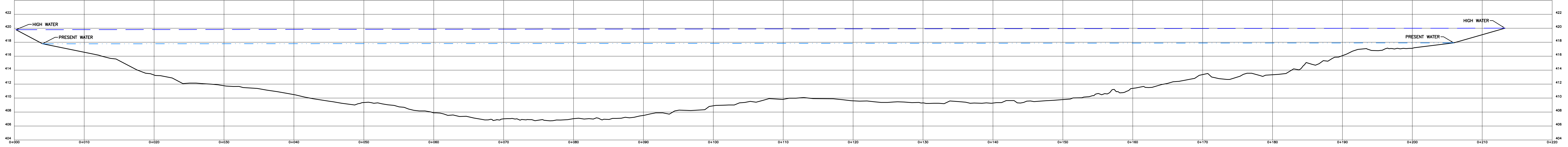

Golder Associates

SPROULERS' ENTERPRISES LIMITED
SURVEY AND DESIGN
509-A LAKE ST. NELSON B.C. Ph:(250)352-7900

SCALE: 1:400		FILE NO.	PROJECT NO.
TITLE: SECTION VIEW OF COLUMBIA RIVER TRANSECTS			
AREA: BRILLIANT			
REVISION	DWG.NO. CT3	SHEET 3 OF 4	

UTM 5462750 N, 452470 E, ZONE 11

PLAN DETAILS		DATE	REVISION	INTL	APPD	DATE
FILENAME:	2012 PROJECTS\Columbia tRANSECTS.dwg		Ⓒ			
SURVEY BY:		NOV 27- NOV 28 2012	Ⓑ			
DESIGN BY:			Ⓐ			
DES. CHECK:			DRAWING BY: C STUBBE			NOV 30 2012

P. ENG

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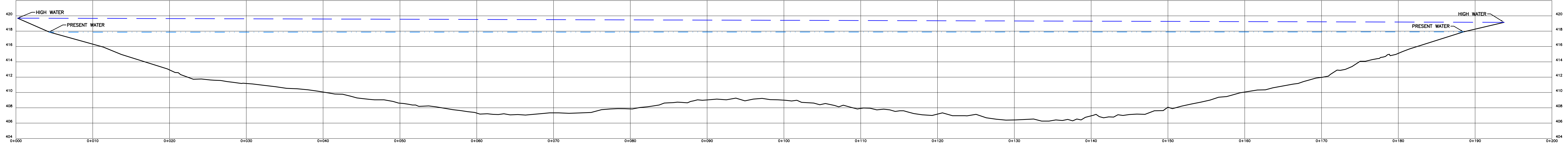

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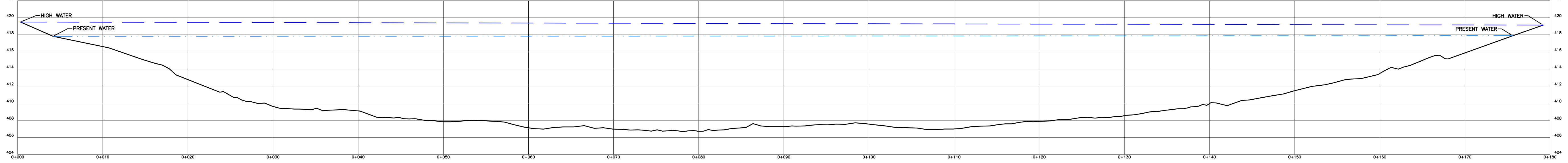

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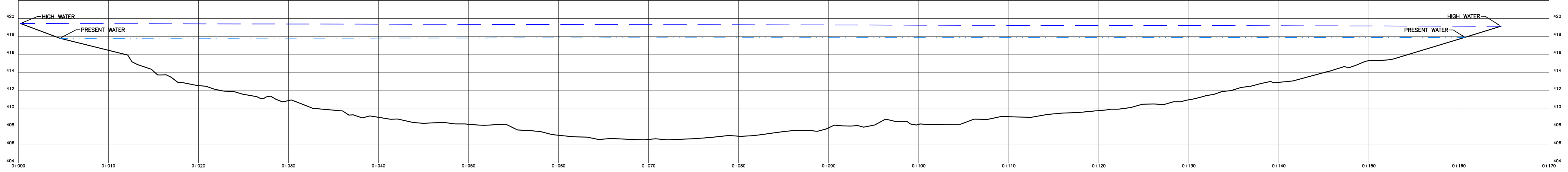

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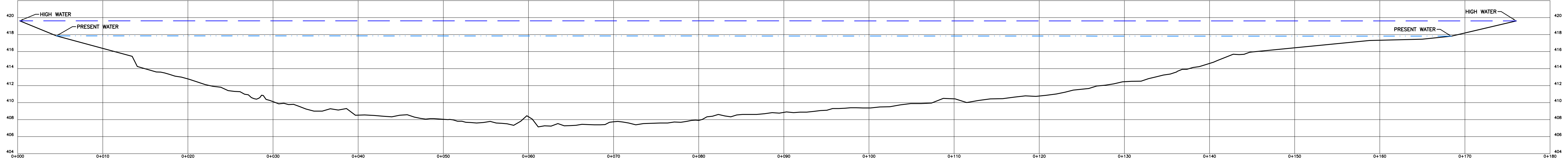

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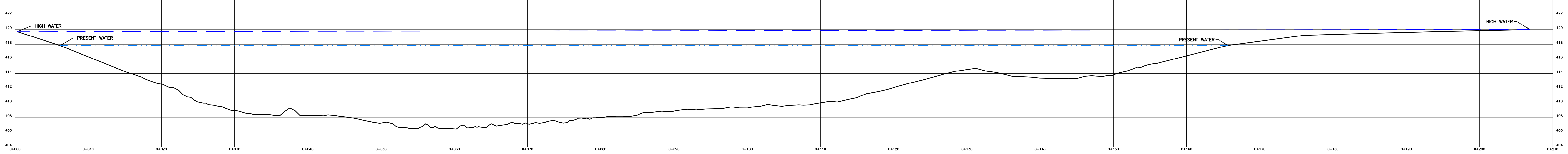

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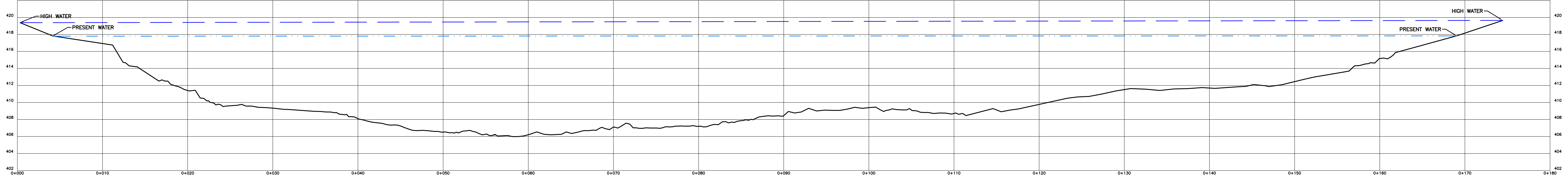

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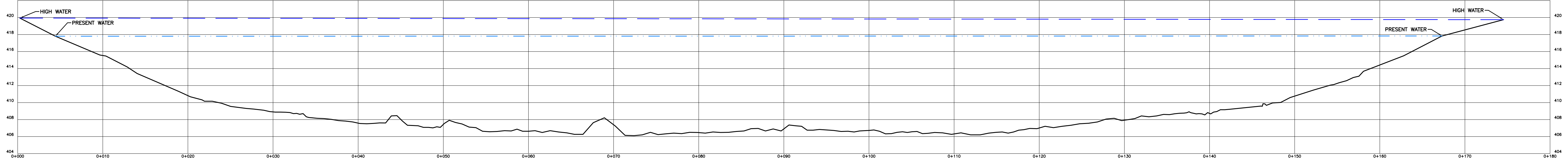

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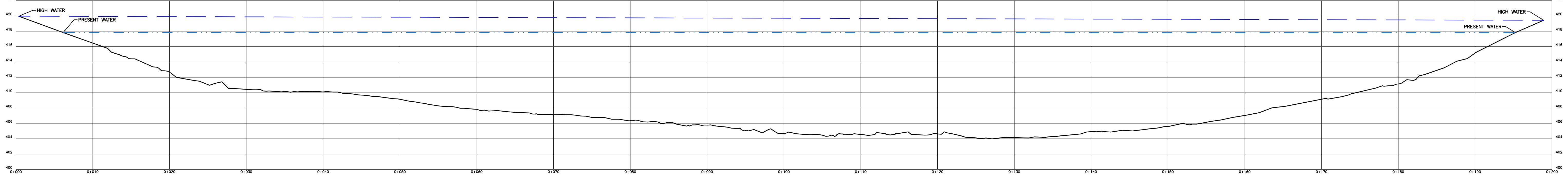

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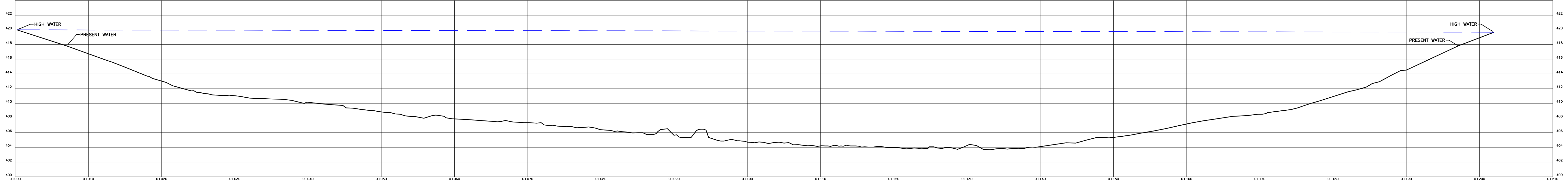

Golder Associates

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SCALE: 1:400		FILE NO.	PROJECT NO.
TITLE: SECTION VIEW OF COLUMBIA RIVER TRANSECTS			
AREA: BRILLIANT			
REVISION	DWG.NO. CT4	SHEET 4 OF 4	

UTM 5462750 N, 452470 E, ZONE 11

PLAN DETAILS		DATE	REVISION	INTL	APPD	DATE
FILENAME:	2012 PROJECTS\Columbia tRANSECTS.dwg		Ⓒ			
SURVEY BY:		NOV 27– NOV 28 2012	Ⓑ			
DESIGN BY:			Ⓐ			
DES. CHECK:			DRAWING BY: C STUBBE			NOV 30 2012

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Table A1: RIVER 2D Model Run Requests for CLBMON-47

CPR Island/Columbia River Model			
Run	Columbia Discharge (cms)	Kootenay Discharge (cms)	Comments
1	1271.02	529.25	During Peak Spawning 4 -Jan-11
2	1529.34	530.08	During Peak Spawning 11-Jan-11
3	1524.74	581.69	During Peak Spawning 18-Jan-11
4	250	250	To characterize habitat over spawning period
5	575	250	To characterize habitat over spawning period
6	900	250	To characterize habitat over spawning period
7	1225	250	To characterize habitat over spawning period
8	1550	250	To characterize habitat over spawning period
9	1875	250	To characterize habitat over spawning period
10	2200	250	To characterize habitat over spawning period
11	2525	250	To characterize habitat over spawning period
12	250	500	To characterize habitat over spawning period
13	575	500	To characterize habitat over spawning period
14	900	500	To characterize habitat over spawning period
15	1225	500	To characterize habitat over spawning period
16	1550	500	To characterize habitat over spawning period
17	1875	500	To characterize habitat over spawning period
18	2200	500	To characterize habitat over spawning period
19	2525	500	To characterize habitat over spawning period
20	250	750	To characterize habitat over spawning period
21	575	750	To characterize habitat over spawning period
22	900	750	To characterize habitat over spawning period
23	1225	750	To characterize habitat over spawning period
24	1550	750	To characterize habitat over spawning period
25	1875	750	To characterize habitat over spawning period
26	2200	750	To characterize habitat over spawning period
27	2525	750	To characterize habitat over spawning period
28	250	1000	To characterize habitat over spawning period
29	575	1000	To characterize habitat over spawning period
30	900	1000	To characterize habitat over spawning period
31	1225	1000	To characterize habitat over spawning period
32	1550	1000	To characterize habitat over spawning period
33	1875	1000	To characterize habitat over spawning period
34	2200	1000	To characterize habitat over spawning period
35	2525	1000	To characterize habitat over spawning period
36	250	1250	To characterize habitat over spawning period
37	575	1250	To characterize habitat over spawning period
38	900	1250	To characterize habitat over spawning period
39	1225	1250	To characterize habitat over spawning period
40	1550	1250	To characterize habitat over spawning period
41	1875	1250	To characterize habitat over spawning period
42	2200	1250	To characterize habitat over spawning period
43	2525	1250	To characterize habitat over spawning period
44	250	1500	To characterize habitat over spawning period
45	575	1500	To characterize habitat over spawning period
46	900	1500	To characterize habitat over spawning period
47	1225	1500	To characterize habitat over spawning period
48	1550	1500	To characterize habitat over spawning period
49	1875	1500	To characterize habitat over spawning period
50	2200	1500	To characterize habitat over spawning period
51	2525	1500	To characterize habitat over spawning period

Kootenay River Model			
Run	Columbia Discharge (cms)	Kootenay Discharge	Comments
1	964.54	882.38	During Peak Spawning 16-Dec-10
2	1267.56	504.41	During Peak Spawning 5-Jan-11
3	1528.61	531.95	During Peak Spawning 12-Jan-11
4	250	250	To characterize habitat over spawning period
5	575	250	To characterize habitat over spawning period
6	900	250	To characterize habitat over spawning period
7	1225	250	To characterize habitat over spawning period
8	1550	250	To characterize habitat over spawning period
9	1875	250	To characterize habitat over spawning period
10	2200	250	To characterize habitat over spawning period
11	2525	250	To characterize habitat over spawning period
12	250	500	To characterize habitat over spawning period
13	575	500	To characterize habitat over spawning period
14	900	500	To characterize habitat over spawning period
15	1225	500	To characterize habitat over spawning period
16	1550	500	To characterize habitat over spawning period
17	1875	500	To characterize habitat over spawning period
18	2200	500	To characterize habitat over spawning period
19	2525	500	To characterize habitat over spawning period
20	250	750	To characterize habitat over spawning period
21	575	750	To characterize habitat over spawning period
22	900	750	To characterize habitat over spawning period
23	1225	750	To characterize habitat over spawning period
24	1550	750	To characterize habitat over spawning period
25	1875	750	To characterize habitat over spawning period
26	2200	750	To characterize habitat over spawning period
27	2525	750	To characterize habitat over spawning period
28	250	1000	To characterize habitat over spawning period
29	575	1000	To characterize habitat over spawning period
30	900	1000	To characterize habitat over spawning period
31	1225	1000	To characterize habitat over spawning period
32	1550	1000	To characterize habitat over spawning period
33	1875	1000	To characterize habitat over spawning period
34	2200	1000	To characterize habitat over spawning period
35	2525	1000	To characterize habitat over spawning period
36	250	1250	To characterize habitat over spawning period
37	575	1250	To characterize habitat over spawning period
38	900	1250	To characterize habitat over spawning period
39	1225	1250	To characterize habitat over spawning period
40	1550	1250	To characterize habitat over spawning period
41	1875	1250	To characterize habitat over spawning period
42	2200	1250	To characterize habitat over spawning period
43	2525	1250	To characterize habitat over spawning period
44	250	1500	To characterize habitat over spawning period
45	575	1500	To characterize habitat over spawning period
46	900	1500	To characterize habitat over spawning period
47	1225	1500	To characterize habitat over spawning period
48	1550	1500	To characterize habitat over spawning period
49	1875	1500	To characterize habitat over spawning period
50	2200	1500	To characterize habitat over spawning period
51	2525	1500	To characterize habitat over spawning period

Table A1: RIVER 2D Model Run Requests for CLBMON-47 Continued.

CPR Island/Columbia River Model			
Run	Columbia Discharge (cms)	Kootenay Discharge (cms)	Comments
52	412.5	375	To characterize habitat over spawning period
53	737.5	375	To characterize habitat over spawning period
54	1062.5	375	To characterize habitat over spawning period
55	1387.5	375	To characterize habitat over spawning period
56	1712.5	375	To characterize habitat over spawning period
57	2037.5	375	To characterize habitat over spawning period
58	2362.5	375	To characterize habitat over spawning period
59	2687.5	375	To characterize habitat over spawning period
60	412.5	625	To characterize habitat over spawning period
61	737.5	625	To characterize habitat over spawning period
62	1062.5	625	To characterize habitat over spawning period
63	1387.5	625	To characterize habitat over spawning period
64	1712.5	625	To characterize habitat over spawning period
65	2037.5	625	To characterize habitat over spawning period
66	2362.5	625	To characterize habitat over spawning period
67	2687.5	625	To characterize habitat over spawning period
68	412.5	875	To characterize habitat over spawning period
69	737.5	875	To characterize habitat over spawning period
70	1062.5	875	To characterize habitat over spawning period
71	1387.5	875	To characterize habitat over spawning period
72	1712.5	875	To characterize habitat over spawning period
73	2037.5	875	To characterize habitat over spawning period
74	2362.5	875	To characterize habitat over spawning period
75	2687.5	875	To characterize habitat over spawning period
76	412.5	1125	To characterize habitat over spawning period
77	737.5	1125	To characterize habitat over spawning period
78	1062.5	1125	To characterize habitat over spawning period
79	1387.5	1125	To characterize habitat over spawning period
80	1712.5	1125	To characterize habitat over spawning period
81	2037.5	1125	To characterize habitat over spawning period
82	2362.5	1125	To characterize habitat over spawning period
83	2687.5	1125	To characterize habitat over spawning period
84	412.5	1375	To characterize habitat over spawning period
85	737.5	1375	To characterize habitat over spawning period
86	1062.5	1375	To characterize habitat over spawning period
87	1387.5	1375	To characterize habitat over spawning period
88	1712.5	1375	To characterize habitat over spawning period
89	2037.5	1375	To characterize habitat over spawning period
90	2362.5	1375	To characterize habitat over spawning period
91	2687.5	1375	To characterize habitat over spawning period
92	412.5	1625	To characterize habitat over spawning period
93	737.5	1625	To characterize habitat over spawning period
94	1062.5	1625	To characterize habitat over spawning period
95	1387.5	1625	To characterize habitat over spawning period
96	1712.5	1625	To characterize habitat over spawning period
97	2037.5	1625	To characterize habitat over spawning period
98	2362.5	1625	To characterize habitat over spawning period
99	2687.5	1625	To characterize habitat over spawning period

Kootenay River Model			
Run	Columbia Discharge (cms)	Kootenay Discharge	Comments
52	412.5	375	To characterize habitat over spawning period
53	737.5	375	To characterize habitat over spawning period
54	1062.5	375	To characterize habitat over spawning period
55	1387.5	375	To characterize habitat over spawning period
56	1712.5	375	To characterize habitat over spawning period
57	2037.5	375	To characterize habitat over spawning period
58	2362.5	375	To characterize habitat over spawning period
59	2687.5	375	To characterize habitat over spawning period
60	412.5	625	To characterize habitat over spawning period
61	737.5	625	To characterize habitat over spawning period
62	1062.5	625	To characterize habitat over spawning period
63	1387.5	625	To characterize habitat over spawning period
64	1712.5	625	To characterize habitat over spawning period
65	2037.5	625	To characterize habitat over spawning period
66	2362.5	625	To characterize habitat over spawning period
67	2687.5	625	To characterize habitat over spawning period
68	412.5	875	To characterize habitat over spawning period
69	737.5	875	To characterize habitat over spawning period
70	1062.5	875	To characterize habitat over spawning period
71	1387.5	875	To characterize habitat over spawning period
72	1712.5	875	To characterize habitat over spawning period
73	2037.5	875	To characterize habitat over spawning period
74	2362.5	875	To characterize habitat over spawning period
75	2687.5	875	To characterize habitat over spawning period
76	412.5	1125	To characterize habitat over spawning period
77	737.5	1125	To characterize habitat over spawning period
78	1062.5	1125	To characterize habitat over spawning period
79	1387.5	1125	To characterize habitat over spawning period
80	1712.5	1125	To characterize habitat over spawning period
81	2037.5	1125	To characterize habitat over spawning period
82	2362.5	1125	To characterize habitat over spawning period
83	2687.5	1125	To characterize habitat over spawning period
84	412.5	1375	To characterize habitat over spawning period
85	737.5	1375	To characterize habitat over spawning period
86	1062.5	1375	To characterize habitat over spawning period
87	1387.5	1375	To characterize habitat over spawning period
88	1712.5	1375	To characterize habitat over spawning period
89	2037.5	1375	To characterize habitat over spawning period
90	2362.5	1375	To characterize habitat over spawning period
91	2687.5	1375	To characterize habitat over spawning period
92	412.5	1625	To characterize habitat over spawning period
93	737.5	1625	To characterize habitat over spawning period
94	1062.5	1625	To characterize habitat over spawning period
95	1387.5	1625	To characterize habitat over spawning period
96	1712.5	1625	To characterize habitat over spawning period
97	2037.5	1625	To characterize habitat over spawning period
98	2362.5	1625	To characterize habitat over spawning period
99	2687.5	1625	To characterize habitat over spawning period

APPENDIX B

Mountain Whitefish Egg Loss Model Detailed Instructions

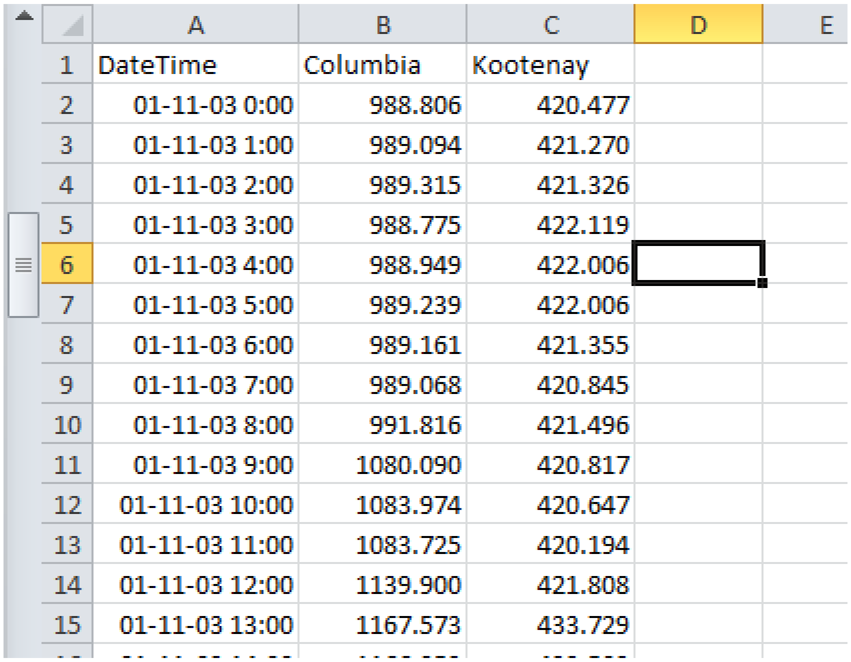
Appendix B, Section B1: Data input and formatting for the ELM.

This appendix provides details on the types of required input data, their format and layout. Screen shots of inputting the data and initializing the model are provided below, in Appendix B2.

There are three types of data input for this model:

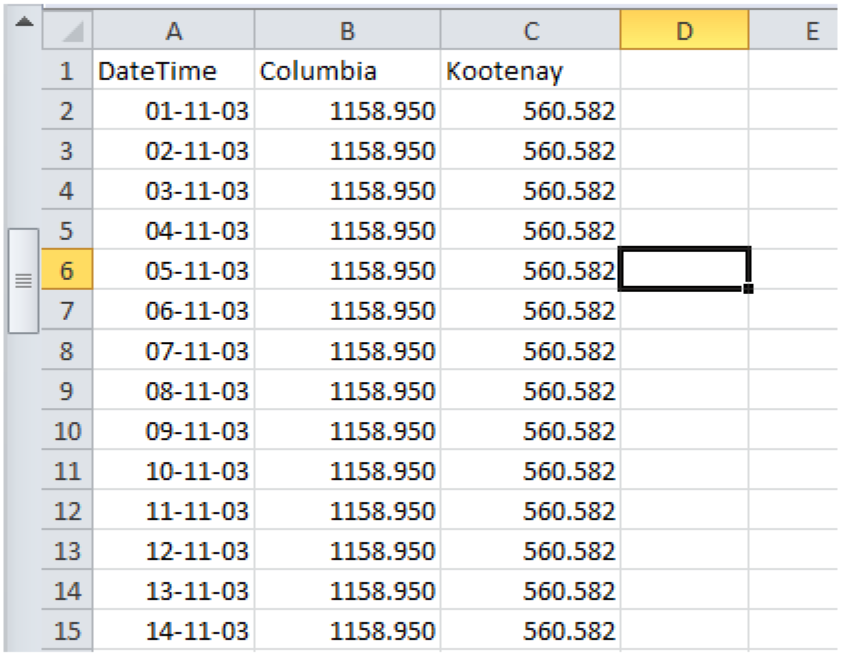
1) Data provided by Golder, used for each run. These include:
    a. 'ATU.coefs': a csv (comma-delimited) file that contains regression coefficients and prediction errors of egg development as a function of accumulated thermal units.
    b. 'Egg.dep.time.coefs': a csv file that contains regression coefficients of egg deposition as function of time.
    c. 'Egg.dep.depth.reg.coefs': a csv file that contains regression coefficients of egg deposition as a function of depth.
    d. 'River2D.Elevation.tab': a csv file that contains depths and water velocities throughout the study areas at different BRD and HLK discharges. These files are the output of the various River 2D runs.

2) Data files supplied by BC Hydro for each run, which include discharge and temperature data from the study area. Discharge and temperature data must be provided in the form of csv files; these can be created by saving an Excel file as csv type. It is important that there are no missing data, skipped rows, or character input where numerical input is expected. The data must range between Nov 1 and May 1, including the end dates. Below are examples of the data required for the model; each example provides a snippet of data, showing the layout and format of the expected input. The layout (number of columns, column names, order of columns) and format (date/time format, discharge/temperature units, etc.) must be followed precisely. Otherwise, the model run will not be able to complete correctly.
    a. Discharge data: the csv file must be named "Data.Discharge.csv". Discharge data may be either hourly (as in Figure B1) or daily (as in Figure B2). If daily values are used, they must represent the minimum daily discharge. In either case, the date must be entered as 'dd-mm-yy'; if the measurements are hourly, the first column's format should be 'dd-mm-yy hh:mm'. The date (or DateTime) column must be followed by two columns containing the mean values of discharge (in m^3/s) for Columbia and Kootenay (HLK and BRD dams, respectively).



	A	B	C	D	E
1	DateTime	Columbia	Kootenay		
2	01-11-03 0:00	988.806	420.477		
3	01-11-03 1:00	989.094	421.270		
4	01-11-03 2:00	989.315	421.326		
5	01-11-03 3:00	988.775	422.119		
6	01-11-03 4:00	988.949	422.006		
7	01-11-03 5:00	989.239	422.006		
8	01-11-03 6:00	989.161	421.355		
9	01-11-03 7:00	989.068	420.845		
10	01-11-03 8:00	991.816	421.496		
11	01-11-03 9:00	1080.090	420.817		
12	01-11-03 10:00	1083.974	420.647		
13	01-11-03 11:00	1083.725	420.194		
14	01-11-03 12:00	1139.900	421.808		
15	01-11-03 13:00	1167.573	433.729		

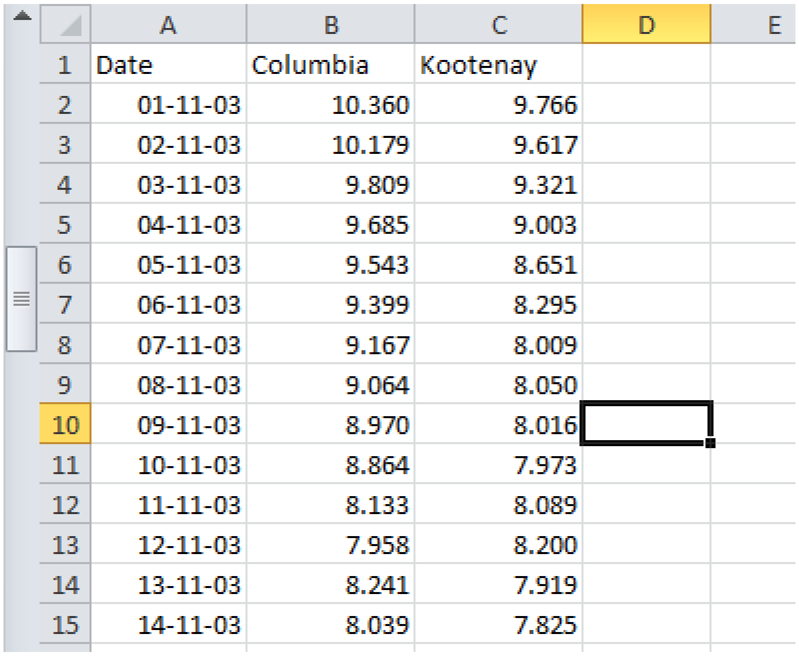
Figure B1: A screen shot of the beginning of a csv file containing hourly discharge data; one option for the discharge data required for egg loss model input.



	A	B	C	D	E
1	DateTime	Columbia	Kootenay		
2	01-11-03	1158.950	560.582		
3	02-11-03	1158.950	560.582		
4	03-11-03	1158.950	560.582		
5	04-11-03	1158.950	560.582		
6	05-11-03	1158.950	560.582		
7	06-11-03	1158.950	560.582		
8	07-11-03	1158.950	560.582		
9	08-11-03	1158.950	560.582		
10	09-11-03	1158.950	560.582		
11	10-11-03	1158.950	560.582		
12	11-11-03	1158.950	560.582		
13	12-11-03	1158.950	560.582		
14	13-11-03	1158.950	560.582		
15	14-11-03	1158.950	560.582		

Figure B2: A screen shot of the beginning of a csv file containing daily discharge data; the second option for the discharge data required for egg loss model input.

b. Temperature data: the csv file must be named “Data.Temp.csv” and contain daily mean values (°C) of water temperature. The first column in the file must contain date information, followed by the measurements at Columbia and Kootenay rivers. Similar to discharge data, dates must be input as ‘dd-mm-yy’ (Figure B3).



	A	B	C	D	E
1	Date	Columbia	Kootenay		
2	01-11-03	10.360	9.766		
3	02-11-03	10.179	9.617		
4	03-11-03	9.809	9.321		
5	04-11-03	9.685	9.003		
6	05-11-03	9.543	8.651		
7	06-11-03	9.399	8.295		
8	07-11-03	9.167	8.009		
9	08-11-03	9.064	8.050		
10	09-11-03	8.970	8.016		
11	10-11-03	8.864	7.973		
12	11-11-03	8.133	8.089		
13	12-11-03	7.958	8.200		
14	13-11-03	8.241	7.919		
15	14-11-03	8.039	7.825		

Figure B3: A screen shot of the beginning of a csv file containing daily temperature (°C) data

3) Numerical and text values required for the model, to be provided for each run. The model will prompt the user to enter these values at the beginning of each run:
    a. ‘Hourly’: a binary parameter related to the input discharge data. The parameter takes the value of 0 if discharge data are daily and the value of 1 if discharge data are hourly.
    b. ‘identifier’: a name to be used when creating the output files. The identifier can change between model runs (e.g., “1Mar2013.run1”, “1Mar2013.run2”), or remain constant (e.g., “BCHydro.egg.sims”). If the identifier is identical to previously used identifiers, the output files from previous runs will be overwritten. The identifier should not contain any spaces.
    c. ‘lag.hours’: a numeric value related to the processing of raw hourly discharge data. Eggs often require more than a single hour of exposure to air to die. Therefore, if discharge is reduced for only one hour, it may strand the eggs, but not cause mortality. To overcome this, if discharge data are hourly, they can be adapted by using a time-lagged function of the raw discharge data. If the hourly discharge data are chosen to be lagged, the maximum discharge of the time window equal to lag.hours will be recorded instead of the original raw data value. Then, the daily minimum value of processed discharge data will be estimated and used for subsequent stranding modeling. In the previous instance of the egg stranding model, a value of 8 h was used to lag the raw discharge data. If input discharge data are daily, lag.hours is not needed for the model, and the user will not be asked for it.
    d. ‘boot.length’: the number of iterations required for the bootstrap analysis. The bootstrapping process requires a lot of computer memory. **Using installed memory (RAM) of 4 GB (3.88 GB usable), only 300 iterations were possible**. Increased RAM

will allow increasing the number of iterations when running the model. Generally, at least 1000 iterations are recommended to stabilize confidence intervals. Note that increasing the number of iterations results in increased computational time (Table B4), and the total number of runs will be dictated by the installed hardware. In the runs performed for testing the model, run time had a linear relationship with bootstrap length (Table B4). Extrapolating the relationship suggests that 1,000 iterations will require 68 minutes (1.13 h) of computational time. <u>It is recommended to run the model on a freshly rebooted computer that is not used for other processes during the run.</u>

. **Table B4. Run times of the egg loss model under several boot.length inputs; runs were made on a Intel® Core™ i5-2520M CPU, 2.5 GHz processor.**

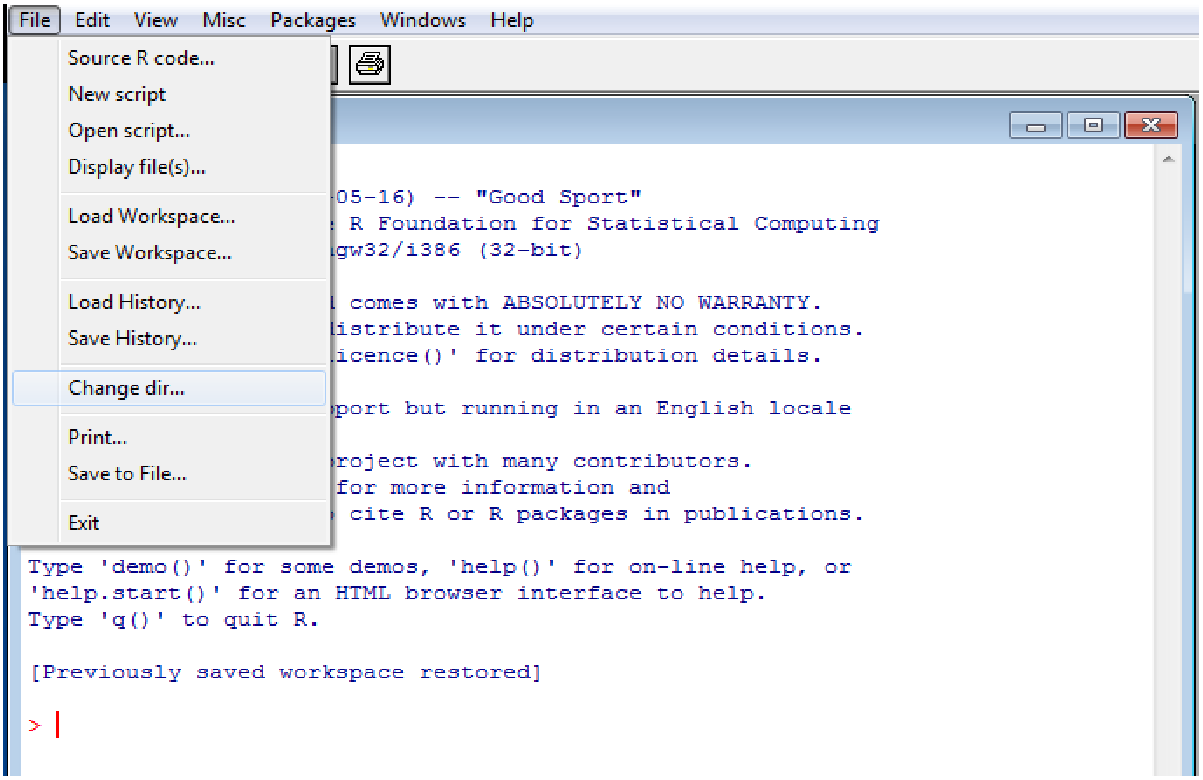
Bootstrap length	Time (sec)	Time (min)
100	715	11.9
200	987	16.45
300	1437	24.5

<u>Appendix B, Table B2: Step-by-step instructions for completing a ELM run</u>

This document builds on Appendix B1 and shows how to operate the software, load data, and run the ELM.

1) To run the ELM, the user will have to install program R on their computer. To install the software, download the executable file from these links for Windows (http://cran.r-project.org/bin/windows/base/R-3.0.2-win.exe) or Mac computers (http://cran.r-project.org/bin/macosx/R-3.0.2.pkg). Double-click the file and follow the prompts. Once the software is installed, open the program (use 64-bit R on 64-bit computers).

2) Following the installation of R, the user will be required to install the add-on packages that are being used within the ELM script. The code for package installation is found within the “first.run.script.R” file that will be supplied as part of this report. To run the code, the user will have to save the script file to a folder of choice on their computer. From within R, navigate to “File” and “Change directory” (see screenshot below). Navigate the folders until the folder containing the script is found. Click “OK”.



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05-16) -- "Good Sport"
 R Foundation for Statistical Computing
gw32/i386 (32-bit)

 comes with ABSOLUTELY NO WARRANTY.
istribute it under certain conditions.
icence()' for distribution details.

port but running in an English locale

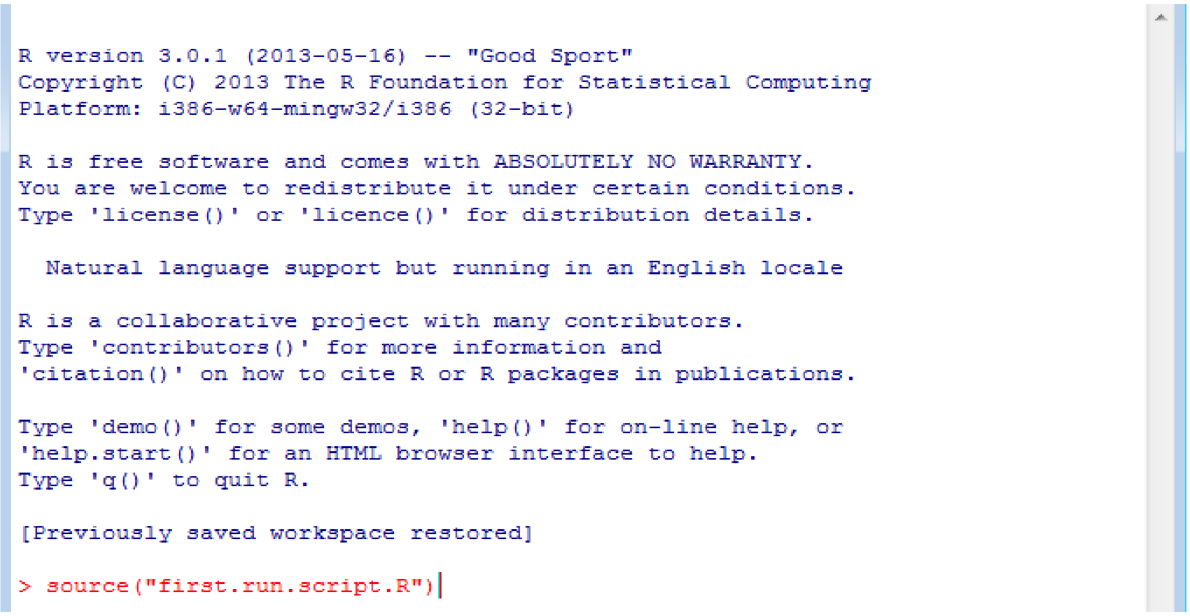
roject with many contributors.
for more information and
 cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[Previously saved workspace restored]

> 
```

3) Once the directory is changed, run the script by typing (or copying from this document the following line:
source("first.run.script.R")
(see screenshot below). Press "Enter" to execute the command.



```
R version 3.0.1 (2013-05-16) -- "Good Sport"
Copyright (C) 2013 The R Foundation for Statistical Computing
Platform: i386-w64-mingw32/i386 (32-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

  Natural language support but running in an English locale

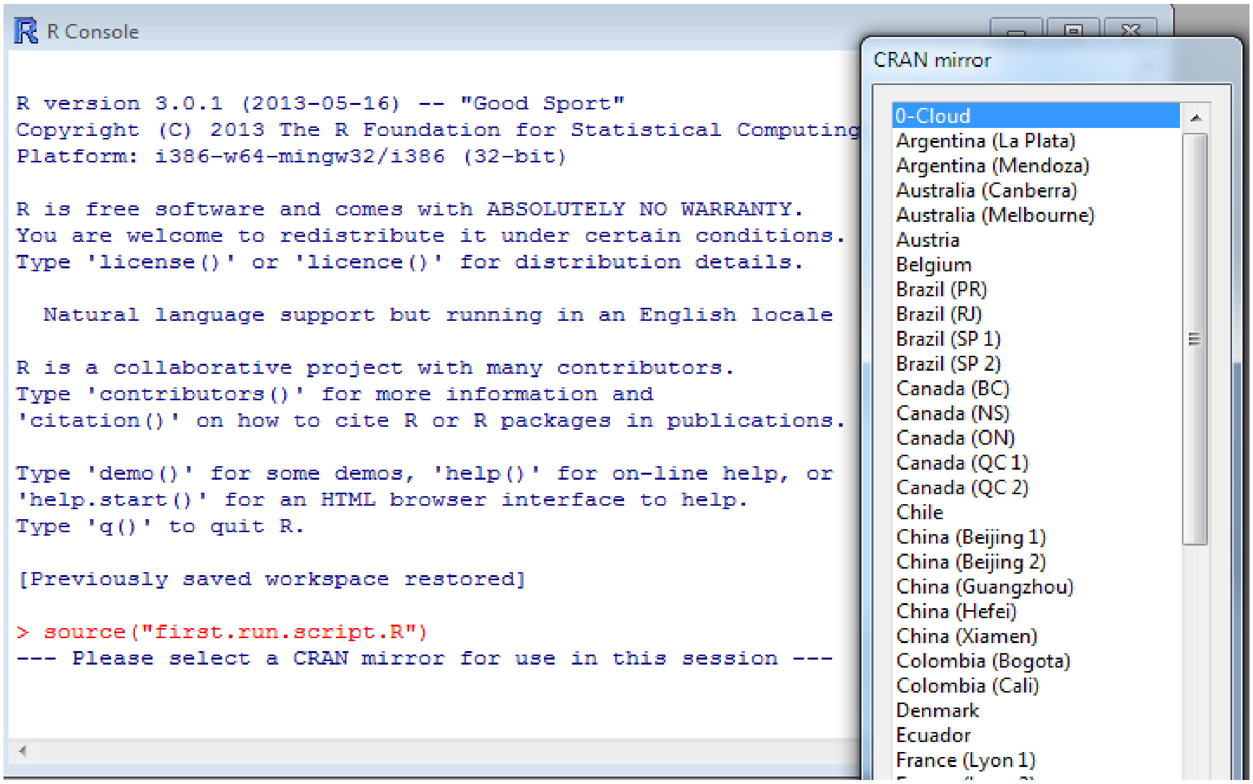
R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[Previously saved workspace restored]

> source("first.run.script.R")
```

4) This script will install add-on packages for any subsequent work. Following this command (hit "Enter" to execute), R will request to choose a mirror for downloading the packages (see screenshot below). Choose the closest mirror (Canada BC), and the installation will proceed.



```
R version 3.0.1 (2013-05-16) -- "Good Sport"
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Platform: i386-w64-mingw32/i386 (32-bit)

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Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[Previously saved workspace restored]

> source("first.run.script.R")
--- Please select a CRAN mirror for use in this session ---
```

5) Once the installation is complete, the model can be run. All following instructions are related to actual runs of the egg loss model.

6) **The files provided by Golder must be stored in a single folder**, to be accessed from R. This folder must also contain the **discharge and temperature data** to be used in the model. Navigate to the folder using the File/Change Dir option from R. This is also the folder where all the output from the egg loss model will be kept. Files provided by Golder are:

   a. two R scripts ("first.run.script.R" and "Egg.loss.model.script.R"),
   b. coefficients of regressions of egg deposition with time and depth,
   c. regressions of egg development with ATU, and
   d. depth and velocity maps predicted by the River 2D model.

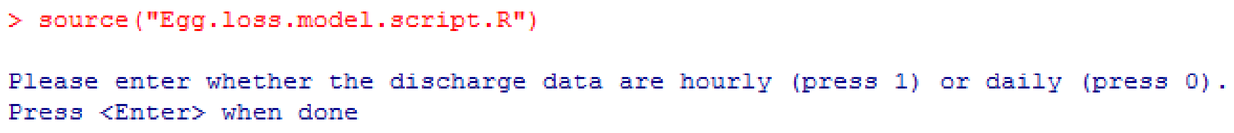
7) Once the data files are all stored in the chosen directory, the model can be called by typing or copying from this document the following line (see screenshot below):
source("Egg.loss.model.script.R")

8) Next, the required input (paragraphs 3-6 in data examples) must be supplied. The user will be prompted by the model to enter these values, with brief explanations and examples included, at the beginning of each model run. Below are example values, change as required:

```
Identifier <- "Simulation1"
lag.hours <- 8
Hourly <- 1
```

boot.length <- 300

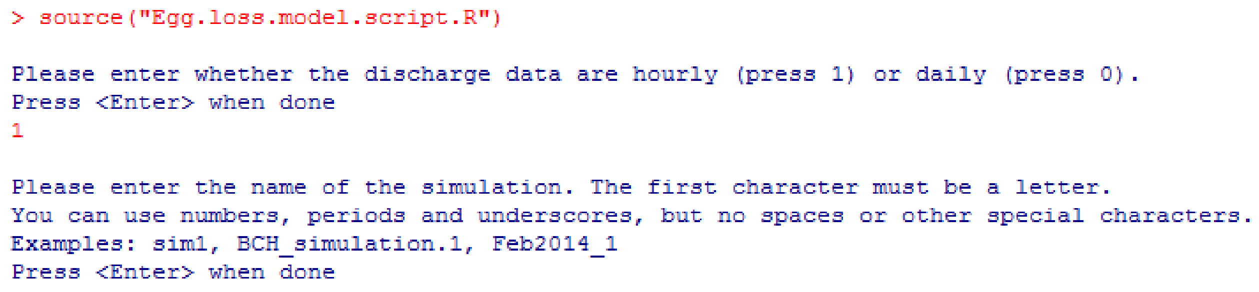
<u>These values can be typed into the console at each prompt (see screenshots below) or copied and pasted from this document</u>. Press “Enter” to execute the commands.



```
> source("Egg.loss.model.script.R")

Please enter whether the discharge data are hourly (press 1) or daily (press 0).
Press <Enter> when done
```

Screenshot 1: call the model; the model prompts the user to enter whether the discharge data are hourly or daily.

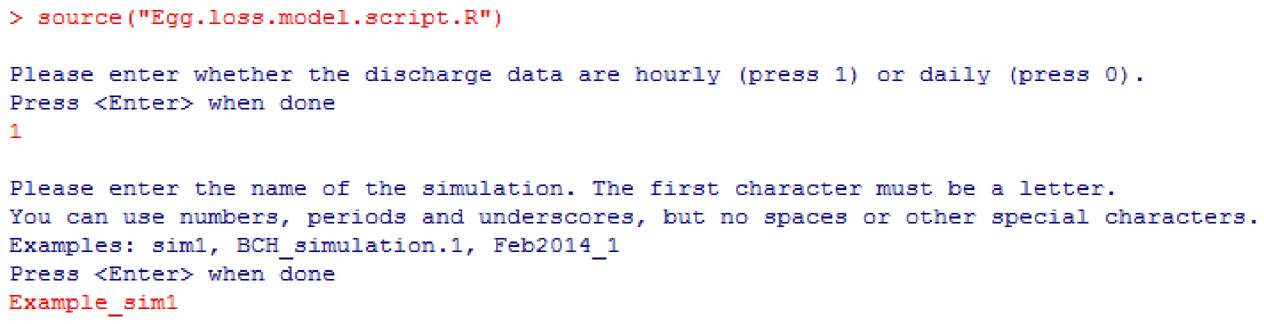


```
> source("Egg.loss.model.script.R")

Please enter whether the discharge data are hourly (press 1) or daily (press 0).
Press <Enter> when done
1

Please enter the name of the simulation. The first character must be a letter.
You can use numbers, periods and underscores, but no spaces or other special characters.
Examples: sim1, BCH_simulation.1, Feb2014_1
Press <Enter> when done
```

Screenshot 2: the model prompts the user for a name for the simulations and provides examples of names.

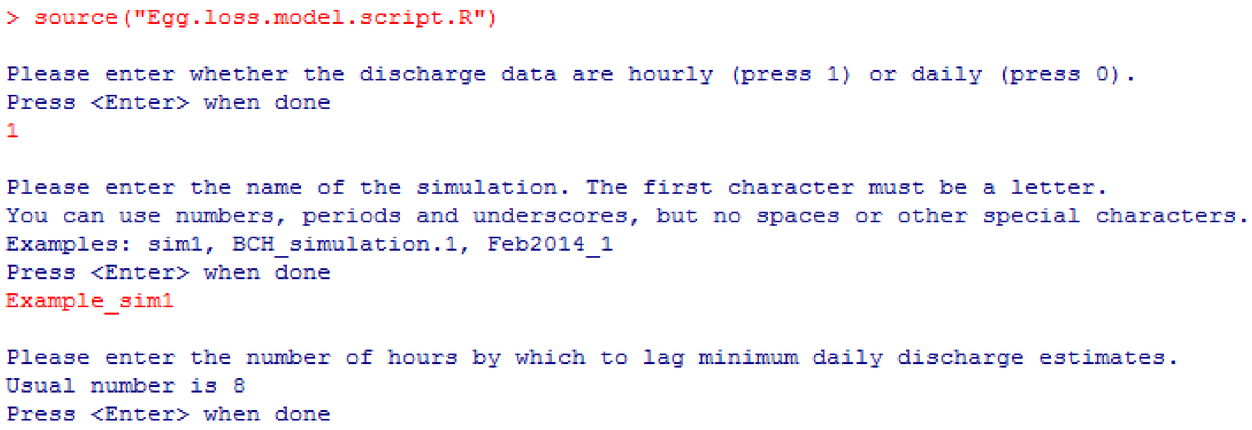


```
> source("Egg.loss.model.script.R")

Please enter whether the discharge data are hourly (press 1) or daily (press 0).
Press <Enter> when done
1

Please enter the name of the simulation. The first character must be a letter.
You can use numbers, periods and underscores, but no spaces or other special characters.
Examples: sim1, BCH_simulation.1, Feb2014_1
Press <Enter> when done
Example_sim1
```

Screenshot 3: The model prompts the user to enter the number of hours by which to lag the hourly discharge data to estimate daily minimum discharges.



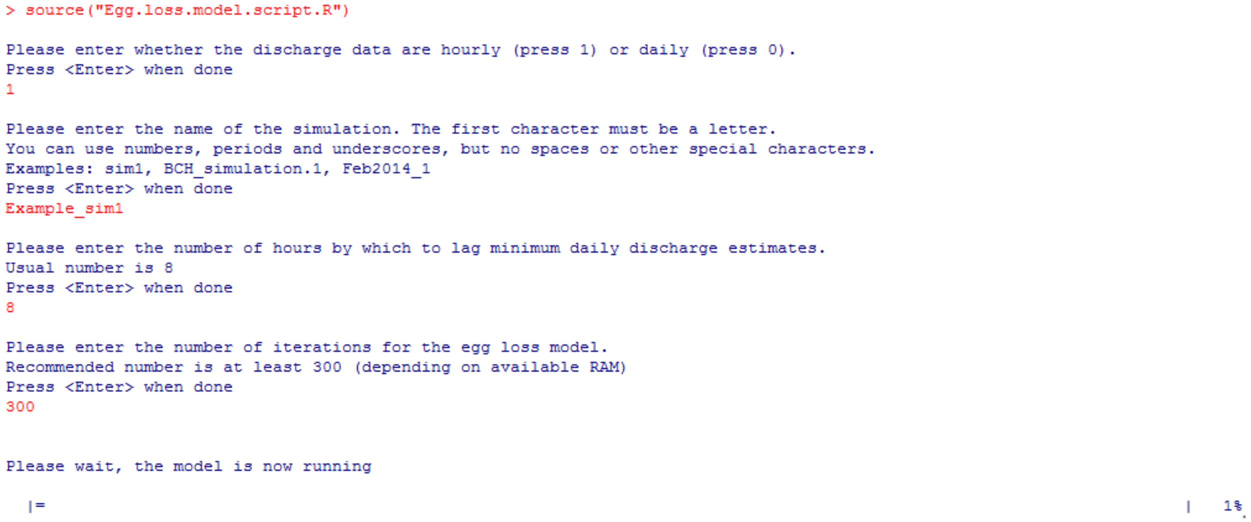
```
> source("Egg.loss.model.script.R")

Please enter whether the discharge data are hourly (press 1) or daily (press 0).
Press <Enter> when done
1

Please enter the name of the simulation. The first character must be a letter.
You can use numbers, periods and underscores, but no spaces or other special characters.
Examples: sim1, BCH_simulation.1, Feb2014_1
Press <Enter> when done
Example_sim1

Please enter the number of hours by which to lag minimum daily discharge estimates.
Usual number is 8
Press <Enter> when done
```

Screenshot 4: The model prompts the user to enter the number of bootstrap iterations.



```
> source("Egg.loss.model.script.R")

Please enter whether the discharge data are hourly (press 1) or daily (press 0).
Press <Enter> when done
1

Please enter the name of the simulation. The first character must be a letter.
You can use numbers, periods and underscores, but no spaces or other special characters.
Examples: sim1, BCH_simulation.1, Feb2014_1
Press <Enter> when done
Example_sim1

Please enter the number of hours by which to lag minimum daily discharge estimates.
Usual number is 8
Press <Enter> when done
8

Please enter the number of iterations for the egg loss model.
Recommended number is at least 300 (depending on available RAM)
Press <Enter> when done
300


Please wait, the model is now running

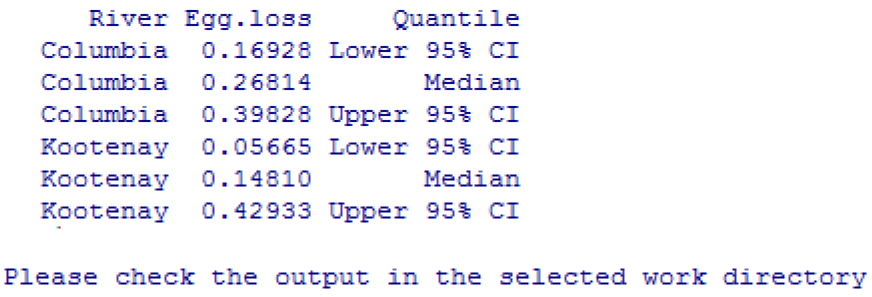
  |=                                                                                    |   1%
```

Screenshot 5: Once all the values have been entered, for a few minutes, there will be no output seen on the screen. This is the initial stage of data processing. Then the model begins running and a progress bar (shown at 1% appears).

9) Once the bootstrap is completed (progress bar reaches 100%), the model will keep on running for a few more minutes, as it completes data plotting and tabular output. When the script finishes its run, the model will notify the user to check the chosen folder for tabular output and maps (Section 3.9.2). All file names will contain the identifier chosen at the beginning of the run, and will include:
    a. Total.stranding.sim1.csv (where sim1 is the chosen identifier), the file containing estimates of stranding, as well as the identifier name, number of bootstrap iterations, discharge lag period, and whether discharge data were hourly or daily.
    b. Egg.deposition.strand.Columbia.maps.sim1.pdf (where sim1 is the chosen identifier) – maps of egg deposition and stranding at CPR Island.
    c. Egg.deposition.strand.Kootenay.maps.sim1.pdf (where sim1 is the chosen identifier) – maps of egg deposition and stranding at the Kootenay spawning site.

d. Data.Discharge.Lagged.sim1.pdf (where sim1 is the chosen identifier) – daily discharge data created using the hourly data and the number of lag hours.
e. ggmapTemp.png – a temporary file created by R and used for mapping.

In to creating the files above, the model will print the stranding estimates directly on the screen for immediate use (see screenshot below).



```
    River Egg.loss     Quantile
 Columbia  0.16928 Lower 95% CI
 Columbia  0.26814       Median
 Columbia  0.39828 Upper 95% CI
 Kootenay  0.05665 Lower 95% CI
 Kootenay  0.14810       Median
 Kootenay  0.42933 Upper 95% CI

Please check the output in the selected work directory
```

APPENDIX C

Egg Loss Model R code (provided on a CD)

At Golder Associates we strive to be the most respected global company providing consulting, design, and construction services in earth, environment, and related areas of energy. Employee owned since our formation in 1960, our focus, unique culture and operating environment offer opportunities and the freedom to excel, which attracts the leading specialists in our fields. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees who operate from offices located throughout Africa, Asia, Australasia, Europe, North America, and South America.

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