Mid-Columbia Physical Habitat Monitoring Project Water Use Plan

Revelstoke Flow Management Water Use Plan Monitoring Program

Implementation Year 6 (2012)

Reference: CLBMON-15a

Synthesis Report

Study Period: Years 1 through 6 (2007 – 2012)

Golder Associates Ltd.
201 Columbia Avenue
Castlegar, BC V1N 1A8
(250) 365-0344

27 January 2014

January 27, 2014

MID-COLUMBIA PHYSICAL HABITAT MONITORING PROJECT WATER USE PLAN

CLBMON-15a Mid-Columbia River Physical Habitat Monitoring Synthesis Report (Years 1 - 6)

Submitted to:
BC Hydro
6911 Southpoint Drive
Burnaby, British Columbia
V3N 4X8

REPORT

Report **Number:** 12-1492-0084

Distribution:

BC Hydro - 3 Copies (one electronic)
Golder Associates Ltd. - 2 Copies

Golder Associates

Suggested Citation: Golder Associates Ltd. 2013. CLBMON-15a Mid-Columbia River Physical Habitat Monitoring. Synthesis Report (Years 1 – 6). Report prepared for BC Hydro, Revelstoke, BC. Golder Report No. 12-1492-0084. 44 p. + 6 app.

EXECUTIVE SUMMARY

BC Hydro implemented the Columbia Water Use Plan (WUP) in 2007. As part of the WUP, the Columbia River Water Use Plan Consultative Committee (WUP CC) recommended the establishment of a year round 142 m^3s^{-1} minimum flow release from Revelstoke Dam to enhance fish habitat in the middle Columbia River (MCR). The study period for the pre-implementation of the 142 m^3s^{-1} minimum flow release regime started in 2007 and concluded in 2010 [Years 1-4 of the Physical Habitat Monitoring Program (CLBMON -15a)].This program specified four years of monitoring where the operation of the Revelstoke Generating Station (REV) did not change (pre-implementation); and up to 10 years of monitoring thereafter, following the implementation of minimum flow and full in service operation of a fifth unit at REV (post-implementation). Two years (2011 and 2012) of post-implementation data had been obtained at the time of this synthesis report.

The main purpose of the synthesis report was to present the preliminary results and analysis for the first six years of this program (2007 to 2012). The physical habitat data collected during the pre and post-implementations years was used to answer the management questions (Table ES1).

Stage and Water Temperature Monitoring

Comparisons of water stage data suggested a greater diel variation in water level after implementation of 142 m^3s^{-1} minimum flows. There was no evidence of differences in seasonal pattern of mean river level fluctuations. This is a probable result because of the greater range of possible discharges under the new flow regime but because of limited post-implementation data and potential confounding variables these conclusions are tentative.

Diel variation of water temperature was significantly greater before minimum flows than after. There was little evidence of differences in the seasonal pattern of mean water temperature. Additional years of data collection are required to better support this conclusion.

The estimate from the 2012 CLBMON-15a HEC-RAS calibrated model results show that minimum flows would increase the permanently wetted riverbed by 32% compared to pre-implementation of minimum flows, when Arrow Lake Reservoir is below 425 m.

Total Gas Pressure Monitoring

There was limited collection of TGP data associated with synchronous condense operations during either the pre or post-implementation of the 142 m^3s^{-1} minimum flow regime; therefore no TGP analysis is provided for the synthesis report.

Seasonal Water Quality Monitoring

In general there were few differences in biological nutrient or electrochemistry variables pre and post-implementation of the 142 m^3s^{-1} minimum flow regime. Potential differences in conductivity and nitrate were identified but conclusions are weak because of small sample sizes.

Table ES1: CLBMON-15a Mid-Columbia River (MCR) Physical Habitat Monitoring STATUS of OBJECTIVES, MANAGEMENT QUESTIONS and HYPOTHESES after Year 6 (2012).

Objectives	Management Questions How does the implementation of the 142 m^3s^{-1} minimum flow affect...	Management Hypotheses Implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly...	Year 6 (2012) Status
Measure differences in the daily and seasonal river water temperature regimes between pre and post-implementation of the 142 m^3s^{-1} minimum flow regime	water temperature in the flowing reach of the MCR	alter the water temperature regime of the MCR • Ho_{1A}:diel variation of water temperature • Ho_{1B}: seasonal pattern of mean water temperature	Diel variation of water temperature was significantly greater before minimum flows than after. Additional years of data collection are required to better support this conclusion. There was little evidence of differences in the seasonal pattern of mean water temperature. Ho_{1B} cannot be rejected.
Measure spatial and temporal differences in river water TGP levels between pre and post-implementation of the 142 m^3s^{-1} minimum flow regime	total gas pressure (TGP) in the flowing reach of the MCR	alter TGP levels in the flowing reach of the MCR • Ho_{2A}: TGP levels	Hypotheses cannot be rejected at this time due to limited TGP data associated with synchronous condense operations collected. No analysis was attempted.
Measure spatial and temporal differences in the daily and seasonal range of river level fluctuations between pre and post-implementation of the 142 m^3s^{-1} minimum flow regime	range and variability in river level fluctuation in the MCR	change the magnitude (i.e., range and variability) of river level fluctuations in the MCR • Ho_{3A}: diel variation of river levels in MCR • Ho_{3B}: seasonal pattern of mean river level fluctuations in the MCR	Comparisons suggested greater diel variation in water level after implementation of minimum flows. This result is plausible because of greater range of possible discharges under the new flow regime but conclusions are tentative because of limited post implementation data and potential confounding variables. There was no evidence of differences in seasonal pattern of mean river level fluctuations.
Collect seasonal nutrient and electrochemistry data at the reach scale to spatially characterize water quality conditions	water quality in terms of electrochemistry and biologically active nutrients	alter the water quality in terms of electrochemistry and biological active nutrients of the MCR • Ho: spatial variation in water quality parameters (developed from the management questions)	Overall, there were few differences in nutrient or electrochemistry variables before and after minimum flows. Potential differences in conductivity and nitrate were identified but conclusions are weak because of small sample sizes.
Estimate changes in the quantity and spatial distribution of permanently inundated river channel resulting from 142 m^3s^{-1} minimum flow releases	total area of river channel that is permanently wetted	increase the area of river channel that is continuously inundated in the MCR • Ho_{4A}: does not increase the minimum total wetted channel area in MCR	The estimate from the 2012 CLBMON-15a HEC-RAS calibrated model results show that minimum flows would increase permanently wetted riverbed by 32% compared to pre-implementation of minimum flows when Arrow Lake Reservoir is below 425 m.

Keywords

Middle Columbia River (MCR)

Arrow Lakes Reservoir (ALR)

British Columbia

Revelstoke Flow Management Plan (RFMP)

REV 5 operations

physical habitat

monitoring

minimum flow release

HEC-RAS model calibration

stage data

temperature

discharge

water quality

ACKNOWLEDGEMENTS

Year 6 (2012) of the Physical Habitat Monitoring Program for the middle Columbia River was funded by BC Hydro as part of the Water Licence Requirements Program. Golder Associates Ltd. would like to thank the following individuals for their contributions to the program:

BC Hydro

Jason Watson	Burnaby, BC
Karen Bray	Revelstoke, BC
Guy Martel	Burnaby, BC
Stan Matthews	Burnaby, BC
Peter McCann	Burnaby, BC
Gillian Kong	Burnaby, BC
Denise Hutt	Revelstoke, BC
Kyle Kivilahti	Revelstoke, BC
Robert Pimer	Burnaby, BC
Kathy Nevissan	Burnaby, BC

Rodman Hydrotechnical Ltd.

Rick Rodman, P. Eng.	Nelson, BC

Water Survey of Canada

Lynne Campo	Burnaby, BC

Solinst Canada Ltd.

Chris Batt	Georgetown, ON

The following employees of **GOLDER ASSOCIATES LTD**. contributed to the collection of data and preparation of this report.

Demitria Burgoon, B.Sc.	Project Biologist/ Author
Dana Schmidt, Ph.D., R.P.Bio.	Senior Fisheries Biologist/Project Director
Greg Burrell, Ph. D.	Senior Aquatics Scientist/Editor
Carissa Canning, B.Sc.	Project Scientist/Project Manager
Dan Walker, Ph.D., P. Eng.	Senior Hydrotechnical/Water Resources Engineer
Mike Paget, B.Sc., E.I.T.	Water Resources Engineer/Co-Author
David Roscoe, M.Sc.	Fisheries Biologist/Statistician/Co-Author
Chris King	Senior Biological Technician
Megan Crozier	Biological Technician
Bob Chapman, R.P.Bio.	Biosciences Group Manager
Ron Giles	Warehouse Technician
Carrie McAllister	Word Processing

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 Background

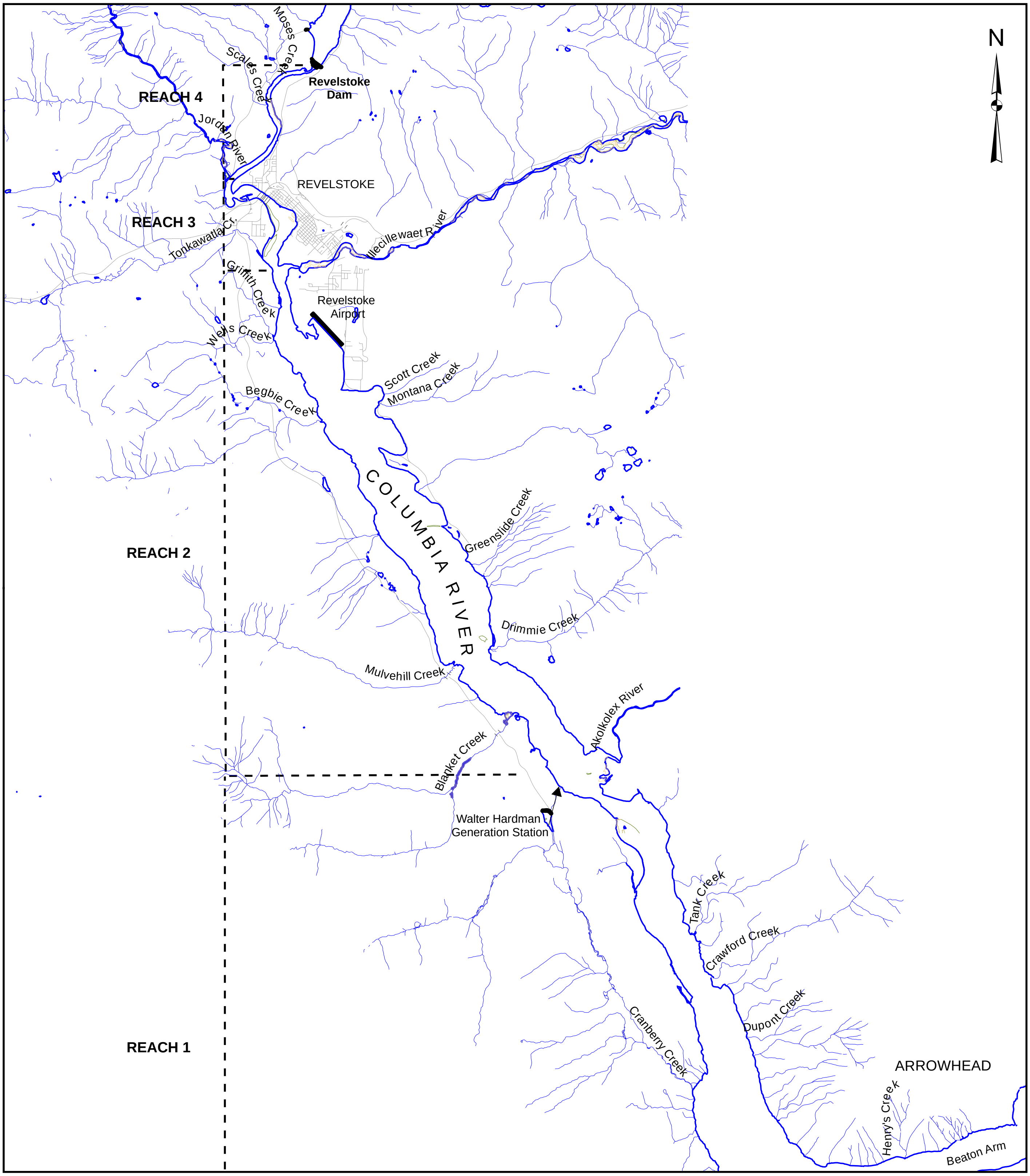
Revelstoke Dam (REV) is located on the middle Columbia River (MCR) in Canada, approximately 8 km upstream from the Trans-Canada Highway Bridge, which crosses the Columbia River at the City of Revelstoke. The facility, brought into service in 1984, was constructed to generate power, using the combined storage capacity of the Revelstoke Reservoir and the upstream Kinbasket Reservoir (impounded by Mica Dam). REV was not constructed as one of the Columbia River Treaty dams [i.e., Mica, Hugh L. Keenleyside (HLK), Duncan, and Libby dams]; however, operation of REV is affected by Treaty operations at both upstream (Mica Dam) and downstream (HLK) dams. The Revelstoke Generating Station is the second largest powerplant in BC Hydro's hydroelectric power generation system, providing 16% of BC Hydro's total system capacity (BC Hydro 2000).

BC Hydro (BCH) implemented the Columbia Water Use Plan (WUP) in 2007 for its hydroelectric and storage facilities on the Columbia River. As part of the WUP, the Columbia River Water Use Plan Consultative Committee (WUP CC) recommended the establishment of a year round 142 m^3s^{-1} minimum flow release from REV to enhance fish habitat in the MCR. To address data gaps in the status of aquatic communities in the MCR, and the uncertainty about the environmental benefits of the proposed minimum flow releases, the WUP CC recommended development and implementation of a number of programs under the Revelstoke Flow Management Plan (RFMP), to measure changes in the MCR aquatic environment in response to minimum flow releases.

In 2010, BCH added a fifth generating unit (REV 5) to the Revelstoke Generating Station. REV 5 went online on December 20, 2010 and added 500 MW to the station's generating capacity; which allows for peak discharge of approximately 2124 m^3s^{-1} (an additional 425 m^3s^{-1} over the previous discharge capacity associated with four units). As a result of the REV 5 Environmental Assessment, an addendum was added to the relevant WUP Terms of Reference (ToR) in 2010 to include monitoring of REV 5 operational impacts (BC Hydro 2010). The intent was to evaluate minimum flow releases or operational changes by constructing a logical linkage between REV operations (including REV 5) and ecological response indicators for the productivity of the benthic community, changes in fish habitat use, and productivity of fish populations.

REV is operated as a peaking facility and daily flow releases fluctuated from approximately 8.5 m^3s^{-1} (seepage flows from the dam during zero generation) to approximately 1750 m^3s^{-1} (i.e., with four generating units) prior to commissioning REV 5. Following the addition of a fifth unit and subsequent implementation of minimum flow on December 20, 2010, daily flows can fluctuate from 142 m^3s^{-1} to approximately 2124 m^3s^{-1}. Prior to December 2010, when Arrow Lakes Reservoir (impounded by HLK) was below El. 437.8 m, BCH attempted to avoid zero discharge during daylight hours (BC Hydro 1998). Daily fluctuations have the potential to affect the availability and suitability of aquatic habitat in the MCR downstream to the river-Arrow reservoir interface zone (see Section 1.2 for description of the interface zone).

The MCR is defined as the flowing portion of the Columbia River, which can extend from REV to Arrowhead, approximately 48 km downstream (Figure 1). The MCR varies in length, depending on the water level elevation of Arrow Lakes Reservoir (ALR).



3 1.5 0 3 6 9 Kilometres

SCALE 1:200,000

LEGEND

River/Stream
Island
Sand Bar
Road
Bridge
Dam

PROJECT
Columbia River Water Use Plan Monitoring Program:
Physical Habitat Monitoring Program

TITLE
Overview of Study Area

Golder Associates
Castlegar, BC

PROJECT No. 09-1480-0024			SCALE AS SHOWN	REV. 0
DESIGN	SS	10 May 2010		
GIS	SS	10 May 2010		
CHECK	BL	10 May 2010		
REVIEW	DS	10 May 2010		

Figure 1

REFERENCE

Digital Data Sets 082M.010, 082M.009, 082L.089, 082L.090, 082L.099 and 082L.100 from BC Hydro. Datum: NAD 83 Projection: UTM Zone 11

1.2 Study Area

The study area for CLBMON-15a Physical Habitat Monitoring Program encompasses the 32-km section of the MCR from the outlet of REV (River kilometre; Rkm 238) downstream to the confluence with the Akolkolex River (Rkm 203.5), and two major tributaries (Figure 1):

- MCR Reach 4 – REV (Rkm 238.0) downstream to the Jordan River confluence (Rkm 231.8);
- MCR Reach 3 – the Jordan River confluence downstream to the Illecillewaet River confluence (Rkm 226.8);
- MCR Reach 2 – the Illecillewaet River confluence downstream to the Akolkolex River confluence (Rkm 203.5); and,
- Tributaries – Illecillewaet River and Jordan River.

The reservoir-river interface zone, defined as the convergence of the MCR with ALR, varies throughout the year and between years, depending upon the ALR surface elevation. The normal operating range of ALR is from El. 420.0 to 440.1 meters above sea level (masl). The length of the MCR riverine section can range from the base of REV at full pool (El. 440.2 m) to Arrowhead 48 km downstream at minimum pool (El. 420.0 m, with lowest reservoir levels typically attained in March). Reach 1 [the Akolkolex River confluence downstream to Arrowhead (RKm 185.8)], was initially proposed as part of the study area in the 2007 ToR. This area was not monitored during Years 1 to 6, as there were no suitable sites for anchoring standpipes that could also collect data during reservoir low pool conditions (i.e., thalweg not along river bank). In 2010, the revised ToR removed Reach 1 from the study area (BC Hydro 2010). The geographic extent of the RFMP was changed from approximately 50 km downstream from REV to approximately 30 km [the Akolkolex River to the tailrace of the REV (Reaches 2, 3, and 4)], which resulted in excluding Reach 1 (the Akolkolex River confluence downstream to the Arrowhead).

1.3 Monitoring Program Overview

The MCR Physical Habitat Monitoring Program was developed to obtain physical habitat and water quality information within the study area, for use by other monitoring programs. The MCR Physical Habitat Monitoring schedule, defined in the WUP (BC Hydro 2005), specified four years of monitoring before implementation of the minimum flow from REV and up to 10 years of monitoring thereafter. To date, six years of monitoring have been completed (2007 through 2012), capturing data for four years of pre-REV 5 operations and two years of post-REV 5 operations. Specific objectives and hypotheses were developed, coupled with an approach and methods designed to address these hypotheses. Given the complex interactions between dam releases, tributary inflows, and ALR levels on physical habitat characteristics, each hypothesis was addressed on a reach-specific basis. The hypotheses were used to draw inferences about the cumulative physical habitat conditions within the entire study area, across a range of REV discharges and ALR water levels. Physical habitat data will also be used by the other monitoring programs of the RFMP to help explain changes in ecological productivity indicators. The approach and methods outlined below were developed to meet the program's objectives and address key management questions.

1.3.1 Monitoring Objectives

The **OBJECTIVES** of the MCR Physical Habitat Monitoring Program are:

1) To measure spatial and temporal differences in the daily and seasonal river water temperature regimes between pre-implementation of the 142 m^3s^{-1} minimum flow regime and post-implementation of the 142 m^3s^{-1} minimum flow regime.

2) To measure spatial and temporal differences in river water TGP levels between pre and post-implementation of the 142 m^3s^{-1} minimum flow regime.

3) To measure spatial and temporal differences in the daily and seasonal range of river level fluctuations between pre and post-implementation of the 142 m^3s^{-1} minimum flow regime.

4) To collect seasonal nutrient and electrochemistry data at the reach scale to spatially characterize water quality conditions.

5) To estimate changes in the quantity and spatial distribution of permanently inundated river channel resulting from 142 m^3s^{-1} minimum flow releases.

The **SCOPE** of the MCR Physical Habitat Monitoring Program is:

1) To continuously monitor water temperature and river stage at index monitoring stations focusing on the upper two reaches of the MCR (Reaches 3 and 4), and in key tributaries (Jordan and Illecillewaet rivers).

2) To conduct strategic, non-continuous TGP monitoring at index stations in the flowing reach of the MCR.

3) To conduct seasonal water quality sampling (electrochemistry and biologically active micronutrients) at index monitoring stations with a focus on the upper two reaches of the MCR (Reaches 3 and 4).

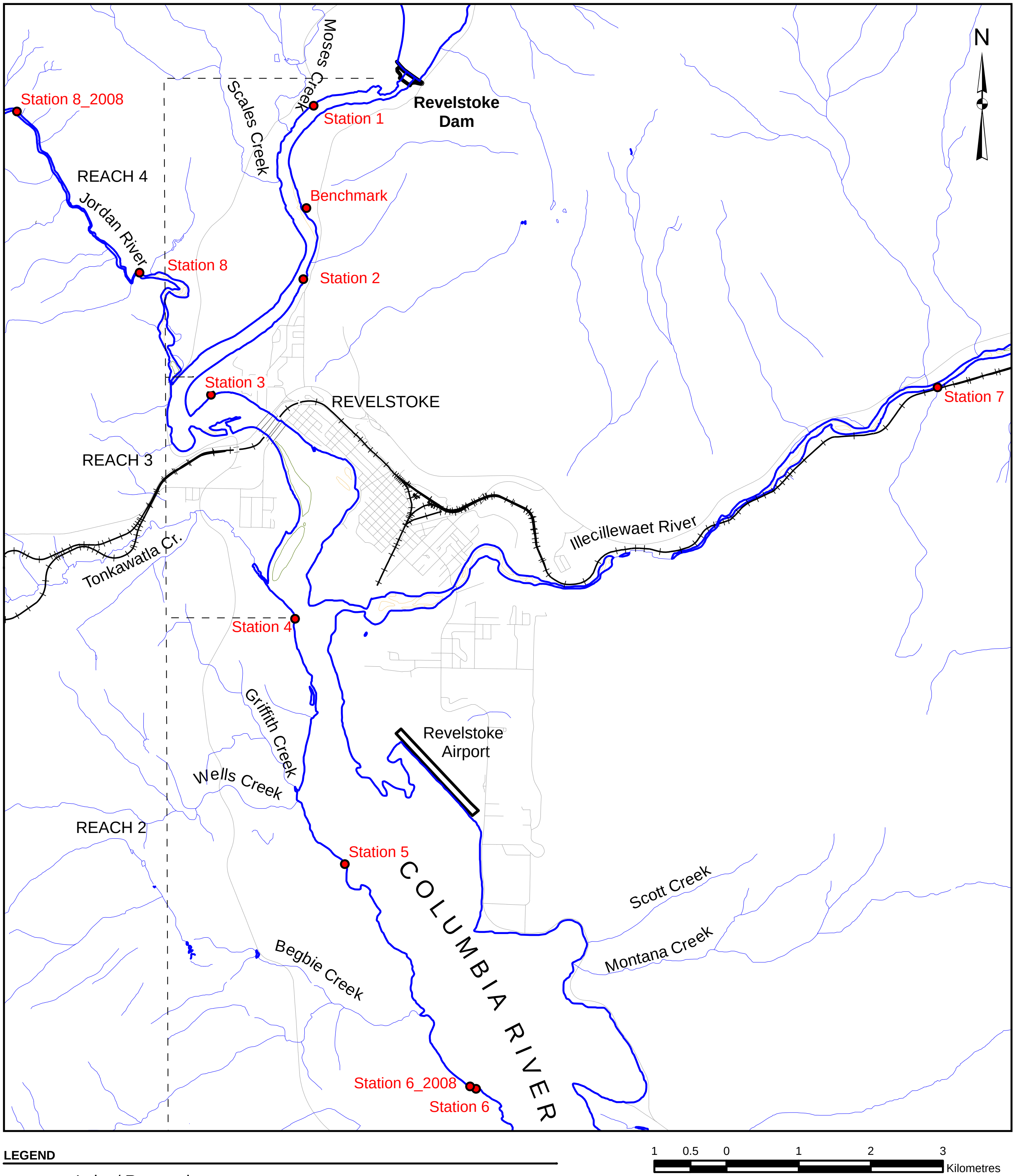
4) To use stage data collected during the monitoring program to calibrate existing 1-d steady and unsteady hydraulic models for the MCR and to use those models to estimate locations of and changes in inundated river channel.

5) To use the empirical data and hydraulic modelling results to test hypotheses about the influence of minimum flow releases on hydraulic characteristics and temperature of the MCR.

6) To develop an electronic database system for systematic storage and retrieval of physical habitat data for the MCR.

1.3.2 Approach

The general approach of this monitoring program was to utilize fixed index (stations were previously established after a review of the cross-section bathymetry locations) monitoring stations (Figure 2) to collect physical habitat and water quality data. The data would help BCH understand the influence of REV operations (including REV 5) on physical aquatic habitat and its effects on ecological productivity, fish population response measures, and fish habitat use under the RFMP.



LEGEND

- Lake / Reservoir
- River
- Railroad
- Road
- Road bridge
- Dam base
- Island
- Sand or gravel bar
- Station Location

REFERENCE

TRIM layers provided by BC Hydro.
Projection: UTM Zone 11 Datum: NAD 83

PROJECT
Columbia River Water Use Plan Monitoring Program: Physical Habitat Monitoring Program

TITLE
Overview of Study Area River Stage Stations on the Middle Columbia River

Golder Associates
Castlegar, BC

PROJECT No. 09-1480-0024			SCALE AS SHOWN	REV. 0
DESIGN	SS	10 May 2010		
GIS	SS	10 May 2010		
CHECK	BL	10 May 2010		
REVIEW	DS	10 May 2010		

Figure 2

1.3.3 Monitoring Program Components

To study the array of physical habitat variables listed in the objectives, the monitoring program was divided into four data collection tasks and one MCR 'CLBMON-15a HEC-RAS Model' calibration and application task. This report is organized by the key management questions. Therefore, each management question, hypothesis, and sub-hypothesis is presented within its associated task, including related methods, results, and discussion. The general overview and design for each task (and subsequent section headings relating to answering each management question) are as follows:

- **Stage and water temperature monitoring** data were collected simultaneously at eight time-synchronized stations in the MCR and two stations in the major MCR tributaries (Figure 2; Appendix A, Table A-2). In addition to the existing BCH station, continuous data loggers, mounted in stainless steel standpipes bolted to rock faces, or deployed on anchor systems, were used to collect data over the large vertical range of possible river stages. The data loggers were downloaded and maintained three times per year. Data were collected at 10-minute intervals (with the exception of the tributaries, which were sampled at 30-minute intervals), with collection times synchronized at the top of the hour at all stations.

- **Hydraulic model calibration and application** using a 1-d HEC-RAS flow model. HEC-RAS is a River Analysis System (RAS) developed by the Hydrologic Engineering Centre (HEC) in Davis California, to aid hydraulic engineers in channel flow analysis and floodplain determination. This model was developed for both steady and unsteady states (depending on river section and temporal operation patterns of interest). The real-time river stage data collected under this monitoring program were used to calibrate the model output to reflect the actual river system response to changes in MCR discharge. The calibrated model was capable of estimating the quantity and spatial distribution of permanently wetted river channel due to changes in REV operations.

- **Total Gas Pressure (TGP) monitoring** information was collected below REV to determine the influence of minimum flows on TGP levels. The TGP monitoring study was scheduled 3 times per year (spring, early summer, and fall) for the first two years of the monitoring program (2007, 2008). Monitoring was scheduled to take place again in Year 5 (2011); however, it was not completed as conditions for synchronous condense operations could not be achieved. The TGP monitoring study was eliminated from Year 6 (2012) and was approved by the CLBMON-15a contracts manager (Watson, J. pers. comm. May 9, 2012). The assumption was that data collected during a separate TGP monitoring program (BCH Contract #055094 Release 11) in conjunction with the 2007 and 2008 data, would be used to answer the management questions. The TGP study under this separate contract was conducted from early June until the end of August 2012 at three monitoring stations along the Columbia River between REV and the highway bridge. However, while the 2012 study captured spill conditions, it did not capture the effects of synchronous condense operations in the flowing reach of the MCR, so could not be used to answer the management questions associated with this report.

- **Seasonal water quality sampling** was conducted at six stations in the MCR and two stations in the main tributaries, for a total of eight stations. Water nutrients and electrochemistry were sampled three times per year, in the same format as the MCR Ecological Productivity Monitoring (CLBMON-15b), but over three seasons (spring, summer, and fall). The samples were sent to two water quality labs for low level nutrient analysis and electrochemistry data were recorded *in situ* using a multimeter.

- **Physical Habitat data QA/QC and database** and storage input system for all the data collected under the MCR Physical Habitat Monitoring Program. An Access database was developed and was maintained and upgraded as needed.

1.3.4 Field Safety Communications

Five of the eight stations were typically accessed by boat and boat operators required real-time communications with dam operators to be safe under fluctuating water levels. Reach 4 anchor stations (AS) and the Jordan River (Station 8) were accessed via wading. The MCR below REV has large daily changes in discharge from REV, often responding to short-term power demands on the hydroelectric system. Real-time dam discharge rate changes were monitored by field crews via remote text messages, automatically sent from the BCH operation control computer to the field crew's cell phone. These messages were sent when dam discharge either increased or decreased over a range of discharge levels every 200 m^3s^{-1} from 200 to 1200 m^3s^{-1}. This real-time discharge information was essential for logistical planning and allowed the crew to maximize monitoring efforts during the period when discharge was sufficient.

When the crew was working between REV and the Highway 1 Bridge, additional river safety communication procedures were required. The REV Dam operators and Planning, Scheduling and Operations Shift Engineers (PSOSE) were contacted to communicate when the crew was on and off the water. This provided another point of contact and ensured that BCH Engineers potentially influencing the operations of REV were aware of the field crews on the water directly below REV.

1.4 Report Scope

Year 6 report is a data compilation (synthesis) report and includes all stage, discharge, temperature and water quality data results collected during the three years pre-implementation of the 142 m^3s^{-1} minimum flow regime and the two years post-implementation of the 142 m^3s^{-1} minimum flow regime. This information will be used to answer the CLBMON-15a management questions. In addition this report provides recommendations for improving assessment methods in the future years of the program.

1.4.1 Key Management Questions

The key management questions of the MCR Physical Habitat Monitoring Program are:

1) How does the implementation of the 142 m^3s^{-1} minimum flow affect water temperature in the flowing reach of the MCR? What is the temporal scale (diel, seasonal) of water temperature changes? Are there spatial differences in the pattern of the water temperature response?

2) How does the implementation of the 142 m^3s^{-1} minimum flow affect total gas pressure (TGP) in the flowing reach of the MCR?

3) How does the implementation of the 142 m^3s^{-1} minimum flow affect the range and variability in river level fluctuation in the MCR? Are there temporal (seasonal scale) or spatial (reach scale) differences in the pattern of response?

4) Does the implementation of the 142 m^3s^{-1} minimum flow affect water quality in terms of electrochemistry and biologically active nutrients?

5) How does the implementation of the 142 m^3s^{-1} minimum flow release from Revelstoke Dam affect the total area of river channel that is permanently wetted?

1.4.2 Hypotheses and Sub-hypotheses

The hypotheses and related sub-hypotheses[1] are:

- Ho_1: Implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter the water temperature regime of the MCR
  - Ho_{1A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam does not significantly change the diel variation of water temperature of the MCR; and
  - Ho_{1B}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter the seasonal pattern of mean water temperature of the MCR.
- Ho_2: Implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter TGP levels in the flowing reach of the MCR.
  - Ho_{2A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter TGP levels.
- Ho_3: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly change the magnitude (*i.e.,* range and variability) of river level fluctuations in the MCR.
  - Ho_{3A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not alter the diel variation of river levels in MCR; and
  - Ho_{3B}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not alter the seasonal pattern of mean river level fluctuations in the MCR.
- Ho_4: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly increase the area of river channel that is continuously inundated in the MCR.

Ho_{4A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam does not increase the minimum total wetted channel area in MCR.

[1] The original hypothesis developed during the WUP was the effects of minimum flows on fish habitat. Modelling and data collection will also provide information to assess the influence of the increase in maximum discharge from Revelstoke Dam by the operation of an additional unit.

2.0 STAGE AND WATER TEMPERATURE MONITORING

2.1 Monitoring Methods

River stage and temperature in the MCR are influenced by REV discharge, tributary inputs, ALR elevations, and local environmental factors. To measure water levels in the MCR, existing stations were used and site-specific stations were installed, to obtain the data with the appropriate spatial distribution, to address the management questions.

2.1.1 Stage, Discharge, and Temperature Monitoring Stations

For the purposes of this monitoring program, data were obtained from the following monitoring sources for calibration and application of the CLBMON-15a HEC-RAS Model:

- Revelstoke Dam Discharge – hourly and 10-minute (data provided by BCH);
- Tributary Inflows – a stage and temperature logger in each of the two major tributaries in the study area (various data sources);
- ALR Elevations as measured at Nakusp in metres (data provided by BCH); and,
- MCR Monitoring Stations (stage and temperature logger) in Reaches 2 through 4 (data provided by Golder and BCH).

In 2007 (Year 1) and 2008 (Year 2), fixed temperature and stage index monitoring stations were installed after reviewing the cross-section bathymetry locations used in the un-calibrated HEC-RAS model of the MCR (Korman et. al. 2002) and related studies. Site selection was based on the following criteria (in order of importance):

1) at least one station was located in each reach of the MCR (Section 1.2) and one in each of the main tributaries in the study area;
2) stations were located at control cross-sections within the un-calibrated HEC-RAS model (Korman et. al. 2002);
3) shore line with vertical rock faces or steep banks were available to allow anchoring of the standpipe stations for stage monitoring; station installation site permitted a design that could withstand the large flow variability associated with the peak discharge with five units and seasonal weather; and,
4) stations were located close to a CLBMON-15b periphyton/benthic substrate location.

Six river stage data loggers were installed, enclosed in standpipes that were attached to steep banks or vertical rock faces to minimize the length of the housing. Data loggers were attached to a known length of wire cable and attached to a hanging bolt that transects the top of the steel pipe. The distance from the ‘constant attachment point’ (hanging bolt) on the steel pipe to the data logger sensor opening and the distance from the ‘constant attachment point’ to the water’s surface were recorded. A summary of these specific station equipment measurements is provided in Appendix A, Table A-1. The water temperature and level data loggers were downloaded and maintained three times each year, typically in the early spring (April), spring or summer (June to August), and fall (October to November; Appendix A, Table A-1).

In addition, two previously established sites serviced and maintained by groups other than Golder were included in the monitoring study: Station 3 (labelled by BCH as REV 'TR2' or 'Tailrace-7km') is maintained by BCH and located within Reach 3 of the MCR, and Station 7 discharge is maintained by Water Survey of Canada (WSC Station No. 08ND013), located on the Illecillewaet River. UTM coordinates and station elevations are shown for all stations in Appendix A, Table A-2.

The standpipe stations in Reach 4 (Stations 1 and 2) were unable to capture the lowest water levels due to the absence of appropriate shoreline with vertical rock faces or steep banks. Therefore, these standpipe stations have data gaps during frequent low flow conditions from 2007 to 2011.The fall field session in Year 4 included a scheduled outage, at which time two additional anchor-based monitoring stations associated with existing index stations (i.e., Stations 1 and 2) were installed. The anchor stations (AS) were designed to capture water levels between zero and minimum flow (142 m^3s^{-1}) from REV in this reach. The two anchor system data loggers were installed when power generation at REV was shut down and most of the channel was dewatered. These new index stations (i.e., Stations 1_AS and 2_AS) were georeferenced (±10 mm) to provide a relational link between the stations in each reach, for use in calibrating the hydraulic model.

The data from Station 1 was often compromised due to sediment build up in the pipe therefore this data set was eventually removed and replaced with data from Station 1_AS for the hydraulic model calibration and application in Year 5 and Year 6. Station 1_AS was situated approximately 15 m downstream.

Water stage and temperature data at the MCR index and Jordan River stations were obtained using a Solinst Levelogger Gold F300 data logger (accuracy for water level ±0.5 cm; temperature ±0.05 °C). Two barometric data loggers (Solinst Barologgers: accuracy ±0.1 cm) were also installed at Station 2 and Station 4. The barometric data loggers were enclosed in separate 1 m (approximate length) standpipes 1 to 2 m above high water mark on rock outcrops. Data from the barologgers were used for barometric compensation of the water level data.

Water stage and temperature at each of the index stations were recorded at 10-minute intervals, with the exception of the Jordan River Station (Station 8) and the Illecillewaet River Station [Station 7 (temperature only)], where data were collected at 30-minute intervals. The 30-minute intervals were sufficient for monitoring changes of water stage and temperature in the tributaries and allowed for additional storage of data readings, in the event the site could not be accessed and downloaded during spring freshet.

Illecillewaet River temperature data were obtained using a TidbiT v2 temperature data logger (±0.2 °C accuracy over a wide temperature range). The data logger is waterproof to 300 m, equipped with an optic interface for data offload and communicates through the Optic USB Base Station or HOBO Waterproof Shuttle.

2.1.2 MCR River Stage and Temperature Monitoring Station Maintenance

Station maintenance was required during all visits and included:

- lengthening standpipes to prevent dewatering;
- adding pipe lengths to top of housing for access during full pool (intent was to make all stations easy to access at a wide range of water levels);
- reinforcement of the structure supports using Hilti Hit™ epoxy and custom stainless steel hardware;
- replacing aircraft cable affecting absolute sensor elevation;
- engraving and marking the pipe housing at 1 m increments, to allow quality control of water level readings during subsequent field service trips;
- flushing out standpipes with an in-line bilge pump to prevent sediment build-up; and,
- changing out data loggers that malfunctioned.

Sediment had been observed on either the data logger housing or the actual sensor at many stations (particularly Station 1 and those stations exposed to riverine conditions in Reaches 3 and 4). In Year 3, the bottoms of the standpipes at each station were wrapped in geotextile material to prevent sediment from affecting data readings or interfering with the data logger sensor. A complete record of seasonal station maintenance activities is included in Appendix A, Table A-1.

In conjunction with seasonal station maintenance, spot measurements were completed using a calibrated thermometer at all stage monitoring stations on the MCR (including BCH's Station 3) and the Illecillewaet and Jordan rivers each sampling session. These quality control procedures provided validation that all CLBMON-15a index station data were comparable and accurately reflected true water temperature. Temperature QA/QC was completed using a MICRONTA Auto Range Digital Multimeter and measurements were collected at any 10-minute interval from the top of the hour for direct comparison with the data loggers.

2.1.3 Statistical Analysis Methods - Water Level

Diel variation was calculated as the difference between the daily maximum and minimum water levels. Descriptive statistics of diel water level variation were calculated for pre and post-implementation of the 142 m^3s^{-1} minimum flow release. Diel variation was compared between the pre and post-implementation of the 142 m^3s^{-1} minimum flow release using a Student's t-test.

2.1.4 Statistical Analysis Methods - Temperature

Linear models were used to assess the effect of minimum flows on water temperature in the MCR. To assess the effect of minimum flow on diel water temperature variation (Ho_{1A}), the model used daily temperature range (daily maximum minus minimum of 10-minute temperature data) as the response variable. The effect of the implementation of the 142 m^3s^{-1} minimum flow regime was included as a fixed categorical predictor variable (before or after). Total discharge from REV was included as a continuous predictor variable. The interaction between the minimum flow factor and discharge was included, which allowed the slope of the discharge-temperature relationship to vary between before and after periods. Plots of water temperature time-series showed a distinct seasonal trend. Therefore, the following sine and cosine functions were used as variables to model the annual pattern in seasonal temperature variation, using a period of 365 days:

- Sin = 2*π*date/365
- Cos =2*π*date/365

To account for temporal autocorrelation in the temperature data, a first order autoregressive (AR1) covariance structure was modeled. Generalized Least Squares (GLS) was used to fit the model because this method allowed autoregressive variance structure to be modeled when the assumption of independent errors is violated (Davidian and Giltinan 1995). A separate model was run for each monitoring station but Station 3 data was not used as there was a +1.0°C difference in the data at this station compared to the other MCR index stations.

Since there were only four years of pre-implementation data and two years of post-implementation data for comparison, there was the potential for random natural variation in weather or discharge to confound the effects of minimum flows on temperature. Therefore, a second set of linear models was used to compare hourly mean water temperature (the response variable) at times when REV discharge was above versus below the 142 m^3s^{-1} minimum flows from pre-implementation dates. The fixed factor representing whether hourly discharge was above or below the minimum flow of 142 m^3s^{-1} was called MinFlow. Total REV discharge and the MinFlow:Discharge interaction were included in the model. Models using an entire year or several years of hourly temperature data could not be fitted because the AR1 covariance matrices were too large. Instead, the data were plotted to select time periods with adequate numbers of observations above and below minimum flows for comparison. The months of July and August were selected as having the best data to assess the effect of minimum flows, whereas in the fall and winter there were very few discharges less than minimum flows. Models of hourly data over a one month period provided a large sample size (~720 observations) without being too large to fit. Models were run with either July or August data for Station 2, 4 and 6 for all years in which there was a complete month of data. Because these models assessed a relatively short time period, the sine and cosine functions to account for seasonal trends were not needed or included in the model. A first order autoregressive covariance structure was included to account for temporal autocorrelation in the data.

All temperature models were fitted using the GLS function in the nlme package of the software R2.15.1 (R Core Team 2012). Significance was assessed at the 0.05 level. In both sets of models described above, if the MinFlow variable or the MinFlow:Discharge interaction were significant, the interpretation was that minimum flows had a significant effect on water temperature in the MCR. Akaike's Information Criterion (AIC) was also used to compare models with and without the MinFlow variable, where the model with the lowest AIC score was considered the best supported model (Burnham and Anderson 2002). The conclusions were the same using AIC scores as when assessing the significance of variables based on p-values. Therefore, AIC scores and reduced models with fewer variables were not presented in this report.

2.1.5 MCR CLBMON-15a Index Station Elevation Synchronization and Orthometric Correction

The collected water elevation data were corrected by adjusting the values using the surveyed orthometric datum (elevation described above sea level) so that all station water elevations were reported using identical metrics. After the initial index stations were established the UTM coordinates and altitude (in metres above sea level) were obtained with a Leica GPS1200 dual frequency geodetic grade GPS system in 2007 (RTK). In 2010, the two anchor stations were installed and UTM coordinates and altitude (in metres above sea level) were obtained with an Altus Positioning System (APS-3) GPS. Additional elevation records were collected for the data logger sensors at Stations 1 and 8, and UTM coordinates and elevation at Water Survey of Canada's (WSC) historic gauge stations benchmarks at the Illecillewaet and Jordan rivers during the 2012 fall session. Due to REV spill conditions in spring/summer 2012, AS_1 had migrated approximately 11.0 m downstream and this station had to be re-installed and new elevation records were collected. All measurements in 2012 were taken using a Trimble R8.

All the GPS systems were used in RTK mode. The details for each unit, including the accuracy is included in Appendix A, Table A-4. When in RTK mode, the units used raw data from a known base station (set-up by the field crew) to achieve the positional accuracy obtained through the use of a portable backpack "rover" unit, used to obtain the position of the desired object or location.

2.1.6 Illecillewaet River Monitoring Station

Tributary water temperature and discharge information was required to assess the impacts of REV discharge on the MCR temperature regime and wetted area in relation to tributary inputs.

WSC maintained a discharge gauging station on the Illecillewaet River, while Golder maintained a continuous temperature monitoring station (installed October 2010). The temperature monitoring locations were chosen to coincide with historic temperature data collection locations (Karen Bray, BC Hydro, pers. comm., September 20, 2010). The temperature loggers were also within close vicinity to the WSC's existing discharge gauging station. Temperature loggers were downloaded twice per year.

2.1.7 Jordan River Monitoring Station

WSC maintained a historic discharge gauging station on the Jordan River between 1963 and 1988. The gauging station was decommissioned in 1988. Golder's hydrotechnical team was involved in the review and establishment of a reliable index monitoring station (Station 8_2008) in 2010 to measure stage, temperature, and velocities that would coincide with the location of this historic gauging station.

In the fall of 2010, the station was compromised due to sediment influx into the standpipe, likely affecting the accuracy of the readings. It was determined that the station may have to be relocated during the next field session. The station could not be accessed due to freshet conditions until the 2011 summer sampling session, at which time the station was re-located (and subsequently re-named Station 8_2011). Due to channel morphology and depositional changes within the reach where the standpipe housing was located, the station was re-located approximately 4 m around the side of the mid-channel rock feature, in an area with higher velocity and main flow conditions. Due to the close proximity of these stations (4 m between Station 8_2008 and Station 8_2011) and in an effort to provide consistent and continuous data, data from Station 8_2008 and Station 8_2011 was utilized together (as one station) by applying a correction factor to each station of known elevation. However, data prior to October 28, 2010 may have been compromised due to sediment compression on the data logger sensors.

Stage-discharge measurements were collected near the WSC Jordan River historic gauge station and index Station 8 in 2010, 2011 and 2012. The transect location is approximately 50 m downstream from Station 8 and WSC's historic gauging station (see Appendix A, Table A-2 for UTM coordinates). Stream discharge measurements and appropriate site (transect) selection were conducted as outlined in Golder 1997. Measurements were taken at 60% of the total depth, using a wading rod and a Marsh McBirney Flo-mate™ portable velocity flow meter.

To estimate Jordan River Inflows to the MCR, a correlation based on a ranked regression analysis of concurrent flow data (26 years of data spanning 1963 to 1988) from the Illecillewaet River at Greeley (WSC Station 08ND013) and Jordan River above Kirkup Creek (WSC station 08ND014) was developed. The resulting relationship was used to correlate measured water level data with the estimated flow data at the Jordan River above Kirkup Creek station in 2011. The resulting hydrograph was compared to measured flow data on the Jordan River and found to be consistent.

3.0 HYDRAULIC MODEL CALIBRATION AND APPLICATION

A hydraulic model was required to describe the hydraulics of the MCR within the study area, by calibrating the model parameters using the monitoring data obtained during this study. The HEC-RAS one-dimensional (1d) backwater hydraulic model, developed by the U.S. Army Corps of Engineers, performs both steady and unsteady state flow analyses in river systems.

A HEC-RAS model of the MCR was developed by Korman et al. (2002) using a variety of cross-section information sources; however, the model was not calibrated at that time (Korman et al. 2002). In 2007, Golder retained Klohn Crippen Berger Ltd. (Klohn) as sub-consultants, primarily to assist with the calibration of the existing model based on river stage data collected by Golder between 2007 and 2009 (Golder 2010, Appendix 3). Further model calibration was completed using 2010, 2011 and 2012 (Golder 2012, Appendix B). Rick Rodman, of Rodman Hydrotechnical Ltd., was sub-contracted as project advisor, due to his direct experience with the MCR Physical Habitat Monitoring Program from 2007 to 2009 and involvement in the hydraulic modelling conducted for the Environmental Assessment (EA) processes for REV 5 and Mica 5/6. This section summarizes CLBMON-15a HEC-RAS Model calibration and application as presented in Appendix B.

3.1.1 CLBMON-15a HEC-RAS Model Methodology

The original MCR HEC-RAS model was constructed using 243 cross-sections to characterize the channel bathymetry from REV to below the confluence with the Akolkolex River, approximately 37 km downstream of the dam (Korman et. al. 2002). For the area from REV to the City of Revelstoke, 76 cross-sections were surveyed by R.L. &L. as part of the Revelstoke tailrace elevation study in the early 1990s (R.L.&L 1994). On average, there is a cross-section every 150 metres along the river channel. A Digital Elevation Model (DEM) was used to develop channel cross-sections downstream of Revelstoke. The DEM was generated by combining elevation points obtained from the year 2000 aerial photographs and coarser elevation data (provided by the Canadian

Hydrographic Surface) for elevations below the water surface at the time the aerial photographs were taken (Korman et. al. 2002). A new DEM was generated from the combined data set from which 169 cross-sections were taken. In addition, cross-section geometries from cross-sections 200 to 158 were updated using Acoustic Doppler Current Profiler (ADCP) data obtained from the CLBMON-20 and 54 projects entitled “Mid-Columbia River White Sturgeon Spawning Habitat Assessment” and “Effects of Flow Changes on Incubation and Early Rearing Habitat. Table 1 summarizes the data sources available for the calibration and application of the CLBMON-15a HEC-RAS Model.

Table 1: Summary of the cross-section geometry data sources used for the CLBMON-15a HEC-RAS hydraulic model of the mid-Columbia River (Appendix B, Figure 1).

Data Source	Data Type	Collection Year	Model Location (cross-sections)	Comments
REV tailrace study	Bathymetry	1990’s	243 to 167	Used to create upper reach cross-sections
BC Hydro	Bathymetry	2002	243 to175	Used in conjunction with existing cross sections for the upper reach
Source unknown[1]	Aerial photographs	2000	166 to1	Used in conjunction with flood plain mapping for the lower reach
Ministry of Environment	Floodplain mapping	1983	166 to1	Used in conjunction with aerial photography for the lower reach
BC Hydro[2]	DEM	N/A	243 to1	Used to extended model cross-section
Golder[3]	ADCP	2010-Ongoing	200 to 158	Model cross-sections updated
Tailrace excavation	N/A	N/A	N/A	Tailrace excavation occurred in 2003, causing changes to channel morphology

[1] The original source of the aerial photographs is unknown; the data were likely sourced from either the Provincial Air photo library or UBC air photo library.
[2] DEM provided by BC Hydro to Klohn Crippen Berger Ltd., Golder does not know year of data collection.
[3]Data obtained from the CLBMON-20 and 54: “Mid-Columbia River White Sturgeon Spawning Habitat Assessment” and “Effects of Flow Changes on Incubation and Early Rearing Habitat.”
N/A indicates not available

3.1.1.1 Tributary Inflows

The MCR has three main tributaries to the MCR within the study area: the Illecillewaet, Jordan and Akolkolex rivers. The Jordan River confluence with the MCR is located at the downstream end of Reach 4, the Illecillewaet River confluence with the MCR is located the downstream end of Reach 3 and the Akolkolex River confluence with the MCR is located at the downstream end of the study area (Rkm 203.5).

Golder’s Stations 8_2008 and 8_2011 (Station 8) were installed on the Jordan River for the purpose of collecting stream discharge data for this monitoring program. Data collected at this station have been used to develop a relationship with flows from the Illecillewaet River, used in the calibration and application of the CLBMON-15a HEC-RAS Model. Station 8 is located near the historic WSC stream gauging site on Jordan River (WSC Station 08ND014). The WSC station was active from 1963 to 1988. WSC does not have the correction factor to convert the rating curve for WSC’s Station 08ND014 to the Geodetic datum, and Golder has not yet obtained enough flow measurements to generate a reliable stage-discharge relationship for the station. WSC operated a stream gauging station on the Akolkolex River (Station 08ND001), which ceased operation in 1954.

The estimated inflows for the Jordan and Akolkolex rivers used in the CLBMON-15a HEC-RAS Model were based on the correlation with the Illecillewaet River from overlapping data periods as described in Appendix B. Once the Jordan River stage-discharge curve is finalized the estimated inflows will be used.

A constant inflow was used for the three small creeks (Begbie, Drimmie, and Mulvehill) that enter the MCR throughout the model. The seasonal variation of these inflows is not anticipated to be significant enough to effect modeling results.

3.1.2 CLBMON-15a HEC-RAS Model Review

HEC-RAS is commonly used to predict the effects of discharge on wetted width, depth, and average velocity at individual river cross-sections. Using 2010, 2011 and 2012 data to build upon the previous calibrations performed by Klohn and Golder, the following was completed for this report:

- calibration of existing CLBMON-15a HEC-RAS Model;
- estimation of tributary inflows; and,
- HEC-RAS model steady runs to provide predicted river hydraulic parameters.

The measured water elevations from Station 1 were consistently out of the expected range of water elevations. Therefore, for the purposes of this year's model calibration, the data from Station 1 were not used. Station 1_AS (anchor station deployed in the deepest part of the channel located proximate to Station 1) was used during the 2011 and 2012 calibration.

The MCR hydraulic model has been calibrated for steady state and unsteady state analysis. The steady flow model results have water elevations within 0.22 m of measured values, while the unsteady flow model results are within 1.08 m. Results replicate the timing and height of peaks in the highly variable flow regime. This is a refinement from the 2010 and 2011 calibration, which steady state results average within 0.01 m of measured levels and unsteady state results average within with 0.04 m of measured levels.

3.2 Discharge and Water Stage Monitoring Results

3.2.1 Pre-Implementation REV 5 Revelstoke Dam Operations

Prior to commissioning REV 5, daily flow releases fluctuated from approximately 8.5 m^3s^{-1} (seepage flows from the dam during zero generation) to approximately 1750 m^3s^{-1} (i.e., with 4 generating units). For the four years of pre-implementation monitoring (2007 to 2010), load factoring and peaking operations at Revelstoke Generating Station resulted in patterns of discharge that varied on a daily, seasonal, and annual basis (Figure 3). Flow releases generally increased through daylight hours and peaked in early evening with releases up to approximately 1750 m^3s^{-1}. During the night, generation was typically reduced due to lower electricity demand,and REV discharge frequently decreased to zero flow.

During 2009 and 2010, the consistent flows of approximately 300 m^3s^{-1} were likely caused by high water levels which created a need to release water during periods of non-peak hours. Revelstoke Dam never discharged water over the spillways between 2007 and 2010.

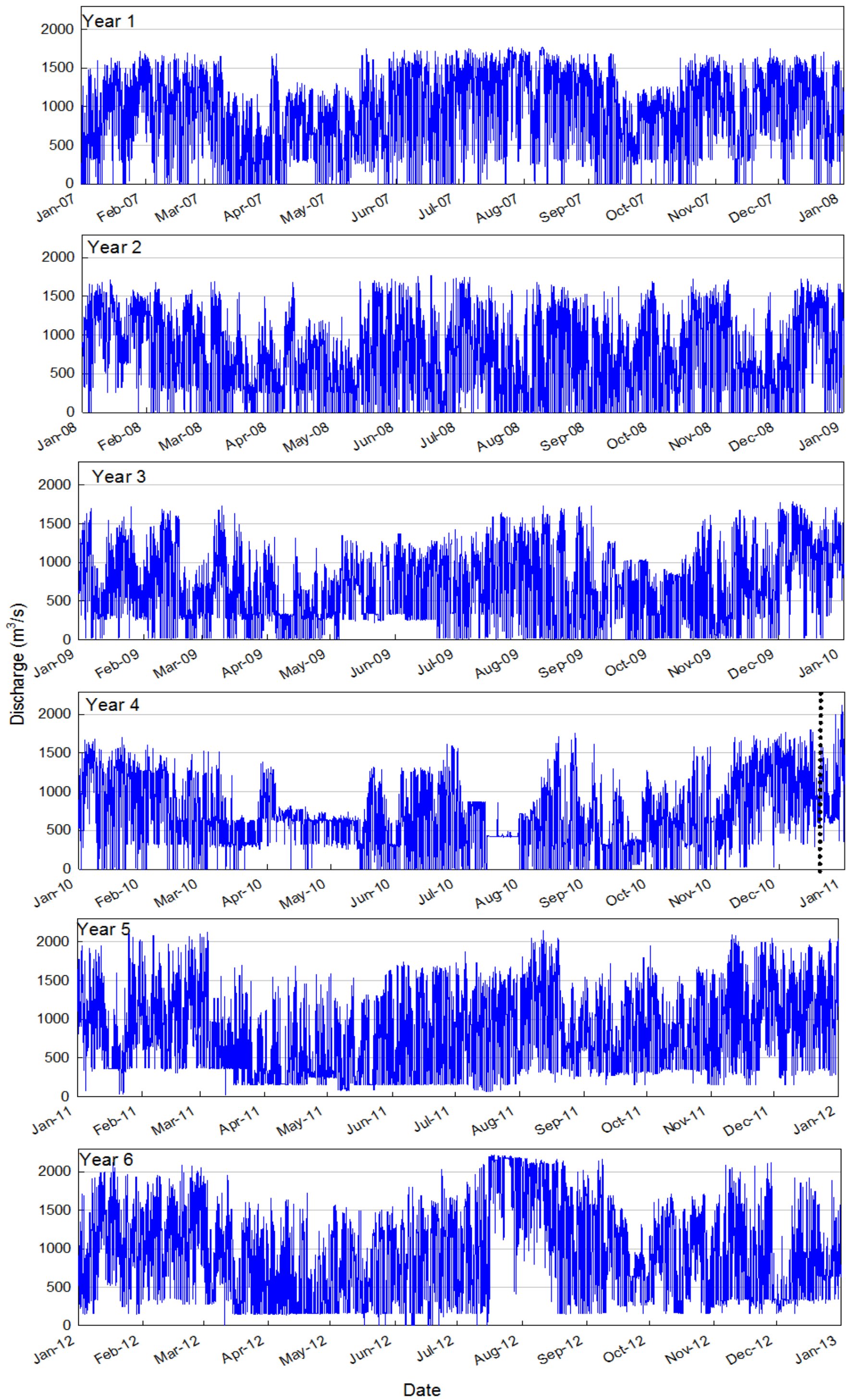


Figure 3: Revelstoke Generating Station hourly discharge for pre-implementation (Years 1-4) of the 142 m^3s^{-1} minimum flow regime and post-implementation the 142 m^3s^{-1} minimum flow regime. Black dotted line separates the pre-implementation and post-implementation data at the end of the 2010 graph.

3.2.2 Post-Implementation REV 5 Revelstoke Dam Operations

Following the addition of a fifth unit and subsequent implementation of minimum flow on December 20, 2010, daily flow variation changed from a minimum of 8.5 m^3s^{-1} to approximately 142 m^3s^{-1} and increased from a maximum of 1750 m^3s^{-1} up to 2124 m^3s^-1. For the two years post-implementation (2011 and 2012), load factoring and peaking operations resulted in similar general patterns of discharge to pre-implementation, that varied on a daily, seasonal, and annual basis (Figure 3).. Flow releases generally increased through daylight hours and peaked in early evening, with releases up to approximately 2224 m^3s^{-1}. During the night, generation was typically reduced due to lower electricity demand, and REV discharge frequently decreased close to prescribed minimum flows (142 m^3s^{-1}). REV discharged water over the spillways during the spring and summer 2012, starting in late May and continuing through the end of July.

3.2.3 Tributary Inflows

Based on current model runs from 2012 (see Appendix B for Hydraulic Model Calibration and Application), the influences of the Jordan, Illecillewaet, and Akolkolex rivers will have a considerable impact on water levels and flows during periods of high tributary inflows and low REV discharges. However, they will have no impact on river water levels during periods when the reservoir-river interface reaches upstream of the three tributaries. The reservoir-river interface reaches the Akolkolex River in periods of low reservoir levels (423.8 masl and above); ALR elevation is typically at or above this level for most of the year. The reservoir-river interface reaches the Illecillewaet River at moderate-high reservoir levels (432.2 masl and above), usually from May to January. The reservoir-river interface reaches the Jordan River in periods of high elevated reservoir levels (434.0 masl and above), usually from June to December.

3.2.4 Arrow Lakes Reservoir Elevations

ALR levels fluctuate over the course of a year and this can affect water levels within the MCR. The ALR water levels are generally high from the start of July with a general decreasing trend until May (Figure 4). The reservoir elevations post-implementation of the 142 m^3s^{-1} flow regime implementation tracked similar to the pre-implementation of the 142 m^3s^{-1} flow regime years (Figure 4).

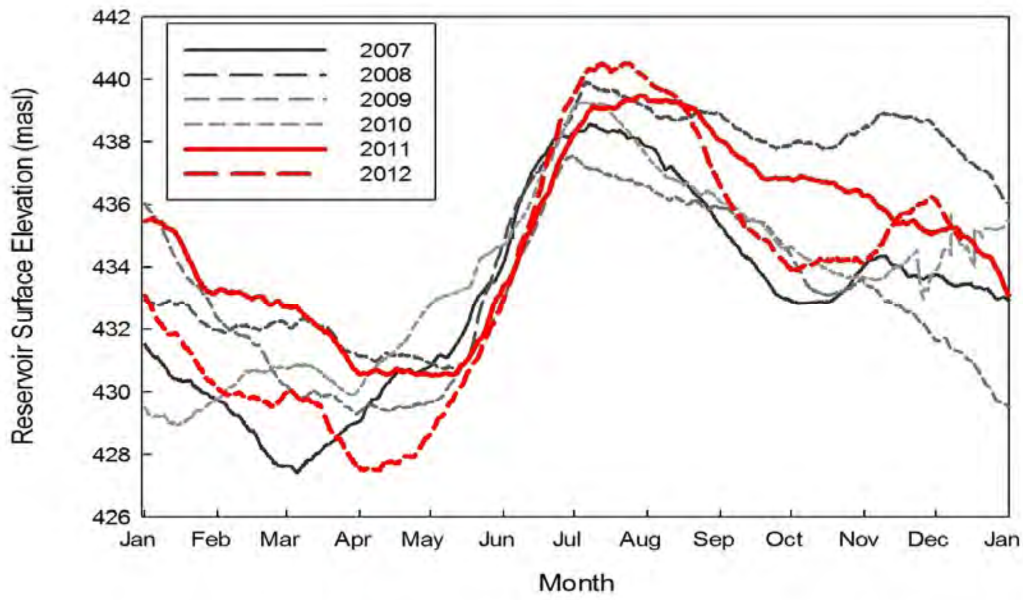


Figure 4: Arrow Lakes Reservoir elevation at Nakusp, BC for 2007, 2008, 2009, and 2010 (pre-implementation of 142 m^3s^{-1} flow regime) and 2011 and 2012 (post-implementation of 142 m^3s^{-1} flow regime). Units are in metres above sea level. Data supplied by BCH. Data collection period from January 1 2007 to December 31 2012.

As the reservoir level increases, the reservoir-river interface zone moves further upstream from Arrowhead toward REV. This interface zone is usually in close proximity to the City of Revelstoke during summer high water (June to September), and then moves downstream close to Arrowhead during periods of low pool, typically in late winter.

The range and variability in river level fluctuations in the MCR are influenced by ALR elevations. When ALR elevations are at or above the values given in Table 2, the reservoir influences the water levels at the CLBMON-15a index stations. These reservoir elevations were generated from modeled water elevations based on the steady state model using ALR levels as the downstream boundary condition.

Table 2: Arrow Lakes Reservoir (ALR) elevation in meters above sea level (masl) at which CLBMON-15a stations are influenced by the reservoir.

CLBMON-15a Index Station	ALR Level (masl)[1]
Station 1_AS	436.4
Station 2_AS	435.9
Jordan River	434.6
Station 3	434.2
Station 4	433.1
Station 5	429.9
Station 6_2008	429.2
Akolkolex River	424.0

[1]This information was obtained through the 2012 CLBMON-15a HEC-RAS Model run (and is subject to change), as it will improve each monitoring year with additional data.

3.3 MCR Water Level Discussion

3.3.1 Related Management Question(s), Hypotheses, and Sub-hypotheses

The key management question of the MCR Physical Habitat Monitoring Program associated with stage monitoring is:

- ***Management Question # 3:*** How does the implementation of the 142 m^3s^{-1} minimum flow affect the range and variability in river level fluctuation in the MCR? Are there temporal (seasonal scale) or spatial (reach scale) differences in the pattern of response?

The hypotheses and related sub-hypotheses[1] are:

- Ho_3: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly change the magnitude (i.e., range and variability) of river level fluctuations in the MCR.
  - Ho_{3A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not alter the diel variation of river levels in MCR; and,
  - Ho_{3B}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not alter the seasonal pattern of mean river level fluctuations in the MCR.

Data from Years 1 to 4 have been grouped as representing the pre-implementation phase prior to the start-up of REV 5. Baseline data collected in Years 1 to 4 (prior to REV 5 and minimum flow initiation) was compared to future conditions produced by REV 5 [Years 4 (after REV 5 and minimum flow initiation), 5 and 6]. The post-implementation phase studied the effect of these operational changes and the resulting 142 m^3s^{-1} minimum flow on physical habitat parameters. For a list of data availability (stage, temperature and discharge) for Years 1–6 (2007-2012), refer to Appendix A, Table A-4.

3.3.2 MCR River Levels: Diel Variation Discussion

Hourly stage data were collected for each of the MCR monitoring stations during the pre-implementation phase (Year 1, 2, 3 and 4). Hourly stage data were also collected for each of the MCR monitoring stations during the post-implementation phase (Year 5 and 6) with the exception of the Standpipe *Stations* 1 and 2, which were omitted from the stage data set. Standpipe *Stations* 1 and 2 did not provide consistent measurements because of their location and position on the slope (angle of 23 degrees at Station 1) or position on vertical rock face (Station 2) (Golder 2011). Two anchor stations (1_AS and 2_AS) were installed in Reach 4 in 2010. With their close proximity (3.8 m to Station 1 standpipe and 10 m to Station 2 standpipe respectively) to the anchor stations the data was duplicated. Station 1_AS and 2_AS provided more complete and consistent data sets and was therefore used instead of Stations 1 and 2 in the HEC-RAS model.

Diel variation decreased with distance downstream of REV, with the greatest variation at Stations 1/1_AS and 2 (Table 3). Diel variation was significantly greater post-implementation of 142 m^3s^{-1} minimum flows than pre-implementation at Stations 1/1_AS, 5 and 6 but not different at Stations 2 and 4. Although Station 1/1_AS had

[1] The original hypothesis developed during the WUP was the effects of minimum flows on fish habitat. Modelling and data collection will also provide information to assess the influence of the increase in maximum discharge from Revelstoke Dam by the operation of an additional unit.

significantly greater variations in water levels post-implementation, this comparison used the combined data set from Stations 1 (2007 to 2010) and 1_AS (2011 to 2012). Stations 1 and 1_AS were intended to be located close enough to be comparable but likely differed somewhat in measurement of water level. Therefore, the significant difference in water level variation at Station 1/1_AS pre and post implementation of 142 m^3s^{-1} minimum flows should be interpreted with caution as the changing location of the station could have influenced these results.

Stations 5 and 6 were located closest to ALR and were most influenced by reservoir levels. At times of year when the reservoir was high, the diel variation caused by fluctuating dam discharges was attenuated by the backwatering effects of the reservoir. Significant differences in diel variation pre and post implementation of 142 m^3s^{-1} minimum flows at Stations 5 and 6 could be related to the change in dam operations, or because of natural differences in reservoir levels that influenced water level variability at these stations. The latter seems more likely because diel variation was not significantly different pre and post implementation 142 m^3s^{-1} minimum flows at Stations further upstream (i.e., Stations 2 and 4) where the impact of minimum flows would be expected to be greater.

Table 3: Diel water level variation (m) in the middle Columbia River (2007-2012) and Student's t-test results comparing pre and post-implementation of 142 m^3s^{-1} minimum flows at Revelstoke Dam.

Station	Distance from Revelstoke Dam (km)	Pre-implementation			Post-implementation			Difference in mean water level variation	Student's t-test	
		Mean	SD	*n*	Mean	SD	*n*		t	P-value
Station 1/1_AS	1	2.40	0.9	1102	2.99	0.8	546	0.59	-13.2	<0.0001
Station 2	4	2.22	1.0	1041	2.28	0.8	674	0.06	-1.5	0.1
Station 4	11	1.14	0.8	1252	1.09	0.6	674	-0.05	1.4	0.2
Station 5	16	0.62	0.6	1169	0.86	0.7	674	0.24	-8.0	<0.001
Station 6	19	0.47	0.5	736	0.59	0.6	674	0.12	-3.9	<0.0001

Although Student's t-tests indicated significantly greater diel water level variation post-implementation of 142 m^3s^{-1} minimum flows compared to pre-implementation of 142 m^3s^{-1} minimum flows at some locations, changing station locations and the effects of year-to-year variation in reservoir elevation could have contributed to these differences. On the other hand, the implementation of minimum flows coincided with the start of REV5 operations, which increased the range of possible discharges from 0-1700 m^3s^{-1} to 142-2124 m^3s^{-1}. Thus, a larger diel variation post-implementation of minimum flows compared to before is plausible because of the larger possible variation in dam discharges. The difference in diel variation in water level between pre and post-implementation was 0.59 m at Station 1/1_AS and 0.24 and 0.12 m at stations 5 and 6, respectively. The observed differences in water level, at least at the most upstream Station 1/1_AS, are large enough that an effect on aquatic productivity is possible. The results presented here suggest that diel variation may be greater since the implementation of minimum flows but the limited data set (i.e., 2 years) following the change in operations, and potential confounding variables discussed above, limit the strength of conclusions at this point. Additional years of data collection and analyses that also account for the potential influence of reservoir levels are recommended.

3.3.3 MCR River Levels: Seasonal Variation Discussion

At Stations 1 and 2 in Reach 4 near REV, there was no clear seasonal pattern in diel water level variation, with similar values throughout the year (Appendix C, Figure C1). However, at Stations 4, 5 and 6, there were seasonal differences in diel water level variation, with much lower variation at certain times of the year, typically between June and September (Appendix C, Figure C1). Reduced diel water level variation was likely caused by high ALR levels, which moderated the impact of fluctuating dam discharges on water levels. However, the trend was not consistent among years with some years with shorter time periods of reduced water level variability, likely due to a combination of weather, environmental conditions, and dam operations. Although not analyzed in detail, the data do not indicate a significant impact of the implementation of 142 m^3s^{-1} minimum flow on the seasonal pattern of river level fluctuations (Ho_{3B}).

3.3.4 MCR Wetted Area Calculations

The key management question of the MCR Physical Habitat Monitoring Program associated with stage monitoring is:

- ***Management Question # 5:*** How does the implementation of the 142 m^3s^{-1} minimum flow release from Revelstoke Dam affect the total area of river channel that is permanently wetted?

The hypotheses and related sub-hypotheses[2] are:

- Ho_4: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly increase the area of river channel that is continuously inundated in the MCR.
  - Ho_{4A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam does not increase the minimum total wetted channel area in MCR.

One of the key hypotheses behind the minimum flow concept is that maintaining a permanently wetted portion of the channel downstream of REV will result in the establishment of a benthic community in the new wetted usable area, with possible benefits to fishes (Perrin et al. 2004). The development of benthic communities in the expanded permanently wetted habitat may increase overall productivity and diversity of the MCR, even if there is no change over time in areal biomass, density, diversity or other metric in the deep strata of the MCR that was previously permanently wetted (Perrin et al. 2004).

After calibrating the CLBMON-15 HEC-RAS Model in 2012, the area of permanently inundated channel was estimated using the steady state HEC-RAS model. The model was run with two minimum flows; seepage (8.5 m^3s^{-1}) and the minimum flow release (142 m^3s^{-1}) with a normal depth downstream boundary condition. This represents a time when no backwater effects occur and the permanently inundated area will be at a minimum. This condition typically occurs throughout Reaches 2 to 4 (February to April). The estimate from the 2012 CLBMON-15a HEC-RAS calibrated model results show that minimum flows would increase permanently wetted riverbed by 32% compared to pre-implementation of minimum flows, when ALR is below 425 m (Appendix B).

---

[2] The original hypothesis developed during the WUP was the effects of minimum flows on fish habitat. Modelling and data collection will also provide information to assess the influence of the increase in maximum discharge from Revelstoke Dam by the operation of an additional unit.

As the ALR water level increases, the reservoir-river interface zone moves further upstream from Arrowhead toward REV. Channel bed downstream of the reservoir-river interface zone is unaffected by implementation of the 142 m^3s^{-1} minimum flow release from REV. This interface zone is usually in close proximity to the City of Revelstoke during summer high water (June to September), when Reaches 1, 2, and 3 are permanently inundated by water levels within the ALR. The resulting estimated change of permanently inundated riverbed area for Reach 4 is 242,850 m^3.

3.4 Temperature Monitoring Results and Discussion

The key management question of the MCR Physical Habitat Monitoring Program associated with water temperature monitoring is:

- ***Management Question #1:*** How does the implementation of the 142 m^3s^{-1} minimum flow affect water temperature in the flowing reach of the MCR? What is the temporal scale (diel, seasonal) of water temperature changes? Are there spatial differences in the pattern of water temperature response?

The hypotheses and related sub-hypotheses are:

- Ho_1: Implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter the **water temperature** regime of the MCR.
  - Ho_{1A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam does not significantly change the diel variation of water temperature of the MCR; and,
  - Ho_{1B}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter the seasonal pattern of mean water temperature of the MCR.

For the purposes of the Physical Habitat Monitoring Program, water temperature was monitored beginning in July 2007 and is ongoing. For the purposes of this report the final seasonal download is used as an end date (October 2012). Temperature was monitored in the mainstem MCR and the Jordan and Illecillewaet rivers during pre and post-implementation of the 142 m^3s^{-1} minimum flow regime. For a list of temperature data availability for Years 1-6 (2007-2012), refer to Appendix A, Table A-4.

3.4.1 Temperature Variation: Temporal

3.4.1.1 General Trends

Because of the hypolimnetic discharge of water from REV, the water temperature of the MCR below the dam is colder during spring and summer, and warmer during fall and winter, when compared to water temperatures during the natural hydrograph prior to hydroelectric development (R.L.&L 2001). MCR maximum temperatures over 12 °C are uncommon and generally not reached until late summer. Water temperatures during winter generally range between 2 and 4 °C (R.L.&L 2001).

During summer months (June through August), diel fluctuations in water temperatures on the MCR study reaches were generally larger than in other seasons. These periods of greatest diel variation were associated with high discharges from REV (Figure D1; Golder 2010, 2011). Larger temperature fluctuations during the summer may be related to dam operations, meteorological factors influencing temperature of discharges from REV reservoir, tributary temperatures (Jordan and Illecillewaet rivers), and the influence of ALR levels. The greatest range in water temperatures occurred slightly earlier in Year 6 compared to previous years (May to June instead of June through August). However, the general pattern of diel variation in water temperature that was observed during the summer of pre-implementation monitoring years (2007-2010) also occurred during the post-implementation monitoring years at all the MCR stations.

The Jordan and Illecillewaet rivers (Stations 7 and 8) showed more temperature variability than the MCR index stations. High variability in these tributaries likely contributed to greater temperature variation at Stations 3 through 6 than at Station 1 and 2 on the MCR (Figure D1). .

In previous years of the study, temperatures measured at Station 3 were greater than 1 °C different from other monitoring stations, which was thought to be related to an un-calibrated or malfunctioning temperature sensor. However, this difference was also observed in 2012, after a replacement sensor was installed. Because of this discrepancy, temperature data from Station 3 were not used in analyses comparing pre and post-implementation of minimum flow release. Further investigation of water temperature near Station 3 and of the calibration procedures used for this station is warranted, but is beyond the scope of this study.

3.4.1.2 Effect of the Implementation of 142 m^3s^{-1} Minimum Flows

Linear models were used to assess the effects of the implementation of a 142 m^3s^{-1} flow release from REV on water temperatures in the flowing reach of the MCR. The results indicated that diel temperature range was significantly greater pre-implementation of minimum flows than post-implementation at all stations except for Station 6, which was the furthest downstream of REV. Models comparing mean water temperature when discharges were above or below minimum flows did not suggest a significant effect of minimum flows for most stations and years. Detailed results and interpretation of these models are provided in the following paragraphs.

In the model that used diel temperature range as the response variable, the categorical variable representing minimum flows (pre or post-implementation) was significant in the models for Station 1/1_AS, 2, 4, and 5 but not for Station 6, after accounting for seasonal variation, first order temporal autocorrelation and the influence of discharge (Table 4). This suggests that the diel temperature range was significantly different pre-implementation versus post-implementation of minimum flows. The positive value of the minimum flow coefficient, which represents the intercept adjustment for pre-implementation of minimum flow in the model, suggested that the diel range of temperatures was greater pre-implementation of minimal flow than post-implementation of minimal flow, for all stations assessed except for Station 6. Based on the plots of diel temperature range (Appendix D, Figure D2), it appeared that differences pre and post-implementation of minimum flows were mostly related to higher diel ranges in 2008 and 2009, whereas ranges were more similar to post-implementation of minimum flow ranges in 2010. Discharge was a significant covariate predicting diel temperature range at downstream stations (Stations 4, 5 and 6) but not at the stations closer to REV (Stations 1/1_AS and 2), but the reasons for this difference are not clear.

Table 4: Coefficients, standard error (SE), and p-values for generalized least squares linear models of daily temperature range at monitoring stations in the middle Columbia River, 2008-2012.

Variable	Coefficient	Standard Error	P-Value
Station 1 (1_AS)			
Intercept	0.48	0.06	<0.001
MinFlow (Pre and post-implementation)	0.25	0.08	0.001
Discharge (1000*m³/s)	-0.03	0.07	0.7
Sin	-0.33	0.02	<0.001
Cos	-0.36	0.02	<0.001
MinFlow:Discharge	-0.15	0.09	0.09
Station 2			
Intercept	0.43	0.04	<0.001
MinFlow (Pre and post-implementation)	0.14	0.06	0.02
Discharge (1000*m³/s)	-0.02	0.04	0.70
Sin	-0.22	0.02	<0.001
Cos	-0.39	0.02	<0.001
MinFlow:Discharge	-0.06	0.06	0.4
Station 4			
Intercept	0.81	0.07	<0.001
MinFlow (Pre and post-implementation)	0.38	0.09	<0.001
Discharge (1000*m³/s)	-0.29	0.06	<0.001
Sin	-0.28	0.03	<0.001
Cos	-0.34	0.03	<0.001
MinFlow:Discharge	-0.21	0.09	0.02
Station 5			
Intercept	0.90	0.06	<0.001
MinFlow (Pre and post-implementation)	0.25	0.08	0.001
Discharge (1000*m³/s)	-0.33	0.06	<0.001
Sin	-0.20	0.03	<0.001
Cos	-0.38	0.03	<0.001
MinFlow:Discharge	-0.09	0.08	0.3
Station 6			
Intercept	0.92	0.05	<0.001
MinFlow (Pre and post-implementation)	0.05	0.07	0.4
Discharge (1000*m³/s)	-0.30	0.05	<0.001
Sin	-0.11	0.02	<0.001
Cos	-0.39	0.02	<0.001
MinFlow:Discharge	0.08	0.07	0.2

Because there were only 3 complete years of temperature data pre-implementation of minimum flows (2008-2010) and 2 years post-implementation of minimal flows (2011-2012), it is possible that these temperature differences could be related to factors other than dam operations, such as weather or other unmeasured variables (e.g. reservoir stratification and temperatures). If the differences in water temperature suggested by the model are actually due to minimum flows causing less variation in daily water temperature, then at very low flows (0 to 142 m^3s^{-1}), water temperatures may be more influenced by air temperature and weather, whereas at higher flows, water temperatures in the MCR may be driven primarily by reservoir hypolimnion temperature and are less prone to fluctuations. Although the model suggested a statistically significant effect of minimum flows on diel water temperature range, it does not necessarily mean that the difference is biologically significant (Johnson 1999). For Station 2 in the MCR, the intercept of the model was a diel variation of 0.4 °C and the effect of minimum flow (intercept adjustment for pre-implementation of minimum flows) was a change in diel variation of 0.1 °C, given the other variables in the model (Table 4). For Station 4 in the MCR, the intercept of the model was 0.8 °C and the effect of minimum flow (i.e., the intercept adjustment for pre-implementation of minimum flows) was 0.4 °C. Whether or not changes in temperature variation of this magnitude are biologically important and whether it will influence productivity and living organisms in the MCR remains unknown and is being studied as part of other monitoring programs of the WUP.

A second set of linear models was used to assess the effect of minimum flow on hourly water temperature. These models compared hourly water temperature when discharge was below minimum flow (0 to 142 m^3s^{-1}), versus above minimum flows (>142 m^3s^{-1}), while accounting for the effect of total discharge and temporal autocorrelation. These models assessed the effect of minimum flows during July or August, which were selected as time periods when there were adequate measurements of water temperatures above and below minimum flow for comparison. In seven of the eleven models (each for a different Station and Year), discharge was a significant variable ($p<0.05$) but MinFlow and the MinFlow:Discharge interaction were not (Appendix D, Table D-1). This suggested that mean hourly water temperatures were not significantly different below minimum flows versus above minimum flows, after accounting for the effect of river discharge.

It is not clear why MinFlow was significant but discharge was not in a few of the models (e.g., Station 4 in July 2008 and Station 5 in August 2010), as the general pattern of temperature and discharge looked similar to other years and stations. The very large standard errors for the intercept term (Appendix D, Table D-1) likely reflected the high degree of autocorrelation among hourly temperatures and the large spread in water temperatures across values of discharge. Overall, the hourly model had poor ability to predict water temperatures in the MCR based on MinFlow and discharge, likely because of the large variation in discharge and temperatures and possibly because other important variables that drive water temperature were not measured or included in the model (e.g., reservoir temperatures and weather; see below).

The hourly temperature models were intended to assess the influence of the change of operations due to minimum flows on water temperature at a fine temporal scale. Prior to minimum flow implementation and during the time of year when minimum flows were more common (i.e., summer), minimum flows did not have a significant effect on water temperature based on these models. In winter, discharge was infrequently below 142 m^3s^{-1}, even prior to the minimum flow regulation, so the change in operations is less likely to have a large effect on water temperature. Therefore, this analysis of the data available to date does not support the idea that minimum flows affect the seasonal pattern of mean water temperature and management hypothesis Ho_{1A} cannot be rejected.

The CLBMON-15a monitoring program was intended to provide continuous monitoring data of physical habitat variables before and after minimum flow implementation to assess the effects of the change in operations. One of the limitations of the dataset for addressing the management hypotheses was that there were large data gaps at some sites and imbalanced sample sizes pre and post-implementation of minimum flows. Some stations had data gaps due to malfunctioning or damaged loggers. With only 1-3 years pre and post-implementation of minimum flows, other factors such as climatic variability could confound interpretation of changes in water temperature. Another limitation of the analysis was that upstream reservoir water temperature and weather data were not available. A study of water temperature in the Columbia River downstream of the HLK found that upstream reservoir temperature-at-depth and wind data were important predictors of downstream water temperatures (Golder 2003). In that study, reservoir wind and temperature data were used as predictors in a regression model, along with dam discharge and other operational variables, to predict downstream water temperatures and assess the effects of operational changes. This analysis used a similar regression approach, which accounted for seasonal trends and temporal autocorrelation, but the models had poor fit and predictive ability, and this was possibly because potentially important predictors of water temperature like upstream reservoir temperatures and weather were not included as predictors. Water temperature-at-depth profiles were measured in Revelstoke Reservoir during part of the monitoring period for this study, but measurements were only made once or twice per month and continuous monitoring data that could be used for modelling downstream water temperature were not available (Pieters and Lawrence 2013).

3.4.2 Temperature Variation: Spatial

3.4.2.1 General Trends

To assess spatial variation in water temperature, data from Stations 1_AS, 2_AS, 4 and 6 were plotted and compared for each month (Appendix D, Figures D3-D7). Water temperature and discharge were also plotted over selected one week time periods to illustrate daily fluctuations and spatial variation in relation to REV discharge and ALR water levels. The general patterns observed and differences among sites were similar to previous years of the monitoring program (pre and post-implementation of minimum flows), with some expected differences because of inter-annual variation in discharge and weather (Golder 2008, 2009, 2010 and 2011).

Daily water temperature fluctuations at all MCR stations were similar, with minor temperature variations from Reach 4 (Stations 1_AS and 2_AS) to Reaches 3 and 2 (Stations 4 and 6) (Appendix D, Figure D2). Water temperature was slightly greater at Stations 4 and 6 compared to further upstream at Stations 1_AS and 2_AS, likely because of the influence of ALR (Appendix D, Figure D8). During the winter and spring, daily water temperature variation was also greater at the downstream stations (Stations 4 and 6) compared to further upstream (Station 1_AS and 2_AS) (Appendix D, Figure D8 top panel). Later in the spring and summer when REV discharge was greater, the spatial difference in water temperature between upstream and downstream sites was reduced (Appendix D, Figure D8 top panel). These general trends were consistent across the monitoring period pre and post-implementation of minimum flows.

Reaches 3 and 2 showed increased temperature variation (i.e., temperature range) in stations downstream of the Jordan and Illecillewaet rivers following spring freshet. Reaches 3 and 2 (Stations 3 to 6) follow the same general trend in daily temperature fluctuations (with decreased variation) as that of the Illecillewaet River, when compared with Reach 4 (Stations 1_AS and 2_AS), which is influenced by REV discharge only (Appendix D, Figure D1).

Downstream spatial variation on the MCR is impacted by both reservoir and dam influences, where Reach 4 (Stations 1_AS and 2_AS) was related to water temperatures from REV and Reach 2 (Station 6) was more influenced by ALR, once the reservoir was above 429.0 m (Figure 9). Station 4 temperatures (transition area between Reaches 2 and 3) are influenced by the reservoir (above 432.2 m), dam discharges (Figure 6 and Figure D1), and tributary effects. The reservoir dampens oscillations of temperatures observed in more riverine conditions (experienced from winter through to spring). This dampening of temperature oscillations is observed moving upstream as the reservoir-river interface zone moves further upstream (Figure 6). This difference and variation can be seen between March and May, compared with June (Figure D1).

Reach 4 (Stations 1_AS and 2_AS) temperature fluctuations lag behind changes in REV discharge. There was also a time lag between temperatures changes caused by REV discharge in Reach 4, compared to temperature changes further downstream (Figures D3-D7). The time lag also varied as a result of location of the reservoir-river interface zone and its influence on water movement rates. The reservoir backwater dampens oscillations of temperatures from riverine conditions, as the reservoir fills and these stations (Stations 4 and 6) start to measure reservoir conditions. Even between Stations 4 and 6, there is a temporal difference in water temperature fluctuations from June to October 2011 (Figures D3-D7). The time lag between Stations 4 and 6 was likely influenced by both reservoir conditions and downstream distance from the dam.

Vertical temperature profiles were not taken during this study. However, within the study area, there is unlikely to be variation of temperatures at depth because of turbulence and mixing in the MCR. Most rivers are well-mixed and have very little vertical temperature variation (Caissie 2006). Monitoring of temperature at depth is needed to confirm lack of thermal stratification in the MCR.

3.4.2.2 Effect of the Implementation of 142 m^3s^{-1} Minimum Flows

The effect of minimum flow implementation on the spatial variation in water temperature was assessed by comparing the linear models for each of the stations. The variable representing pre and post-implementation of minimum flows was significant in the model predicting daily temperature range at Station 1 (1_AS), 2, 4, and 5, but not at Station 6, which was the furthest downstream. This suggests that the effect of minimum flows on daily temperature range may be more pronounced in reaches closer to the dam and less pronounced further downstream, which could be related to the moderating effect of ALR and tributary influences. Models of hourly water temperature had poor fit and predictive ability but, overall, did not indicate a significant effect of minimum flows at most sites, which did not provide support for spatial differences in the effect of minimum flows. With only two years of data collection following the implementation of minimum flows, conclusions based on these results are tentative and additional years of monitoring are required to assess the effect of minimum flows.

4.0 TOTAL GAS PRESSURE MONITORING

During Year 1 and 2 of the study Total Gas Pressure (TGP) levels were measured at 3 sites in Reaches 3 and 4. This data was presented in the annual summary reports for Year 1 (Golder 2008) and for Year 2 (Golder 2009). Seasonal TGP sampling was not scheduled to be conducted during Year 3 and 4. Although TGP sampling was proposed for Year 5 to capture the range of operations associated with REV 5, synchronous condense operations were never achieved that year. Year 6 TGP sampling was conducted during spill conditions, therefore not directly comparable to the Year 1 and 2 data (Golder 2012a).

4.1 Total Gas Pressure Sampling Methodology

4.1.1 Total Gas Pressure Sampling Stations

During Year 1 and 2 of the study Total Gas Pressure (TGP) levels were measured at 3 sites in Reaches 3 and 4 of the middle Columbia River. (Appendix E, Table E-1):

- The Upper site was located approximately 1.4 km downstream of Revelstoke Dam.
- The Middle site was located adjacent to the Revelstoke Golf and Country Club, as per Ramsay and Associates (2004).
- The Lower site was located downstream of the confluence of the Jordan River.

4.1.2 Total Gas Pressure Sampling Methods

Point4TM Tracker TGP meters were deployed at the sites below the compensation depth (approximately 3 m) for the expected high concentration of TGP (130%). The probes were enclosed in protective wire caging with a float attached to keep the cage suspended off the bottom. This assembly was weighted down to ensure the probe maintained a constant position in the river over a variety of water levels. The data cables were attached together and connected to the handheld tracker meter. On shore, the meters were placed in a plastic container to protect the equipment from the elements, and anchored in sheltered locations along the shoreline, above the high water mark. The meters were set to record every 10 minutes. The recording start and end date and time were recorded by the field crew. UTM coordinates were recorded at each site using the Garmin Global Positioning System (GPS) 12 handheld unit. Following the 24-hour monitoring period, the TGP meters and probes were retrieved from each site. The logger was stopped and the data were downloaded to a laptop computer and values were checked to ensure the data had been downloaded correctly.

4.2 Total Gas Pressure Results and Discussion

4.2.1 Related Management Question(s), Hypotheses, and Sub-hypotheses

The key management question of the MCR Physical Habitat Monitoring Program associated with the Total Gas Pressure (TGP) is:

- ***Management Question # 2:*** How does the implementation of the 142 m^3s^{-1} minimum flow affect total gas pressure (TGP) in the flowing reach of the MCR?

The hypotheses and related sub-hypotheses[3] are:

- Ho_2: Implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter TGP levels in the flowing reach of the MCR.
  - Ho_{2A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter TGP levels.

TGP monitoring was to be conducted for a single continuous 24-hour period at three different seasonal periods (summer, fall and winter) during the study program. During the 4 years pre-implementation of 142 m^3s^{-1} minimum flow, TGP monitoring was only conducted in the first 2 years. In 2007, TGP level monitoring during synchronized condensed operations mode of three of the four units was conducted during the winter session on November 15 and 16 for a single 24-continous period. All three sites were monitored during the winter 2007 session. In 2008, TGP level monitoring during synchronized condensed operations mode of three of the four units was conducted on April 10 and 11 for a single 24-hour continuous period. Only two sites (Upper and Lower) were monitored in the spring 2008 session due to equipment malfunctioning on one of the TGP meters. No TGP monitoring was conducted during Years 3 and 4 as mentioned above.

No TGP monitoring during synchronous condense operations was conducted during Years 5 and 6 (post-implementation of 142 m^3s^{-1} minimum flow). TGP monitoring was initially proposed for Year 5 (2011) to capture the TGP levels in the MCR associated with a range of operations at REV 5, with the data collected in a manner consistent with Ramsay (2004). However, given the difficulty in actually operating synchronous condense operations for a 72-hour period and the preliminary nature of the minimum flow operations during the first year of implementation of REV 5, TGP monitoring was postponed until Year 6 (2012). A TGP monitoring program was conducted under a separate BC Hydro contract during summer 2012 to monitor TGP during spill conditions from Revelstoke Dam (Golder 2012a).

Since there was not the opportunity to sample TGP levels from synchronous condensed turbine operations post-implementation of 142 m^3s^{-1} minimum flow, no conclusions were drawn regarding the effect of minimum flows on the TGP levels in the flowing reach of the MCR. However, because of more rapid dilution, it would be expected that any impact would be reduced. Additionally, implementation of 142 m^3s^{-1} minimum flows would not have an impact on spill-related TGP.

5.0 SEASONAL WATER QUALITY MONITORING

The water quality sampling program aimed to parallel the MCR Benthic Productivity Program (CLBMON-15b) by sampling for the same nutrients and turbidity over a seasonal range. Water quality data was collected three times a year, with the exception of Year 1 spring data due to the contract start date. Sampling dates were chosen because they overlapped sensitive times of the year for rearing and spawning of important sportfish species, including SARA listed white sturgeon. A summary of all of the raw water quality data collected for Years 1-6 is included in Appendix F, Tables F-3 to F-14.

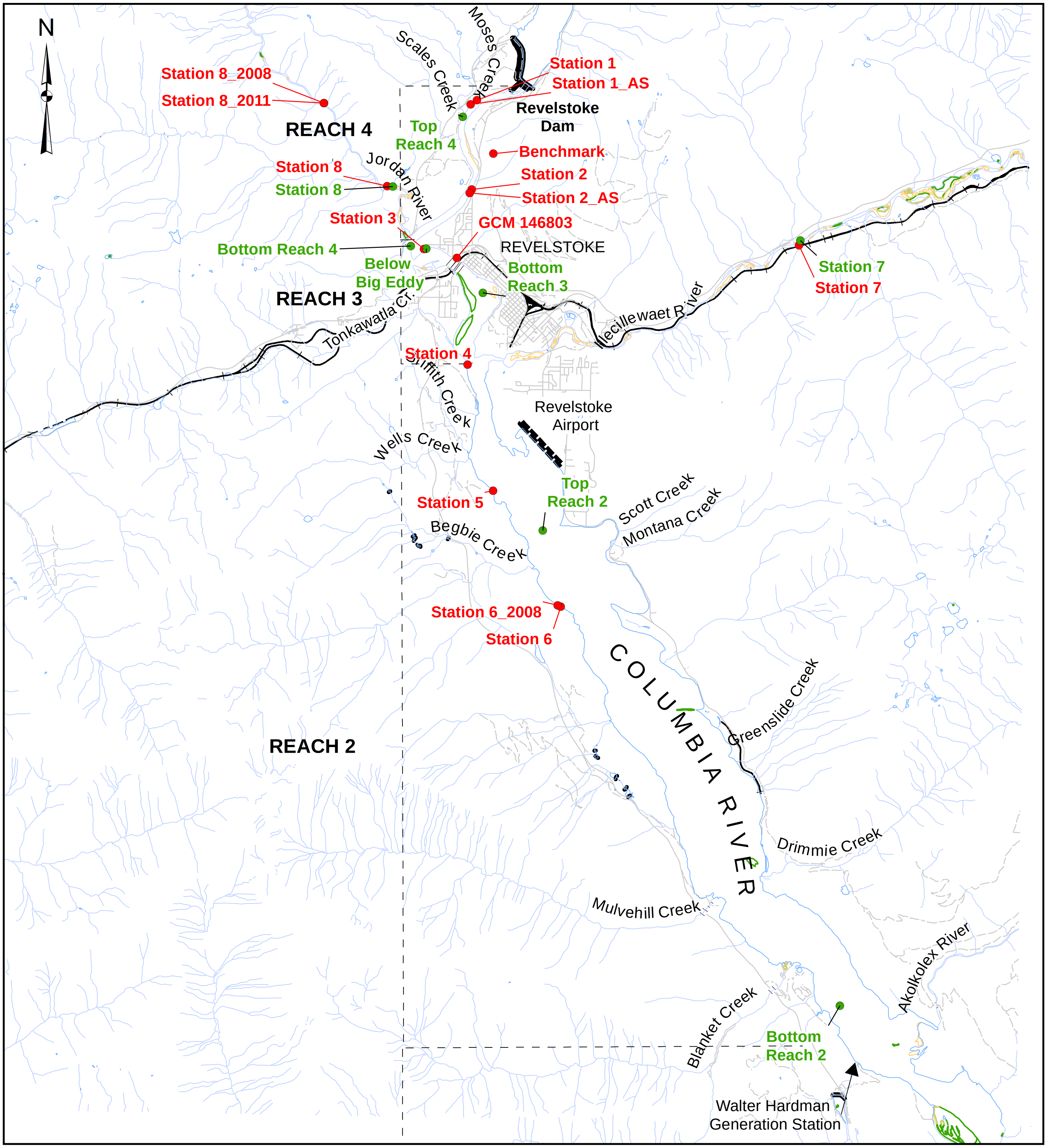
[3] The original sub-hypothesis developed during the WUP included the effects of minimum flows on TGP levels at the Revelstoke sturgeon spawning area.

5.1 Seasonal Water Quality Sampling Methodology

5.1.1 Water Quality Sampling Stations

Surface water samples were collected seasonally at 8 stations (Figure 5). In the spring of 2010 (Year 4), river mainstem water quality sampling stations were relocated from the CLBMON-15a stage/temperature index stations to coincide as much as possible with the periphyton/benthic substrate sites for MCR Ecological Productivity Monitoring CLBMON-15b (identified in green on Figure 5 and Appendix F, Table F-1). These sites were previously identified and routinely sampled by both programs (CLBMON-15a-15b) to uphold a consistency of sampling locations over time. The changes were made to better align the two studies and were not considered to negatively impact the interpretation of previously collected data. Table F-15 (Appendix F) shows the site names from the Ecological Productivity study (CLBMON-15b) and the Physical Habitat stage and temperature monitoring (CLBMON-15a) that correspond to the water quality station numbers presented here.

Table 5 outlines the water quality parameters collected, the frequency of sampling and the stations.



LEGEND

- WATER QUALITY SAMPLE LOCATION
- STATION LOCATION
- REACHES
- WATERCOURSE
- DAM BASE
- ISLAND
- SAND OR GRAVEL BAR
- ROUGH ROAD
- PAVED ROAD
- ROAD BRIDGE
- AIR FACILITY
- RAIL

4 2 0 4

SCALE 1:150,000 KILOMETRES

REFERENCE

TRIM MAPS PROVIDED BY BC HYDRO.
PROJECTION: UTM ZONE 11 DATUM: NAD 83

PROJECT

COLUMBIA RIVER WATER USE PLAN MONITORING PROGRAM
PHYSICAL HABITAT MONITORING PROGRAM

TITLE

CLBMON-15A RIVER STAGE STATIONS
CLBMON-15B PERIPHYTON/BENTHIC SUBSTRATE LOCATIONS

Golder Associates
Castlegar, British Columbia

PROJECT No. 12-1492-0084			SCALE AS SHOWN	REV. 0
DESIGN	CC	31 May 2012	FIGURE 5	
GIS	AL	31 May 2012		
CHECK				
REVIEW				

N:\Active\GIS\2012\12-1492-0084\Mapping\MXD\General\12-1492-0084_FIG_5.mxd

Table 5: CLBMON-15a monitoring program water quality parameters and frequency.

CLBMON-15a and 15b Water Quality Index Station(s)[1]	Parameter	Year	Season[2]	Monitoring Frequency	Data Relationship
Top Reach 4 Bottom Reach 4 Top Reach 3 Below Big Eddy Top Reach 2 Bottom Reach 2 Stn 7 (Illecillewaet) Stn 8 (Jordan)	Water Temperature (°C)	All Years	All Seasons	Continuous (10-minute intervals)	Influence of Revelstoke discharge and tributary inputs on river temperature
	Spot Water Temperature (°C)	All Years	No Summer Year 2	3 times/year	CLBMON 15-b monitoring locations for periphyton/benthic substrate samplers
	Nutrients-(µg/L) Total Nitrogen Total Nitrogen Kjeldahl Nitrate Nitrite Ammonia Soluble Reactive Phosphorus, Total Phosphorus Total Dissolved Phosphorus	All Years	No TN spring Year 5	3 times/year	
	Turbidity Total Suspended Solids (mg/L) Total Dissolved Solids (mg/L) Turbidity (NTU)	All Years	All Seasons	3 times/year	
	Electrochemistry (µS/cm) Specific Conductivity Conductivity	All Years	All Seasons	3 times/year	
	Dissolved Oxygen (% saturation)	All Years	No Fall Year 1 or 4; no summer Year 2	3 times/year	
	Dissolved Oxygen (mg/l)	All Years	No Summer Year 1 or 2		
	pH	All Years	All seasons	3 times/year	

[1]Reach number locations are described in Section 1.2 and shown in Figure 5.

[2]No water quality sampling conducted during spring of Year 1.

[3]TKN was only collected in Year 6.

5.1.2 Water Quality Sampling Methods

Water samples were collected following the procedures provided by the laboratories where the samples were analyzed. These procedures are provided in Appendix F. Water samples were sent to two water quality laboratories for low level nutrient analysis. Low level nutrients were analyzed at the DFO Cultus Lake Salmon Research Laboratory (DFO) near Chilliwack, BC. All other parameters were tested by Caro Analytical Services (Caro) in Kelowna, BC. Electrochemistry data were recorded *in situ* using a multimeter. All water quality data were stored in the CLBMON-15a Physical Habitat Monitoring database. Blank and duplicate samples were collected at different stations on each sampling session for quality assurance and quality control for both sample delivery and laboratory analysis.

The DFO and Caro laboratories were used by both CLBMON-15a and 15b for analyses of all parameters to maintain consistency between lab analyses, reporting, parameters, methodology, and detection limits. Detection limits are the lowest concentration level that can be determined to be statistically different (99% confidence). For the purposes of laboratory certification, detection limits are approximately equal to the method detection limit (MDL) for those tests that the MDL can be calculated. The MDL is the minimum concentration of a substance that can be measured and reported with 99% confidence; where the analyte concentration is greater than zero and the MDL is determined from analysis of a series of blind samples, from a known matrix of concentrations of the analyte. A summary of all detection limits is provided in Appendix F, Table F-2.

5.1.3 Water Quality Analysis Methods

Water quality data was collected three times annually at six stations in the mainstem MCR for four years prior to minimum flows and two years after. One sample was collected and analyzed for each site and sampling occasion; replicate water samples were not taken to assess variation within a site or season. Because there were few data points each year and only two years of data post-implementation of minimum flows, the water quality data-set is fairly limited, such that no strong inferences can be drawn about the effects of 142 m^3s^{-1} minimum flows on water quality in the MCR. The preliminary analyses presented here provide an indication of potential differences pre and post-implementation of 142 m^3s^{-1} minimum flow, but additional years of data collection are required to draw conclusions about effects on water quality.

Key water quality variables were compared pre and post-implementation of minimum flows. The water quality variables tested were pH (laboratory and *in-situ* field measurements were combined), total phosphorus, nitrate and specific conductivity. The remainder of the variables collected had large data gaps throughout (with some variables only collected during the post-implementation of 142 m^3s^{-1} minimum flow period). The analysis used only stations 1 and 2. All other stations were excluded for the following reasons:

1) Stations 1 and 2 are closest to the dam and therefore most likely to be affected by minimum flows.
2) Stations 3 to 6 were located downstream of major tributaries that likely have a large influence on water quality in the MCR, which could confound the effects of minimum flows.
3) The small sample sizes did not allow an analysis that included all the explanatory variables (station, season, and minimum flows) in one model, and analyzing all station-season combinations separately would require a large number of tests, which would increase the chances of a Type I error (incorrectly rejecting a true null hypothesis).

A two-way analysis of variance (ANOVA) was conducted for each of the four water quality response variables, with station (station 1 or 2) and season (spring, summer, or fall) as the main effects. If the station factor was not significant, then data from stations 1 and 2 were pooled for subsequent analyses on the effect of minimum flows on water quality. To assess the effects of minimum flows on water quality, a two-way ANOVA was conducted with minimum flow (before or after) and season (spring, summer, or fall) as the main effects. Tukey's tests were used for post-hoc comparisons to assess which levels of the factors differed. For all ANOVAs, if assumptions of normality or homoscedasticity were not met, data were natural log-transformed to better meet assumptions. For all analyses, significance was assessed at the 0.05 level.

The four water quality variables were summarized graphically in boxplots showing the 25^{th} percentile, median and 75^{th} percentile. Whiskers on the boxplots represent 1.5 times the interquartile range and values outside of whiskers are shown as points.

5.2 Seasonal Water Quality Results and Discussion

5.2.1 Related Management Question(s), Hypotheses, and Sub-hypotheses

The key management question of the MCR Physical Habitat Monitoring Program associated with seasonal water quality monitoring is:

Management Question #3: Does the implementation of the 142 m^3s^{-1} minimum flow affect water quality in terms of electrochemistry and biologically active nutrients?

There are no hypotheses and sub-hypotheses outlined in the ToR, related to seasonal water quality monitoring; however, the hypothesis and related sub-hypothesis developed from the management questions are:

- Ho_3: Implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter water quality in terms of electrochemistry and biological active nutrients of the MCR.
- Ho_{3A}: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter spatial variation in water quality parameters.

5.2.2 Water Quality Results and Interpretation

Under the MCR Physical Habitat Monitoring Program, seasonal water quality sampling was undertaken to collect data for other users. A summary of the seasonal raw data is presented in Appendix F, Tables F-3 to F-14.

The range in water quality parameters measured in the study area in spring, summer, and fall during the pre and post-implementation years were typical of an oligotrophic system and were similar among all stations within the mainstem of the MCR (Appendix F, Tables F-3 to F-14). The two main tributaries (Jordan and Illecillewaet rivers) occasionally showed considerably different values than those found in the MCR (Appendix F, Tables F-3 to F-14).

Four key water quality variables were compared when attempting to answer the management question. These were surface water pH, total phosphorus, nitrate and specific conductivity. Water quality did not differ between stations 1 and 2 for pH ($F_{1,20}$=1.6; P=0.2), total phosphorus ($F_{1,20}$=0.001; P=0.9), nitrate ($F_{1,20}$=1.2; P=0.3), or conductivity ($F_{1,16}$=0.07; P=0.8). Therefore, stations 1 and 2 were pooled for subsequent analyses on the effect of minimum flows on water quality.

Surface water pH was similar at all mainstem stations of the MCR across all seasons (Appendix F, Figure F-1). Pre-implementation, the pH ranged between 6.7 and 8.2 and the average was 7.8. Post-implementation, the pH ranged between 7.1 and 8.2 and the average was 7.7. It is worth noting that the number of data points (*n*=100) collected during the pre-implementation sampling was approximately twice the number of data points (*n*=52) collected during the post-implementation sampling. There is an additional year of sampling during the pre-implementation study and there were data gaps present during each season in each year (due to meter malfunctions and sites not visited). Mean pH was not significantly different pre and post-implementation of minimum flows ($F_{1,20}$=0.6; P=0.4; Figure 6).

Tributary surface water pH data was also collected seasonally during this study. The average surface water pH for the Jordan River, pre-implementation was 7.4 and post-implementation was 7.5. The average surface water pH for the Illecillewaet River, pre-implementation was 7.9 and post-implementation was 7.7. Based on the limited data collected for these two major tributaries (Jordan and Illecillewaet rivers) there does not appear to be a change in surface water pH since the implementation of the 142 m^3s^{-1} minimum flow release from Revelstoke Dam.

Mean pH values were within typical surface water values for an oligotrophic system in the southern interior of the province (range: 7.0-9.7) as indicated by the British Columbia Approved Water Quality Guidelines (McKean and Nagpal 1991).

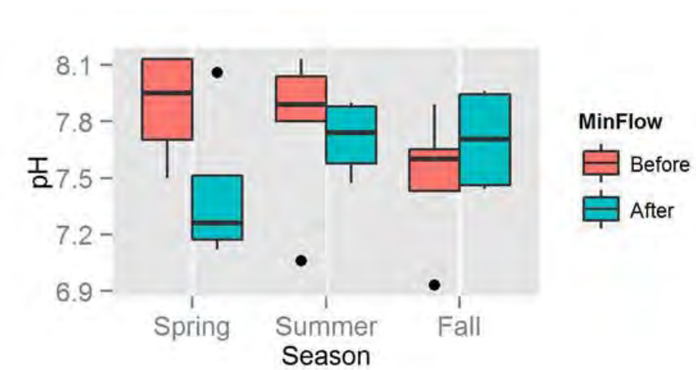


Figure 6: The pH in the middle Columbia River by season before the implementation flows (2007-2010) and after the implementation of minimum flows (2011-2012). Data are from Stations 1 and 2 only and water quality was only measured once per year, season and station. Boxes show 25th percentile, median and 75th percentile. Whiskers represent 1.5 times the interquartile range and values outside of whiskers are shown as points.

Total phosphorus (TP) in the mainstem MCR likely reflected Revelstoke Reservoir conditions upstream, since there is little biological activity affecting nutrient values immediately below the dam. Peak concentrations during the summer ranged from 2.1 to 26.6 µg/L, possibly due to spring overturn in the upstream reservoir (Appendix F, Figure F-2). TP typically ranged from 2 to 10 µg/L during most years and seasons. TP concentrations below REV from 1984 to 1998 (Regnier 1998) were similar to TP concentrations found within the study area during recent monitoring years (Golder 2011). Regnier (1998) concluded that changes in TP concentrations could not be statistically linked to REV discharges. However, stations below both tributary inputs (particularly the Illecillewaet River) showed higher concentrations than locations closer to the dam. A range of total phosphorus concentration of 5-15 µg/L is recommended by the British Columbia water quality guidelines for aquatic life in lakes (Nordin 1985). There is no guideline for aquatic life for phosphorus concentration in streams in British Columbia. Total phosphorus was not significantly different pre and post-implementation of minimum flows ($F_{1,20}$=0.4; P=0.6; Figure 7).

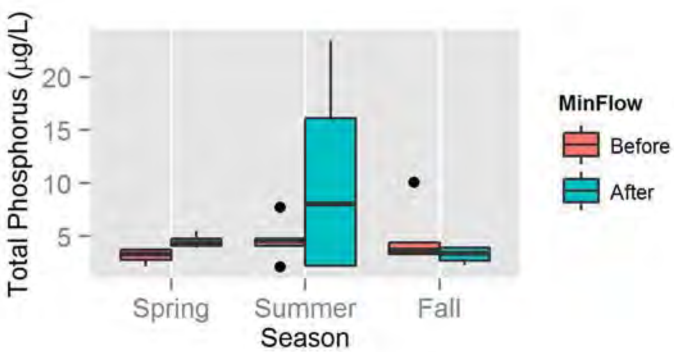


Figure 7: Total phosphorus concentration in the middle Columbia River by season before the implementation flows (2007-2010) and after the implementation of minimum flows (2011-2012). Data are from Stations 1 and 2 only and water quality was only measured once per year, season and station. Boxes show 25th percentile, median and 75th percentile. Whiskers represent 1.5 times the interquartile range and values outside of whiskers are shown as points.

Nitrate (NO^-_3) concentrations ranged from 99.6 to 178.0 µg/L (spring), 117.4 to 167.2 µg/L (summer), and 100.5 to 132.1 µg/L (fall) in the mainstem MCR during sampling in the pre-implementation years (Appendix F, Figure F-3; Figure 8). Post-implementation, NO^-_3 concentrations ranged from 96.1 to 180.6 µg/L (spring), 107.7 to 145.5 µg/L (summer), and 98.1 to 112.2 µg/L (fall) in the mainstem MCR.

Nitrate concentration was significantly greater pre-implementation of minimum flows (mean ± standard deviation: 126.7 ± 20.9 µg/L) than post-implementation (113.1 ± 15.4 µg/L; $F_{1,20}$=5.0; P=0.04). Nitrate also differed by season ($F_{2,20}$=8.2; P=0.002). Nitrate was significantly greater in summer (135.4 ± 15.5 µg/L) than in spring (108.7 ± 23.2 µg/L; Tukey's test, P=0.002) or fall (115.9 ± 7.9 µg/L; P=0.03). Nitrate was not significantly different between fall and spring (P=0.4). The interaction between minimum flow and season was not significant ($F_{2,20}$=0.4; P=0.7), which suggests that the effect of minimum flows on nitrate did not depend on season.

Future years of monitoring are required to assess whether the greater nitrate concentrations in the two years following the implementation of minimum flows were caused by the change in dam operations or natural variability in nutrient levels. Discharge in the Columbia River was greater than average during the two years following minimum flow implementation (Golder and Poisson Consulting 2013). It is possible that either minimum flows, high discharge, or both resulted in greater dilution or flushing of nitrate in the MCR in 2011 and 2012 than in previous years. However, phosphorus concentration was not lower in 2011 and 2012, which would be expected if greater flows in the MCR diluted nutrient concentrations in the MCR during these years.

It is unknown whether the greater nitrate concentration in years after minimum flows than before could be biologically significant and affect aquatic life in the MCR. As with the general water quality results, further monitoring is required to assess whether nitrate concentrations, and primary producers, are affected by minimum flows. Biological effects would also depend on additional factors, such as whether the system is nitrogen or phosphorus limited. Minimum flow impacts on primary productivity are beyond the scope of this report, but are the subject of the related MCR Ecological Productivity Monitoring program (CLBMON-15b).

The tributary nitrate concentrations ranged between 68.0 (fall) to 325.5 µg/L (spring) in the Illecillewaet River and between 70.7 (fall) to 310.8 µg/L (spring) in the Jordan River pre-implementation. Post-implementation of the 142 m^3s^{-1} minimum flow release from REV, tributary nitrate concentrations ranged between 48.9 (summer) to 453.8 µg/L (spring) in the Illecillewaet River and between 57.9 (summer) to 387.0 µg/L (spring) in the Jordan River.

All nitrate concentrations recorded were below the water quality standards for protection of aquatic life (maximum value of 200 mg/L) by the British Columbia Approved Water Quality Guidelines (Nordin and Pommen 1986).

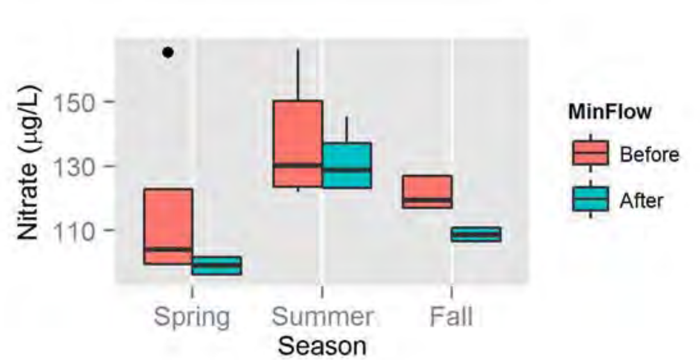


Figure 8: Nitrate concentration in the middle Columbia River by season before the implementation flows (2007-2010) and after the implementation of minimum flows (2011-2012). Data are from Stations 1 and 2 only and water quality was only measured once per year, season and station. Boxes show 25th percentile, median and 75th percentile. Whiskers represent 1.5 times the interquartile range and values outside of whiskers are shown as points.

Specific conductivity of the mainstem MCR ranged between 151-176 µS/cm (spring) and 92-140 µS/cm (summer), and 50-300 µS/cm (fall) (Appendix F, Figure F-4; Figure 9). Specific conductivity was significantly greater post-implementation of minimum flow (164.1 ± 85.4 µS/cm) than pre-implementation (123.1 ± 31.7 µS/cm; $F_{1,16}$=8.2; P<0.001). Specific conductivity also differed by season (P<0.001) and the interaction term was significant (P<0.001), suggesting that the effect of minimum flows was dependent on season. Tukey's tests indicated that the effect of minimum flows on specific conductivity was significant in the fall season, but not significant in spring (P=0.9) or summer (P=0.051).

The significant effect of minimum flows on conductivity was related to very high conductivity measurements in the fall of 2012 (Appendix F, Figure F-4). Conductivity was nearly 300 µS/cm at all sites in the fall of 2012, whereas measurements in all previous years and seasons ranged from ~90 to 160 µS/cm. Measurements of specific conductivity during the MCR Fish Population Indexing Surveys (CLBMON-16) ranged from 140 to 150 µS/cm in October of 2012 (Golder and Poisson Consulting 2013). This suggests that the anomalously high measurements from this monitoring program may not be representative of general conditions in the fall of 2012. The level of total dissolved solids (TDS) measured in the fall of 2012 (range: 146-150 mg/L) was also much greater than values in the spring (range: 71-88 mg/L; Appendix F, Table F-13) which likely contributed to greater conductivity. Reasons for greater TDS and conductivity in the fall of 2012 than in all previous years are unknown. As water quality data from the fall of 2012 were collected by other researchers and the data were provided to Golder Associates Ltd., we cannot speculate further on potential reasons for these anomalously high values. It is recommended that the methods, instruments, and calibration procedures be reviewed prior to future water quality data collection to ensure measurement errors do not influence the results. Because the significant difference in conductivity pre and post-implementation of minimum flows was primarily related to anomalously high values in the fall of 2012, the interpretation is that minimum flows did not have a significant effect on specific conductivity.

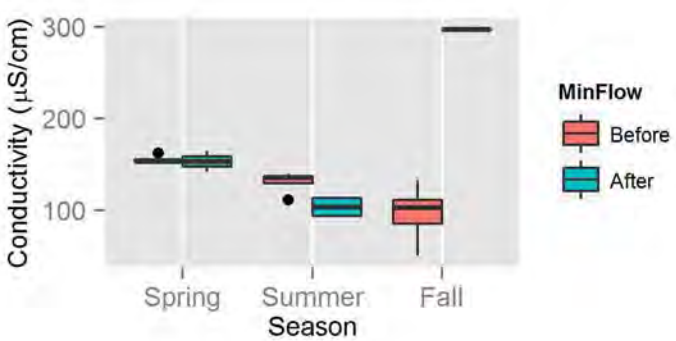


Figure 9: Specific conductivity in the middle Columbia River by season before the implementation flows (2007-2010) and after the implementation of minimum flows (2011-2012). Data are from Stations 1 and 2 only and water quality was only measured once per year, season and station. Boxes show 25th percentile, median and 75th percentile. Whiskers represent 1.5 times the interquartile range and values outside of whiskers are shown as points.

These water quality results are preliminary and based on a limited data set, so strong conclusions regarding minimum flow effects should not be drawn at this point. Overall, the results do not suggest substantial effect of minimum flows on water quality in the MCR, although nitrate concentrations were lower after implementation of the minimum flows. Further monitoring is required before the effects can be attributed to the implementation of the 142 m^3s^{-1} minimum flow regime as opposed to natural year-to-year variation in water quality.

The main objective of the water quality component of this monitoring program is to assess the effects of the new minimum flow. However, water quality was always sampled during the day-time when flows were typically greater than minimum flows, both before and after the implementation of the year-round minimum flow. This sampling design could make it difficult to detect changes caused by the minimum flow, especially if differences in water quality related to minimum flow are smaller in magnitude than natural year-to-year variation. A recommendation for an alternative study design in provided below in Section 6.0.

6.0 RECOMMENDATIONS

1. Re-installation and regular calibration of the equipment at BCH's Station 3 (also referred to as 'TR2' or 'Tailrace-7km_A'; located 7 km downstream from REV, in Reach 3, on the left bank of the MCR) is recommended to provide a comparison between measurements recorded at BCH's MCR station and MCR index stations. As Station 3 will likely provide long term monitoring of water temperatures for Revelstoke tailwaters, proper calibration and consistency among all sampling stations is important (e.g., logging in Standard Time at 10-minute intervals from the top of the hour). Water temperatures at Station 3 were approximately 1.0 to 1.4 °C higher than the temperatures recorded by the calibrated Solinst data loggers used at the Golder installed stations, although both data sets show similar temporal patterns.

2. Modelling scenarios for periods of interest to other investigators should be considered for future hydraulic modelling to accurately predict changes in wetted riverbed area over the time intervals and flow regimes of interest. These changes in wetted area may reflect fish habitat and potential annual aquatic productivity under the new operations.

3. Studies that intend to use the CLBMON-15a HEC-RAS Model should provide feedback on the model and the intended use of model output, so that any modifications can be incorporated in future model calibration and application. To continue to refine the model calibration process, the Jordan River Stage Discharge Curve should continue to be defined to improve the flow estimation, as it is an important inflow source to the MCR during low REV discharges.

4. For the purposes of this monitoring program, the Winter-Kennedy method is used to determine an accurate flow rate of through Units 1 to 4 of the REV turbines. However, Unit 5 flow rate is estimated by apportioning the total flow released to the REV 5 component, based on head and power production of the unit. This flow estimation leads to errors when the turbine is spinning without generating. As total REV discharge is an important input to the CLBMON-15a HEC-RAS Model, it is recommended to either implement the Winter-Kennedy method on REV 5 or perform a sensitivity analysis. A sensitivity analysis could be conducted using the CLBMON-15a HEC-RAS Model to examine the possible effects of the REV 5 flow errors on modelled water elevations of the MCR. By varying REV flow at low ALR levels, the resulting range of water surface elevations along the reach length could be determined. With this information, BCH will be able to make a decision as to whether to proceed with the appropriate sensor installation required for the Winter-Kennedy method on REV 5.

5. It is recommended that future studies examine the relationship between forebay temperature profiles, forebay stratification, tailrace temperatures, and dam operations. This is because forebay temperature stratification is known to have a large influence on water temperatures downstream of other dams on the Columbia River. In this study, the greatest diel temperature variations were associated with sustained high discharges from REV (Appendix D, Figure D1; Golder 2010, 2011).

6. Remove TGP monitoring from this program as it is rare to get appropriate conditions at REV.

7. Compare water quality measurements taken during zero generation to measurements during various discharges at, or greater than minimum flows. Water quality was always sampled during the day-time when flows were typically greater than minimum flows. To our knowledge water quality was never

measured at very low flows or with zero power generation (i.e. only seepage flow of 8.5 m^3s^{-1}). An alternative way to assess the effects of minimum flows on water quality is to compare measurements taken during zero generation to measurements during various discharges at, or greater than minimum flows within the same year and season. This approach would be less influenced by natural year-to-year variation, which can confound the effects of minimum flow, and could improve understanding of potential mechanisms through which minimum flows may affect physical habitat variables. Combining the current before-after monitoring program with an adaptive management approach that manipulates discharge and measures subsequent water quality could provide a more powerful approach to assess the effects of minimum flow, or other operational changes.

7.0 LITERATURE CITED

BC Hydro. 1998. System Operating Order No. 4P-30, Revelstoke Project Prepared by BC Hydro Power Facilities. 14 pp.

BC Hydro. 2000. Making the connection: The BC Hydro electric system and how it operates. 56 p.

BC Hydro. 2005. Consultative Committee report: Columbia River Water Use Plan, Volumes 1and 2. Report prepared for the Columbia River Water Use Plan Consultative Committee by BC Hydro, Burnaby, BC.

BC Hydro, 2010. RFP-375 CLBMON-15a Mid Columbia River Physical Habitat Monitoring. Issue date 16 June, 2010. 70 pp + appendices.

Bray, K. (October 13, 2011). Email correspondence entitled, “REV Operations for October”.

Bray, K. (September 20, 2010). CLBMON-15a Kick-off Meeting with Carissa Canning. Revelstoke, BC.

Burnham, K.P. and D.R. 2002. Anderson. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd Ed. Springer-Verlag Inc., New York, USA.

Caissie, D. 2006. The thermal regime of rivers: a review. Freshwater Biology 51: 1389-1406.

Davidian, M. and D.M Giltinan. 1995. Nonlinear Mixed Effects Models for Repeated Measurement Data. Chapman and Hall, London, UK.

Golder Associates Ltd. 1997. TP-8.24-0 Stream Discharge Measurement Methods. Revision 0. Prepared for Golder Associates. 12 pp.

Golder Associates Ltd. (Golder). 2003. Hugh L. Keenleyside Dam and Arrow Lakes Generation Station Post-Project Downstream Temperature Assessment. Report prepared for Columbia Power Corporation, Castlegar, BC. Golder Report No. 0228009F: 60 p. + 1 app.

Golder Associates Ltd. 2008. Columbia River Water Use Plan Monitoring Program: Physical Habitat Monitoring Study Period: 2007. Prepared for BC Hydro CLBMON#15a. 23 pp + appendices.

Golder Associates Ltd. 2009. Columbia River Water Use Plan Monitoring Program: Physical Habitat Monitoring Study Period: Year 2 – 2008. Prepared for BC Hydro, Castlegar, B.C. Golder Report No. 08-1480-0035. 23pp + appendices.

Golder Associates Ltd. 2010. Columbia River Water Use Plan Monitoring Program: Physical Habitat Monitoring Study Period: Year 3 – 2009. Prepared for BC Hydro, Castlegar, B.C. Golder Report No. 09-1480-0024. 33pp + appendices.

Golder Associates Ltd. 2011. CLBMON-15a Mid Columbia River Physical Habitat Monitoring. Annual Technical Report – 2010. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 10-1492-0084. 40 p. + 6 app.

Golder Associates Ltd. (Golder). 2012. CLBMON-15a Mid Columbia River Physical Habitat Monitoring. Annual Technical Report – 2011. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 11-1492-0084: 44 p. + 6 app.

Golder Associates Ltd. (Golder). 2012a. Revelstoke Dam Total Gas Pressure (TGP) Monitoring in 2012. Technical Memo – 2012. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 12-1492-0097: 10p. + 3 app.

Golder Associates Ltd. and Poisson Consulting Ltd. 2013. CLBMON-16 Middle Columbia River Fish Population Indexing Surveys – Synthesis Report. Report prepared by BC Hydro Generation, Water Licence Requirements, Revelstoke, BC. Golder Report No. 10-1492-0079D: 62 p. + 8 app.

Hutt, D. (February 14, 2011). Telephone conversation regarding Mid Columbia REV Tailrace2 station and historical calibration records, “TR2 Sensor Failure”.

Johnson, D.H. 1999. The insignificance of statistical significance testing. Journal of Wildlife Management 63: 763-772.

Kivilahti, K. And D. Hutt (December 13, 2011). Email correspondence and associated attachments entitled, “TR2 Sensor Failure”.

Korman, J., L. Lan, L. Hildebrand, and L. Failing. 2002. Fish Habitat Performance Measures to Evaluate Minimum Discharge Requirements for Revelstoke Canyon Dam. Appendix Q. Prepared for Columbia WUP Fisheries Technical Committee. Consultative Committee Report Columbia River Water Use Plan.

McKean, C.J.P, and N.K. Nagpal. 1991. Ambient water quality criteria for pH – Technical Appendix. Ministry of Environment, Province of British Columbia, 122 pp.
Online: http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html#approved

Nordin, R.N. 1985. Water quality criteria for nutrients and algae – Technical Appendix. Ministry of Environment, Province of British Columbia, 104 pp.
Online: http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html#approved

Nordin, R.N. and L.W. Pommen. 1986. Water quality criteria for nitrogen (nitrate, nitrite, and ammonia) – Technical Appendix. Ministry of Environment, Province of British Columbia, 84 pp.
Online: http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html#approved

Pieters, R. and G. Lawrence. 2013. CTD Surveys – Kinbasket and Revelstoke Reservoirs, 2011. Prepared for BC Hydro, Water License Requirements. 10 pp.+ apps. Appendix 3 in Bray, K.E. 2013. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 4 (2011). BC Hydro, Environment. Study No. CLBMON-3.

Perrin, C.J., J. Korman, and D. Schmidt. 2004. A monitoring protocol for benthic invertebrates and periphyton in the middle and lower Columbia River. Report prepared by Limnotek Research and Development Inc., Ecometric Research Ltd. and Golder Associates Ltd. for BC Hydro. 59p.

Ramsay, I.C. and Associates. 2004. Data Report: Total Gas Pressure Monitoring downstream of Revelstoke Dam. 12 pp + appendices.

R Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

R.L.&L Environmental Services Ltd. 1994. Fish Stock and Habitat Assessments of the Columbia River below Revelstoke Canyon Dam. Prepared for BC Hydro, Environmental Resources.

R.L.&L Environmental Services Ltd. 2001. Water Use Plans – Environmental information review and data gap analysis. Volume 1: Upper Columbia – Mica and Revelstoke Projects. Prepared for BC Hydro, Burnaby, B.C. by RL&L Environmental Services in Association with Robertson Environmental Services Ltd., Pandion Ecological Research Ltd., Bruce Haggerstone Landscape Architect, Pomeroy & Neil Consulting Inc. and DVH Consulting. RL&L Report No. 858V1-F: 498 p.

Regnier, Robin. 1998. Trend Analyses of Total Phosphorus in the Columbia River at Revelstoke 1986 – 1996. Prepared for Water Management Branch, Environment and Resource Management Department, Ministry of Environment, Lands and Parks, Victoria. B.C. Online report: http://www.env.gov.bc.ca/wat/wq/trendstuff/colrev/index.html.

8.0 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.

Demitria Burgoon, B.Sc.
Aquatic Biologist

Greg Burrell, Ph. D.
Principal, Senior Aquatic Scientist

David Roscoe, M.Sc.
Fisheries Biologist

DB/DR/GB/cmc

n:\active_2012\1492\12-1492-0084 revy phys habitat\07 deliverables\synthesis report\1214920084_001_r_rev1_clbmon 15a synthesis_27jan2014.docx

APPENDIX A

Site Identification and Station Maintenance Logs

Table A-1 River stage monitoring standpipe stations constant attachment point measurements of the river stage data for CLBMON-15a Middle Columbia Physical Habitat Monitoring Program. Data to correct altitude of each station's data logger sensor and summarize station maintenance efforts.

Station Designation	Installation or Servicing Dates	Type of Logger Installed or Re-Deployed	Station Relocation Notes	Distance from Constant Attachment Point or RTK Pad to Sensor (m)	Total Change in Top of Standpipe Height Affecting Orthometric Height (m)	RTK Values Used (Year Obtained)	Sensor Elevation (m)	Comments	Data Downloaded During Visit
Station 1	25-Aug-07	Solinst Levelogger (M10)		10.80		2007	438.28	Standpipe housing is situated on a moderately angled slope.	Install
	15-Nov-07			10.80		2007	438.28		Yes
	10-Apr-08			12.03		2010	438.58	Galvanized standpipe housing was replaced with stainless steel housing during download.	Yes
	26-Jun-08			12.03		2010	438.58		Yes
	28-Nov-08			12.03		2010	438.58	Replaced existing wire from constant attachment point to levelogger cap with aircraft cable for increased strength and durability.	Yes
	16-Apr-09			12.03		2010	438.58	Wrapped bottom of pipe housing with geotextile material in order to prevent excess sediment from affecting data readings or interfering with sensor.	Yes
	23-Jun-09			12.03		2010	438.58		Yes
	26-Oct-09			12.03		2010	438.58		Yes
	14-Apr-10			12.03		2010	438.58	One meter increments were engraved along the pipe housing for field quality control water level verifications during subsequent field service trips.	Yes
	17-Jun-10			12.03		2010	438.58	Flushed out pipe using water pump to ensure there is no sediment build-up occurring within the pipe housing.	Yes
	5-Oct-10			12.03		2010	438.58	During outage, RTK taken right at sensor, during redeployment was able to ensure levelogger got right to the bottom of the pipe; new sensor elevation taken 5:50am. Installed benchmark on large rock 21.8 m downstream of pipe housing on left upstream bank; replaced geotextile material at bottom of pipe housing during scheduled outage for Stn 1_AS installation.	Yes
	27-Apr-11			12.03		2010	438.58	During retrieval of the levelogger, a considerable amount of sediment was entrained in the standpipe housing; visible on the bottom 3 m of aircraft cable and the levelogger sensor holes were filled with compact sediment (i.e., sand granules). Levelogger was not redeployed; it required proper cleaning, recalibration, and testing to ensure the sensors were not damaged.	Yes
	17-Aug-11			12.06		Spring 2013	n.d.	In the event that there was sediment at the bottom of the standpipe housing, potentially caused by high sediment loads from spring freshet, the standpipe housing was flushed out before redeploying the levelogger in standpipe housing. Aircraft cable was changed out. RTK value was scheduled to be obtained in Fall 2011 (see below).	No
	29-Oct-11			12.06		Spring 2013	n.d.	Because of last minute scheduling change by the Operations Planners for the sustained minimum flow request required for the fall field session, the RTK survey was unable to be completed in conjunction with the scheduled sustained minimum flow on 30 October 2011. On 9 November 2011, a field crew attempted to complete this survey; however, due to equipment malfunction, the task was unable to be completed. RTK values will be obtained Spring 2012.	Yes
	19-Jun-12			12.06		Spring 2013	n.d.	During retrieval of the levelogger, a considerable amount of sediment was entrained in the standpipe housing; visible on the bottom 2 m of aircraft cable.	Yes
	15-Aug-12			12.06		Spring 2013	n.d.	Standpipe could not be accessed due to full pool and REV spill conditions (top of standpipe was underwater) Bank has also caved in from erosion related to REV spilling activities.	No
	24-Oct-12			12.06		Spring 2013	n.d.	Top of standpipe was buried in rock debris due to failing banks, resulting from full pull and REV spill conditions in spring/summer of 2012. Logger could not be dislodged from standpipe as a considerable amount of sediment was entrained in the standpipe.	No
Station 1_Anchor Station (AS)	6-Oct-10	Solinst Levelogger (M10)		0.06		2010	435.73	Standpipe housing is welded onto a 30 lb anchor and deployed during a scheduled outage to capture water levels between zero to minimum flow (142 m³s-1) from Revelstoke Dam (REV) in Reach 4.	Install
	15-Nov-10			0.06		2010	435.73	Water was coming up before scheduled time as indicated by PSOSE during night download; therefore, station was able to be downloaded at this time.	No
	28-Nov-10			0.06		2010	435.73	Attempted to download logger during unscheduled outage between ~2:00 and 05:00. Water levels were too high to access without disturbing the anchor. In discussions with Karen Bray on 29 Nov 2010, she indicated maintenance is planned at MICA in Spring 2011, they are trying to push through water in Kinbasket and store water further down in system; therefore, ALR was backed up to REV even with outage.	No
	27-Apr-11			0.06		Spring 2011	437.70	Obtained precise altitudinal value of the data logger sensor with the real-time kinematic (RTK) unit. Added additional line length to float line as line had become severed and floats were missing. Floats were replaced.	Yes
	30-Oct-11			0.06		Spring 2011	437.70	Added plastic sheath around data logger to protect from advancing rust. RTK values will be confirmed in the Spring of 2012.	Yes
	19-Jun-12			0.06		Spring 2011	437.70	Sustained minimum flows (i.e., ≤155 m3/s) could not be achieved from REV for safe retreival of the data logger. High snowpack conditions and REV spill conditions did not allow for minimum flows below 170 m^3/s.	No
	24-Oct-12			0.06		Fall 2012	436.51	Two sustained minimum flow requests (i.e., ≤155 m3/s) were cancelled due a number of unit outages across the province and cold weather conditions; therefore stations could not be acceesed safely.	No
	18-Nov-12			0.058		Fall 2012	437.36	Anchor station had become dislodged (likley during REV spill conditions) and drifted 11m downstream and flipped over 180°. Anchor station was reployed using new highly reflective anchor.	Yes
	25-Aug-07	Solinst Levelogger (M10)		3.61		2007	438.62		Install
	16-Nov-07			3.61	-0.12	2007	438.27	Standpipe housing had slipped down 0.12 m since August visit; pipe was left at current elevation.	Yes
	10-Apr-08			3.61		2007	438.27		Yes
	23-Apr-08			5.13		2009	436.79	Galvanized standpipe housing was replaced with stainless steel housing and additional length added on to prevent dewatering.	Yes
	26-Jun-08			5.13		2009	436.79		Yes
	28-Nov-08			5.13		2009	436.79		Yes
	19-Mar-09			5.12		2009	436.79	Replaced logger suspension wire with heavy duty aircraft cable.	Yes
	16-Apr-09			5.12		2009	436.79	Following download and review of the data, the logger appeared to be malfunctioning and was therefore replaced. Installed new stainless steel brackets along pipe housing with Hilti Hit epoxy.	Yes
	25-Jun-09			5.12		2009	436.79		Yes
	19-Oct-09			5.12		2009	436.79	Changed out remaining galvanized pipe section with stainless steel pipe to mitigate internal raised metal edge abrading levelogger cap. In addition, bottom of pipe was wrapped with geotextile material to prevent excess sediment from affecting data readings or interfering with sensor and a stainless steel metal bracket was installed on the lower section of the rock face.	No
	22-Oct-09			5.12		2009	436.79		Yes
	14-Apr-10			5.12		2009	436.79	One meter increments were engraved along the pipe housing from for field quality control water level verifications during subsequent field service trips.	Yes
	17-Jun-10			5.12		2009	436.79		Yes
	5-Oct-10			5.12		2009	436.79		Yes
	27-Apr-11			5.12		2009	436.79	Installed 'Fisheries Research Please Do Not Disturb' sign.	Yes
	16-Aug-11			5.12		2009	436.79	Replaced 'Fisheries Research Please Do Not Disturb' sign.	Yes
	29-Oct-11			5.12		2009	436.79	An additional section of pipe was secured parallel to the present standpipe housing, to provide increased robustness for the top section of the standpipe housing, that was previously compromised from large woody debris and high velocity conditions.	Yes

Station Designation	Installation or Servicing Dates	Type of Logger Installed or Re-Deployed	Station Relocation Notes	Distance from Constant Attachment Point or RTK Pad to Sensor (m)	Total Change in Top of Standpipe Height Affecting Orthometric Height (m)	RTK Values Used (Year Obtained)	Sensor Elevation (m)	Comments	Data Downloaded During Visit
	22-Jun-12			5.12		2009	436.79		Yes
	15-Aug-12			5.12		2013	436.79	Top of standpipe was snapped off; likely from high flows and REV spill conditions; therefore remaining length of standpipe was underwater at time of site visit and data logger could not be accessed.	No
	24-Oct-12			4.11		2013	436.79	Changed out aircraft cable to account for top section of standpipe that was severed during high flows and created new constant attachment point on existing standpipe.	Yes
Station 2	25-Aug-07	Solinst Barologger (M1.5)		0.53		n/a	--	Barologger is positioned in standpipe housing with levelogger.	Install
	16-Nov-07			0.53	-0.12	n/a	--	Attempt to download in field; logger was malfunctioning. Following download and review of the data in the office, the logger appeared to be malfunctioning and was therefore not redeployed. See comments for levelogger regarding change in orthometric height.	Yes
	23-Apr-08		Relocated from Station 6 to ensure accessibility at all flow levels	0.69		n/a	--	Logger from Station 6 was relocated to Station 2 as accessibility could be ensured at all reservoir levels and Station 2 logger had malfunctioned during last visit. Galvanized standpipe housing was replaced with stainless steel housing and additional length added on to prevent dewatering.	Yes
	26-Jun-08			0.69		n/a	--		Yes
	28-Nov-08			0.69		n/a	--		Yes
	19-Mar-09			0.40		n/a	--	Barologger was relocated in it's own standpipe housing further away from water's edge to ensure logger is not at risk of higher flows from REV 5 and 6.	Yes
	16-Apr-09			0.40		n/a	--		Yes
	26-Jun-09			0.40		n/a	--		Yes
	21-Oct-09			0.40		n/a	--		Yes
	14-Apr-10			0.40		n/a	--		Yes
	17-Jun-10			0.40		n/a	--		Yes
	5-Oct-10			0.40		n/a	--	Pipe housing appears to have been bent where pipe leaves vertical rock face; after close inspection pipe housing maintained it's integrity and does not require any maintenance.	Yes
	29-Apr-11			0.40		n/a	--	An error message was received, indicating that the data could not be downloaded. Upon calling the manufacturer and completing a few checks on the unit in the field, it was removed and sent back to the manufacturer for repair. Data was retreived by manufacturer.	No
	24-Jun-11			0.40		n/a	--	The malfunctioning unit was repaired; the data retrieved, and was redeployed.	No
	16-Aug-11			0.40		n/a	--		Yes
	30-Oct-11			0.40		n/a	--		Yes
	22-Jun-12			0.40		n/a	--		Yes
	16-Aug-12			0.40		n/a	--		Yes
	24-Oct-12			0.40		n/a	--	An error message was received, indicating that the data could not be downloaded. Upon calling the manufacturer and completing a few checks on the unit in the field, it was removed and sent back to the manufacturer for repair. Data was retreived by manufacturer.	No
	18-Nov-12			0.40		n/a	--	New Solinst Barologger Edge was purchased by BC Hydro and re-deployed by Golder during scheduled minimum flows in Reach 4 due to ongoing malfunctioning issues with older logger during downloads.	No

Station Designation	Installation or Servicing Dates	Type of Logger Installed or Re-Deployed	Station Relocation Notes	Distance from Constant Attachment Point or RTK Pad to Sensor (m)	Total Change in Top of Standpipe Height Affecting Orthometric Height (m)	RTK Values Used (Year Obtained)	Sensor Elevation (m)	Comments	Data Downloaded During Visit
Station 2_Anchor Station (AS)	6-Oct-10	Solinst Levelogger (M10)		0.06		2010	436.10	Standpipe housing is welded onto a 30 lb anchor and deployed during a scheduled outage to capture water levels between zero to minimum flow (142 m^3s-1) from Revelstoke Dam (REV) in Reach 4.	Install
	15-Nov-10			0.06		2010	436.10	Downloaded prior to implementation of minimum flows (142 m^3s-1) from Revelstoke Dam (REV).	Yes
	28-Apr-11			0.06		Spring 2011	436.94	Obtained precise altitudinal value of the data logger sensor with the real-time kinematic (RTK) unit. Added additional line length to float line as line had become severed and floats were missing. Floats were replaced.	Yes
	30-Oct-11			0.06		Spring 2011	436.94	Because of last minute scheduling change by the Operations Planners for the sustained minimum flow request required for the fall field session, the RTK survey was unable to be completed in conjunction with the scheduled sustained minimum flow on 30 October 2011. On 9 November 2011, a field crew attempted to complete this survey; however, due to equipment malfunction, the task was unable to be completed. RTK values will be confirmed in Spring 2012.	Yes
	19-Jun-12			0.06		Spring 2011	436.94	Sustained minimum flows (i.e., ≤155 m3/s) could not be achieved from REV for safe retreival of the data logger. High snowpack conditions and REV spill conditions did not allow for minimum flows below 170 m^3/s.	No
	24-Oct-12			0.06		Fall 2012	436.92	Two sustained minimum flow requests (i.e., ≤155 m3/s) were cancelled due a number of unit outages across the province and cold weather conditions; therefore stations could not be acceesed safely.	No
	18-Nov-12			0.058		Fall 2012	436.92	Anchor station had become dislodged (likely during REV spill conditions) and drifted 11m downstream and flipped over 180°. Anchor station was redeployed using new highly reflective anchor.	Yes
Station 4	18-Jul-07	Solinst Levelogger (M20)		3.59		2007	436.25		Install
	23-Aug-07		Prior to download and station re-location	7.32	Pipe moved	2007	433.61	At time of visit, standpipe housing was ~1 ft underwater, however, station was re-located ~15 m downstream to provide increased depth.	Yes
			Following station re-location	7.32		2007			No
	16-Nov-07			7.32		2007	433.61		Yes
	10-Apr-08			9.10		2007	431.78	Galvanized standpipe housing was replaced with stainless steel housing and additional length added on to prevent dewatering.	Yes
	26-Jun-08			9.10		2007	431.78	Logger could not be retrieved for downloading at current water level, as entire standpipe housing is underwater.	No
	24-Oct-08			9.10		2007	431.78		No
	15-Nov-08			9.10		2007	431.78		No
	27-Nov-08			9.10	+0.94	2007	431.18	Standpipe/logger height was increased by 0.94 m to access logger, entire housing was underwater.	Yes
	16-Apr-09			10.10		2009	432.23	Installed new stainless steel brackets along pipe housing with Hilti Hit epoxy, as station appeared to have been vandalized.	Yes
	25-Jun-09			10.10		2009	432.23	Added two stabilizer arms on upper section of pipe housing to increase robustness of standpipe housing.	Yes
	22-Oct-09			10.10		2009	432.23		
	14-Apr-10			10.10		2009	432.23	One meter increments were engraved along the pipe housing from for field quality control water level verifications during subsequent field service trips.	Yes
	17-Jun-10			10.10		2009	432.23		Yes
	5-Oct-10			10.10		2009	432.23	Upon inspection, stabilizer arm had been compromised. Replaced bolt that connected stabilizer arm to pipe housing clamp; replaced 'Fisheries Research Please Do Not Disturb' sign.	Yes
	28-Apr-11			10.10		2009	432.23	In the event that there was sediment at the bottom of the standpipe housing, potentially caused by high sediment loads from spring freshet, the standpipe housing was flushed out.	Yes
	16-Aug-11			10.10		2009	432.23		Yes
	29-Oct-11			10.10		2009	432.23		Yes
	22-Jun-12			10.10		2009	432.23		Yes
	15-Aug-12			10.10		2009	432.23		Yes
	24-Oct-12			10.10		2009	432.23	In the event that there was sediment at the bottom of the standpipe housing, potentially caused by high sediment loads from spring freshet, the standpipe housing was flushed out.	Yes
	28-Nov-08	Solinst Barologger (M1.5)	Barologger installed in separate pipe	0.40		n/a	--	A second barologger was added to study area in the event that the other logger malfunctions.	Install
	18-Mar-09			0.40		n/a	--		Yes
	16-Apr-09			0.40		n/a	--		Yes
	25-Jun-09			0.40		n/a	--		Yes
	22-Oct-09			0.40		n/a	--		Yes
	14-Apr-10			0.40		n/a	--		Yes
	17-Jun-10			0.40		n/a	--		Yes
	5-Oct-10			0.40		n/a	--		Yes
	28-Apr-11			0.40		n/a	--		Yes
	16-Aug-11			0.40		n/a	--		Yes
	29-Oct-11			0.40		n/a	--		Yes
	22-Jun-12			0.40		n/a	--		Yes
	15-Aug-12			0.40		n/a	--		Yes
	24-Oct-12			0.40		n/a	--		Yes
Station 5	18-Jul-07	Solinst Levelogger (M10)		3.53		2007	433.43		Install
	22-Aug-07			7.29	Pipe moved	2007	433.27	Standpipe housing and levelogger were ~ 6 inches out of the water at time of service, therefore measurements prior to download could not be attained. Measurements listed in this table are following station re-location 1.2 m upstream.	Yes
	15-Nov-07			7.29		2007	433.27		Yes
	11-Apr-08			7.29		2007	431.90	Added stainless steel pipe lengths to bottom end of standpipe housing. Top 10 ft of galvanized pipe could not be replaced as it was unsafe to access due to lower reservoir levels.	Yes
	26-Jun-08			9.00		2007	431.90	Replaced logger suspension wire with heavy duty aircraft cable, as existing wire became kinked.	Yes
	28-Nov-08			9.00		2007	431.90		Yes
	18-Apr-09			10.14	Pipe moved	2009	430.99	Entirely new stainless steel pipe housing was installed directly beside existing galvanized/stainless pipe housing. This maintenance was completed to ensure additional pipe housing lengths could be installed easily during low water levels. Logger changed out with new one.	Yes
	25-Jun-09			10.14		2009	430.99	Installed 2 stabilizer arms on top 2.5 m of pipe housing to increase robustness and increase attachment points to rock face.	Yes
	22-Oct-09			10.14		2009	430.99		Yes
	14-Apr-10			10.14		2009	430.99	One meter increments were engraved along the pipe housing from for field quality control water level verifications during subsequent field service trips.	Yes
	17-Jun-10			10.14		2009	430.99	Two access windows were added near the top of the standpipe housing to allow for safe datalogger retrieval at a wide range of water levels; without changing the elevation of the data logger, an additional length of threaded pipe (0.94m) was added to the top of the existing standpipe housing to maintain the entire standpipe housing above water at peak reservoir levels and ensure access for downloading of the data logger; standpipe housing was flushed with an in-line bilge pump, as a minor amount of sediment was observed on the levelogger sensor during the spring and summer 2010 download.	Yes
	5-Oct-10			10.14		2009	430.99		Yes

Station Designation	Installation or Servicing Dates	Type of Logger Installed or Re-Deployed	Station Relocation Notes	Distance from Constant Attachment Point or RTK Pad to Sensor (m)	Total Change in Top of Standpipe Height Affecting Orthometric Height (m)	RTK Values Used (Year Obtained)	Sensor Elevation (m)	Comments	Data Downloaded During Visit
	28-Apr-11			10.14		2009	430.99	In the event that there was sediment at the bottom of the standpipe housing, potentially caused by high sediment loads from spring freshet, the standpipe housing was flushed out.	Yes
	16-Aug-11			10.14		2009	430.99	Installed 'Fisheries Research Please Do Not Disturb' sign.	Yes
	29-Oct-11			10.14		2009	430.99		Yes
	22-Jun-12			10.14		2009	430.99		Yes
	15-Aug-12			10.14		2009	430.99		Yes
	24-Oct-12			10.12		2009	430.99	In the event that there was sediment at the bottom of the standpipe housing, potentially caused by high sediment loads from spring freshet, the standpipe housing was flushed out.	Yes
Station 6	17-Jul-07	Solinst Levelogger (M20)		3.87		2007	no angle		Install
	22-Aug-07		Prior to download	3.87		2007	no angle	Added extra pipe length and decreased elevation of standpipe housing by 0.14 m to increase maximum depth.	Yes
			Following re-deployment	5.72	1.71	2007	no angle		Yes
	15-Nov-07			5.72	-0.20	2007	no angle	Decreased elevation of standpipe housing by another 0.20 m to increase maximum depth.	Yes
	11-Apr-08			5.72		2007	no angle	Logger was downloaded and after reviewing data logger appeared to have malfunctioned. Logger was switched out with spare logger and redeployed in current location, however, standpipe housing was 0.74 m out of water at time of site visit. No additional pipe could be added due to rock ledge encountered at 0.4 m bottom of pipe.	Yes
	17-Jul-07	Solinst Barologger (M1.5)		0.37		2007	no angle		Install
	24-Aug-07			0.37	+0.14			Added extra pipe length on 22-Aug-07 and decreased elevation of standpipe housing by 0.14 m to increase maximum depth.	Yes
	15-Nov-07			0.37	+0.34				Yes
	11-Apr-08			0.37				Logger could not be retrieved due to low reservoir levels.	No
	22-Apr-08			0.37				Station was relocated approximately 75 m, on ~70° angled rock face, upstream and renamed Stn 6_2008 as previous location was dewatered and not suitable to add additional pipe lengths as a rock bench was encountered at lower elevations. Galvanized standpipe housing was replaced with stainless steel.	Yes

Station Designation	Installation or Servicing Dates	Type of Logger Installed or Re-Deployed	Station Relocation Notes	Distance from Constant Attachment Point or RTK Pad to Sensor (m)	Total Change in Top of Standpipe Height Affecting Orthometric Height (m)	RTK Values Used (Year Obtained)	Sensor Elevation (m)	Comments	Data Downloaded During Visit
Station 6_2008	22-Apr-08	Solinst Barologger (M1.5) and Levelogger (M20)		11.98	Pipe moved	2009	429.35	Station was relocated approximately 75 m, on ~70° angled rock face, upstream and renamed Stn 6_2008 as previous location was dewatered and not suitable to add additional pipe lengths as a rock bench was encountered at lower elevations. Galvanized standpipe housing was replaced with stainless steel.	Install
	26-Jun-08	Solinst Levelogger (M20)		11.98		2009	429.35	Logger malfunctioned, therefore no data is available from 22-Apr-08 to 26-Jun-08.	Yes; only 6 readings stored
	28-Nov-08			11.98		2009	429.35		Yes
	19-Mar-09			11.98		2009	429.35		Yes
	17-Apr-09			11.60		2009	429.35	Added 1.25m of extra pipe length as data showed pipe was out of water periodically in Feb and Mar 09. The line which attaches the logger to the top of standpipe was damaged when the 1.25 m of pipe was added. Since the top of pipe was inaccessible due to low water levels, a loop had to be tied in the existing line to prevent the line from snapping. The line will be replaced with aircraft cable during the next high water session. (cable length was decreased by 0.38m).	Yes
	24-Jun-09			13.35		2009	429.35	Changed out line which attaches the logger to the top of standpipe with aircraft cable; added one stabilizer arm ~3m from top of pipe; added 2 flush stainless steel brackets within top 1m of pipe. (1.75 m was added to total cable length).	Yes
	26-Oct-09			13.35		2009	429.35	Need stabilizer arm below top stabilizer arm and between 2nd and 3rd access window.	Yes
	14-Apr-10			13.35		2009	429.35	One meter increments were engraved along the pipe housing from 4m to 9m for field quality control water level verifications during subsequent field service trips.	Yes
	17-Jun-10			13.35		2009	429.35	One meter increments were engraved along the pipe housing from 10m to 13m for field quality control water level verifications during subsequent field service trips.	Yes
	5-Oct-10			13.35		2009	429.35		Yes
	28-Apr-11			13.35		2009	429.35	In the event that there was sediment at the bottom of the standpipe housing, potentially caused by high sediment loads from spring freshet, the standpipe housing was flushed out.	Yes
	16-Aug-11			13.35		2009	429.35		Yes
	29-Oct-11			13.35		2009	429.35		Yes
	22-Jun-12			13.35		2009	429.35		Yes
	15-Aug-12			13.35		2009	429.35		Yes
	24-Oct-12			13.35		2009	429.35	In the event that there was sediment at the bottom of the standpipe housing, potentially caused by high sediment loads from spring freshet, the standpipe housing was flushed out.	Yes
Station 8	23-Aug-07	Solinst Levelogger (M10)		4.24		2007	no angle		Install
	13-Nov-07			4.24		2007	no angle		Yes
	9-Apr-08			4.24		2007	no angle		Yes
	24-Jun-08			4.24		2007	no angle	Attempt to download logger, however, wire attaching logger to constant attachment point was severed. Could not properly assess standpipe housing due to high water levels.	No
	25-Oct-08			4.24		2007	no angle	Visit at lower water levels showed that the bottom section of standpipe housing and logger are missing. High velocities during spring freshet are likely responsible as pipe threading is severed on remaining section of standpipe housing.	No
Station 8_2008	26-Nov-08	Solinst Levelogger (M10)	Relocated u/s (above Kirkup Creek) in order to correlate with WSC historical station	1.09	Pipe moved	2009	532.72	Set to 30 minute intervals in order to ensure enough room for data recordings if site could not be accessed during spring freshet.	Install
	15-Sep-09			1.09		2010	532.59		Yes
	21-Oct-09			1.09		2010	532.59	Installed two stainless steel brackets along standpipe housing to increase robustness of standpipe housing.	Yes
	15-Apr-10			1.09		2010	532.59		Yes
	18-Jun-10			1.09		2010	532.59	Could not be accessed due to late spring freshet conditions (i.e., high flow conditions); therefore, the data was not retrieved as the station is located mid-channel and Jordan River was unsafe to wade across.	No
	5-Oct-10			1.09		2010	532.59	The historic Water Survey of Canada (WSC) benchmark was located; both the standpipe housing and benchmark were surveyed with the RTK unit to be tied into WSC's historic flow rating curve; stage-discharge measurements were conducted near the WSC Jordan River historic gauge station and the standpipe housing.	Yes
	29-Apr-11			1.09		2010	532.59	Could not be accessed due to late spring freshet conditions and snow cover on access road; therefore, the data was not retrieved.	No
Station 8_2011	18-19-Aug-11	Solinst Levelogger (M10)		1.95	Pipe moved	Oct 2012	534.29	Standpipe housing was re-located ~5m around side of rock as existing location became a sand depositional area following changes to channel morphology. RTK value was scheduled to be obtained in Fall 2011 (see below).	Yes
	28-Oct-11			1.95		Oct 2012	534.29	The RTK survey was unable to be completed in conjunction with the scheduled sustained minimum flow on 30 October 2011. On 9 November 2011, a field crew attempted to complete this survey; however, due to equipment malfunction, the task was unable to be completed. RTK values will be obtained in 2012.	Yes
	16-Aug-12			1.95		Oct 2012	534.29		Yes
	23-Oct-12			1.95		Oct 2012	534.29		Yes

Table A-2 Locations, distances, and elevations at data logger sensors, benchmarks and known monument locations for CLBMON-15a Physical Habitat Monitoring Program stage and temperature index stations in the Middle Columbia, Illecillewaet, and Jordan rivers, 2012.

Site Designation	Installed By	River	River Kilometer (Rkm)[a]	Bank[b]	UTM Coordinates			Sensor Elevation (m)
					Zone	Easting	Northing	
GCM #143803	ILMB	Columbia	229.8	LB	11	414518.663	5651354.121	445.79
Benchmark (2010)	Ecoscape	Columbia	235.5	LB	11	414893.783	5654223.797	452.73
Benchmark (2011)	Golder	Columbia	235.5	LB	11	414894.902	5654224.084	452.77
Control Point (2011)	Golder	Columbia	235.5	LB	11	414897.204	5654218.521	452.74
Control Point (2012)	Golder	Columbia	235.5	LB	11	414897.547	5654221.873	452.93
Station 1 Benchmark (2010)	Golder	Columbia	237.2	RB	11	415035.056	5655576.847	443.40
Station 1	Golder	Columbia	237.4	RB	11	415057.223	5655583.607	438.58
Station 1_AS[c]	Golder	Columbia	237	RB	11	415070.093	5655564.164	435.73
Station 2	Golder	Columbia	234	LB	11	414915.903	5653187.726	436.79
Station 2_AS[c]	Golder	Columbia	232.5	LB	11	414904.765	5653174.730	436.10
Station 3	Golder	Columbia	230.3	LB	11	413637[d]	5651589[d]	434.43
Station 4	Golder	Columbia	227	RB	11	414799.586	5648492.091	432.23
Station 5	Golder	Columbia	222	RB	11	415487.506	5645102.815	430.99
Station 6	Golder	Columbia	218.9	RB	11	417306.832	5641996.013	n/a[e]
Station 6_2008	Golder	Columbia	219	RB	11	417225.706	5642026.934	429.35
Station 7_discharge	Golder	Illecillewaet	5.5	LB	11	423700[d]	5651691[d]	n/a[e]
Station 7_temperature	Golder	Illecillewaet	5.6	RB	11	424197[d]	5652110[d]	503[d]
Station 7_temperature	Golder	Illecillewaet	5.6	RB	11	424199[d]	5652110[d]	503[d]
Station 7 Benchmark 5 (WSC)[f]	WSC	Illecillewaet	5.6	LB	11	423861.868	5651777.706	505.253
Station 8	Golder	Jordan	2	LB	11	412646.391	5653277.718	n/a[e]
Station 8_2008	Golder	Jordan	6	MID	11	410947.094	5655507.170	532.59
Station 8_2011	Golder	Jordan	6	MID	11	410949.503	5655513.707	532.4
Station 8 Benchmark (WSC)[f]	WSC	Jordan	6	RB	11	410917.717	5655469.483	534.69
Station 8_Velocity Transect[g]	Golder	Jordan	6	RB	11	410948[d]	5655457[d]	533[d]

[a] River kilometres downstream from Revelstoke Dam (MCR stations) or confluence with Columbia River (for tributaries)

[b] RB=Right bank looking downstream; LB=Left bank looking downstream; MID=mid channel

[c] AS=Anchor system stations deployed nearby related station number to capture water levels between zero to minimum flow (142 m^3s^{-1}).

[d] Obtained with handheld global positioning system.

[e] Data not available.

[f] To provide an elevational link to the Golder stage data, the Water Survey of Canada (WSC) benchmarks were located and reference elevations linked to Golder stage data, as there was no precise elevation available from WSC for these historic station.

[g] Future velocities measurements will be collected over a range of discharges to generate a revised stage-discharge curve for the Jordan River. The Jordan River discharges will be used to calculate influence of the Jordan River on MCR when developing in the CLBMON-15a HEC-RAS model.

ILMB = Integrated Land Management Bureau

GCM = Geodetic Control Marker

Table A-3 Manufacturer Real Time Kinematic (RTK) performance specifications for the systems used during the CLBMON-15a Physical Habitat

Name	Horizontal Accuracy (mm)	Horizontal Accuracy Root Mean Square (RMS) (ppm)	Vertical Accuracy (mm)	Vertical Accuracy Root Mean Square (RMS) (ppm)	Initialization time (seconds)	Initialization Reliability (%)	Year Used
Leica GPS1200	10	1	20	1	8	99.9	2009
Altus APS-3	10	1	20	2	7	99.8	2011
Trimble R8	8	1	15	1	<8	99.9	2010

Table A-4 Data Availability for Years 2009, 2010, 2011 and 2012 for CLBMON-15a Physical Habitat Monitoring Program stage and water temperature index stations on the middle Columbia River near Revelstoke, BC.

CLBMON-15a Site Designation	Alternative Station Reference	Maintained By	Data
Station 1		Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
Station 1_AS		Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
Station 2		Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
Station 2_AS		Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
Station 3	TR2 or Tailrace-7km	BC Hydro	*Temperature (°C)*
			Stage (m)
Station 4		Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
Station 5		Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
Station 6_2008		Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
Station 7	Illecillewaet River 08ND013	Golder Associates Ltd. Water Survey of Canada	*Temperature (°C)*
			Stage (m)
			Hourly discharge (cms)
Station 8_2008	Jordan River	Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
Station 8_2011	Jordan River	Golder Associates Ltd.	*Temperature (°C)*
			Stage (m)
REV	Revelstoke Dam	BC Hydro	*10-min discharge (cms)*
			Hourly discharge (cms)

Monitoring years: 2007 Monitoring Year (Jul–Dec), 2008 Monitoring Year (Jan–Dec), 2009 Monitoring Year (Jan–Dec), 2010 Monitoring Year (Jan–Dec), 2011 Monitoring Year (Jan–Dec), 2012 Monitoring Year (Jan–Dec).

Colour	Legend
Blue	Temperature Data
Red	Water Elevation in Geodatic Datum
Purple	Water Elevation in Local Datum
Green	Discharge Data

APPENDIX B

HEC-RAS Model and Calibration

Golder Associates

TECHNICAL MEMORANDUM

DATE January 24, 2014 **REFERENCE No.** 1214920084-001-TM-Rev0

TO Demitria Burgoon
Golder Associates Ltd.

CC Rick Rodman

FROM Mike Paget, Dan Walker **EMAIL** mpaget@golder.com, drwalker@golder.com

CLBMON-15A MIDDLE COLUMBIA RIVER, PHYSICAL HABITAT MONITORING-TASK 5 HYDRAULIC MODEL CALIBRATION AND APPLICATION

1.0 INTRODUCTION

The Revelstoke Dam (REV) is located on the middle Columbia River (MCR) in British Columbia, Canada, approximately 8 km upstream from the Trans-Canada Highway Bridge, which crosses the Columbia River at the City of Revelstoke. Discharges from the dam flow down the MCR and into the Arrow Lakes Reservoir (ALR), which is impounded by the Hugh L. Keenleyside Dam (HLK) approximately 250 km downstream of the REV.

The REV is operated as a daily peaking facility and daily flow releases can fluctuate from approximately 8.5 m^3s^{-1}(seepage flows from the dam during zero generation) up to approximately 2,124 m^3s^{-1} (with the addition of a fifth turbine REV5 in December 2010; peak flows prior to REV5 were approximately 1,750 m^3s^{-1}). The operational procedures at the REV were amended in December of 2010 such that the minimum discharge was increased to 142 m^3s^{-1} in order to increase available fish habitat in the MCR.

ALR levels can fluctuate between 420.0 m and 440.2 m, and can cause a backwater effect into the MCR during times of high reservoir levels (Klohn 2010). In addition, there is the potential for the ALR to surcharge to 440.7 m. The MCR-ALR interface zone is pushed upstream by high ALR levels and downstream by high MCR flows. It can reach up to REV when ALR levels are high and the discharges from REV are low. At low ALR levels, the MCR-ALR interface extends as far as 50 km downstream of the REV.

The daily REV discharge fluctuations significantly affect the availability and suitability of MCR aquatic habitat between the REV and the MCR-ALR interface zone. In 2007, BC Hydro commissioned the MCR Physical Habitat Monitoring Program to collect physical habitat and water quality information on the MCR. The study area includes the reaches of the MCR from the REV downstream to the confluence with the Akolkolex River, a distance of approximately 37 km. Given the dynamic and complex nature of the regulated flow regime, and the geographic extent of the MCR study area, a hydraulic model is required to predict the effects of REV discharge and local inflows on hydraulic parameters along the river, such as wetted width, flow depth, and average flow velocity.

A HEC-RAS model of the MCR was developed by Korman et al. in 2002; however, the model was not calibrated at that time (Korman et al. 2002). In 2007, Golder retained Klohn Crippen Berger Ltd. (Klohn) as sub-consultants to assist with the calibration of the existing model based on river stage data collected by Golder between 2007 and 2009. In 2010 and 2011, Golder, with the assistance of Rodman Hydrotechnical Ltd., assumed responsibility for the model calibration exercise, using 2010, 2011 and 2012 data to build upon the previous calibrations performed by Klohn (2010). Rick Rodman, of Rodman Hydrotechnical Ltd., was sub-contracted by Golder as project advisor to the model calibration and application. Mr. Rodman has direct experience with the MCR Physical Habitat Monitoring program from 2007 to 2009, and was also involved in the hydraulic model used in the Environmental Assessment (EA) process for REV5 and Mica5/6.

The objectives of the MCR hydraulic model calibration and application are as follows:

- To use stage data collected during the monitoring program to calibrate the existing one-dimensional (1-d) steady and unsteady state hydraulic models for the MCR and to use those models to estimate potential changes in the wetted river channel;
- To estimate changes in the quantity and spatial distribution of a permanently inundated river channel resulting from 142 m^3s^{-1} minimum flow releases; and
- To use the empirical data and hydraulic modelling results to test hypotheses about the influence of minimum flow releases on the hydraulic characteristics of the MCR.

2.0 2010 SITE VISIT

A site visit was completed in October of 2010. The objective of the site visit was to familiarize Golder hydrologists with the study area and to understand and assess the following major physical features in the MCR for modelling purposes: the dam, the conveyance systems, the floodplains, and the downstream valley. This was considered important for providing a realistic representation of the physical system in the modelling analysis.

The site visit focused on understanding and defining the characteristics of the flow conveyance channels, including geometry, roughness, and types of ground cover. Additionally, the site visit provided a time for the Golder field staff to review the river stage/temperature monitoring stations, which provide the measured water elevations used for calibrating the HEC-RAS Hydraulic model.

3.0 RIVER HYDRAULIC MODEL

HEC-RAS version 4.1.0 (USACE 2010) is a 1-d hydraulic model developed for modelling water profiles within river systems for both steady and unsteady state flow conditions. In steady state analysis, discharge does not vary with time, while in unsteady state analysis, the discharge changes with time. HEC-RAS is widely used throughout the world and is approved for use in river inundation studies by the U.S. Federal Emergency Management Agency.

The following sections outline the HEC-RAS model inputs and assumptions for the MCR, including the following:

- Cross Section Characteristics;
- Stage and Discharge Gauging Stations;

- Tributary Inflows;
- Bridges; and
- Contraction and Expansion Coefficients.

3.1 MCR Model: Cross Section Geometry Sources

The existing MCR HEC-RAS developed by Korman et al. (2002) covers the Columbia River from the Revelstoke Dam to just downstream of the confluence with the Akolkolex River; a distance of approximately 37 km (Figure 1). The model consists of 243 cross sections. The 76 cross sections within the upper reaches of the model were developed from surveys conducted during the early 1990s for the REV tailrace study (R.L.&L Environmental Services, 1994). The remaining cross sections were developed from a combination of topography obtained from aerial photographs taken in 2000, Ministry of Environment 1983 floodplain mapping, and bathymetric data obtained from the Canadian Hydrographic Service (CHS). Klohn used DEM files provided by BC Hydro to extend the cross sections during the 2009 model calibrations (Klohn 2010). In addition, cross sections 200 to 158 were updated using Acoustic Doppler Current Profiler (ADCP) data obtained the following studies: “Mid Columbia River White Sturgeon Spawning Habitat Assessment” (CLBMON-20; Golder 2011a) and “Effects of Flow Changes on Incubation and Early Rearing Habitat” (CLBMON-54; Golder 2001b).

Apart from the cross section extensions and updates described above, the existing CLBMON-15a HEC-RAS Model was calibrated based on the assumption that there have been no substantive changes in the river geometry or bedforms since the model was developed in 2002. Table 1 below provides a summary of the available cross section data.

Table 1: Summary the Cross-Section Geometry Data Sources - CLBMON-15a HEC-RAS Hydraulic Model of the middle Columbia River (see Figure 1 for cross section locations)

Data Source	Data Type	Collection Year	Model Location (Cross Sections)	Comments
REV tailrace study	Bathymetry	1990s	243 to 167	Used to create upper reach cross sections
BC Hydro	Bathymetry	2002	239 to 175	Used to update upper reach cross sections
NA[1]	Aerial photographs	2000	166 to 1	Used in conjunction with flood plan mapping for the lower reach
Ministry of Environment	Floodplain mapping	1983	166to 1	Used in conjunction with Aerial photography for the lower reach
BC-Hydro[2]	DEM	NA	243 to 1	Used to extend model cross sections
Golder[3]	ADCP	2010	200 to 158	Used to update cross sections for this study
Tailrace excavation	N/A	N/A	N/A	Tailrace excavation occurred in 2003 causing changes to channel morphology

Notes:
[1] The original source of the aerial photographs is unknown; the data were likely sourced from either the Provincial Air photo library or UBC air photo library.
[2] DEM provided by BC Hydro to Klohn Crippen Berger Ltd.; year of data collection unknown.
[3] Data obtained from the CLBMON-20 and 54: “Mid Columbia River White Sturgeon Spawning Habitat Assessment” and “Effects of Flow Changes on Incubation and Early Rearing Habitat” (Golder 2011a,b).
N/A indicates not available.

3.2 Stage, Discharge, and Temperature Gauging Stations

A series of measured stage hydrographs (water levels) were used to validate the CLBMON-15a HEC-RAS model results. This section describes the information collected for the stage hydrographs, and the data used in the hydraulic model.

Data were collected from a total of nine stage/temperature monitoring locations for calibration and running the CLBMON-15a HEC-RAS Model. Table 2 summarizes the index station details. Golder's field program included the maintenance and download of Station Numbers 1, 2, 4, 5, and 6_2008; the remaining stations (Station 3 and Arrow Lake at Nakusp) are pre-existing and operated by BC Hydro. The locations of the index stations are shown in Figure 1 and their data availability is shown in Figure 2.

Index stations for the Physical Habitat Monitoring Program are located in 3 reaches of the MCR and 2 tributaries:

- MCR Reach 4 – Revelstoke Dam downstream to the Jordan River confluence (cross sections 243-183);
- MCR Reach 3 – the Jordan River confluence downstream to the Illecillewaet River confluence (cross sections 182-150);
- MCR Reach 2 – the Illecillewaet River confluence downstream to the Akolkolex River confluence(cross sections 149-16); and
- Tributaries – Illecillewaet River at the Greeley Bridge crossing and Jordan River upstream from the mouth.

Reach 1 (the Akolkolex River confluence downstream to Arrowhead), was proposed as a part of the study area in the Request For Proposal; however, stage/temperature monitoring stations were not feasible due to the large changes in vertical water level in this area coupled with the shallow sloping of the banks. The hydraulic model extends 3.7 km downstream of the confluence of the Akolkolex River (cross sections 15-1).

On examination of the data from Station 1 and Station 2, it was determined that both Station 1 and Station 2 data loggers were not submerged during periods of low flow. This data gap was filled by the addition of two new data loggers installed in a deeper section of the river channel in October of 2010 (Station 1_AS and Station 2_AS). As described in Golder (2008, 2010), two different locations are shown for Station Number 6 as the station was re-located in June 2009. The data from Station 6_2008 were used in the model calibration as this station provided a more complete measurement data set.

Table 2: Summary of Temperature and Stage Recording Stations in the MCR.

Index Station	Station Operator	Model Reach	Model Cross Section	Parameters	Data Interval	River Kilometer (Rkm)
Station 1	Golder	Reach 4	221	Stage/Temp	10 minute	237.4
Station 1_AS	Golder	Reach 4	221	Stage/Temp	10 minute	237
Station 2	Golder	Reach 4	182	Stage/Temp	10 minute	234
Station 2_AS	Golder	Reach 4	182	Stage/Temp	10 minute	232.5
Station 3	BC Hydro	Reach 3	175	Stage/Temp	10 minute & hourly	230.3
Station 4	Golder	Reach 2	150	Stage/Temp	10 minute	227
Station 5	Golder	Reach 2	129	Stage/Temp	10 minute	222
Station 6	Golder	Reach 2	111	Stage/Temp	10 minute	218.9
Station 6_2008	Golder	Reach 2	111	Stage/Temp	10 minute	219
Arrow Lake at Nakusp[2]	BC Hydro	N/A[3]	NA[3]	Water Level	Hourly	137

Notes:
[1] Stage/discharge curve still under development for this Station.
[2] Water level from Arrow Lakes Reservoir is used as the downstream boundary condition when reservoir level is high (i.e., above El. 430 m).
[3] Station is located downstream of the model.

The data collected from Stations 1_AS, Station 2_AS, Station 3 through 5, and Station 6_2008 were used to calibrate the HEC-RAS steady state and unsteady state models. Water level data provided by BC Hydro for the ALR at Nakusp were used as the downstream boundary condition for the model during periods of elevated reservoir levels; that is, when the ALR surface water elevation was above El. 430 m.

3.3 Tributary inflows

The MCR has three large tributaries: the Illecillewaet River; the Jordan River; and the Alkolkolex River. The Illecillewaet River, which is the largest of the three tributaries, has an active WSC stream gauging station (WSC Station 08ND013; labeled as Station 7 for this study). As shown in Figure 2, discharge data for the Illecillewaet are available for the monitoring period March 2009 to December 2012, with only a few data gaps due to frozen conditions.

Golder's monitoring Station 8 and Station 8_2008 were installed on the Jordan River for the purpose of collecting stream flow data for this study. Station 8_2008 is located near the historic Water Survey of Canada (WSC) stream gauging site on the Jordan River (WSC Station 08ND014). The WSC station was active from 1946-1957 and 1963 to 1988. WSC does not have the correction factor to convert the rating curve for Station 08ND014 to the Geodetic datum, and additional discharge measurements are required to generate a reliable stage-discharge relationship for the station.

To estimate Jordan River Inflows to the MCR, a correlation based on a ranked regression analysis of concurrent flow data (twenty-six years of data spanning 1963 to 1988) from the Illecillewaet River at Greeley (WSC Station 08ND013) and Jordan River above Kirkup Creek (WSC station 08ND014) was developed. The resulting relationship was used to correlate measured water level data with the estimated flow data at the Jordan River above Kirkup Creek station in 2011. The resulting hydrograph was compared to measured flow data on the Jordan River collected in October and August 2011, and were found to be consistent. The flows were then scaled by watershed area to provide estimated total flow in Jordan River at its confluence with the MCR.

Since there is no water level or flow data available for the Akolkolex River, Akolkolex flows were estimated based on a ranked regression analysis of four years of concurrent data (four years if data spanning 1912 to 1916) from the Illecillewaet River at Greeley (WSC Station 08ND013) and Akolkolex River near Revelstoke (WSC station 08ND001).

The 2012 CLBMON-15a HEC-RAS Model has tributary inflows at select locations. The estimated inflows were based on the relationships discussed above. The mean annual discharges for the three largest tributaries are estimated as follows:

- Jordan River 24 m^3s^{-1};
- Illecillewaet River 57 m^3s^{-1}; and
- Akolkolex River 24m^3s^{-1}.

In addition to the Illecillewaet, Jordon and Akolkolex rivers, three smaller tributaries also enter the MCR; namely, Begbie Creek, Drimmie Creek, and Mulvehill Creek. A constant inflow was assumed for each of these creeks as the seasonal variation is not anticipated to be significant enough to effect modelling results. Tributary and monitoring details are summarized in Table 3 below.

Table 3: Tributaries Inflows for the Hydraulic Model of the Mid Columbia River[1]

Tributary	Period of Record[1]	Length of Record (years)[1]	Mean Annual Flow $(m^3s^{-1})^2$	Model Cross Section	Model Inflow Estimate Method
Jordan River (Station 8_2008)	1946-1957 1963-1988	4 26	17	182	Station 8_2008 flows based on measured level data correlated to Illecillewaet flows
Illecillewaet River (Station 7)	1911-1916 1963-2010	4 47	43	150	WSC Station Data
Akolkolex River	1912-1922 1954	11	14	16	Akolkolex flows based on Illecillewaet flows adjusted using historical correlation.
Begbie	NA	NA	3.4	104	Constant inflow
Drimmie	NA	NA	5.5	68	Constant inflow
Mulvehill	NA	NA	2.8	49	Constant inflow

Notes:
[1] WSC station data
[2] Mean annual flows estimated from BC Hydro (1985 to 2000)

3.4 Bridges

Three bridges cross the MCR within the study area: the Trans-Canada Highway Bridge, Railway Bridge, and Big Eddy Road Bridge. All three bridges are located within the City of Revelstoke, approximately 8 km downstream of REV between cross sections 168 and 171.

The 2002 HEC-RAS model did not include the bridges. The bridges were added to the model by Klohn (2010) based on information taken from GoogleTM satellite and Street View imagery. The number of bridge piers, pier shapes and pier widths were determined by Klohn from the imagery and confirmed by Golder during the October 2010 site visit. The bridge details are summarized in Table 4 below.

Table 4: Bridge Details Located within the Mid Columbia River Study Area for CLBMON-15a Physical Habitat Monitoring.

Bridge	No. of Piers	Pier Type	Width of Piers (m)	Bridge Deck Clearance
Trans-Canada Highway	1 1	Semi-circular	3 14	Above flood level
Railway	7	Semi-circular	2	Above flood level
Big Eddy	7	Semi-circular	2	Above flood level

3.5 Contraction and Expansion Coefficients

Energy is lost as flowing water expands and contracts due to the widening and narrowing of channel geometry. Contraction and expansion coefficients are used to compute the energy losses between cross sections. Except in the vicinity of Big Eddy, typical contraction and expansion coefficients of 0.1 and 0.3, respectively, were assumed in the model. These values correspond to gradual contractions and expansions. At Big Eddy, the river contracts and expands abruptly; therefore, a contraction coefficient of 0.4 and an expansion coefficient of 0.5 were assumed to model cross sections 178 to 176 (Figure 1).

4.0 MODEL CALIBRATION

4.1 Steady State Calibration Procedure

The model was first run in steady state under a variety of REV discharges and ALR water levels. Discharges were selected during periods when discharge was maintained at a constant value for a minimum of 160 minutes. The constant flow allowed the river system to reach a steady state water level, and provided a more accurate comparison of modeled and measured water levels. The 2012 model calibration used 2011 and 2012 discharge data as they are the most complete and are consistent with flows measured in other years.

To ensure an unbiased calibration, the discharge series selected from the REV were divided into calibration and validation runs. In calibrations runs, model parameters are adjusted to create similar measured and modelled results; while in validation runs, no parameters are adjusted. Model parameters, particularly Manning's roughness coefficients, were adjusted when running the calibration runs such that the results of the model agreed with the recorded stream gauging data as closely as possible. Once the model was calibrated for the steady flows, it was run against the series of steady flow validation runs to verify that measured and modelled results were similar.

Based on general observations of roughness made on site, the model was divided into five roughness sections with a general decreasing trend in the downstream direction. The one exception to this trend is the area from downstream of the bridges to just above the junction of the Illecillewaet River, where the roughness increases due to the meandering nature of the main river channel and floodplain in this area.

A Manning's "n" value was selected for each cross-section based on a comparison between the field observations and literature values (Hicks, 1998; USGS, 2001). Based on field observations, the main channel in Reach 4 (cross sections 243 to 183) was assumed to be composed of mainly boulders and cobbles ("n" values of 0.03 to 0.035). Reach 3 and the upper section of Reach 2 also exhibited mainly boulders and cobbles (cross section 182 to 126); however, higher "n" values were required at low flows in this reach to reflect energy losses due to low flow channel sinuosity, rock outcrops, large eddies and sand/cobble bars ("n" values of 0.035 to 0.08). The lower section of Reach 2 and the upper section of Reach 1 exhibited smaller sediments, with more sands and cobbles ("n" values of 0.017 to 0.04).

The Manning's "n" typically decreased with increasing flows or a reduction in the relative influence of channel bed and bank roughness on the flow. The steady state model calibration n values are shown in Table 5 below.

Table 5: Manning's "n" Coefficients for Varying Flow Rates for the Steady State Hydraulic Model of the middle Columbia River.

Model Cross Section Range	Reach	Flow Range				
		0-200 (m^3s^{-1})	200-400 (m^3s^{-1})	400-1000 (m^3s^{-1})	1000-2000 (m^3s^{-1})	Greater than 2000 (m^3s^{-1})
243-201	Reach 4	0.035	0.035	0.030	0.030	0.030
200-183	Reach 4	0.030	0.030	0.030	0.030	0.030
182-168	Reach 3	0.080	0.050	0.045	0.035	0.035
167-126	Reach 3-Reach 2	0.080	0.050	0.045	0.035	0.030
125-1	Reach 2-Reach 1	0.040	0.030	0.020	0.017	0.017

In addition to adjusting the Manning's n values, the elevation of cross sections 125 to 127 was lowered by 0.5 m, while cross sections 143 and 173 were raised by 0.5 m (see Figure 1 for cross-section locations). These adjustments are within the range of accuracy of the mapping used to generate the cross sections.

4.2 Steady State Verification Results

Table 6 shows the modelled versus observed water levels for the 10 validation runs. The modelled water levels had a maximum difference of 0.22 m from observed water levels. The calculated BIAS coefficient for the modelled results, or the average of the difference between observed and modelled water elevations for each verification run, is 0.01 m. The root mean squared error (RMSE), or the average of the absolute values of the differences, was 0.12 m. These results demonstrate that the steady state model is capable of predicting observed water elevations for a range of ALR levels and discharges from REV (Figures 3 and 4).

Table 6: Verification Results for the Steady State Hydraulic Model of the middle Columbia River Using Revelstoke Dam (REV) Discharge and Arrow Lakes Reservoir Levels at Nakusp, BC.

Reservoir Condition		**Low Arrow Lakes Reservoir Levels [1]**						**High Arrow Lakes Reservoir Levels [2]**			
Profile Date		16-Apr-12	27-Apr-11	13-Apr-11	1-Apr-11	10-Apr-12	24-Feb-12	12-Jun-12	20-Oct-11	29-Aug-11	7-Jun-12
REV Dam Discharge (m^3s^{-1})		155	311	678	1120	1455	2039	157	352	925	1706
Arrow Lakes Reservoir Level (masl)		427.73	430.56	430.57	430.56	427.64	429.62	435.43	436.59	438.17	434.58
Cross Section	Station	Observed Water Levels (masl)									
221	Station 1_AS	438.17	438.86	440.04	441.15	441.83	442.81	438.22	439.03	440.93	442.38
200	Station 2_AS	437.37	438.03	439.01	439.90	440.47	441.19	437.45	438.15	439.75	440.87
175	Station 3	NA	436.40	437.09	437.62	NA	NA	NA	436.87	438.59	NA
150	Station 4	434.16	434.44	435.10	435.72	436.24	436.68	435.61	436.57	438.24	436.79
129	Station 5	431.66	431.95	432.65	433.31	433.79	434.23	435.28	436.55	438.19	435.20
111	Station 6_2008	430.29	430.80	431.22	431.65	432.17	432.76	435.45	436.59	438.17	434.95
Cross Section	Station	Modelled Water Levels (masl)									
221	Station 1_AS	438.03	438.89	440.07	441.18	441.85	442.8	438.08	439.10	440.83	442.29
200	Station 2_AS	437.41	438.09	439.16	440.01	440.56	441.34	437.52	438.30	439.90	440.93
175	Station 3	435.88	436.19	437.17	437.68	438.21	438.83	436.52	437.04	438.75	438.67
150	Station 4	433.91	434.34	435.24	435.80	436.34	436.76	435.83	436.69	438.32	437.01
129	Station 5	431.43	431.83	432.54	433.09	433.60	434.11	435.48	436.60	438.19	435.17
111	Station 6_2008	430.36	430.65	431.14	431.71	432.16	432.69	435.44	436.60	438.18	434.80

Reservoir Condition		Low Arrow Lakes Reservoir Levels [1]						High Arrow Lakes Reservoir Levels [2]			
Cross Section	Station	Modelled Water Levels minus Observed Water Levels (m)									
221	Station 1_AS	0.14	-0.03	-0.03	-0.03	-0.02	0.01	0.14	-0.07	0.10	0.09
200	Station 2_AS	-0.04	-0.06	-0.15	-0.11	-0.09	-0.15	-0.07	-0.15	-0.15	-0.06
175	Station 3	NA	0.21	-0.08	-0.06	NA	NA	NA	-0.17	-0.16	NA
150	Station 4	0.25	0.10	-0.14	-0.08	-0.10	-0.08	-0.22	-0.12	-0.08	-0.22
129	Station 5	0.23	0.12	0.11	0.22	0.19	0.12	-0.20	-0.05	0.00	0.03
111	Station 6_2008	-0.07	0.15	0.08	-0.06	0.01	0.07	0.01	-0.01	-0.01	0.15

Notes:
[1] For ‘Low Arrow Lakes Reservoir Levels ‘(less than 431 masl) the downstream boundary assumed an energy slope of 0.00024 to determine the normal depth for each specific flow.
[2] For ‘High Arrow Lakes Reservoir Levels ‘(greater than 431 masl). The downstream boundary for the model was the reservoir water level recorded by BC Hydro.

4.3 Unsteady State Calibrations

The unsteady state calibrations were conducted using the same methodology as the steady state calibrations, and with no modifications to the cross section geometries. Varying the Manning's "n" coefficient based on the discharge level led to less accurate results. Manning's "n" was therefore fixed for the unsteady state simulations at the values presented in Table 7 below. Lower "n" values adversely affected the timing of the dynamic flow changes and so where not used.

Table 7: Manning's "n" Coefficients for the 2011 Unsteady State Hydraulic Model Runs of the middle Columbia River.

Model Cross Section Range	Manning's "n"
243-201	0.035
200-183	0.030
182-168	0.045
167-124	0.038
123-116	0.028
115-1	0.020

Four validation runs were performed for the unsteady state model. A low ALR level (427.73 masl), a medium-low ALR level (433.01 to 434.86 masl), a medium-high ALR level (437.0 masl), and a high ALR level (439.1 masl). The flow varied throughout each run. The unsteady state model verification results are presented in Table 8.

For low ALR levels, the unsteady model produced a maximum difference of -0.63 m between observed and measured water levels and an average difference of -0.03 m. Modelled water levels are, on average the same as measured levels for all stations (refer to Figure 5).

For medium-low ALR levels, the unsteady model has a maximum difference of -0.86 m between observed and measured water levels and an average difference of 0.08 m. Modelled water levels are, on average the same as measured levels for all stations (refer to Figure 6).

For medium-high ALR levels, the unsteady model has a maximum difference of 1.08 m between observed and measured water levels and an average difference of 0.05 m. Modelled water levels are, on average the same as measured levels for all stations (refer to Figure 7).

For High Arrow Lakes Reservoir levels, the model has a maximum difference of 0.60 m between observed and measured water levels and an average difference of 0.05 m. Modelled water levels are, on average the same as measured levels for all stations (refer to Figure 8).

Overall, the unsteady modelled flows mimic the peaks and timing of the measured water levels. Although there is a maximum difference of 1.08 m between the measured and modelled water levels, these differences are attributed to the small shifts in the timing of the large discharge fluctuations. The average differences vary between -0.21 m and 0.13 m, indicating that the unsteady model is capable of predicting the measured patterns in water levels. These average differences in water levels are within the expected accuracy of the model.

Table 8: Verification Results-Modelled Water Levels Minus Observed Water Levels for the Unsteady State Model of the middle Columbia River Using Three Validation Runs of the Arrow Lakes Reservoir.

Reservoir Level	Parameter[1]	Station 1_AS	Station 2_AS	Station 3	Station 4	Station 5	Station 6
Low (April 18 to April 26, 2012)	Lower bound (m)	-0.47	-0.43	NA	-0.43	-0.63	-0.60
	Upper Bound (m)	0.42	0.35	NA	0.41	0.27	0.32
	Average Difference (m)	-0.04	0.04	NA	-0.13	-0.12	0.08
Medium-Low (June 1 to June 9, 2012)	Lower bound (m)	-0.86	-0.45	NA	-0.19	0.00	-0.25
	Upper Bound (m)	0.38	0.63	NA	0.54	0.30	0.09
	Average Difference (m)	0.03	0.06	NA	0.21	0.17	-0.08
Medium High (Sept 14 to Sept 21, 2011)	Lower bound (m)	-0.28	-0.15	-0.52	0.00	-0.07	-0.08
	Upper Bound (m)	0.38	0.31	1.08	0.17	0.10	0.08
	Average Difference (m)	-0.01	0.05	0.14	0.08	0.02	0.00
High (July 16 to July 22, 2011)	Lower bound (m)	-0.27	-0.05	-0.57	-0.07	-0.12	-0.12
	Upper Bound (m)	0.36	0.28	0.60	0.19	0.13	0.09
	Average Difference (m)	0.07	0.11	0.09	0.04	0.00	-0.02
Summary	BIAS(m)	0.01	0.07	0.12	0.05	0.01	-0.01
	RMSE (m)	0.09	0.14	0.17	0.26	0.21	0.11

Note:
[1] Values presented are the difference between modelled and measured water levels. For all three parameters, positive values indicate that modelled water levels were above observed levels and negative values indicate that modelled levels were below observed values.

5.0 MODEL RESULTS FOR FISHERIES TIME PERIODS

Steady state model runs were selected to represent the two critical time periods for fish habitat, June to August (which typically have high ALR levels) and November to February (which typically have lower ALR levels). The model was run for discharges of 8.5 m^3s^{-1} (dam seepage only), 142 m^3s^{-1} (minimum flow release set for the REV), and 2,124 m^3s^{-1} (approximately the five unit discharge). Modelled water levels include the historical maximum (440.2 masl) and minimum ALR levels (420 masl) together with the mean of maximum and minimums levels during these periods. Table 9 below presents a summary of modelled water levels. The resulting water surface profiles for steady flows are presented in Figures 9 to 11.

Table 9: Table: Modelled ALR Water Elevations of the middle Columbia River Arrow Lakes Reservoir.

Time Period	Mean of Maximums[2] (masl)	Mean of Minimums[3] (masl)
June to August	438	430.5
November to February	435.1	423[1]

Notes:
[1] ALR levels modelled using the Normal depth downstream boundary condition.
[2] The “Mean of Maximums” is the mean of all the historical maximum Arrow Lakes Reservoir levels.
[3] The “Mean of Minimums” is the mean of all the historical minimum Arrow Lakes Reservoir levels.

The area of permanently inundated channel and changes in minimum flow depth were also estimated by running the model in steady state with a normal depth downstream boundary condition. This represents a condition when no backwater effects from ALR occur and the flooded surface area of the channel will be at its smallest. In this case, the model was run using 8.5 m^3s^{-1} (zero discharge) and 142 m^3s^{-1} (minimum discharge) discharges (the current estimated dam seepage and the minimum flow release, respectively). Results are shown in Table 10 below.

Table 10: Wetted Riverbed Areas, by Reach, for the middle Columbia River from Revelstoke Dam to the Alkokolex River at Zero and Minimum Discharge.

Reach	142 m^3s^{-1} Flow and Low ALR Levels		8.5 m^3s^{-1} Flow and Low ALR Levels		Change in Wetted Area (m^2)	Change in Maximum Flow Depth
	Wetted Riverbed Area (m^2)	Average Flow Depth (m)	Wetted Riverbed Area (m^2)	Average Flow Depth (m)		
Reach 4 (cross sections 243 to 183)	846,260	5.2	603,410	3.4	242,850	1.8
Reaches 3, 2, and 1 (cross sections 182 to 1)	9,156,320	3.9	6,950,610	3.0	2,205,710	0.9
Total Area	10,002,580	4.2	7,554,020	3.1	2,448,560	1.1
Sub-Reach 2 (cross sections 75 to 55)[1]	2,089,710	2.4	1,480,180	1.8	609,530	0.6

Note:

[1] This sub-reach in Reach 2 accounts for the largest change in area.

The estimated total wetted riverbed area increases by approximately 32% with an increase in discharge from 8.5 m^3s^{-1} to the REV minimum of 142 m^3s^{-1}. The area that accounted for the largest increase in surface area was cross section 75 to 55, which accounts for approximately 334,790m^2 of the total surface area change, or roughly 25%. The estimated maximum flow depth increases by approximately 1.1 m or 37% with an increase in discharge from 8.5 m^3s^{-1} to the REV minimum of 142 m^3s^{-1}.

Unsteady flow model runs were also conducted with the daily REV discharge varying from a minimum of 8.5 m^3s^{-1} to a maximum of 2,124 m^3s^{-1}. ALR water levels were modeled as the maximum recorded water level (440.2 masl) and the minimum ALR water levels (modelled with normal depth) for the critical fisheries periods (June to August and November to February). The results are presented in Figures 12 to 13 for illustrative purposes. The REV discharge hydrograph used for the modelling results shown in Figures 12 and 13 was assumed. Actual daily flow variation hydrographs will be determined by power demand and may not be the same as that assumed herein.

6.0 RECOMMENDATIONS

The MCR hydraulic model has been calibrated for steady state and unsteady state analysis. The steady flow analysis predicts river water elevations to within 0.25 m of measured values, while the unsteady flow model replicates the timing and peaks of the highly variable flow regime on the MCR. In order to continue to refine the model calibration process, the following are recommended:

- Modelling scenarios for periods of interest to other investigators should be considered for future hydraulic modelling to accurately predict changes in wetted riverbed area over the time intervals and flow regimes of interest. These changes in wetted area may reflect fish habitat and potential annual aquatic productivity under the new operations.
- For the purposes of this monitoring program, the Winter-Kennedy method is used to determine an accurate flow rate through Units 1 to 4 of the REV turbines. However, Unit 5 flow rate is estimated by apportioning the total flow released to the REV 5 component, based on head and power production of the unit. This flow estimation leads to errors when the turbine is spinning without generating. As total REV discharge is an important input to the CLBMON-15a HEC-RAS Model it is recommended to either implement the Winter-Kennedy method on REV 5 or perform a sensitivity analysis. A sensitivity analysis, could be conducted using the CLBMON-15a HEC-RAS Model to examine the possible effects of the REV 5 flow errors on modelled water elevations in the MCR. By varying REV flow at low ALR levels, the maximum possible variation in water surface elevation error could be determined. With this information, BCH will be able to make a decision as to whether or not to proceed with the appropriate sensor installation required for the Winter-Kennedy method on REV 5.

7.0 CLOSURE

We trust that the information contained in this document meets your requirements at this time. Should you have any questions relating to the above, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

Mike Paget, EIT
Water Resources Engineer

Dan Walker, Ph.D., P.Eng. (BC, NT/NU)
Principal

MLP/DW/cmc/md

Attachments: Figures 1 – 13

o:\final\2012\1492\12-1492-0084\1214920084-001-tm-rev0\1214920084-001-tm-rev0-5000-physical habitat year 24jan_14.doc

REFERENCES

Golder Associates Ltd. 2011a. Mid Columbia River White Sturgeon Spawning Habitat Assessment. Prepared for BC Hydro CLBMON#20. ADCP Data.

Golder Associates Ltd. 2011b. Effects of Flow Changes on Incubation and Early Rearing Habitat. Prepared for BC Hydro CLBMON#54 ADCP Data.

Golder Associates Ltd. 2010. Columbia River Water Use Plan Monitoring Program: Physical Habitat Monitoring Study Period: Year 3 – 2009. Prepared for BC Hydro CLBMON#15a. 33pp + appendices.

Golder Associates Ltd. 2008. Columbia River Water Use Plan Monitoring Program: Physical Habitat Monitoring Study Period: 2007. Prepared for BC Hydro CLBMON#15a. 23 pp + appendices.

Hicks, D.M.; Mason, P.D., 1998. Roughness Characteristics of New Zealand Rivers, National Institute of Water and Atmospheric Research Ltd.

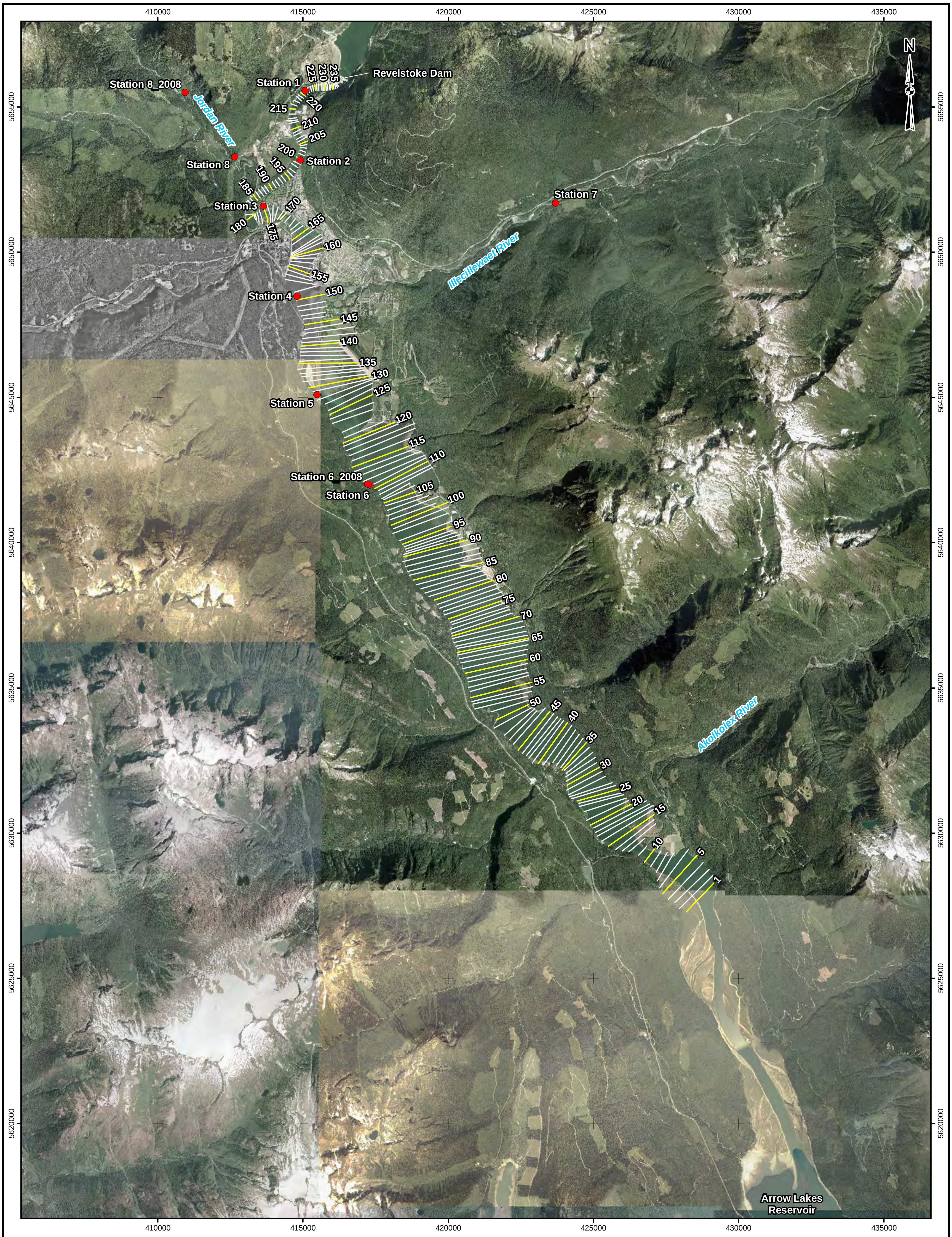
Klohn Crippen Berger. 2010. CLBMON-15A Middle Columbia River, Physical Habitat Monitoring BC Hydro Contract No. Q7-7129 HEC-RAS Model Calibration, May 21, 2010

Korman, J., Hildebrand, L., and Failing, L., 2002.Fish Habitat Performance Measures to Evaluate Minimum Discharge Requirements for Revelstoke canyon Dam. Appendix Q. Prepared for Columbia WUP Fisheries technical Committee.

R.L.&L Environmental Services Ltd. 1994. Fish habitat utilization and productive capacity of the Columbia River below Revelstoke Canyon Dam. Draft Report. Prepared for B.C. Hydro, Environmental Affairs. R.L.&L Rep. No. 419D:96 p. + 3 app.

USACE (U.S. Army Corps of Engineers), 2010. HEC-RAS Hydrologic Modeling System, Version 4.1.0 (computer software). Hydrologic Engineering Center, Davis CA.

USGS (United States Geological Survey), 2001. Surface Water Field Techniques – Verified Roughness Characteristics of Natural Channels.
http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/indirects/nvalues/



LEGEND

- Station

5 0 5

SCALE 1:125,000 KILOMETRES

PROJECT

BC HYDRO
CLBMON-15a MID COLUMBIA RIVER
PHYSICAL HABITAT MONITORING

TITLE

HEC-RAS TRANSECT LOCATIONS

PROJECT No. 10-1492-0084			PHASE No.	
DESIGN	MLP	11FEB11	SCALE AS SHOWN	REV. 0
GIS	CDB	11FEB11		
CHECK	MLP	23FEB11	FIGURE 1	
REVIEW	DRW	23FEB11		

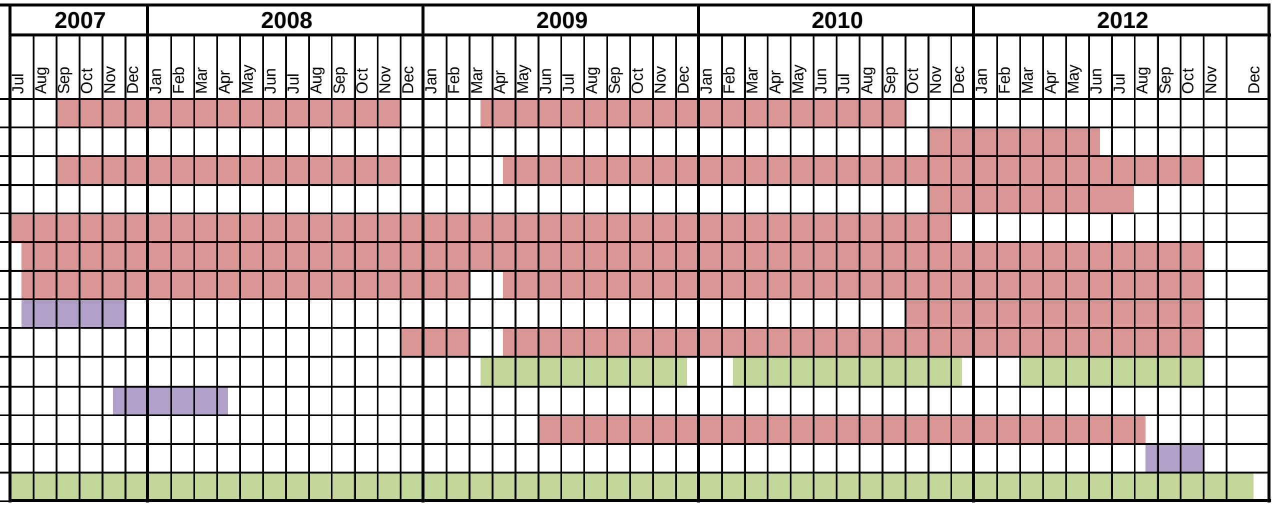
Golder Associates
Greater Vancouver Office, B.C.

REFERENCE

Orthophotos obtained from the Province of British Columbia
Projection: UTM Zone 11 Datum: NAD 83

N:\Bur-Graphics\Projects\2010\1492\10-1492-0084\GIS\projects\figure-01_transect-locations.mxd

Station	Alternative Station	Maintained By
Station 1		Golder
Station 1_AS		Golder
Station 2		Golder
Station 2_AS		Golder
Station 3	Tailrace 2	BC Hydro
Station 4		Golder
Station 5		Golder
Station 6		Golder
Station 6_2008		Golder
Station 7	Illecillewaet River	Water Survey Canada
Station 8		Golder
Station 8_2008	Jordan River	Golder
Station 8_2011	Jordan River	Golder
REV	Revelstoke Dam	Golder



Legend

(red)	Water Elevation in Geodatic Datum
(purple)	Water Elevation in Local Datum
(green)	Discharge Data

PROJECT
BC HYDRO
CLBMON-15a MID COLUMBIA RIVER
PHYSICAL HABITAT MONITORING

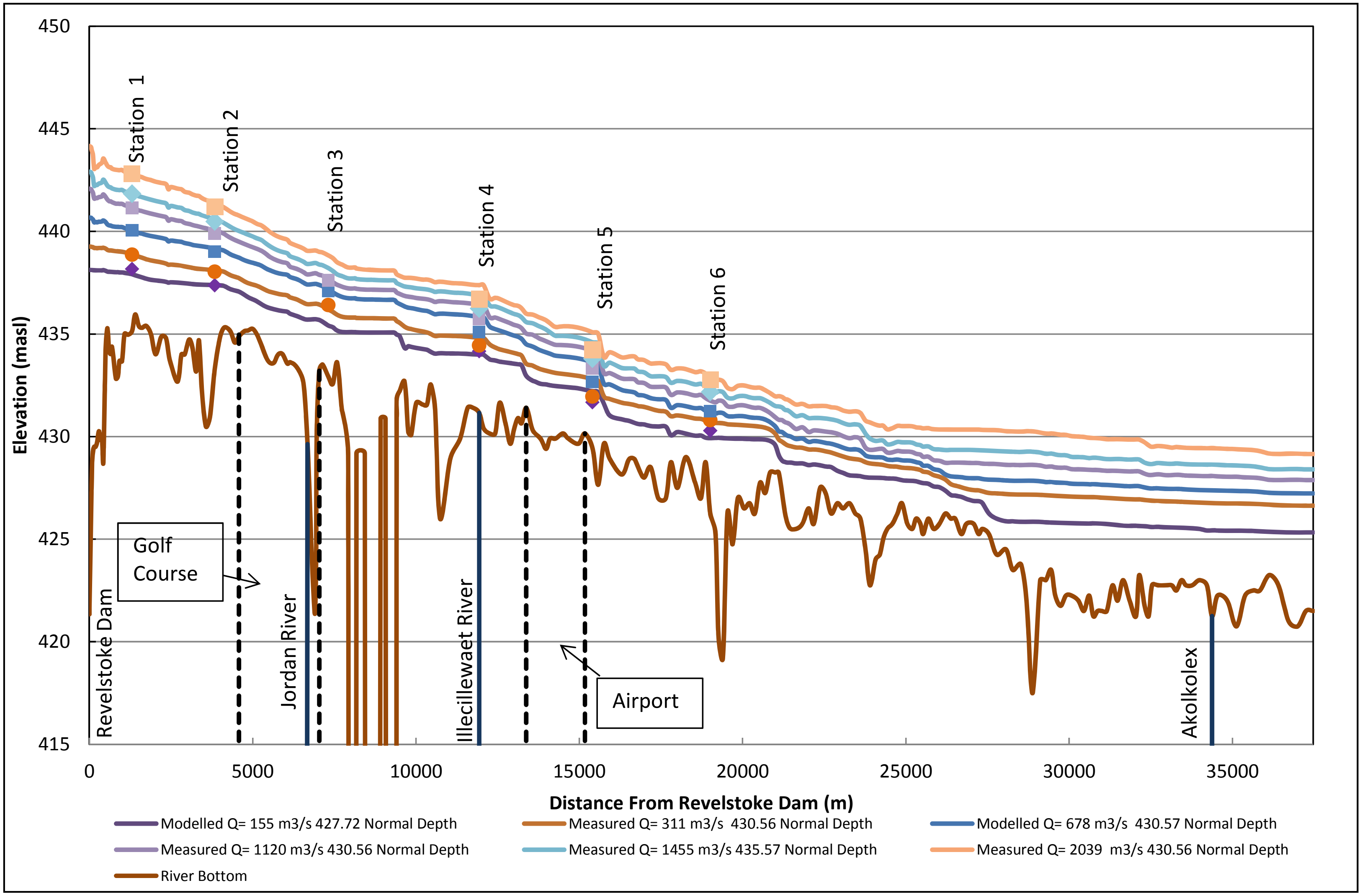
TITLE

Hydrometric Station Data Availability

Golder Associates

PROJECT No. 12-1492-0084			PHASE No. 5000	
DESIGN	MLP	16FAPR13	SCALE NTS	REV. 1
CADD	MLP	16APR13	**FIGURE 2**	
CHECK				
REVIEW				

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12

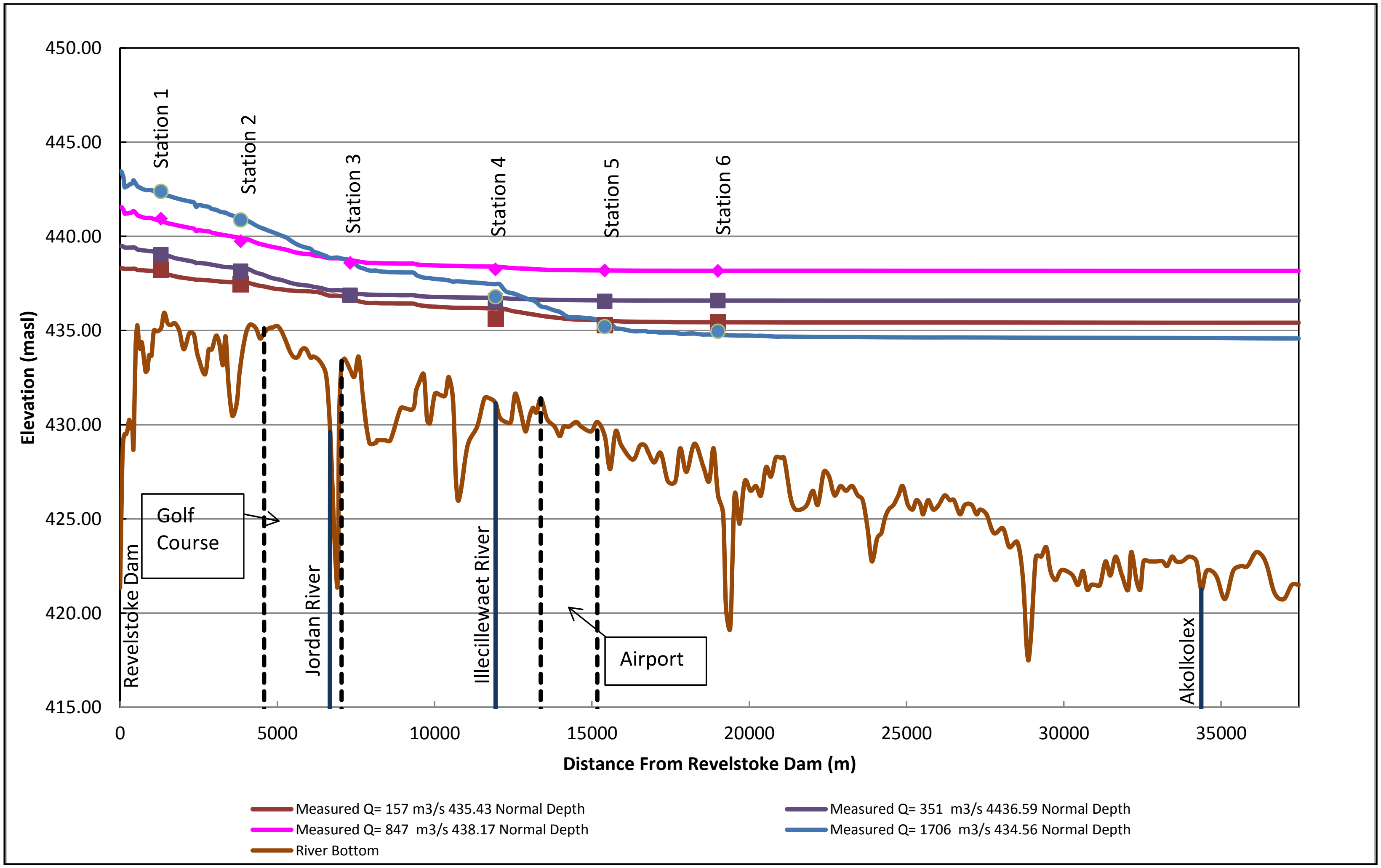


PROJECT	**BC HYDRO** **CLBMON-15a MID COLUMBIA RIVER** **PHYSICAL HABITAT MONITORING**
TITLE	**Mid Columbia River Profile** **Steady Flow-Validation** **No Backwatering**

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No.	11-1492-0084		PHASE No. 5000	
DESIGN	MLP	13MAR12	SCALE NTS	REV. 1
CADD	MLP	13MAR12	**FIGURE 3**	
CHECK	MLP	13MAR12		
REVIEW	DRW			

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12

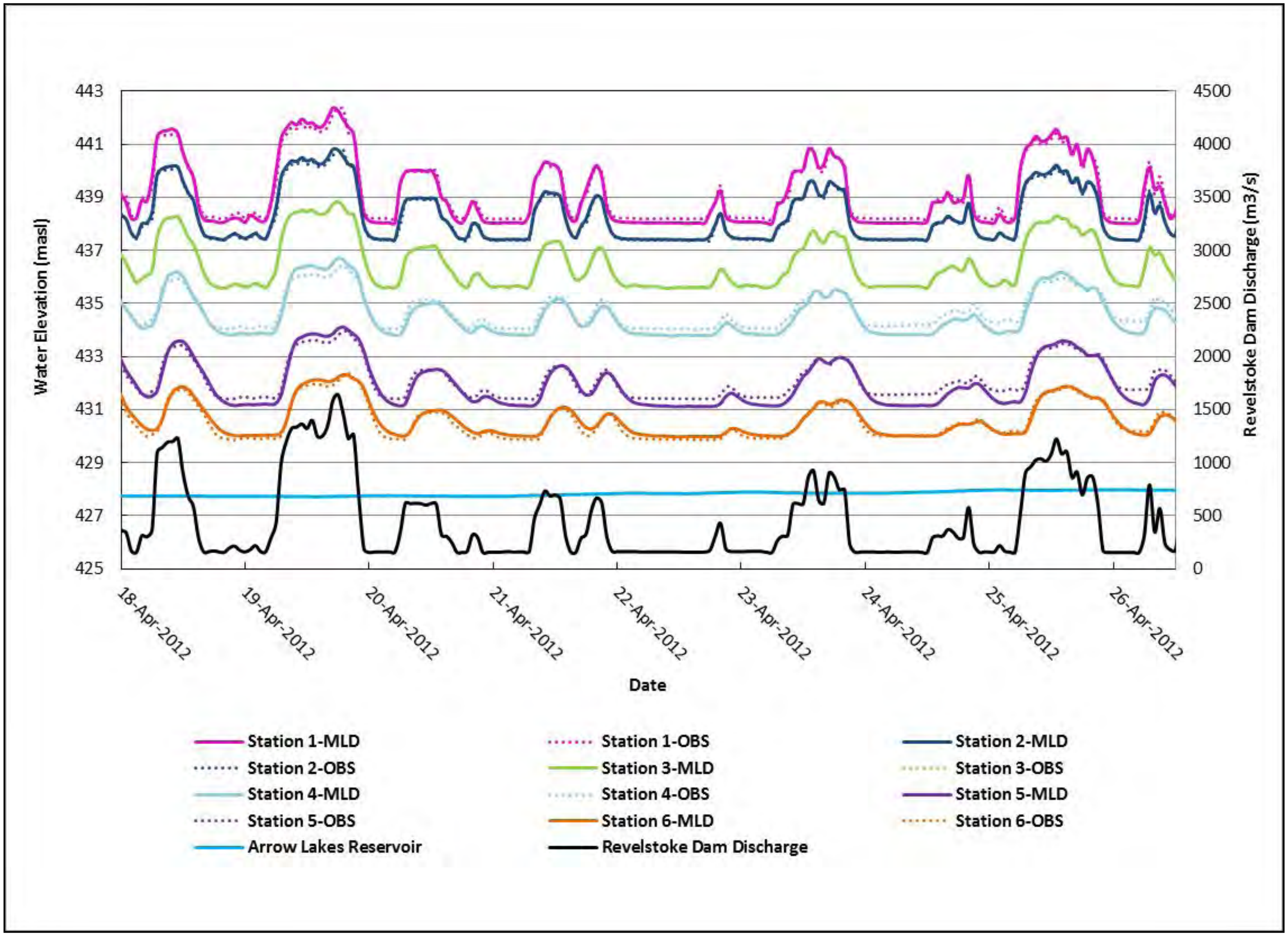


PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING
TITLE	Mid Columbia River Profile Steady Flow-Validation ALR Backwatering

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No.	11-1492-0084		PHASE No. 5000	
DESIGN	MLP	13MAR12	SCALE NTS	REV. 1
CADD	MLP	13MAR12	FIGURE 4	
CHECK	MLP	13MAR12		
REVIEW	DRW			

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12



* Notes

1. Solid lines are modelled (MLD) water elevations, dashed lines are observed (OBS) water elevations

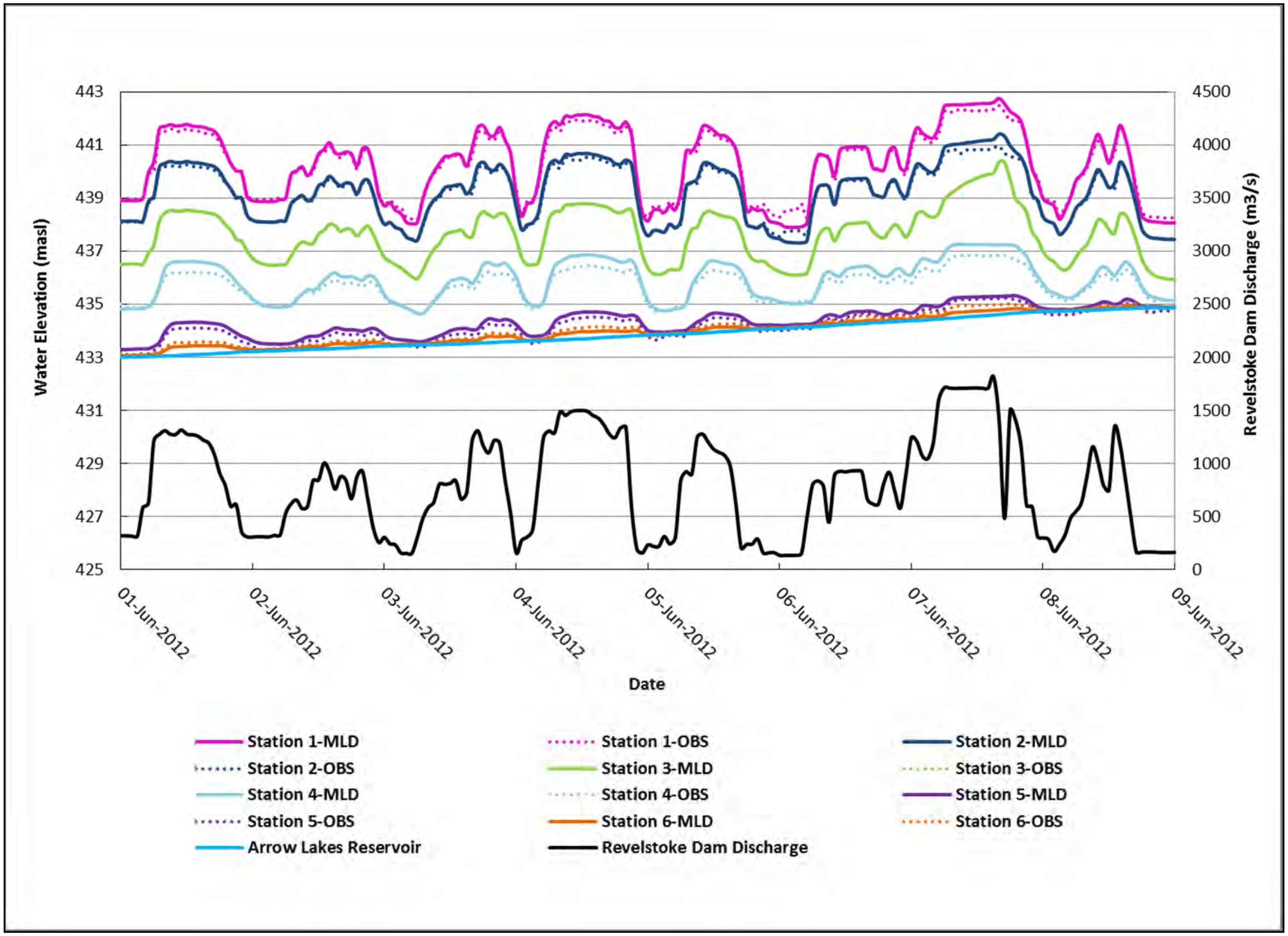
PROJECT **BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING**

TITLE **Mid Columbia River Profile Unsteady Flow-Validation April 18-26, 2012 Low Arrow Lake Levels**

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 11-1492-0084			PHASE No. 5000
DESIGN	MLP	13MAR12	SCALE NTS REV. 1
CADD	MLP	13MAR12	FIGURE 5
CHECK	MLP	13MAR12	
REVIEW	DRW		

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12



* Notes

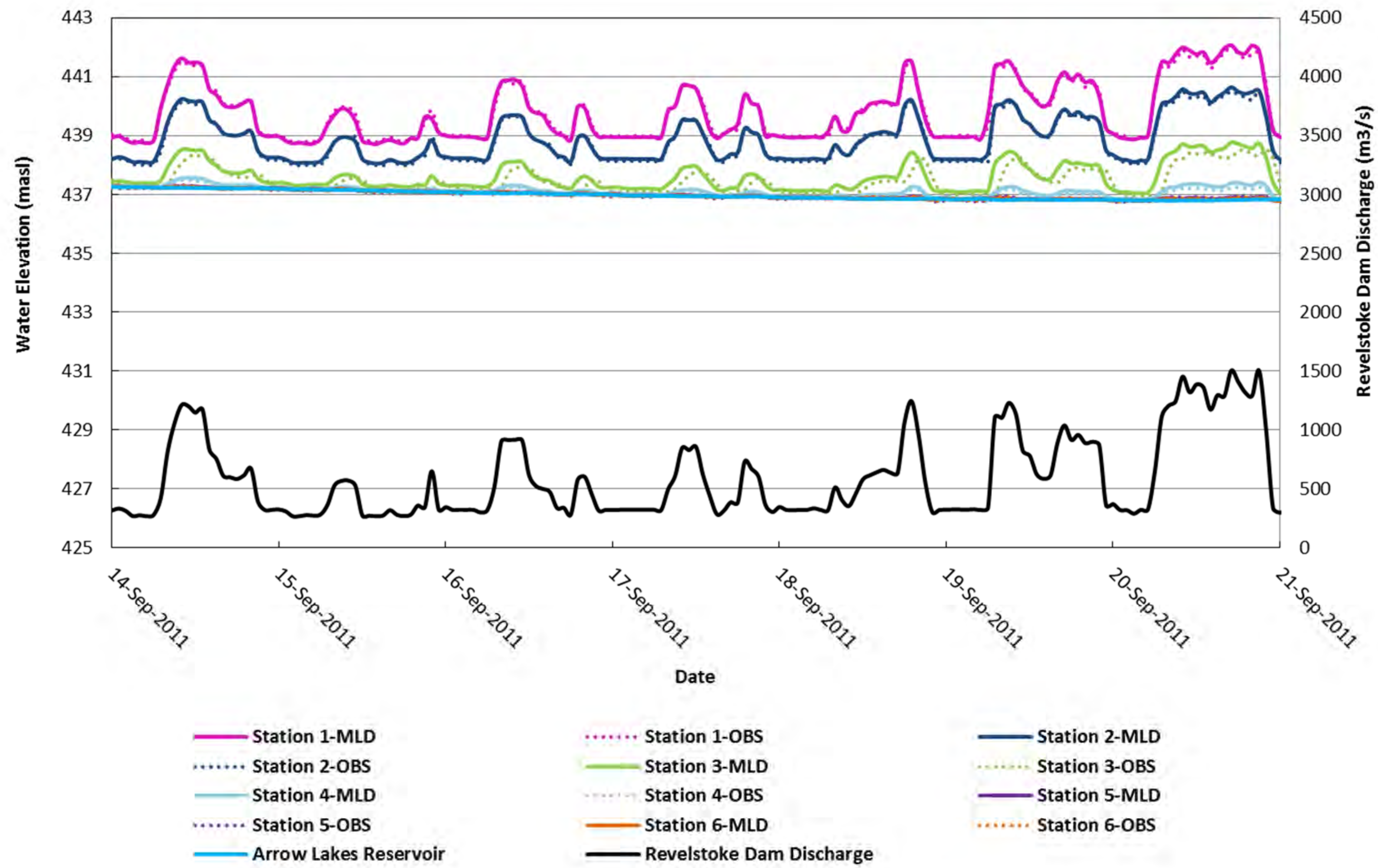
1. Solid lines are modelled (MLD) water elevations, dashed lines are observed (OBS) water elevations

PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING
TITLE	Mid Columbia River Profile Unsteady Flow-Validation June 1-9, 2012 Medium-Low Arrow Lake Levels

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No.	11-1492-0084		PHASE No.	5000
DESIGN	MLP	13MAR12	SCALE NTS	REV. 1
CADD	MLP	13MAR12	FIGURE 6	
CHECK	MLP	13MAR12		
REVIEW	DRW			

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12



* Notes

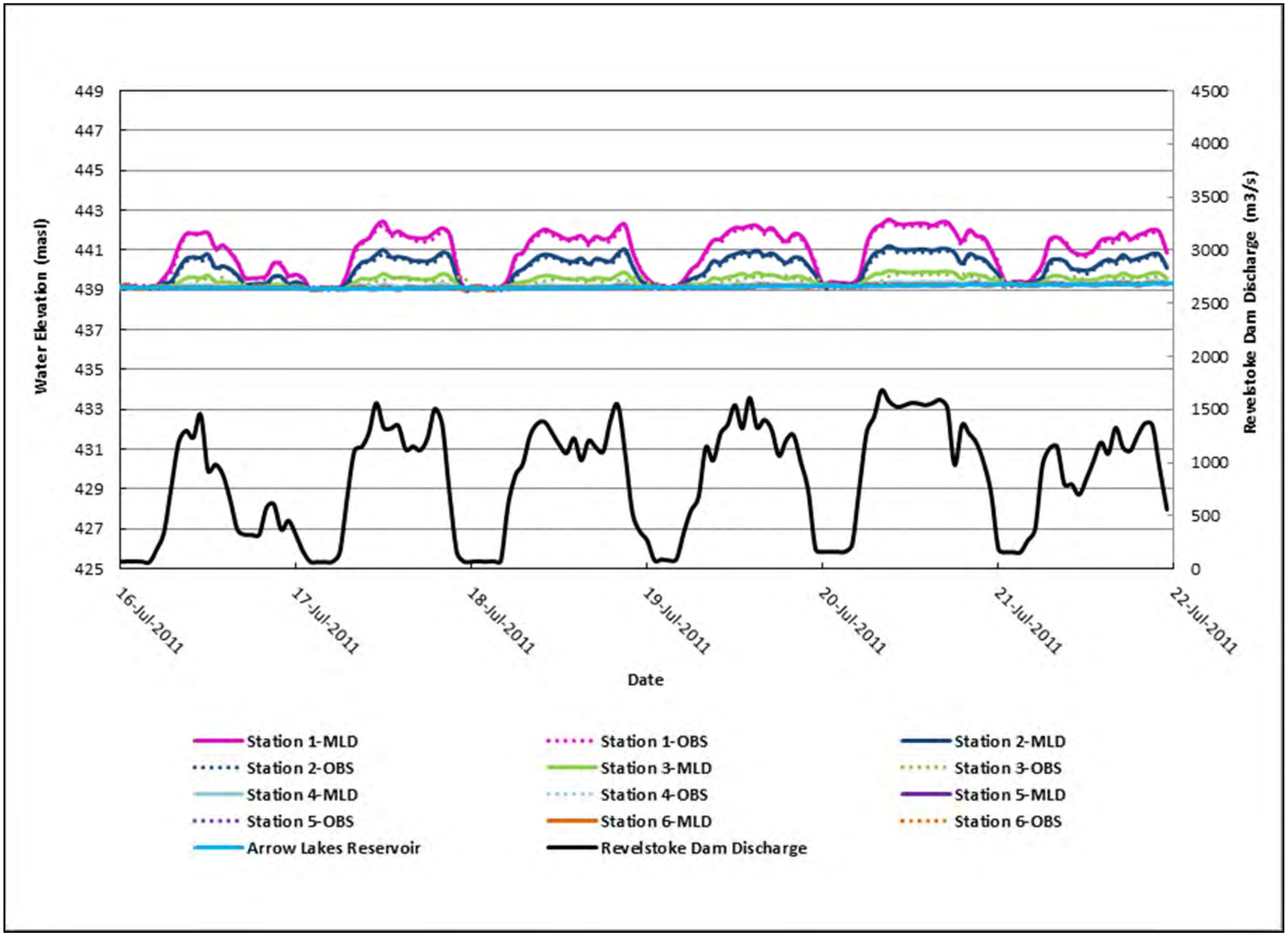
1. Solid lines are modelled (MLD) water elevations, dashed lines are observed (OBS) water elevations

PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING
TITLE	Mid Columbia River Profile Unsteady Flow-Validation Sept 14-21, 2011 Medium-High Arrow Lake Levels

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No.	11-1492-0084		PHASE No. 5000	
DESIGN	MLP	13MAR12	SCALE NTS	REV. 1
CADD	MLP	13MAR12	FIGURE 7	
CHECK	MLP	13MAR12		
REVIEW	DRW			

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12

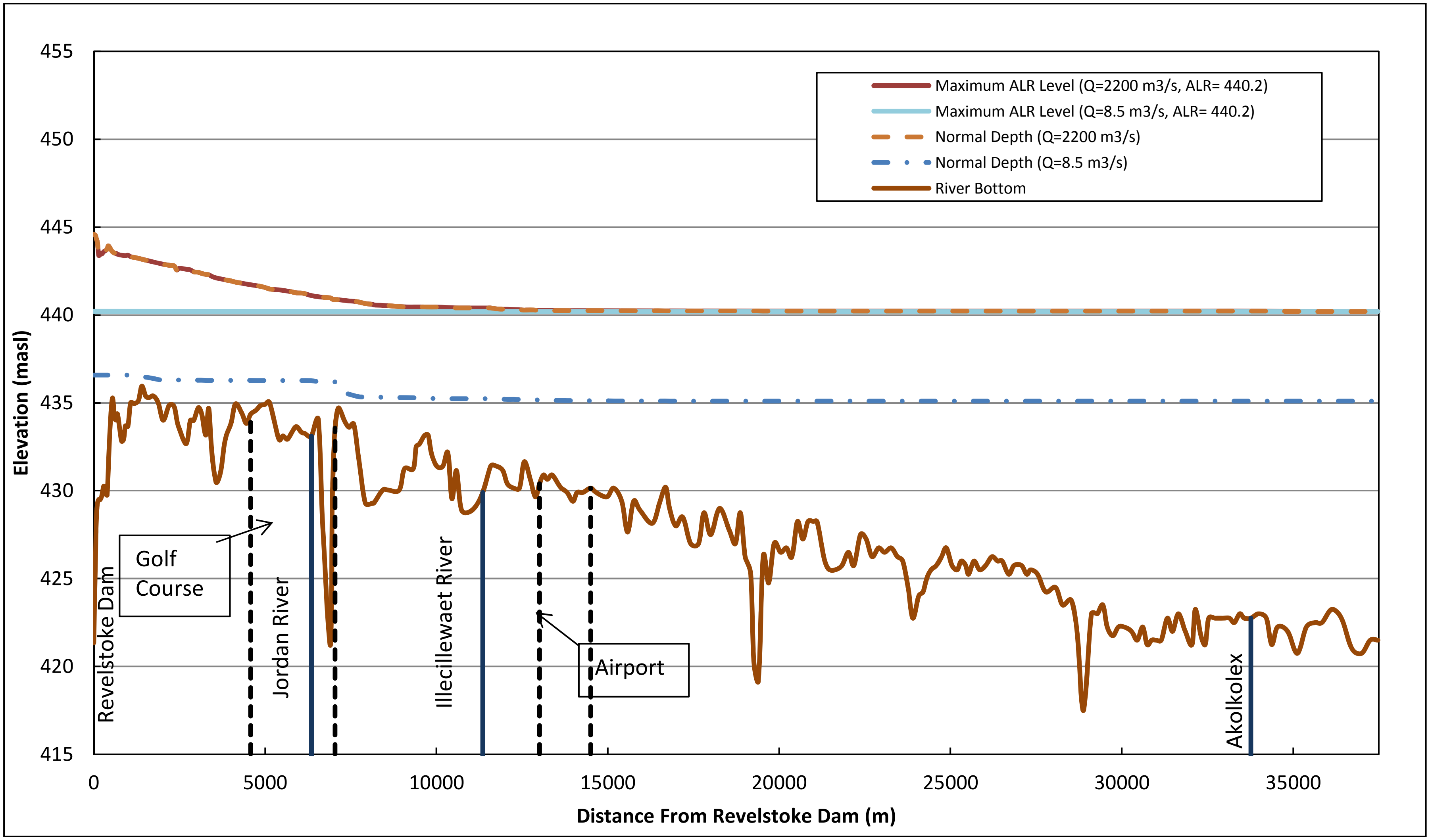


* Notes

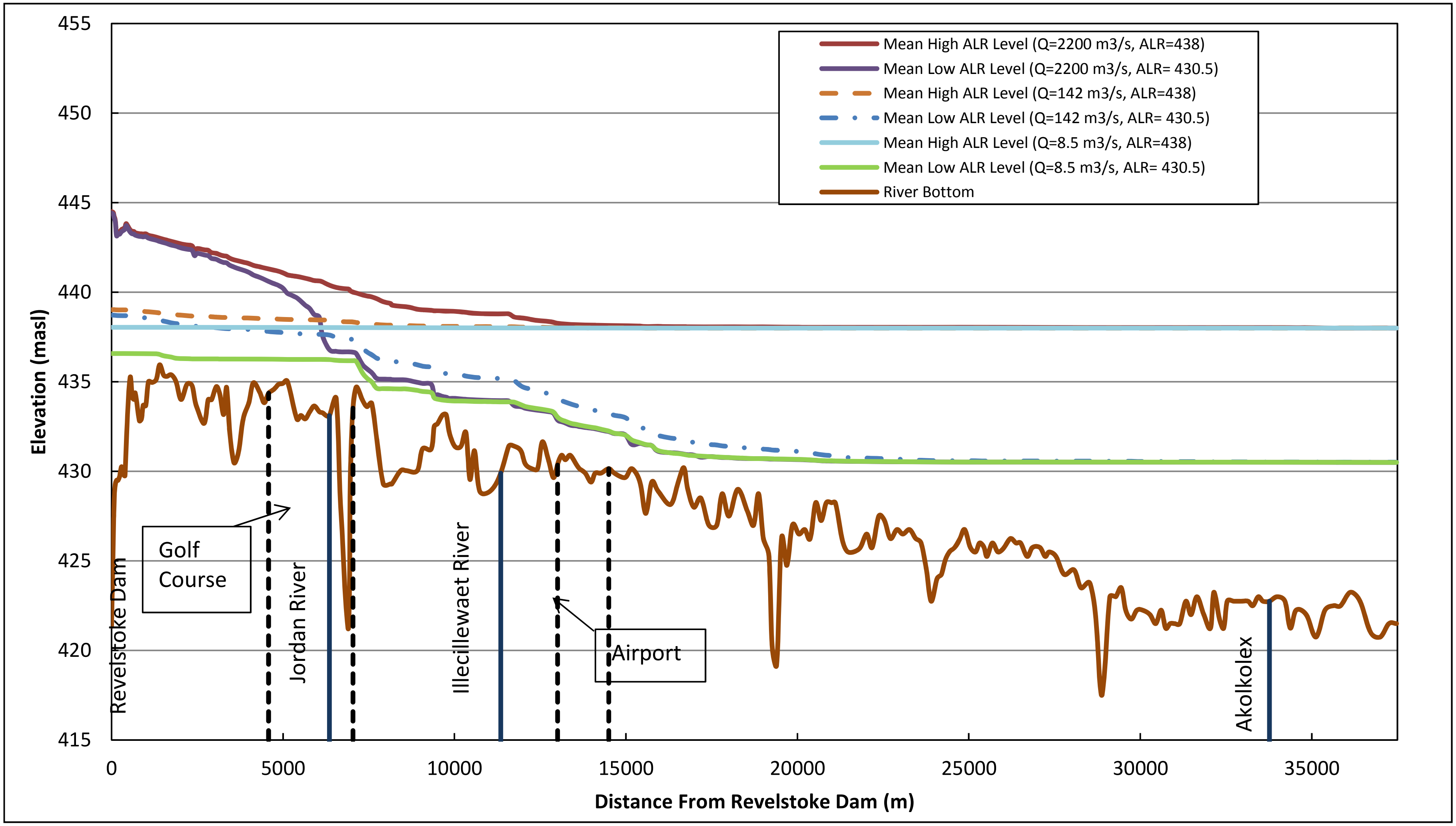
1. Solid lines are modelled (MLD) water elevations, dashed lines are observed (OBS) water elevations

PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING			
TITLE	**Mid Columbia River Profile Unsteady Flow-Validation July 16-22 2011 High Arrow Lake Levels**			
Golder Associates Greater Vancouver Office, B.C.	PROJECT No. 11-1492-0084		PHASE No. 5000	
	DESIGN	MLP	13MAR12	SCALE NTS REV. 1
	CADD	MLP	13MAR12	**FIGURE 8**
	CHECK	MLP	13MAR12	
	REVIEW	DRW		

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12

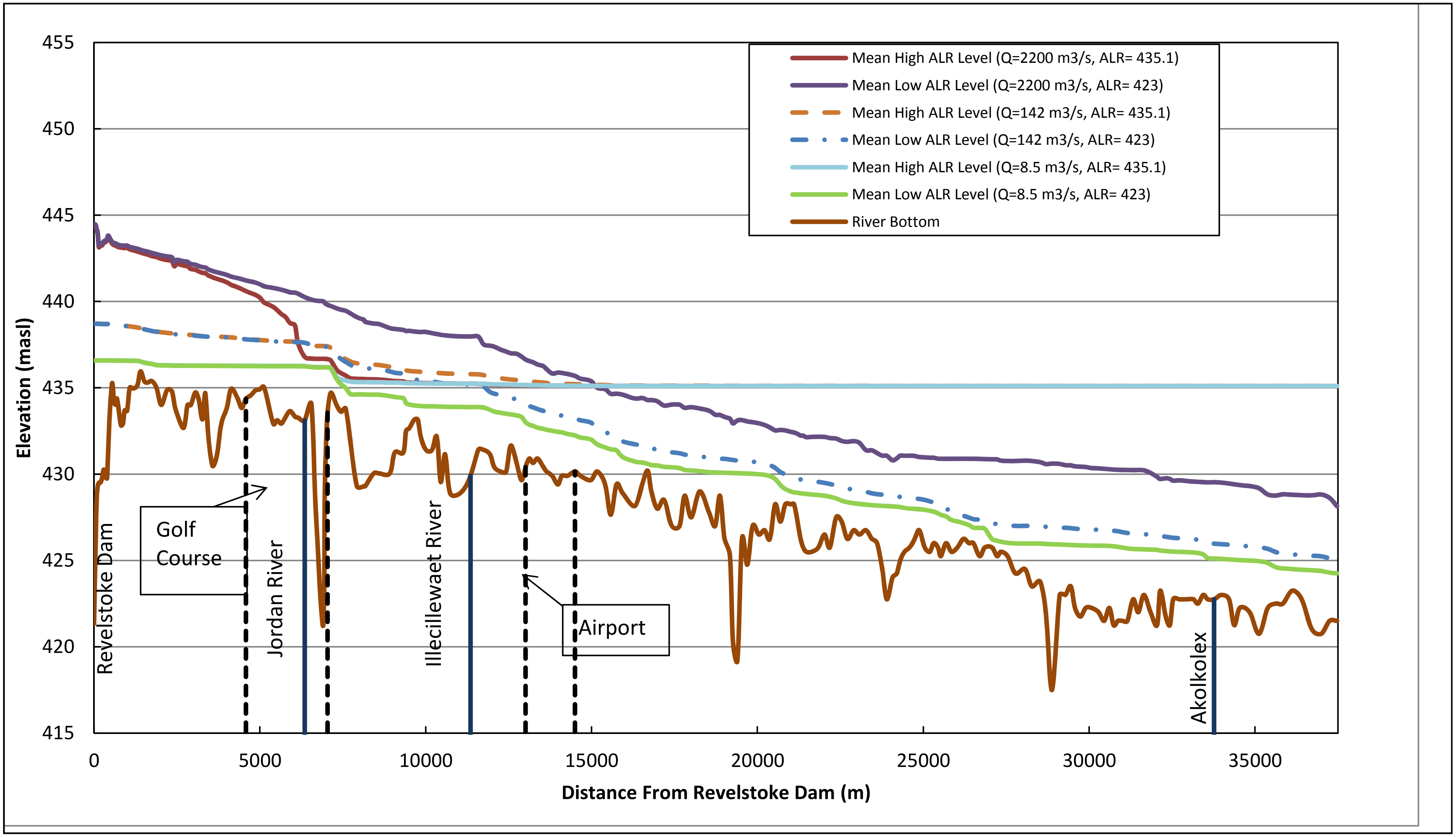


PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING			
TITLE	Mid Columbia River Profile Steady Flow-Results Max and Min Flow and ALR Levels			
Golder Associates Greater Vancouver Office, B.C.	PROJECT No. 11-1492-0084			PHASE No. 5000
	DESIGN	MLP	13MAR12	SCALE NTS REV. 1
	CADD	MLP	13MAR12	FIGURE 9
	CHECK	MLP	13MAR12	
	REVIEW	DRW		



PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING			
TITLE	**Mid Columbia River Profile** **Steady Flow-Results** **June-August with Mean ALR Levels**			
Golder Associates Greater Vancouver Office, B.C.	PROJECT No.	11-1492-0084		PHASE No. 5000
	DESIGN	MLP	13MAR12	SCALE NTS REV. 1
	CADD	MLP	13MAR12	**FIGURE 10**
	CHECK	MLP	13MAR12	
	REVIEW	DRW		

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12

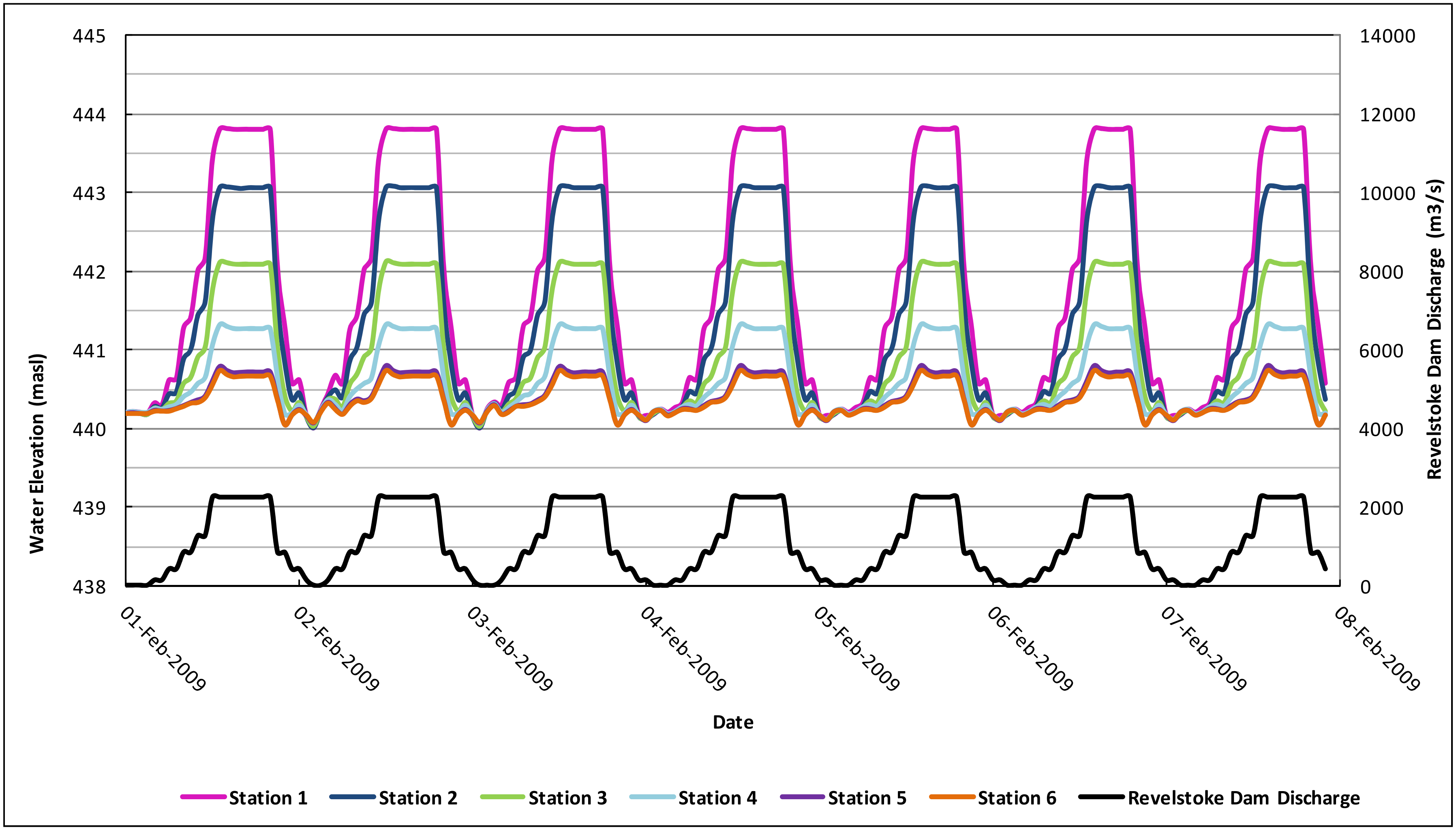


PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING
TITLE	Mid Columbia River Profile Steady Flow-Results November to February with Mean ALR Levels

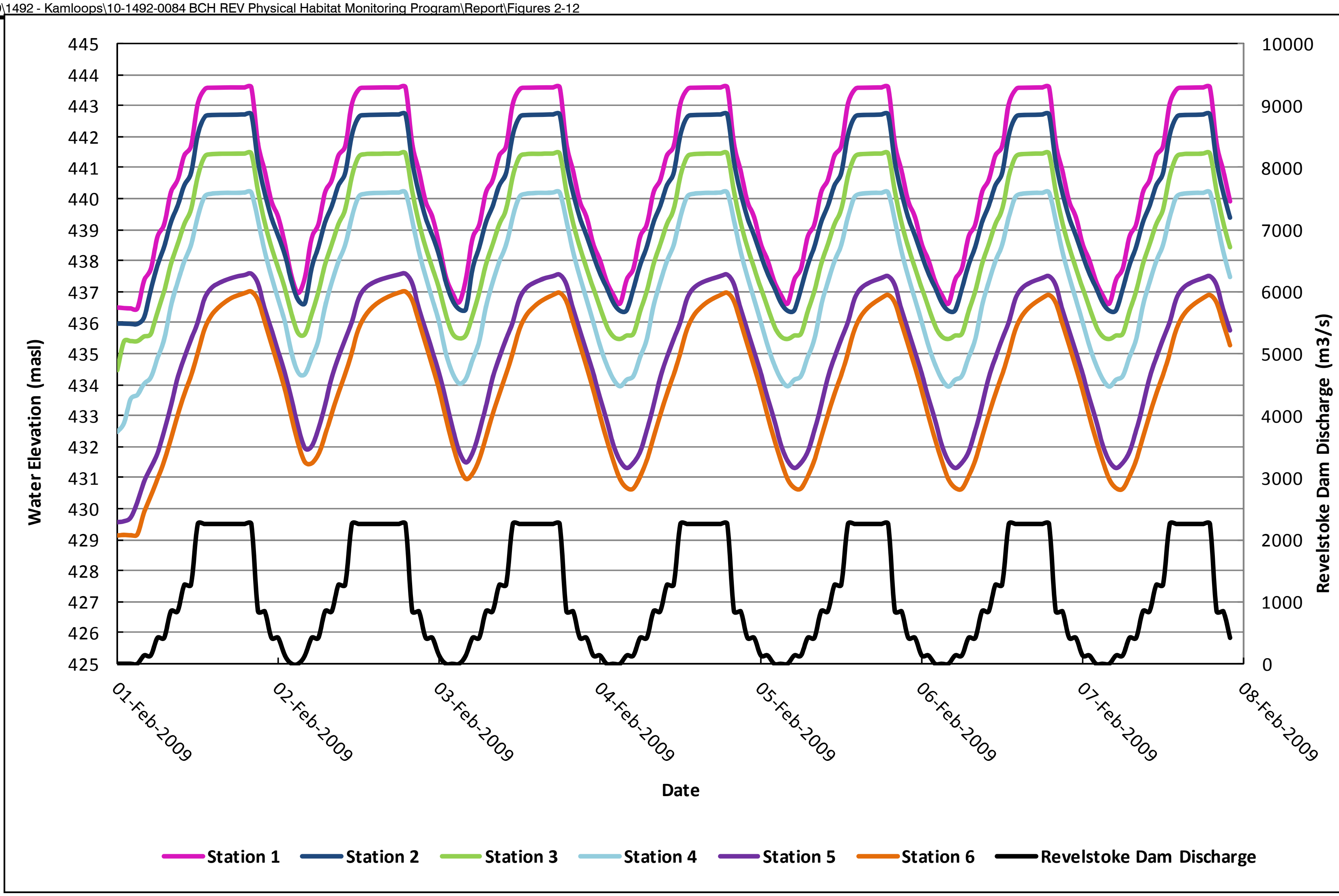
Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 11-1492-0084			PHASE No. 5000	
DESIGN	MLP	13MAR12	SCALE NTS	REV. 1
CADD	MLP	13MAR12	FIGURE 11	
CHECK	MLP	13MAR12		
REVIEW	DRW			

FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12



PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING				
TITLE	Mid Columbia River Profile Unsteady Flow-Results ALR 440.2 m Downstream Boundary				
Golder Associates Greater Vancouver Office, B.C.	PROJECT No.	11-1492-0084		PHASE No. 5000	
	DESIGN	MLP	13MAR12	SCALE NTS	REV. 1
	CADD	MLP	13MAR12	FIGURE 12	
	CHECK	MLP	13MAR12		
	REVIEW	DRW			



PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING		
TITLE	Mid Columbia River Profile Unsteady Flow-Results Normal Depth Downstream Boundary		
Golder Associates Greater Vancouver Office, B.C.	PROJECT No. 11-1492-0084		PHASE No. 5000
	DESIGN MLP	13MAR12	SCALE NTS REV. 1
	CADD MLP	13MAR12	FIGURE 13
	CHECK MLP	13MAR12	
	REVIEW DRW		

APPENDIX C

Middle Columbia River Water Level Variation

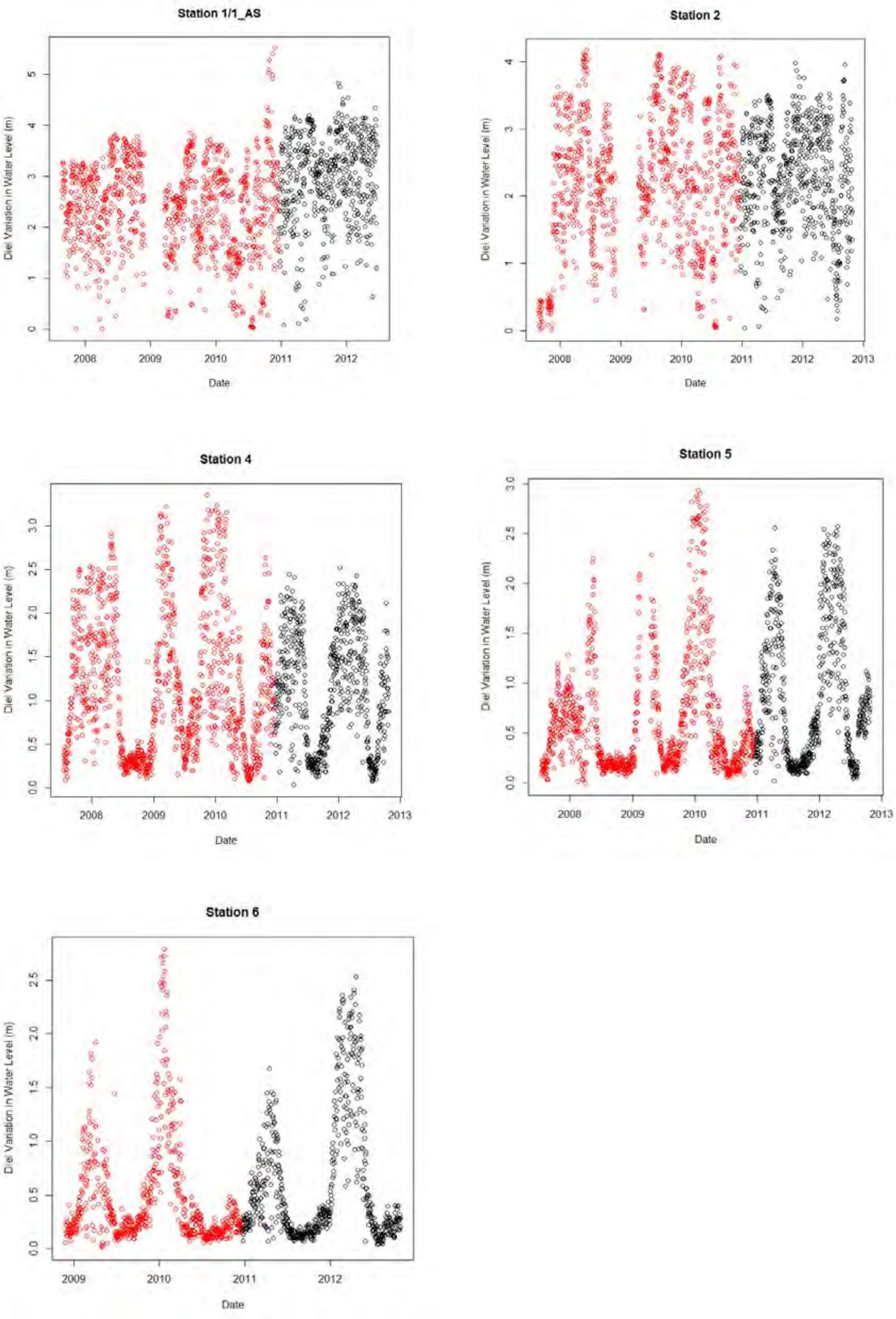
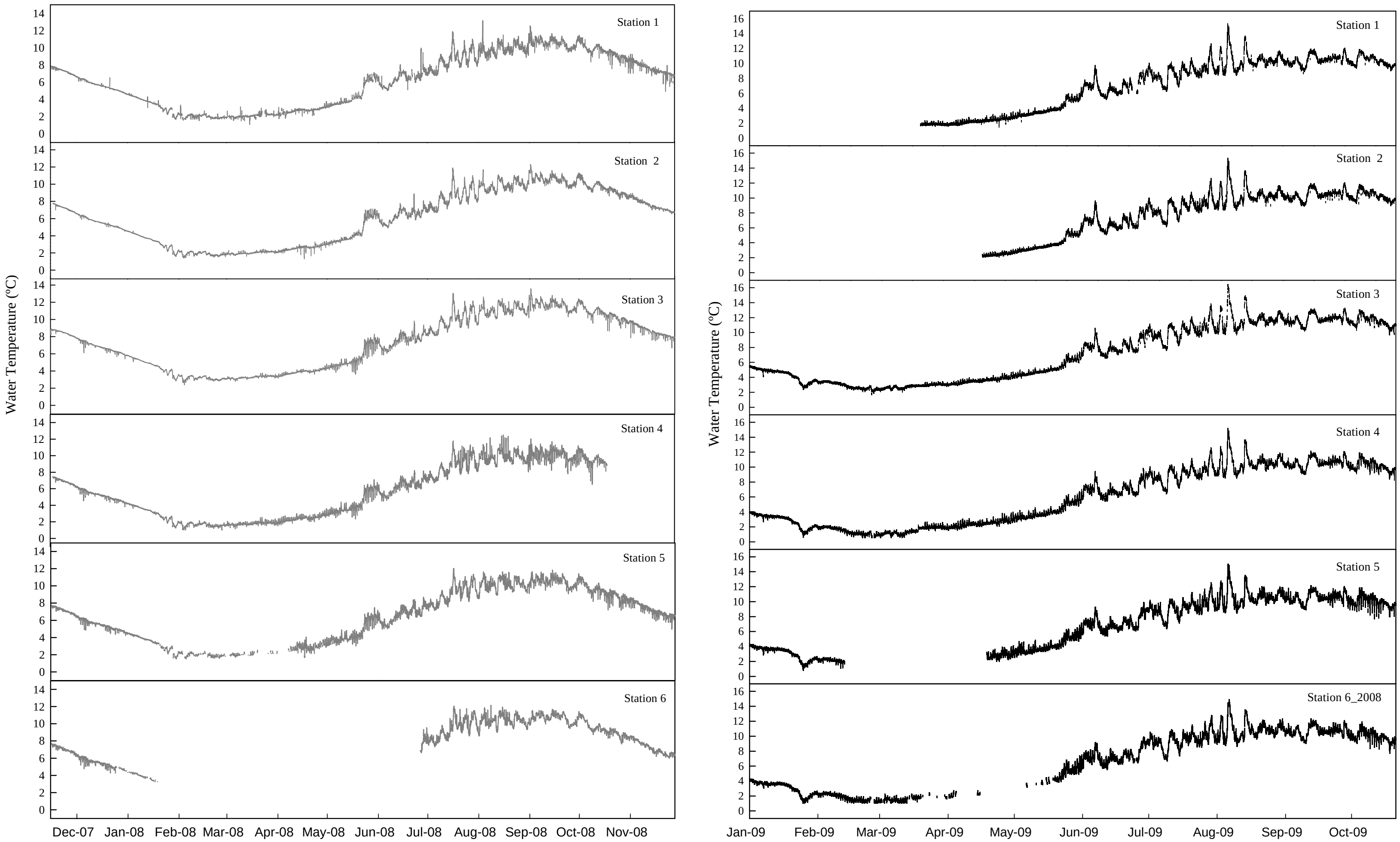
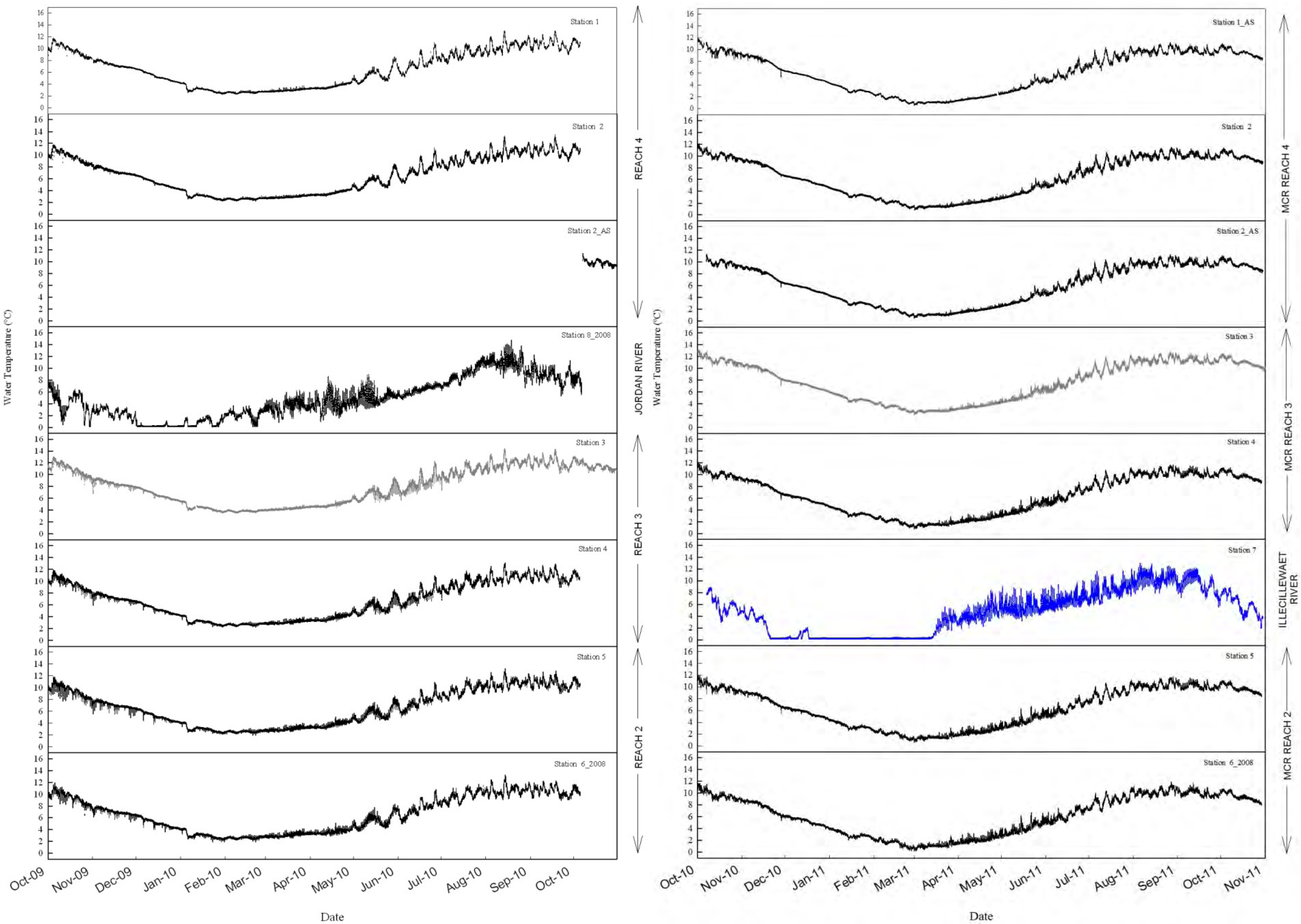


Figure C1: Diel variation in water level at monitoring stations in the Middle Columbia River, 2007-2012. Measurements from the pre-implementation (red points) and post- implementation (black points) of the of 142 m^3s^{-1} minimum flow regime are shown.

APPENDIX D

Middle Columbia River Temperature Data


Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Water Temperature (ºC)
Dec-07 Jan-08 Feb-08 Mar-08 Apr-08 May-08 Jun-08 Jul-08 Aug-08 Sep-08 Oct-08 Nov-08
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6_2008
Water Temperature (ºC)
Jan-09 Feb-09 Mar-09 Apr-09 May-09 Jun-09 Jul-09 Aug-09 Sep-09 Oct-09



Station 1
Station 2
Station 2_AS
Station 8_2008
Station 3
Station 4
Station 5
Station 6_2008
REACH 4
JORDAN RIVER
REACH 3
REACH 2
Water Temperature (°C)
Oct-09
Nov-09
Dec-09
Jan-10
Feb-10
Mar-10
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Date
Station 1_AS
Station 2
Station 2_AS
Station 3
Station 4
Station 7
Station 5
Station 6_2008
MCR REACH 4
MCR REACH 3
ILLECILLEWAET RIVER
MCR REACH 2
Water Temperature (°C)
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Date

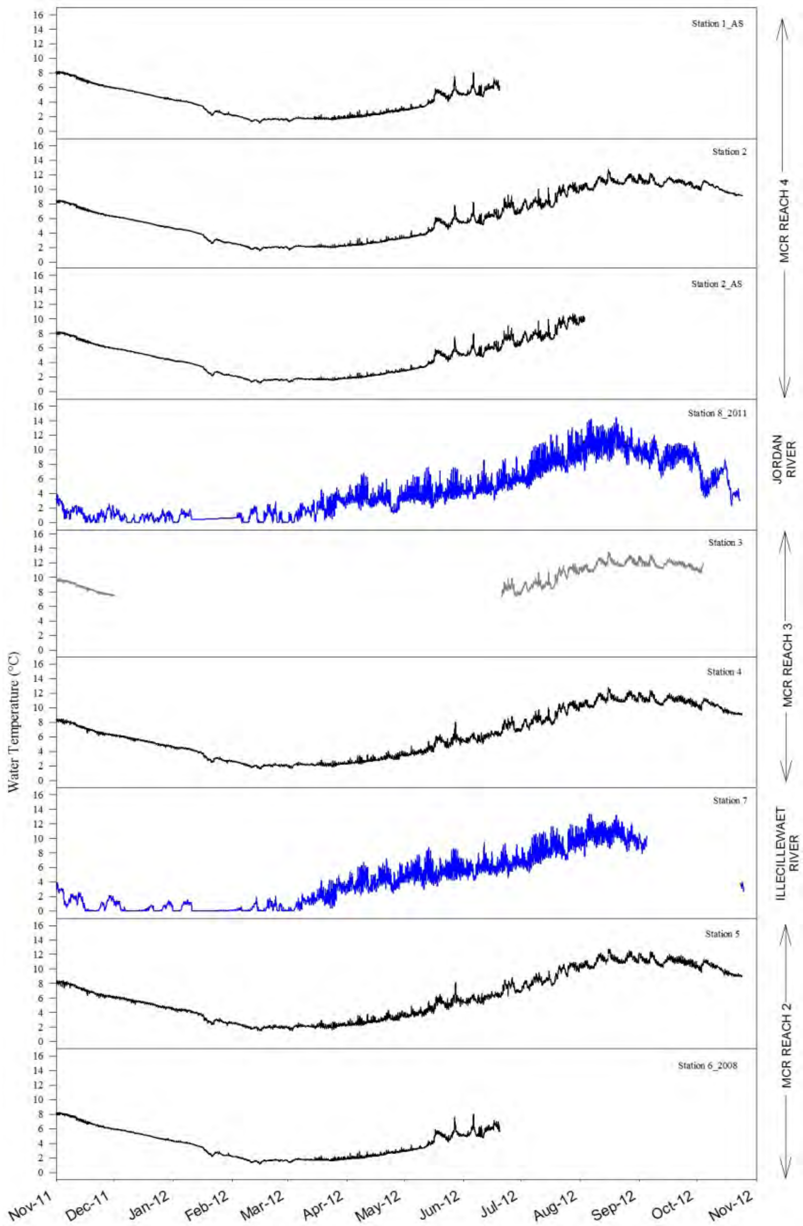


Figure D1: Water temperature readings at six (two anchor stations were added in Year 4) index stations, in the middle Columbia River and two tributary stations, Years 2-6 (2008-2012). Note that some stations during some time periods are missing data for the provided plots. Year 1 (2007) was not included because the data was incomplete and there was not a continuous data set for the year.

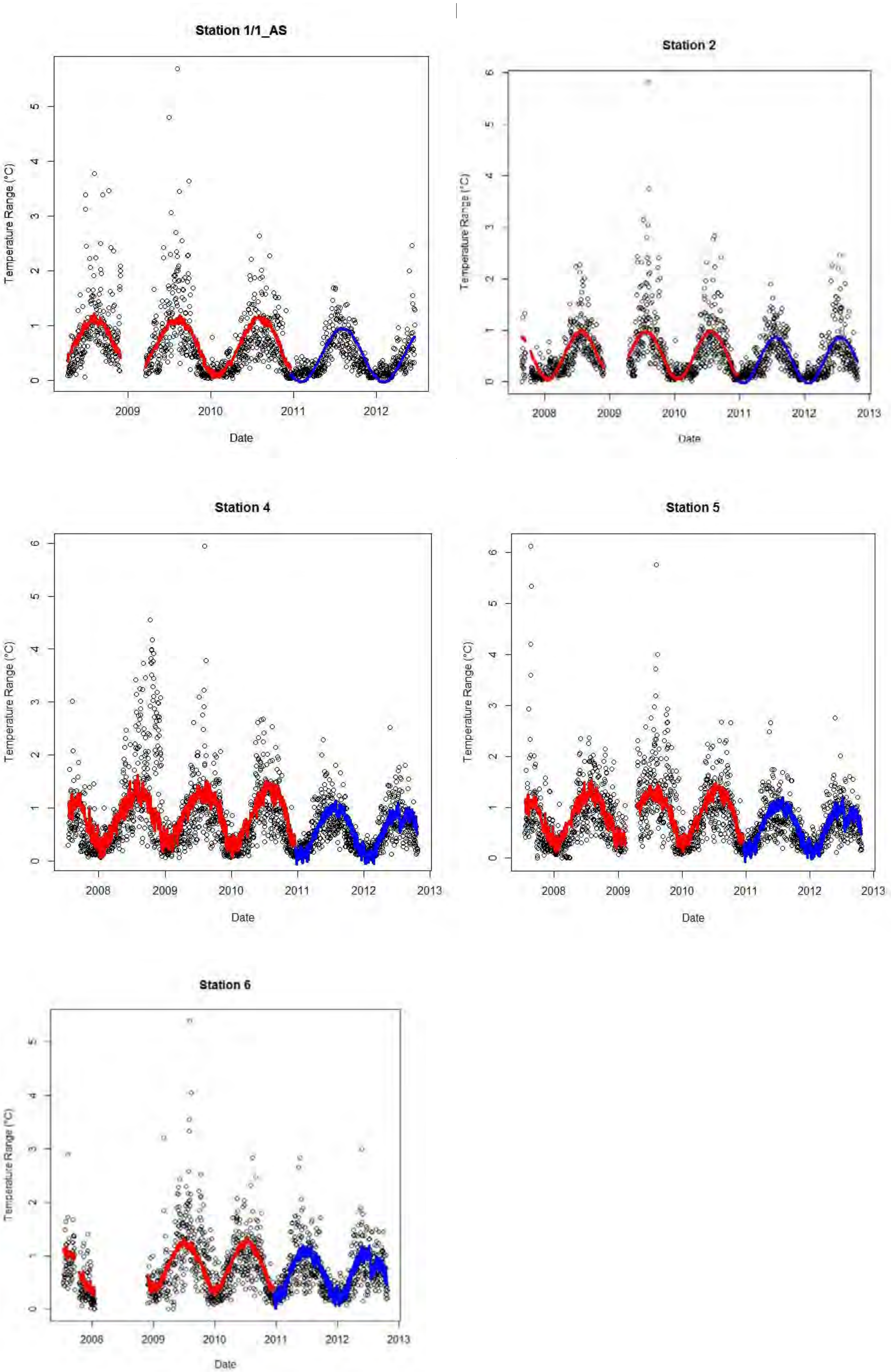
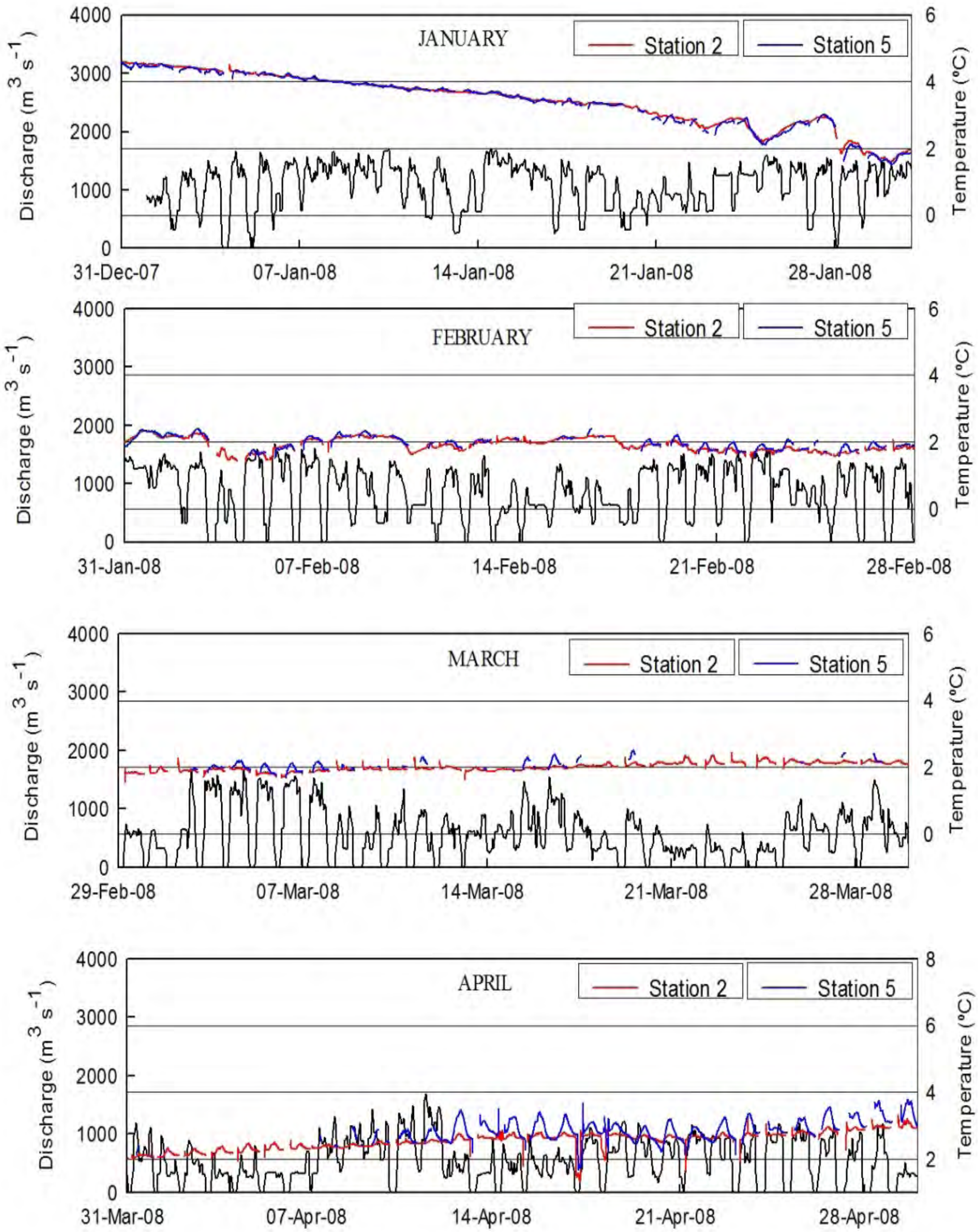
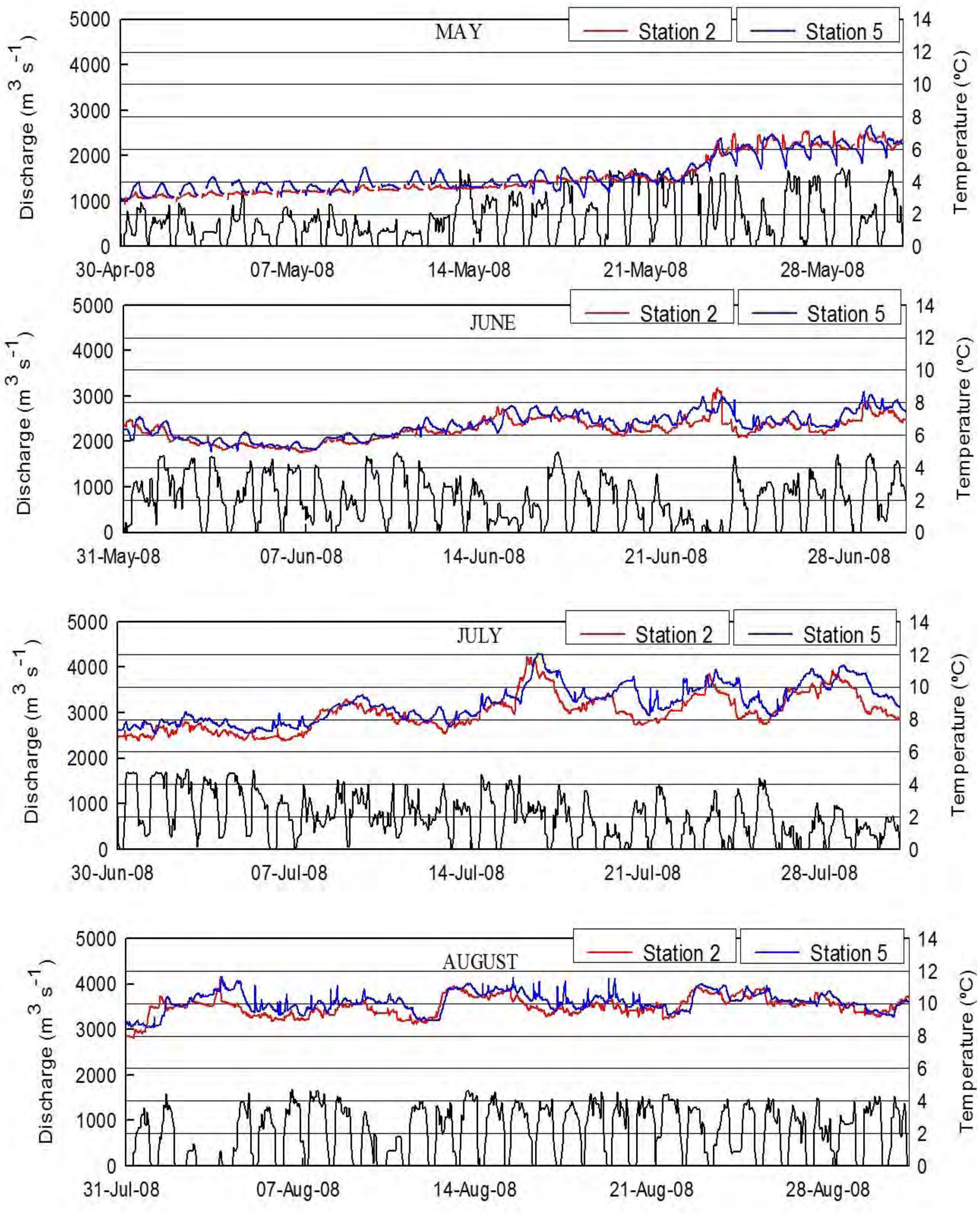


Figure D2: Diel temperature range at monitoring stations in the Middle Columbia River, 2007-2012. Coloured lines show fitted values from generalized least squares model comparing the pre-implementation (red) and post-implementation (blue) of the of 142 m^3s^{-1} minimum flow regime.


JANUARY
Station 2
Station 5
Discharge (m3 s-1)
Temperature (ºC)
31-Dec-07
07-Jan-08
14-Jan-08
21-Jan-08
28-Jan-08
FEBRUARY
31-Jan-08
07-Feb-08
14-Feb-08
21-Feb-08
28-Feb-08
MARCH
29-Feb-08
07-Mar-08
14-Mar-08
21-Mar-08
28-Mar-08
APRIL
31-Mar-08
07-Apr-08
14-Apr-08
21-Apr-08
28-Apr-08


MAY
Station 2
Station 5
Discharge (m 3 s -1)
Temperature (ºC)
30-Apr-08
07-May-08
14-May-08
21-May-08
28-May-08
JUNE
31-May-08
07-Jun-08
14-Jun-08
21-Jun-08
28-Jun-08
JULY
30-Jun-08
07-Jul-08
14-Jul-08
21-Jul-08
28-Jul-08
AUGUST
31-Jul-08
07-Aug-08
14-Aug-08
21-Aug-08
28-Aug-08

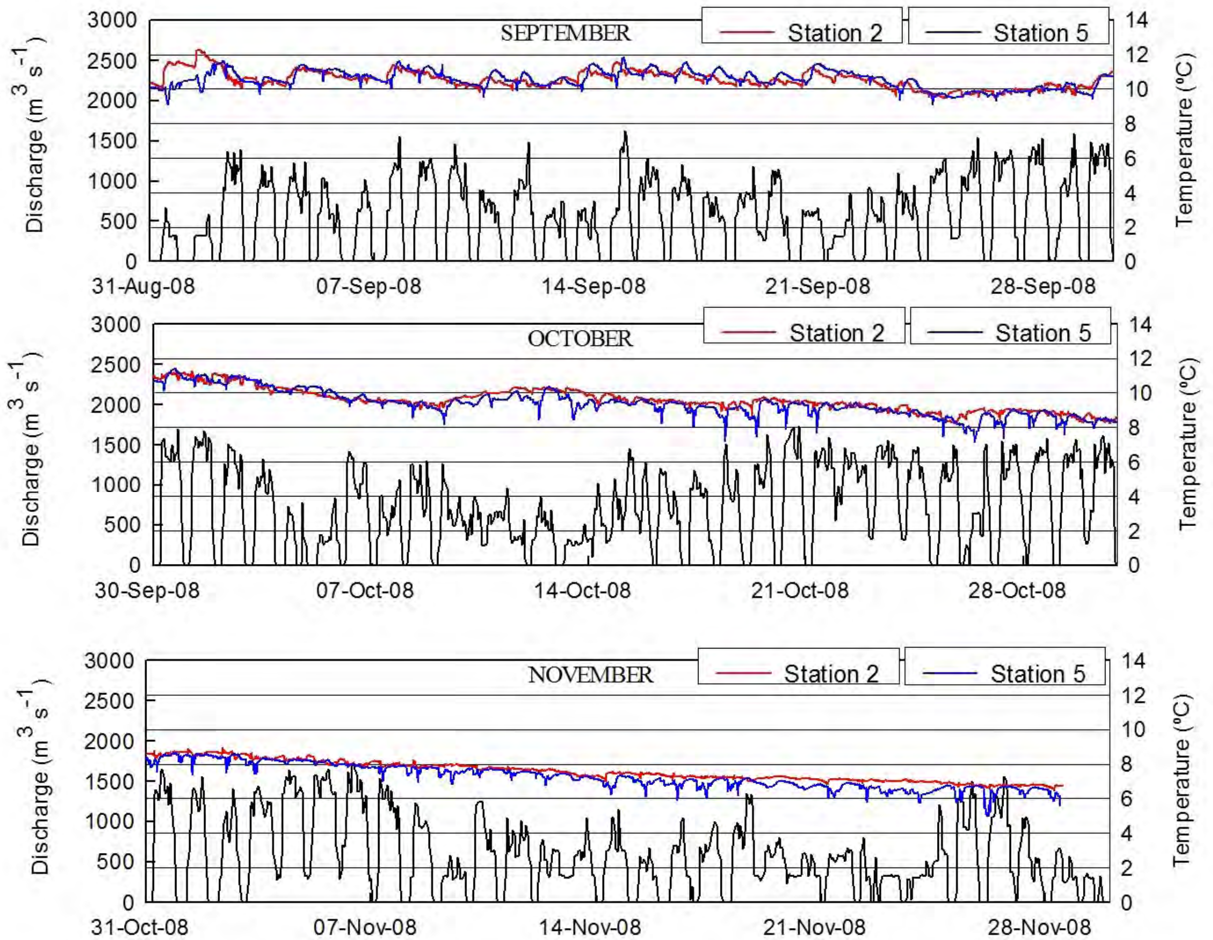
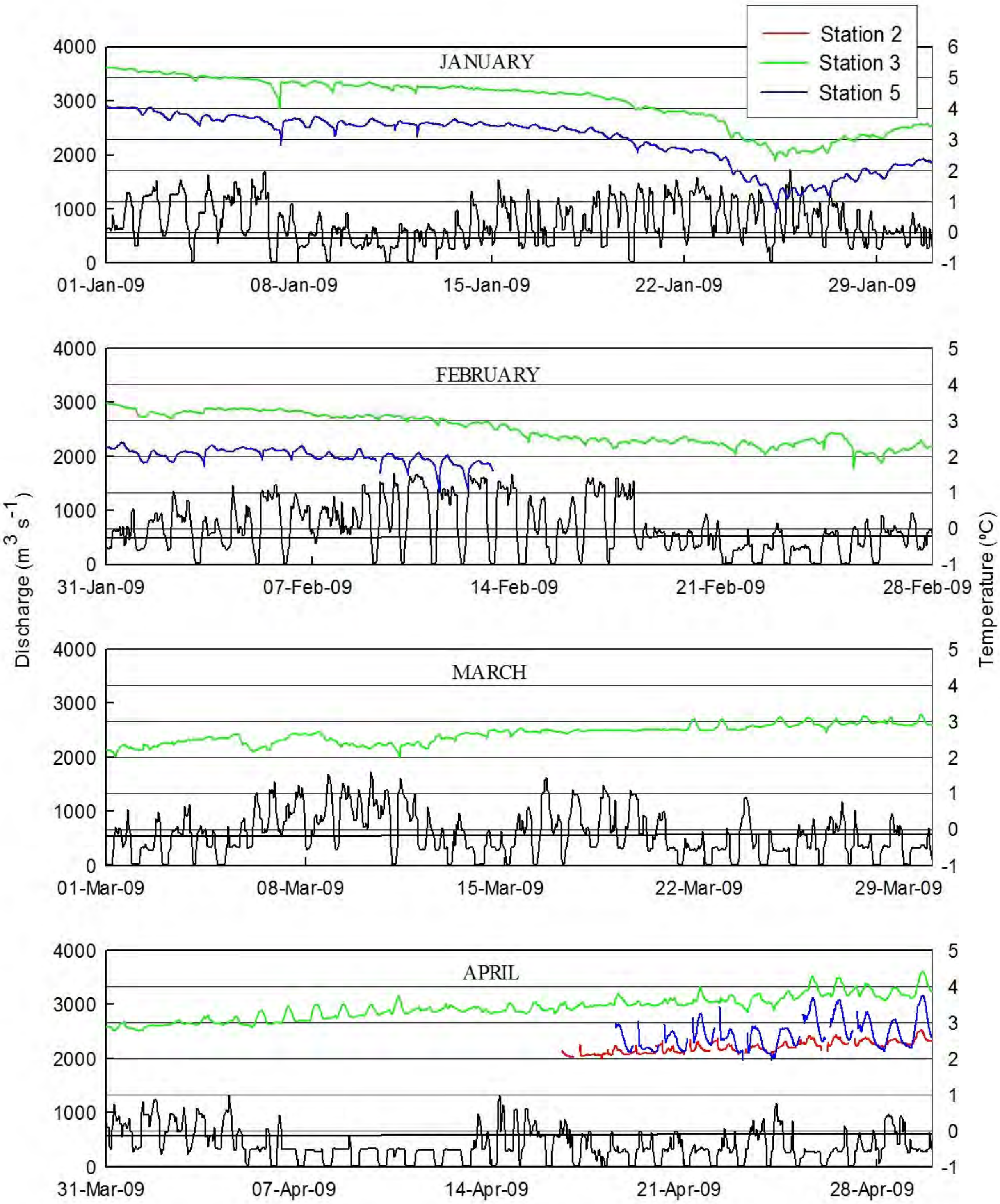
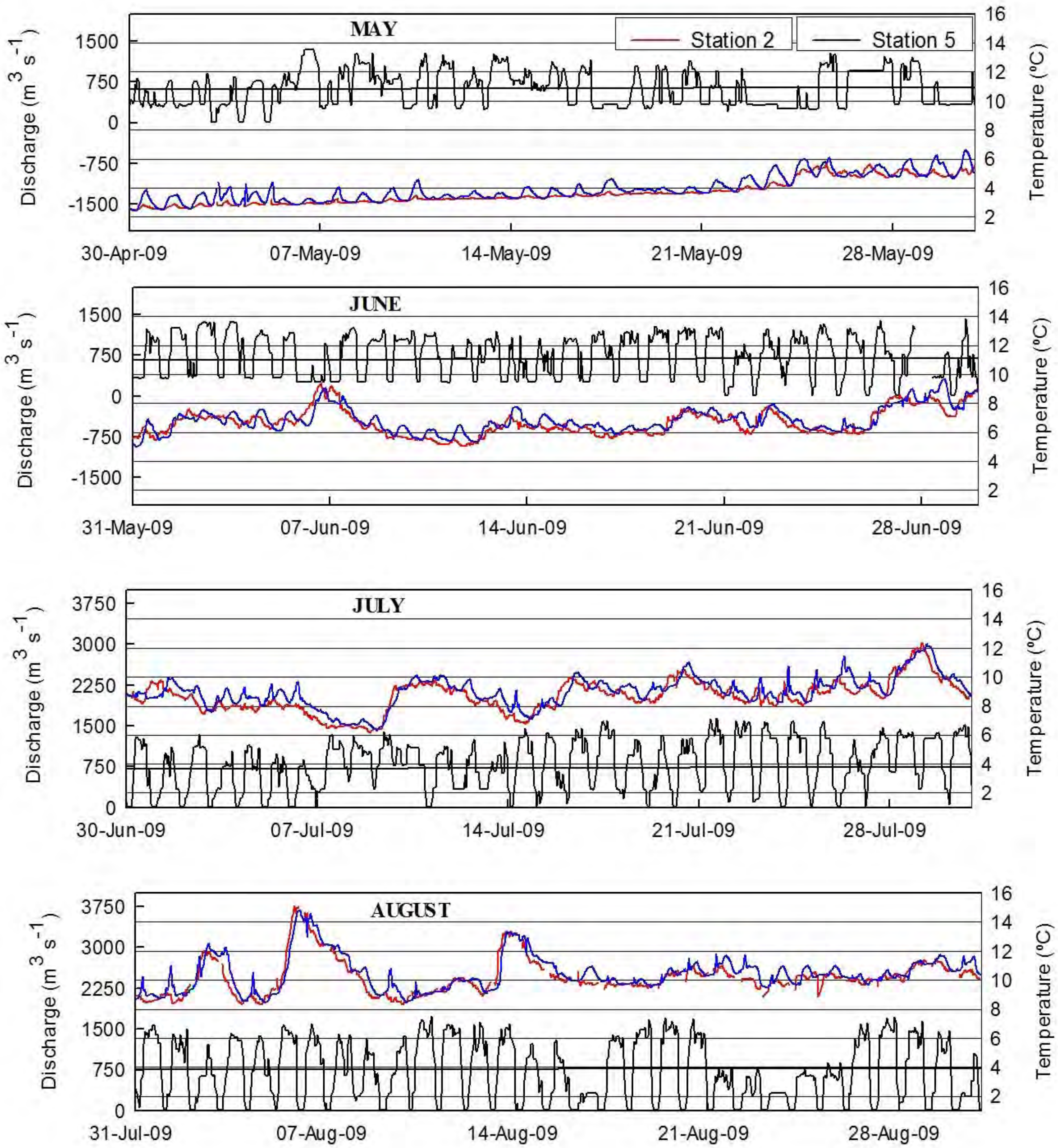


Figure D3: Discharge (grey line) from REV and water temperatures by month at selected monitoring stations in the Middle Columbia River in 2008.



Station 2
Station 3
Station 5
JANUARY
FEBRUARY
MARCH
APRIL
Discharge (m 3 s -1)
Temperature (ºC)
01-Jan-09
08-Jan-09
15-Jan-09
22-Jan-09
29-Jan-09
31-Jan-09
07-Feb-09
14-Feb-09
21-Feb-09
28-Feb-09
01-Mar-09
08-Mar-09
15-Mar-09
22-Mar-09
29-Mar-09
31-Mar-09
07-Apr-09
14-Apr-09
21-Apr-09
28-Apr-09



MAY
JUNE
JULY
AUGUST
Station 2
Station 5
Discharge (m 3 s -1)
Temperature (ºC)
30-Apr-09
07-May-09
14-May-09
21-May-09
28-May-09
31-May-09
07-Jun-09
14-Jun-09
21-Jun-09
28-Jun-09
30-Jun-09
07-Jul-09
14-Jul-09
21-Jul-09
28-Jul-09
31-Jul-09
07-Aug-09
14-Aug-09
21-Aug-09
28-Aug-09

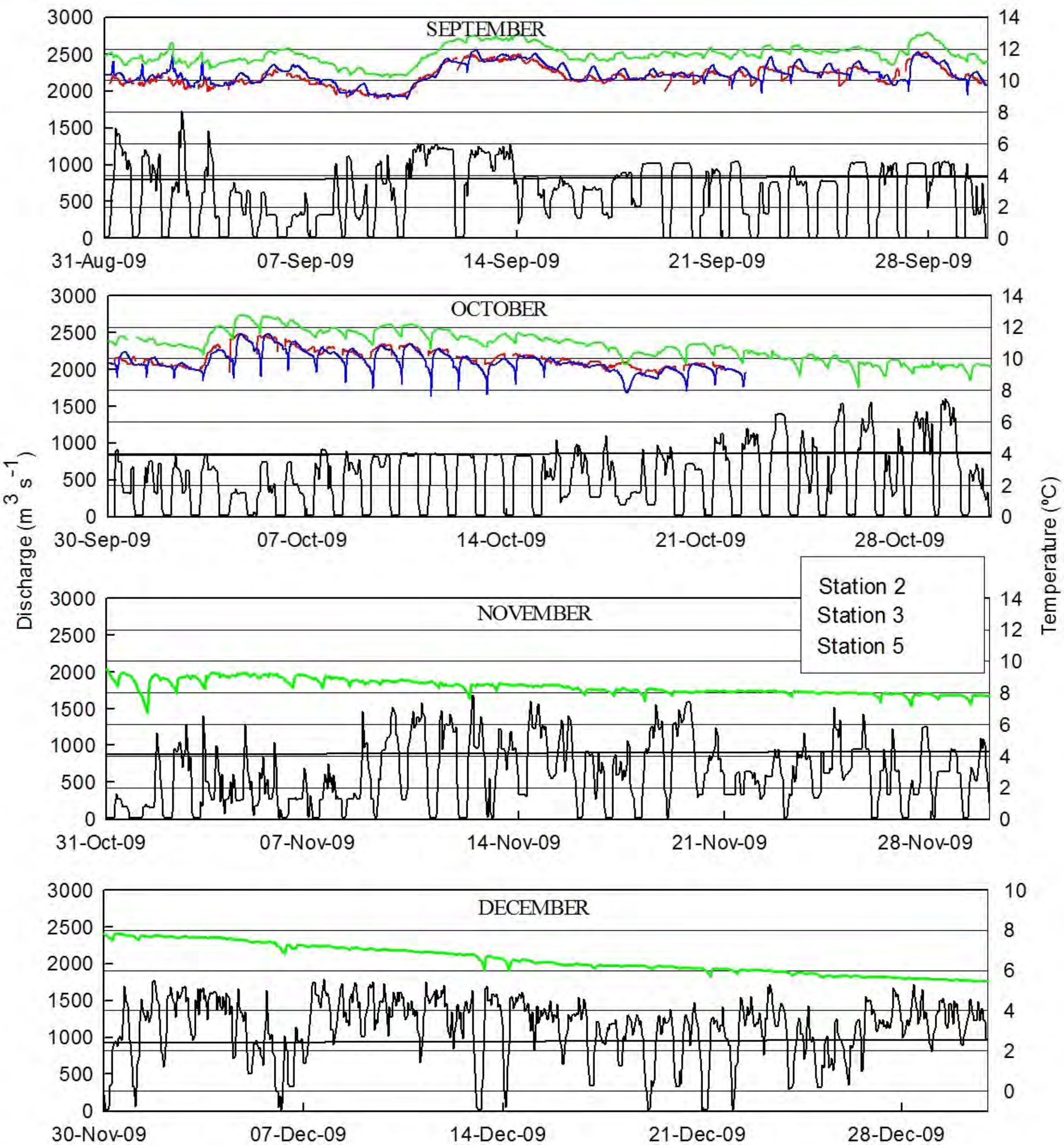
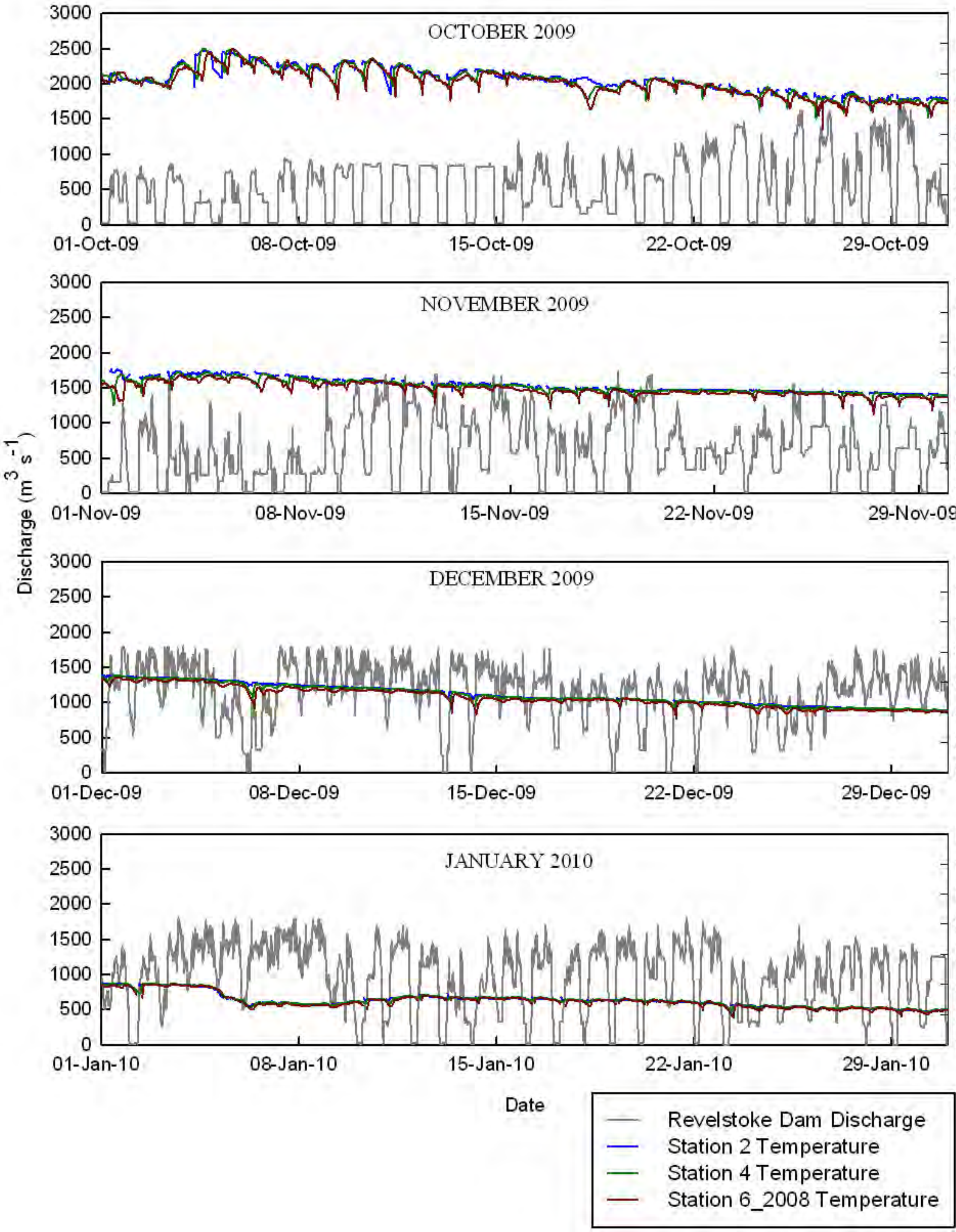
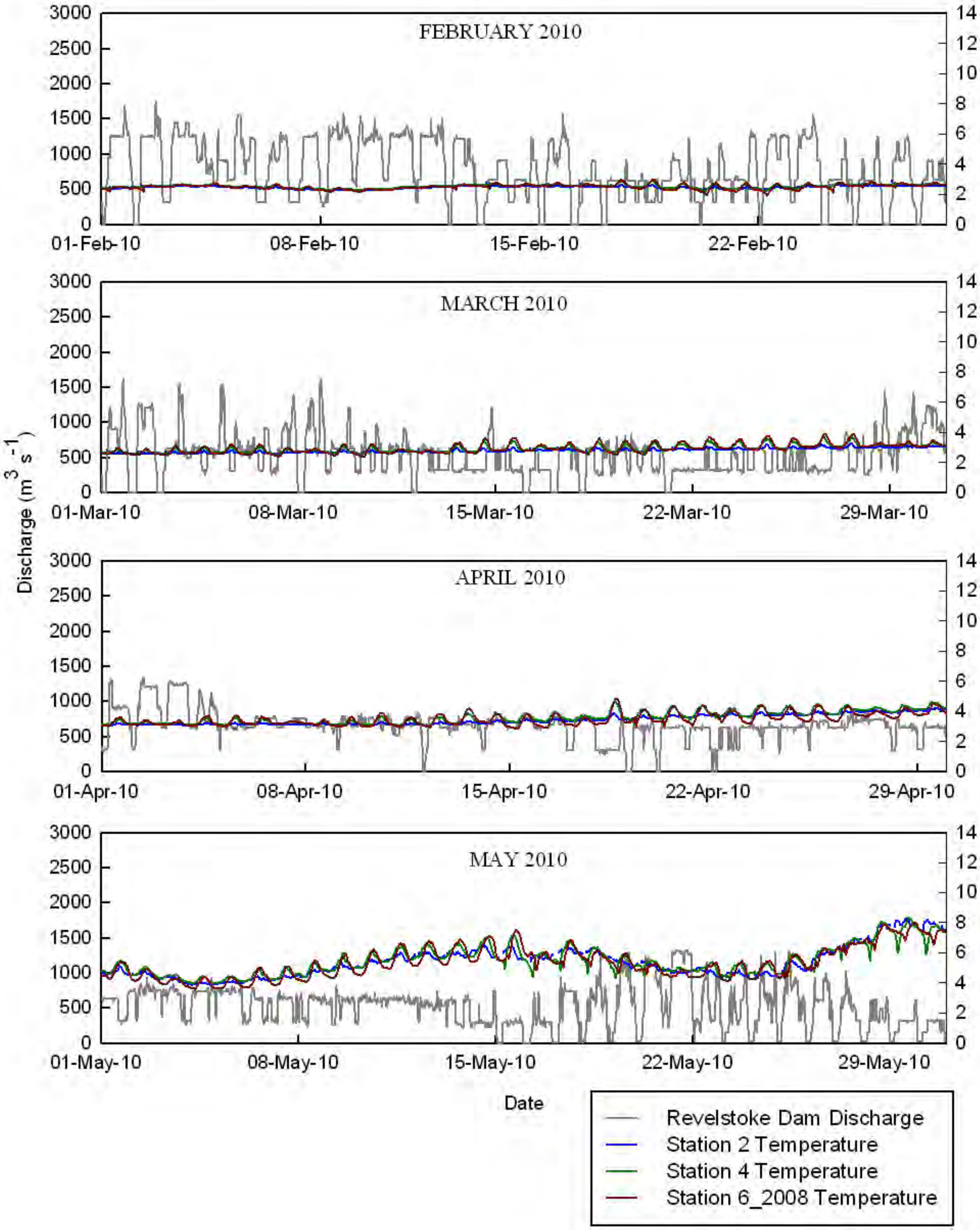
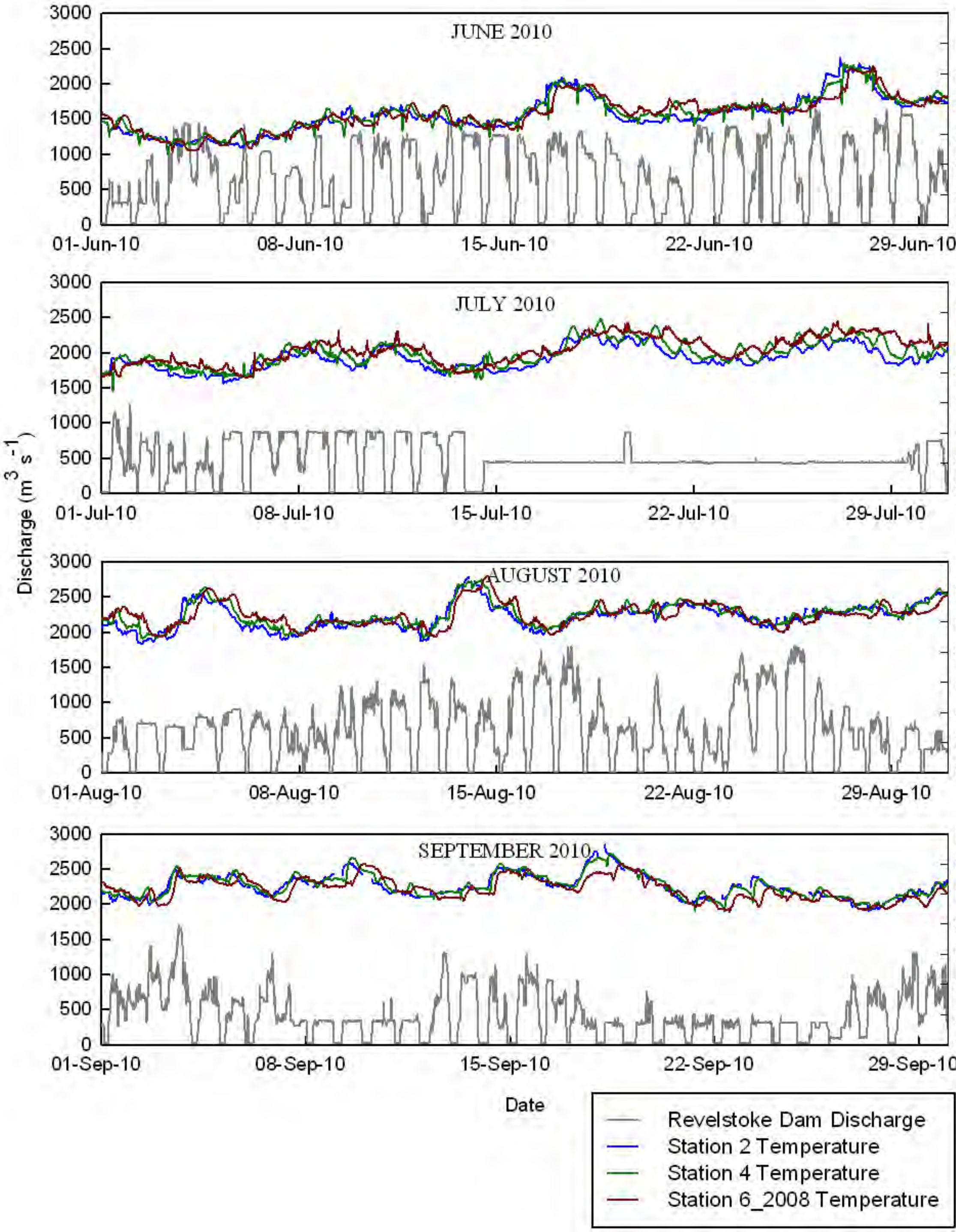


Figure D4: Discharge (grey line) from REV and water temperatures by month at selected monitoring stations in the Middle Columbia River in 2009.



OCTOBER 2009
NOVEMBER 2009
DECEMBER 2009
JANUARY 2010
Discharge (m3 s-1)
Temperature (°C)
Date
01-Oct-09
08-Oct-09
15-Oct-09
22-Oct-09
29-Oct-09
01-Nov-09
08-Nov-09
15-Nov-09
22-Nov-09
29-Nov-09
01-Dec-09
08-Dec-09
15-Dec-09
22-Dec-09
29-Dec-09
01-Jan-10
08-Jan-10
15-Jan-10
22-Jan-10
29-Jan-10
Revelstoke Dam Discharge
Station 2 Temperature
Station 4 Temperature
Station 6_2008 Temperature


FEBRUARY 2010
MARCH 2010
APRIL 2010
MAY 2010
Discharge (m^3 s^{-1})
Temperature (^{0}C)
Date
01-Feb-10
08-Feb-10
15-Feb-10
22-Feb-10
01-Mar-10
08-Mar-10
15-Mar-10
22-Mar-10
29-Mar-10
01-Apr-10
08-Apr-10
15-Apr-10
22-Apr-10
29-Apr-10
01-May-10
08-May-10
15-May-10
22-May-10
29-May-10
Revelstoke Dam Discharge
Station 2 Temperature
Station 4 Temperature
Station 6_2008 Temperature



JUNE 2010
JULY 2010
AUGUST 2010
SEPTEMBER 2010
Discharge (m3 s-1)
Temperature (°C)
0
500
1000
1500
2000
2500
3000
0
2
4
6
8
10
12
14
01-Jun-10
08-Jun-10
15-Jun-10
22-Jun-10
29-Jun-10
01-Jul-10
08-Jul-10
15-Jul-10
22-Jul-10
29-Jul-10
01-Aug-10
08-Aug-10
15-Aug-10
22-Aug-10
29-Aug-10
01-Sep-10
08-Sep-10
15-Sep-10
22-Sep-10
29-Sep-10
Date
Revelstoke Dam Discharge
Station 2 Temperature
Station 4 Temperature
Station 6_2008 Temperature

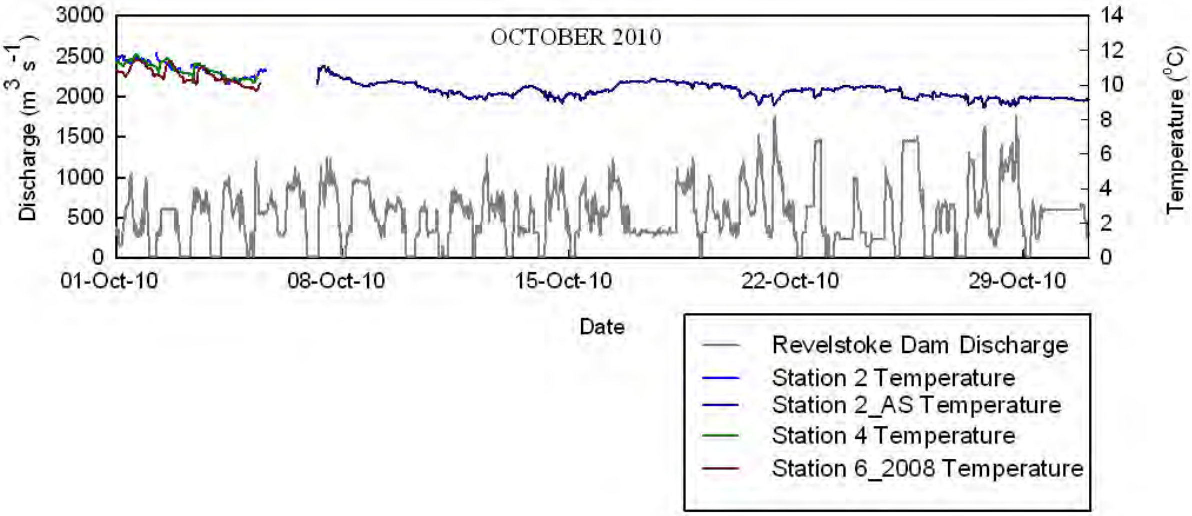
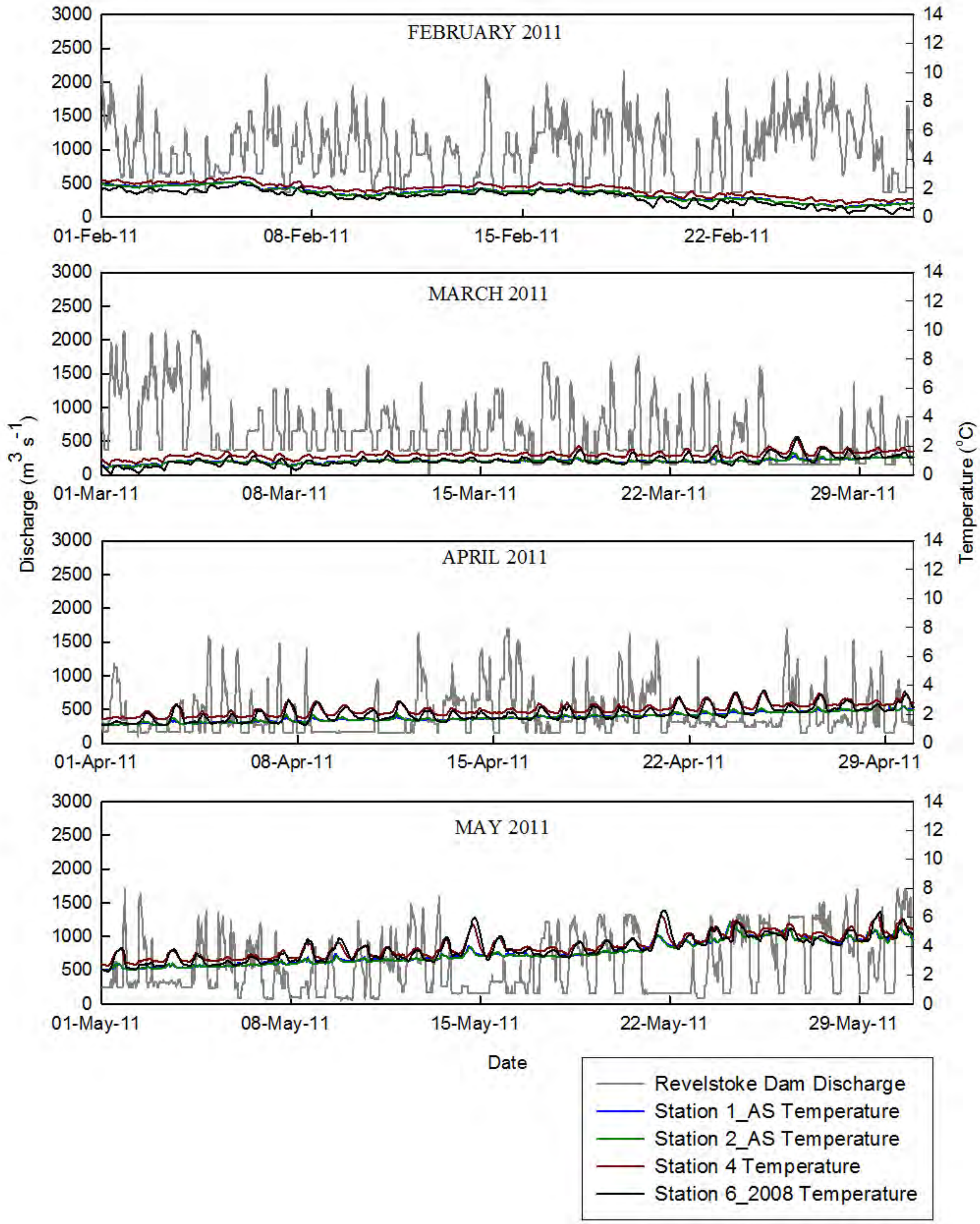
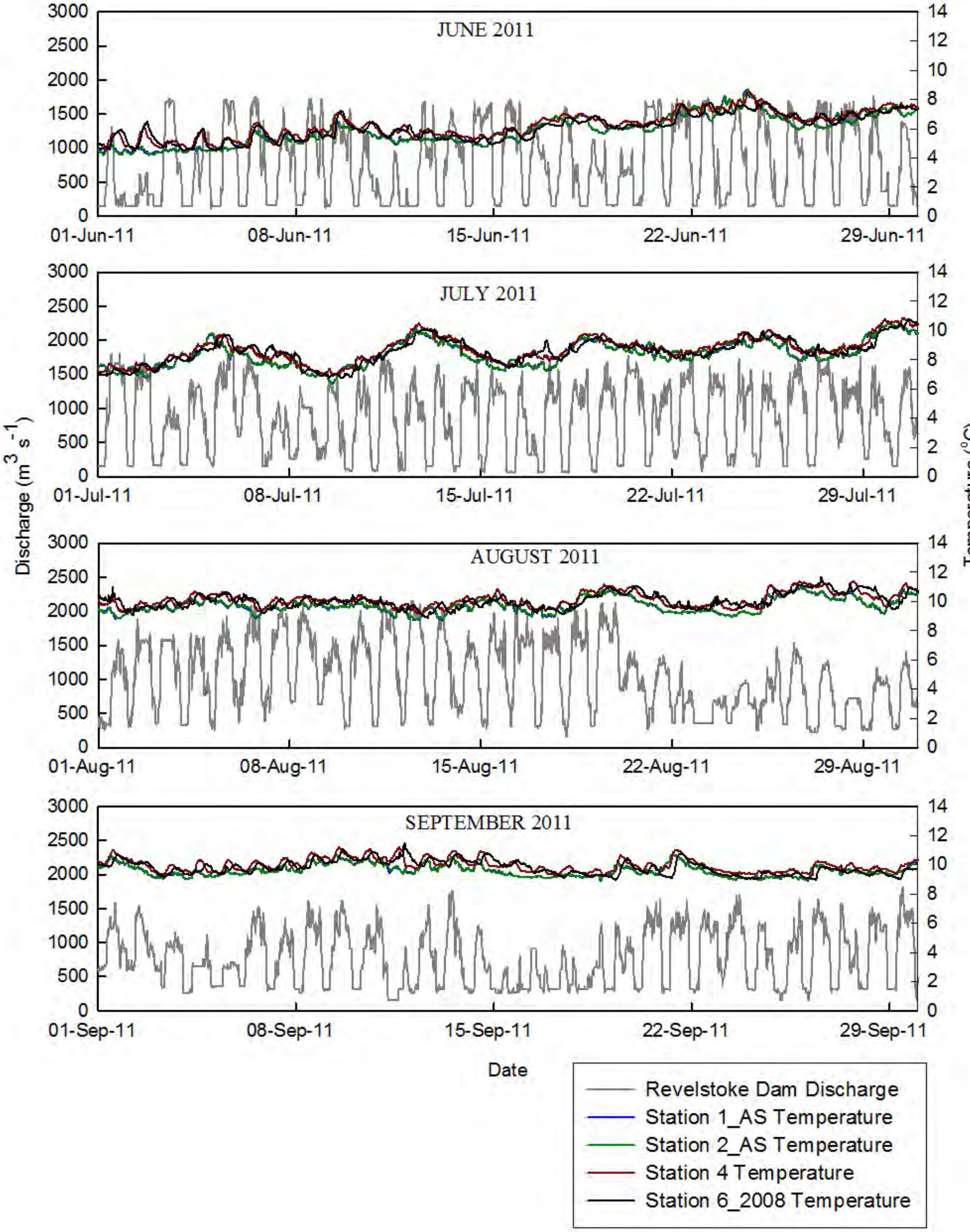


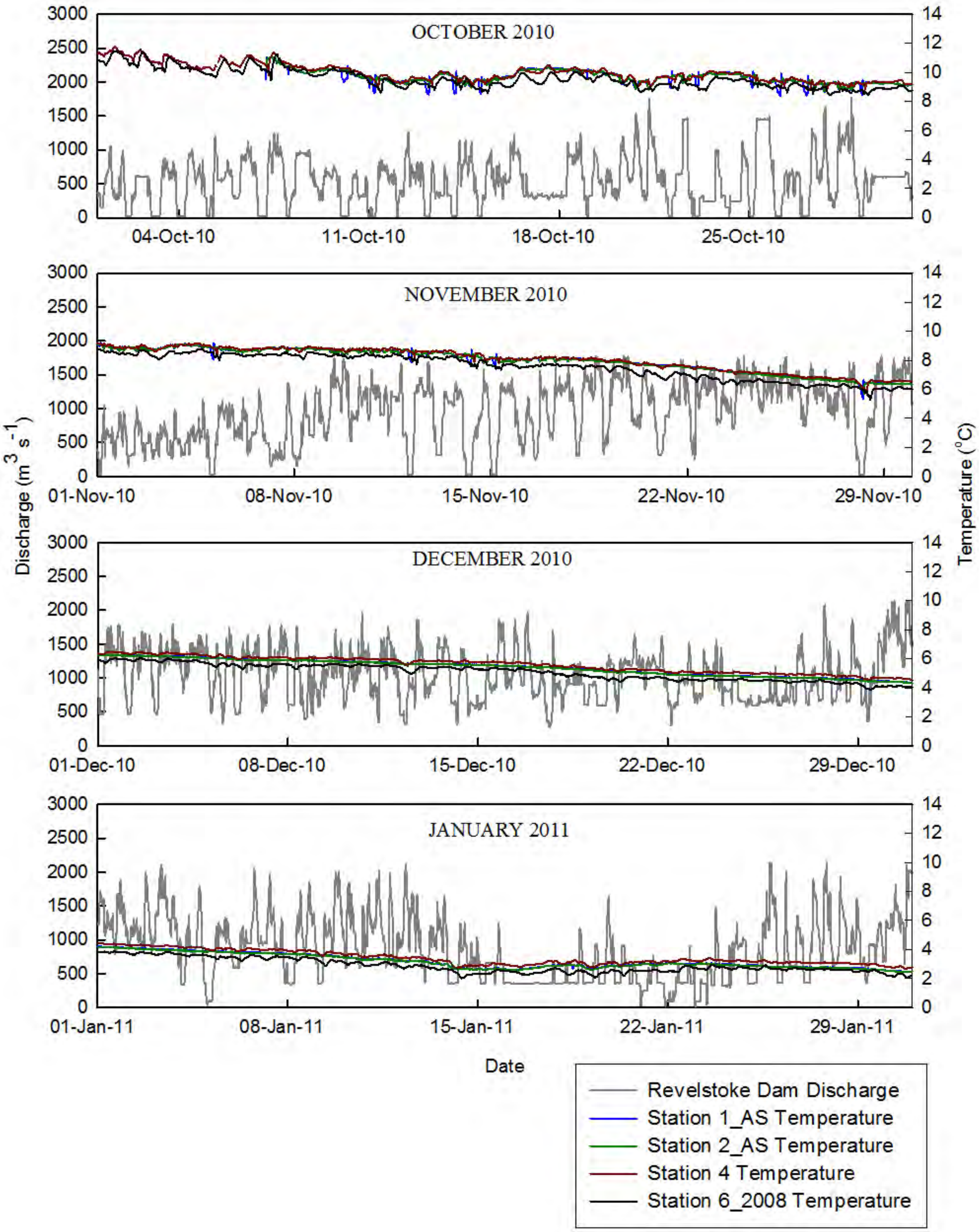
Figure D5: Discharge (grey line) from REV and water temperatures by month at selected monitoring stations in the Middle Columbia River in 2010.



FEBRUARY 2011
MARCH 2011
APRIL 2011
MAY 2011
Discharge ($m^3 s^{-1}$)
Temperature (°C)
Date
01-Feb-11
08-Feb-11
15-Feb-11
22-Feb-11
01-Mar-11
08-Mar-11
15-Mar-11
22-Mar-11
29-Mar-11
01-Apr-11
08-Apr-11
15-Apr-11
22-Apr-11
29-Apr-11
01-May-11
08-May-11
15-May-11
22-May-11
29-May-11
Revelstoke Dam Discharge
Station 1_AS Temperature
Station 2_AS Temperature
Station 4 Temperature
Station 6_2008 Temperature



JUNE 2011
JULY 2011
AUGUST 2011
SEPTEMBER 2011
Discharge (m3 s-1)
Temperature (oC)
Date
01-Jun-11
08-Jun-11
15-Jun-11
22-Jun-11
29-Jun-11
01-Jul-11
08-Jul-11
15-Jul-11
22-Jul-11
29-Jul-11
01-Aug-11
08-Aug-11
15-Aug-11
22-Aug-11
29-Aug-11
01-Sep-11
08-Sep-11
15-Sep-11
22-Sep-11
29-Sep-11
Revelstoke Dam Discharge
Station 1_AS Temperature
Station 2_AS Temperature
Station 4 Temperature
Station 6_2008 Temperature


OCTOBER 2010
NOVEMBER 2010
DECEMBER 2010
JANUARY 2011
Discharge (m3 s-1)
Temperature (oC)
3000
2500
2000
1500
1000
500
0
14
12
10
8
6
4
2
0
04-Oct-10
11-Oct-10
18-Oct-10
25-Oct-10
01-Nov-10
08-Nov-10
15-Nov-10
22-Nov-10
29-Nov-10
01-Dec-10
08-Dec-10
15-Dec-10
22-Dec-10
29-Dec-10
01-Jan-11
08-Jan-11
15-Jan-11
22-Jan-11
29-Jan-11
Date
Revelstoke Dam Discharge
Station 1_AS Temperature
Station 2_AS Temperature
Station 4 Temperature
Station 6_2008 Temperature

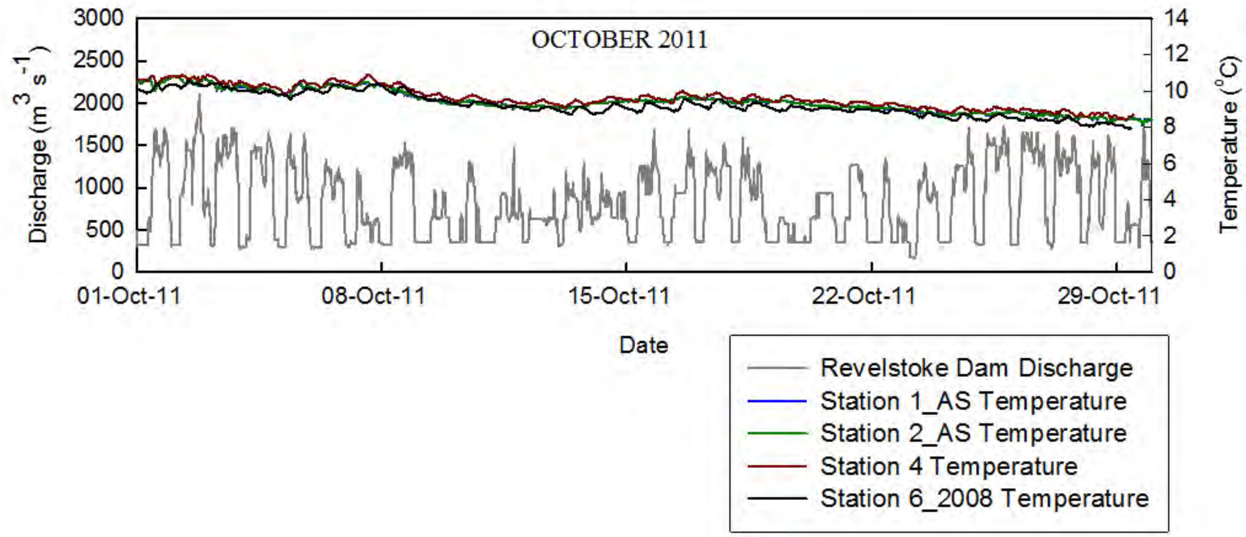
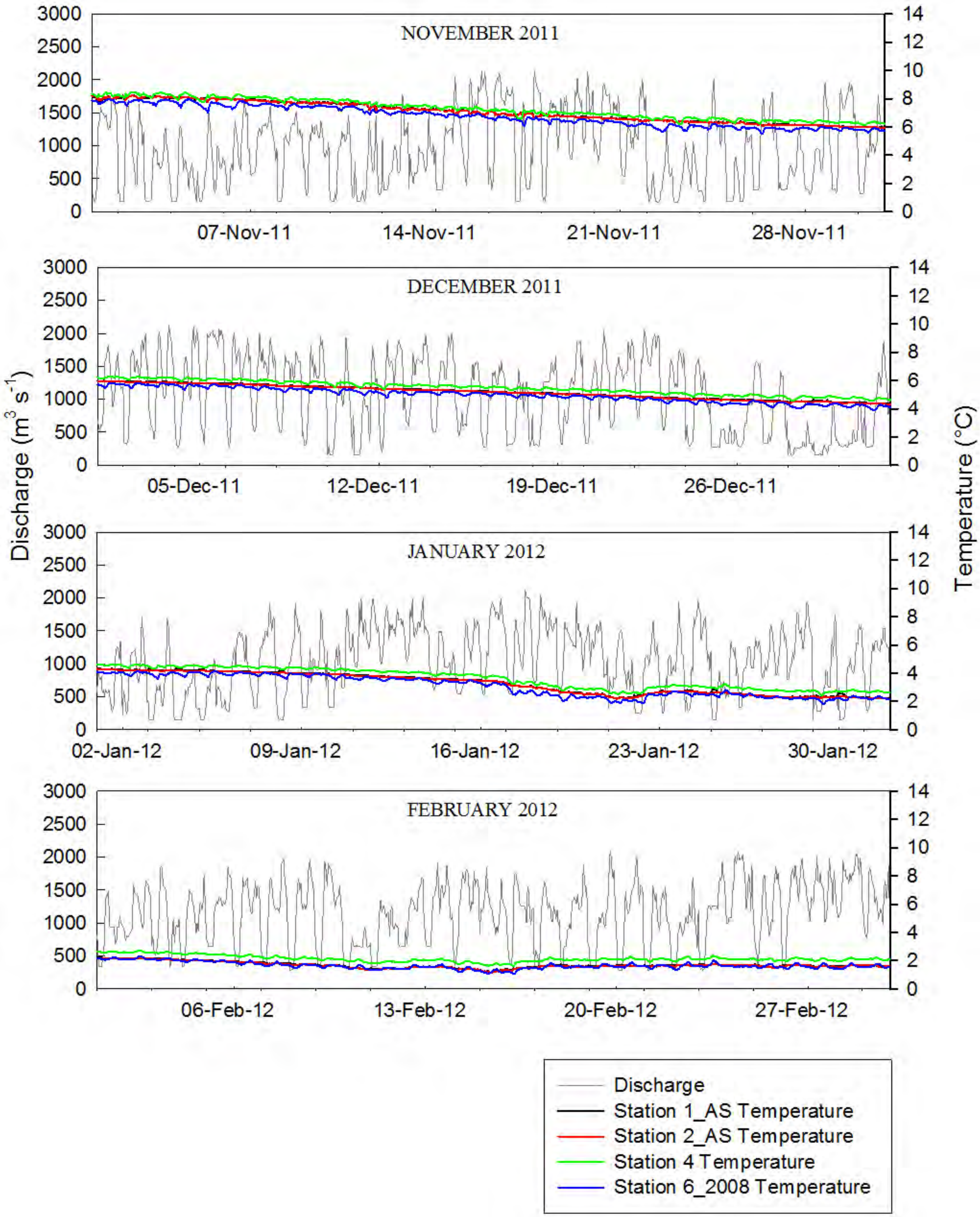
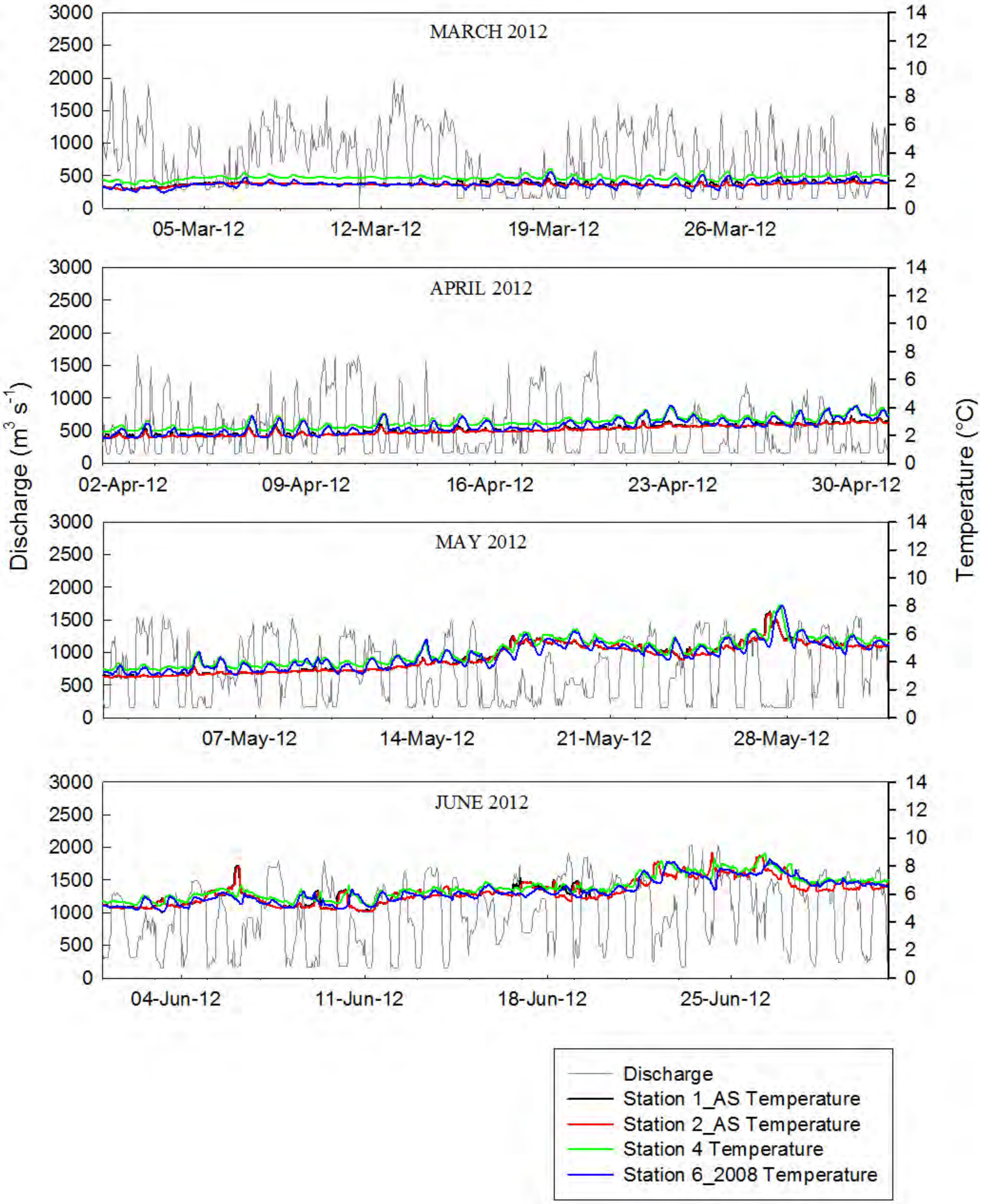


Figure D6: Discharge (grey line) from REV and water temperatures by month at selected monitoring stations in the Middle Columbia River in 2011.



NOVEMBER 2011
DECEMBER 2011
JANUARY 2012
FEBRUARY 2012
Discharge (m3 s-1)
Temperature (°C)
07-Nov-11
14-Nov-11
21-Nov-11
28-Nov-11
05-Dec-11
12-Dec-11
19-Dec-11
26-Dec-11
02-Jan-12
09-Jan-12
16-Jan-12
23-Jan-12
30-Jan-12
06-Feb-12
13-Feb-12
20-Feb-12
27-Feb-12
Discharge
Station 1_AS Temperature
Station 2_AS Temperature
Station 4 Temperature
Station 6_2008 Temperature


MARCH 2012
APRIL 2012
MAY 2012
JUNE 2012
Discharge (m^3 s^{-1})
Temperature (°C)
05-Mar-12
12-Mar-12
19-Mar-12
26-Mar-12
02-Apr-12
09-Apr-12
16-Apr-12
23-Apr-12
30-Apr-12
07-May-12
14-May-12
21-May-12
28-May-12
04-Jun-12
11-Jun-12
18-Jun-12
25-Jun-12
Discharge
Station 1_AS Temperature
Station 2_AS Temperature
Station 4 Temperature
Station 6_2008 Temperature

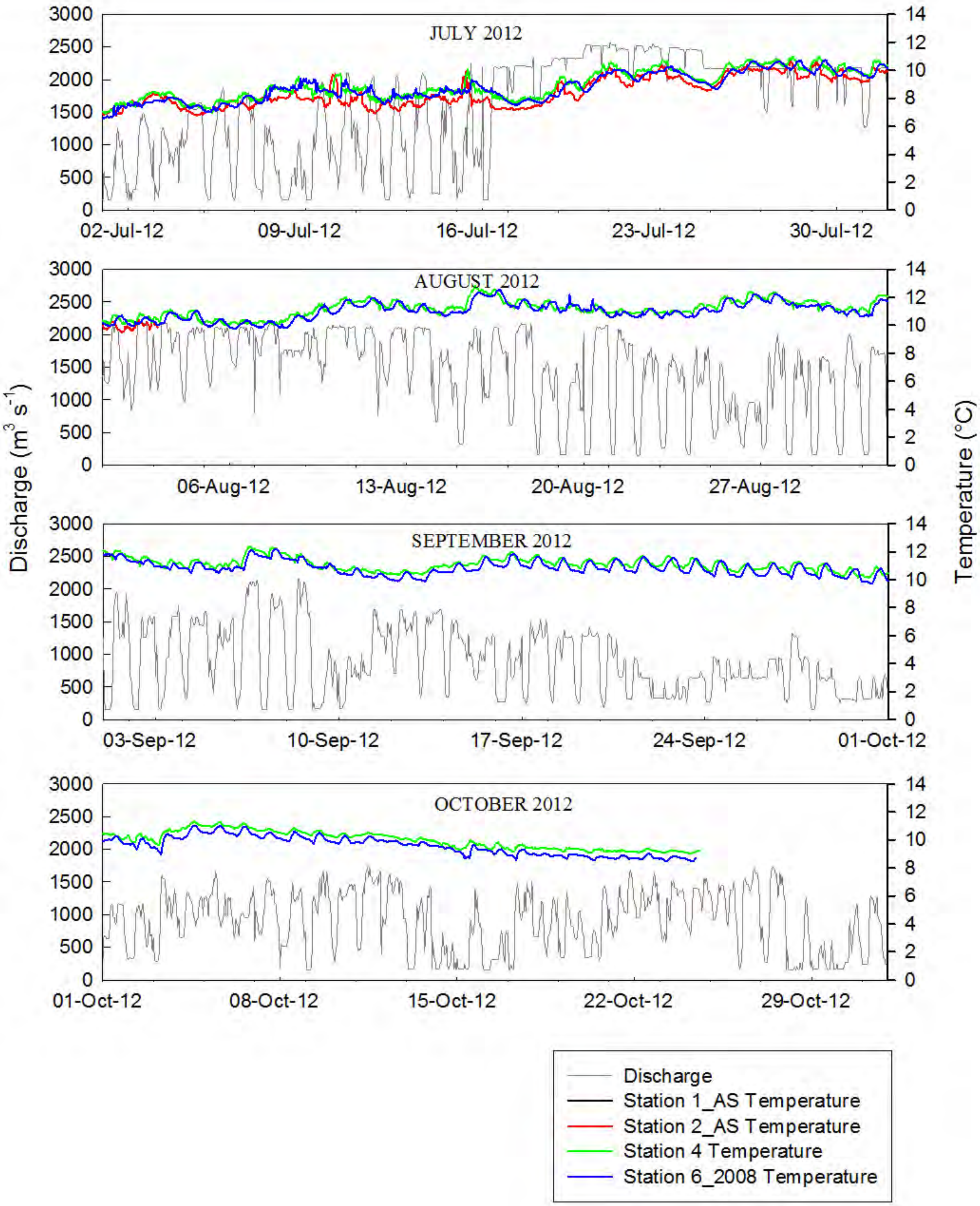


Figure D7: Discharge (grey line) from REV and water temperatures by month at selected monitoring stations in the Middle Columbia River in 2010.

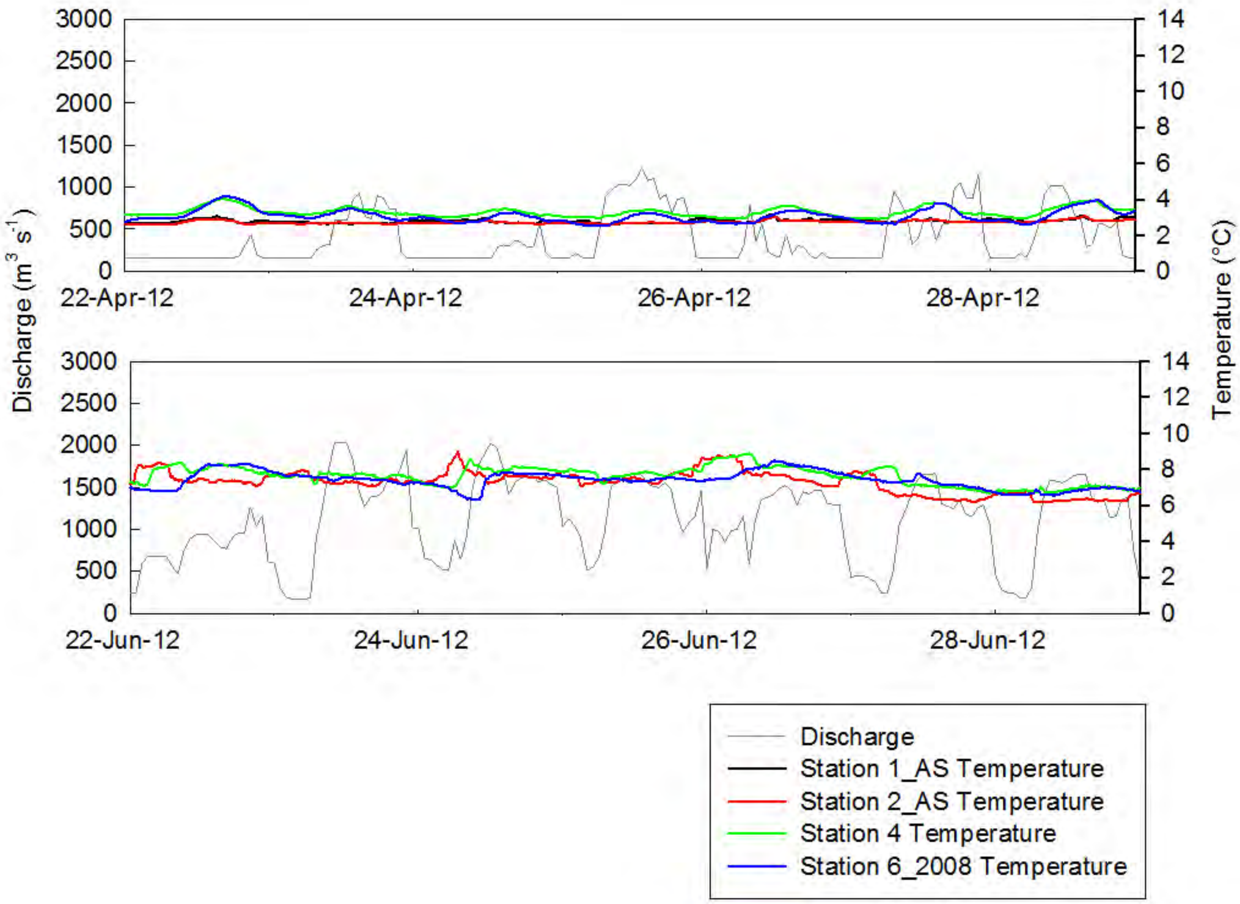


Figure D8: Discharge (grey line) from REV and water temperatures on the Middle Columbia River at Station 1_AS, Station 2_AS (Reach 4), Station 4 (transition area between Reaches 3 and 2) and Station 6_2008 (Reach 2) from April 22-28 and June 22-28, 2012.

Table D1. Coefficients, standard error (SE), and p-values for generalized least squares linear models of mean hourly temperature at monitoring stations in the Middle Columbia River, 2008-2012.

Variable	Coefficient	SE	P-value
Station 2 - July 2008			
Intercept	8.40	195.46	1.0
Discharge (1000 m^3/s)	-0.05	0.02	0.04
MinFlow (Above/Below)	0.00	0.02	0.8
Discharge:MinFlow	0.08	0.25	0.7
Station 2 - July 2009			
Intercept	9.31	195.18	1.0
Discharge (1000 m^3/s)	-0.11	0.03	<0.001
MinFlow (Above/Below)	0.02	0.03	0.5
Discharge:MinFlow	0.20	0.36	0.6
Station 2 - August 2010			
Intercept	9.92	184.49	1.0
Discharge (1000 m^3/s)	-0.11	0.03	<0.001
MinFlow (Above/Below)	-0.03	0.02	0.2
Discharge:MinFlow	0.19	0.28	0.5
Station 4 - July 2008			
Intercept	7.92	279.39	1.0
Discharge (1000 m^3/s)	0.01	0.03	0.7
MinFlow (Above/Below)	-0.18	0.03	<0.001
Discharge:MinFlow	0.56	0.35	0.1
Station 4 - July 2009			
Intercept	9.03	183.75	1.0
Discharge (1000 m^3/s)	-0.09	0.02	0.0
MinFlow (Above/Below)	-0.02	0.02	0.3
Discharge:MinFlow	-0.01	0.34	1.0
Station 4 - August 2010			
Intercept	10.29	169.48	1.0
Discharge (1000 m^3/s)	-0.03	0.03	0.2
MinFlow (Above/Below)	-0.01	0.02	0.6
Discharge:MinFlow	0.05	0.24	0.8
Station 5 - July 2008			
Intercept	8.23	208.03	1.0
Discharge (1000 m^3/s)	-0.06	0.03	0.02
MinFlow (Above/Below)	-0.09	0.02	<0.001
Discharge:MinFlow	1.07	0.26	<0.001

Variable	Coefficient	SE	P-value
Station 5 - July 2009			
Intercept	8.78	253.32	1.0
Discharge (1000 m^3/s)	-0.05	0.03	0.1
MinFlow (Above/Below)	-0.15	0.03	<0.001
Discharge:MinFlow	0.66	0.46	0.2
Station 5 - August 2010			
Intercept	10.40	199.53	1.0
Discharge (1000 m^3/s)	0.03	0.03	0.3
MinFlow (Above/Below)	-0.06	0.02	0.01
Discharge:MinFlow	0.14	0.28	0.6
Station 6 - July 2009			
Intercept	8.79	202.73	1.0
Discharge (1000 m^3/s)	0.10	0.03	0.0
MinFlow (Above/Below)	-0.02	0.03	0.5
Discharge:MinFlow	0.12	0.37	0.7
Station 6 - August 2010			
Intercept	10.57	153.53	0.9
Discharge (1000 m^3/s)	0.13	0.02	0.0
MinFlow (Above/Below)	0.02	0.02	0.2
Discharge:MinFlow	-0.08	0.22	0.7

APPENDIX E

Total Gas Pressure Data

Table E-1

CLBMON-15a Physical Habitat Monitoring Program seasonal Total Gas Pressure (TGP) sampling stations on the middle Columbia River.

Site Designation	Reach	Bank[a]	UTM Coordinates			UTM Coordinates Obtained From[b]	General Reach Location Description
			Zone	Easting	Northing		
TGP 1 - Upper Station	4	LDB	11	415235	5655549	CLBMON-15a (2007)	1.4 km downstream of Revelstoke Dam
TGP 2 - Middle Station	4	LDB	11	413480	5651854	CLBMON-15a (2007)	Adjacent to the Revelstoke Golf and Country Club
TGP 3 - Lower Station	3	RDB	11	413351	5651148	CLBMON-15a (2007)	Downstream of Jordan River

Notes:

[a] RDB=Right bank as viewed facing downstream; LDB=Left bank as viewed facing downstream.

[b] Sampled under CLBMON-15a MCR Physical Habitat Monitoring by Golder Associates Ltd.

APPENDIX F

Seasonal Water Quality Data

Water Filtering Procedures

For Collection in Field:

- ⇒ Pre-label all bottles using the label template and place the **3 bottles** listed below in one Ziploc bag per station
- ⇒ 2 1L plastic bottles
- ⇒ 1 glass test tube not filtered (TP) – keep cool but **DO NOT freeze**

Each station will have:

- ⇒ 2 125 ml plastic bottles (filtered) – **freeze** once filtered
- ⇒ 1 glass test tube filtered (TDP) – keep cool but **DO NOT freeze**
- ⇒ 1 glass test tube not filtered (TP) – keep cool but **DO NOT freeze**

Additional Samples for Analysis:

- ⇒ Field duplicate (Stn 4 disguised as Stn 10) – complete entire round of samples at **Stn 4** for analysis

Important Filtering Procedures:

- ⇒ Cover table/working area with clean paper towels
- ⇒ Keep samples cool in cooler and pull one sample out at a time
- ⇒ Prior to filtering, mix each bottle 20 full rotations to ensure nutrients have not settled to the bottom.
- ⇒ Fill 2 full syringes of DDW and run through at the start of each new sample (i.e. each station)
- ⇒ Triple rinse all sample bottles and test tubes by running through syringe and filtering apparatus
- ⇒ Put filtered samples on ice immediately
- ⇒ Change nitrile gloves and filters with each station during filtering
- ⇒ Change filter with clean, blunt-nose forceps only
- ⇒ Keep rough side of filter up
- ⇒ Only touch sides of filtering apparatus, not tips and do not place tip down on table
- ⇒ Tip up on filtering apparatus to attach to syringe
- ⇒ Refer to *Nutrient Sample Collection Procedures_PESC* for additional methods
- ⇒ Place all bottles and test tubes in **labelled** Ziplocs to prevent contamination with ice melt water during transport
- ⇒ Use refrigerator and freezer at GAL REV

Shipping:

- ⇒ Samples should be sent out by Tuesday/Wednesday by **Purolator 1-888-744-7123** to Cultus Lake (no later). If they can’t be sent out by then, wait until following week to ship.

- ⇒ Three coolers with COC’s:
    1. One with blocked and cubed ice and 1 litre bottles to be sent to Caro
    2. One with dry ice and 125 mL frozen samples wrapped to Cultas Lake – place samples in middle of cooler with ice on top and bottom, wrapped and separated with paper packing material to ensure bottles are not damaged by dry ice

3. One with cubed ice, lots of packing material and wrapped test tubes, filtering supplies and extra sample bottles to Cultas Lake

⇒ Phone **Kerry Parish (604-824-4704)** at Cultus prior to shipping to ensure someone will be available to receive samples on proposed arrival date and pass on waybill information via email.

⇒ Phone **Ed Hoppe (250-765–9646)** at Caro prior to shipping to ensure someone will be available to receive samples on proposed arrival date and pass on waybill information via email.

Nutrient Samples Collection Procedure

Make sure the nutrient samples are kept frozen and test tubes are cool during transport to Cultus Lake Lab. This is critically important so **use as much cubed ice in plastic bags** as necessary. Prepare a field sample submission sheet, enclose it in a Ziploc bag, and place it inside the cooler.

Be sure not to touch the test tube mouth or inside of the cap as the Total Phosphorus and Total Dissolved Phosphorus analyses are extremely sensitive to contamination.

For TP samples, fill the labeled test tube with unfiltered sample water, cap, shake the tube to rinse and discard the sample water. Refill the test tube with unfiltered sample water. **Make sure the bottom of the meniscus rests on the top of the shoulder of the test tube**. Screw lids on tightly. Make sure all labels are legible and they state the lake or stream name, station, date, depth (if from a lake or reservoir), and test required. **Only use circular labels** attached to the tube cap. Do not label the pyrex tube. Once per field trip, prepare 1 labeled test tube with unfiltered DDW for a TP blank. **Do not freeze test tubes, but keep them cool.**

Avoid finger contact with filters. Use only clean blunt-nosed forceps to handle filters. For the 125 ml plastic bottles and TDP tubes, filter the sample using a 47 mm Swinnex holder with an ashed GFF filter and a clean 60 cc syringe. The same syringe can be used for a complete sample set from several sites on the same day but do not use the same syringe on different filtering days. Prepare the GFF filter by placing it in the Swinnex holder and rinsing it with 3 full syringes of DDW. If water runs through the filter with little or no resistance, the filter is either torn or not sealed properly in the holder. Adjust or replace the filter if leakage is found. Use one ashed GFF filter for each station unless the filter becomes plugged in which case use more than one per station.

For nitrate/ammonium/SRP samples, filter one full syringe of sample water into the appropriate labeled plastic bottle. Cap the bottle, shake, and discard the sample water. Refill the bottle to the shoulder with filtered sample water (equivalent to about 2 full syringes). Put caps on tightly. Make sure all labels are legible and they state the lake or stream name, station, date, depth (if from a lake or reservoir), and test required (ammonium/SRP/nitrate). **Freeze the bottles immediately after filtration**. Once per field trip, prepare a filtered DDW blank (2 bottles with filtered DDW).

For TDP samples, filter one full syringe of sample into the appropriate test tube. Cap the tube, shake, and discard the sample water. Refill the test tube with filtered sample water. **Make sure the bottom of the meniscus rests on the top of the shoulder of the test tube**. Screw lids on tightly. Make sure all labels are legible and they state the lake or stream name, station, date, depth (if from a lake or reservoir), and test required. **Only use circular labels** attached to the tube cap. Do not label the pyrex tube. Once per field trip, prepare 1 labeled test tube with unfiltered DDW for a TDP blank. **Do not freeze test tubes, but keep them cool**.

For added QAQC you may want to add a field duplicate for any one or several of the tests. A field duplicate is labeled as “field duplicate” for station name so lab techs do not know where it is from. Note the field duplicate station in your field notes.

Table F-1 **CLBMON-15a Physical Habitat Monitoring Program seasonal water quality sampling stations on the middle Columbia River that coincide as much as possible with the periphyton/benthic substrate locations for CLBMON-15b MCR Ecological Productivity Monitoring.**

Site Designation[a,b]	River	Bank[d]	UTM Coordinates			UTM Coordinates Obtained From	General Reach Location Description
			Zone	Easting	Northing		
Top of Reach 4	mid Columbia	mid	11	414673	5655141	CLBMON-15b (2008)	Upstream end of Reach 4
Bottom of Reach 4	mid Columbia	mid	11	413282	5651668	CLBMON-15b (2009)	Downstream end of Reach 4
Below Big Eddy	mid Columbia	mid	11	413697	5651598	CLBMON-15a (2009)	Below Big Eddy to capture full mixing of Jordan River
Bottom Reach 3	mid Columbia	mid	11	415218	5650414	CLBMON-15b (2009)	Downstream end of Reach 3
Top Reach 2	mid Columbia	mid	11	416825	5644041	CLBMON-15b (2009)	Upstream end of Reach 2; location captures full mixing of Illicillewaet River
Bottom Reach 2	mid Columbia	mid	11	424796	5631284	CLBMON-15b (2009)	Downstream end of Reach 2
Illecillewaet River	Illecillewaet	RB	11	423700	5651691	CLBMON-15a (2009)	~200 m downstream of the Greeley Road bridge crossing; ~10 km east of Revelstoke on Highway 1
Illecillewaet River d/s	Illecillewaet	mid	11	416886	5648830	CLBMON-15b (2011)	Site is above backwatering but below the sewage treatment plant to capture the total influence from Illecillewaet River.
Jordon River	Jordon	LB	11	412646	5653278	CLBMON-15a (2009)	Upstream of Jordan River Bridge past parking area for Boulder Mountain Snowmobile area

Notes:

[a] See Figure 5 for map of study area.

[b] Named under CLBMON-15b MCR Ecological Productivity Monitoring by Ecoscape Environmental Consultants Ltd.

[c] Sampled under CLBMON-15a MCR Physical Habitat Monitoring by Golder Associates Ltd.

[d] RB=Right bank as viewed facing downstream; LB=Left bank as viewed facing downstream; MID=mid channel.

Table F-2 **Summary of Method Detection Limits (MDL) for surface low-level nutrient water quality results from from DFO Cultas Lake Salmon Research Laboratory and Caro Analytical Services for CLBMON-15a and 15b seasonal water quality analyses.**

Laboratory Analyses Completed By	Laboratory Location	pH (pH units)	Total Dissolved Solids (mg/L)	Total Suspended Solids (mg/L)	Total Silica (mg/L)	Total Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	NO_3 (µg/L)	NH_3 (µg/L)	SRP (µg/L)	TP (µg/L)	TP Turbidity (µg/L)	TDP (µg/L)
DFO Cultas Lake Salmon Research	Cultas Lake, BC	n/a	n/a	n/a	n/a	n/a	n/a	1.0	0.1	0.5	0.5	0.5	0.5
Caro Analytical Services	Kelowna, BC	0.01	5	1	0.05	0.05	0.05	n/a	n/a	n/a	n/a	n/a	n/a

Notes:

n/a indicates not applicable; analysis was not completed by that particular laboratory; however was completed by alternative laboratory.

Units shown are those reported by a given laboratory.

Table F-3 Summary of in-situ surface water quality field parameters for Revelstoke Water Use Planning physical habitat assessments, 2007.

Site[a]	Season	Date	Time	Water Temperature (°C)	pH	pHmV	Disolved oxygen (%)	Disolved oxygen (mg/L)	Specific Conductivity (µs/cm)	Conductivity (µS/cm)	Salinity	ORP
Stn 1	summer	21-Aug-2007	11:49	9.7	7.06	n.d.	96.5	n.d.	111	n.d.	n.d.	n.d.
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 4	summer	21-Aug-2007	14:03	9.9	6.69	n.d.	97.5	n.d.	109	n.d.	n.d.	n.d.
Stn 5	summer	21-Aug-2007	13:43	10.0	6.95	n.d.	97.7	n.d.	109	n.d.	n.d.	n.d.
Stn 6	summer	21-Aug-2007	13:20	10.0	7.06	n.d.	98.8	n.d.	109	n.d.	n.d.	n.d.
Stn 7	summer	21-Aug-2007	15:40	9.7	7.41	n.d.	99.1	n.d.	101	n.d.	n.d.	n.d.
Stn 8	summer	21-Aug-2007	16:12	11.4	7.08	n.d.	102.2	n.d.	34	n.d.	n.d.	n.d.
Stn 1	fall	15-Nov-2007	11:13	7.9	7.89	-49.3	n.d.	18.82	112	75	0.05	116.0
Stn 2	fall	16-Nov-2007	12:06	7.9	7.87	-72.1	n.d.	101.16	109	73	0.05	97.1
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 4	fall	16-Nov-2007	11:09	7.8	7.72	-65.5	n.d.	23.63	117	80	0.05	108.1
Stn 5	fall	16-Nov-2007	10:54	7.7	7.98	-80.5	n.d.	55.41	120	78	0.05	86.5
Stn 6	fall	15-Nov-2007	14:07	7.7	7.59	-55.8	n.d.	17.12	110	74	0.05	104.4
Stn 7	fall	14-Nov-2007	13:07	2.7	7.52	-53.2	n.d.	22.61	136	78	0.06	132.7
Stn 8	fall	14-Nov-2007	13:36	2.6	7.08	-42.6	n.d.	46.24	36	21	0.02	115.4

[a] See Figures 5 sample site locations.

[b] BC Hydro station not maintained and/or visited by Golder

n.d. indicates no data available

Table F-4 Summary of surface low-level nutrient water quality results from Cultus Lake Labs and Pacific Environmental Labs for August and November sampling sessions, 2007.

Site[a]	Season	Date	Time	alkalinity (mg $CaCO^3$/L)	true color	pH	total suspended solids (mg/L)	total nitrogen (µg/L)	NO^3 (µg/L)	NH^3 (µg/L)	SRP (µg/L)	TP (µg/L)	TP turbidity (µg/L)	TDP (µg/L)
Stn 1	summer	23-Aug-2007	11:49	47	2.5	7.97	5	200	122.1	5.3	0.3	2.1	0.9	1.8
Stn 2	n/a	n/a	n/a	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Stn 3[b]	n/a	n/a	n/a	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Stn 4	summer	23-Aug-2007	14:03	47.2	2.5	7.98	<5	160	120.7	5.2	0.3	2.8	1.1	1.7
Stn 5	summer	23-Aug-2007	13:43	46.9	2.5	7.99	<5	170	121.7	4.9	0.3	2.5	0.9	1.6
Stn 6	summer	23-Aug-2007	13:20	46.6	2.5	8	<5	150	120.7	5.1	0.5	2.9	0.8	1.4
Stn 7	summer	23-Aug-2007	15:40	42.2	2.5	8.01	<5	90	66.1	2.1	0.6	10.3	4.3	1.9
Stn 8	summer	23-Aug-2007	16:12	13.9	2.5	7.56	<6	130	98.8	2.7	0.4	2.5	0.9	1.1
Stn 10 (duplicate)	summer	23-Aug-2007	14:03	n.d	n.d	n.d	n.d	n.d	121.1	5.6	0.5	2.4	0.6	2
Stn 1	fall	13-Nov-2007	12:26	58.0	2.5	8.00	<5	130.0	127.4	2.4	0.2	10.1	1.6	1.8
Stn 2	n/a	n/a	n/a	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Stn 3[b]	n/a	n/a	n/a	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Stn 4	fall	13-Nov-2007	11:59	57.4	2.5	8.02	<5	130.0	129.6	1.8	0.4	2.3	<0.1	1.6
Stn 5	fall	13-Nov-2007	11:43	57.6	2.5	8.03	<5	130.0	128.5	1.5	0.3	2.6	<0.1	1.6
Stn 6	fall	13-Nov-2007	11:16	57.1	2.5	8.01	<5	130.0	129.3	1.7	0.3	2.4	<0.1	1.3
Stn 7	fall	13-Nov-2007	13:54	63.4	5.0	8.09	<5	220.0	194.4	23.7	2.2	6.8	1.2	4.1
Stn 8	fall	13-Nov-2007	14:20	16.2	7.5	7.51	6	260.0	246.7	1.7	0.5	2.1	<0.1	1.5
Stn 10 (duplicate)	fall	13-Nov-2007	11:59	57.7	2.5	8.03	<5	130.0	129.3	1.3	0.3	2.2	<0.1	1.4

[a] See Figure 5 for sample site locations.

[b] BC Hydro station not maintained and/or visited by Golder

n.d. indicates no data available

Table F-5 Summary of in-situ surface water quality field parameters for Revelstoke Water Use Planning physical habitat assessments, 2008.

Site[a]	Season	Date	Time	Water Temperature (°C)	pH	pHmV	Disolved oxygen (%)	Disolved oxygen (mg/L)	Specific Conductivity (µS/cm)	Conductivity (µS/cm)	Salinity	ORP	Comments
Stn 1	spring	8-Apr-2008	15:46	2.6	7.50	-39.8	108.4	14.73	162	92	0.08	239.3	
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 4	spring	8-Apr-2008	15:32	2.7	7.66	-48.3	108	14.64	160	92	0.08	181.9	
Stn 5	spring	8-Apr-2008	17:10	2.8	7.64	-47.5	107.5	14.57	160	92	0.08	184.7	
Stn 6	spring	8-Apr-2008	16:32	3.1	7.65	-49.6	108.5	14.63	161	94	0.08	174.0	
Stn 7	spring	8-Apr-2008	11:17	4.0	7.90	-61.1	115.5	15.09	213	127	0.10	200.1	
Stn 8	spring	8-Apr-2008	12:02	4.0	7.22	n.d.	112.5	14.68	62	30	0.03	244.0	
Stn 1	summer	24-Jun-2008	0:00	n.d.	7.98	n.d.	n.d.	n.d.	n.d.	132	n.d.	n.d.	In-situ data is not available due to 25-Jun-08 hotel theft of YSI meter and subsequent field water quality parameters data sheet.
Stn 2	summer	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 3[b]	summer	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 4	summer	24-Jun-2008	0:00	n.d.	7.99	n.d.	n.d.	n.d.	n.d.	126	n.d.	n.d.	
Stn 5	summer	24-Jun-2008	0:00	n.d.	7.97	n.d.	n.d.	n.d.	n.d.	122	n.d.	n.d.	
Stn 6	summer	24-Jun-2008	0:00	n.d.	7.96	n.d.	n.d.	n.d.	n.d.	114	n.d.	n.d.	
Stn 7	summer	24-Jun-2008	0:00	n.d.	7.95	n.d.	n.d.	n.d.	n.d.	92	n.d.	n.d.	
Stn 8	summer	24-Jun-2008	0:00	n.d.	7.43	n.d.	n.d.	n.d.	n.d.	24	n.d.	n.d.	
Stn 1	fall	24-Oct-2008	9:40	9.0	6.93	-21.2	91.6	10.52	118	82	0.06	n.d.	Limnotek meter (YSI 650 MDS) was not equipped to measure ORP
Stn 2	fall	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 3[b]	fall	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 4	fall	24-Oct-2008	10:58	9.0	7.82	-63.3	88.3	10.16	115	80	0.05	n.d.	
Stn 5	fall	24-Oct-2008	11:16	9.0	7.89	-66.8	88	10.1	114	79	0.05	n.d.	
Stn 6	fall	24-Oct-2008	11:25	8.8	7.89	-66.4	86.6	10.03	113	78	0.05	n.d.	
Stn 7	fall	25-Oct-2008	17:59	4.1	7.98	-73	92.9	12.15	156	94	0.07	n.d.	
Stn 8	fall	25-Oct-2008	17:22	4.3	7.97	-64.7	100	13.03	42	26	0.02	n.d.	

[a] See Figure 5 for sample site locations.

[b] BC Hydro station not maintained and/or visited by Golder

n.d. indicates no data available

Table F-6 Summary of surface low-level nutrient water quality results from Cultus Lake Labs and Pacific Environmental Labs for April, June, and October sampling sessions, 2008.

Site[a]	Season	Date	Time	Alkalinity (mg $CaCO^3$/L)	True Color	pH	Total Suspended Solids (mg/L)	Total Nitrogen (µg/L)	NO^3 (µg/L)	NH^3 (µg/L)	SRP (µg/L)	TP (µg/L)	TP Turbidity (µg/L)	TDP (µg/L)
Stn 1	spring	8-Apr-2008	0:00	70.2	< 2.5	7.68	< 5	140	108.5	3.5	0.3	2.2	<0.1	1.6
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 4	spring	8-Apr-2008	0:00	70.2	< 2.5	7.57	< 5	120	107.9	3.0	0.3	2.1	<0.1	1.9
Stn 5	spring	8-Apr-2008	0:00	69.9	< 2.5	7.60	< 5	130	108.0	1.7	0.4	3.5	<0.1	1.9
Stn 6	spring	8-Apr-2008	0:00	70	< 2.5	7.71	< 5	130	107.9	2.2	0.4	2.4	<0.1	1.8
Stn 7	spring	8-Apr-2008	0:00	83.8	< 2.5	8.02	< 5	190	166.5	2.8	0.5	2.5	<0.1	1.6
Stn 8	spring	8-Apr-2008	0:00	27.6	< 2.5	7.54	< 5	270	257.7	3.3	0.5	2.0	<0.1	3.3
Stn 10 (duplicate)	spring	8-Apr-2008	0:00	69.7	< 2.5	7.67	< 5	140	113.0	2.4	0.3	2.3	<0.1	1.9
Stn 1	summer	24-Jun-2008	0:00	57.5	2.5	7.98	< 5	240	166.3	4.5	1.3	7.7	<0.1	8.3
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 4	summer	24-Jun-2008	0:00	54.5	5	7.98	< 5	180	167.2	2.9	1.3	8.9	<0.1	8.1
Stn 5	summer	24-Jun-2008	0:00	53.1	5	7.97	< 5	190	160.0	2.8	1.5	8.6	<0.1	6.7
Stn 6	summer	24-Jun-2008	0:00	49.8	5.0	7.96	6	170	144.9	3.5	1.1	10.2	1.2	10.1
Stn 7	summer	24-Jun-2008	0:00	40.6	2.5	7.95	28	150	135.2	<0.1	1.3	8.1[c]	1.1[c]	30.0[c]
Stn 8	summer	24-Jun-2008	0:00	10.5	5.0	7.43	< 5	150	122.7	<0.1	0.5	n.d.[d]	n.d.[d]	8.6
Stn 10 (duplicate)	summer	24-Jun-2008	0:00	54.7	< 2.5	7.99	< 5	190	163.8	3.0	1.6	8.8	0.5	5.7
Stn 1	fall	24-Oct-2008	0:00	48.5	< 2.5	7.87	< 5	130	117.1	4.0	0.7	3.7	<0.1	2.9
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 4	fall	24-Oct-2008	0:00	47.9	< 2.5	7.89	< 5	120	115.8	5.2	0.6	3.2	<0.1	2.6
Stn 5	fall	24-Oct-2008	0:00	47.8	< 2.5	7.88	< 5	150	114.8	2.9	0.6	6.7	<0.1	3.4
Stn 6	fall	24-Oct-2008	0:00	47.3	< 2.5	7.88	< 5	160	115.5	3.3	0.5	3.0	<0.1	2.7
Stn 7	fall	25-Oct-2008	0:00	63.4	< 2.5	8.03	< 5	150	156.2	2.8	0.7	3.6	<0.1	3.2
Stn 8	fall	25-Oct-2008	0:00	15.8	2.5	7.51	< 5	240	187.6	3.2	0.4	2.4	<0.1	2.6
Stn 10 (duplicate)	fall	24-Oct-2008	0:00	48.0	< 2.5	7.88	< 5	160	114.4	3.6	0.5	3.6	<0.1	3.6

[a] See Figure 5 for sample site locations.
[b] BC Hydro station not maintained and/or visited by Golder
[c] TDP concentration is higher than TP, indicating an anomaly in the results. Results were reran to verify.
[d] Glass vials arrived to the laboratory empty due to freezing during transport and subsequent broken glass.
n.d. indicates no data available

Table F-7 Summary of in-situ surface water quality field parameters for Revelstoke Water Use Planning physical habitat assessments, 2009.

Site[a]	Season	Date	Time	Water Temperature (°C)	pH	Turbidity (NTU)	Disolved oxygen (%)	Disolved oxygen (mg/L)	TDS (g/L)	Specific Conductivity (µS/cm)	Conductivity (µS/cm)	Salinity	ORP	Comments
Stn 1	spring	15-Apr-2009	13:06	2.36	7.77	n/a	99.3	13.58	0.102	153	89	0.07	165.3	Pine Environmental meter (YSI 556) was not equipped to measure turbidity
Stn 2	n/a	n/a	n/a	n/a	n.d.	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 4	spring	15-Apr-2009	12:08	2.6	8.01	n/a	102.3	13.79	0.099	154	88	0.07	158.7	
Stn 5	spring	15-Apr-2009	11:39	2.6	7.74	n/a	99.4	13.53	0.1	153	88	0.07	146.7	
Stn 6	spring	15-Apr-2009	11:09	2.5	7.81	n/a	100.6	13.57	0.099	154	86	0.07	121.7	
Stn 7	spring	15-Apr-2009	15:51	6.6	8.10	n/a	103.1	12.64	0.119	185	122	0.09	155	
Stn 8	spring	15-Apr-2009	14:58	5.5	7.52	n/a	102.4	12.81	0.032	49	33	0.02	156.9	
Stn 1	summer	23-Jun-2009	13:57	6.57	7.80	n/a	106.2	13.03	0.093	140	91	0.07	75.5	Pine Environmental meter (YSI 556) was not equipped to measure turbidity
Stn 2	n/a	n/a	n/a	n/a	n.d.	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 4	summer	23-Jun-2009	13:10	6.96	7.84	n/a	106.2	12.87	0.087	135	86	0.06	71.2	
Stn 5	summer	23-Jun-2009	12:40	6.94	7.86	n/a	107.0	13.01	0.084	133	88	0.06	80.1	
Stn 6	summer	23-Jun-2009	12:12	7.39	7.7	n/a	108.9	12.94	0.079	121	81	0.06	81.9	
Stn 7	summer	23-Jun-2009	8:07	6.11	7.6	n/a	108.2	13.34	0.06	92	59	0.04	81.9	
Stn 8	summer	23-Jun-2009	10:00	6.17	6.42	n/a	114.7	14.26	0.015	23	15	0.01	152.1	
Stn 1	fall	24-Oct-2009	10:27	8.5	7.60	1.2	94.5	11.05	0.086	133	91	0.06	n.d.	Limnotek meter (YSI 650 MDS) was not equipped to measure ORP
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Stn 4	fall	24-Oct-2009	10:54	8.35	7.68	1.1	91.6	10.75	0.086	132	90	0.06	n.d.	
Stn 5	fall	24-Oct-2009	11:19	8.26	7.60	1.4	95.1	11.19	0.086	132	90	0.06	n.d.	
Stn 6	fall	24-Oct-2009	11:55	7.86	7.60	1.1	94.4	11.22	0.085	131	88	0.06	n.d.	
Stn 7	fall	24-Oct-2009	8:47	2.3	7.50	1.8	96.1	13.2	0.100	154	87	0.07	n.d.	
Stn 8	fall	24-Oct-2009	9:10	2.3	7.30	0.9	97.4	13.4	0.027	42	24	0.02	n.d.	

[a] See Figure 5 for sample site locations.

[b] BC Hydro station not maintained and/or visited by Golder

n.d. indicates no data available

Table F-8 Summary of surface low-level nutrient water quality results from Cultus Lake Labs and Pacific Environmental Labs for April, June, and October sampling sessions, 2009.

Site[a]	Season	Date	Time	Alkalinity (mg $CaCO^3$/L)	True Color	pH	Total Suspended Solids (mg/L)	Total Nitrogen (µg/L)	NO^3 (µg/L)	NH^3 (µg/L)	SRP (µg/L)	TP (µg/L)	TP Turbidity (µg/L)	TDP (µg/L)
Stn 1	spring	15-Apr-2009	13:06	68.6	< 2.5	8.11	< 5	244	165.4	0.2	0.9	3.7	<0.1	2.4
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 4	spring	15-Apr-2009	12:08	64.8	< 2.5	8.06	< 5	242	167.1	0.4	0.9	3.2	<0.1	2.0
Stn 5	spring	15-Apr-2009	11:39	64.6	< 2.5	8.06	< 5	240	170.7	1.1	0.9	10.1	<0.1	3.1
Stn 6	spring	15-Apr-2009	11:09	65.9	< 2.5	8.03	< 5	246	178.0	2.3	1.1	3.2	<0.1	2.6
Stn 7	spring	15-Apr-2009	15:51	74.6	2.5	8.15	< 5	253	325.5	2.5	1.8	5.5	<0.1	3.3
Stn 8	spring	15-Apr-2009	14:58	22.9	5	7.73	< 5	257	310.8	1.8	1.6	3.8	<0.1	3.3
Stn 10 (duplicate	spring	15-Apr-2009	12:08	65.9	< 2.5	8.10	< 5	242	170.3	2.1	0.9	2.9	<0.1	3.2
Stn 1	summer	23-Jun-2009	13:57	59.5	2.5	8.02	< 5	160	130.1	3.6	1.0	4.1	<0.1	4.3
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 4	summer	23-Jun-2009	13:10	57.1	< 2.5	8.03	< 5	160	130.3	2.3	0.8	5.2	<0.1	4.0
Stn 5	summer	23-Jun-2009	12:40	56.4	2.5	8.03	< 5	180	131.2	2.8	0.8	4.5	<0.1	4.1
Stn 6	summer	23-Jun-2009	12:12	52.2	< 2.5	8.01	< 5	200	131.4	2.2	0.7	4.3	<0.1	4.1
Stn 7	summer	23-Jun-2009	8:07	40.6	< 2.5	8.01	34	130	110.4	0.7	1.1	33.3	7.9	4.8
Stn 8	summer	23-Jun-2009	10:00	9.2	5.0	7.36	7	140	99.7	0.8	0.3	6.3	<0.1	2.5
Stn 10 (duplicate	summer	23-Jun-2009	13:10	56.8	< 2.5	8.03	< 5	170	132.0	3.4	0.9	5.4	<0.1	3.0
Stn 1	fall	27-Oct-2009	10:27	55.4	< 2.5	7.89	< 5	140	127.0	1.6	0.3	3.3	<0.1	2.9
Stn 2	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 3[b]	n/a	n/a	n/a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Stn 4	fall	27-Oct-2009	10:54	54.7	< 2.5	7.91	< 5	140	130.1	1.1	0.3	3.1	<0.1	2.5
Stn 5	fall	27-Oct-2009	11:19	55.0	< 2.5	7.92	< 5	140	128.4	1.1	0.4	5.2	<0.1	3.4
Stn 6	fall	27-Oct-2009	11:55	54.8	< 2.5	7.91	< 5	150	132.1	1.2	0.2	3.7	<0.1	2.7
Stn 7	fall	27-Oct-2009	8:47	62.0	< 2.5	7.97	< 5	170	174.8	1.9	0.4	4.2	<0.1	3.1
Stn 8	fall	27-Oct-2009	9:10	15.5	< 2.5	7.45	< 5	260	227.3	1.5	0.5	3.2	<0.1	2.6
Stn 10 (duplicate	fall	27-Oct-2009	10:54	55.3	< 2.5	7.92	< 5	150	131.6	2.2	0.3	3.2	<0.1	2.8

[a] See Figure 5 for sample site locations.

[b] BC Hydro station not maintained and/or visited by Golder

n.d. indicates no data available

Table F-9 **Summary of in-situ surface water quality field parameters for Revelstoke middle Columbia River Physical Habitat Monitoring Program, 2010.**

Golder Site Designation[a]	Ecoscape Site Designation[a]	Sampling Program Index Station	Season	Sampled By[b]	Sample Date	Sample Time	Water Temperature (°C)	pH	Turbidity (NTU)	Disolved oxygen (%)	Disolved oxygen (mg/L)	TDS (g/L)	Specific Conductivity (µS/cm)	Conductivity (µS/cm)	ORP	Comments
R4S7	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	10:26	3.32	8.13	n.d.	99.2	13.25	0.099	153	89	132.0	Pine Environmental meter (YSI 556) was not equipped to measure turbidity
R4S1	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	10:44	3.38	8.13	n.d.	104.1	13.82	0.099	152	89	158.7	
R3S6	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	10:53	3.46	8.13	n.d.	105.0	13.88	0.098	151	89	172.0	
R3S3	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	11:03	3.50	8.14	n.d.	99.1	13.21	0.098	151	90	172.0	
R2S5	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	11:25	3.71	8.07	n.d.	99.8	13.15	0.098	151	90	200.3	
R2S1	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	11:49	3.57	8.15	n.d.	99.9	13.17	0.099	152	90	173.8	
R1S1	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	12:16	4.24	8.06	n.d.	99.6	12.97	0.099	152	92	222.4	
Stn 7	n/a	CLBMON-15a	spring	Golder	13-Apr-2010	14:45	7.67	8.32	n.d.	111.7	13.28	0.128	198	133	160.4	
Stn 8	n/a	CLBMON-15a	spring	Golder	13-Apr-2010	16:07	7.41	8.1	n.d.	100.3	12.05	0.034	52	34	165.3	
RXSX (duplicate of R2S5)	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	11:25	3.71	8.07	n.d.	99.8	13.15	0.098	151	90	200.3	
R4S7	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	16:11	9.44	8.13	0.4	95.2	10.89	0.088	135	95	223.6	
R4S1	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	15:57	9.31	8.04	0.5	95.1	10.91	0.088	136	95	226.4	
R3S6	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	15:46	9.09	7.89	0.5	95.2	10.97	0.086	131	92	222.7	
R3S3	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	15:33	9.03	7.86	0.5	95.8	11.06	0.085	131	91	202.9	
R2S5	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	14:50	8.82	7.53	1.5	97.5	11.29	0.083	128	88	235.6	
R2S1	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	11:56	8.18	7.80	1.9	96.5	11.38	0.080	122	83	193.9	
R1S1	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	11:20	8.59	7.77	2.4	99.9	11.60	0.081	125	86	182.8	
Stn 7	n/a	CLBMON-15a	summer	Golder	16-Jun-2010	17:04	7.54	7.84	7.7	90.7	10.86	0.069	107	71	227.7	
Stn 8	n/a	CLBMON-15a	summer	Golder	16-Jun-2010	17:45	7.58	7.23	1.3	96.1	11.50	0.018	28	18	214.4	
R4S7	TR4	CLBMON-15b	fall	Ecoscape	28-Sep-2010	12:23	10.4	7.43	0.9	n.d.	11.1	n.d.	50	n.d.	n.d.	Yellow Springs Instrument Environmental (YSI 550 A) was not equipped to measure ORP
R4S1	BR4	CLBMON-15b	fall	Ecoscape	28-Sep-2010	14:25	10.3	7.65	1.4	n.d.	11.2	0.047	96	n.d.	n.d.	
R3S6	BBE	CLBMON-15b	fall	Ecoscape	28-Sep-2010	14:07	10.4	7.24	36.9	n.d.	11.3	0.048	80	n.d.	n.d.	
R3S3	BR3	CLBMON-15b	fall	Ecoscape	28-Sep-2010	18:22	10.9	7.32	12.6	n.d.	11.0	0.036	75	n.d.	n.d.	
R2S5	TR2	CLBMON-15b	fall	Ecoscape	28-Sep-2010	17:50	10.8	7.12	283.0	n.d.	11.1	0.040	81	n.d.	n.d.	
R2S1	BR2	CLBMON-15b	fall	Ecoscape	28-Sep-2010	17:04	10.9	7.20	14.1	n.d.	10.6	0.039	81	n.d.	n.d.	
R1S1	BR1	CLBMON-15b	fall	Ecoscape	28-Sep-2010	16:29	11.7	7.78	4.8	n.d.	11.0	0.039	79	n.d.	n.d.	
Stn 7	IR	CLBMON-15a	fall	Ecoscape	28-Sep-2010	20:02	10.2	7.82	9999.0	n.d.	11.7	0.042	101	n.d.	n.d.	
Stn 8	JR	CLBMON-15a	fall	Ecoscape	28-Sep-2010	19:30	10.7	7.61	76.0	n.d.	11.3	0.006	11	n.d.	n.d.	
RXSX (duplicate of R4S7)	FD	CLBMON-15b	fall	Ecoscape	28-Sep-2010	12:30	10.4	7.43	0.9	n.d.	11.1	n.d.	50	n.d.	n.d.	

[a] Station names were changed during Year 4; 'R' defines the reach the sampler is located in and 'S' defines the sampler number in a given reach for CLBMON-15b station locations.

[b] Sampled under CLBMON-15a by Golder Associates Ltd. or CLBMON-15b by Ecoscape Environmental Consultants Ltd.

n.d. indicates no data available

n/a indicates not applicable

Table F-10 **Summary of surface low-level nutrient water quality results from Cultus Lake Labs and Pacific Environmental Labs for April, June, 2010 sampling sessions and from Cultas Lake Labs and Caro Analytical Services for October 2010 sampling session.**

Golder Site Designation[a]	Ecoscape Site Designation[a]	Sampling Program Index Station	Season	Sampled By[b]	Sample Date	Sample Time	Alkalinity (mg $CaCO_3$/L)	True Color	pH	Total Suspended Solids (mg/L)	Total Nitrogen (µg/L)	NO^3 (µg/L)	NH^3 (µg/L)	SRP (µg/L)	TP (µg/L)	TP Turbidity (µg/L)	TDP (µg/L)
R4S7	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	10:26	68.2	n.d.[d]	8.18	n.d.[d]	140	99.6	<0.1	0.9	3.0	<0.1	3.1
R4S1	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	10:44	68.1	n.d.[d]	8.16	n.d.[d]	180	99.9	<0.1	0.8	3.8	<0.1	3.0
R3S6	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	10:53	67.3	n.d.[d]	8.14	n.d.[d]	180	104.5	<0.1	0.9	3.2	<0.1	3.5
R3S3	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	11:03	67.0	n.d.[d]	8.14	n.d.[d]	180	110.0	<0.1	0.8	4.0	<0.1	2.9
R2S5	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	11:25	67.3	n.d.[d]	8.16	n.d.[d]	180	103.2	<0.1	0.9	3.2	<0.1	2.8
R2S1	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	11:49	68.1	n.d.[d]	8.19	n.d.[d]	190	104.8	0.7	0.9	4.4	<0.1	2.4
R1S1	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	12:16	68.7	n.d.[d]	8.18	n.d.[d]	190	109.9	1.7	1.2	3.8	<0.1	3.6
Stn 7	n/a	CLBMON-15a	spring	Golder	13-Apr-2010	14:45	84.1	n.d.[d]	8.27	n.d.[d]	280	178.2	0.7	1.3	4.4	<0.1	3.9
Stn 8	n/a	CLBMON-15a	spring	Golder	13-Apr-2010	16:07	24.0	n.d.[d]	7.76	n.d.[d]	360	240.1	1.2	1.3	3.4	<0.1	3.3
RXSX (duplicate of R2S5)	n/a	CLBMON-15b	spring	Golder	13-Apr-2010	11:25	67.5	n.d.[d]	8.17	n.d.[d]	180	103.7	<0.1	0.9	3.5	<0.1	3.1
R4S7	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	16:11	60.3	n.d.[d]	8.12	n.d.[d]	180	123.5	2.0	0.7	4.8	<0.1	3.8
R4S1	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	15:57	60.7	n.d.[d]	8.12	n.d.[d]	200	150.3	4.0	0.7	4.6	<0.1	3.5
R3S6	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	15:46	59.4	n.d.[d]	8.11	n.d.[d]	160	122.3	2.7	1.0	4.2	<0.1	3.1
R3S3	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	15:33	59.1	n.d.[d]	8.11	n.d.[d]	180	121.0	9.2	1.0	5.0	<0.1	3.1
R2S5	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	14:50	57.8	n.d.[d]	8.12	n.d.[d]	180	128.4	4.5	1.0	5.7	<0.1	3.4
R2S1	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	11:56	54.7	n.d.[d]	8.09	n.d.[d]	170	117.4	3.1	0.8	5.9	<0.1	3.2
R1S1	n/a	CLBMON-15b	summer	Golder	16-Jun-2010	11:20	56.7	n.d.[d]	8.10	n.d.[d]	160	126.7	5.7	1.0	8.6	<0.1	3.2
Stn 7	n/a	CLBMON-15a	summer	Golder	16-Jun-2010	17:04	49.4	n.d.[d]	8.11	n.d.[d]	210	141.4	1.8	1.0	17.5	2.0	3.8
Stn 8	n/a	CLBMON-15a	summer	Golder	16-Jun-2010	17:45	13.2	n.d.[d]	7.49	n.d.[d]	190	150.8	2.0	0.8	15.8	<0.1	2.9
RXSX (duplicate of Stn 8)	n/a	CLBMON-15a	summer	Golder	16-Jun-2010	17:45	10.0	n.d.[d]	7.48	n.d.[d]	180	144.8	1.3	0.6	4.8	<0.1	2.8
R4S7	TR4	CLBMON-15b	fall	Ecoscape	29-Sep-2010	12:23	n.d.[e]	<5	n.d.[e]	n.d.[e]	n.d.[e]	119.5	1.6	0.9	4.4	<0.1	3.1
R4S1	BR4	CLBMON-15b	fall	Ecoscape	29-Sep-2010	14:25	n.d.[e]	<5	n.d.[e]	47	n.d.[e]	117.1	1.9	1.1	3.3	<0.1	2.8
R3S6	BBE	CLBMON-15b	fall	Ecoscape	29-Sep-2010	14:07	n.d.[e]	<5	n.d.[e]	48	n.d.[e]	112.7	2.1	1.5	44.0	13.2	3.7
R3S3	BR3	CLBMON-15b	fall	Ecoscape	29-Sep-2010	18:22	n.d.[e]	<5	n.d.[e]	36	n.d.[e]	104.5	2.0	1.1	30.0	10.2	3.3
R2S5	TR2	CLBMON-15b	fall	Ecoscape	29-Sep-2010	17:50	n.d.[e]	6	n.d.[e]	40	n.d.[e]	100.5	5.0	3.8	994.0	518.4	17.6
R2S1	BR2	CLBMON-15b	fall	Ecoscape	29-Sep-2010	17:04	n.d.[e]	<5	n.d.[e]	39	n.d.[e]	110.6	3.2	1.3	18.7	8.8	3.5
R1S1	BR1	CLBMON-15b	fall	Ecoscape	29-Sep-2010	16:29	n.d.[e]	<5	n.d.[e]	39	n.d.[e]	99.5	3.3	1.2	9.3	1.2	3.0
Stn 7	IR	CLBMON-15a	fall	Ecoscape	29-Sep-2010	20:02	n.d.[e]	n.d.[e]	n.d.[e]	42	n.d.[e]	68.0	19.0	10.7	3255.4	2944.3	22.4
Stn 8	JR	CLBMON-15a	fall	Ecoscape	29-Sep-2010	19:30	n.d.[e]	n.d.[e]	n.d.[e]	6	n.d.[e]	70.7	4.8	1.7	192.5	75.6	6.4
RXSX (duplicate of R4S7)	FD	CLBMON-15b	fall	Ecoscape	29-Sep-2010	12:30	n.d.[e]	<5	n.d.[e]	n.d.[e]	n.d.[e]	115.1	2.9	0.9	2.6	<0.1	2.9

[a] Station names were changed during Year 4; 'R' defines the reach the sampler is located in and 'S' defines the sampler number in a given reach for CLBMON-15b station locations.

[b] Sampled under CLBMON-15a by Golder Associates Ltd. or CLBMON-15b by Ecoscape Environmental Consultants Ltd.

[c] Analysis was performed after recommended holding time; therefore, data was not presented in the summary graphs.

[d] Analysis was not conducted by Pacific Environmental Science Centre under CLBMON-15a .

[e] Analysis was not conducted by Caro Analytical Services under CLBMON-15b .

n.d. indicates no data available

n/a indicates not applicable

Table F-11 **Summary of *in-situ* surface water quality field parameters for CLBMON-15a Revelstoke middle Columbia River Physical Habitat Monitoring Program, 2011.**

Golder Site Designation[a]	Ecoscape Site Designation[a]	BC Hydro WLR[b] Sampling Program	Season	Sampled By[c]	Sample Date	Sample Time	Water Temperature (°C)	pH	Turbidity (NTU)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Total Dissolved Solids (mg/L)	Specific Conductivity (µS/cm)	Conductivity (µS/cm)	ORP	Comments
Top Reach 4	TR4	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	4.5	7.19	n.d	84	10.9	n.d	n.d	172	n.d	
Bottom Reach 4	BR4	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	4.9	7.33	n.d	90	11.6	n.d	n.d	153	n.d	
Below Big Eddy	BBE	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	4.9	7.51	n.d	83	10.4	n.d	n.d	166	n.d	
Bottom Reach 3	BR3	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	4.9	7.49	n.d	84	10.8	n.d	n.d	166	n.d	
Top Reach 2	TR2	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	Hannah Instruments (HI 9828)
Bottom Reach 2	BR2	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	
Stn 7_Illicillewaet River	IR	CLBMON-15a	spring	Ecoscape	18-May-2011	n.d	8.4	7.34	n.d	82	9.7	n.d	n.d	155.2	n.d	
Stn 7_Illicillewaet River d/s[d]	IRD	CLBMON-15a	spring	Ecoscape	18-May-2011	n.d	8.4	7.49	n.d	82	9.9	n.d	n.d	165.1	n.d	
Stn 8_Jordan River	JR	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	7.5	7.06	n.d	89	10.3	n.d	n.d	37.5	n.d	
Top Reach 4	TR4	CLBMON-15b	summer	Golder	17-Aug-2011	14:30	9.45	7.47	0.7	98.5	11.27	61	94	66	182.7	
Bottom Reach 4	BR4	CLBMON-15b	summer	Golder	17-Aug-2011	13:18	9.42	7.61	0.7	110.5	12.65	61	93	66	128.1	
Below Big Eddy	BBE	CLBMON-15b	summer	Golder	17-Aug-2011	12:54	9.51	7.57	0.7	108.1	12.35	61	94	66	126.8	
Bottom Reach 3	BR3	CLBMON-15b	summer	Golder	17-Aug-2011	12:38	9.47	7.54	0.7	109.7	12.53	61	94	66	103.3	Pine Environmental meter (YSI 650 MDS)
Top Reach 2	TR2	CLBMON-15b	summer	Golder	17-Aug-2011	11:10	9.94	7.56	1.4	110.4	12.47	60	93	66	93.6	
Bottom Reach 2	BR2	CLBMON-15b	summer	Golder	17-Aug-2011	10:05	11.34	7.69	0.9	109	11.88	60	92	68	100.1	
Stn 7_Illicillewaet River	IR	CLBMON-15a	summer	Golder	17-Aug-2011	16:43	10.15	7.77	7.3	104.3	11.73	74	113	81	110.2	
Stn 8_Jordan River	JR	CLBMON-15a	summer	Golder	17-Aug-2011	16:08	10.75	7.44	3.7	107.3	11.89	24	38	27	79	
Top Reach 4	TR4	CLBMON-15b	fall	Ecoscape	5-Oct-2011	n.d	10.35	7.47	n.d	92.4	9.87	n.d	n.d	106	n.d	
Bottom Reach 4	BR4	CLBMON-15b	fall	Ecoscape	5-Oct-2011	n.d	10.33	7.44	n.d	90.4	9.68	n.d	n.d	113	n.d	
Below Big Eddy	BBE	CLBMON-15b	fall	Ecoscape	5-Oct-2011	n.d	10.36	7.49	n.d	92.8	9.48	n.d	n.d	105	n.d	
Bottom Reach 3	BR3	CLBMON-15b	fall	Ecoscape	5-Oct-2011	n.d	10.48	7.55	n.d	92.9	9.72	n.d	n.d	97	n.d	Hanna Instrument was not equipped to measure ORP, specific conductivity, TDS, or turbidity
Top Reach 2	TR2	CLBMON-15b	fall	Ecoscape	5-Oct-2011	n.d	7.55	7.81	n.d	95.7	10.74	n.d	n.d	109	n.d	
Bottom Reach 2	BR2	CLBMON-15b	fall	Ecoscape	5-Oct-2011	n.d	10.41	7.79	n.d	91.9	n.d	n.d	n.d	101	n.d	
Stn 7_Illicillewaet River	IR	CLBMON-15a	fall	Ecoscape	5-Oct-2011	n.d	7.47	7.76	n.d	93.3	10.04	n.d	n.d	93	n.d	
Stn 7_Illicillewaet River d/s[d]	IRD	CLBMON-15a	fall	Ecoscape	5-Oct-2011	n.d	7.51	7.82	n.d	93.7	10.14	n.d	n.d	112	n.d	
Stn 8_Jordan River	JR	CLBMON-15b	fall	Ecoscape	5-Oct-2011	n.d	7.92	7.78	n.d	93.3	10.36	n.d	n.d	29	n.d.	

[a] See Figure 5 for sample site locations.

[b]WLR = Water Licence Requirements.

[c] Sampled under CLBMON-15a by Golder Associates Ltd. or CLBMON-15b by Ecoscape Environmental Consultants Ltd.

[d] Illicillewaet River d/s = downstream. Sample site located just above the confluence with the middle Columbia River. Sampled under CLBMON-15b by Ecoscape Environmental Consultants Ltd., not part of CLBMON-15a's objectives.

n.d. indicates no data available

Table F-12 **Summary of surface low-level nutrient water quality results from DFO Cultus Lake Salmon Research Laboratory and Caro Analytical Services for May, August, and October 2011 sampling sessions conducted for CLBMON-15a Revelstoke middle Columbia River Physical Habitat Monitoring Program.**

Golder Site Designation[a]	Ecoscape Site Designation[a]	Sampling Program Index Station	Season	Sampled By[b]	Sample Date	Sample Time	Total Nitrogen Kjeldahl (µg/L) (TKN)	Total Nitrogen (TN) (µg/L)	pH	Total Suspended Solids (TSS)	Total Dissolved Solids (TDS) (mg/L)	Nitrate (NO_3^-) (µg/L)	Ammonia (NH_3) (µg/L)	Soluable Reactive Phosphorus (SRP)	Total Phosphorus (TP) (µg/L)	TP Turbidity (µg/L)	Total Dissolved Phosphorus (TDP) (µg/L)
Top Reach 4	TR4	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d.	n.d.[c]	n.d.[c]	n.d.[c]	<1	112	102.0	3.1	1.1	4.2	<0.1	3.6
Bottom Reach 4	BR4	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d.	n.d.[c]	n.d.[c]	n.d.[c]	<1	116	101.7	5.1	1.0	4.5	<0.1	4.3
Below Big Eddy	BBE	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	<1	117	110.9	6.4	1.0	4.6	<0.1	3.9
Bottom Reach 3	BR3	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	<1	88	111.9	5.8	1.0	5.0	<0.1	3.5
Top Reach 2	TR2	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	2	112	180.6	10.3	1.3	8.8	0.6	4.4
Bottom Reach 2	BR2	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	4	113	166.1	11.6	1.1	12.3	0.7	3.9
Stn 7_Illicillewaet River	IR	CLBMON-15a	spring	Ecoscape	18-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	19	107	453.8	9.6	1.9	19.7	5.6	6.1
Illicillewaet River d/s	IR d/s	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	13	109	455.2	14.2	2.6	25.5	6.2	6.7
Stn 8_Jordan River	JR	CLBMON-15a	spring	Ecoscape	18-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	<1	56	387.0	11.4	1.6	n.d.[d]		3.6
Field Duplicate (Top Reach 4)	FD	CLBMON-15b	spring	Ecoscape	18-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	<1	103	93.6	6.3	0.9	4.2	<0.1	3.5
Field Blank	FB	CLBMON-15b	spring	Ecoscape	19-May-2011	n.d	n.d.[c]	n.d.[c]	n.d.[c]	n.d	n.d	<0.1	4.3	<0.1	<0.1	n/a	**No Sample[d]**
Top Reach 4	TR4	CLBMON-15b	summer	Golder	17-Aug-2011	14:30	310	310	7.35	2	123	122.9	8.4	1.4	2.1	0.4	1.5
Bottom Reach 4	BR4	CLBMON-15b	summer	Golder	17-Aug-2011	13:18	380	490	7.57	<1	72	123.2	8.6	1.3	2.3	0.6	1.2
Below Big Eddy	BBE	CLBMON-15b	summer	Golder	17-Aug-2011	12:54	230	330	7.63	<1	84	122.9	8.1	1.1	2.2	0.7	1.5
Bottom Reach 3	BR3	CLBMON-15b	summer	Golder	17-Aug-2011	12:38	120	220	7.65	<1	139	123.2	5.6	1.0	2.6	0.6	1.4
Top Reach 2	TR2	CLBMON-15b	summer	Golder	17-Aug-2011	11:10	220	320	7.65	<1	65	111.5	7.4	1.0	4.2	0.7	1.6
Bottom Reach 2	BR2	CLBMON-15b	summer	Golder	17-Aug-2011	10:05	250	340	7.67	<1	80	117.4	4.0	1.3	2.9	0.8	1.8
Stn 7_Illicillewaet River	IR	CLBMON-15a	summer	Golder	17-Aug-2011	16:43	270	330	7.86	13	68	74.8	4.6	1.6	19.9[e]	2.7	1.6[e]
Stn 8_Jordan River	JR	CLBMON-15a	summer	Golder	17-Aug-2011	16:08	240	310	7.42	2	30	88.2	5.0	0.8	3.1	1.1	1.4
Field Duplicate (Below Big Eddy)	FD	CLBMON-15a	summer	Golder	17-Aug-2011	12:54	140	240	7.63	<1	92	121.8	6.9	1.8	2.1	0.5	1.2
Field Blank	FB	CLBMON-15a	summer	Golder	17-Aug-2011	n/a	<0.50	<0.50	6.36	<1	<5	<0.1	21.1[f]	1.0	<0.1	n/a	<0.1
Top Reach 4	TR4	CLBMON-15b	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d.	90	200	n.d.[c]	<1	62	106.8	2.0	1.0	3.9	0.4	3.0
Bottom Reach 4	BR4	CLBMON-15b	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	130	240	n.d.[c]	<1	59	106.2	0.9	0.9	2.3	0.5	2.4
Below Big Eddy	BBE	CLBMON-15b	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	220	320	n.d.[c]	<1	59	104.4	0.7	0.8	2.8	0.3	2.5
Bottom Reach 3	BR3	CLBMON-15b	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	70	180	n.d.[c]	<1	57	103.3	0.5	1.0	2.8	0.4	2.1
Top Reach 2	TR2	CLBMON-15b	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	210	330	n.d.[c]	2	62	108.0	2.6	1.2	6.3	1.0	3.0
Bottom Reach 2	BR2	CLBMON-15b	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	n.d	n.d	n.d.[c]	<1	61	98.1	0.9	0.9	3.2	0.6	3.1
Stn 7_Illicillewaet River	IR	CLBMON-15a	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	100	260	n.d.[c]	4	63	102.6	0.9	1.2	5.6	2.0	2.8
Stn 8_Jordan River	JR	CLBMON-15a	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	80	250	n.d.[c]	3	41	113.2	1.0	0.8	2.3	0.7	1.7
Field Duplicate (Jordan River)	FD	CLBMON-15b	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	170	300	n.d.[c]	1	32	111.5	2.2	0.9	2.3	0.6	2.1
Field Blank	FB	CLBMON-15b	fall	Ecoscape	5-Oct-2011 28-Oct-2011	n.d	<0.50	<0.50	n.d.[c]	<1	3	0.6	<0.1	<0.1	<0.1	n/a	<0.1

[a] See Figure 5 for sample site locations.

[b] Sampled under CLBMON-15a by Golder Associates Ltd. or CLBMON-15b by Ecoscape Environmental Consultants Ltd.

[c] Analysis was not conducted by Caro Analytical Services under CLBMON-15b .

[d] Test tube arrived to lab empty; test tube broke during transport.

[e] DFO Cultas Lake Salmon Research Laboratory re-ran sample 2 times for QA/QC purposes

[f] DFO Cultas Lake Salmon Research Laboratory re-ran sample 4 times for QA/QC purposes

n.d. indicates no data available

[f] DFO Cultas Lake Salmon Research Laboratory re-ran sample 4 times for QA/QC purposes

n.d. indicates no data available

Table F-13 **Summary of *in-situ* surface water quality field parameters for CLBMON-15a Revelstoke middle Columbia River Physical Habitat Monitoring Program, 2012.**

Golder Site Designation[a]	Ecoscaspe Site Designation[a]	BC Hydro WLR[b] Sampling Program	Season	Sampled By[c]	Sample Date	Sample Time	Water Temperature (°C)	pH	Turbidity (NTU)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Total Dissolved Solids (mg/L)	Specific Conductivity (µS/cm)	Conductivity (µS/cm)	ORP	Comments
Top Reach 4	TR4	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	5.34	7.12	n.d	92.9	10.83	82	164	103	n.d	Hannah Instruments (HI 9828)
Bottom Reach 4	BR4	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	5.11	8.06	n.d	94.6	11.05	71	142	88	n.d	
Below Big Eddy	BBE	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	5.30	7.57	n.d	98.9	11.49	85	170	106	n.d	
Bottom Reach 3	BR3	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	5.13	7.89	n.d	96.2	11.22	86	171	107	n.d	
Top Reach 2	TR2	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	5.23	7.81	n.d	98.1	11.40	88	176	110	n.d	
Bottom Reach 2	BR2	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	6.22	7.77	n.d	97.4	11.03	79	157	101	n.d	
Stn 7_Illicillewaet River	IR	CLBMON-15a	spring	Ecoscape	22-May-2012	n.d	9.59	7.67	n.d	98.4	10.24	73	147	104	n.d	
Stn 8_Jordan River	JR	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	9.12	7.77	n.d	98.9	10.42	14	28	20	n.d	
Top Reach 4	TR4	CLBMON-15b	summer	Golder	14-Aug-2012	13:02	10.69	7.87	0.5	140.4	15.54	73	113	82	93.7	Pine Environmental meter (YSI 650 MDS)
Bottom Reach 4	BR4	CLBMON-15b	summer	Golder	14-Aug-2012	13:38	10.76	7.9	0.5	130.0	14.35	73	113	82	106.7	
Below Big Eddy	BBE	CLBMON-15b	summer	Golder	14-Aug-2012	12:38	10.56	7.8	0.6	122.4	13.63	73	113	82	166.5	
Bottom Reach 3	BR3	CLBMON-15b	summer	Golder	14-Aug-2012	12:12	10.49	7.64	0.7	119.3	13.31	73	113	81	187.9	
Top Reach 2	TR2	CLBMON-15b	summer	Golder	14-Aug-2012	11:40	10.68	7.63	1.5	115.6	12.84	72	111	80	193.4	
Bottom Reach 2	BR2	CLBMON-15b	summer	Golder	14-Aug-2012	10:30	12.20	7.76	0.9	113.7	12.13	70	107	82	103.9	
Stn 7_Illicillewaet River	IR	CLBMON-15a	summer	Golder	14-Aug-2012	14:40	10.14	7.66	9.1	112.5	12.68	57	88	63	132.5	
Stn 8_Jordan River	JR	CLBMON-15a	summer	Golder	14-Aug-2012	16:28	11.57	7.28	2.0	112.2	12.2	19	30	22	212.7	
Top Reach 4	TR4	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	9.54	7.94	n.d	89.7	9.52	149	297	210	n.d	Hannah Instruments (HPRC 2500)
Bottom Reach 4	BR4	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	9.54	7.96	n.d	90.5	9.60	149	297	210	n.d	
Below Big Eddy	BBE	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	9.54	8.02	n.d	91.3	9.69	148	296	209	n.d	
Bottom Reach 3	BR3	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	9.59	8.02	n.d	89.9	9.55	148	296	210	n.d	
Top Reach 2	TR2	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	9.68	8.02	n.d	90.0	9.67	150	300	213	n.d	
Bottom Reach 2	BR2	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	9.53	8.01	n.d	88.6	9.57	146	291	206	n.d	
Stn 7_Illicillewaet River	IR	CLBMON-15a	fall	Ecoscape	17-Oct-2012	n.d	5.81	8.03	n.d	91.6	10.59	149	298	190	n.d	
Stn 8_Jordan River	JR	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d.	5.7	7.62	n.d	95.5	11.12	97	194	123	n.d	

[a] See Figure 5 for sample site locations.

[b]WLR = Water Licence Requirements.

[c] Sampled under CLBMON-15a by Golder Associates Ltd. or CLBMON-15b by Ecoscape Environmental Consultants Ltd.

n.d. indicates no data available

Table F-14 **Summary of surface low-level nutrient water quality results from DFO Cultus Lake Salmon Research Laboratory and Caro Analytical Services for May, August, and October 2012 sampling sessions conducted for CLBMON-15a Revelstoke middle Columbia River Physical Habitat Monitoring Program.**

Golder Site Designation[a]	Ecoscape Site Designation[a]	Sampling Program Index Station	Season	Sampled By[b]	Sample Date	Sample Time	Total Nitrogen Kjeldahl (µg/L) (TKN)	Total Nitrogen (TN) (µg/L)	pH	Total Suspended Solids (TSS)	Total Dissolved Solids (TDS) (mg/L)	Nitrate (NO_3^-) (µg/L)	Ammonia (NH_3) (µg/L)	Soluable Reactive Phosphorus (SRP)	Total Phosphorus (TP) (µg/L)	TP Turbidity (µg/L)	Total Dissolved Phosphorus (TDP) (µg/L)
Top Reach 4	TR4	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d.	140	240	n.d.[c]	<1	80	96.5	4.0	1.8	5.5	0.7	4.9
Bottom Reach 4	BR4	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d.	90	190	n.d.[c]	<1	85	96.1	0.3	1.9	3.9	0.8	4.1
Below Big Eddy	BBE	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	160	260	n.d.[c]	<1	79	105.7	1.2	1.7	4.2	0.8	3.9
Bottom Reach 3	BR3	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	100	210	n.d.[c]	<1	71	107.6	1.2	1.6	4.1	0.7	3.9
Top Reach 2	TR2	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	280	400	n.d.[c]	<1	79	120.2	0.8	1.5	5.9	0.9	5.5
Bottom Reach 2	BR2	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	140	290	n.d.[c]	<1	62	143.4	1.2	1.9	4.5	0.9	6.1
Stn 7_Illicillewaet River	IR	CLBMON-15a	spring	Ecoscape	22-May-2012	n.d	230	590	n.d.[c]	11	76	374.1	5.4	2.8	11.7	2.2	6.8
Illicillewaet River d/s	IR d/s	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	190	560	n.d.[c]	2	31	341.8	7.0	2.9	10.5	2.3	5.4
Stn 8_Jordan River	JR	CLBMON-15a	spring	Ecoscape	22-May-2012	n.d	220	520	n.d.[c]	6	23	355.9	2.1	1.0	5.2	0.9	3.7
Field Duplicate (Top Reach 4)	FD	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	90	190	n.d.[c]	<1	84	95.6	1.1	1.6	3.9	0.8	5.0
Field Blank	FB	CLBMON-15b	spring	Ecoscape	22-May-2012	n.d	n.d.[c]	n.d.[c]	n.d.[c]	n.d	n.d	<0.1	<0.1	0.3	<0.1	n.d	<0.1
Top Reach 4	TR4	CLBMON-15b	summer	Golder	14-Aug-2012	13:02	170	330	7.70	2	74	145.5	7.0	6.4	13.7	<0.1	13.4
Bottom Reach 4	BR4	CLBMON-15b	summer	Golder	14-Aug-2012	13:38	60	210	7.79	2	73	134.3	7.4	11.2	23.4	<0.1	21.2
Below Big Eddy	BBE	CLBMON-15b	summer	Golder	14-Aug-2012	12:38	180	320	7.81	2	73	119.7	8.1	4.3	10.2	<0.1	8.6
Bottom Reach 3	BR3	CLBMON-15b	summer	Golder	14-Aug-2012	12:12	200	350	7.82	2	69	120.7	5.4	5.3	9.7	<0.1	8.3
Top Reach 2	TR2	CLBMON-15b	summer	Golder	14-Aug-2012	11:40	120	260	7.81	2	71	125.3	7.0	9.2	21.9	<0.1	22.2
Bottom Reach 2	BR2	CLBMON-15b	summer	Golder	14-Aug-2012	10:30	120	230	7.79	4	56	107.7	6.2	10.9	26.6	<0.1	23.3
Stn 7_Illicillewaet River	IR	CLBMON-15a	summer	Golder	14-Aug-2012	14:40	80	130	7.79	4	49	48.9	1.6	2.3	15.2	5.6	4.5
Stn 8_Jordan River	JR	CLBMON-15a	summer	Golder	14-Aug-2012	16:28	100	160	7.40	<1	5	57.9	2.0	1.9	4.0	<0.1	3.0
Field Duplicate (Below Big Eddy)	FD	CLBMON-15a	summer	Golder	14-Aug-2012	12:38	220	370	7.81	2	63	125.2	8.0	7.7	23.2	<0.1	22.6
Field Blank	FB	CLBMON-15a	summer	Golder	14-Aug-2012	n/a	n.d.[c]	n.d.[c]	n.d.[c]	n.d	n.d	<0.1	1.3	0.3	<0.1	n.d	<0.1
Top Reach 4	TR4	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d.	100	230	7.94	<1	85	111.3	1.4	1.0	4.0	<0.1	3.0
Bottom Reach 4	BR4	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	130	250	7.91	<1	72	110.6	0.1	1.1	2.9	<0.1	3.4
Below Big Eddy	BBE	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	130	260	7.94	<1	72	112.2	1.5	1.0	3.5	<0.1	4.0
Bottom Reach 3	BR3	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	150	280	7.93	<1	65	110.1	0.2	0.9	6.0	<0.1	2.6
Top Reach 2	TR2	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	100	230	7.94	<1	85	111.3	1.4	1.0	4.0	<0.1	3.0
Bottom Reach 2	BR2	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	160	280	7.90	<2	66	108.3	0.9	1.2	5.8	1.2	3.5
Stn 7_Illicillewaet River	IR	CLBMON-15a	fall	Ecoscape	17-Oct-2012	n.d	150	290	7.95	2	60	127.7	0.5	1.3	8.3	2.0	3.7
Stn 8_Jordan River	JR	CLBMON-15a	fall	Ecoscape	17-Oct-2012	n.d	180	340	7.46	1	27	152.4	0.6	0.8	2.5	<0.1	2.0
Field Duplicate (Jordan River)	FD	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	270	390	7.76	<2	61	85.9	2.0	1.2	5.8	1.2	2.8
Field Blank	FB	CLBMON-15b	fall	Ecoscape	17-Oct-2012	n.d	50	70	5.83	<1	5	0.1	1.3	1.4	0.1	n.d	<0.1

[a] See Figure 5 for sample site locations.

[b] Sampled under CLBMON-15a by Golder Associates Ltd. or CLBMON-15b by Ecoscape Environmental Consultants Ltd.

[c] Analysis was not conducted by Caro Analytical Services under CLBMON-15b .

[d] Test tube arrived to lab empty; test tube broke during transport.

[e] DFO Cultas Lake Salmon Research Laboratory re-ran sample 2 times for QA/QC purposes

[f] DFO Cultas Lake Salmon Research Laboratory re-ran sample 4 times for QA/QC purposes

n.d. indicates no data available

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.

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
201 Columbia Avenue
Castlegar, British Columbia, V1N 1A8
Canada
T: +1 (250) 365 0344

Golder Associates