Mid-Columbia Physical Habitat Monitoring Project Water Use Plan

Revelstoke Flow Management Water Use Plan Monitoring Program

Implementation Year 5 (2011)

Reference: CLBMON-15a

Annual Technical Report

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REVELSTOKE FLOW MANAGEMENT PLAN WATER USE PLAN MONITORING PROGRAM

CLBMON-15a Mid Columbia River Physical Habitat Monitoring Annual Technical Report Year 5 (2011)

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Cover photo: Station 5 standpipe on the Middle Columbia River looking u/s. Photo showing habitat and flow characteristics of Reach 2 during high Arrow Lakes Reservoir Levels. Photos © Carissa Canning, Golder Associates Ltd.

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). 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 productivity of the MCR ecosystem in response to minimum flow releases.

In 2010, BC Hydro added a fifth unit to the Revelstoke Generating Station (REV 5). 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 previous the 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) to include monitoring of REV 5 operational impacts in 2010 (BC Hydro 2010). The intent was to evaluate minimum flow releases or operational changes by constructing a logical linkage between Revelstoke Dam 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. In 2007, BC Hydro commissioned Year 1 of the Physical Habitat Monitoring Program (CLBMON-15a). This program specified four years (2007-2010) of monitoring where the operation of the Revelstoke Generating Station (REV) does 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). The program currently continues through to Year 6 (2011-2012).

The primary purpose of the monitoring program is to establish index monitoring stations to assess river stage, water temperature, water quality, and seasonal total dissolved gas pressure (TGP) in the MCR. A database format was developed for managing physical habitat data associated with the WUP program in the MCR. The MCR study area for this program includes the reaches of the Columbia River from the outlet of Revelstoke Dam downstream to the confluence with the Akolkolex River. Index stations for the Physical Habitat Monitoring Program are located in three reaches of the MCR and two tributaries:

- MCR Reach 4 – Revelstoke Dam (RKm 238) 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 at the Greeley Bridge crossing, and Jordan River upstream from the mouth.

As REV 5 was commissioned in the fall of 2010 and minimum flows were implemented in December 2010, Year 5 data were collected during the first year of the minimum flows.

The data collection for Year 5 included the period of October 1, 2010 to October 29, 2011, with site visits and seasonal data collection conducted during the spring (April), late summer (August), and fall (October). The tasks and outcomes for the Year 5 (2011 season) are summarized below.

1) Ten river stage/temperature continuous monitoring stations were maintained by Golder Associates Ltd. (Golder) in the study area. Data were also retrieved from the existing BC Hydro continuous monitoring station (located 200 m downstream from Big Eddy) and the Water Survey of Canada station in the Illecillewaet River. Water stage and temperature collected in 2011 showed similar trends to the 2010 data, with stage data at all stations consistently tracking the water levels variations from flow changes at REV.

2) An existing HEC-RAS flow model for the MCR was calibrated in steady and unsteady states using water stage data from 0ctober 1, 2010 to October 29, 2011. By using cross-sections previously established in the MCR, together with stage data, the hydraulic model (CLBMON-15a HEC-RAS Model) was recalibrated to predict wetted area in the MCR. This model will be used to predict cross-sectional velocities and wetted widths under different operational regimes in the next phase of work.

3) In Year 5, seasonal water quality sampling coordination occurred with the MCR Ecological Productivity Monitoring Program (CLBMON-15b). Under CLBMON-15a, Golder conducted 2011 summer water sampling on the MCR, at periphyton/benthic substrate locations (from CLBMON-15b), as well as CLBMON-15a water quality stations on the Jordan and Illecillewaet rivers. During the spring and fall, water quality sampling was completed by Ecoscape Environmental Consultants Ltd. (under CLBMON-15b) at the same stations on the MCR and Jordan and Illecillewaet rivers. The two main tributaries (Jordan River and Illecillewaet River) occasionally showed considerable differences in values (i.e., total phosphorus, total nitrogen, and nitrates) from those found in the MCR.

4) TGP monitoring was initially proposed for Year 5 (2011); 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), and is therefore only briefly discussed in this report.

Based on the 2007 to 2011 monitoring program data collection and the overall objectives of the RFMP for the MCR, recommendations to improve the program include:

1) Re-installation and regular calibration of the equipment at BC Hydro'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) to provide a comparison between measurements recorded at BC Hydro's MCR station and Golder's 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 are important (e.g., logging in Standard Time at 10-minute intervals from the top of the hour).

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) Review the ability of the HEC-RAS model calibration to meet the objectives of the program and determine if supplemental information is needed to refine the projections of flow impacts. 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 applications. To continue to refine the model calibration process, the following key recommendations from the CLBMON-15a Model calibration (Appendix C) are:

- Continue to define the Jordan River Stage Discharge Curve to improve the flow estimation as it is an important inflow source to the MCR during low REV discharges.
- Continue to refine Manning's "n" coefficients and channel geometry using the data from the CLBMON-20 ("Mid Columbia River White Sturgeon Spawning Habitat Assessment") and CLBMON-54: and ("Effects of Flow Changes on Incubation and Early Rearing Habitat") studies. These studies will provide an assessment of stream bed substrates within the MCR for the 2011 calibration.

4) For the purposes of this monitoring program, the Winter-Kennedy method is used to determine an accurate flow rate through REV Units 1 to 4. 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, we recommended either implementing the Winter-Kennedy method on REV 5 or performing 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.

Keywords: Mid Columbia River, 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, benthic

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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 as such, 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). These daily fluctuations have the ability to affect the availability and suitability of aquatic habitat in the MCR downstream to the river-Arrow reservoir 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).

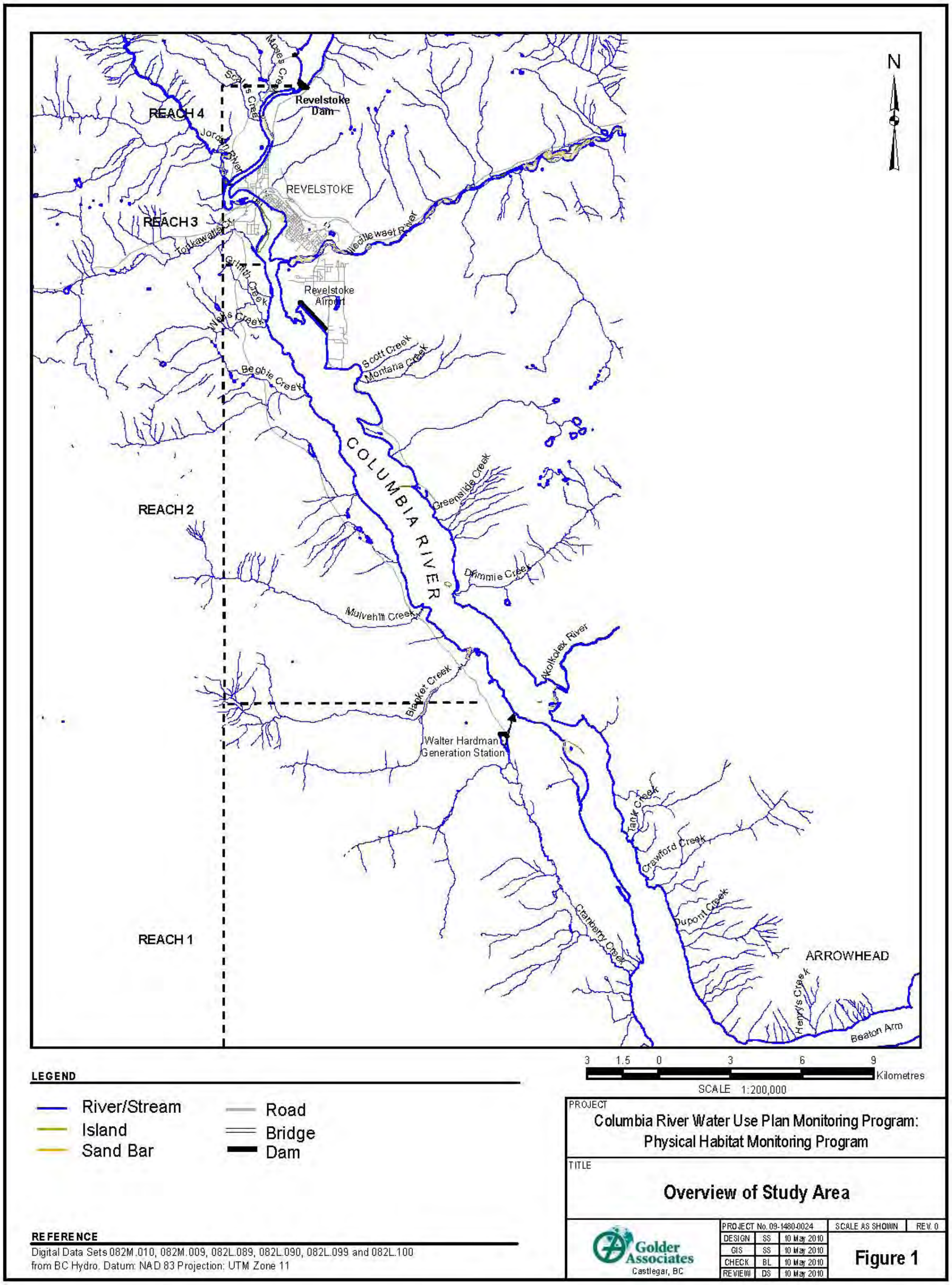

Figure 1: Overview of study area for the middle Columbia River.

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 2 tributaries (Figure 1):

- MCR Reach 4 – REV (Rkm 238) 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 masl. The length of the MCR riverine section can range from the base of REV at full pool (El. 440.1 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 5, 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), specifies four years of monitoring before implementation of the minimum flow from REV and up to ten years of monitoring thereafter. Five years of monitoring have been completed to date (2007 through 2011), capturing data for four years of pre-REV 5 operations and one year post-REV 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 are 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. 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 current operations and the 142 m^3s^{-1} minimum flow regime.
2) To measure spatial and temporal differences in river water TGP levels between current operations and 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 current operations and 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 2 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 focusing on the upper 2 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 is to utilize fixed index monitoring stations (Figure 2) to collect physical habitat and water quality data. The data will help BCH understand the influence of REV operations (including REV 5) on physical aquatic habitat and their effects on ecological productivity, fish population response measures, and fish habitat use under the RFMP.

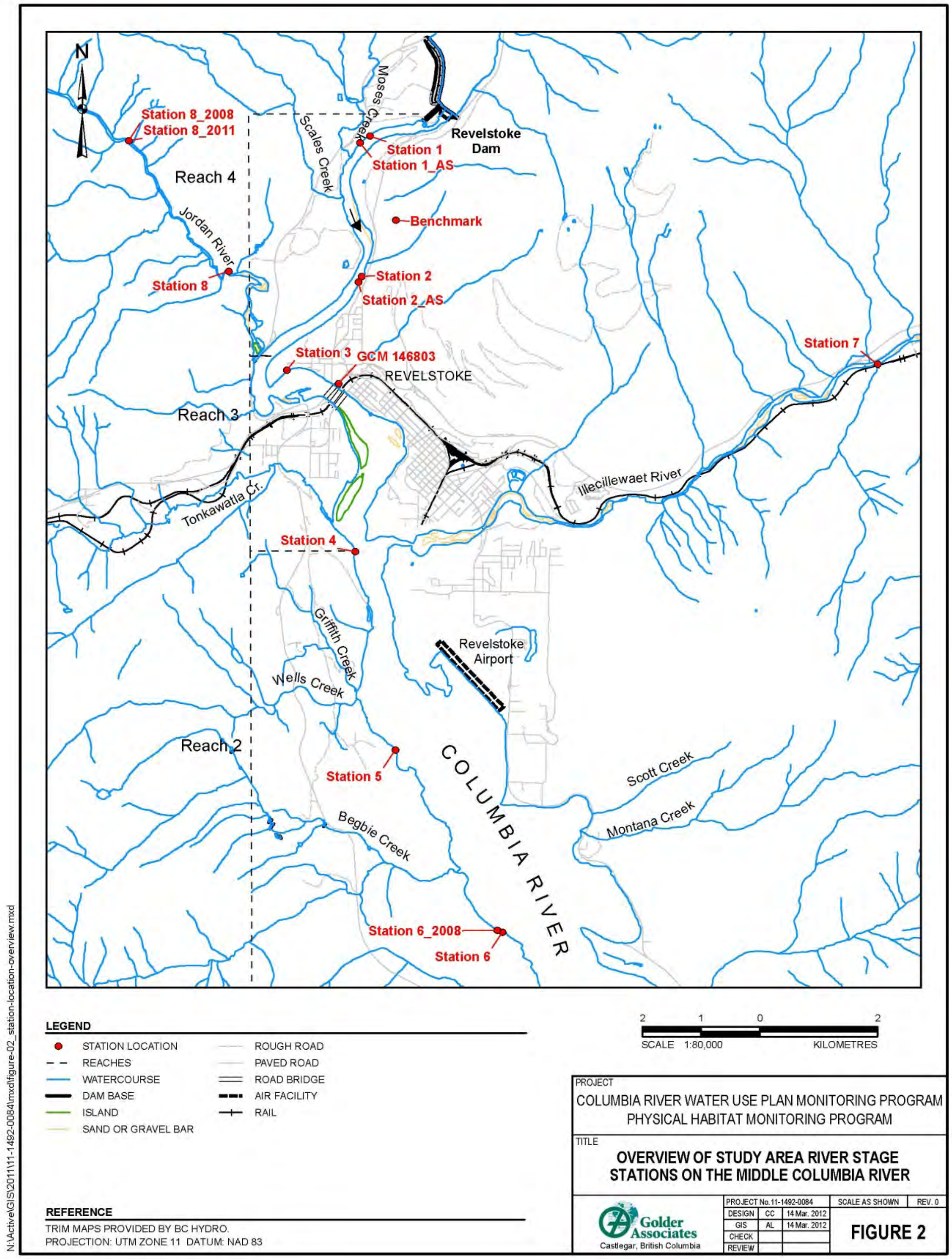

Figure 2: CLBMON-15a stage and temperature monitoring stations CLBMON-15a on the MCR.

1.3.3 Monitoring Program Components

To study the array of physical habitat variables listed in the objectives, the monitoring program is 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 are collected simultaneously at 8 time-synchronized stations in the MCR and 2 stations in the major MCR tributaries. In addition to the existing BCH station, continuous data loggers, mounted in stainless steel standpipes bolted to rock faces, or deployed on anchor systems, are used to collect data over the large vertical range of possible river stages. The data loggers are downloaded and maintained 3 times per year. Data are collected at 10-minute intervals (with the exception of the tributaries, which are 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 is capable of estimating the quantity and spatial distribution of permanently wetted river channel due to changes in REV operations. The comparisons between REV 5 pre-implementation and post-implementation conditions will be completed following discussions with BCH in Year 6 (2012), when time periods of interest and operational assumptions will be defined.

- **Total Gas Pressure (TGP) monitoring** information is being 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 were unable to be achieved and is therefore postponed until Year 6 (2012). The TGP study in Year 6 is expected to consist of two 72-hr continuous monitoring periods, at 3 monitoring stations along the Columbia River between REV and the highway bridge. The monitoring program will capture effects of synchronous condense operations in the flowing reach of the MCR.

- **Seasonal water quality sampling** is conducted at 6 stations in the MCR and 2 stations in the main tributaries, for a total of 8 stations. Water nutrients and electrochemistry were sampled 3 times per year, in the same format as the MCR Ecological Productivity Monitoring (CLBMON-15b), but over 3 seasons (spring, late summer, and fall). In 2011, samples were sent to 2 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 is continually 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.

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 - one in each of the 2 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 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 is located in each reach of the MCR (Section 1.2) and one in each of the main tributaries in the study area;

2) stations are 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 are available to allow anchoring of the standpipe stations for stage monitoring; station installation site permit a design that can withstand the large flow variability associated with the peak discharge with 5 units and seasonal weather; and,

4) stations are located close to a CLBMON-15b periphyton/benthic substrate location.

During the 2011 field sessions, Golder maintained 9 existing index stations at Stations 1, 1_AS, 2, 2_AS, 4, 5, 6_2008, 7, 8_2008 (Figure 2; Golder 2011) (AS indicates anchor stations). In addition, 2 previously established sites serviced and maintained by groups other than Golder are also 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 in Appendix A, Table A-1.

The standpipe stations in Reach 4 (Stations 1 and 2) are unable to capture the lowest water levels due to the absence of appropriate shoreline with vertical rock faces or steep banks (Appendix B, Photo 1). Therefore, the standpipe stations located in Reach 4 have data gaps during frequent low flow conditions from 2007 to 2011. Station 1 data logger monitors at El. 438.58 m, while Station 2 is El. 436.79 m (Appendix A, Table A-1). The anchor stations (AS) that coincide with each of these stations (Stations 1_AS and 2_AS) measure low water levels below El. 436 m (Appendix B, Photos 2 and 3).

The spring and fall field sessions in Year 5 included a scheduled outage on April 29 and October 30, 2011, at which time Golder downloaded the anchor-based monitoring stations associated with existing index stations (i.e., Stations 1 and 2). The anchor stations capture minimum flow (142 m^3s^{-1}) water levels from REV in this reach. Golder downloaded and re-deployed 2 anchor system data loggers when power generation at REV maintained minimum flows. For details regarding the anchor systems specifications and deployment methods refer to Golder (2011).

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 stage and temperature 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 Golder index stations were recorded at 10-minute intervals, with the exception of the Jordan River Station (Station 8_2008) 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 Year 5 MCR River Stage and Temperature Monitoring Station Maintenance

In Year 5 (2010-2011), download and maintenance activities for each river stage station were conducted at Golder stations within Reaches 2, 3, and 4 of the MCR and Jordan and Illecillewaet rivers. Site descriptions, UTM locations, dates of downloading sessions, and maintenance activities for all reaches and sites are listed in Appendix A, Tables A – 1 and A- 2.

CLBMON-15a annual station maintenance in 2011 (April, August, and October) included:

- installing additional standpipe protection in Reach 4 (Station 2), to protect standpipe housing under high velocity conditions and large woody debris; therefore allowing for successful data logger retrieval;
- changing out malfunctioning data loggers;
- re-locating standpipe housing on the Jordan River (Station 8_2008) to an area of higher velocity and main flow conditions due to considerable changes in channel morphology and depositional changes, thus affecting the data logger readings (further described in Section 2.1.5);
- replacing aircraft cable affecting absolute sensor elevation (Station 1);
- installing additional access windows, to allow for easier data retrieval at all water levels;
- engraving the pipe housing at 1 m increments, to allow quality control of water level readings during subsequent field service trips; and,
- flushing out standpipes with an in-line bilge pump to prevent sediment build-up.

In conjunction with seasonal station maintenance, Golder completed spot measurements with 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 (April, August, October). These quality control procedures provide validation that all CLBMON-15a index station data are comparable and accurately reflect 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.

Inspections of the standpipe housings were conducted over a wide range of water levels (influenced by ALR elevation). The intent of inspection of the standpipe housing at varying water levels was to make all stations robust and easy to access at a wide range of water levels. For past standpipe housing maintenance activities and reinforcement of the structure supports, refer to Golder (2008, 2009, 2010, 2011).

Sediment has 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 (Appendix B, Photo 4). In Years 4 (2010) and 5 (2011), the standpipe housing at each station was also flushed with an in-line bilge pump, as minor amounts of sediment were observed on the data logger sensors during the spring and summer 2011 downloads.

Despite the protection of the geotextile material, Station 1 had a considerable amount of sediment on the data logger housing and the sensor during the spring field visit (Appendix B, Photos 5 and 6). The data logger was removed from service during the spring sample session because of high sediment entrained in the standpipe housing, causing potential damage to the data logger sensors. Therefore, due to data gaps at this station (April 27 to August 17, 2011) and inability to capture minimum flows (due to sensor elevation), this station was removed from the hydraulic model calibration and application in Year 5.

Data from Stations 1_AS and 2_AS, (the data loggers at the bottom of the river bed) can be retrieved in one of two ways. The anchor, complete with a welded piece of pipe that houses the data logger (Appendix B, Photo 3), can either be pulled from the float line from a boat during moderate to high flows, or retrieved by wading during constant, scheduled minimum flow conditions. Ongoing coordination with the contract monitor at BCH is required so that outages (i.e., outages that maintain the minimum flow) related to other programs (e.g., CLBMON-15b) can be used for installation and retrieval of these data loggers. REV minimum flow discharge conditions (142 m^3s^{-1}) are required for the anchors and associated data loggers to be downloaded and reset into the substrate at locations that capture water elevations at minimum and low flows.

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

The collected 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. Time synchronization was applied to all of Golder's index stations at the top of the hour using GPS time. UTM coordinates and altitude (in metres above sea level) were obtained during September 2009 at the stations established or moved after initial orthometric data were recorded with a Leica GPS1200 dual frequency geodetic grade GPS system in 2007 (RTK). For details on Leica GPS1200 system, elevation measurements obtained in previous years, survey monuments, system set up, benchmark establishment, and relational links refer to Golder (2008, 2010, 2011).

The measurements collected in 2011 were recorded with an Altus Positioning System (APS-3) GPS. The APS-3 system stated accuracy is 10 mm $\pm$ 1 ppm, often with less than 10 mm accuracy both horizontally and vertically. The APS-3 antenna (based on the Rose Technology from Aero Antenna) is well beyond the sensitivity normally associated with a rover and maintains the best reception, even when in difficult satellite visibility conditions (Altus Positioning Systems 2010). Accuracy is recorded in the data files; therefore, both horizontal and vertical accuracy are listed for each point surveyed and can be viewed in the field, before recording any given measurement to obtain the desired level of accuracy.

The APS-3 system was used in RTK mode during the satellite navigation survey. When in this mode, the units use 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. The base station can be upwards of 30 km from the rover if radio conditions are adequate. If the radio link was not functional during the measurements, the data were post processed. All raw data were stored and collected on both the rover and base station. In 2011, post processing was accomplished using Carlson CE software under the direction of Golder's Geographical Information Systems (GIS) Department in Calgary, AB.

In 2011, Golder used a benchmark located within the gravel pit owned by Speers Construction of Revelstoke, BC. Permission was obtained from the owner of the gravel pit, to access the property and set up the RTK GPS equipment. The base station location at the gravel pit was an ideal location, as it provided a level of security for the equipment (gated facility) and was located in a treeless area of adequate elevation. It is also located within Reach 4 (between Stations 1 and 2), and from 3 km of a known Geodetic Control Monument (GCM) #143803 (Appendix A, Table A-1, Figure 2). These conditions allowed the rover unit to easily communicate with the base station.

This benchmark was previously established by Ecoscape Environmental Consultants Ltd. (Ecoscape) under MCR Ecological Productivity Monitoring (CLBMON-15b) (Appendix A, Table A-1). Golder then set up a control point approximately 1 m away from Ecoscape's benchmark and tied in both points with the BC's Crown Registry and Geographic Base of the Integrated Land Management Bureau's GCM #143803. The Spear's Construction gravel pit benchmark and control point were utilized for orthometric data correction of the stage data elevations with the GCM. All data were corrected prior to use in CLBMON-15a HEC-RAS Model calibration.

During the spring field session, the RTK rover unit was placed on the custom built RTK pad, welded to the side of the pipe housing on the 4-pronged anchor (Appendix B, Photos 2 and 3), and the elevation and UTM coordinates of the RTK pad were recorded. Other data recorded at the anchor stations included distance from the RTK pad to the data logger sensor (Appendix A, Table A-2). For details on how the RTK elevation for each station was tied in with sensor elevations, refer to Golder (2011).

Additional elevation measurements were obtained during April 2011 for the sensors at the anchor station systems in Reach 4 (i.e., Station 1_AS and 2_AS). Elevation measurements were obtained only from the sensors that were downloaded and reset during scheduled minimum flow operations. Because of last minute scheduling change by the Operations Planners the sustained minimum flow request required for the fall field session (October 2011) did not occur; consequently, the RTK survey was unable to be completed in conjunction with the scheduled sustained minimum flow on October 30, 2011. The intent was to obtain water elevations in Reach 4, new elevation records 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. Obtaining water levels in Reach 4 at any 10-minute interval from the top of the hour would have provided an additional QA/QC measure to determine if anchor migration occurred at high flows (i.e., measurement could be directly compared to data logger reading from Stations 1_AS and 2_AS). When the anchor stations were re-installed during the spring field session (April 29, 2011), they were driven in place using a rebar pounder. The anchors are affixed to 8 m of chain and one additional 40 lb. anchor, making migration unlikely to occur. During the fall field session, the anchors were inspected and it appeared that no migration had occurred. Data from the standpipe housing stations in this reach (Stations 1 and 2) were cross-referenced to confirm that anchor migration did not occur. RTK surveys at Stations 1 and 8 were required to obtain precise altitudinal values of the data logger sensors, given that both elevations of the standpipe housing at the 2 stations were altered during summer 2011 field maintenance activities (described above).

To date, all 2011 data have been downloaded from all of Golder's CLBMON-15a stations. Golder's 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. To estimate Jordan River inflows to the MCR, a correlation based on historical Water Survey of Canada (WSC) stations on the Jordan and Illecillewaet rivers was developed. The resulting relationship was used to correlate measured water level data with the estimated flow data at the Jordan River. This relationship provides a rough estimate of discharge (correlated to measured water levels), but will require further refinement with additional flow measurements and RTK data.

For the purposes of the 2011 CLBMON-15a HEC-RAS Model calibration (Year 5), the data from Stations 1 and 2 were not used. Station 1_AS and Station 2_AS (anchor stations deployed in the deepest part of the channel located proximate to Station 1 and Station 2) will be used instead, as these stations provide continuous and consistent data at all water levels.

2.1.4 Illecillewaet River Monitoring Station

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

WSC maintains a discharge gauging station on the Illecillewaet River, while Golder maintains a current continuous temperature monitoring program (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 are also within close vicinity to the WSC's existing discharge gauging station. Temperature loggers are downloaded twice per year.

During the spring field session (April 2011), Golder attempted to obtain a precise altitudinal value of the data logger sensor at the WSC's existing discharge gauging station on the Illecillewaet River, as part of the RTK satellite navigation survey. Due to snow cover, the benchmarks could not be located. This was postponed for October 2011 when the RTK satellite navigation survey was scheduled to occur. However, this was not completed (Section 2.1.3). Three WSC benchmarks were located and identified during August 2011 and positional information will be obtained during the 2012 field sessions that will include an RTK satellite navigation survey.

2.1.5 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 summer sampling session (August 2011), 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. The existing standpipe housing location had become a sand depositional area, covering the bottom of the pipe and causing an influx of sand into the standpipe housing, thus affecting the data logger sensors and its elevation (Appendix B, Photo 7). 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 will be utilized together (as one station) by applying a correction factor to each station of known elevation. However, data prior to October 28, 2010 may be compromised due to sediment compression on the data logger sensors. Therefore, for the purposes of the 2011 stage and temperature monitoring objective, data from Station 8_2008 and 8_2011 will not be used. RTK satellite navigation surveys scheduled for Year 6 (2012) will allow the Year 5 (2011) data to be adjusted using surveyed orthometric datum (Elevation above sea level) and subsequently will be reported in Year 6. Data will also be reviewed to determine its validity, prior to inclusion in the CLBMON-15a HEC-RAS Model calibration for Year 6.

Stage-discharge measurements were collected near the WSC Jordan River historic gauge station and Golder's index station (Station 8) on August 19 and October 28, 2011. The transect location is approximately 50 m downstream from Golder's index station and WSC's historic gauging station (see Appendix A, Table A-1 for UTM coordinates). To maintain repeatability, the transect was identified with large, plastic, bright orange markers affixed to mature tree stems on both river banks. Stream discharge measurements and appropriate site (transect) selection were conducted as outlined in (Golder 1997). As the water was less than 0.75 m deep on both occasions, measurements were taken at 60% of the total depth, using a wading rod and a Marsh McBirney Flo-mate™ portable velocity flow meter.

During the remainder of the study, stage-discharge data collection will occur over a range of Jordan River discharges to generate a revised stage-discharge curve for the Jordan River. These data will be used to calculate influence of the Jordan River on the MCR with the results used to calibrate the CLBMON-15a HEC-RAS Model. Given the high velocities and overall volume of Jordan River, the stage discharge curve for this river may only be calibrated at low water.

2.2 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). In 2010, Golder decided to undertake further model calibration in-house, using 2010 data to promote a better understanding of the project by having the monitoring program under one umbrella (Golder 2011, Appendix C). 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 Golder's CLBMON-15a HEC-RAS Model calibration and application as presented in Appendix C.

2.2.1 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-sections geometries from 200 to 158 were updated using Acoustic Doppler Current Profiler (ADCP) 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. BCH Bathymetric data (2002) will be compared against existing cross-sections in Year 6. Table 1 summarizes the data sources available for the calibration and application of the CLBMON-15a HEC-RAS Model.

Table 1: Summary the cross-section geometry data sources used for the CLBMON-15a HEC-RAS hydraulic model of the mid Columbia River (Appendix C, 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	Model will be updated with these data in Year 6
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

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., 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

2.2.2 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 2011 data to build upon the previous calibrations performed by Klohn and Golder, Golder's hydrotechnical tea (in consultation with Rodman Hydrotechnical Ltd.) completed the following tasks in Year 5 of the monitoring program (Appendix C):

- 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. The newly installed Station 1_AS (anchor station deployed in the deepest part of the channel located proximate to Station 1) was used during the 2011 calibration.

The MCR hydraulic model has been calibrated for steady state and unsteady state analysis. The steady flow model results have water elevations within 0.23 m of measured values, while the unsteady flow model results are within 1.05 m. Results replicate the timing and height of peaks in the highly variable flow regime. This is a refinement from the 2010 calibration, which steady state results were within 0.32 m of measured levels and unsteady state results were with 2.0 m of measured levels. In the subsequent years, the model will be run over a full year or other appropriate interval to predict the potential impact of minimum flow on available productive benthic habitat. Studies that intend to use the CLBMON-15a HEC-RAS Model will need to provide feedback on the model and provide desirable scenarios over appropriate time intervals. The runs of the model should be predicated on the intended use of the data, so that any modifications to the model can be incorporated in future model calibration and application.

2.3 Discharge and Water Stage Monitoring Results

2.3.1 2010-2011 Revelstoke Dam Operations

Load following and peaking operations at Revelstoke Generating Station result in patterns of discharge that vary on a daily, seasonal, and annual basis (Figure 3). Flow releases generally increase through daylight hours and peak in early evening at releases up to approximately 2124 m^3s^{-1} (post REV 5). During the night, generation is typically reduced due to lower electricity demand, and REV discharge frequently decreases close to prescribed minimum flows (142 m^3s^{-1}).

From October 1 to December 20, 2010 (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). 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 1750 m^3s^{-1} up to 2124 m^3s^{-1}. During Year 5 of the MCR Physical Habitat Monitoring Program, daily generation varied depending on generation needs and REV did not discharge water over the spillways.

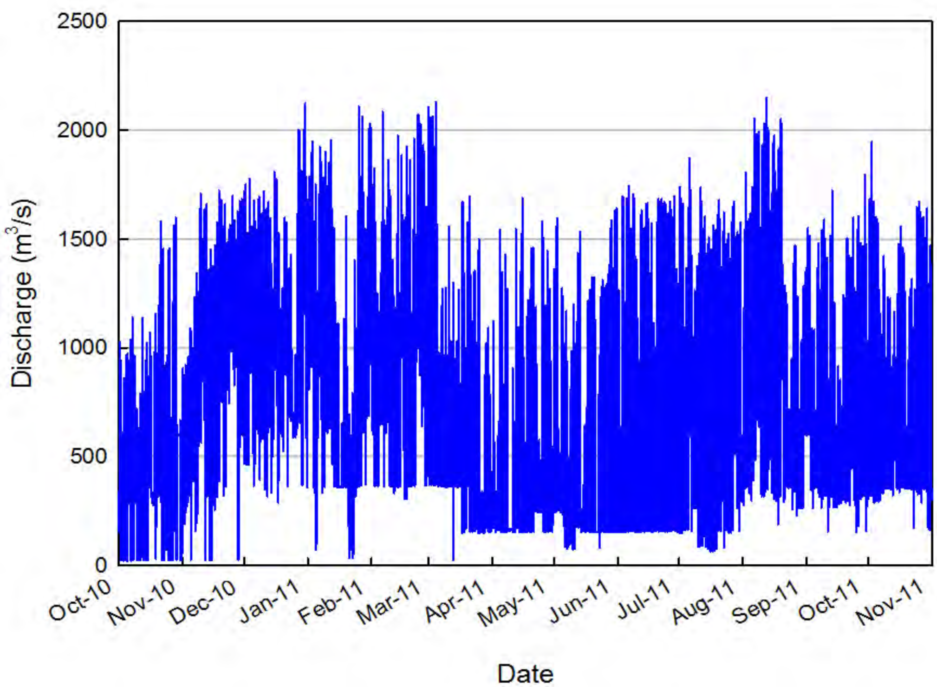

Figure 3: Revelstoke Generating Station hourly discharge for Year 5 (2010-2011) of the Physical Habitat Monitoring Program.

2.3.2 2010-2011 Tributary Inflows

The MCR has two main tributaries to the MCR within the study area: the Illecillewaet and Jordan rivers. The Akolkolex River confluence with the MCR is at the downstream end of the study area (Rkm 203.5). An annual hydrograph of the Illecillewaet River is presented Figure 4. The Illecillewaet River followed a similar trend when compared to the Annual hydrograph presented in Golder (2011), with a spike in discharge in early October, followed by low discharge throughout the winter months, increasing through spring and summer, and decreasing in late fall. Due to spring freshet, discharge increased in mid May (Figure 4), whereas last year's annual hydrograph showed increased discharge beginning in April 2010 (Golder (2011). This year's annual hydrograph also showed a higher hourly peak discharge on July 8, 2011 (382.51 m^3/s), while 2010 peak discharge occurred on September 28 (251.37 m^3/s) (Golder 2011).

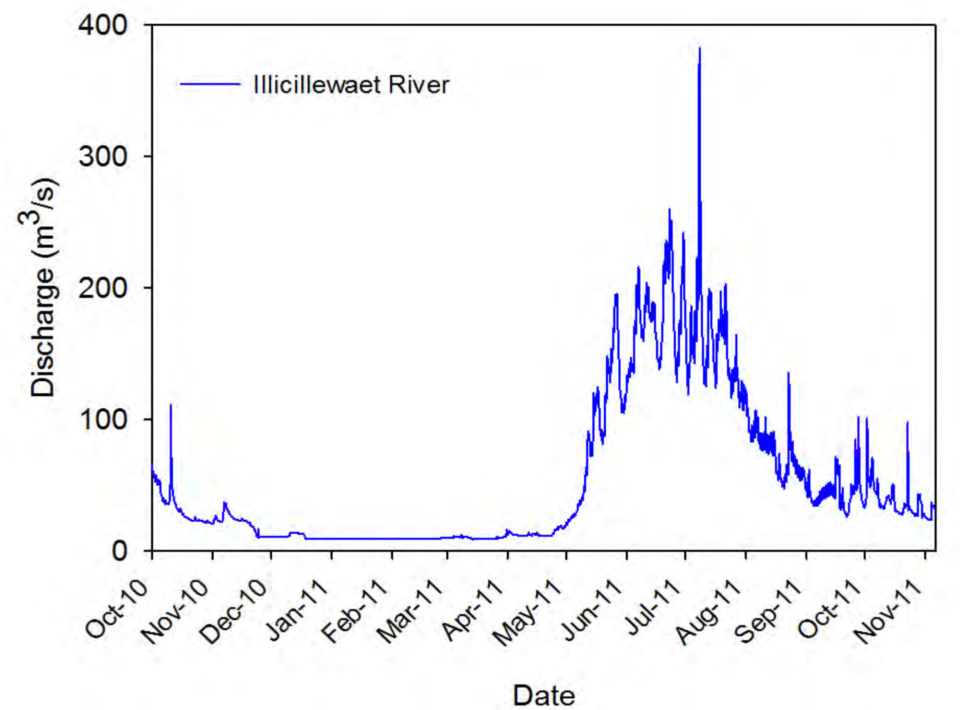

Figure 4: Hourly discharge of the Illecillewaet River, October1 2010 to November 5, 2011.

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. However, the relationship will require further refinement with additional flow measurements and RTK data obtained in Year 6. For the purposes of the 2011 stage and temperature monitoring objective, data from Station 8_2008 and 8_2011 will not be used. RTK satellite navigation surveys scheduled for Year 6 (2012) will allow the 2011 data to be adjusted using surveyed orthometric datum (Elevation above sea level) and subsequently reported in Year 6.

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 C. 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.

Based on current model runs from 2011 (see Appendix C for Hydraulic Model Calibration and Application), the influence 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. For typical ALR water elevations, the reservoir-river interface reaches the Akolkolex River in periods of low reservoir levels (423.8 masl and above), often occurring year round and reaches the Illecillewaet River at moderate-high reservoir levels (432.2 masl and above), often from May to January. The reservoir-river interface reaches the Jordan River in periods of high elevated reservoir levels (434.0 masl and above), often from June to December.

2.3.3 2010-2011 Arrow Lakes Reservoir Elevations

ALR levels fluctuate over the course of a year and this can affect the flowing section of the MCR and water level variations. Generally, 2011 reservoir elevations tracked similar to previous monitoring years (Figure 5), with the exception of higher reservoir elevations (and subsequently less variation) recorded in January to April. Full pool conditions in 2011 were slightly delayed, potentially affected in part by late snowmelt conditions. ALR elevations were also sustained longer in 2011 than in previous years (i.e., 2007, 2009, 2010) before beginning to decline in mid August and tracking higher through to December 2011.

Figure 6 shows the water level sensor elevations at all CLBMON-15a stations in the MCR compared to 2011 reservoir surface elevation recorded at Nakusp. 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 (Figure 6).

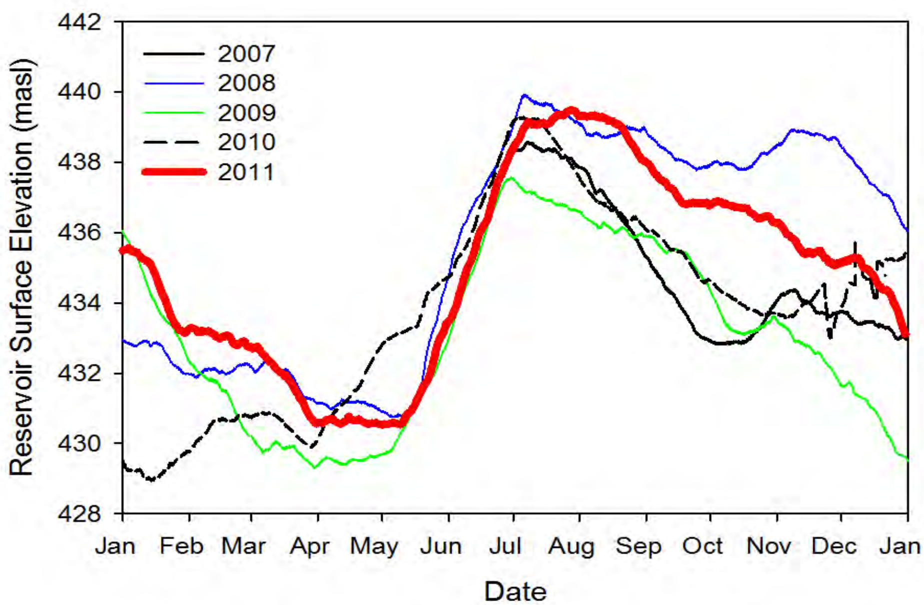

Figure 5: Arrow Lakes Reservoir elevation at Nakusp, BC for 2007, 2008, 2009, and 2010 (pre-implementation of REV 5 and 2011 (post-implementation of REV 5). Units are in metres above sea level. Data supplied by BCH. Data collection period was from January 1, 2007 to December 31, 2011.

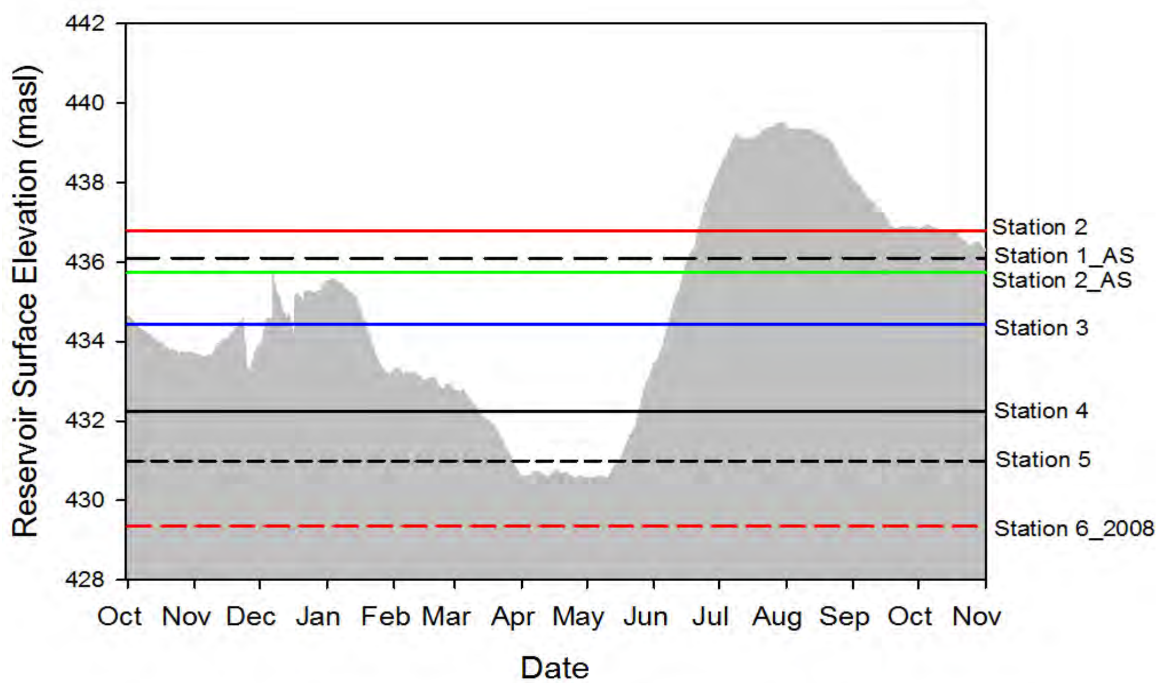

Figure 6: Reservoir height at Nakusp, BC with sensor elevations at CLBMON-15a stage data recording stations in the MCR. Units are in metres above sea level. Data supplied by BCH. Data collection period from October 1, 2010 to October 31, 2011. Refer to Figure 2 for approximate location of stations.

During 2011, Station 6 (Reach 2) recorded reservoir conditions for the entire year (Figure 6). Stations 4 (Reach 3) and 5 (Reach 2) recorded riverine conditions from April to mid May, while Station 3 (Reach 3) recorded riverine conditions for approximately 6 months (mid October to December and mid January to June). Reach 4 (Stations 1_AS, 2, and 2_AS) recorded riverine conditions for most of the year, except during the high water period between mid June to September and holding into November.

During monitoring Year 4 (2010), Station 5 (Reach 2) recorded riverine conditions for approximately 3 and a half months (mid December to April) (Golder 2011). During 2011, Station 5 recorded riverine conditions for approximately one and a half months (April to mid May). The reservoir-river interface zone moved through all the reaches during 2011; however, Reach 2 and the downstream portion of Reach 3 (Stations 4, 5, and 6) were inundated by the reservoir much longer than the upstream portion of Reach 3 (Station 3) and Reach 4 (Stations 1 and 2) (Figure 6).

The range and variability in river level fluctuations in the MCR are influenced by ALR elevation. Based on 2011 stage data and subsequent model runs, the ALR water levels that start to exert influence on the CLBMON-15a index stations are presented in Table 2. The elevations are generated from modeled water elevations and are the results from 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	435.8
Station 2_AS	435.6
Jordan River	434.0
Station 3	434.0
Station 4	432.2
Station 5	429.5
Station 6_2008	429.0
Akolkolex River	423.8

[1]This information was obtained through the 2011 CLBMON-15a HEC-RAS Model run (and is subject to change), as it will improve each monitoring year with additional data.

2.4 MCR Water Level Discussion

2.4.1 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.

The hypotheses and related sub-hypotheses will not be examined until Year 6 of the monitoring program, once additional post-implementation flow data has been gathered. Data from Years 1 to 4 will be 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) will be compared to future conditions produced by REV 5 [Years 4 (after REV 5 and minimum flow initiation), 5 and 6]. The post-implementation phase will study 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 Year 5 (2010-2011), refer to Appendix D.

[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.

2.4.2 MCR River Levels: Diel Variation Discussion

Hourly stage data were collected for each of the MCR monitoring stations during the 2010-2011 monitoring period (Year 5). Standpipe *Stations* 1 and 2 were omitted from the stage data set, as they 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) (Sections 2.1.2 and 2.2.2). With the addition of the anchor systems installed in Reach 4 in 2010 and close proximity (3.8 m to Station 1 standpipe and 10 m to Station 2 standpipe respectively), the stations duplicate data collected from the anchor stations (Stations 1_AS and 2_AS). Station 1_AS and 2_AS provide more complete and consistent data sets and will therefore be used instead of Stations 1 and 2.

Water stage recordings for all stations, with the exception of Station 3, reflected water level changes relative to the position of the pressure sensor in the water column. Station 3 data (shown in grey; Figure 7) were supplied to Golder with orthometrically corrected water levels. Surveyed elevations and corrections were incorporated into the database during the 2011 sampling year (Section 2.1.3). Similar to previous years, daily water level variations from REV attenuated with downstream distance from the dam and tributary inputs (Figure 7).

2.4.3 MCR River Levels: Seasonal Variation Discussion

There was no detailed review of variations in seasonal water levels within the MCR. However, dam discharge, tributary inputs, and ALR levels all influence water level fluctuations. In future years, it would be beneficial to define specific water level fluctuations related hypotheses for analysis (e.g., water level fluctuations in Reach 4 during sturgeon spawning season for linkages with CLBMON-20 MCR White Sturgeon Spawning Habitat Assessment, CLBMON-54 MCR Effects of Flow Changes on Incubation and Early Rearing Sturgeon Monitoring, CLBMON-23 MCR White Sturgeon Spawn Monitoring programs, and other RFMP studies).

2.4.4 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.

[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.

After calibrating the CLBMON-15 HEC-RAS Model in 2011, the area of permanently inundated channel was estimated using the steady state HEC-RAS model. The model was run with 2 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 2011 CLBMON-15a HEC-RAS calibrated model results show that minimum flows would increase permanently wetted riverbed by 37% over current operations (Appendix C) when ALR is below 425 m.

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 fish (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).

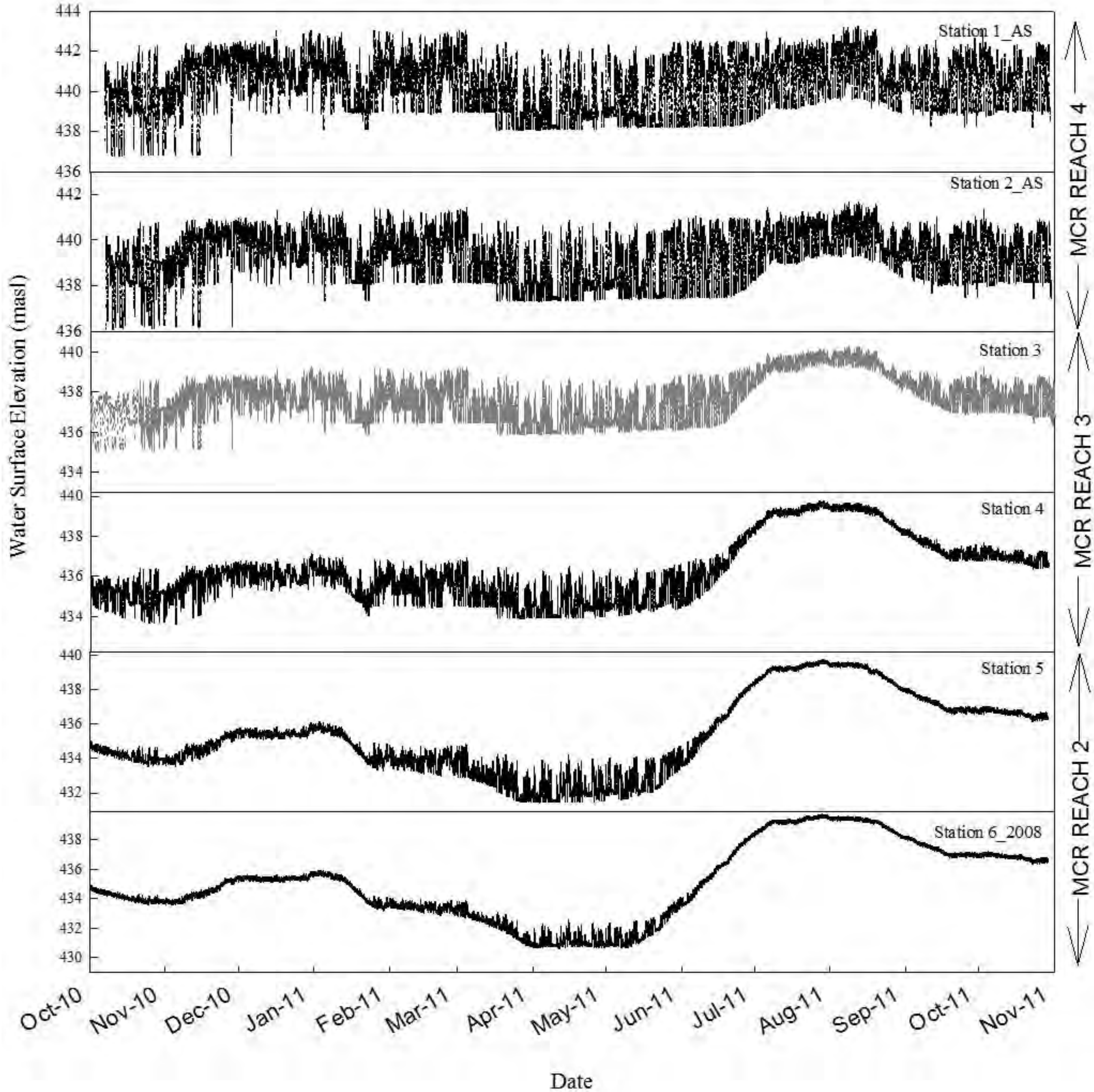

Figure 7: Water surface elevation (metres above sea level) recorded at 7 river stations in the MCR, October 1 2010 to October 31, 2011. Refer to Figure 2 for location of stations.

2.5 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. In Year 5 (2010-2011), temperature was monitored in the mainstem MCR and the Jordan and Illecillewaet rivers (Figure 8). Temperature data at Golder Station 8 (Jordan River) for Year 5 were unavailable for this report, due to absence of RTK data (Section 2.1.3 and 2.1.5). Data will be available following the April 2012 field session and will be incorporated in Year 6. For a list of temperature data availability for Year 5 (2010-2011), refer to Appendix D.

Continuous water temperature monitoring was not conducted at Station 7 between 2007 and 2010 (Illecillewaet River; WSC Station No. 08ND013; Lynne Campo, WSC, *pers. comm*., January 20, 2010) (Appendix D). Beginning October 2010, Golder installed Onset TidbiT v2 temperature loggers in close vicinity to the WSC's existing discharge gauging station. The loggers are set to record temperature in 30-minute intervals, to coincide with the Solinst 300 'Gold' mini logger currently installed at the Jordan River. Station 3 data loggers were maintained and downloaded by BCH.

In Year 5, Golder measured water temperatures at Station 3 to be approximately 1.0 to 1.4 °C higher than the Solinst data loggers used at the Golder installed stations, although both data sets showed similar temporal patterns (Figure 8). In Year 4, Golder proposed differences (of 1.5 °C) were likely due to the type of data logger systems used (different technological specifications between Golder's Solinst data loggers and BCH's station) or that BCH's Station 3 water temperature logger has not been calibrated (Denise Hutt, BCH REV, *pers. comm*., February 14, 2011). On December 5, 2011 the logger sensor was noted to have malfunctioned and then ultimately failed on December 12, 2011. BCH REV indicated a new logger would be installed "for duration of winter readings" (Kivilahti, K and D. Hutt, BCH REV, *pers. comm*., December 13, 2011).

As Station 3 will likely provide long term monitoring of water temperatures for Revelstoke tailwaters, proper calibration of this station for consistency among all sampling stations is important. For the purposes of CLBMON-15a monitoring program our concerns regarding Station 3 (labelled by BCH as REV 'TR2' or 'Tailrace-7km') in Reach 3 are as follows:

- Due to sensor failure, data gaps will continue to exist after December 12, 2011, unless a new logger is reinstalled by BCH.
- Logger may not be set up to log in a manner consistent with other loggers for CLBMON-15a (i.e., logging from top of the hour, in 10-minute intervals, and Standard time instead of Daylight Savings time).
- Logger may not be capturing both temperature and water level readings (both measurements would be ideal).
- Based on BCH REV personnel comment's regarding "Winter readings" (Kivilahti, K and D. Hutt, BCH REV, *pers. comm*., December 13, 2011), it is unclear if these data will be available for the duration of the monitoring program.

The assessment of diel, seasonal, and spatial temperature variations below REV will not be analysed in detail until Year 6. The following information provides an overview of information collected to date.

2.5.1 Temperature Variation: Temporal

During the winter months of 2010, MCR water temperatures decreased to a low of 0.5 °C on March 1, 2011 [Stations 1_AS and 2_AS (Reach 4) 6_2008 (Reach 2)] (Figure 8). Low temperatures in Reach 2 may be attributed to tributary influences (e.g., Illecillewaet River), which recorded temperatures ranging from 0.02 to 0.77 °C between mid December and mid March (Figure 8). Temperatures generally followed an increasing trend during spring and summer months and briefly reached a study area maximum on the MCR of 11.7 °C on August 27, 2011 (Station 6; Reach 2) (Figure 8). In Reach 4, temperatures reached a maximum of 11.0 °C on August 26, 2011 (Stations 1_AS and 2_AS; Reach 4). 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 prior to hydroelectric development (RL&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 (RL&L 2001).

Diel water temperatures fluctuate more during the summer than in winter months. Larger temperature fluctuations during the summer are likely related to dam operations, meteorological factors influencing temperature of discharges from REV reservoir, daily temperature fluctuations in the tributaries (Jordan and Illecillewaet rivers), and the influence of ALR levels on temperatures. The Illecillewaet River data (Station 7) show more variability than the MCR index stations (Figure 8).

During the summer months (June through August), diel fluctuations in water temperatures on the MCR study reaches were generally larger than fluctuations observed in other seasons; with the greatest monthly diel range measured on June 24 (6.8 to 8.7 °C) at Station 2_AS (Reach 2), July 29 (9.0 to 10.8 °C) at Station 4 (Reach 3), and on August 1 (at Station 6_2008 (Reach 2).The diel water temperature pattern that was observed during the summer of previous monitoring years (2008, 2009, and 2010) also occurred during 2011 at all MCR stations and was associated with sustained high discharges from REV (Figure 8; Golder 2010, 2011). This issue may warrant further examination of the relationships between forebay temperature profiles, forebay stratification, tailrace temperatures, and operations; however, it is outside the scope of this monitoring program. Diel fluctuations in water temperatures in May through September are also influenced by the Jordan and Illecillewaet rivers; with increasing temperature variation in Stations 3 through 6_2008 (Figure 8). Fluctuations seen in the spring and summer months on the Illecillewaet are likely related to the influence of late snowmelt conditions in 2011.

Temperatures at Station 7 (Illecillewaet River) hovered near freezing temperatures between mid-December and mid March. Temperatures ranged from 0.024 to 1.859°C during this time period. The MCR stations below the Illecillewaet River varied more than the upstream stations during the spring, likely because of the influence of the Illecillewaet River and more kilometres of river upstream that are subjected to diel solar warming.

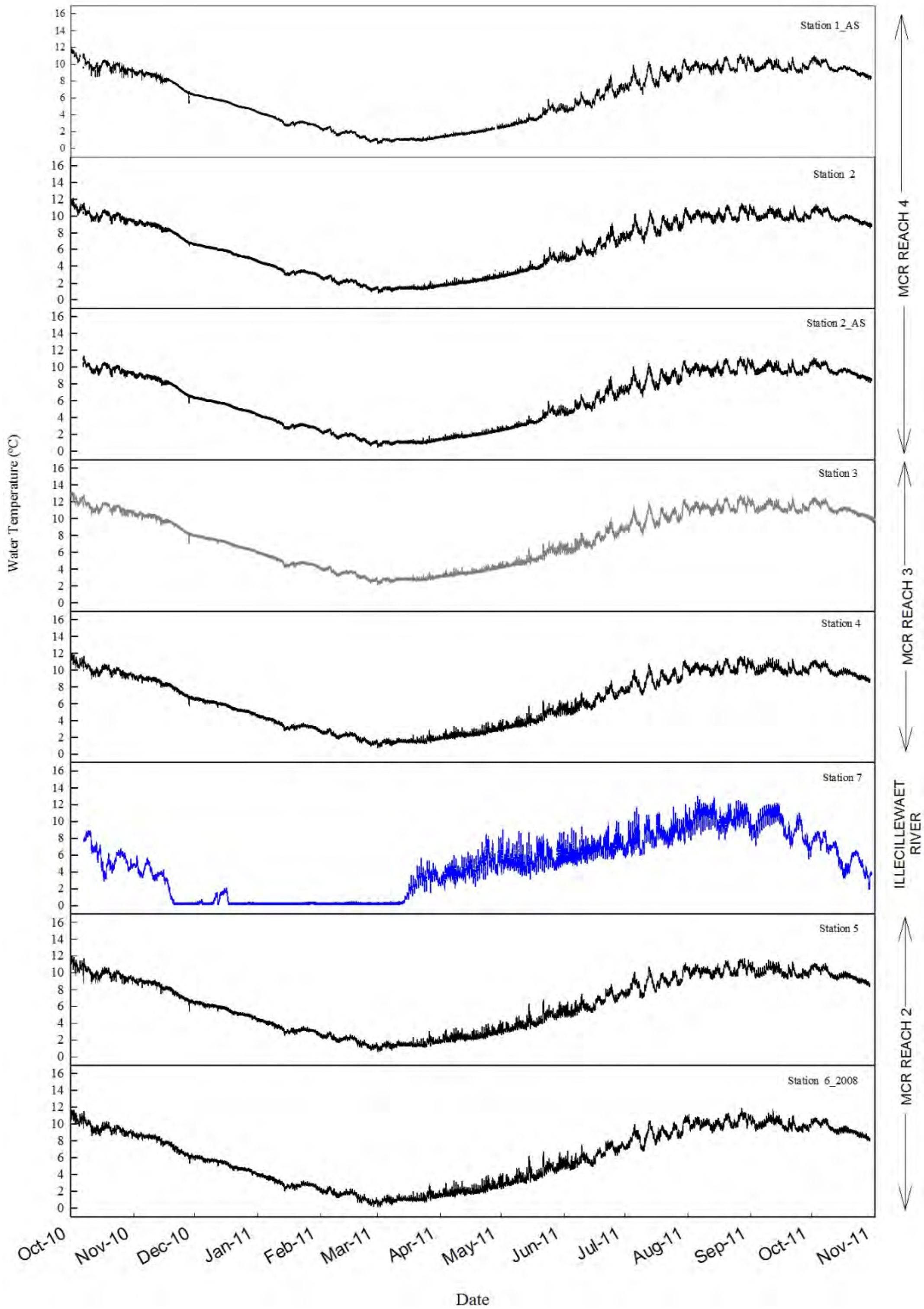

Figure 8: Water temperature readings from October 1, 2010 to October 30, 2011 at 7 river stations in Reaches 4, 3, and 2 of the MCR (10-minute intervals) and one station on the Illecillewaet River (30-minute intervals). Refer to Figure 2 for location of stations.

2.5.2 Temperature Variation: Spatial

To assess the spatial variation in temperature, temperature data (collected from October 1, 2010 to October 29, 2011) from Station 1_AS (Reach 4 – 1.5 km downstream from the dam), Station 2_AS (Reach 4 - 3.7 km downstream from dam); and 2 stations located further downstream from dam [Station 4 (Reach 3; 11.4 km) and Station 6_2008 (Reach 2; 17.2 km)]; were compared (Appendix E). Figure 9 provides a 'snapshot' of MCR temperature fluctuations and spatial variation in relation to REV discharge and ALR water levels. All four MCR stations appear to be tracking similar riverine water temperature fluctuations (Figure 8 and Appendix E). There was a temperature difference of approximately 1.0 to 1.4 °C between BCH's Station 3 and Golder MCR index stations (Figure 8). As mentioned above (Section 2.5), this was likely caused by a failing sensor of BCH's Station 3 water temperature logger (Kivilahti, K and D. Hutt, BCH REV, *pers. comm*., December 13, 2011).

Riverine water temperature daily fluctuations at all four MCR stations were similar from November 2010 to March 2011, with minor temperature variations from Reach 4 (Stations 1_AS and 2_AS) to Reaches 3 and 2 (Stations 4 and 6_2008) (Appendix E). Towards the end of March, temperatures in Reach 4 (Stations 1_AS and 2_AS) were hovering around 1.5 °C, whereas Stations 4 and/or 6_2008 showed increased temperature fluctuations up to 2.6 °C (Figure 9). Reach 4 was exhibiting riverine conditions from October 2010 to June 2011, while Reaches 2 and 3 temperatures are likely influenced by ALR from October 2010 to the end of March 2011 (Figure 6).

Reaches 3 and 2 show increased temperature variation in stations downstream of the Jordan and Illecillewaet rivers following spring freshet (Figures 4, 8, and 9). Reaches 3 and 2 (Stations 3 through 6_2008) 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 (Figure 8).

Downstream spatial variation on the MCR is impacted by both reservoir and dam influences in June, where Reach 4 (Stations 1_AS and 2_AS) was related to water temperatures from REV, while Reach 2 (Station 6_2008) is more influenced by ALR, once the reservoir was above 429.0 m (Figure 9). Station 4 (transition area between Reaches 2 and 3) is influenced by both reservoir (above 432.2 m) and dam influences (Figures 6 and9). 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 (Figure 9), compared with June (Figure 9). In June 2011, all 3 reaches are influenced by the reservoir (Figure 6) and less from tributary temperatures (e.g., Illecillewaet River, Figure 8); however, the spatial variation and influence of temperatures from REV, combined with the ALR influence, is still apparent between the MCR stations (Figures 8 and 9).

In real time, Reach 4 (Stations 1_AS and 2_AS) temperature fluctuations lag behind both changes in REV discharge, as well as a lag in temperature variation, that was also apparent in water flows downstream of the various stations (Appendix E and Figure 9). The lag time also varies 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_2008) start to measure reservoir conditions (Section 2.3.3). Even between Stations 4 and 6_2008, there is a temporal difference in water temperature fluctuations from June to October 2011 (Appendix E). The lag time between Stations 4 and 6_2008 was likely influenced by both reservoir conditions and downstream distance from the dam (Section 2.5.1).

Within the temperature sampling zone, vertical mixing of water unlikely results in any depth variation because of the turbulence and mixing, although vertical temperature profiles were not taken during this study.

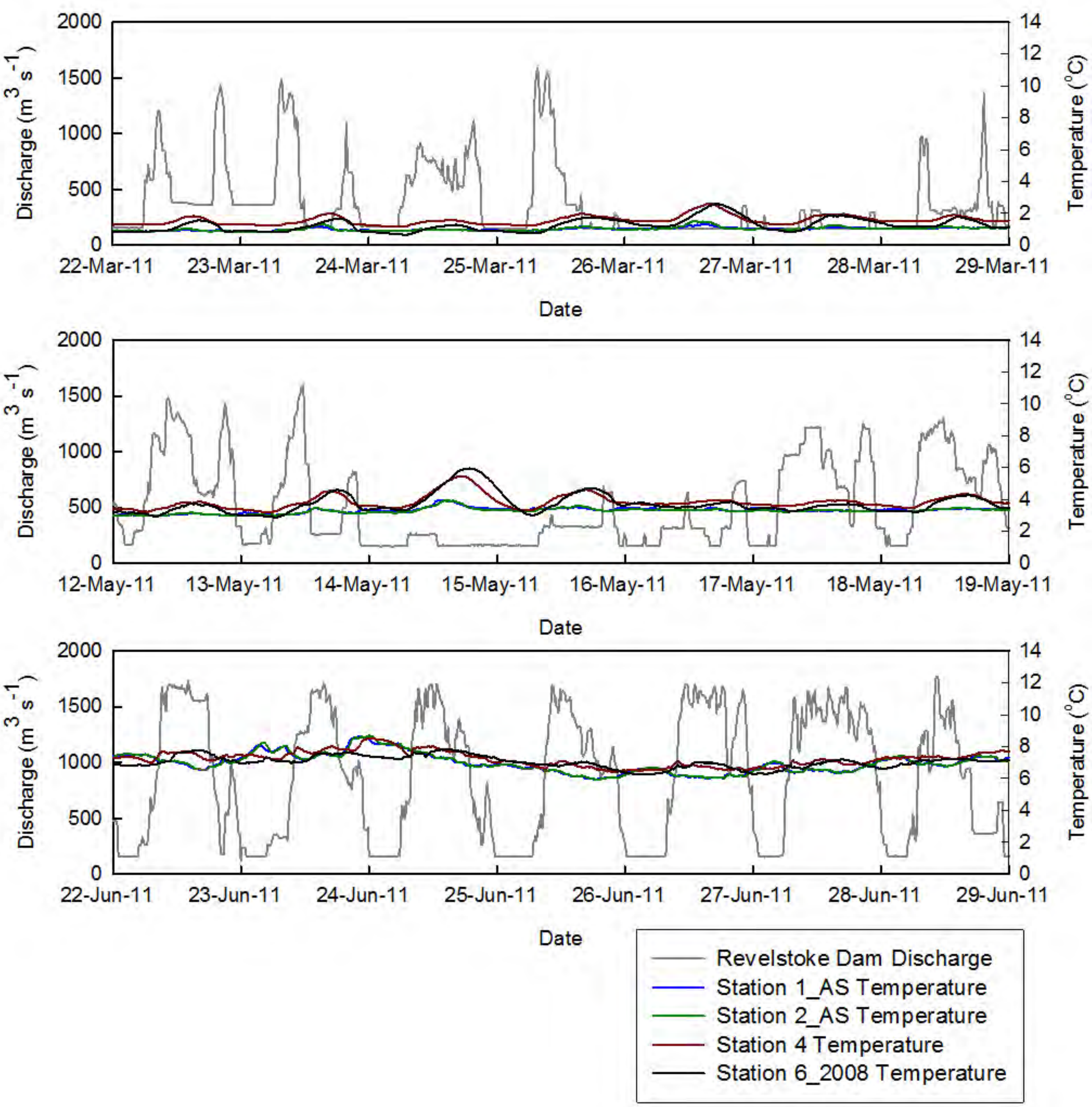

Figure 9: Discharge (grey line) from REV and water temperatures on the MCR at Stations 1_AS, 2_AS (Reach 4), Station 4 (transition area between Reaches 3 and 2), Station 6_2008 (Reach 2) and from March 22-29, May 12-19, and June 22-29, 2011.

3.0 TOTAL GAS PRESSURE (TGP) MONITORING

3.1.1 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 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, postponement of TGP monitoring until Year 6 (2012) was approved by the CLBMON-15a contracts manager (Karen Bray *pers. comm.* October 13, 2011). This postponement will allow time for flow operations to stabilize, operation plans to be clarified, and Operations Planners to better understand the seasonal and diel range of generating station operations and provide guidance for future synchronous condense operating scenarios.

4.0 SEASONAL WATER QUALITY MONITORING

4.1 Seasonal Water Quality Sampling Methodology

4.1.1 Water Quality Sampling Stations

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 10 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 2 studies and are not considered to negatively impact the interpretation of previously collected data.

Ten water samples were collected, including; 6 CLBMON-15b stations located from Reach 4 to Reach 2; 2 tributary stations (i.e., Illecillewaet and Jordan rivers); and, 1 station duplicate and field blank.

Blank and duplicate samples were collected at different stations each sample session [Top Reach 4 (spring), Below Big Eddy (summer), Jordan River (fall)] (Figure 10) for quality assurance and quality control for both sample delivery and laboratory analysis.

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

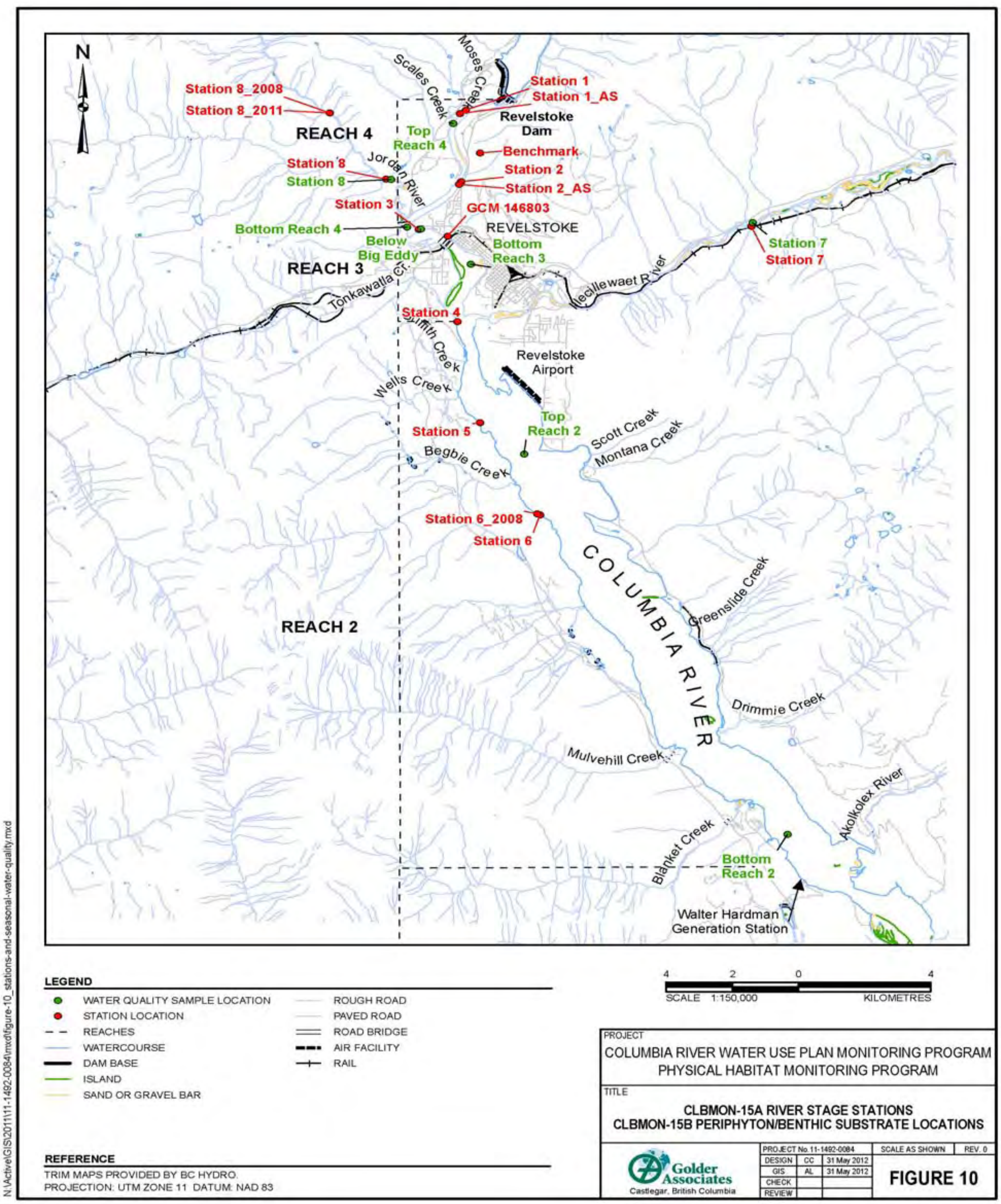

Figure 10: CLBMON-15a River Stage Stations (in red) and CLBMON-15b periphyton/benthic substrate locations where seasonal water quality sampling was completed in 2011 (in green) on the MCR.

4.1.2 Water Quality Sampling Methods

Surface water samples were collected seasonally at 8 stations (Appendix F, Table F-2 and F-3) (Figure 10). The nutrient sample component of the water quality sampling program parallels the MCR Ecological Productivity Monitoring (CLBMON-15b) by sampling the same parameters (identified in Table 3) over 3 seasons. In 2011, Golder conducted seasonal water sampling on August 17 (summer), with Ecoscape undertaking the spring (May 18) and fall (October 5) monitoring at periphyton/benthic substrate locations and the related tributary stations (identified in green on Figure 10). Low level nutrients were analyzed at the DFO Cultus Lake Salmon Research Laboratory (DFO) near Chilliwack, BC. All other values were tested by Caro Analytical Services (Caro) in Kelowna, BC. All water quality data are stored in the CLBMON-15a Physical Habitat Monitoring database maintained by Golder.

Table 3: CLBMON-15a monitoring program water quality parameters and frequency.

CLBMON-15a and 15b Water Quality Index Station(s)[1]	Parameter	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	Continuous (10-minute intervals)	Influence of Revelstoke discharge and tributary inputs on river temperature
	Spot Water Temperature	3 times/year	CLBMON 15-b monitoring locations for periphyton//benthic substrate samplers
	Nutrients (TN, TKN, NO_3, NO_2, NH_3, SRP, TP, TDP)	3 times/year	
	Turbidity (TSS, TDS, Turbidity)	3 times/year	
	Electrochemistry (SpCond, Conductivity)	3 times/year	
	Dissolved Oxygen (% saturation and mg/l)	3 times/year	
	pH	3 times/year	

[1]Reach number locations are described in Section 1.2 and shown in Figure 10.

For the spring and fall sampling sessions in 2011 (Year 5), water quality sampling was completed by Ecoscape (at the same stations as Golder) under CLBMON-15b including: 6 CLBMON-15b stations located from Reach 4 to Reach 2, 2 tributary stations (Illecillewaet and Jordan rivers), and one station duplicate and field blank (Figure 10; Appendix F, Tables F-1 and F-2).

Although the main intent for CLBMON-15a is to spatially characterize seasonal water quality conditions in the MCR (at the reach scale), these water quality parameters are used in analyses to link habitat attributes and benthic invertebrate assemblages for the Ecological Productivity Monitoring (CLBMON-15b). These data may also be useful for other WUP projects as part of the RFMP. Tables 4 (*in situ*) and 5 (laboratory analyses) provide a summary of water quality information that may be useful for the purposes of providing baseline data collection to a number of programs within the MCR study area.

Table 4: List of Year 5 and 6 in situ parameter codes and descriptions for use in analyses to link habitat attributes and benthic invertebrate assemblages for CLBMON-15a and 15b.

Code	Units	Description and Additional Notes
Sample time	00:00	Military time at which water sample was collected
Water temperature	°C	
pH	--	Measure of acidity (potential hydrogen)
Turb	NTU	Turbidity
DO	%	Dissolved oxygen in percent saturation
DO	mg/L	The concentration of dissolved oxygen in water
TDS	mg/L	Total dissolved solids
Cond	µS/cm	Conductivity - can be affected by temperature or type of probe
SpCond	µS/cm	Specific conductivity standardizes conductivity to a temperature of 25°C for direct comparison between sites with different water temperatures
ORP	--	oxidation-reduction potential

The DFO and Caro labs are 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-4.

Table 5: Available laboratory analytes for CLBMON-15a and 15b during spring, summer, and fall 2011 sample sessions under both CLBMON-15a and 15b monitoring programs.

Analyte	Abbreviation	Units	Lab Completing Analyses	Field Preservative Required (Y/N)	Additional Notes
total Kjeldahl nitrogen	TKN	mg/L	Caro Analytical Ltd. (Kelowna)	N	Not a separate analysis, but a method to obtain TN
total nitrogen	TN	mg/L	Caro Analytical Ltd. (Kelowna)	H_2SO_4	Request TN using TKN method
percent hydrogen	pH	--	Caro Analytical Ltd. (Kelowna)	N	
total suspended solids	TSS	mg/L	Caro Analytical Ltd. (Kelowna)	N	
total dissolved solids	TDS	mg/L	Caro Analytical Ltd. (Kelowna)	N	
total silicon/silica[1]	T-Si	mg/L	Caro Analytical Ltd. (Kelowna)	HNO_3	
nitrite-nitrogen	NO_2	µg/L	DFO Cultus Lake Salmon Research Laboratory	N	Once filtered, freeze immediately
nitrate-nitrogen	NO_3	µg/L	DFO Cultus Lake Salmon Research Laboratory	N	Once filtered, freeze immediately
ammonia	NH_3	µg/L	DFO Cultus Lake Salmon Research Laboratory	N	Once filtered, freeze immediately
soluble reactive phosphate	SRP	µg/L	DFO Cultus Lake Salmon Research Laboratory	N	Once filtered, freeze immediately
total phosphorus	TP	µg/L	DFO Cultus Lake Salmon Research Laboratory	N	Not filtered
total phosphorus turbidity	TP Turb	µg/L	DFO Cultus Lake Salmon Research Laboratory	N	
total dissolved phosphorus	TDS	µg/L	DFO Cultus Lake Salmon Research Laboratory	N	Filtered immediately following collection, prior to shipment to lab

[1] Total silicon/silica was collected for the purposes of CLBMON-15b and is not part of the scope for CLBMON-15a; therefore, the results are not discussed in this report.

4.2 Seasonal Water Quality 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 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: 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: The implementation of a 142 m^3s^{-1} minimum flow release from Revelstoke Dam will not significantly alter spatial variation in water quality parameters.

4.2.2 Water Quality Results and Interpretation

Under the MCR Physical Habitat Monitoring Program, seasonal water quality sampling is undertaken to collect data for other users. A summary of the 2011 seasonal raw data is presented in Appendix F (Tables F-1 and F-2).

The range in water quality parameters measured in the study area in spring, summer, and fall of 2011 were typical of an oligotrophic system and were similar among all stations within the mainstem of the MCR (Appendix F). The 2 main tributaries (Jordan and Illecillewaet rivers) occasionally showed considerably different values than those found in the MCR.

Surface water pH was similar at all mainstem stations of the MCR across all seasons, between 7.19 and 7.51 (spring), 7.47 to 7.69 (summer), and 7.44 to 7.81 (fall). The Illecillewaet River pH ranged from 7.34 (spring), 7.77 (summer), and 7.76 (fall), while the Jordan River was slightly more acidic [pH 7.06 (spring), 7.44 (summer)], with the exception of the fall reading (7.78), which is similar to the Illecillewaet. These values are within typical surface water values as indicated by the British Columbia Approved Water Quality Guidelines (BCWLAP 2006).

Dissolved oxygen surface values were recorded in both mg/L and percent saturation. Mainstem MCR dissolved oxygen in 2011 ranged between 10.4 to 11.6 mg/L (spring), 11.27 to 12.65 mg/L (summer), and 9.48 to 10.74 mg/L (fall) corresponding to saturation levels of 83-90% (spring), 99-111% (summer), and 90-96% (fall). Salmonids species are known to prefer dissolved oxygen values greater than 9 mg/L. Both tributaries showed greatest saturation values of 104% (or 11.73 mg/L) in the Illecillewaet and 107% (or 11.89 mg/L) in the Jordan River during the summer sampling session, but were within typical surface water values (BCWLAP 2006). In 2010, both tributaries showed saturation values as high as 112% (or 13 mg/L) during the spring freshet period. The seasonal variation between 2010 and 2011 was likely due to late snowmelt conditions in 2011.

Specific conductivity of the mainstem MCR ranged between 153-172 µS/cm (spring) and 66-68 µS/cm (summer), and 97 to 113 µS/cm (fall) within the typical range of surface water values in BC (BCWLAP 2006). The Illecillewaet River values were consistently higher in the spring (up to 155 µS/cm during spring freshet), reflecting the glacial nature of the headwaters and the presence of softer parent materials containing high calcium deposits. The Jordan River values for specific conductivity [38 µS/cm (spring) and 27 µS/cm (summer) and 29 µS/cm (fall)] were generally lower than at the other sample stations. Streams in the BC interior have specific conductivity values that can range up to 500 µS/cm (BCWLAP 2006).

Nitrate (NO^-_3) concentrations ranged from 101.7 to 180.6 µg/L (spring), 111.5 to 123.2 µg/L (summer), and 98.1 to 108.0 µg/L (fall) in the mainstem MCR, while they ranged between 74.8 (summer) to 453.8 µg/L (spring) in the Illecillewaet River and between 88.2 (summer) to 387.0 µg/L (spring) in the Jordan River (Stations 7 and

8_2008 respectively; Appendix F). The nitrate levels in the tributaries followed a seasonal pattern with decreases in nitrate concentrations during the summer sample sessions for all 5 monitoring years (August 2007, June 2008, June 2009, June 2010, and August 2011) (Golder 2011and Figure 11), with peak concentrations during the start of freshet in April/May. This pattern would suggest that biological uptake of nitrate is at its highest during the warmer summer months. Most surface waters have less than 300 µg/L of nitrate where anthropogenic inputs do not exist (BCWLAP 2006). Seasonal peak concentrations in Reach 2 of the mainstem MCR were also recorded during the spring sample session downstream of the Illecillewaet River (Figure 10). This would suggest the Illecillewaet River appears to influence Reach 2 of the mainstem MCR, as the confluence with the MCR occurs at the top of Reach 2 (Figure 9). Anthropogenic influences (e.g., sewage treatment plant) along the Illecillewaet River may contribute to increased nutrient loading in Reach 2 of the MCR. This is not mirrored in nitrate concentrations in Reach 3, downstream of the Jordan River (Figure 9), even with peak concentrations and subsequent input from the Jordan River (Figure 10). These values are below water quality standards for protection of aquatic life by the British Columbia Approved Water Quality Guidelines (BCWLAP 2006).

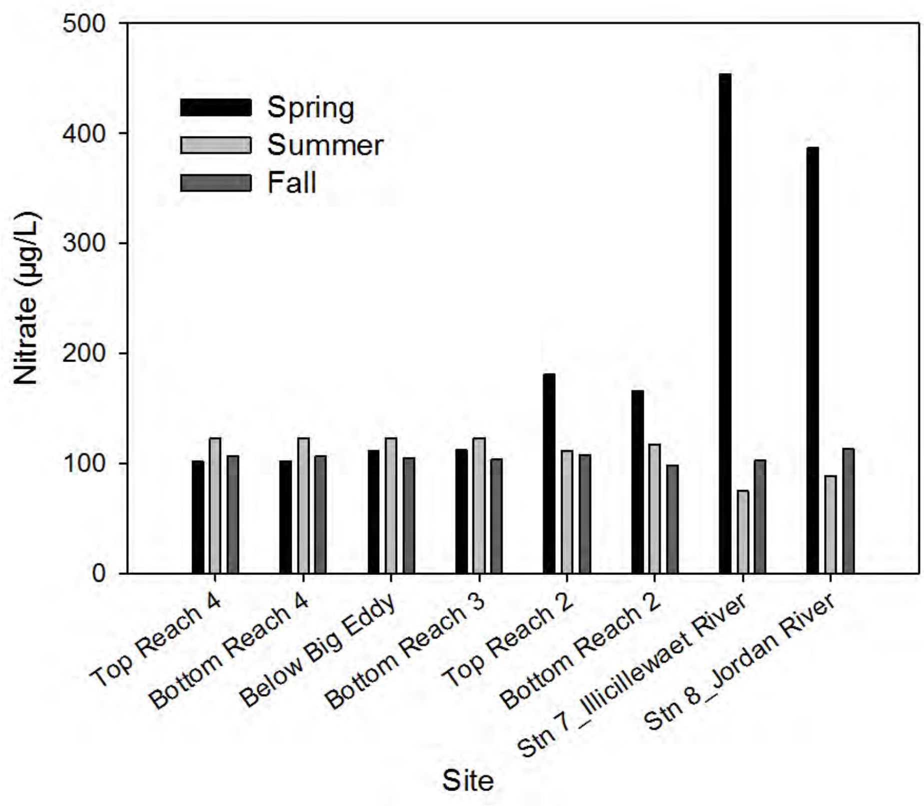

Figure 11: Nitrate (NO_3) concentrations in surface water at CLMON-15a and 15b water quality index stations on the MCR (Top Reach 4 to Bottom Reach 2), and Illecillewaet and Jordan rivers in spring (May 18), summer (August 17) and fall (October 5) 2011.

Nitrogen can be measured as total nitrogen (TN) or total Kjeldahl nitrogen (TKN). TN is similar to total phosphors (TP) and is used to measure of all forms of nitrogen (organic and inorganic). TKN represents the fraction of TN that is unavailable for growth or bound up in organic form. TN and TKN are not available for the spring sample session; therefore, TN and TKN are only reported for the summer and fall of 2011 and were therefore not presented in graph form. TN ranged between 0.22 to 0.49 mg/L (summer) and 0.18 to 0.33 mg/L (fall), while TKN ranged from 0.07 to 0.21 mg/L (spring) and 0.12 to 0.38 mg/L (summer) and displayed the same seasonal pattern as nitrate concentrations. The tributaries followed a pattern of decreasing TN and TKN concentrations from summer to fall. Total Nitrogen does not have established water quality guidelines in BC as the components of nitrate, nitrite, and ammonia have separate guidelines.

Total phosphorus in the mainstem MCR likely reflects the reservoir conditions upstream, since there is little biological activity affecting nutrient values immediately below the dam. The data showed peak concentrations during the spring ranging from 4.2 to 5.0 µg/L (from Top of Reach 4 to Bottom of Reach 3), possibly due to spring overturn in the upstream reservoir. TP concentrations below REV from 1984 to 1998 (Regnier 1998) were similar to TP concentrations found within the study area in 2011 and during previous 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 those locations closer to the dam (Figure 12). Reach 2 showed peak concentrations during the spring, ranging from 8.8 µg/L (top of Reach 2) to 12.3 µg/L (bottom of Reach 2). The concentration of TP in lakes not affected by anthropogenic inputs is generally less than 10 µg/L (BCWLAP 2006). The Illecillewaet River measured a TP concentration of 19.7 µg/L during the spring and is likely influenced by anthropogenic sources (e.g., sewage treatment plant), causing increased nutrient loading and subsequent higher TP concentrations measured at the water quality index station downstream of the Illecillewaet River (Bottom Reach 2) (Figure 10). TP analysis was not completed for the Jordan River in spring, as the test tube arrived to the lab empty (likely damaged during transit).

TP in the Illecillewaet River ranged from 5.6 (fall) to 19.9 µg/L (summer), while levels in the Jordan River ranged from 2.3 (fall) to 3.1 µg/L (summer). Water sample index stations (Top Reach 2 and Bottom Reach 2) (Figure 10) are located downstream of the Illecillewaet River and 2 other small tributaries (Griffith and Wells creeks). Bottom Reach 2 index station measured the highest TP concentration on the MCR in spring 2011, while in the summer and fall of 2011 the station closer to the Illecillewaet (Top of Reach 2) (Figure 9) measured a higher value than the index station downstream of the Illecillewaet River (Bottom of Reach 2) (Figure 9). High oxygen and a lower water temperature generally cause the movement of mineral nutrients through tributaries (Atlas and Bartha 1998). Most microbial organisms in fast flowing water are attached to the surface of submerged rocks (Ministry of Environment 2007). As the water moves swiftly over the rocky substrate, nutrients such as elemental phosphorus are taken up by the biomass (Ministry of Environment 2007). Dissolved nutrients are rapidly absorbed by these microorganisms. Because of limited biological activity, much of the TP in this area may be related to inorganic particulate phosphorus, which is generally unavailable to aquatic organisms until slowly mobilized through bacterial and physical processes. TP values include this particulate phosphorus that is biologically unavailable and is often associated with increased colloidal particulates related to flows originating from glaciers, in addition to biologically available nutrients.

Where glacial suspended material is present in the water column, TP concentrations can increase substantially and may reflect the seasonal changes observed in tributaries and in the mainstem MCR. In these conditions, **total dissolved phosphorus (TDP)** is more indicative of nutrient availability than TP (Figure 12). TDP concentrations ranged from 3.5 to 4.4 µg/L (spring), 1.2 to 1.8 µg/L (summer), and 2.1 to 3.1 µg/L (fall) in the mainstem MCR, while they ranged from 6.1 µg/L (spring), 1.6 µg/L (summer), 2.8 µg/L (fall) in the Illecillewaet River and from 3.6 µg/L (spring), 1.4 µg/L (summer), 1.7 µg/L (fall) in the Jordan River (Stations 7 and 8_2008 respectively; Appendix F).

The Illecillewaet River has softer parent materials and more glacial contributions than the Jordan River. In the 5 years of this monitoring program, the Illecillewaet River showed consistently higher TP levels during all seasons (spring, summer, fall) compared to the Jordan River, which has less glacial influence than the Illecillewaet River.

These values are below water quality standards for protection of aquatic life by the British Columbia Approved Water Quality Guidelines (BCWLAP 2006).

Soluble reactive phosphorus (SRP) was included in the analysis of water samples, as SRP better reflects bioavailable phosphorus than TP. The TP concentrations were highest during spring in the mainstem stations, while SRP typically decreased from summer to fall, reflecting increased inorganic fractions (increasing TP) and increased biological activity (reducing SRP). SRP concentrations ranged from 1.0 to 1.3 µg/L (spring), 1.0 to 1.4 µg/L (summer), and 0.8 to 1.2 µg/L (fall) in the mainstem MCR, while they ranged from 1.2 µg/L (fall), to 1.6 µg/L (summer), and 1.9 µg/L (spring) in the Illecillewaet River and from 0.8 µg/L (summer and fall) to 1.6 µg/L (spring) in the Jordan River (Stations 7 and 8_2008 respectively; Appendix F). These very low values are typical of phosphorus limited systems where periphyton rapidly assimilates available nutrients into biomass. Soluble phosphorus is a component of TP and a specific criteria for this component has not been established in BC.

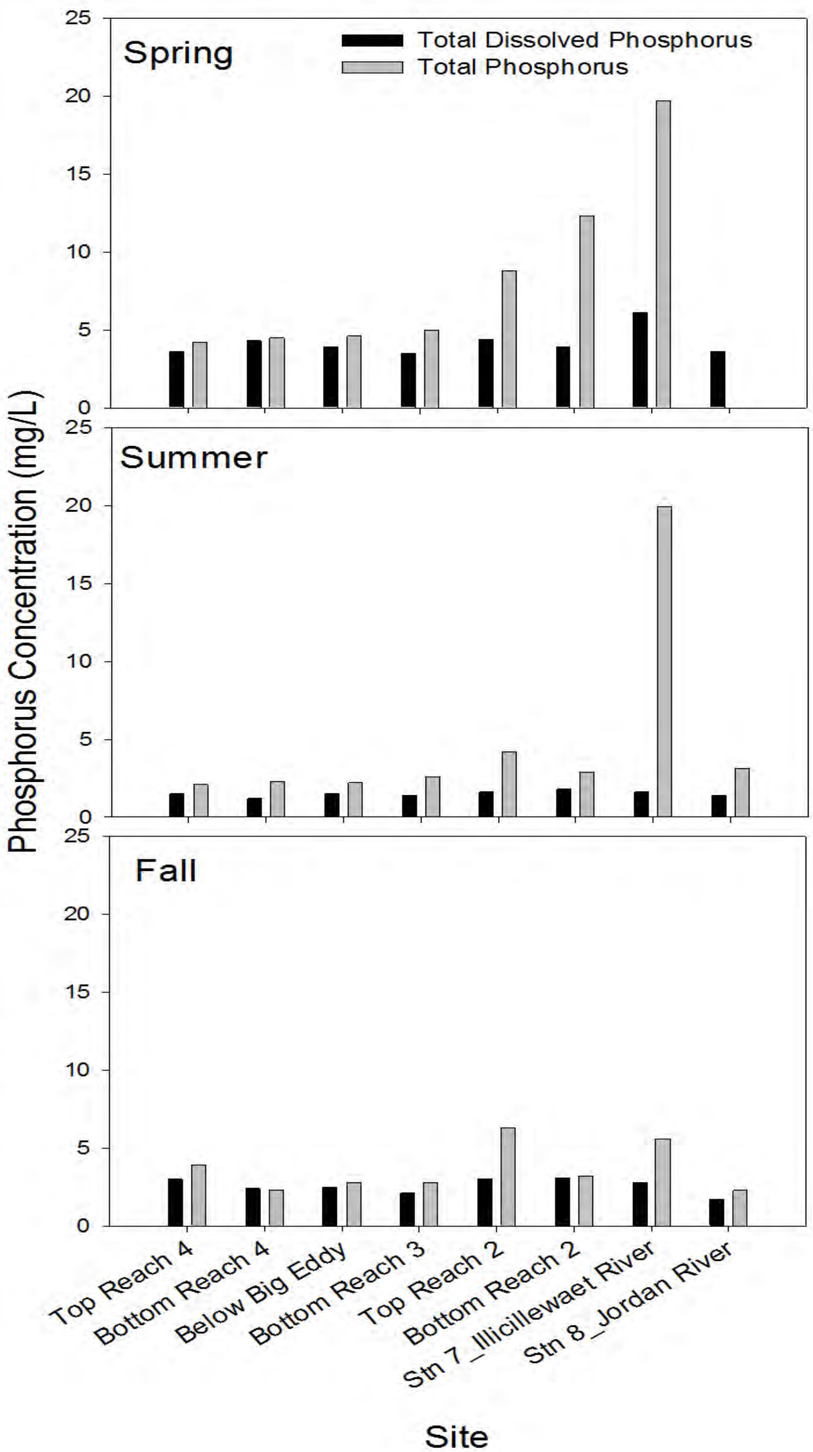

Figure 12: Total Phosphorus (TP) and Total Dissolved Phosphorus (TDP) concentrations in surface water at CLMON-15a and 15b water quality index stations on the MCR (Top Reach 4 to Bottom Reach 2), and Illecillewaet and Jordan rivers in spring (May 18), summer(August 17) and fall (October 5) 2011.

5.0 MCR PHYSICAL HABITAT DATA QA/QC AND DATABASE

Data collected within the scope of this program were entered directly (or uploaded) into the MCR Physical Habitat Database and verified to maintain a standard level of Quality Assurance/Quality Control (QA/QC) (data Attachment I). River station elevations were corrected in the database and QA/QC measures were applied for Years 1 (2007) through 5 (2011), prior to supplying the data for the CLBMON-15a HEC-RAS Model calibration. Additional QA/QC procedures include field measurements that were used to cross reference data. Examples are air and water temperatures recorded at time of site visit, which are compared with data logger readings; surface water elevations, which are measured on standpipe housing at each water elevation data logger station at time of site visit; and measuring the distance from the constant attachment point on the standpipe housing to water's surface, which can be compared with data logger sensor readings.

All raw levelogger data for this year's report were reviewed and erroneous data removed. The cleaned data were summarized in figures using Microsoft® Excel and Sigmaplot. Stage and temperature data were removed during periods of sensor dewatering; negative water level readings indicated a dewatering event. Additionally, up to one minute per one degree Celsius is required for the sensor readings to equilibrate with the true water temperature after submersion; therefore, temperature readings were discarded for the first 30-minutes post re-submersion. Issues can also arise when the sensor is near the water surface. To maintain accurate data, water levels and temperature readings were discarded when the sensor was less than 3.5 cm below the water surface. In past years, sensor data errors that were thought to be from a dewatering event were also identified by a temperature change greater than 0.5 °C, over a 10-minute period. This latter data screening qualifier was removed in 2010 because other than water level readings indicating that the sensor was dewatered or in very little water, water temperature fluctuations should be included as true data.

An electronic skeleton database (Microsoft® Access 2007) was developed to facilitate archiving time series data of key physical habitat variables measured during the monitoring program (i.e., water temperature, river stage elevation, water quality, and TGP data). External data used for the model runs were also maintained within the Physical Habitat Monitoring Database and included:

- REV discharge (10-minute and hourly);
- ALR elevation (in metres) at Nakusp;
- Station 3 (BCH's Station referred to as both 'TR2' or 'Tailrace-7km') temperature and stage data; and,
- WSC's Illecillewaet River (Station 7) stage data (i.e., hourly and daily average).

The database currently includes 24 lookup tables and 7 forms. The forms were created for data entry, while the tables were used for data queries and model runs. To calculate the water elevations from the raw stage data logger readings, a module was created within the database. The module incorporated the trigonometry calculations for elevation, applied a calculated sensor elevation to each levelogger reading (n= 1095709) and added the sensor elevation to the levelogger reading, to estimate a corrected masl water elevation record. Any changes made to a station were included in the module calculations.

CLBMON-15a HEC-RAS Model data will have to be housed in a separate database due to the volume of data. The CLBMON-15a HEC-RAS Model does not provide a lookup table in the database, as this is not possible with a dynamic model. The temporal sequence of REV flow changes and associated tributary inflows determines the predicted velocities, and depths and area at any cross-section. Consequently, these data can only be produced for a particular scenario and cannot be used for developing a database to look up the values at a particular discharge from REV and ALR elevation, without taking the temporal sequence of the flow changes into account. Therefore, operational runs of the models would be needed in the future to address issues of minimum flow combined with a particular reservoir elevation scenario for management questions of interest.

6.0 RECOMMENDATIONS FOR 2012

As indicated in the ToR, the MCR Physical Habitat Monitoring program is to consider REV 5 operations and the influence of minimum flows. However, there is a shift from the approach of the RFMP studies from a pre- vs. post-implementation of analysis to treating the effects of operations as one of several sets of continuous data, where all variations in flow regime and other habitat variables that vary during the investigations are considered in the analysis.

The following recommendations are based on the 2011 results:

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 Golder's 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. Review the ability of the HEC-RAS model calibration to meet the objectives of the program and determine if supplemental information is needed to assure accurate projections of flow impacts. 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 following key recommendations from the CLBMON-15a Model calibration (Appendix C) are:

   - Continue to define the Jordan River Stage Discharge Curve to improve the flow estimation as it is an important inflow source to the MCR during low REV discharges.

- Continue to refine Manning's "n" coefficients and channel geometry using the data from the CLBMON-20 ("Mid Columbia River White Sturgeon Spawning Habitat Assessment") and CLBMON-54: and ("Effects of Flow Changes on Incubation and Early Rearing Habitat") studies. These studies will provide an assessment of stream bed substrates within the MCR for the 2011 calibration.

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, we recommended either implementing the Winter-Kennedy method on REV 5 or performing 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.

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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.

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CC/DS/cmc

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APPENDIX A

CLBMON-15a Index Stations UTM Coordinates, and Standpipe Housing Maintenance and Measurements

Table A-1 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, 2011.

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
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]	n/a[e]
Station 7_temperature	Golder	Illecillewaet	5.6	RB	11	424199[d]	5652110[d]	n/a[e]
Station 7 Benchmark (WSC)[f]	WSC	Illecillewaet	5.6	LB	11	n/a[f]	n/a[f]	n/a[f]
Station 8	Golder	Jordon	2	LB	11	412646.391	5653277.718	n/a[e]
Station 8_2008	Golder	Jordon	6	MID	11	410947.094	5655507.170	532.59
Station 8_2011	Golder	Jordon	6	MID	11	n/a[g]	n/a[g]	n/a[g]
Station 8 Benchmark (WSC)[f]	WSC	Jordan	6	RB	11	410917.717	5655469.483	534.69
Station 8_Velocity Transect[h]	Golder	Jordon	6	RB	11	410921[d]	5655417[d]	538[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] Data not available at this time. Data will be obtained during the RTK navagational survey in 2012.

[h] 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-2 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	Total Length of Pipe (m)	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	10.85	25-Aug-07	Solinst Levelogger (M10)		10.80		2007	438.28	Standpipe housing is situated on a moderately angled slope.	Install
	10.85	15-Nov-07			10.80		2007	438.28		Yes
	12.14	10-Apr-08			12.03		2010	438.58	Galvanized standpipe housing was replaced with stainless steel housing during download.	Yes
	12.14	26-Jun-08			12.03		2010	438.58		Yes
	12.14	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
	12.14	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
	12.14	23-Jun-09			12.03		2010	438.58		Yes
	12.14	26-Oct-09			12.03		2010	438.58		Yes
	12.14	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
	12.14	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
	12.14	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
	12.14	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
	12.14	17-Aug-11			12.06		Spring 2012	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
	12.14	29-Oct-11			12.06		Spring 2012	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
Station 1_Anchor Station (AS)	0.18	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 m^3s-1) from Revelstoke Dam (REV) in Reach 4.	Install
	0.18	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
	0.18	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
	0.18	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
	0.18	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
Station 2	3.96	25-Aug-07	Solinst Levelogger (M10)		3.61		2007	438.62		Install
	3.96	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
	3.96	10-Apr-08			3.61		2007	438.27		Yes
	5.19	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
	5.19	26-Jun-08			5.13		2009	436.79		Yes
	5.19	28-Nov-08			5.13		2009	436.79		Yes
	5.19	19-Mar-09			5.12		2009	436.79	Replaced logger suspension wire with heavy duty aircraft cable.	Yes
	5.19	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
	5.19	25-Jun-09			5.12		2009	436.79		Yes
	5.28	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
	5.28	22-Oct-09			5.12		2009	436.79		Yes
	5.28	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
	5.28	17-Jun-10			5.12		2009	436.79		Yes
	5.28	5-Oct-10			5.12		2009	436.79		Yes
	5.28	27-Apr-11			5.12		2009	436.79	Installed 'Fisheries Research Please Do Not Disturb' sign.	Yes
	5.28	16-Aug-11			5.12		2009	436.79	Replaced 'Fisheries Research Please Do Not Disturb' sign.	Yes
	5.28	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
	3.96	25-Aug-07	Solinst Barologger (M1.5)		0.53		n/a	--	Barologger is positioned in standpipe housing with levelogger.	Install
	3.96	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
	5.19	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
	5.19	26-Jun-08			0.69		n/a	--		Yes
	5.19	28-Nov-08			0.69		n/a	--		Yes
	0.60	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
	0.60	16-Apr-09			0.40		n/a	--		Yes
	0.60	26-Jun-09			0.40		n/a	--		Yes
	0.60	21-Oct-09			0.40		n/a	--		Yes
	0.60	14-Apr-10			0.40		n/a	--		Yes
	0.60	17-Jun-10			0.40		n/a	--		Yes
	0.60	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
	0.60	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.	No
	0.60	24-Jun-11			0.40		n/a	--	The malfunctioning unit was repaired; the data retrieved, and was redeployed.	No
	0.60	16-Aug-11			0.40		n/a	--		Yes
	0.60	30-Oct-11			0.40		n/a	--		Yes
Station 2_Anchor Station (AS)	0.18	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
	0.18	15-Nov-10			0.06		2010	436.10	Downloaded prior to implementation of minimum flows (142 m^3s-1) from Revelstoke Dam (REV).	Yes
	0.18	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
	0.18	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

Station 4	3.96	18-Jul-07	Solinst Levelogger (M20)		3.59		2007	436.25		Install
	7.32	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
	7.32	16-Nov-07			7.32		2007	433.61		Yes
	9.20	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
	9.20	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
	9.20	24-Oct-08			9.10		2007	431.78		No
	9.20	15-Nov-08			9.10		2007	431.78		No
	9.20	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
	11.65	16-Apr-09			10.12		2009	432.23	Installed new stainless steel brackets along pipe housing with Hilti Hit epoxy, as station appeared to have been vandalized.	Yes
	11.65	25-Jun-09			10.12		2009	432.23	Added two stabilizer arms on upper section of pipe housing to increase robustness of standpipe housing.	Yes
	11.65	22-Oct-09			10.12		2009	432.23		
	11.65	14-Apr-10			10.12		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
	11.65	17-Jun-10			10.12		2009	432.23		Yes
	11.65	5-Oct-10			10.12		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
	11.65	28-Apr-11			10.12		2009	432.23		
	11.65	16-Aug-11			10.12		2009	432.23		
	11.65	29-Oct-11			10.12		2009	432.23		
	0.60	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
	0.60	18-Mar-09			0.40		n/a	--		Yes
	0.60	16-Apr-09			0.40		n/a	--		Yes
	0.60	25-Jun-09			0.40		n/a	--		Yes
	0.60	22-Oct-09			0.40		n/a	--		Yes
	0.60	14-Apr-10			0.40		n/a	--		Yes
	0.60	17-Jun-10			0.40		n/a	--		Yes
	0.60	5-Oct-10			0.40		n/a	--		Yes
	0.60	28-Apr-11			0.40		n/a	--	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
	0.60	16-Aug-11			0.40		n/a	--		Yes
	0.60	29-Oct-11			0.40		n/a	--		Yes
Station 5	3.96	18-Jul-07	Solinst Levelogger (M10)		3.53		2007	433.43		Install
	7.32	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
	7.32	15-Nov-07			7.29		2007	433.27		Yes
	9.05	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
	9.05	26-Jun-08			9.00		2007	431.90	Replaced logger suspension wire with heavy duty aircraft cable, as existing wire became kinked.	Yes
	9.05	28-Nov-08			9.00		2007	431.90		Yes
	10.18	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
	10.18	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
	10.18	22-Oct-09			10.14		2009	430.99		Yes
	10.18	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
	10.18	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
	10.18	5-Oct-10			10.14		2009	430.99		Yes
	10.18	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
	10.18	16-Aug-11			10.14		2009	430.99	Installed 'Fisheries Research Please Do Not Disturb' sign.	Yes
	10.18	29-Oct-11			10.14		2009	430.99		Yes
Station 6	3.96	17-Jul-07	Solinst Levelogger (M20)		3.87		2007	no angle		Install
	5.79	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
	5.79	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
	5.79	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
	3.96	17-Jul-07	Solinst Barologger (M1.5)		0.37		2007	no angle		Install
	5.79	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
	5.79	15-Nov-07			0.37	+0.34				Yes
	5.79	11-Apr-08			0.37				Logger could not be retrieved due to low reservoir levels.	No
	5.79	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 6_2008	12.19	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
	12.19	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
	12.19	28-Nov-08			11.98		2009	429.35		Yes
	12.19	19-Mar-09			11.98		2009	429.35		Yes
	13.44	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
	13.44	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
	13.44	26-Oct-09			13.35		2009	429.35	Need stabilizer arm below top stabilizer arm and between 2nd and 3rd access window.	Yes
	13.44	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
	13.44	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
	13.44	5-Oct-10			13.35		2009	429.35		Yes
	13.44	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
	13.44	16-Aug-11			13.35		2009	429.35		Yes
	13.44	29-Oct-11			13.35		2009	429.35		Yes
Station 8	4.27	23-Aug-07	Solinst Levelogger (M10)		4.24		2007	no angle		Install
	4.27	13-Nov-07			4.24		2007	no angle		Yes
	4.27	9-Apr-08			4.24		2007	no angle		Yes
	4.27	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
	4.27	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	1.22	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
	1.22	15-Sep-09			1.09		2010	532.59		Yes
	1.22	21-Oct-09			1.09		2010	532.59	Installed two stainless steel brackets along standpipe housing to increase robustness of standpipe housing.	Yes
	1.22	15-Apr-10			1.09		2010	532.59		Yes
	1.22	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
	1.22	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
	1.22	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	1.97	18-19-Aug-11	Solinst Levelogger (M10)		1.95	Pipe moved	Spring 2012	n.d.	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
	1.97	28-Oct-11			1.95		Spring 2012	n.d.	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

APPENDIX B

CLBMON-15a Monitoring Program Photos

Photo 1: Bottom of Station 1 standpipe housing (Reach 4) unable to capture the lowest water levels due to the absence of appropriate shoreline with vertical rock faces or steep banks. Photo taken April 27, 2011.

Photo 2: Station 2_AS (anchor system circled in red) measuring low water levels below El. 436 m. Photo taken October 30, 2011.

Photo 3: Close up of anchor system (Station 2_AS) measuring low water levels below El. 436 m. Red circle showing a welded piece of pipe that houses the data logger. Photo taken October 30, 2011.

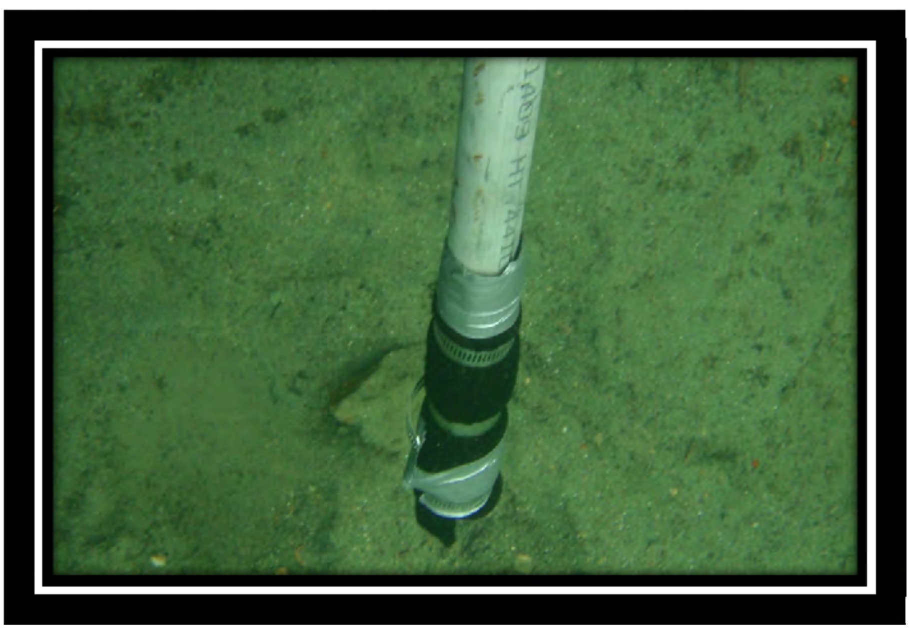

Photo 4: Bottom of Station 5 standpipe housing wrapped with geotextile material to prevent excess sediment from affecting data readings or interfering with sensor. Photo taken April 18, 2009.

Photos 5 & 6: Station 1 data logger showing a considerable amount of sediment on the data logger housing and the sensor affecting data readings. Photo taken April 27, 2011.

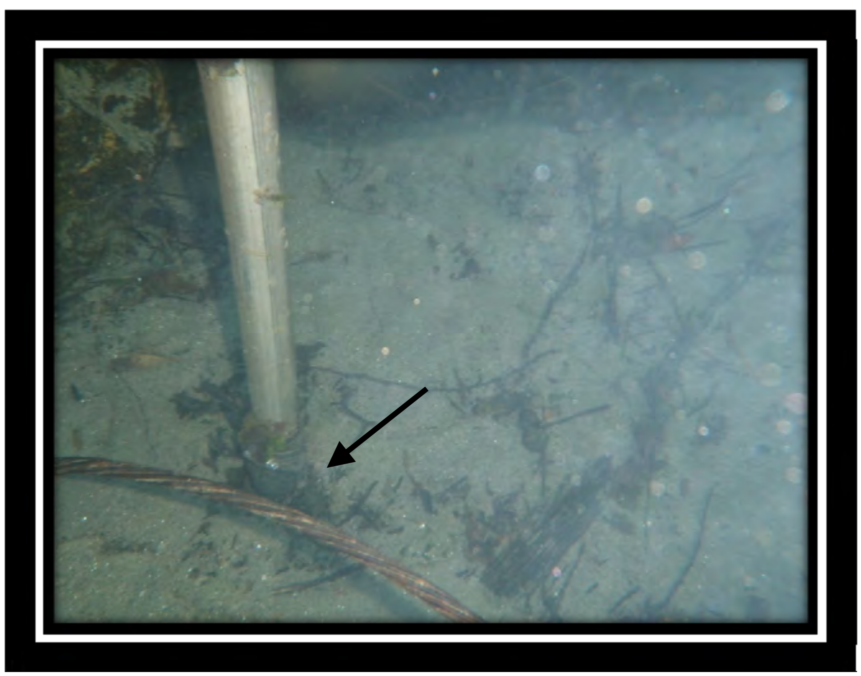

Photo 7: Changes in channel morphology at Station 8_2008 created a sand depositional area, covering the bottom of the standpipe (black arrow) and causing an influx of sand into the standpipe housing through the geotextile material. Photo taken October 28, 2010.

APPENDIX C

CLBMON-15a HEC-RAS Model Calibration and Application (2011)

TECHNICAL MEMORANDUM

DATE March 20, 2012 **PROJECT No.** 1114920084-001-TM-Rev0

TO Carissa Canning
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 Mid-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 440.2 m and 420.0 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 Mid-Columbia River. 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 and 2011 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 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 Mid 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	243 to 175	Model cross sections to be updated with these data in Year 6
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 though 5, and Station 6_2008 were used to calibrate the HEC-RAS steady state and unsteady state models. While, 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 July 2007 to December 2011, 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, 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 resulting relationship was used to estimate Akolkolex flows from Illecillewaet flows.

The 2011 CLBMON-15a HEC-RAS Model has tributary inflows at select locations. The estimated inflows were based on the relationships discussed above. The mean annual discharge for the three largest tributaries are estimated as follows:

- Jordan River 23 m^3s^{-1};
- Illecillewaet River 53 m^3s^{-1}; and
- Akolkolex River 21 m^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 Google™ 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. No profile was run for the periods where there were gaps in the measured data. The 2011 model calibration used 2011 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 0.065). The lower section of Reach 2 and the upper section of Reach 1 exhibited smaller sediments, with more sands and cobbles ("n" values of 0.02 to 0.03). 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 Mid Columbia River

Model Cross Section Range	Flow Range			
	0-200 (m^3s^{-1})	200-400 (m^3s^{-1})	400-1000 (m^3s^{-1})	Greater than 1000 (m^3s^{-1})
243-201	0.035	0.035	0.030	0.030
200-183	0.030	0.030	0.030	0.030
182-168	0.065	0.050	0.045	0.035
167-126	0.065	0.050	0.045	0.035
125-1	0.030	0.025	0.020	0.020

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 9 validation runs. The modelled water levels had a maximum difference of 0.23 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 0.11 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 Mid 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		05-Apr-2011	03-May-2011	13-Apr-2011	16-Jul-2011	21-Jan-2011	19-Dec-2010	21-Oct-2011	03-Aug-2011	04-Mar-2011
REV Dam Discharge (m^3s^{-1})		153	319	678	62	362	598	1275	1574	2005
Arrow Lakes Reservoir Level (masl)		430.6	430.6	430.6	439.1	433.9	435.1	436.5	439.3	432.7
Cross Section	Station	Observed Water Levels (masl)								
221	Station 1_AS	438.1	439.0	440.0	439.2	439.0	439.9	441.5	442.3	442.8
200	Station 2_AS	437.3	438.1	439.0	439.0	438.1	438.9	440.2	440.8	441.2
175	Station 3	435.9	436.4	437.1	439.1	436.4	437.1	438.2	439.8	439.1
150	Station 4	433.9	434.5	435.1	439.0	434.6	435.5	437.0	439.4	436.8
129	Station 5	431.5	432.0	432.7	439.1	434.0	435.1	436.7	439.4	434.7
111	Station 6_2008	430.8	430.8	431.2	439.1	433.9	435.1	436.6	439.4	433.7
Cross Section	Station	Modelled Water Levels (masl)								
221	Station 1_AS	438.0	438.9	440.1	439.2	439.1	439.8	441.5	442.2	442.8
200	Station 2_AS	437.4	438.1	439.2	439.1	438.3	439.0	440.3	441.0	441.3
175	Station 3	435.7	436.3	437.2	439.1	436.4	437.1	438.2	439.8	438.9
150	Station 4	433.8	434.4	435.2	439.1	434.8	435.7	437.1	439.4	437.0
129	Station 5	431.3	431.8	432.6	439.1	434.0	435.2	436.6	439.3	434.5
111	Station 6_2008	430.8	431.0	431.4	439.1	433.9	435.1	436.6	439.3	433.5
Cross Section	Station	Modelled Water Levels minus Observed Water Levels (m)								
221	Station 1_AS	-0.1	-0.1	0.0	0.0	0.1	-0.1	-0.0	-0.1	-0.0
200	Station 2_AS	0.0	-0.0	0.1	0.1	0.2	0.0	0.1	0.2	0.1
175	Station 3	-0.2	-0.2	0.1	0.0	-0.0	-0.0	-0.1	-0.0	-0.2
150	Station 4	-0.1	-0.1	0.1	0.1	0.1	0.2	0.1	-0.0	0.2
129	Station 5	-0.1	-0.2	-0.1	0.0	0.0	0.0	-0.1	-0.0	-0.2
111	Station 6_2008	0.0	0.2	0.2	0.0	-0.0	0.0	-0.1	-0.0	-0.2

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 "Greater than 1000 (m^3s^{-1})" values presented in Table 7 below. Lower "n" values adversely affected the timing of the dynamic flow changes so where not used.

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

Model Cross Section Range	Manning's "n"
243-201	0.030
200-183	0.030
182-168	0.035
167-126	0.035
125-1	0.020

Four validation runs were performed for the unsteady state model. A low ALR level (430.6 masl), a medium-low ALR level (433.6 masl), a medium-high ALR level (437.0 masl), and a high ALR level (439.2 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 1.05 m between observed and measured water levels and an average difference of -0.10 m. Modelled water levels are generally lower than observed water levels (see Figure 5).

For medium-low ALR levels, the unsteady model has a maximum difference of 0.97 m between observed and measured water levels and an average difference of -0.09 m. Modelled water levels are generally lower than observed water levels (see Figure 6).

For medium-high ALR levels, the unsteady model has a maximum difference of -1.02 m between observed and measured water levels and an average difference of -0.02 m. Modelled water levels at Station 1_AS are, on average, lower than measured levels. However, the difference between modeled and measured water elevations is negligible in the remaining stations (see Figure 7).

For High Arrow Lakes Reservoir levels, the model has a maximum difference of -0.57 m between observed and measured water levels and an average difference of -0.01 m. Modelled water levels are, on average the same as measured levels for all stations (see Figure 8).

Overall, the unsteady modelled flows mimic the peaks and timing of the measured water levels. Although there is a maximum difference of 1.05 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 -0.3 m and 0.1 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 Mid 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	Lower bound (m)	-0.5	-0.2	-1.0	-0.3	-0.6	-0.1
	Upper Bound (m)	0.6	0.7	1.0	0.3	0.1	0.2
	Average Difference (m)	-0.1	0.1	-0.3	-0.1	-0.3	0.1
Medium-Low	Lower bound (m)	-0.5	-0.3	-1.0	-0.4	-0.2	-0.2
	Upper Bound (m)	0.4	0.3	1.0	0.2	0.1	0.1
	Average Difference (m)	-0.1	0.0	-0.2	-0.1	0.0	0.0
Medium High	Lower bound (m)	-0.5	-0.2	-1.0	0.0	-0.1	-0.1
	Upper Bound (m)	0.2	0.3	0.9	0.1	0.1	0.1
	Average Difference (m)	-0.2	0.0	0.0	0.1	0.0	0.0
High	Lower bound (m)	-0.5	-0.2	-0.6	-0.1	-0.1	-0.1
	Upper Bound (m)	0.3	0.3	0.5	0.2	0.1	0.1
	Average Difference (m)	-0.1	0.0	0.0	0.0	0.0	0.0
Summary	BIAS(m)	-0.1	0.0	-0.1	0.0	-0.1	0.0
	RMSE (m)	0.3	0.1	0.3	0.2	0.3	0.1

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 Mid 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 was 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 Mid Columbia River from Revelstoke Dam to the Alkokolex River at Zero and Minimum Discharge

Reach	Wetted Riverbed Area during 142 m^3s^{-1} flow and low ALR Levels (m^2)	Wetted Riverbed Area during 8.5 m^3s^{-1} flow and low ALR Levels (m^2)	Change in Wetted Area (m^2)
Reach 4 (cross sections 243 to 183)	709,540	460,110	249,430
Reaches 3, 2, and 1 (cross sections 182 to 1)	7,892,120	5,821,650	2,070,470
Total Area	8,601,660	6,281,760	2,319,900
Sub-Reach 2 (cross sections 75 to 55)[1]	1,400,670	1,004,440	396,230

Note:

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

The estimated total wetted riverbed area increases by approximately 37% 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 396,000m^2 of the total surface area change, or roughly 17%.

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 0.2 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:

- Review the ability of the CLBMON-15a HEC-RAS model calibration to meet the objectives of the program and determine if supplemental information is needed to assure accurate projections of flow impacts. 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.

- To continue to refine the model calibration process, it is recommended that effort be focussed on:
  - Continue to define the Jordan River Stage Discharge Curve to improve the flow estimation as it is an important inflow source to the MCR during low REV discharges.
  - Continue to refine Manning's "n" coefficients and channel geometry using the data from the CLBMON-20 ("Mid Columbia River White Sturgeon Spawning Habitat Assessment") and CLBMON-54: and ("Effects of Flow Changes on Incubation and Early Rearing Habitat") studies. These studies will provide an assessment of stream bed substrates within the MCR for the 2011 calibration.
- 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.

Finally, to reflect fish habitat and annual productivity accurately, the model should be run over a full year to predict the potential impact of minimum flow on available productive benthic habitat. We recommend that model scenarios or data sets for a full annual run be selected for future modelling exercises to predict wetted riverbed area under observed or hypothetical future flow regimes and operational scenarios of interest.

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.

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Attachments: Figures 1 – 13

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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

Golder Associates
Greater Vancouver Office, B.C.

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		

REFERENCE

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

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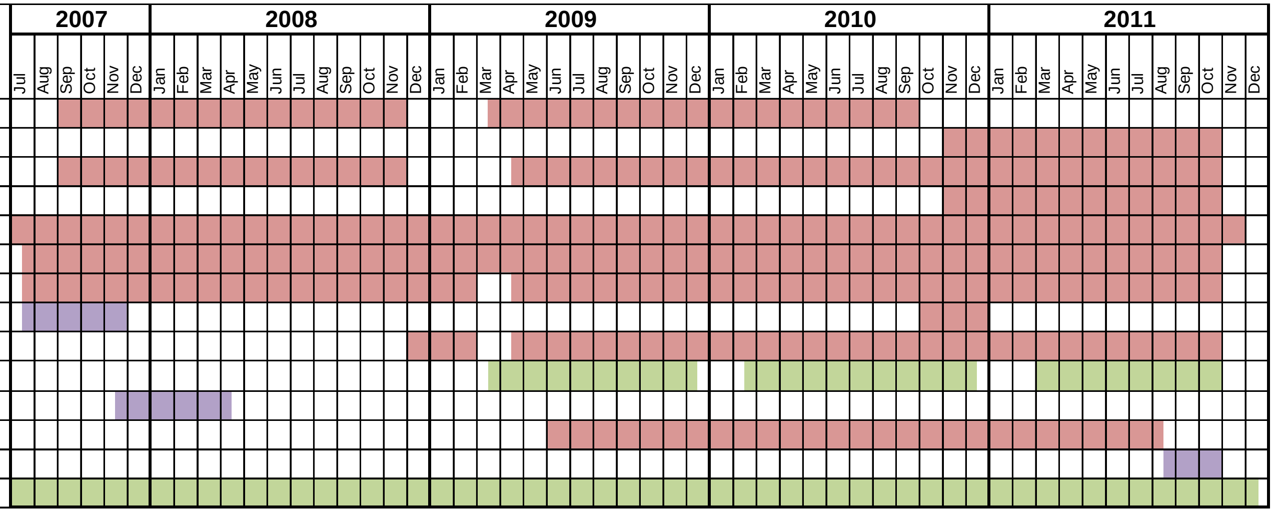
Station	Alternative Station	Maintained By
Station 1		Golder
Station 1_AS		Golder
Station 2		Golder
Station 2_AS		Golder
Station 3	Tailrace 2	BC Hydro
Station 4		Golder
Station 5		Golder
Station 6		Golder
Station 6_2008		Golder
Station 7	Illecillewaet River	Water Survey Canada
Station 8		Golder
Station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

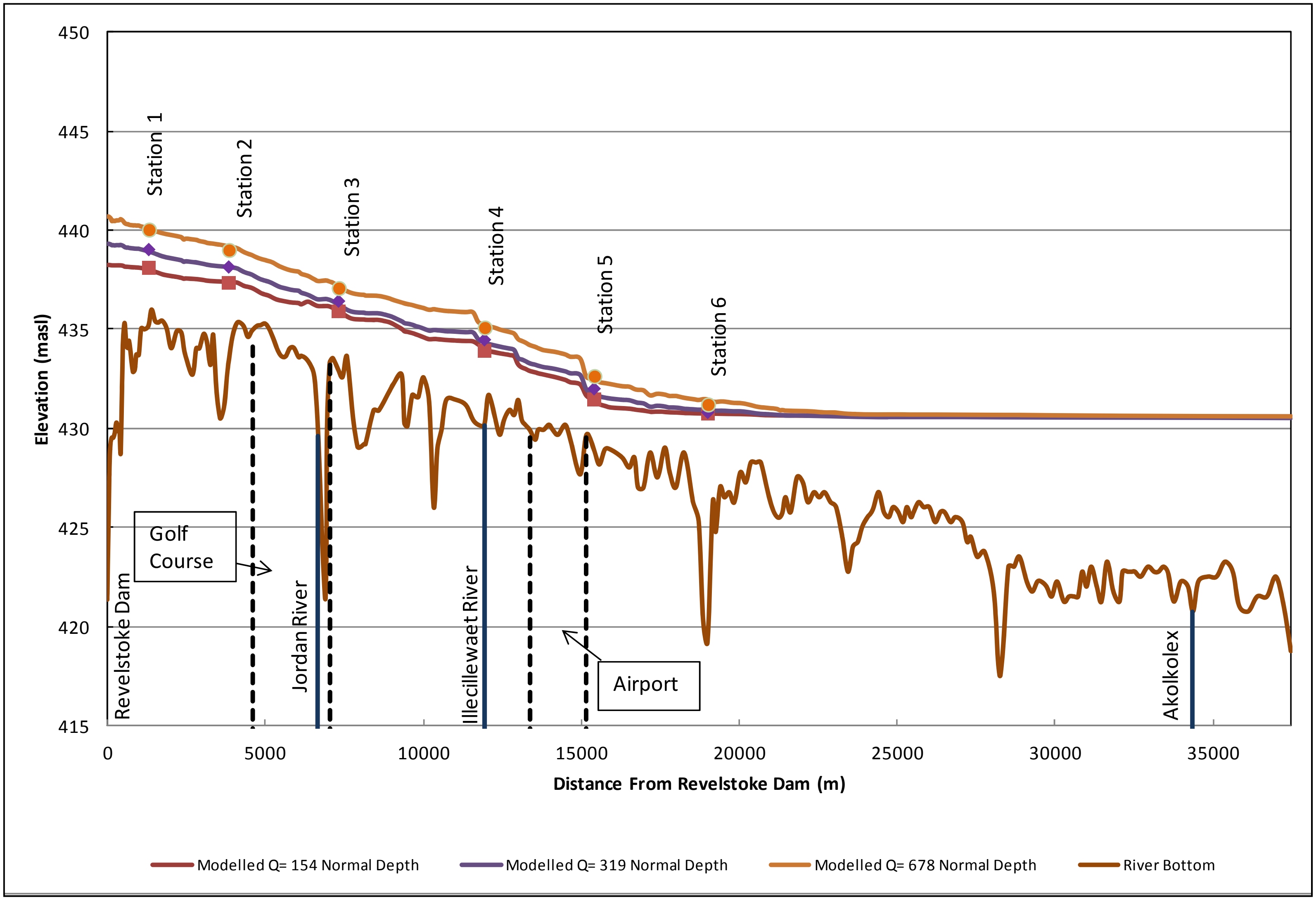
PROJECT
BC HYDRO
CLBMON-15a MID COLUMBIA RIVER
PHYSICAL HABITAT MONITORING

TITLE
Hydrometric Station Data Availability

Golder Associates

PROJECT No.	11-1492-0084		PHASE No. 5000	
DESIGN	MLP	22FEB12	SCALE NTS	REV. 1
CADD	MLP	22FEB12	**FIGURE 2**	
CHECK	MLP	22FEB12		
REVIEW	DRW			

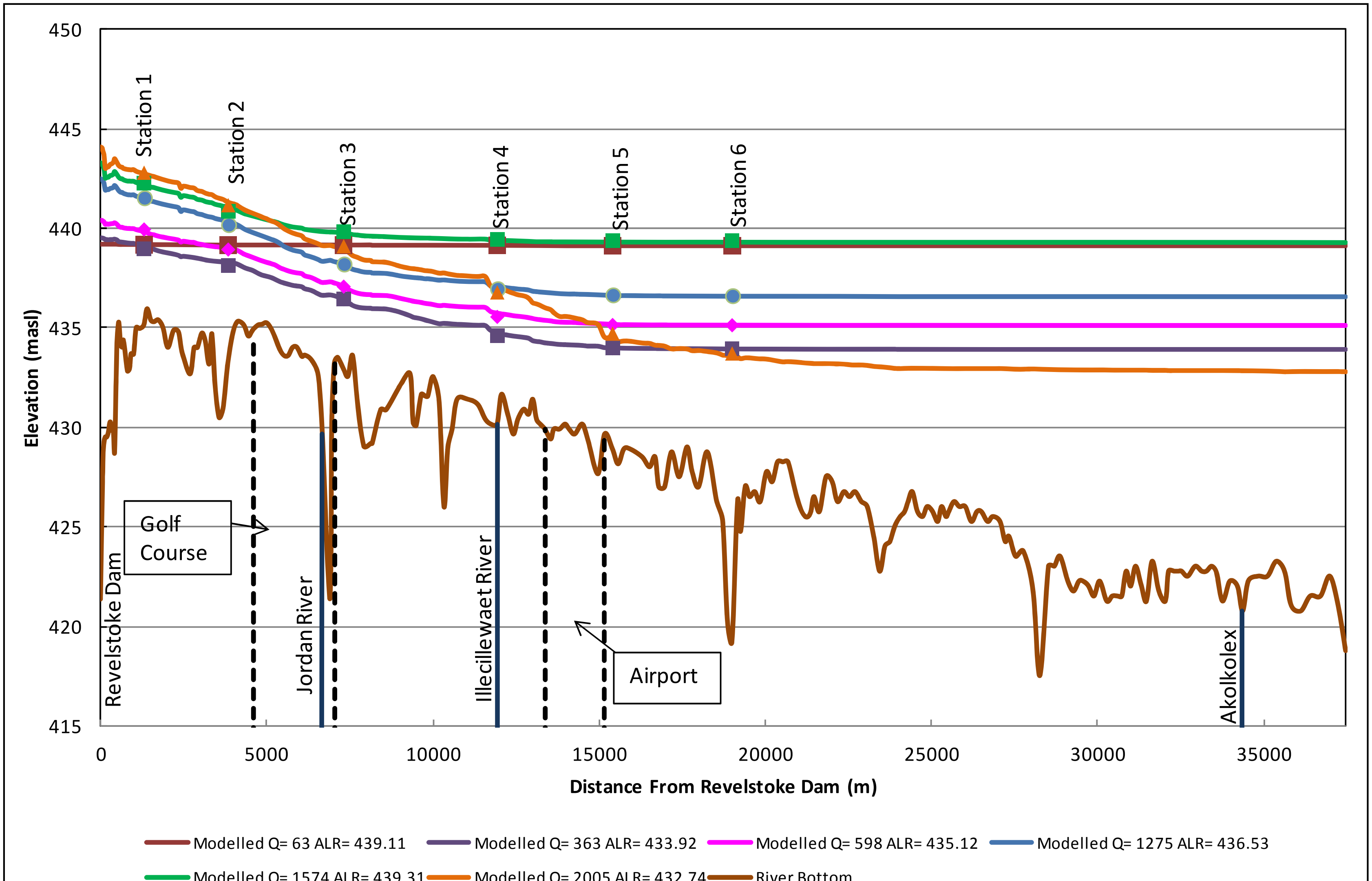
FILE:O:\Active_2010\1492 - Kamloops\10-1492-0084 BCH REV Physical Habitat Monitoring Program\Report\Figures 2-12



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



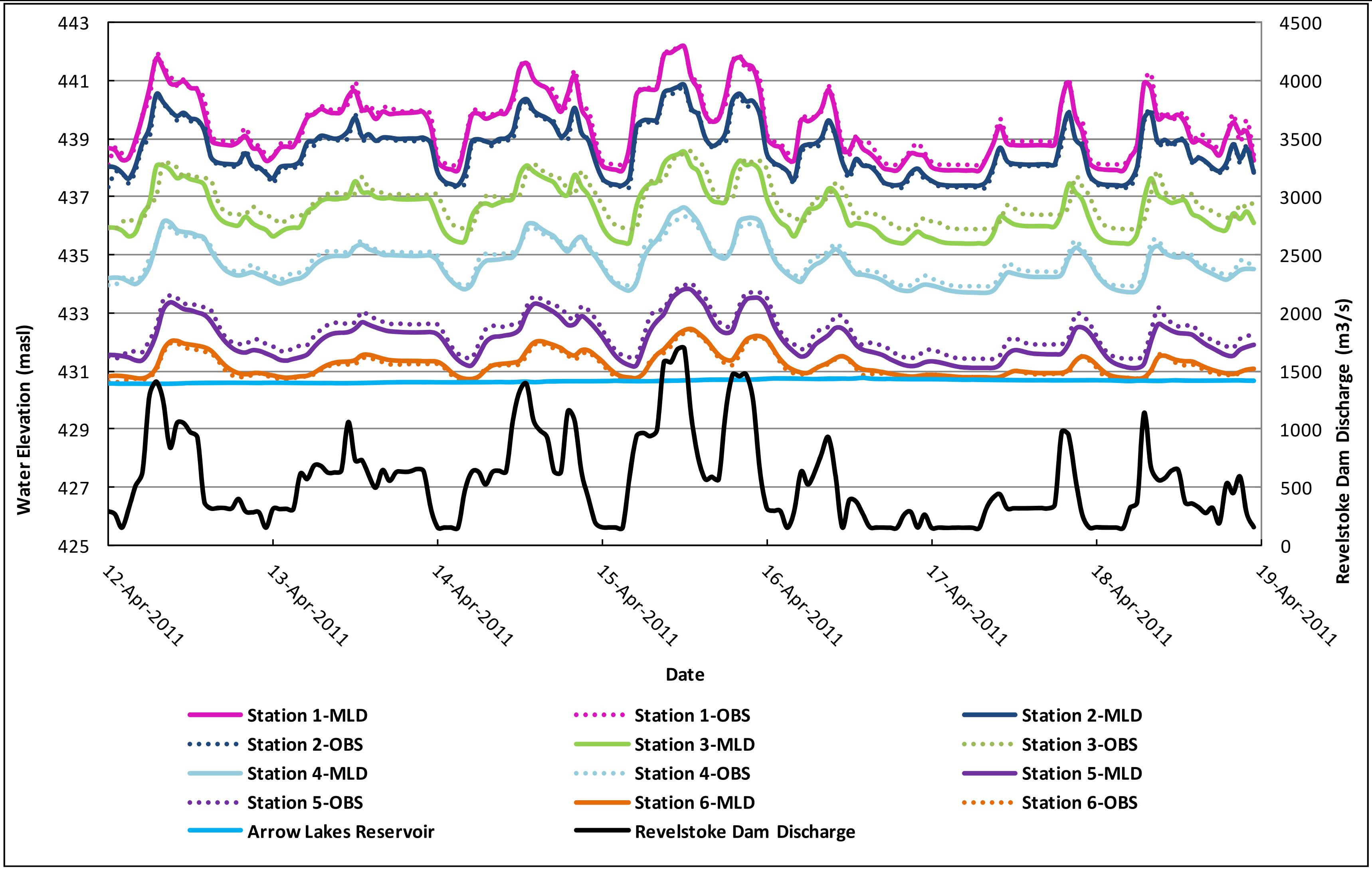
PROJECT
BC HYDRO
CLBMON-15a MID COLUMBIA RIVER
PHYSICAL HABITAT MONITORING

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 12-18, 2011 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	

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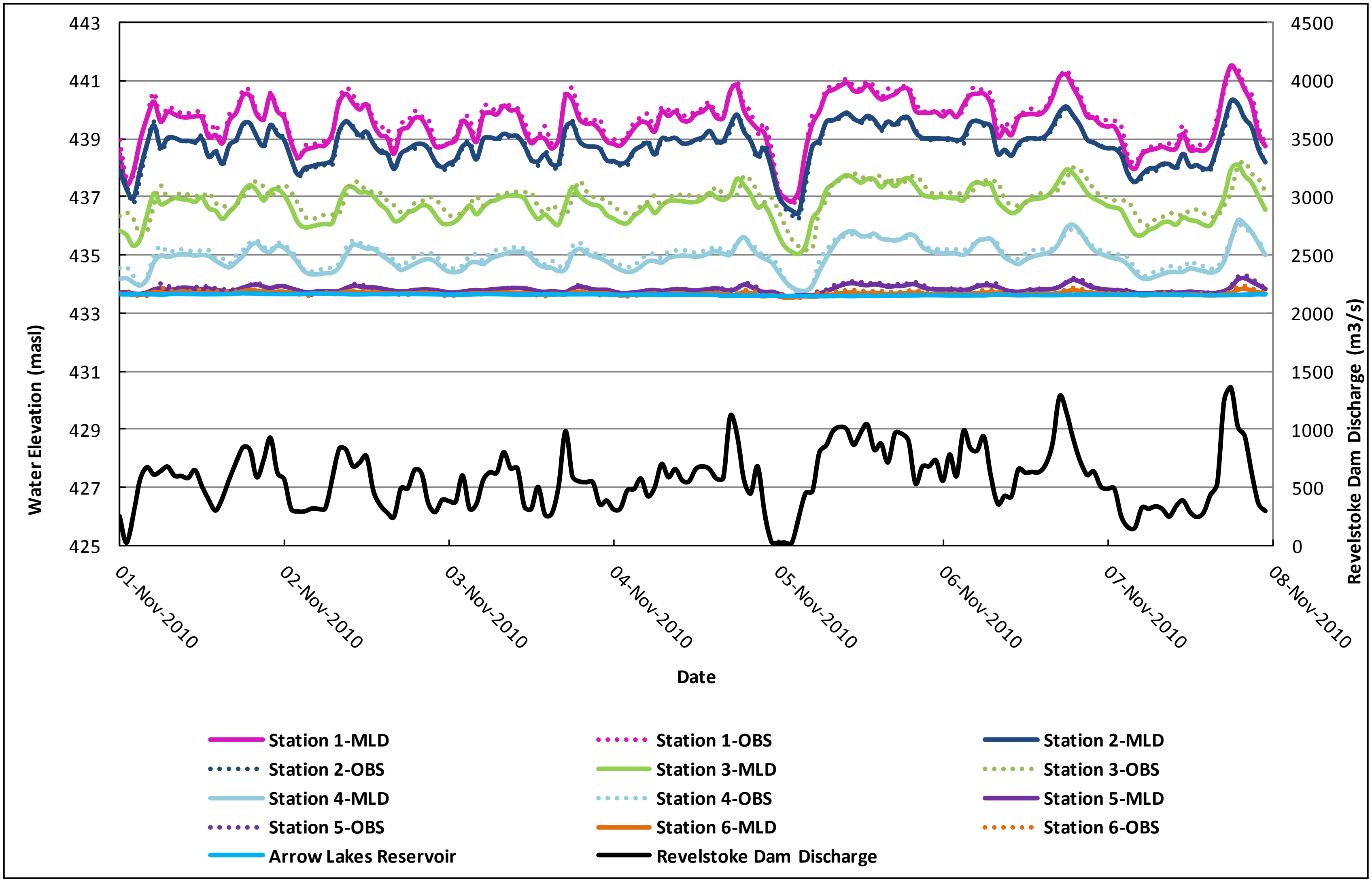


* Notes

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

PROJECT

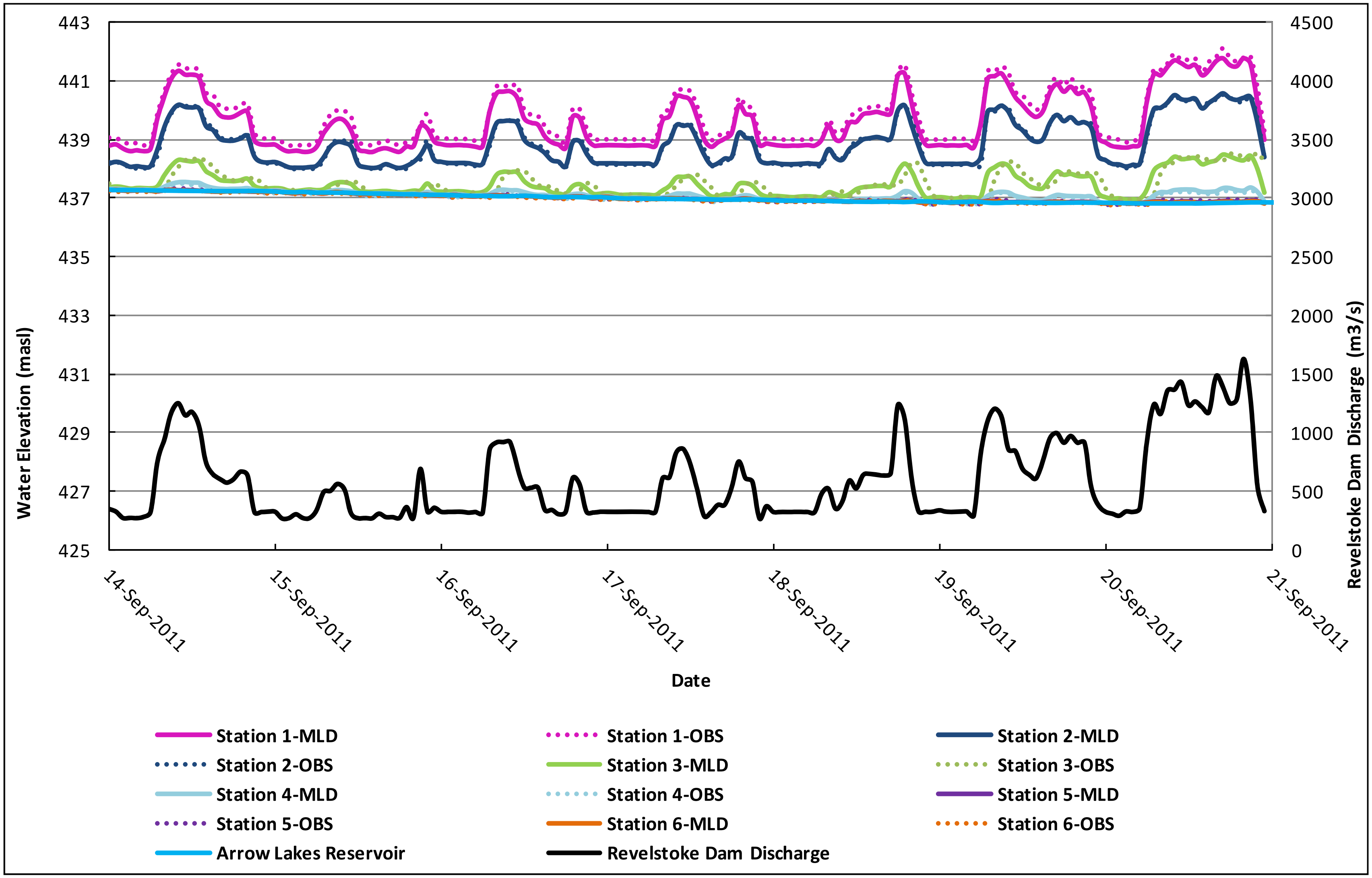
BC HYDRO
CLBMON-15a MID COLUMBIA RIVER
PHYSICAL HABITAT MONITORING

TITLE

Mid Columbia River Profile
Unsteady Flow-Validation November 1-7, 2010
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			

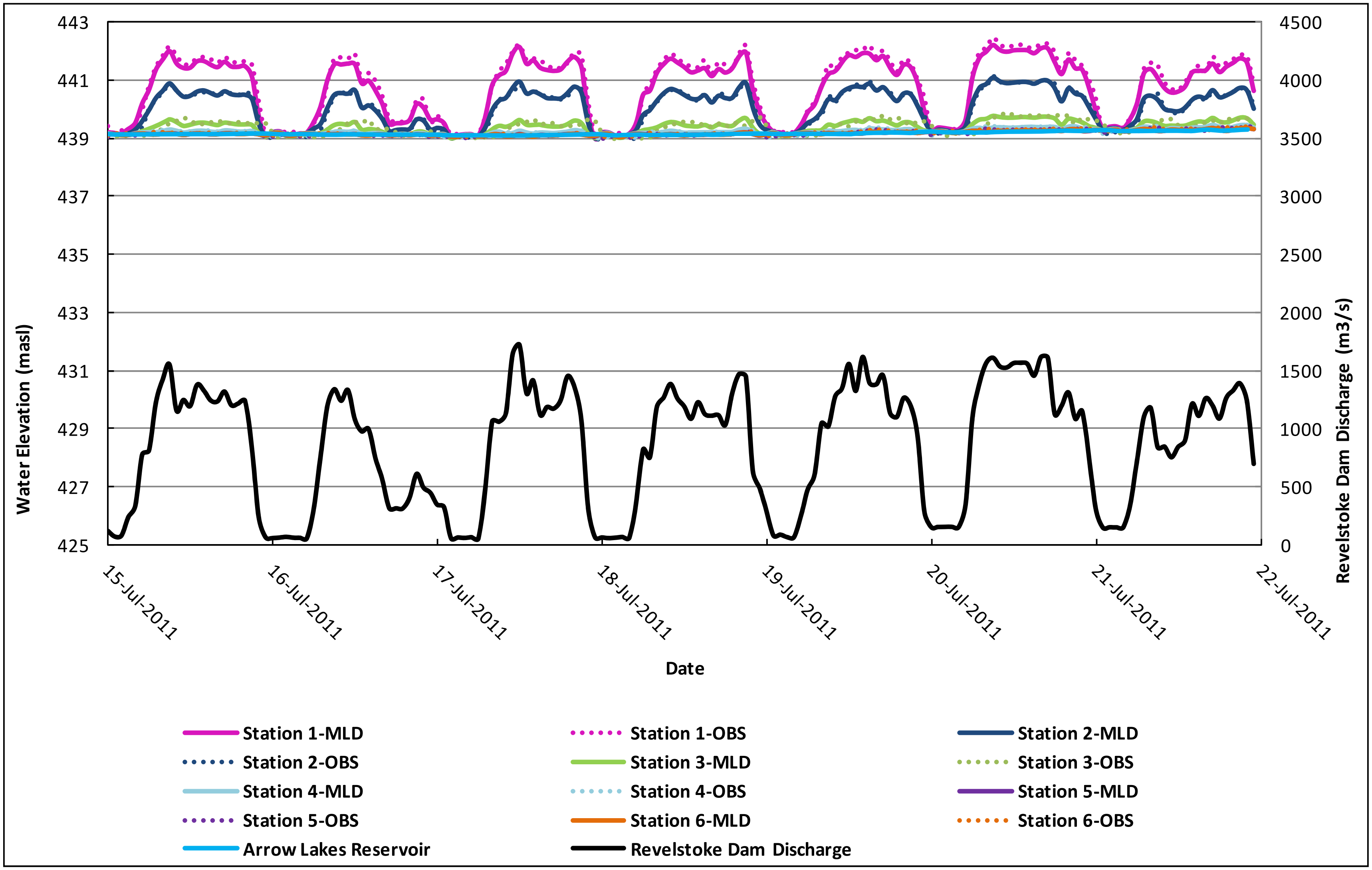


* Notes

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			



* Notes

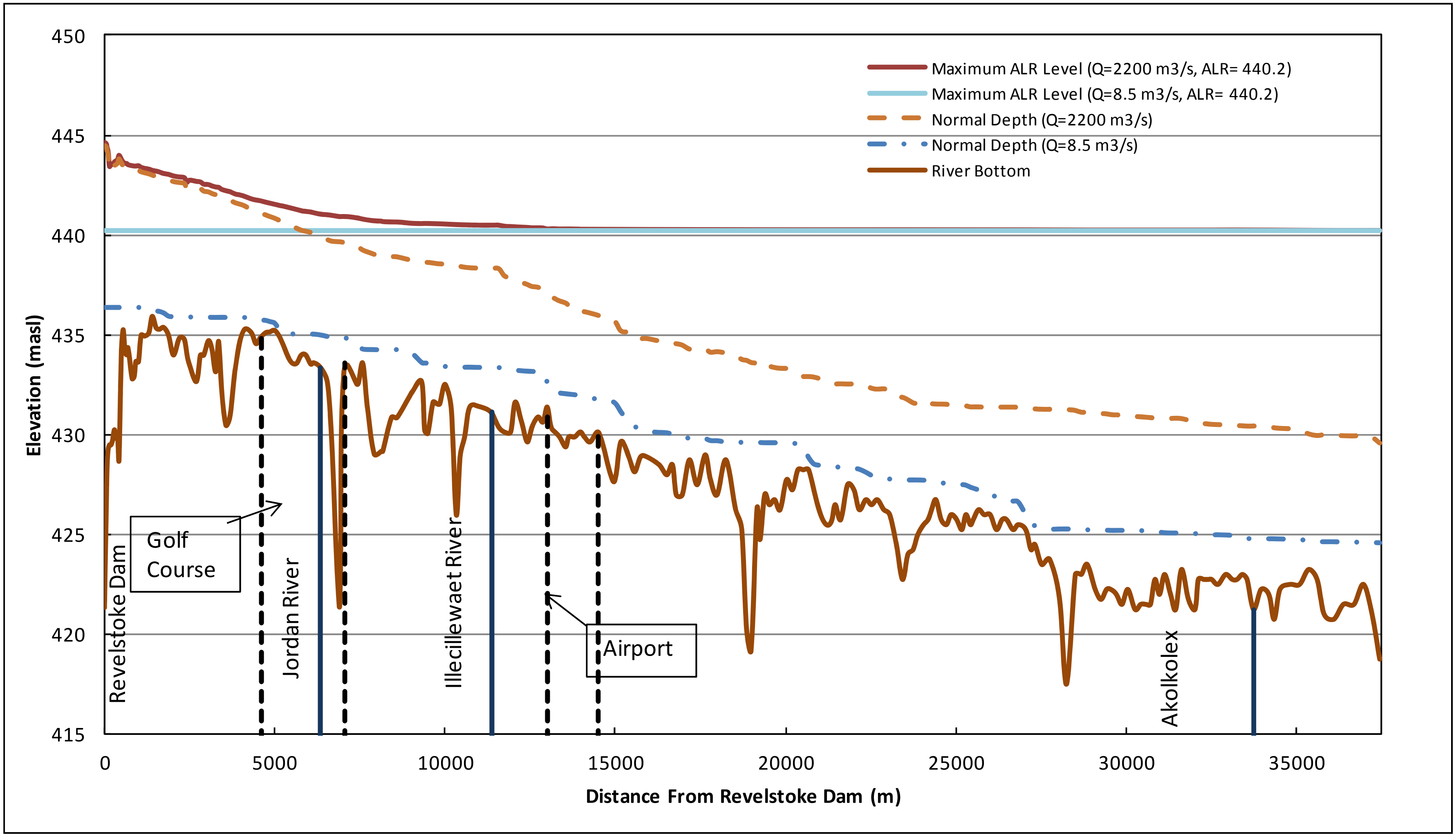
1. Solid lines are modelled (MLD) water elevations, dashed lines are observed (OBS) water elevations

PROJECT	**BC HYDRO** **CLBMON-15a MID COLUMBIA RIVER** **PHYSICAL HABITAT MONITORING**
TITLE	**Mid Columbia River Profile** **Unsteady Flow-Validation July 15-22 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		

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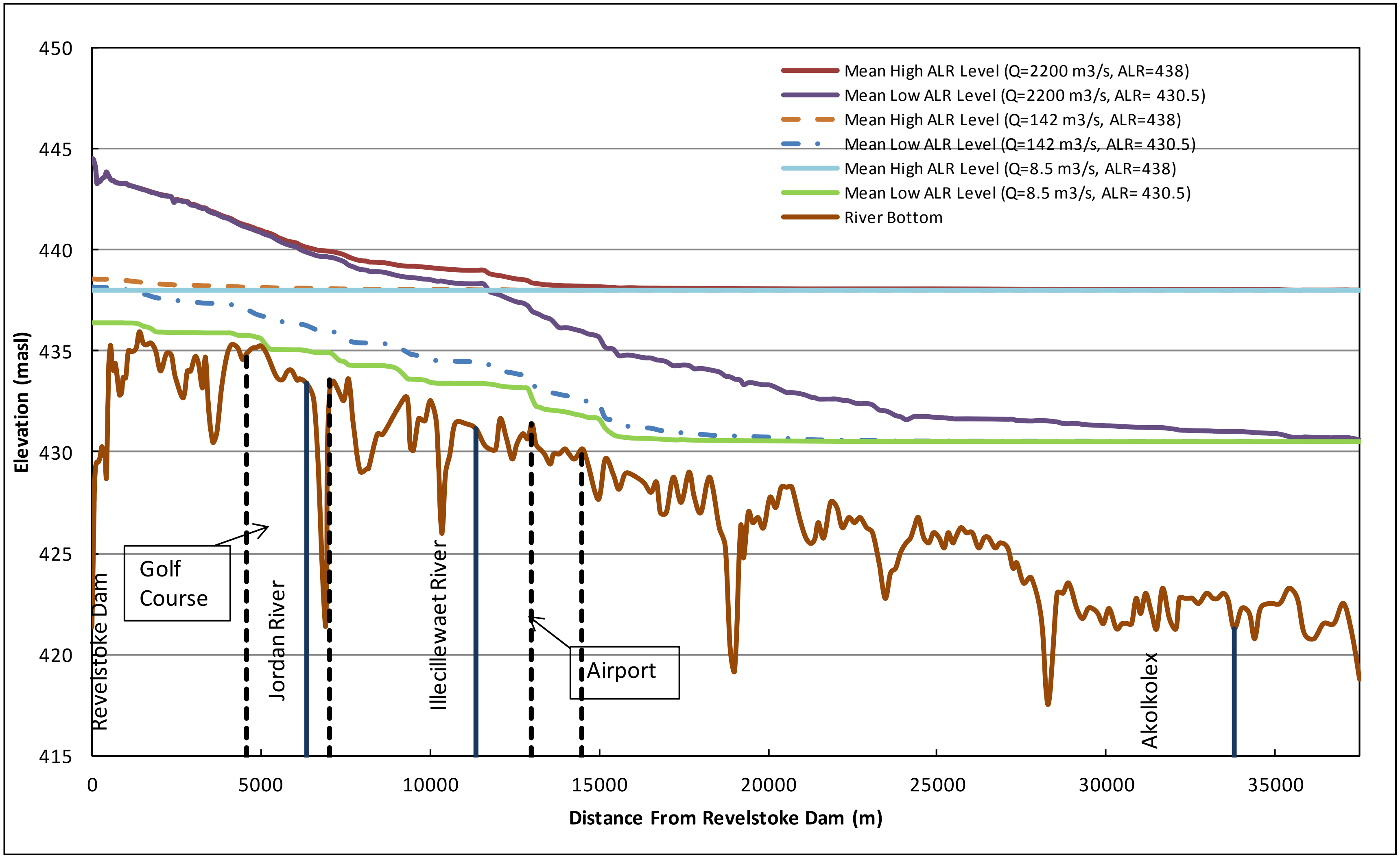

PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING
TITLE	Mid Columbia River Profile Steady Flow-Results June-August with Mean ALR Levels

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			

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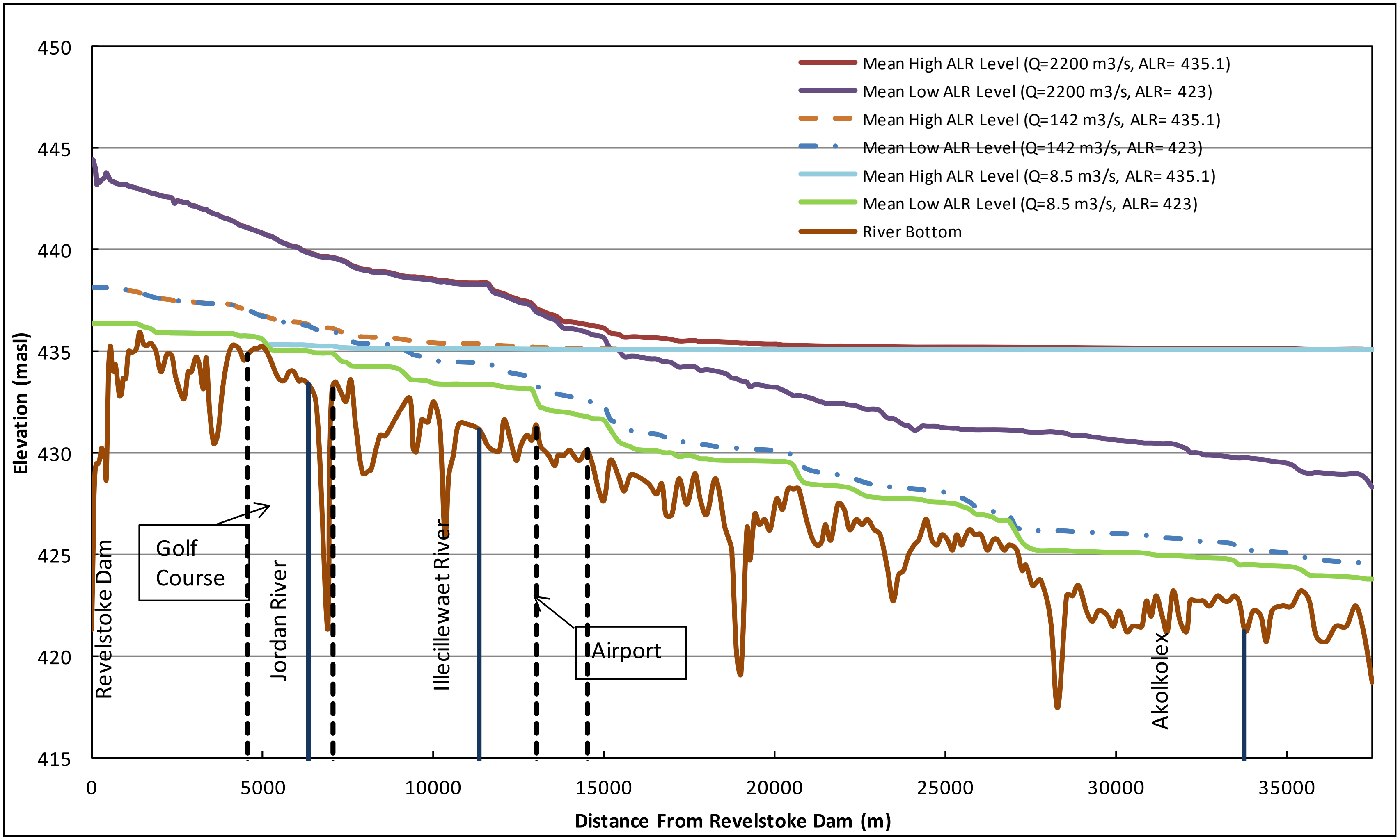

PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING
TITLE	**Mid Columbia River Profile Steady Flow-Results November to February with Mean ALR Levels**

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		

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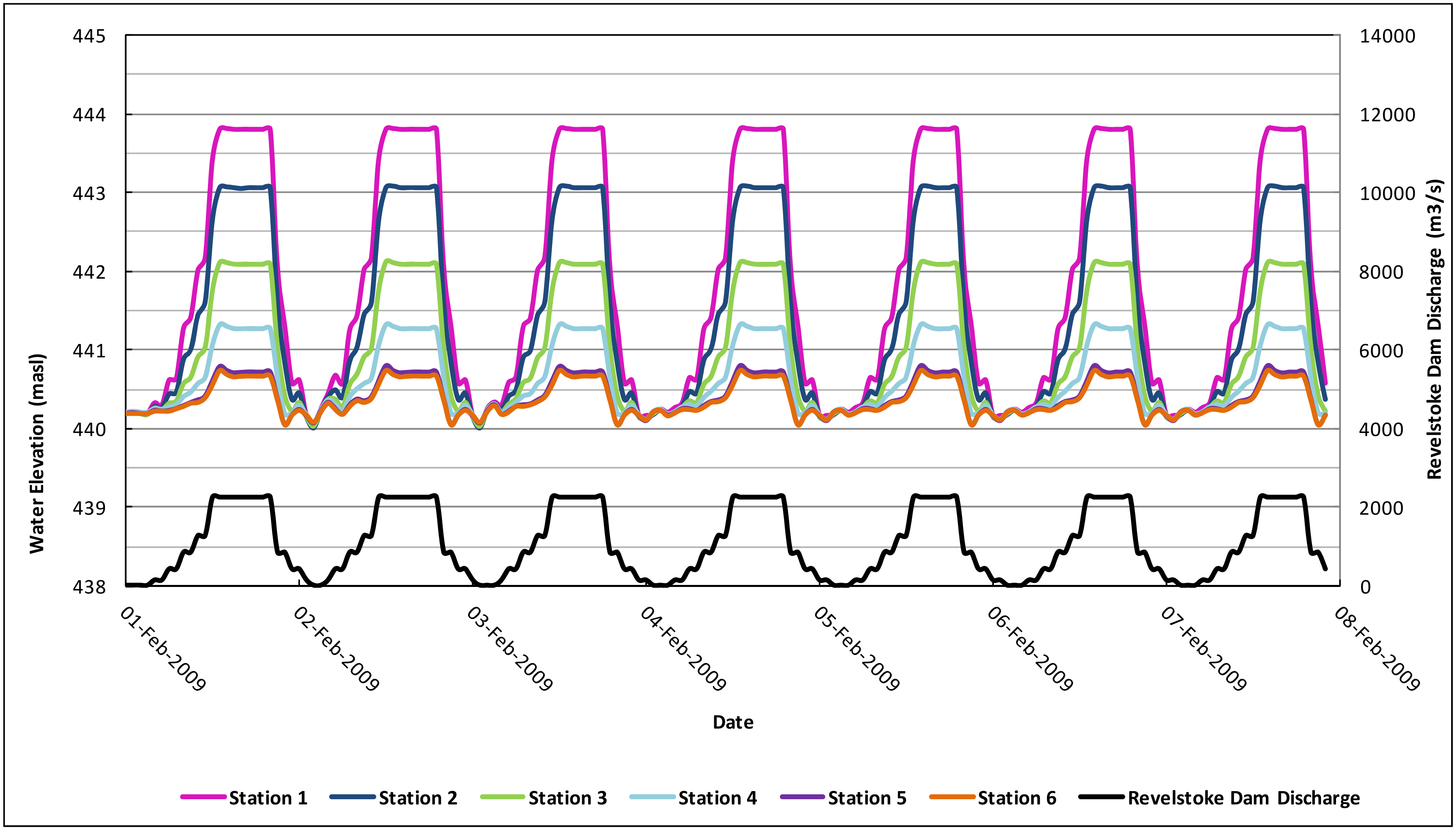

PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING
TITLE	Mid Columbia River Profile Unsteady Flow-Results ALR 440.2 m Downstream Boundary

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			

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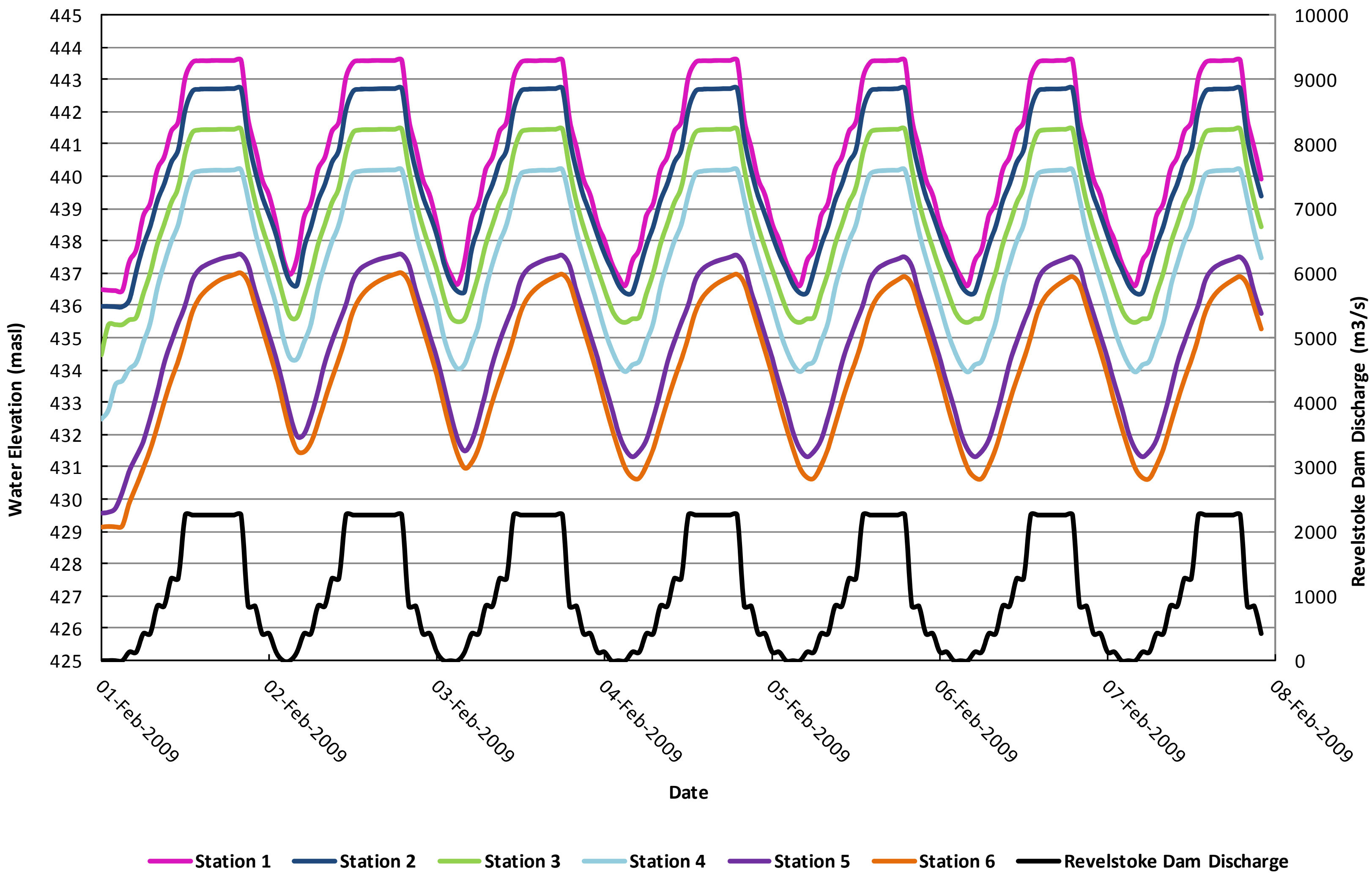


PROJECT	BC HYDRO CLBMON-15a MID COLUMBIA RIVER PHYSICAL HABITAT MONITORING				
TITLE	Mid Columbia River Profile Unsteady Flow-Results Normal Depth Downstream Boundary				
Golder Associates Greater Vancouver Office, B.C.	PROJECT No.	11-1492-0084		PHASE No. 5000	
	DESIGN	MLP	13MAR12	SCALE NTS	REV. 1
	CADD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

APPENDIX D

Water Temperature and River Stage Data Logger Availability (2010-2011)

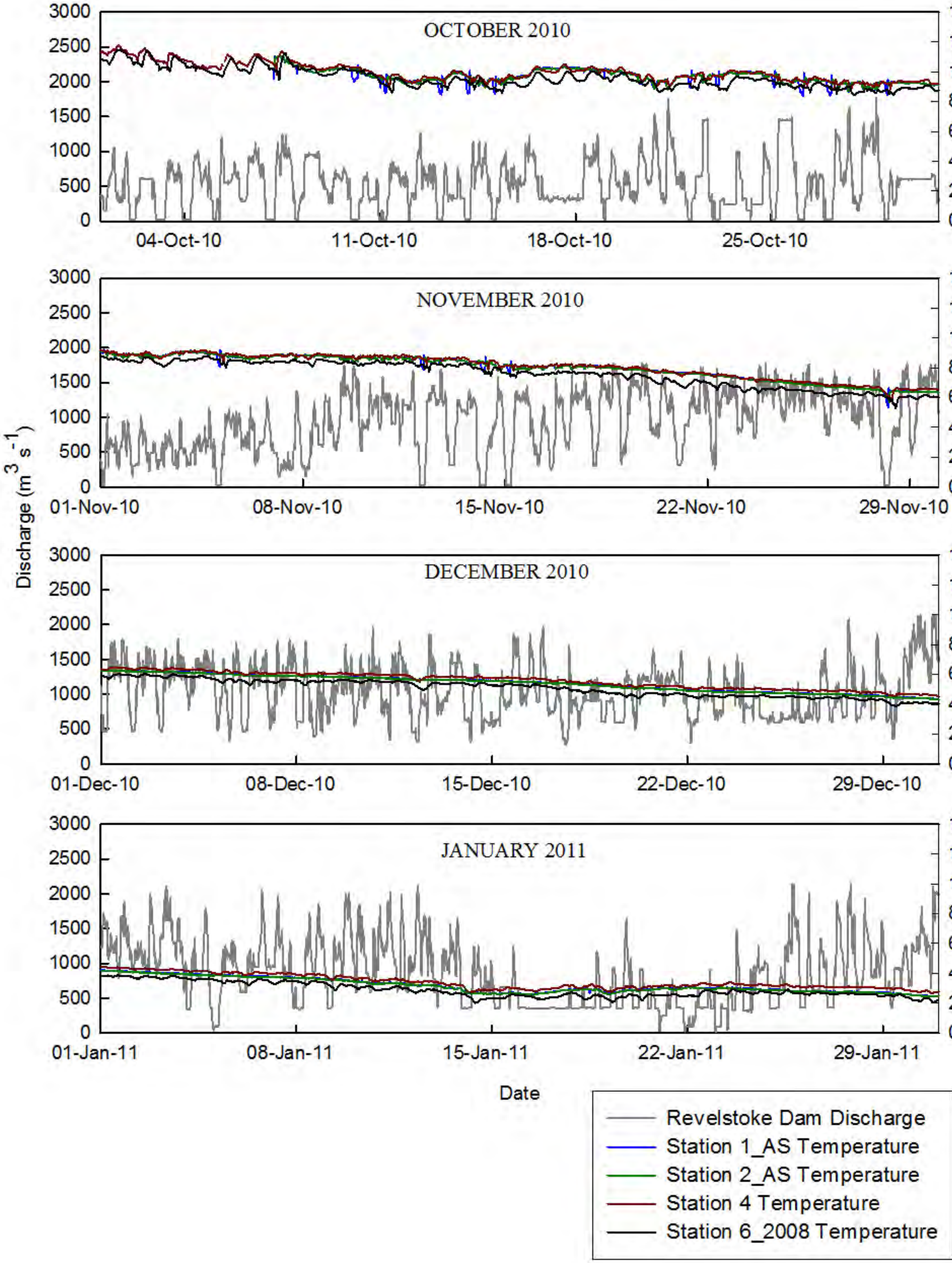
Table D-1 **Data Availability for Years 2010, 2011 for CLBMON-15a Physical Habitat Monitoring Program stage and water temperature index stations on the middle Columbia River near Revelstoke, BC.**

CLBMON-15a Site Designation	Alternative Station Reference	Maintained By	Data	2010 Monitoring Year												2011 Monitoring Year											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

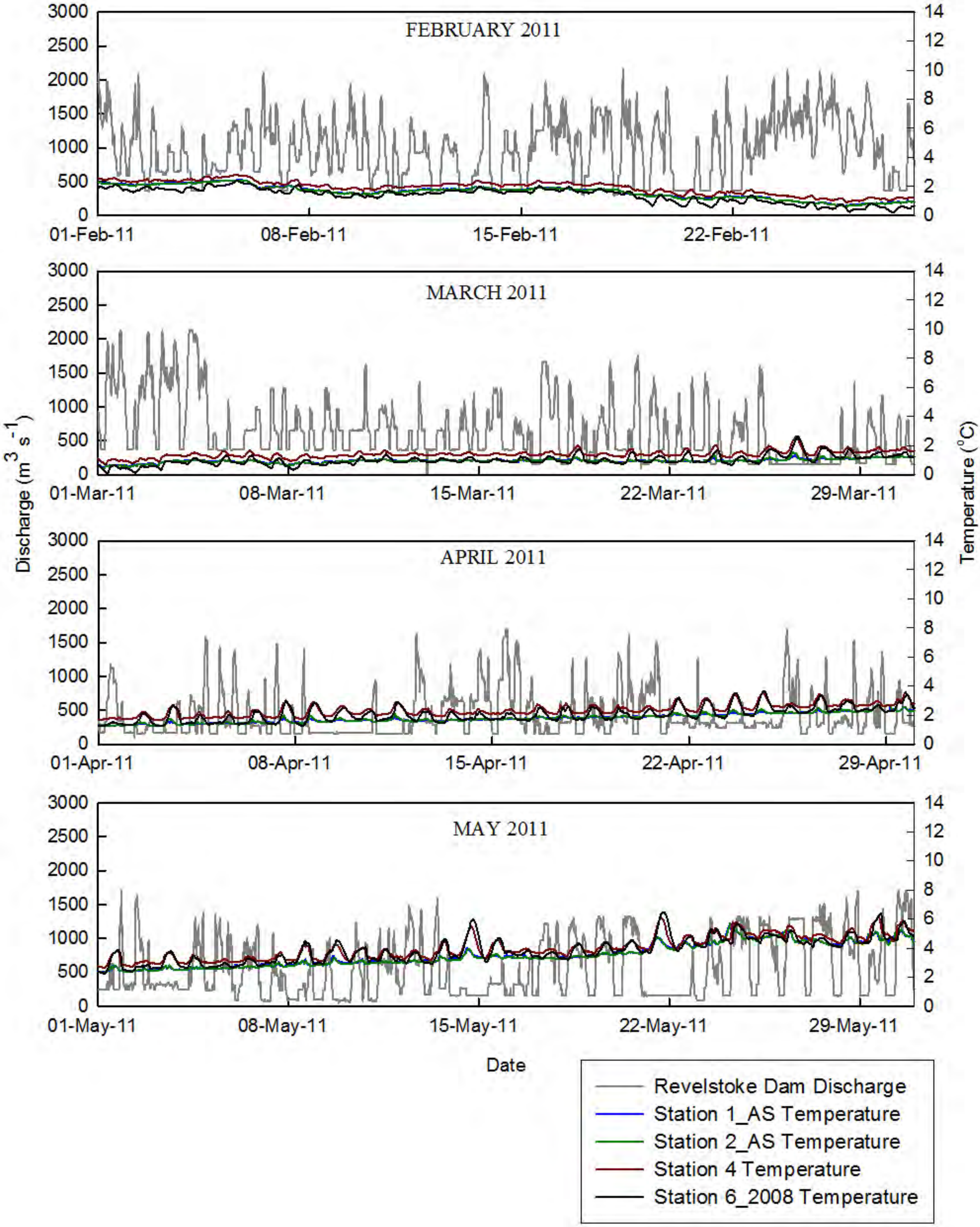
(blue)	Temperature Data
(red)	Water Elevation in Geodatic Datum
(purple)	Water Elevation in Local Datum
(green)	Discharge Data

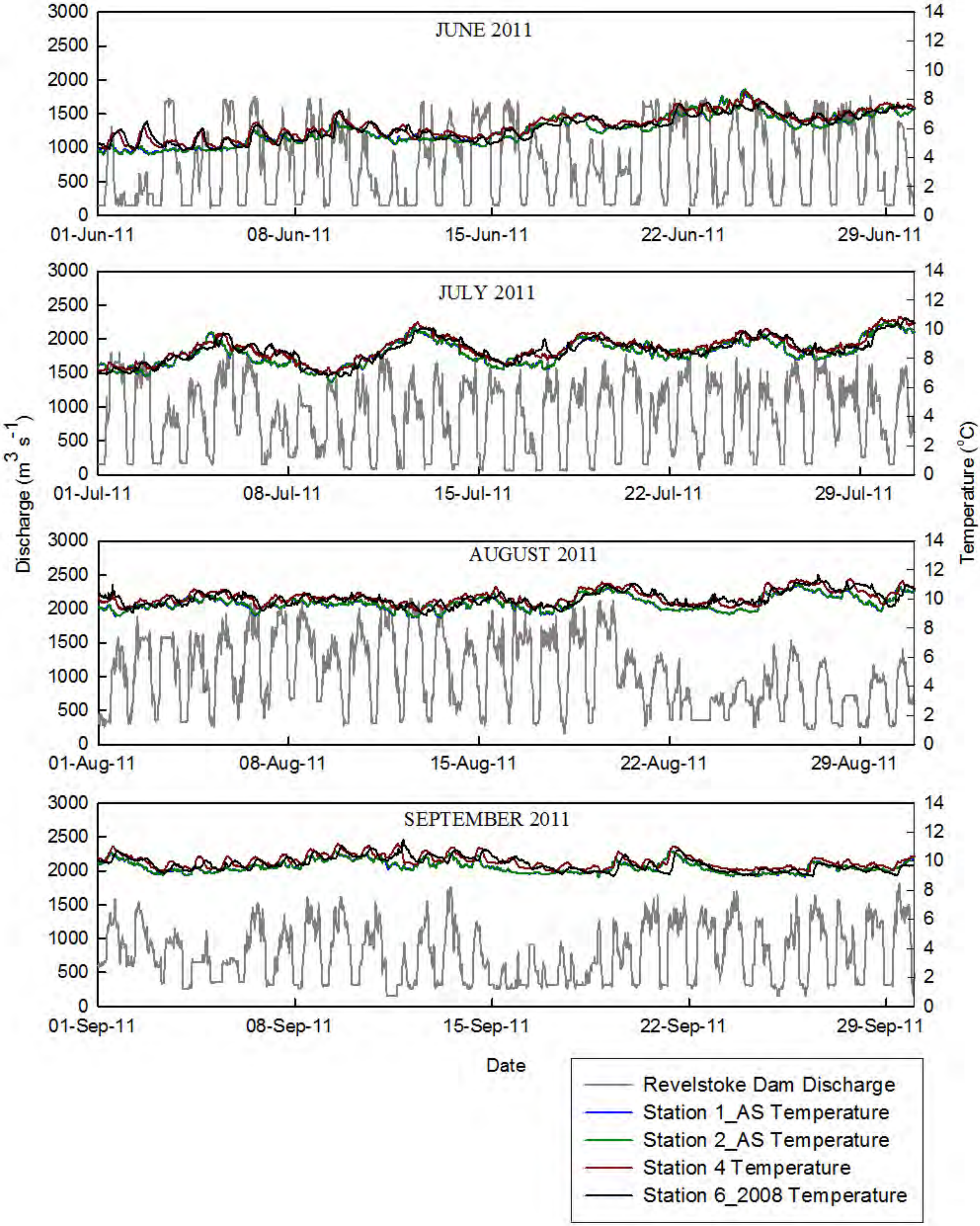
APPENDIX E

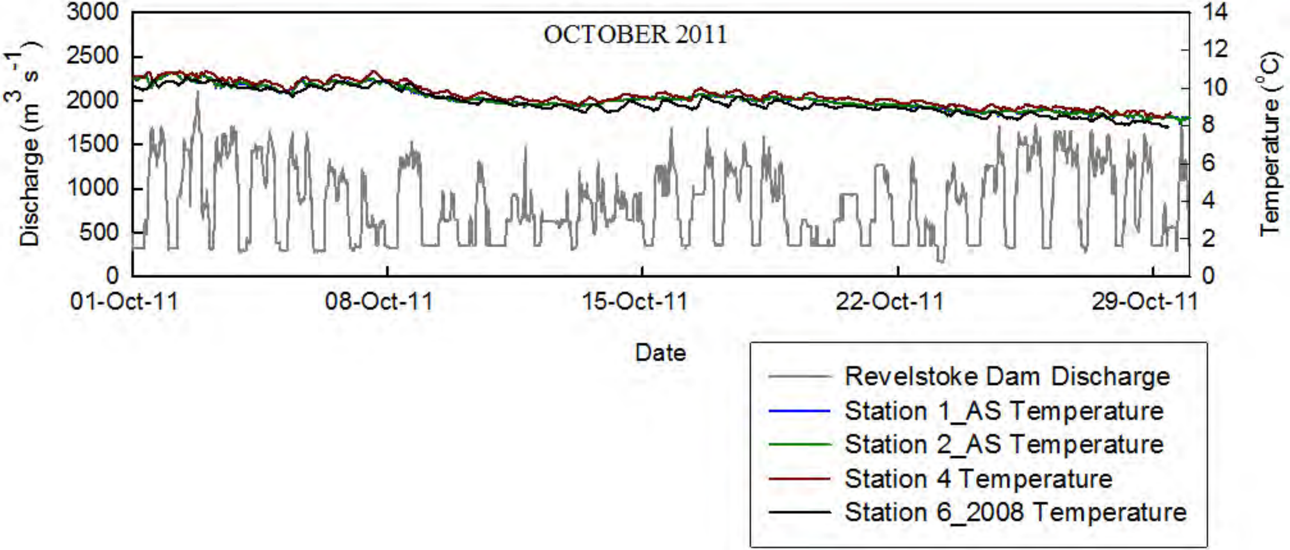
Spatial Difference in Water Temperatures on the mid Columbia River; discharge from Revelstoke Dam and water temperatures at Stations 1_AS, 2_AS (Reach 4), Station 4 (transition area between Reaches 3 and 2), and Station 6_2008 (Reach 2) (October 1, 2010 to October 30, 2011)



OCTOBER 2010
NOVEMBER 2010
DECEMBER 2010
JANUARY 2011
Discharge (m3 s-1)
Temperature (°C)
Date
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
Revelstoke Dam Discharge
Station 1_AS Temperature
Station 2_AS Temperature
Station 4 Temperature
Station 6_2008 Temperature


FEBRUARY 2011
MARCH 2011
APRIL 2011
MAY 2011
Discharge (m3 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 (m^3 s^{-1})
Temperature (^{o}C)
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 2011
Discharge (m^3 s^{-1})
Temperature (^{o}C)
3000
2500
2000
1500
1000
500
0
14
12
10
8
6
4
2
0
01-Oct-11
08-Oct-11
15-Oct-11
22-Oct-11
29-Oct-11
Date
Revelstoke Dam Discharge
Station 1_AS Temperature
Station 2_AS Temperature
Station 4 Temperature
Station 6_2008 Temperature

APPENDIX F

CLBMON-15a and 15b Seasonal Water Quality Sampling Station UTM Coordinates and Water Quality Data (Year 5)

Table F-1 **2011 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 Illicilewaet 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 Mountian Snowmobile area

Notes:

[a] See Figure 12 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 *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	Hannah Instruments (HI 9828)
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	
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	Pine Environmental meter (YSI 650 MDS)
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	
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	Hanna Instrument was not equipped to measure ORP, specific conductivity, TDS, or turbidity
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	
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.	

Notes:

[a] See Figure 12 and Appendix F, Table F-1 for sample site locationsstation 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-3 **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 (TKN) (mg/L)	Total Nitrogen (TN) (mg/L)	pH	Total Suspended Solids (TSS) (mg/L)	Total Dissolved Solids (TDS) (mg/L)	Nitrate (NO_3^-) (µg/L)	Ammonia (NH_3) (µg/L)	Soluable Reactive Phosphorus (SRP) (µg/L)	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	0.31	0.31	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	0.38	0.49	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	0.23	0.33	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	0.12	0.22	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	0.22	0.32	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	0.25	0.34	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	0.27	0.33	7.86	13	68	74.8	4.6	1.6	19.9e	2.7	1.6
Stn 8_Jordan River	JR	CLBMON-15a	summer	Golder	17-Aug-2011	16:08	0.24	0.31	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	0.14	0.24	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	<0.05	<0.05	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.	0.09	0.20	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	0.13	0.24	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	0.22	0.32	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	0.07	0.18	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	0.21	0.33	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	0.1	0.26	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	0.08	0.25	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	0.17	0.30	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	<0.05	<0.05	n.d.[c]	<1	3	0.6	<0.1	<0.1	<0.1	n/a	<0.1

Notes:

[a] See Figure 12 and Appendix F, Table F-1 for sample site locations; '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 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] DFOCultas Lake Salmon Research Laboratory re-ran sample 4 times for QA/QC purposes

n.d. indicates no data available

Table F-4 **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.

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