Mid-Columbia Physical Habitat Monitoring Project

Implementation Year 7 (2013)

Reference: CLBMON-15a

Study Period: Year 7 (2013)

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EXECUTIVE SUMMARY

To enhance fish habitat in the Middle Columbia River (MCR) and as part of the Columbia Water Use Plan (WUP) a year-round minimum flow release of 142 m^3/s from Revelstoke Dam was implemented along with the commissioning of a fifth turbine in Revelstoke Dam at the end of 2010. The commissioning of the fifth turbine in turn led to an increase of diel maximum flows. To assess the effects of the increased minimum and maximum flows, BC Hydro initiated the CLBMON-15a program in 2006 and started with Implementation Year 1 in 2007 the monitoring the physical environment of the MCR. The 2007 implementation start date allowed for four years of data collection pre-minimum flow implementation and three years of post WUP flow implementation data collection to the end of 2013. In this report, the physical monitoring results from November 2012 to November 2013 (Implementation Year 7) are summarized. For results of earlier Implementation Years, the reader is referred to Golder (2013) and Golder summary reports from 2008 to 2012 (available at *www.bchydro.com/about/sustainability/conservation/water_use_planning/southern_interior/columbia_river/revelstoke-flow.html*).

The main task of CLBMON-15a is the monitoring of water stage and temperature at five stations in the MCR reaches 2 to 4 and one station each in the Illecillewaet and Jordan rivers. These monitoring data were used to calibrate a HEC-RAS model for the MCR. As of December 2013, the HEC-RAS model has been adequately calibrated and can predict stage and wetted area for the MCR accurately. In addition, the HEC-RAS model output was used to provide data for the prediction of wetted area, stage or flows for all flow releases from Revelstoke Dam at different elevations of Arrow Lake Reservoir. Arrow Lake Reservoir at full or close to full pool backs up the MCR well into the CLBMMON-15a monitoring area.

In addition to this main task, water nutrient data and physical parameters were sampled during all downloading site visits at the index stations in the MCR as well as the Illecillewaet and Jordan river tributaries.

Stage and Water Monitoring Results

Based on the stage data collected by Golder from 2007–2012 and confirmed by the data collected as part of this study in 2013, the implementation of the 142 m^3/s minimum flows and the increase in maximum flows at the end of 2010 led to a greater variation or imum range of amplitude in diel water levels and flows, as expected. Currently, there is no evidence that the WUP flows have changed the seasonal variations in flows or water levels. Similarly, diel variation in water temperature was significantly smaller post WUP flow implementation based on the data by Golder (2013) and this study, but no changes to water temperature were detected on a seasonal basis. Although significant, the changes in the diel range of water temperatures were very small ranging from 0.1–0.4 °C and do not appear to be ecologically significant.

Seasonal Water Quality Monitoring

Physical and nutrient water parameters were used as indicators of trophic status for a particular year. Due to their low sample size, these results should not be used to draw conclusions about effects of the implementation of the increased WUP minimum and the increased Revelstoke Dam turbine 5

maximum flow discharges from Revelstoke Dam. In general, all physical and nutrient water parameters were typical of highly oligotrophic systems and in line with the results obtained in earlier studies (Golder 2013).

Table 1 CLBMON-15a status of objectives, management questions and hypotheses (Year 7, 2013).

Objectives	Management Question: How does the 142m³/s minimum flow affect…	Management Hypothesis: Implementation of a 142m³/s minimum flow release from REV will not significantly…	Year 7 (2013) Status
Measure differences in the daily and seasonal river water temperature regimes between pre- and post-implementation of the 142 m³/s minimum flow regime	…water temperature in the flowing reach of the MCR	…alter the water temperature regime of the MCR • Ho 1a: diel variation of water temperature • Ho 1b: seasonal pattern of mean water temperature	Diel variation of water temperature following implementation of the 142 m³/ minimum flows and REV 5 was 0.1-0.4 °C smaller than before. The ecological significance of such a small change is questionable. The seasonal pattern of mean water temperatures does not appear to be affected by WUP flows and REV 5.
Measure spatial and temporal differences in river water Total Gas Pressure (TGP) levels between pre- and post-implementation of the 142 m³/s minimum flow regime	…TGP in the flowing reach of the MCR	…alter TGP levels in the flowing reach of the MCR (Ho 2)	TGP values are no longer measured as part of the CLBMON-15a program. No 2013 status update possible.
Measure spatial and temporal differences in the daily and seasonal range of river level fluctuations between pre- and post-implementation of the 142 m³/s minimum flow regime	…range and variability in river level fluctuations in the MCR	…change the magnitude (i.e., range and variability) of river level fluctuations in the MCR • Ho 3a: diel variation of river levels in MCR • Ho 3b: seasonal pattern of mean river fluctuations in the MCR	Diel variation in water level following WUP flows and REV 5 is larger because of greater range of possible discharges. The seasonal pattern of mean river fluctuations does not appear to be affected by WUP flows and REV 5.
Collect seasonal nutrient and electrochemistry data at the reach scale to spatially characterize water quality conditions	…water quality in terms of electrochemistry and biologically active nutrients	…alter the water quality in terms of electrochemistry and biological active nutrients of the MCR • Ho: spatial variation in water quality parameters	The sampling frequency (three times year) for nutrients, physical parameters and electrochemistry is too low to determine any differences between the pre- and post-WUP flows and REV5 conditions. Little to no differences were found in the MCR stations. Tributaries weredifferent.
Estimate changes in the quantity and spatial distribution of permanently inundated river channel resulting from 142 m³/s minimum flow releases	…total area of river channel that is permanently wetted	…increase the area of river channel that is continuously inundated in the MCR • Ho 4a: does not increase the minimum total wetted channel area in the MCR	The estimates based on the 2013 HEC-RAS model show that the wetted river bed area at minimum flows will increase by 32% when compared with pre-WUP flows and REV 5 when Arrow Lake Reservoir is below 425 masl. When ALR is higher, the effect is lessened.

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1. INTRODUCTION

1.1. Background

The Revelstoke Dam (REV) is located on the middle Columbia River (MCR) in British Columbia, Canada, approximately 8 km upstream from 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 MCR is defined as the flowing portion of the Columbia River, which varies in length, depending on the water level in the ALR. The Revelstoke Generating Station is the second largest power plant in BC Hydro's hydroelectric power generation system, providing 16% of BC Hydro's total system capacity (BC Hydro 2000).

As part of the BC Hydro implementation of the Columbia Water Use Plan (WUP) for its hydroelectric and storage facilities on the Columbia River in 2007, the Columbia River Water Use Plan Consultative Committee (WUP CC) recommended the establishment of a year round 142 m^3/s minimum flow release from REV to enhance fish habitat in the MCR. The 142 m^3/s minimum flows replaced previous minimum flows of 8.5 m^3/s (seepage flows during zero generation). To address the uncertainty about the environmental benefits of the proposed minimum flow releases it was further recommended to develop and implement programs under the Revelstoke Flow Management Plan (RFMP) to measure changes in the MCR non-physical aquatic environment in response to minimum flow releases. These potential changes in the non-physical aquatic environment were investigated as part of other studies carried out under the CLBMON umbrella and are informed by the CLBMON-15a results presented here.

The recommended 142 m^3/s minimum flow release from REV was implemented in 2010, when BC Hydro added a fifth generating unit (REV 5) to the Revelstoke Generating Station. REV 5 was commissioned on December 20, 2010 and added 500 MW to the station's generating capacity. This increase in power generation also increased the peak discharge from 1,700 m^3/s to 2,124 m^3/s. Therefore the impacts of the operation of REV 5 and the implementation of the 142 m^3/s minimum flow were assessed in one program. The monitoring of the physical habitat carried out in this study developed logical linkages between REV operations (including REV 5) and physical changes in fish habitat that can be used to inform the other biological studies carried out under the CLBMON umbrella.

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 ALR. ALR levels can fluctuate between 420.0 m and 440.2 m, and can cause a backwater effect into the MCR during times of high reservoir levels (Golder 2013). The highest ALR levels can backwater the MCR to about 8 km from REV.

In 2007, BC Hydro commissioned the MCR Physical Habitat Monitoring Program (CLBMON-15a) to collect physical habitat and water quality information on the MCR. The study area for CLBMON-

15a encompasses the 32-km section of the MCR from the outlet of REV downstream to the confluence with the Akolkolex River, and is divided as follows (Figure 1):

- MCR Reach 4 (Rkm 238–231.8) – REV downstream to the Jordan River confluence;
- MCR Reach 3 – (Rkm 231.8–226.8) the Jordan River confluence downstream to the Illecillewaet River confluence;
- MCR Reach 2 – (Rkm 226.8–203.5) the Illecillewaet River confluence downstream to the Akolkolex River confluence; and
- Two tributaries – the Illecillewaet (Station 7 at Greely Bridge) and Jordan (Station 8, 6 km from mouth).

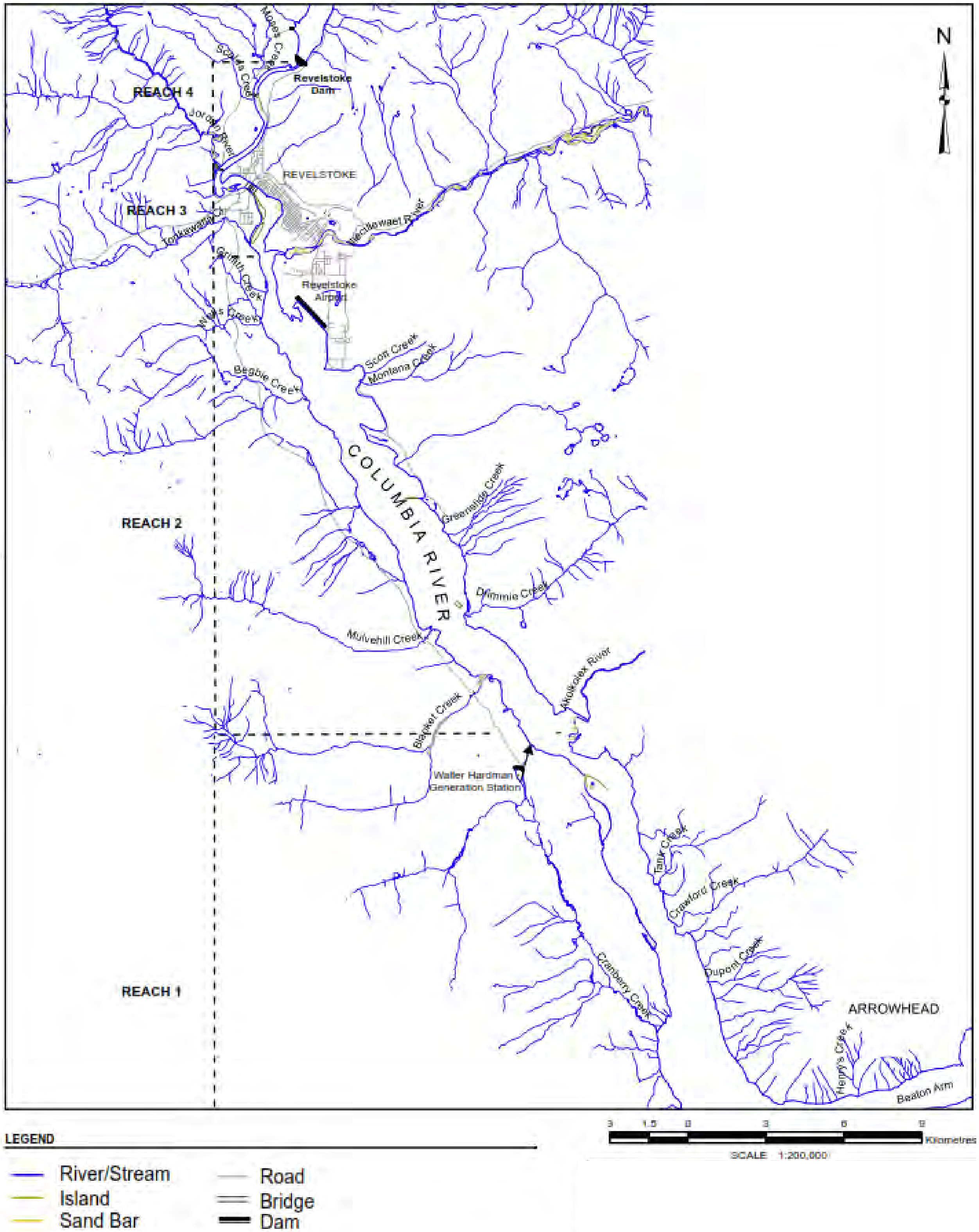

Figure 1 Map showing an overview of the CLBMON-15a study area and the reach naming conventions (Source: Golder 2012).

1.2. Monitoring Program Overview and Objectives

As defined in the WUP (BC Hydro 2005), the objective of CLBMON-15a was to monitor physical parameters for four years pre-REV 5 operations and for up to 10 years of post-REV 5 operations. The year 2013 or Year 7 of the program marked the third year of post-REV 5 operations. The physical data gathered as part of CLBMON-15a addresses the following objectives:

1) To measure spatial and temporal differences in the daily and seasonal river water temperature regimes between pre-implementation of the 142 m^3/s minimum flow regime and post-implementation of the 142 m^3/s minimum flow regime (ongoing).
2) To measure spatial and temporal differences in river water TGP levels between pre and post-implementation of the 142 m^3/s minimum flow regime (completed in 2011).
3) To measure spatial and temporal differences in the daily and seasonal range of river level fluctuations between pre and post-implementation of the 142 m^3/s minimum flow regime (ongoing).
4) To collect seasonal nutrient and electrochemistry data at the reach scale to spatially characterize water quality conditions (ongoing).
5) To estimate changes in the quantity and spatial distribution of permanently inundated river channel resulting from 142 m^3/s minimum flow releases (ongoing).

The SCOPE of the MCR Physical Habitat Monitoring Program is:

1) To continuously monitor water temperature and river stage at index monitoring stations focusing on the upper two reaches of the MCR (Reaches 3 and 4), and in key tributaries (Jordan and Illecillewaet rivers) (ongoing).
2) To conduct strategic, non-continuous TGP monitoring at index stations in the flowing reach of the MCR (completed in 2011).
3) To conduct seasonal water quality sampling (electrochemistry and biologically active micronutrients) at index monitoring stations with a focus on the upper two reaches of the MCR (Reaches 3 and 4) (ongoing).
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 (ongoing).
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. General Approach and Monitoring Program Components

In general, previously installed (Golder 2008, 2009, 2010, 2011, 2012) fixed index monitoring stations continuously recorded river stage and water temperature information while water quality was sampled three times per year at index sites (Figure 2). The monitoring program was divided into the following main data collection and analysis tasks.

- Stage and water temperature monitoring: Stage and temperature data were collected at seven time-synchronized stations in the MCR and one station in the Jordan River, a major tributary (Table 2). In addition, only temperature data was collected from the Illecillewaet River. Data were provided by outside sources for the stage of the Illecillewaet River (Environment Canada automated stream gauging station 08ND013 – Illecillewaet River at Greeley). All continuous data loggers were deployed in stainless steel standpipes bolted to rock faces or coarse substrate or deployed on anchor systems, and collected data over the large vertical range of possible river stages. MCR data loggers were downloaded and maintained three times per year. In general, data were collected at 10-minute intervals (Jordan River, 30-minute intervals).
- Hydraulic model calibration and application: A HEC-RAS (Hydrologic Engineering Centre - River Analysis System) model was developed for both steady and unsteady states (depending on river section and temporal operation patterns of interest) and calibrated with empirical river stage data collected under this monitoring program. The calibrated model was then used to estimate the quantity and spatial distribution of permanently wetted river channel due to changes in REV operations and backwatering of the ALR.
- Seasonal water quality sampling: Sampling was conducted three times per year (spring, summer and fall) at five index stations in the MCR and one station each in the Jordan and the Illecillewaet Rivers for a total of 21 samples collected in 2013. All samples were sent to a lab for low level nutrient analysis. Physical and electrochemistry data were recorded *in situ* using a handheld multimeter.
- Physical data storage and quality assurance: All data were entered into a project data repository established earlier by Golder Associates for CLBMON-15a.

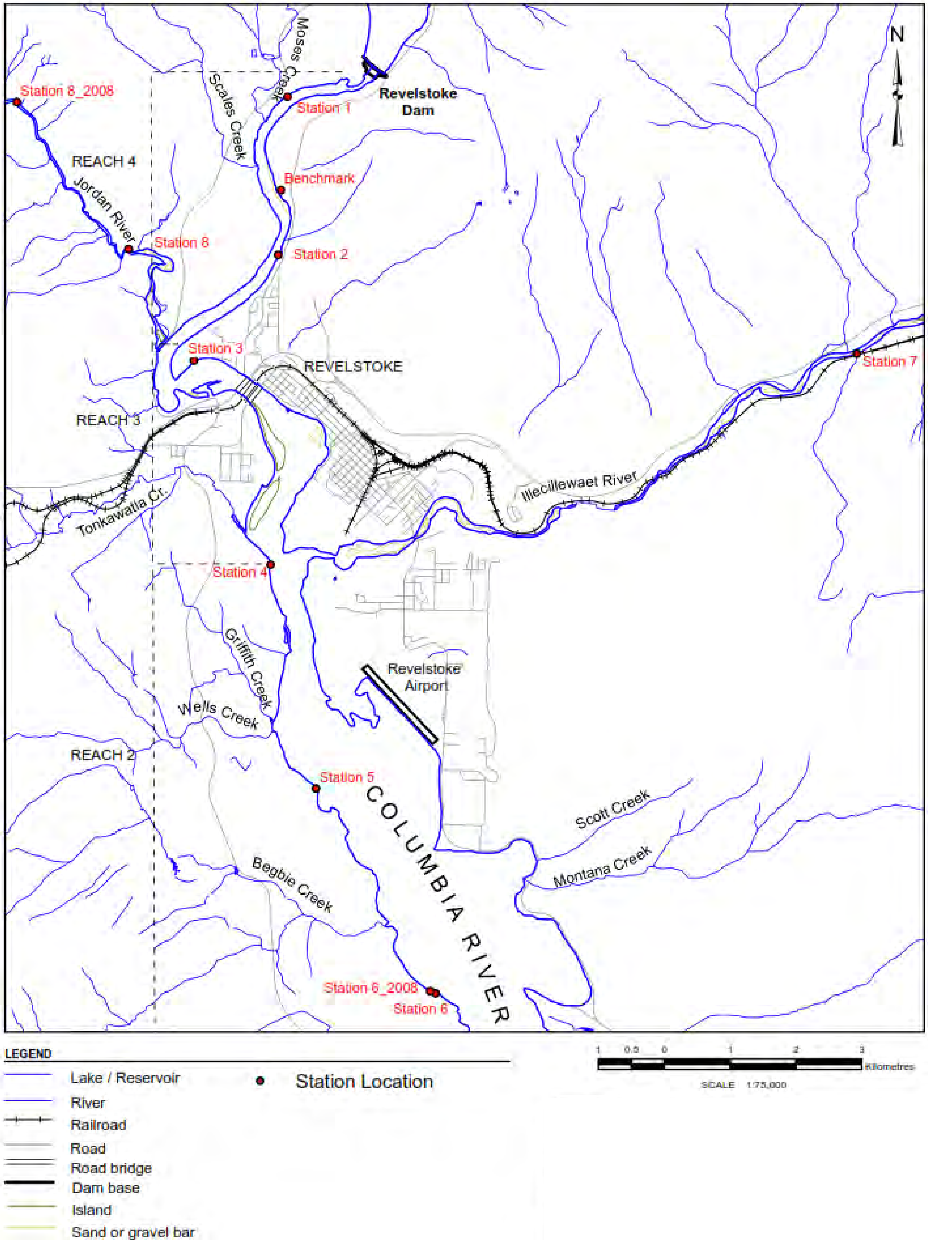

Figure 2 Map showing an overview of the MCR study area and the location of all monitoring index stations (Source: Golder 2012).

1.4. Key CLBMON-15a Management Questions and Hypotheses

The key management questions for CLBMON-15a are:

1. How does the implementation of the 142 m^3/s minimum flow affect water temperature in the flowing reach of the MCR? What is the temporal scale (diel, seasonal) of water temperature changes? Are there spatial differences in the pattern of the water temperature response?
2. How does the implementation of the 142 m^3/s minimum flow affect total gas pressure (TGP) in the flowing reach of the MCR?
3. How does the implementation of the 142 m^3/s minimum flow affect the range and variability in river level fluctuation in the MCR? Are there temporal (seasonal scale) or spatial (reach scale) differences in the pattern of response?
4. Does the implementation of the 142 m^3/s minimum flow affect water quality in terms of electrochemistry and biologically active nutrients?
5. How does the implementation of the 142 m^3/s minimum flow release from Revelstoke Dam affect the total area of river channel that is permanently wetted?

The hypotheses based on the management questions are:

Hypothesis 1. Implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly alter the water temperature regime of the MCR.

- Hypothesis 1A: The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam does not significantly change the diel variation of water temperature of the MCR; and
- Hypothesis 1B: The implementation of a 142 m m^3/s minimum flow release from Revelstoke Dam will not significantly alter the seasonal pattern of mean water temperature of the MCR.

Hypothesis 2. Implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly alter TGP levels in the flowing reach of the MCR. (Note that the TGP monitoring program was terminated in 2011 and therefore no data were collected in 2013)

- Hypothesis 2A: The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly alter TGP levels.

Hypothesis 3. The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not significantly change the magnitude (i.e., range and variability) of river level fluctuations in the MCR.

- Hypothesis 3A: The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not alter the diel variation of river levels in MCR;

- Hypothesis 3B: The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam will not alter the seasonal pattern of mean river level fluctuations in the MCR.

Hypothesis 4. The implementation of a 142 m^3/s minimum flow release from Revelstoke Dam does not increase the minimum total wetted channel area in MCR.

2. STAGE AND WATER TEMPERATURE MONITORING

2.1. Stage and Temperature Monitoring Methods

River Stage and Temperature Loggers – Locations, Surveying and Maintenance

For the purposes of this monitoring program, stage and temperature data were obtained from the following monitoring stations and sources:

- MCR Monitoring Stations 1, 1AS, 2, 2AS, 4, 5 and 6 (stage and temperature loggers) – (Figure 2) in Reaches 2 through 4;
- MCR Monitoring Station 3 – was downloaded by BC Hydro, but data were not available as HEC-RAS model input before the 2013 HEC-RAS model was run, but will be included in the 2014 model run, if available;
- Tributary Inflows Study Internal Sources – a stage and temperature logger in the Jordan River and a temperature logger in the Illecillewaet River;
- Tributary Inflows External Sources – an automated stage logger in the Illecillewaet River (Environment Canada automated stream gauging station 08ND013 – Illecillewaet River at Greeley).
- Revelstoke Dam Discharge – hourly and 10-minute (data provided by BC Hydro; note that 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 (Golder 2013);
- ALR Elevations – as measured at Nakusp in metres (data provided by BC Hydro).

The seven river stage data loggers (deployed in five standpipe and two anchor stations) were installed on the MCR by Golder (2013). These loggers were attached to wire cables of known length for retrieval and enclosed in standpipes that are attached to steep banks or vertical rock faces. The wire cables were attached to a bolt inside the standpipe with known elevation as a fixed elevation reference point. Two additional river stage data loggers were installed on anchors at the standpipe stations in Reach 4 (Stations 1 and 2). The anchor-based monitoring stations (Stations 1_AS and 2_AS) were used in calibrating the hydraulic model in previous years. To maintain consistency between years, stations 1_AS and 2_AS were used in model calibration and application for the 2013/2014 monitoring year. Installation and location details for all river stage data loggers are described in Golder (2008; 2013).

In previous years, the HEC-RAS model was also calibrated using data from Station 3 (labelled by BC Hydro as REV 'TR2' or 'Tailrace-7km'), maintained by BC Hydro and located within Reach 3 of the MCR. However, this station could not be located despite an extensive search during the three field visits, and was therefore not used for model calibration in 2013/2014. Following the HEC-RAS Model calibration process in the spring of 2014, BC Hydro located the data for Station 3 and forwarded it to the study team. Station 3 is planned for maintenance by BC Hydro in 2014. Data will be included in model calibration in 2014/15, if available.

Station 7 discharge measurements for the Illecillewaet River are recorded by Water Survey of Canada (WSC Station No. 08ND013). Data from this station were used to determine inflows to the MCR from this tributary.

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 Stations 2 and 4. The barometric data loggers were enclosed in separate 1 m (approximate length) standpipes, located ~1-2 m above high water mark on rock outcrops. Data from the baraloggers were used for barometric compensation of the water level data.

Water stage and temperature at each of the index stations were recorded at 10-minute intervals, with the exception of the Jordan River Station (Station 8), 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 in the event the site could not be accessed and downloaded during spring freshet.

The collected water elevation data were corrected by adjusting the values using the surveyed orthometric datum (elevation described above sea level; obtained during the April 30, 2013 field visit), so that all station water elevations were reported using identical metrics. UTM coordinates, elevations (masl), data available, and logging interval are provided for all stations in Table 2.

Table 2 Logger information of the hydrometric gauges installed at MCR for the 2013/2014 monitoring period.

Station Name	Solinst Logger	UTM Zone 11 Easting	UTM Zone 11 Northing	Start Date (PST)	End Date (PST)	Duration (Days)	Logging Interval	Elevation (masl)
CLB-Station 1	Level	415049	5655566	19-Jun-2012 20:40:00	06-Nov-2013 02:20:00	504.2	10 minute	438.26
CLB-Station 1_AS	Level	415049	5655566	18-Nov-2012 08:20:00	06-Nov-2013 02:00:00	352.7	10 minute	437.38
CLB-Station 2	Level	414925	5653213	24-Oct-2012 16:40:00	05-Nov-2013 23:50:00	377.3	10 minute	436.66
"	Baro[1]	414925	5653213	18-Nov-2012 14:00:00	06-Nov-2013 00:30:00	352.4	10 minute	-
CLB-Station 2_AS	Level	414925	5653213	18-Nov-2012 09:50:00	06-Nov-2013 01:30:00	352.7	10 minute	436.83
CLB-Station 4	Level	414807	5648490	24-Oct-2012 14:00:00	06-Nov-2013 13:10:00	378.0	10 minute	432.16
"	Baro[1,2]	414807	5648490	24-Oct-2012 13:50:00	06-Nov-2013 12:00:00	377.9	10 minute	-
CLB-Station 5	Level	415490	5645100	24-Oct-2012 12:20:00	06-Nov-2013 12:00:00	378.0	10 minute	430.79
CLB-Station 6	Level	417171	5642074	24-Oct-2012 11:30:00	06-Nov-2013 12:00:00	378.0	10 minute	429.36
CLB-Station 8	Level	410904	5655521	23-Oct-2012 10:30:00	05-Nov-2013 13:00:00	378.1	30 minute	534.29

[1]No specific coordinates available; located at the gauging station.

[2]Data file used for barometric compensation of stage at all stations. The barologger at Station 2 is back-up.

Station maintenance in 2013 was carried out as part of all three station visits and consisted of the following measures:

- Reviewing the downloaded data to ensure that at least one station at each location had been immersed continuously in water and measuring river stage.
- Checking and potentially reinforcing standpipe support structures. None of the stations needed additional support in 2013.
- Checking the condition of aircraft cables connecting the stage and temperature loggers to the bolt of known elevation on the inside of the standpipe. None of the aircraft cables needed to be replaced in 2013.
- Checking for sediment build up inside the standpipes and flushing out sediment. Sediment had only built up in the standpipe at Station 1. Sediments were compacted in the standpipe from top to bottom and could not be cleared out of the standpipe with a jet from a high pressure gas-powered water pump. Consequently, the lower part of the standpipe was cleaned and a new access window was cut into the standpipe at an elevation that can only be accessed at discharges of $<400 m^3/s$ through REV. To avoid further accumulation of sediment entering from the top of the standpipe during very high discharges, a plug was fastened to the inside of the standpipe above the download window. The download window was covered with wire-reinforced radiator hose held in place with three stainless steel hose clamps.
- Cleaning of the water permeable end covers of the standpipes and re-attaching them. End covers were cleaned at Stations 1 and 2 and were not accessible at the remaining MCR stations since the water level was too high to reach them. All standpipe end covers will be replaced in 2014 using a dry-suit and a snorkel. Data logger readings in 2013 appeared accurate and consistent with readings in 2012.
- Checking all data loggers for proper operations and exchange them if necessary. All data loggers operated as expected in 2013 and therefore none of the data loggers were exchanged. Two new back-up data loggers will be taken into the field in 2014.

2.2. Index Station Elevation Synchronization and Orthometric Correction

All stations were re-surveyed on April 30, 2013 for position and elevation by Brian Sansom of Browne Johnson Land Surveying using the following method. A Global Navigation Satellite System (GNSS) base station was set up on a control monument of known position (GCM335372) near the City of Revelstoke. Based on this reference station, precise coordinate and elevation information for the five MCR stations was collected as follows:

1. Two GNSS receivers were set up at each station to derive precise three dimensional coordinates at the site relative to the base station.

2. A ground-based instrument (a total station) was set-up and three dimensional positions were measured for points as instructed by the field crew.

2.3. Tributary inflows

Tributary inflows were included as inputs to the HEC-RAS hydraulic model for six tributaries to the MCR. Unsteady (variable) flows were estimated for the three largest tributary inflows to the MCR: the Illecillewaet River, the Jordan River, and the Akolkolex River. Steady (constant) flows were used for the three smaller tributaries (Begbie Creek, Drimmie Creek, and Mulvehill Creek), as seasonal variations on these creeks are assumed to have a negligible effect on the model results. Table 3 summarises the methods used to estimate tributary inflows to the MCR, for each of the six tributaries included in the HEC-RAS model.

Flow data for the Illecillewaet, Jordan, and Alkolkolex rivers were daily averages. For application of the HEC-RAS model, these daily-average flows were transformed to hourly flows using linear interpolation. In general, inaccuracies in the estimated hourly flows for Illecillewaet, Jordan, and Alkolkolex Rivers have minor effect on the HEC-RAS model results; the annual-average flow for these rivers is an order of magnitude smaller than the annual-average mean discharge from REV.

Table 3 Methods of estimating tributary inflows to the MCR.

Tributary	Mean Annual Discharge[1] (m^3/s)	Method of estimating inflow to MCR
Illecillawaet River	43	Drainage area pro-ration
Jordan River	17	Ranked regression; Drainage area pro-ration
Akolkolex River	14	Ranked regression
Begbie Creek	3.4	Steady (constant) inflow
Drimmie Creek	5.5	Steady (constant) inflow
Mulvehill Creek	2.8	Steady (constant) inflow

[1] Taken from Golder 2013, Appendix B; estimated from BC Hydro (1985 to 2000)

2.4. Illecillewaet River

The Illecillewaet River is the largest tributary included in the model, with an active WSC gauging station (Illecillewaet River at Greeley: WSC 08ND013) located approximately 10 km upstream of its confluence with the MCR. WSC provided provisional flow data for this station for the modelled period (2012-2013). Illecillewaet inflows to the MCR were estimated by applying a drainage area pro-ration factor to these daily average flow data, to account for the additional inflows to the

Illecillewaet River between the WSC station (08ND013) and the confluence with the MCR. (Note, the WSC data are provisional and subject to revision).

2.5. Jordan River

Station 8, Station 8_2008, and Station 8_2011 were established on the Jordan River with the intention of collecting stage data and discharge measurements, enabling a rating curve to be developed and flow data to be collected for the Jordan River. However, due to the unstable nature of these stations, insufficient data have been collected on the Jordan River, and it has not been possible to create a rating curve that can estimate discharge with high confidence. As such, tributary inflows from the Jordan River have been estimated using a correlation based on ranked regression analysis between historic data from two WSC Stations: Illecillewaet River at Greeley (WSC 08ND013) and Jordan River above Kirkup (WSC 08ND014).

Available concurrent records of mean daily discharge from the two stations (over 25 years of data between November 1963 and December 1988) were filtered to remove unreliable data, and the remaining datasets were ranked and correlated. The best-fit relationship between the ranked flows was tested by applying it to the unranked data. A comparison of estimated against actual flows at the WSC Jordan River station (1963-1988) resulted in a Nash Sutcliffe Efficiency (NSE) of 0.90, showing the equation to have excellent predictive power. Further details of this ranked regression analysis are provided in Table 4.

The relationship was then applied to the provisional flow data from the Illecillewaet River at Greeley (WSC 08ND013) station for the period required for the HEC-RAS model (2012-2013), in order to estimate concurrent flows at the Jordan River above Kirkup (WSC 08ND014) station over the same period. As an additional check, these data were compared with available level data from Station 8_2011 (October 24, 2012 to November 6, 2013), resulting in a correlation with an r^2 value of 0.8649. Finally, the estimated flows for the Jordan River at the WSC station location (WSC 08ND014) were scaled by drainage area pro-ration, to estimate Jordan River flows at its confluence with the MCR.

Three discharge measurements were collected on the Jordan River during the 2013/2014 monitoring period. Two of these measurements were taken under similar flow conditions, and as such, do not yet provide a reliable stage-discharge rating curve. Two additional discharge measurements are scheduled to be collected during the 2014/2015 monitoring period. It is hoped that these additional measurements will be sufficient to develop a reliable relationship between stage and discharge for the Jordan River.

2.6. Akolkolex River

There has been no active gauging station on the Akolkolex River during the HEC-RAS modelling period (2012-2013), therefore no flow data are available to use as inputs to the hydraulic model. As with the Jordan River, tributary inflows have therefore been estimated using a correlation based on ranked regression analysis between historic data from two WSC Stations: Illecillewaet River near Revelstoke (WSC 08ND003) and Akolkolex River near Revelstoke (WSC 08ND001).

Available concurrent records of mean daily discharge from the two stations (3.7 years of data between May 1913 - December 1916) were filtered to remove unreliable data, and the remaining datasets were ranked and correlated. The best-fit relationship between the ranked flows was tested by applying it to the unranked data. A comparison of estimated against actual flows at the WSC Akolkolex River station (1913-1916) resulted in a Nash Sutcliffe Efficiency (NSE) of 0.74, showing the equation to have reasonable predictive power. Further details of this ranked regression analysis are provided in Table 4.

The relationship was then applied to the provisional flow data from the Illecillewaet River at Greeley (WSC 08ND013) station (adjusted by drainage area pro-ration to represent flows near the Illecillewaet River near Revelstoke (WSC 08ND003) station) for the period required for the HEC-RAS model (2012-2013), in order to estimate concurrent flows at the Akolkolex River near Revelstoke (WSC 08ND001) station over the same period. No further adjustment to the flow data was required, as the Akolkolex River near Revelstoke (WSC 08ND001) station is located within a few hundred metres of the confluence with the MCR. Further, errors in the estimated flow for Akolkolex River likely have negligible effect on the HEC-RAS model results; Akolkolex River flows into MCR near the downstream boundary of the modelled domain.

Table 4 Details of the ranked regression analyses and resultant correlations developed for the Jordan and Akolkolex Rivers.

Tributary:	**Jordan River**	**Akolkolex River**
Stations used	Illecillewaet River at Greeley (WSC 08ND013); Jordan River above Kirkup (WSC 08ND014)	Illecillewaet River near Revelstoke (WSC 08ND003); Akolkolex River near Revelstoke (WSC 08ND001)
Period of concurrent record	November 1963 - December 1988	May 1913 - December 1916
Length of concurrent record	25.1 years	3.7 years
No. cases	8592	1109
Type of equation	4th order polynomial	3rd order polynomial
Equation	$y = 9.17768E\text{-}09x^4 - 6.52058E\text{-}06x^3 + 1.74521E\text{-}03x^2 + 1.91278E\text{-}01x + 9.65814E\text{-}01$	$y = -1.75858E\text{-}06x^3 + 1.71844E\text{-}03x^2 + 1.73827E\text{-}01x + 3.02360E{+}00$
r^2	0.9992	0.9964
NSE *	0.90	0.74

*NSE=Nash Sutcliffe Efficiency, a measure of comparison between actual versus model-predicted flows

3. HYDRAULIC MODEL CALIBRATION AND APPLICATION

3.1. Introduction

Given the dynamic and complex nature of the regulated flow regime, and the geographic extent of the MCR study area, a hydraulic model (HEC-RAS) 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) and calibrated by Golder (2011, 2012, and 2013).

Ecofish Ltd. (Ecofish) was retained by LGL Limited (LGL) to calibrate the existing unsteady state HEC-RAS model of the MCR for the 2013/2014 monitoring period. Additional tasks included the QA and processing of the stage and temperature data collected during the monitoring period, and an analysis of local inflows from three MCR tributaries. These data were used for calibration of the HEC-RAS model of the MCR.

3.2. Scope

The existing HEC-RAS model provided by BC Hydro was reviewed, new flow data were entered into the model, unsteady-state simulations were ran with the model, and results were exported to MS Excel. Validation periods were selected and for each validation period model predictions were compared to stage data to determine if further model calibration was necessary. The model results were used to estimate hydraulic parameters that are important to fish habitat.

3.3. Methods

Model Setup

The HEC-RAS model was used to simulate three periods between November 18, 2012 and November 6, 2013. The simulated periods were November 18, 2012, to February 10, 2013 (84 days); February 11 to May 10, 2013 (88 days); and May 11 to November 6, 2013 (179 days). For these periods, data were generally available for Revelstoke Dam, stations along the MCR, Arrow Lakes Reservoir, and major tributaries. Short gaps in the data records were filled using linear interpolation. For all simulated periods, a time step of 10 min was used. This short time step ensured the accuracy of the model results, in particular during rapid changes in REV discharge.

The modelled domain extended 37 km downstream of Revelstoke Dam (REV). Discharge from REV was applied at the upstream boundary of the domain. Six tributary inflows were accounted for in the model including flows from the major tributaries, Illecillewaet, Jordan, and Akolkolex rivers, and the smaller tributaries, Begbie, Drimmie, and Mulvehill creeks. At the downstream boundary of the domain, ALR water level was applied except for the period from February 11 to May 10, 2013. During this period, the ALR data were unreliable and were not used in the model (BC Hydro confirmed that the gauge was not operating at this time).

Two scenarios were considered for this period (February 11 to May 10, 2013). In the first scenario, the ALR water level was assumed to be lower than the MCR and a uniform-flow depth was applied at the downstream boundary of the modelled domain. The uniform-flow depth was computed using a friction slope of 0.024%. This slope was used in previous versions of the model (Golder 2013) and is approximately the average bed slope of MCR.

In the second scenario, the ALR water level was assumed to be the weekly-minimum level observed at Station 6. This scenario should give higher stages at stations along MCR compared to the uniform-flow depth scenario. The actual ALR level was likely between the values used for the two scenarios, and the stages at the MCR stations are expected to be bounded by the stages simulated for the two scenarios.

Preliminary runs with the model had numerical instabilities. These instabilities were caused by how the Jordan River was represented in the model. Except for Jordan River, tributaries were accounted for in the model using lateral inflows and the geometry of the tributaries was not included explicitly. For Jordan River, a 0.6 km reach was used to represent this tributary (this reach was not described in Golder 2012 and 2013). The 0.6 km reach had three cross-sections. The mid-reach cross-section was lower than the other two cross-sections. This depression in the bed caused numerical instabilities when running the model for high flow rates in Jordan River. To eliminate these instabilities, the geometry for Jordan River was slightly adjusted from the previous version of the model. The depression in the middle of the reach was removed by raising the mid-reach cross-section (river station 417.458) by 0.5 m and lowering the downstream cross-section (river station 192.286) by 0.5 m.

Model Calibration

Preliminary runs with the HEC-RAS model indicated that model calibration was required. Calibration of the model involved comparing observed and simulated stages at five stations. These stations were 1_AS, 2_AS, 4, 5, and 6 (Table 2). Data from Station 3 were included in model calibration for previous years (Golder 2013). However, data for this station were not available for late 2012-2013 and were not used for calibrating the current version of the model.

For calibrating the MCR model, Manning roughness coefficients were adjusted to improve the agreement between observed and simulated stages at hourly intervals. Two measures of agreement were used; root mean square error and bias. For each station along MCR, root mean square error (RMSE) was calculated using,

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2} \tag{1}$$

where S_i and O_i are the simulated and observed stages at hour i, and n is the number of hours in the simulation. Bias was calculated as the average of differences between simulated and observed stages,

$$\text{Bias} = \frac{1}{n}\sum_{i=1}^{n}(S_i - O_i). \qquad (2)$$

Adjustment of the Manning roughness coefficients was restricted to the ranges expected for MCR. To further improve the model results, slight adjustments to the cross-section elevations were considered. These adjustments were consistent with the accuracy of the bathymetry data used for developing the model and were smaller than previous elevation adjustments of 0.5 m applied by Golder (2012).

Analysis of Simulated Hydraulic Parameters

Model results for November 2012 to November 2013 were used to estimate hydraulic parameters that are important to fish habitat. The estimated parameters were wetted bed area, average flow velocity, and average flow depth. These parameters were estimated for Reaches 1 to 4 and also for the entire modelled domain.

Wetted bed area was calculated for each reach using,

$$A_i = \sum_{j=2}^{n_i}\left(\frac{P_{j-1} + P_j}{2}\right)\Delta x_{j-\frac{1}{2}} \qquad (3)$$

where $A_i(t)$ is the wetted bed area for reach $i = 1,2,3,4$ at time t; $\Delta x_{j-\frac{1}{2}}$ is the distance between adjacent cross-sections *j* - 1; and *j* and n_i is the number of cross-sections in reach i. For the modelled domain, the wetted bed area A was set to the sum of wetted areas for the four reaches,

$$A = \sum_{i=1}^{4} A_i \qquad (4)$$

In equation 3, P_{j-1} and P_j are the wetted perimeters of the adjacent cross-sections $j - 1$ and j, respectively (Figure 3). After computing the wetted area for individual reaches using equation 3, the mean wetted perimeter for each reach was computed as the reach wetted area divided by the reach length,

$$\overline{P}_i = \frac{A_i}{L_i} \qquad (5)$$

where $L_i = \sum_{j=2}^{n_i}\Delta x_{j-\frac{1}{2}}$ is the length of reach i.

$$d_i = \frac{\forall_i}{s_i} \qquad (6)$$

where d_i, $\forall_i$, and s_i are the average flow depth, volume, and surface area for reach i, respectively. The average flow depth for the entire domain was computed using,

$$d = \frac{\sum_{i=1}^{4} \forall_i}{\sum_{i=1}^{4} s_i} \tag{7}$$

where $\sum_{i=1}^{4} \forall_i$ is the total volume of water in the domain at time t and $\sum_{i=1}^{4} s_i$ is the corresponding surface area.

The average flow velocity for each reach was estimated using the distance-weighted mean,

$$\overline{U}_i = \frac{1}{L_i} \sum_{j=2}^{n_i} \left(\frac{U_{j-1} + U_j}{2} \right) \Delta x_{j-\frac{1}{2}} \tag{8}$$

where $\overline{U}_i$ is the average flow velocity for reach $i = 1,2,3,4$; U_{j-1} and U_j are the average flow velocities through cross-sections $j - 1$ and j, respectively; $\Delta x_{j-\frac{1}{2}}$ is the distance between cross-sections $j - 1$ and j; $L_i = \sum_{j=2}^{n_i} \Delta x_{j-\frac{1}{2}}$ is the length of reach i; and n_i is the number of cross-sections in reach i. For the modelled domain, the average flow velocity was also calculated using a distance-weighted mean,

$$\overline{U} = \sum_{i=1}^{4} \overline{U}_i \frac{L_i}{L} \tag{9}$$

where $L = \sum_{i=1}^{4} L_i$ is the length of the modelled domain.

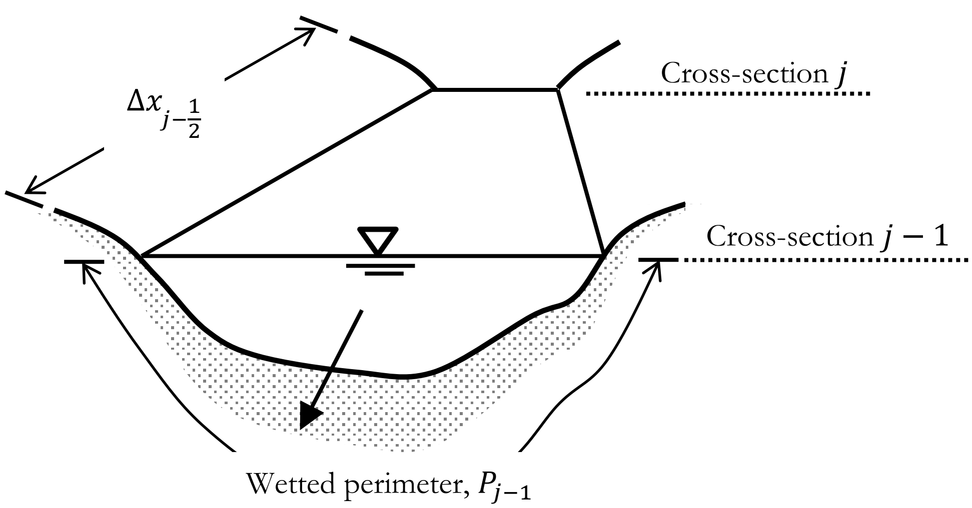

Figure 3. Schematic of stream cross-sections showing variables used in calculating wetted area.

4. RESULTS

4.1. Model Calibration

Model calibration for November 18, 2012 to November 6, 2013 determined the Manning roughness coefficients (Table 5). Compared to the values used in the previous version of the model (Golder 2013), there were no changes in the calibrated roughness coefficients for Reach 1 (cross-sections 115-1) and the lower part of Reach 4 (cross-sections 200-183). For the upper part of Reach 4, the calibrated roughness coefficient decreased insignificantly from 0.035 to 0.030. The calibrated roughness coefficients also decreased slightly for the lower part of Reach 3 and the upper part of Reach 2 (cross-sections 167-124 and 123-116).

For the upper part of Reach 3 (cross-sections 182-168), the Manning roughness coefficient was set to 0.08 which is the upper bound for roughness expected for this reach based on channel morphology and bed type (Golder 2013). Agreement between observed and simulated stages at Station 2_AS can be further improved by increasing the roughness coefficient above 0.08. However, instead of using a higher roughness coefficient that is not justified by channel characteristics, agreement between observed and simulated stages at Station 2_AS was improved by raising cross-sections 171 to 182 by 0.4 m. This adjustment of 0.4 m is smaller than previous elevation adjustments of 0.5 m done by Golder (2013) and is consistent with the accuracy of the bathymetry data used for developing the model.

Table 5. Calibrated Manning roughness coefficients for the unsteady hydraulic model. Shown are the calibrated roughness coefficients for the current version of the model and the previous version (Golder 2013). Also shown is the expected range of roughness coefficients based on channel morphology and bed type (Golder 2013).

Cross-section Range†	Range	Manning Roughness Coefficient	
		Golder (2013)	This Report
243-201	0.03 to 0.035	0.035	0.030
200-183	0.03 to 0.035	0.030	0.030
182-168	0.035 to 0.08	0.045	0.080
167-124	0.035 to 0.08	0.038	0.030
123-116	0.017 to 0.04	0.028	0.017
115-1	0.017 to 0.04	0.020	0.020

† cross-section 243 is at the upstream end of the modelled domain (i.e. at REV). Cross-section numbers decrease in the downstream direction.

4.2. Model Validation, Water Stage and Discharge

Figure 13 and Figure 14 in Appendix D show the graphical representations of the simulations done with the calibrated Manning roughness coefficients for November 18, 2012, to February 10, 2013, and for May 11 to November 6, 2013. In general, there is good agreement between the simulated and observed stages at Stations 1_AS, 2_AS, 4, 5, and 6.

Quantitative measures of agreement are summarized in Table 6 which gives error bounds, bias, and root mean square error. For the simulation covering November 18, 2012, to February 10, 2013, the model gives a bias between -0.03 m and +0.09 m and a root mean square error (RMSE) between 0.12 m and 0.26 m. These values are comparable to those for the previous version of the model which gave a bias between -0.01 m and +0.07 m and a RMSE between 0.09 m and 0.26 m (Golder 2013). For the simulation covering May 11 to November 6, 2013, the agreement between model results and observations was lower; the bias ranged between -0.37 m and +0.05 m and the RMSE ranged between 0.19 m and 0.39 m.

Further validation of the model performance is supported by the results of the simulations for February 11 to May 10, 2013. Graphical representations of the results are shown in Figure 15 and Figure 16 (in Appendix D) which compare the simulated and observed stages for two scenarios with different downstream boundary conditions (Table 7). The effect of the downstream boundary condition was limited to the stage at Stations 5 and 6; the simulated stage for the upstream Stations 1_AS, 2_AS, and 4 was similar for the two scenarios. The bias for Stations 1_AS, 2_AS, and 4 ranged between -0.19 m and +0.05 m and the RMSE error ranged between +0.05 m and +0.23 m (Table 6, Table 7).

It should be noted that the validation runs for the 2012/2013 model are considerably longer than those done by Golder (2013) for the previous version of the model. The total duration of validation runs in Golder (2013) was ~30 days. For the updated 2012/2013 model, validation runs amount to 270 days (excluding the simulation for February 11 to May 10, 2013). From these long validation runs, shorter periods with remarkable agreement between model results and observations can be identified. These shorter periods give lower RMSE and bias than the values in Table 6 and Table 7 but do not take advantage of data having been collected for the whole year.

Table 6. Agreement between simulated and observed stages at the MCR stations. Given are the root mean square error (RMSE), bias, and bounds for differences between simulated and observed stages. Results are shown for the previous version of the model (Golder 2013) and for the validation runs done with the current version of the model.

Validation Period	**Parameter**	**Station 1_AS**	**Station 2_AS**	**Station 4**	**Station 5**	**Station 6**
Golder (2013)	Upper Bound (m)	0.42	0.63	0.54	0.3	0.32
	Lower Bound (m)	-0.86	-0.45	-0.43	-0.63	-0.6
	BIAS (m)	0.01	0.07	0.05	0.01	-0.01
	RMSE (m)	0.09	0.14	0.26	0.21	0.11
18-Nov-2012 to 10- Feb-2013	Upper Bound (m)	0.86	0.62	0.16	0.26	0.41
	Lower Bound (m)	-1.75	-2.12	-1.14	-1.27	-0.42
	BIAS (m)	0.09	-0.06	-0.06	-0.05	-0.03
	RMSE (m)	0.22	0.26	0.15	0.22	0.12
11-May-2013 to 06-Nov-2013	Upper Bound (m)	0.72	0.52	0.2	0.12	0.56
	Lower Bound (m)	-1.24	-1.38	-1.03	-1.26	-0.8
	BIAS (m)	0.05	-0.14	-0.19	-0.37	-0.06
	RMSE (m)	0.19	0.29	0.23	0.39	0.19

Table 7 Agreement between simulated and observed stages at the MCR stations for February 11 to May 10, 2013. Given are the root mean square error (RMSE), bias, and bounds for differences between simulated and observed stages. The results are given for two scenarios with different downstream boundary conditions

Scenario	**Downstream Boundary Condition**	**Parameter**	**Station 1_AS**	**Station 2_AS**	**Station 4**	**Station 5**	**Station 6**
1	Uniform-flow depth	Upper Bound(m)	0.72	0.52	0.2	0.12	0.56
		Lower Bound(m)	-1.24	-1.38	-1.03	-1.26	-0.8
		BIAS(m)	0.05	-0.14	-0.19	-0.37	-0.06
		RMSE(m)	0.19	0.29	0.23	0.39	0.19
2	Weekly-minimum level at station 6	Upper Bound(m)	0.72	0.52	0.19	0.15	0.69
		Lower Bound(m)	-1.24	-1.38	-1.03	-1.2	-0.48
		BIAS(m)	0.05	-0.14	-0.19	-0.33	0.14
		RMSE(m)	0.19	0.29	0.23	0.36	0.2

4.3. Discharge, Water Stage and Hydraulic Characteristics

REV Discharge: Before REV 5 went online in 2010, **discharge** from REV fluctuated from 8.5 m^3/s to approximately 1,750 m^3/s with a total range of 1,741.5 m^3/s between highest and lowest seasonal discharge (Figure 4). Following the start-up of REV5 and the implementation of 142 m^3/s minimum flows at the end of 2010, the total range of discharges increased by 266.5 m^3/s to 2,008 m^3/s and ranged from 142–2,150 m^3/s in 2011 and 2012 (Figure 4). This pattern continued in 2012–2013 (Nov 18, 2012–Nov 6, 2013), when discharges fluctuated from 142 m^3/s (end of January 2013, Figure 18, a in Appendix E) to 2,150 m^3/s (Figure 17 to Figure 25, panel a in Appendix E).

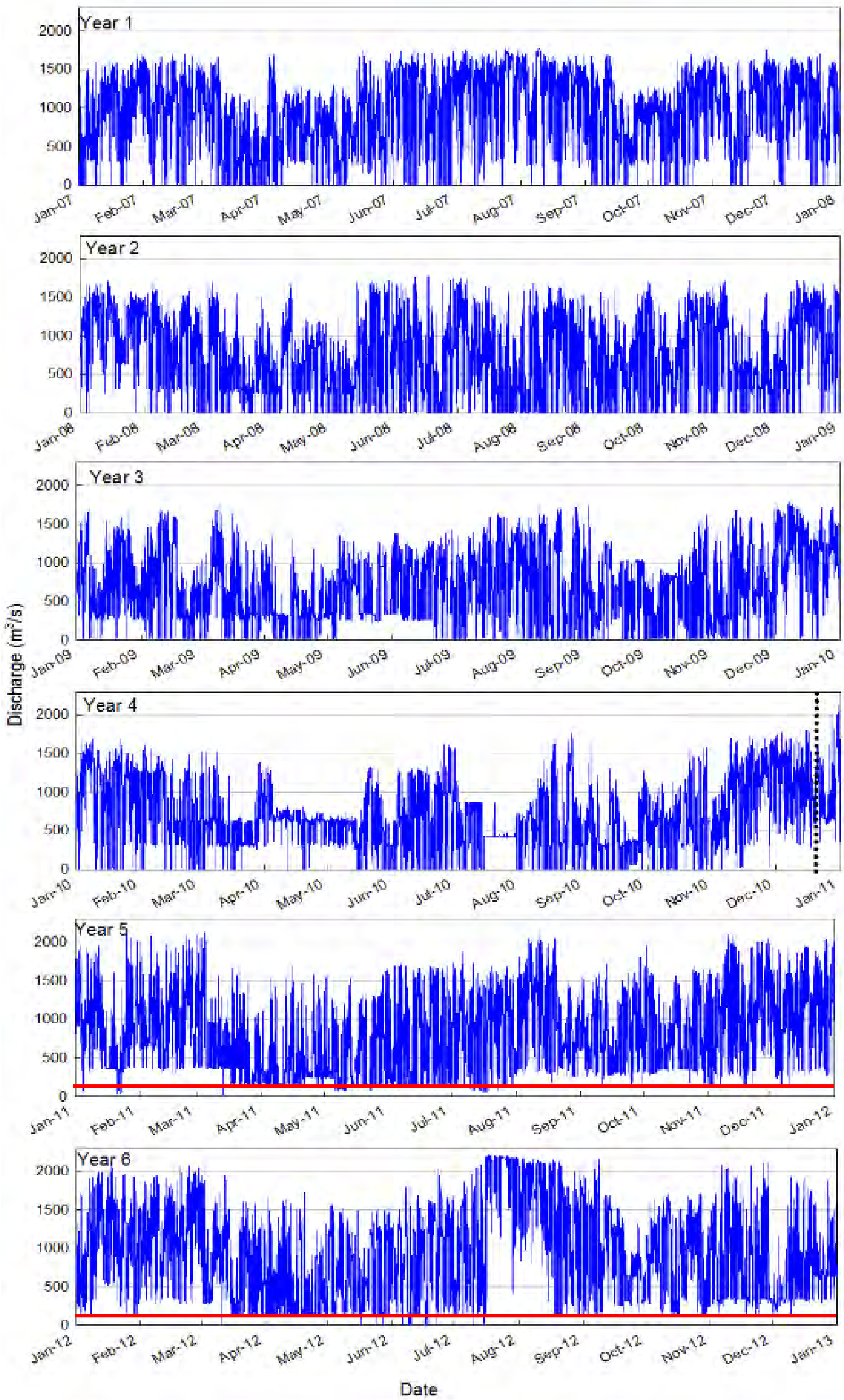

Figure 4 Revelstoke Dam generating stations hourly discharge 2007–2012. REV 5 came online and 142 m^3/s minimum flows (red solid line) were implemented at the end of 2010 (Year 4, black dotted line (Source: modified from Golder 2013).

Diurnal Fluctuations in Flow Depth, Flow Velocity and Wetted Area: In addition to seasonal variations in discharge, there were diurnal fluctuations in the average flow depth, average flow velocity, and wetted area of the modelled river reaches (Figure 17 to Figure 25 in Appendix E). In general, diurnal fluctuations followed the expected pattern of low flows close to the WUP minimum flows at night and high flows during the day.

Over the period of simulation (November 18, 2012, to November 06, 2013), the mean diurnal **wetted area** fluctuated by 1.9 km^2 (or 7% of the mean wetted perimeter (see definition of wetted perimeter in methods, Figure 3). The smallest diurnal fluctuations of 0.1 km^2 in **wetted area** occurred in late June and early July 2013 while the largest diurnal fluctuations of 5.7 km^2 occurred in February and March 2013.

Diurnal fluctuations in **wetted perimeter** were largest in Reach 3 where the mean diurnal fluctuation was 26%. Reach 4 also had relatively large diurnal fluctuations in **wetted perimeter** with a mean diurnal fluctuation of 22%. In Reaches 1 and 2, the mean diurnal fluctuations in wetted perimeter were 2% and 6%, respectively. The smaller fluctuations in Reaches 1 and 2 were based on the stabilizing effect of the ALR.

Over the period of simulation, the mean diurnal fluctuation in **flow depth** of the whole domain was 0.15 m which amounts to 4% of the mean **flow depth**. The average fluctuation in flow depth was small because fluctuations were minimal in Reaches 1 and 2, which were affected by backwatering of the ALR (see Figure 17 to Figure 25 in Appendix E). The maximum diurnal fluctuation in flow depth was 3.9 m (or 50% of the mean flow depth) in Reach 4. Reach 3 also had relatively large diurnal fluctuations with a mean diurnal fluctuation in flow depth of 0.64 m (or 32% of the mean flow depth). For Reaches 1 and 2, the mean diurnal fluctuations in flow depth were 0.02 m (or 2% of the mean flow depth) and 0.04 m (or 4% of the mean flow depths).

Whole Study Period Ranges of Wetted Area, Flow Depth and Flow Velocity: Over the whole study period from November 18, 2012– November 06, 2013, the **wetted area** for the modelled reaches ranged from 11.8– 48.6 km^2 (mean=27.7 km^2)the average **flow depth** ranged from 2.3– 7.5 m (mean=3.9 m), and the average **flow velocity** ranged from 0.1– 1.4 m/s (mean=0.7 m/s)(overview Figure 5, detail for all reaches in Table 12 to Table 15, Table 20 to Table 30 in Appendix F and Figure 17 to Figure 25 in Appendix E). For February 11 to May 10, 2013, these ranges included values of wetted area, average flow depth, and average flow velocity corresponding to the scenario with the weekly-minimum stage at Station 6 applied to the downstream boundary (detail for all reaches Table 20 to Table 23 in Appendix F and Figure 19 to Figure 20 in Appendix D). For the same simulation period with uniform-flow depth applied to the downstream boundary, the lower bound for wetted area was 7.7 km^2, the lower bound for average flow depth was 1.6 m, and the upper bound for average flow velocity was 1.6 m/s (Table 16 to Table 19 in Appendix F). This minimum wetted area of 7.7 km^2 is lower than the value of 10.0 km^2 estimated by Golder (2013) using a steady state model for a flow of 142 m^3/s and low ALR water level. The smaller wetted area of 7.7 km^2 that was obtained with this year's unsteady state model is likely due to smaller flow depths resulting from the lower calibrated Manning roughness coefficients for several parts of the domain (Table 5).

In general, the modeled increase of minimum discharges from 8.5 m^3/s before 2010 to the minimum WUP implemented discharge of 142 m^3/s increased wetted area at minimum flows by approximately 24% over the whole study area (this study and Golder 2013).

Over the period of simulation, the largest mean flow depth of 6.4 m was found in Reach 1, while the smallest mean flow depth of 3.0 m was found in Reach 3. For Reaches 2 and 4, the mean flow depths were 3.6 m and 3.9 m, respectively. The largest mean flow velocity of 1.25 m/s was found in Reach 4, while the smallest mean flow velocity of 0.35 m/s was found in Reach 1. For Reaches 2 and 3, the mean flow velocities were 0.57 m/s and 0.80 m/s, respectively.

Average Monthly Wetted Area, Flow Depth and Flow Velocity: The **maximum monthly average wetted area** was 46.0 km^2 and occurred in July 2013 when the ALR water level was high (437 masl to 440 masl). The **minimum monthly average wetted area** was 18.83 km^2 and occurred in April 2013 (overview Figure 5, reach data for April in Table 18 in Appendix F). The **maximum monthly average flow depth** was 6.3 m and also occurred in July 2013 due to high ALR water level. The **minimum monthly average flow depth** was 2.6 m and also occurred in April 2013 (overview Figure 5, reach details in Table 18 in Appendix F).). The **maximum monthly average velocity** was 1 m/s and occurred in February 2013 due to low ALR water levels and no backwatering combined with high discharges through REV. The **minimum monthly velocity** was 0.32 m/s and occurred in July 2013 due to high ALR levels and backwatering combined with low discharges through REV (overview Figure 5, reach details in Table 18 in Appendix F).

Table 8 summarizes the modeled variations in hydraulic characteristics parameters discussed in the previous paragraphs.

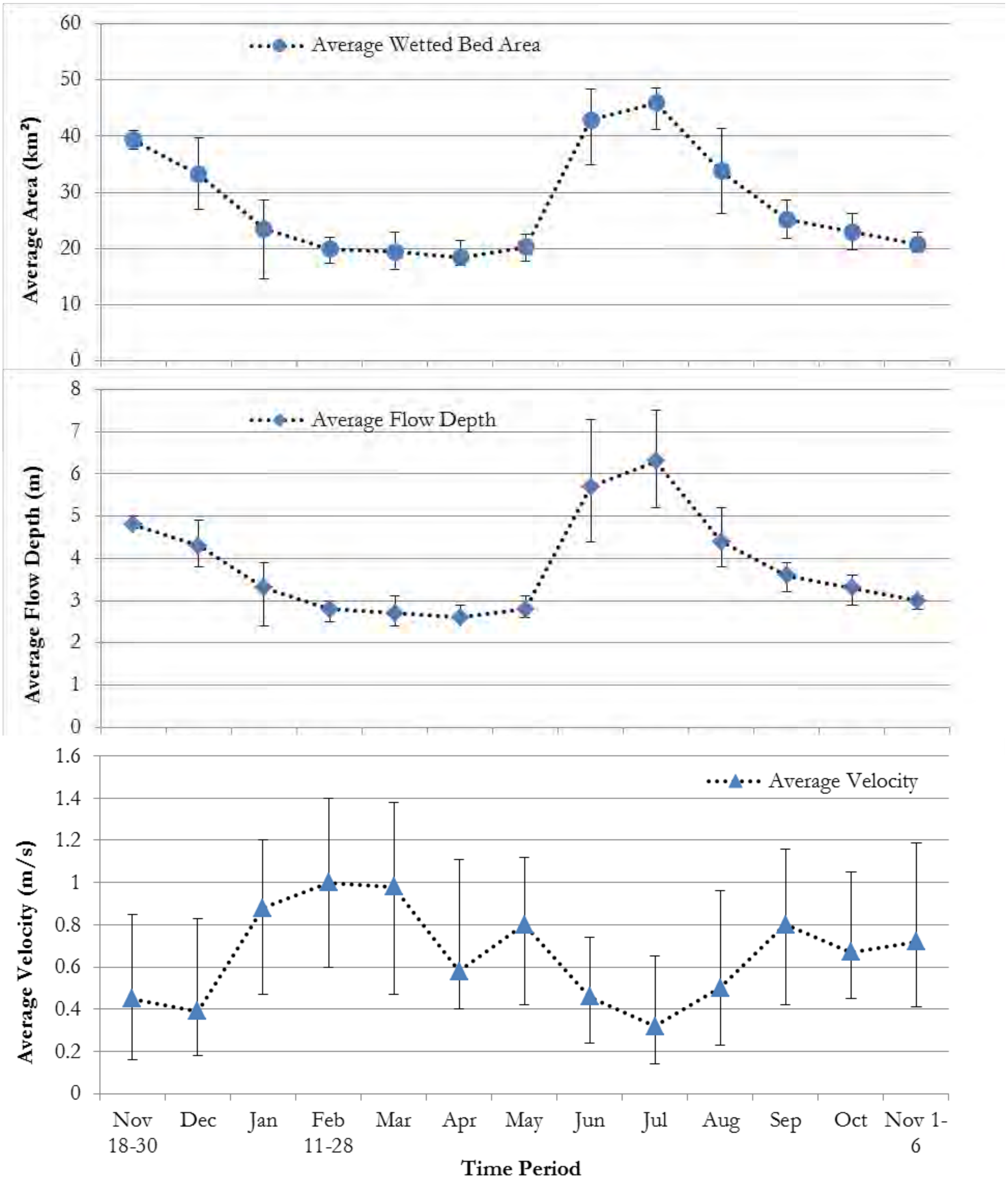

Figure 5 HEC-RAS modeled average wetted bed area (top panel), flow depth (middle panel) and velocity (bottom panel) for MCR reaches 1-4 from November 18, 2012–November 6, 2013. The error bars stand for the maximum and minimum values for each time period.

Table 8 Summary of HEC-RAS modeled variations in wetted area, flow depth and velocity

Hydrological Parameter	Whole	Min	Max
Diurnal Fluctuations			
Wetted Area	Whole Period: 1.9 km²	June-July: 0.1 km²	Feb-March: 5.7 km²
Flow Depth	Whole Study Area: 0.15 m	Reach 1: 0.02 m (or 2% of mean flow depth)	Reach 4: 3.9 m (or 50% of mean flow depth)
Fluctuations over the Whole Study Period (All Reaches)			
Wetted Area	27.7 km²	11.8 km²	48.6 km²
Flow Depth	3.9 m	2.3 m	7.5 m
Velocity	0.7	0.1	1.4
Reach Average Min and Max of Flow Depth & Velocity (Whole Study Period)			
Flow Depth		Reach 3: 3 m	Reach 1: 6.4 m
Velocity		Reach 1: 0.35 m/s	Reach4: 1.25 m/s
Monthly Average Min and Max of Wetted Area & Flow Depth (All Reaches)			
Wetted Area		July 2013 (high ALR): 46 km²	April 2013 (low ALR); 9.7 km²
Flow Depth		July 2013 (high ALR); 6.3 m	April 2013 (low ALR): 2 m

4.4. HEC-RAS Model Summary and Recommendations

The HEC-RAS hydraulic model for the Mid-Columbia River was updated to include new data for November 2012 to November 2013. The model was calibrated by adjusting the Manning roughness coefficients to improve the agreement between simulated and observed water surface levels at five stations along the Mid-Columbia River. The performance of the model was validated by running the model for the length of the data record from November 2012 to November 2013. The performance of the updated model is comparable to that of the previous version (which was validated with data for only ~4 weeks).

Data from Station 3 (Tailrace-7km) were not available and were not used in calibrating and validating the model for 2012/2013. It is recommended that monitoring stage at this station be continued and that these stage data be used for future calibration and validation of the HEC-RAS model. Using the data from this station will improve the calibration results for the model and increase confidence in the calibrated Manning roughness coefficient for Reach 3 where the station is located.

Model calibration suggests that, in the previous version of the model, the elevation of cross-sections between Station 2 and Station 4 is inaccurate or is changing with time. To maintain model reliability, cross-section surveys are recommended for the section between Station 2 and Station 4.

4.5. Temperature Variation Results and Discussion

When comparing the annual water temperature variations between index stations in the MCR and index stations in two of its tributaries, a clear trend is apparent (Figure 6). The water discharged through REV is taken from the hypolimnetic layer of the water column in Revelstoke Reservoir and therefore warmer than the naturally fed Jordan and Illecillewaet rivers in the winter and spring and colder in summer and fall (Figure 6). Winter water temperatures from January–March ranged from 2–4 ˚C at the MCR stations but only 0–2 ˚C in the tributaries. Temperatures from July–September at the tributary index stations ranged from 10–14 ˚C and from 10–12 °C at the MCR index stations.

In the spring and summer, the day and night temperature differences were more pronounced than in fall and winter. This phenomenon can be seen in little diurnal temperature variation in the MCR stations in the fall and winter when compared to spring and summer (Figure 6).

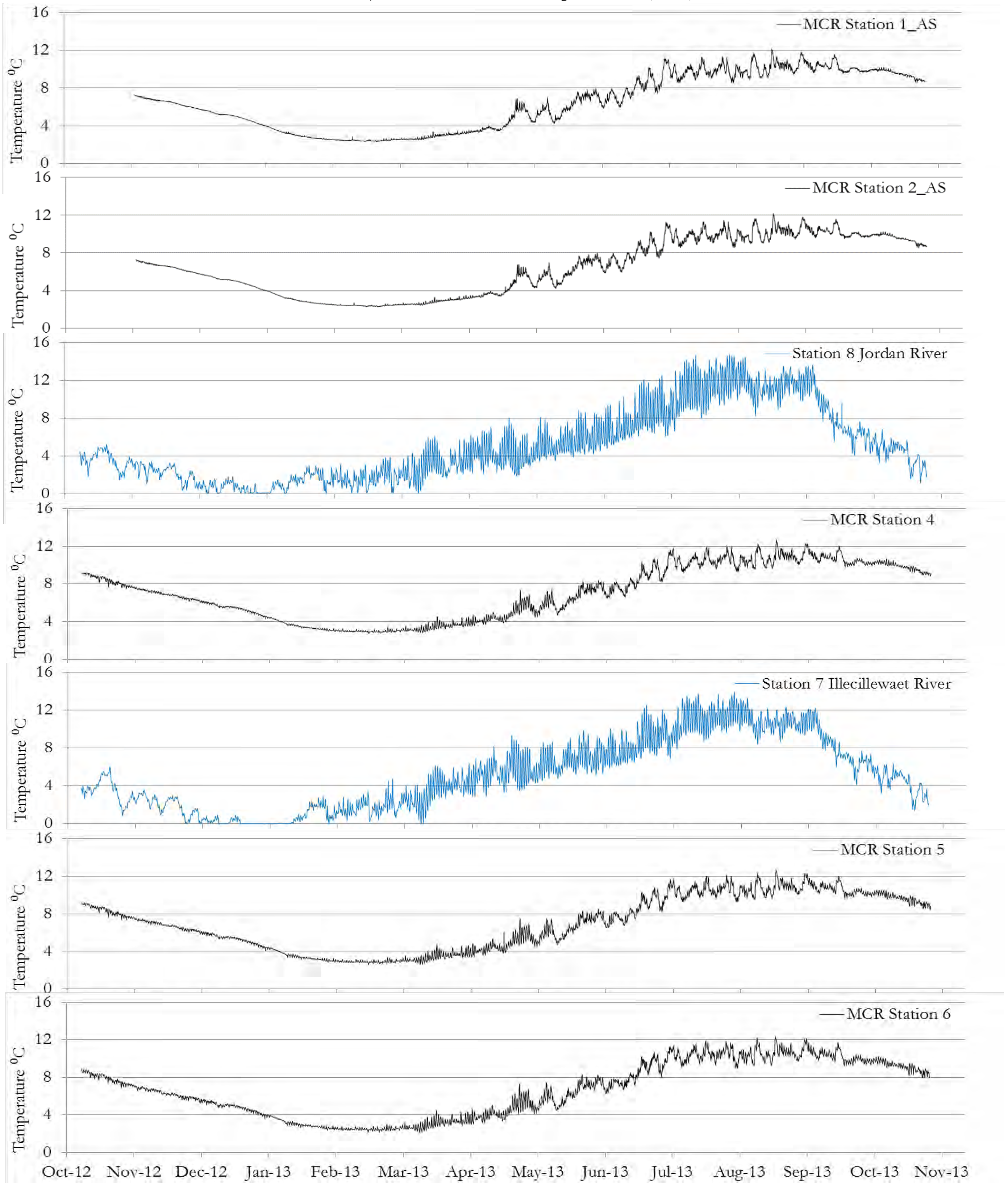

Figure 6 Water temperatures at 5 MCR and 2 tributary (Jordan and Illecillewaet Rivers) index stations from Oct 2012–Nov-2013.

Overall, daily water temperature fluctuations were also greater for the two naturally fed tributaries. The temperature patterns found in 2013 closely resembled temperature patterns found from 2007–2012 and stayed consistent pre- and post-minimum flow application (this study, Golder 2013). It is therefore it is assumed that the WUP implemented minimum discharge did not affect the general temperature pattern over the whole study period and all reaches. The annual temperature variation pattern in the MCR appears to be more affected by the contribution of tributary waters that are colder in winter and warmer in the summer. Therefore the annual temperature range for Stations 4–6 (influenced by Jordan and Illecillewaet Rivers) was larger than for Stations 1 and 2 (no tributary effect).

Water temperature analyses post-implementation of the WUP minimum flow of 142 m^3/s assessed the effect of flow fluctuations on daily temperature variation and showed a decrease in diel variation of 0.1–0.4 ˚C (Golder 2013). Models to assess the hourly water temperature variations in response to discharge pre- and post-minimum flow implementation had poor fit and predictive ability and did not show an effect (Golder 2013). Other programs initiated under the WUP are tasked to show whether such a small change in diel temperature variation will have ecological effects.

5. SEASONAL WATER QUALITY MONITORING

The seasonal water quality sampling program was meant to give an indication of the general annual productivity trends in the MCR and its two tributaries Illecillewaet and Jordan Rivers based on three annual samples in the spring, summer and fall. This low sampling frequency makes it highly questionable that annual trends in productivity can be observed or that pre- and post-minimum flow differences can be detected. Nevertheless, water quality sampling and analysis were carried out in 2013 and all previous years (2007–2012) of CLBMON-15a (Golder 2013).

5.1. Water Quality Sampling Stations and Schedule

Water samples were collected three times in 2013 from the 5 MCR index sites and the two index sites at the tributaries (Jordan and Illecillewaet Rivers) (Figure 2). No samples were taken at MCR Station 3 in 2013 because the stage and temperature logger could not be located in the field and therefore it was unclear to the field crew where previous water samples had been taken. If seasonal water sampling is to be continued in 2014, samples from MCR Station 3 will be again included as they were in all other years (2007–2012) of this project (Golder 2013). MCR Index locations were chosen to be in close proximity of the periphyton/benthic substrate sites for MCR Ecological Productivity Monitoring CLBMON-15b. Table 9 shows the schedule for the 2013 physical parameter measurements and the collection of water samples and Table 10 outlines the water quality parameters either measured *in situ* or analysed in a laboratory from collected water samples.

Table 9 Field schedule of the 2013 *in situ* physical water parameter measurements and water sample collections for laboratory analysis.

Date mm/dd	Arrival Time (24h)	Location Name
30-Apr	10:12	MCR Station #6
30-Apr	12:39	MCR Station #5
30-Apr	14:21	MCR Station #4
30-Apr	16:10	MCR Station #1
30-Apr	18:22	MCR Station #2
1-May	9:30	Illecillewaet River Station #7
1-May	14:12	Jordan River Station #8
29-Sep	10:00	Jordan River Station #8
29-Sep	13:20	MCR Station #4
29-Sep	14:35	MCR Station #5
29-Sep	15:32	MCR Station #6
29-Sep	23:00	MCR Station #2
30-Sep	1:52	MCR Station #1
30-Sep	15:00	Illecillewaet River Station #7
5-Nov	9:58	Jordan River Station #8
5-Nov	14:45	Illecillewaet River Station #7
6-Nov	0:16	MCR Station #2
6-Nov	1:19	MCR Station #1
6-Nov	12:02	MCR Station #4
6-Nov	12:57	MCR Station #5
6-Nov	13:20	MCR Station #6

Table 10 Physical parameters measured and nutrient parameters analysed in a laboratory for the 2013 season.

Physical Parameters: In-Situ Measurement	Nutrients: Samples Collected for Analysis at Water Chemistry Laboratory
Temperature (°C)	Nitrate
Conductivity. (μS/cm)	Ammonia
Specific Conductivity (μS/cm)	Total Kjeldahl Nitrogen
Total Dissolved Solids (mg/L)	Total Nitrogen
Dissolved Oxygen Saturation (%)	Total Phosphorus
Dissolved Oxygen Absolute (mg/L)	Total Dissolved Phosphorus
pH	Total Soluble Reactive Phosphorus
Turbidity (NTU)	Total Dissolved Solids
	Total Suspended Solids

5.2. Water Quality Sampling Methods

All water samples for laboratory analysis (Table 10, right column) were collected as follows:

1. The 1 L and the 150 mL water sampling bottles were pre-labelled and transported to the sampling locations with tightly closed lids to avoid contamination.
2. The sampling protocol for 1 L and 150 mL bottles was the same.
3. At each site the sampling bottle was opened and rinsed out three times with the sampling water before the actual sample was taken.
4. Samples were always taken upstream of the sampler, boat and all other sampling equipment and in a depth of 30 cm from the surface in steady flow. During sampling it was ensured that no disturbed sediment was collected.
5. Once filled, the sample bottles were immediately closed and stored in a cooler with ice at a temperature of <7 °C.
6. The 150 mL bottle was filled for the analysis of Soluble Reactive Phosphorus and the water for rinsing and the actual sample itself were filtered through a 45 µm filter attached to a Luer-Taper on a 100 mL syringe.
7. While Soluble Reactive Phosphorus was analysed out of the 150 mL filtered sample, all other parameters (Table 10, right column) were analysed out of the 1 L sample.
8. All samples were delivered to CARO Analytical Services in Kelowna, BC (#102-3677 Highway 97N, V1X 5C3) within 48 hours of sampling and kept at a temperature below 7 °C. Upon arrival, CARO contacted LGL Ltd. and confirmed sample temperature and condition.

In the past, the Department of Fisheries and Oceans Cultus Lake Salmon Research Laboratory near Chilliwack, BC was contracted for low level nutrient analysis but this option was not available in 2013. Therefore all samples were analysed by CARO Analytical Services. Lowest possible reporting limits, analysis methods and storage details for all parameters are shown in Table 11.

Table 11 Nutrient parameter sampling, storage and analysis detail.

Parameter	Sampling Jar	Preservation	Storage	Holding Time	Comments	Lowest Possible Reporting Limit	Analysis Method	Method Reference
Nitrate	1 L	No	Under 10 °C	3 days		0.004 mg/L	Colorimetric	EPA 353.2
Ammonia	1 L	No	Under 10 °C	3 days		0.005 mg/L	Colorimetric	APHA 4500-NH3 G
Total Kjeldahl Nitrogen	1 L	No	Under 10 °C	3 days		0.023 mg/L	Colorimetric	EPA 821-R-01-004
Total Nitrogen	1 L	No	Under 10 °C	3 days		0.05 mg/L	Colorimetric	EPA 351 - 351.4
Total Phosphorus	1 L	No	Under 10 °C	3 days		0.001 mg/L	Colorimetric, Kjeldahl Digestion	EPA 365.4
Total Dissolved Phosphorus	1 L	No	Under 10 °C	3 days		0.001 mg/L	Colorimetric, Kjeldahl Digestion	EPA 365.4
Soluble Reactive Phosphorus	150 mL	No	Under 10 °C	3 days	Filter in the field, 45 µm filter	0.002 mg/L	Colorimetric	APHA 4500-P D
Total Dissolved Solids	1 L	No	Under 10 °C	7 days		5 mg/L	Gravimetric	APHA 2540 C
Total Suspended Solids	1 L	No	Under 10 °C	7 days		1 mg/L	Gravimetric	APHA 2540 D

5.3. Water Quality Data Analysis Methods

Three water samples or measurements taken per year can be used to give an indication of the condition of the MCR at the index stations or its two tributaries, but this sampling frequency is too low to determine statistical differences between years, stations or sampling times. This sampling frequency is also too low to pick up any potential effects directly related to the WUP minimum flows combined with a larger range of flows based on REV 5. The low sampling frequency and inherent variability of water quality with climate and hydrologic events also prevents an accurate examination of the variability of water quality concentrations with flows or other factors. For example, water quality in the Jordan River fluctuates following every average precipitation event and is highly dependent on snow run-off. Illecillewaet River water quality is even more variable due to the strong glacial contribution to its flow. During warm and sunny summer days glacial streams typically increase in flow and Total Suspended Sediment and many other parameters fluctuate because of increased glacial run-off. In the context of CLBMON-15a, the water quality and physical parameter results at the index stations are used as indicators of the general status on a certain date. Nutrient and physical parameter values are therefore graphically presented without statistical analysis or detailed comparisons to previous years, other stations or changes in discharge from REV.

5.4. Seasonal Water Quality Results and Interpretation

In Situ Measurements of Physical Parameters

Temperature: Temperatures on each of the three sampling dates in spring, summer and fall showed minor differences between the five index stations. In general, temperatures increased from spring to summer and then decreased in the fall of 2013 (Figure 7, top left panel). Temperatures ranged from 4 °C in the spring to 10.3 °C in the fall. Based on the glacial and snow run-off that enters the Jordan River and especially the Illecillewaet River, temperatures measured in those two systems were ~3.2 °C in the spring, increased to a high of ~10.3 °C in late summer and decreased to a much lower temperature of ~1.61 °C in the fall (Figure 8, top left panel).

Conductivity: The conductivities in the five MCR index stations and the Illecillewaet River were similar and ranged from 0.12–0.18 µS/cm over the three seasons (Figure 7, top right panel, Figure 8, top right panel). The conductivity measured in the very nutrient poor Jordan River was even lower and ranged from 0.036–0.06 µS/cm (Figure 8, top right panel). The patterns and values with regards to variations by season and among stations were very similar for specific conductivity (Figure 7, second from top row, left panel, Figure 8, second from top row, left panel).

Total Dissolved Solids (TDS): Over the three seasons, TDSs values were low and stable in the five MCR index stations and the Illecillewaet River but lower in Jordan River (Figure 7, second from top row, right panel, Figure 8, second from top row right panel).

Dissolved Oxygen (DO): DO saturation and total DO values were typical of oligotrophic riverine systems. DO saturation and total DO values in the MCR index stations ranged from 95–104 % and

11–13 mg/L, respectively over the three seasons and all stations (Figure 7, third from top row, left and right panel). Over the three seasons, DO saturation and total DO values in the Illecillewaet and Jordan rivers ranged from 97–116 % and from 12–15 mg/L, respectively with Jordan River showing consistently lower values than Illecillewaet River (Figure 8, third from top row, left and right panel).

pH: pH Values for the five MCR Index stations and the Illecillewaet River were quite consistent and ranged from pH 7.8–8.1 (Figure 7, bottom panel, Figure 8, bottom panel). These slightly alkaline values were similar to the pH values measured by Golder (2013) in 2012 and appear to be typical for MCR and its tributaries. The pH values for Jordan River were slightly lower and ranged from 7.4-7.9 (Figure 8, bottom panel) but within the range observed for Jordan River in 2012 (Golder 2013).

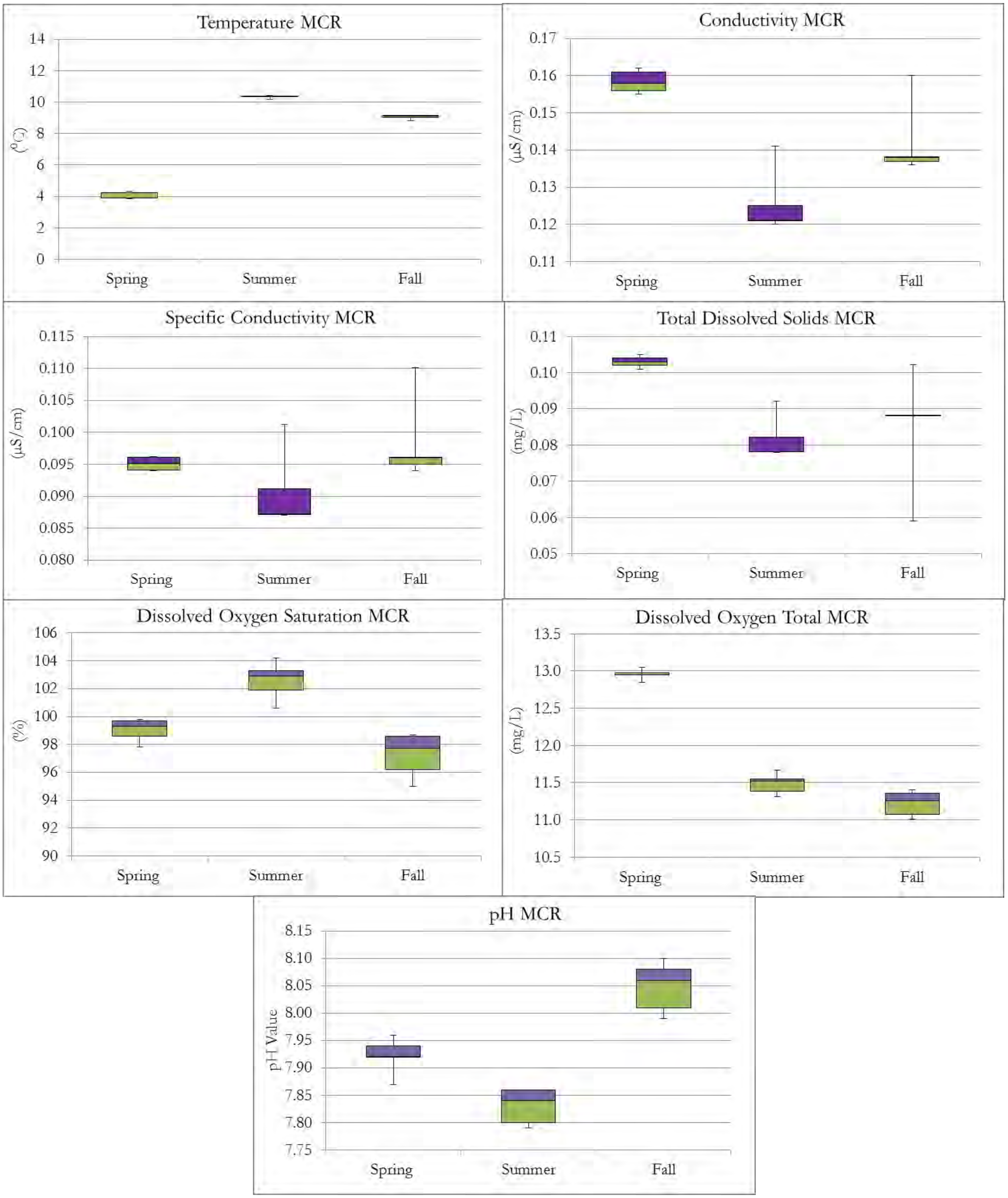

Figure 7 Results for physical parameters measured in situ at the five MCR index stations in 2013 (lower error bar = minimum–25% percentile, green box = 25%–median, purple box = median–75% percentile, upper error bar = 75% percentile–maximum).

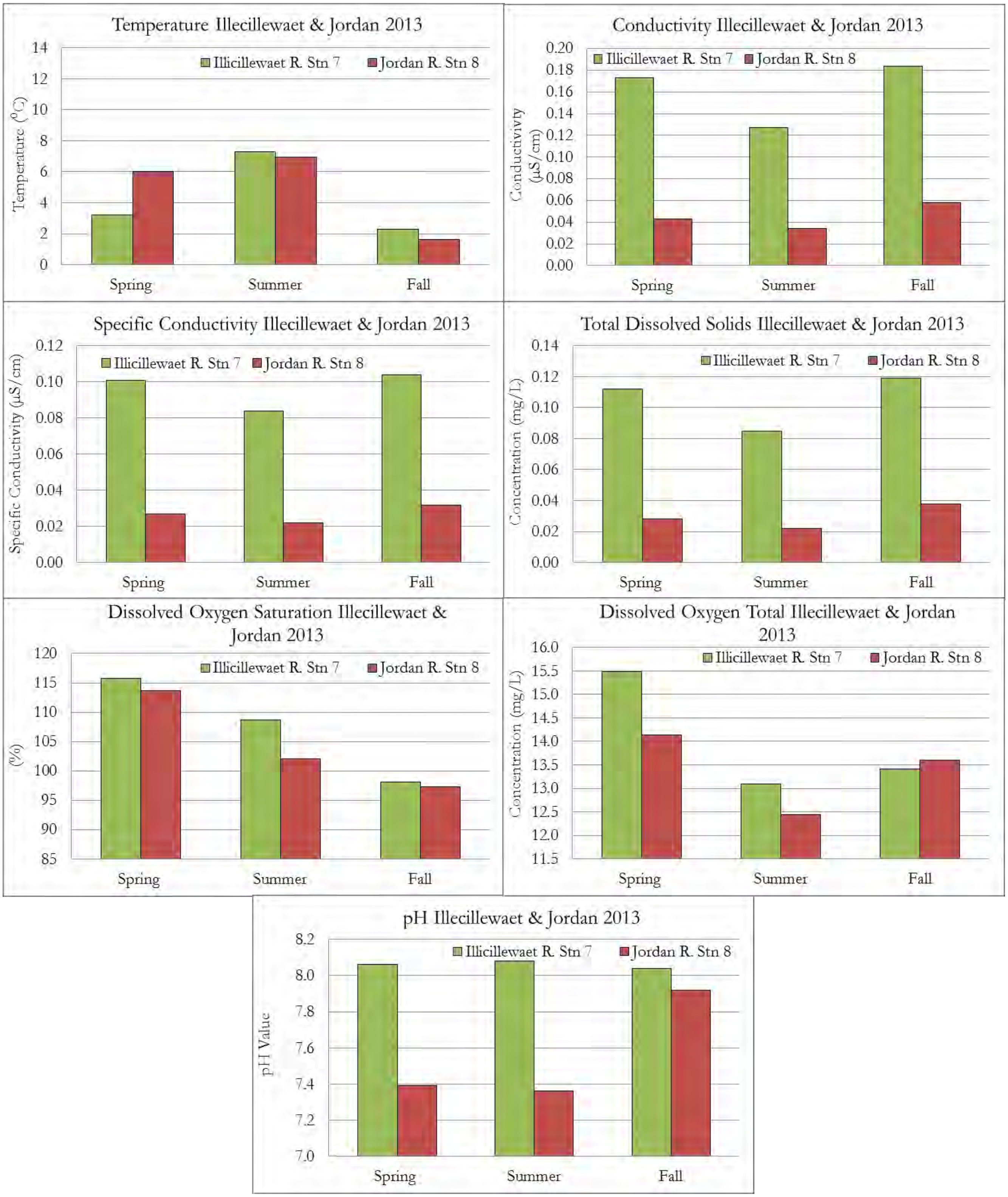

Figure 8 Results for physical parameters measured in situ at the Illecillewaet and Jordan River index stations in 2013.

Laboratory Analysis of Nutrient Parameters

Nitrate: Nitrate concentration samples collected at the MCR index stations showed little variability between sampling dates started from low values in the spring (93–103 µg/L) to slightly higher values in late summer (112–121 µg/L) and fall (107–122 µg/L) (Figure 9, top left panel). Nitrate concentrations in the Illecillewaet and Jordan rivers were higher than in the MCR throughout the year but particularly in the spring (402 µg/L Illecillewaet, 356 µg/L Jordan) (Figure 10, top left panel).

Ammonia: In the spring of 2013, Ammonia concentrations were below the detection limits in the MCR, and Illecillewaet and Jordan rivers (Figure 9, top right panel, Figure 10, top right panel). For the late summer sampling date, the Ammonia concentration rose to a range of 0–44 µg/L in the MCR and stayed below the detection limit in the tributaries. The MCR fall water samples had Ammonia concentrations ranging from 44–73 µg/L while the concentrations in the Illecillewaet and Jordan rivers rose to 59 and 73 µg/L, respectively.

Total Kjeldahl Nitrogen (TKN) and Total Nitrogen (TN): Both forms of Nitrogen in the MCR were higher in the spring (TKN: 164–570 µg/L; TN: 6—480 µg/L) and then decreased in the late summer (TKN: 112–180 µg/L; TN: 0–60 µg/L) and fall (TKN: 195–275 µg/L; TN: 90–160 µg/L) (Figure 9, second row from top). TKN and TN concentrations behaved in a similar pattern in the Illecillewaet and Jordan rivers. TKN and TN concentrations in the Illecillewaet River were high in the spring (TKN: 688 µg/L; TN: 290 µg/L) and then decreased in the late summer (TKN: 198 µg/L; TN: 60 µg/L) and fall (TKN: 277 µg/L; TN: 130 µg/L) (Figure 10, second row from top). Similarly, TKN and TN concentrations in the Jordan River were high in the spring (TKN: 933 µg/L; TN: 580 µg/L) and then decreased in the late summer (TKN: 417 µg/L; TN: 180 µg/L) and fall (TKN: 305 µg/L; TN: 120 µg/L) (Figure 10, second row from top).

Total Phosphorus (TP) and Total Dissolved Phosphorus (TDP): TP and TDP in the MCR and the tributaries showed a similar pattern for the three sampling dates. TP and TDP were low in spring, decreased in late summer and fell back to spring levels in fall (Figure 9, third row from top, Figure 10, third row from top). Within this pattern, TP concentrations ranged from 2–35 µg/L in the MCR and from 4–47 µg/L in the Illecillewaet and Jordan rivers. TDP concentrations ranged from 0-25 µg/L in the MCR and 2–34 µg/L in the Illecillewaet and Jordan rivers.

Total Dissolved Reactive Phosphorus (TDRP): In general, TDRP concentrations were low, ranging from 0–14 µg/L in the MCR and 0–6 µg/L in the Illecillewaet and Jordan rivers (Figure 9, bottom panel, Figure 10, bottom panel). The TDRP concentrations for the MCR and the tributary stations in the fall were all 0 µg/L. They are therefore invisible in the graphs.

All nutrient concentrations measured in 2013 were similar to the range of nutrient concentrations measured in 2012 (Golder 2013).

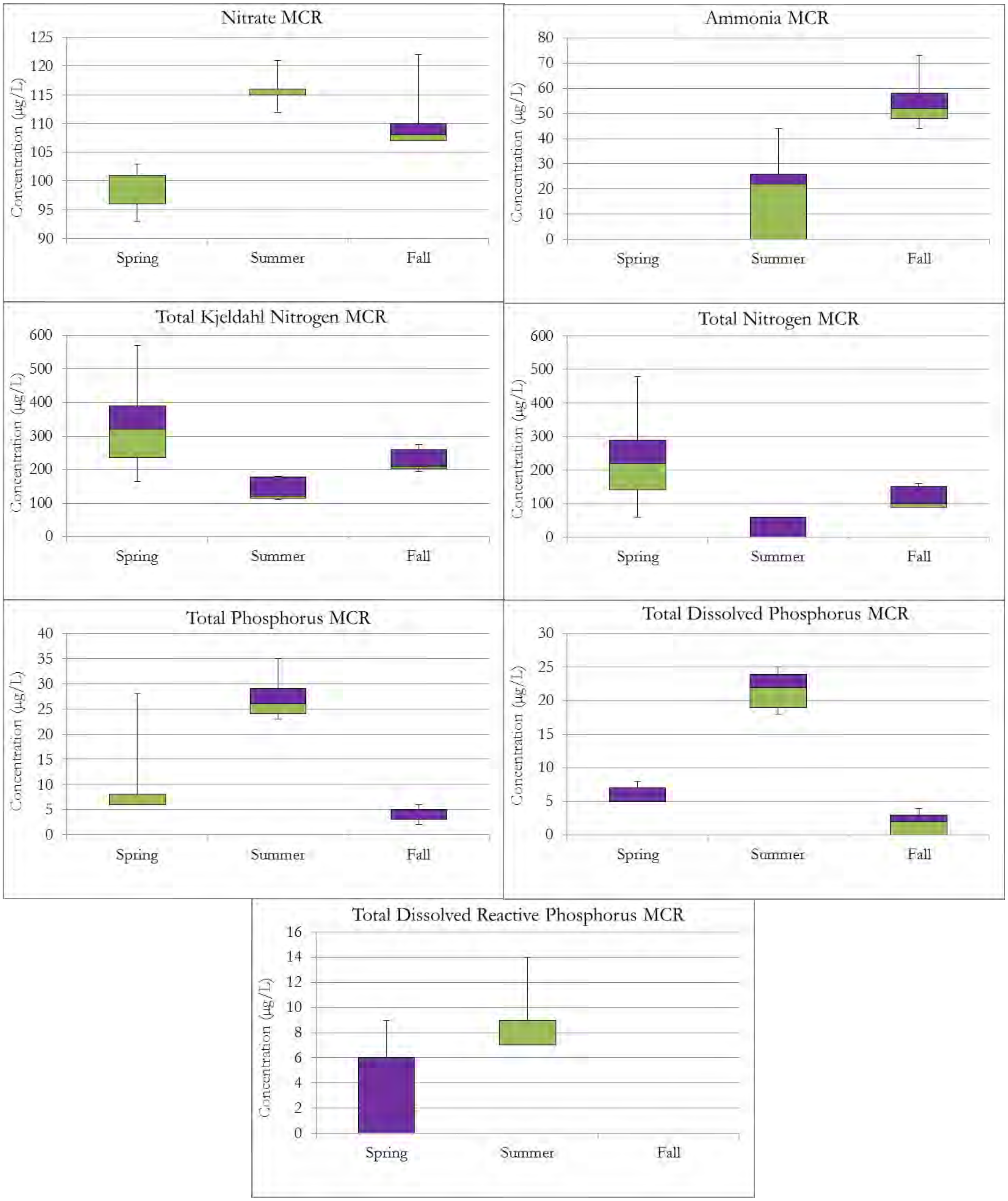

Figure 9 Results for nutrient concentrations at the five MCR index stations in 2013 (lower error bar = minimum–25% percentile, green box = 25%–median, purple box = median–75% percentile, upper error bar = 75% percentile–maximum).

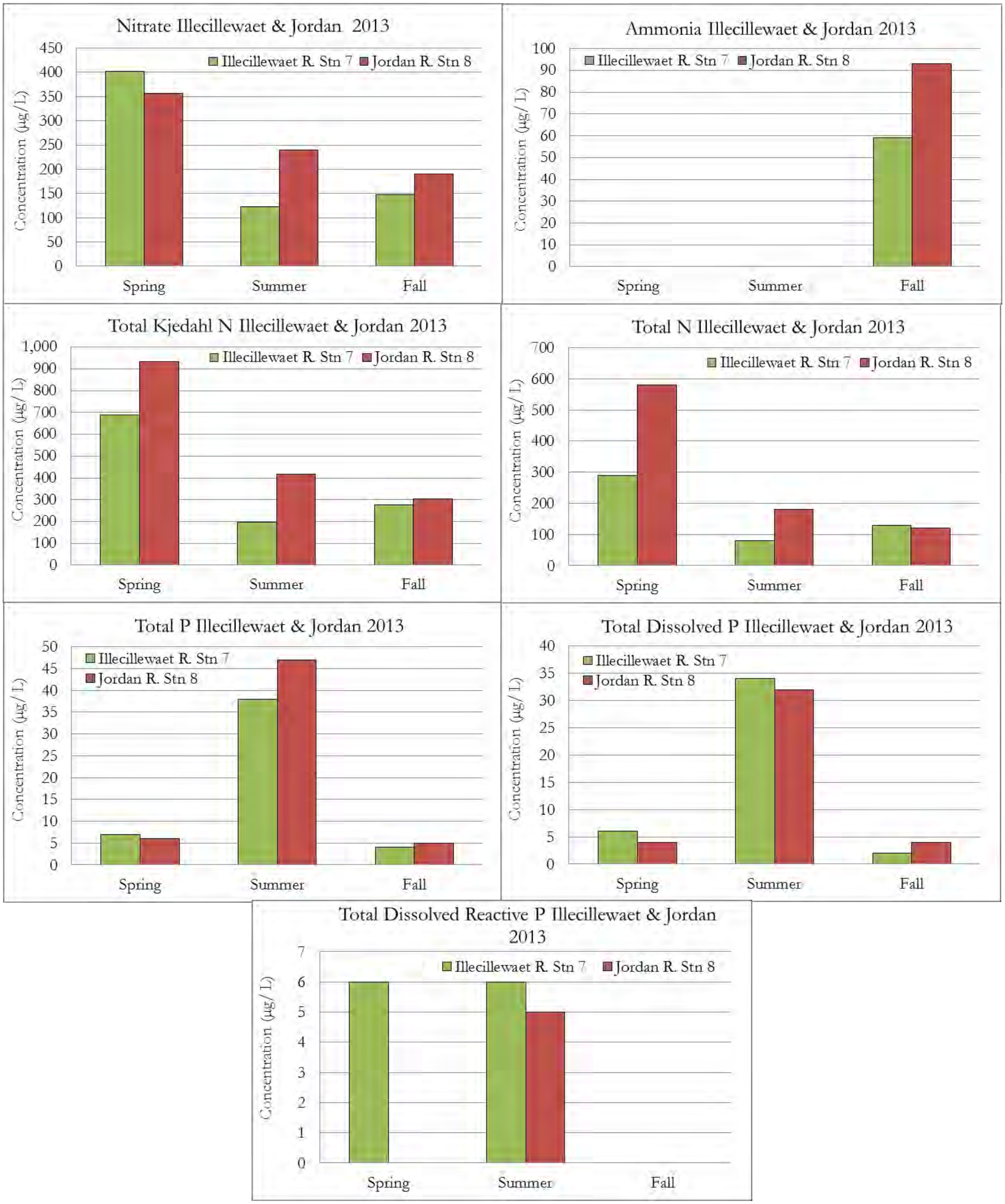

Figure 10 Results for nutrient concentrations in water samples collected at the Illecillewaet and Jordan River index stations in 2013.

Laboratory Analysis of Physical Parameters

Total Dissolved Solids (TDS): TDS concentrations at MCR (range: 66–104 mg/L) and Illecillewaet River (range: 82–100 mg/L) stations were similar and did not show great variability within sampling locations or sampling dates (Figure 11, top panel, Figure 12, top panel). TDS concentrations in Jordan River were much lower throughout the year and ranged from 23–33 mg/L.

Total Suspended Solids (TSS): TSS values were generally very low throughout all sampling dates and locations and ranged from 0–4 mg/L aside from one sample that was taken in the Jordan River in late summer following a strong overnight rainfall that elevated the TSS concentration to 27 mg/L (Figure 11, second panel from top, Figure 12, second panel from top).

Turbidity: Turbidity in samples from the MCR and the tributaries was very low in the spring and fall and higher in the summer (Figure 11, second panel from bottom, Figure 12, second panel from bottom). Within this general pattern, turbidity ranged from 0.3–2.1 NTUs in the MCR and from 0.2–7 NTUs in the Illecillewaet and Jordan rivers.

pH: pH values at the MCR index and Illecillewaet River stations were quite stable within locations and seasons and ranged from pH 7.69–7.95 (Figure 11, bottom panel, Figure 12, bottom panel). In comparison, pH values for the Jordan River were slightly lower for all three sampling dates and ranged from pH 7.23–7.54. These slightly alkaline pH values were also observed as part of the in-situ measurements of this study and in 2012 (Golder 2013) and appear to be typical for the MCR area.

Conclusions

Based on the low sampling frequencies for physical and nutrient parameters, a statistical analysis of the potential effects of the WUP flows was not advisable. As described above, physical and nutrient parameters were sampled to provide a very general indication of seasonal values and did not represent an accurate representation of the range in values within each season. In addition, the collection of point samples three times per year cannot indicate any effects of the WUP 142 m^3/s minimum flows or the higher maximum discharges through REV based on the installation of REV 5.

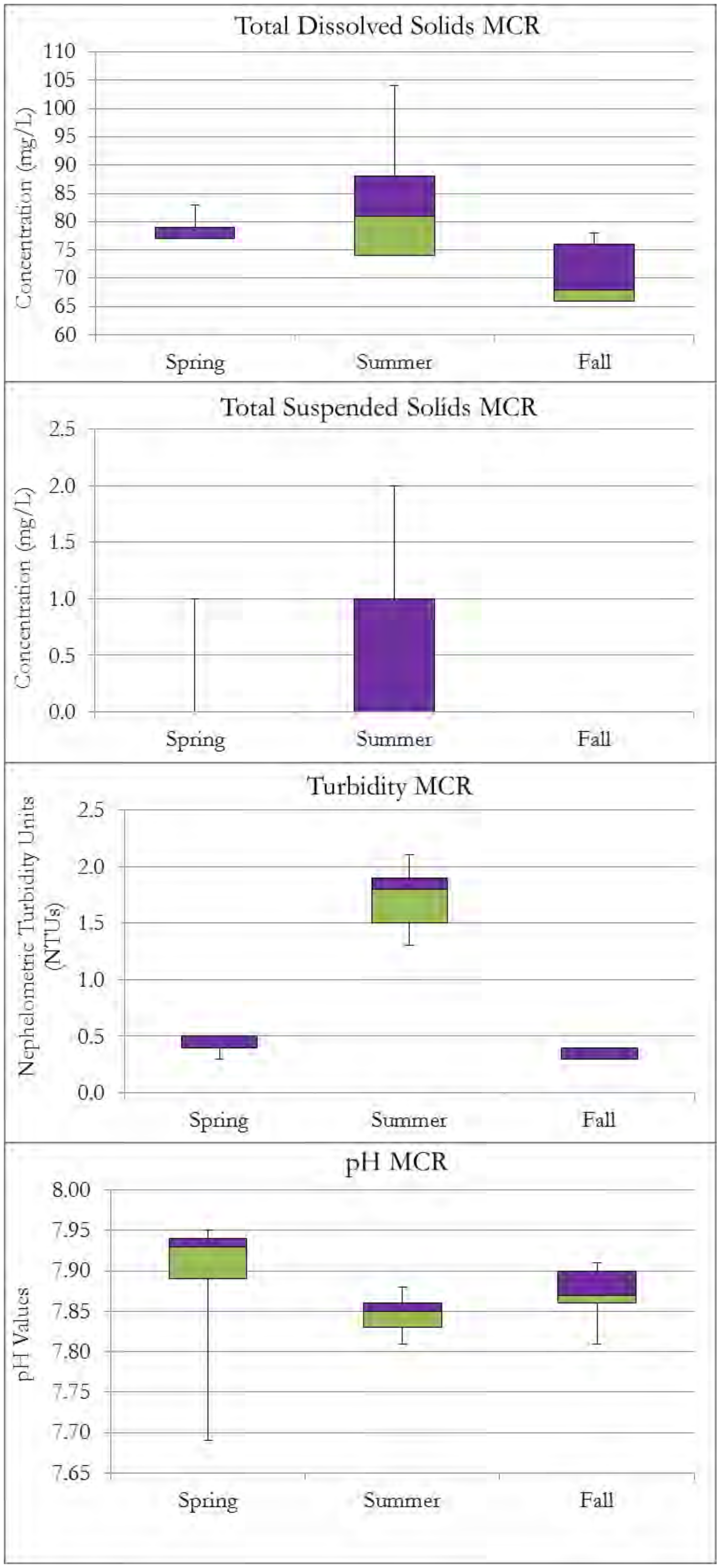

Figure 11 Results for TDS, TSS, turbidity and pH measured in water samples taken at the five MCR index stations in 2013.

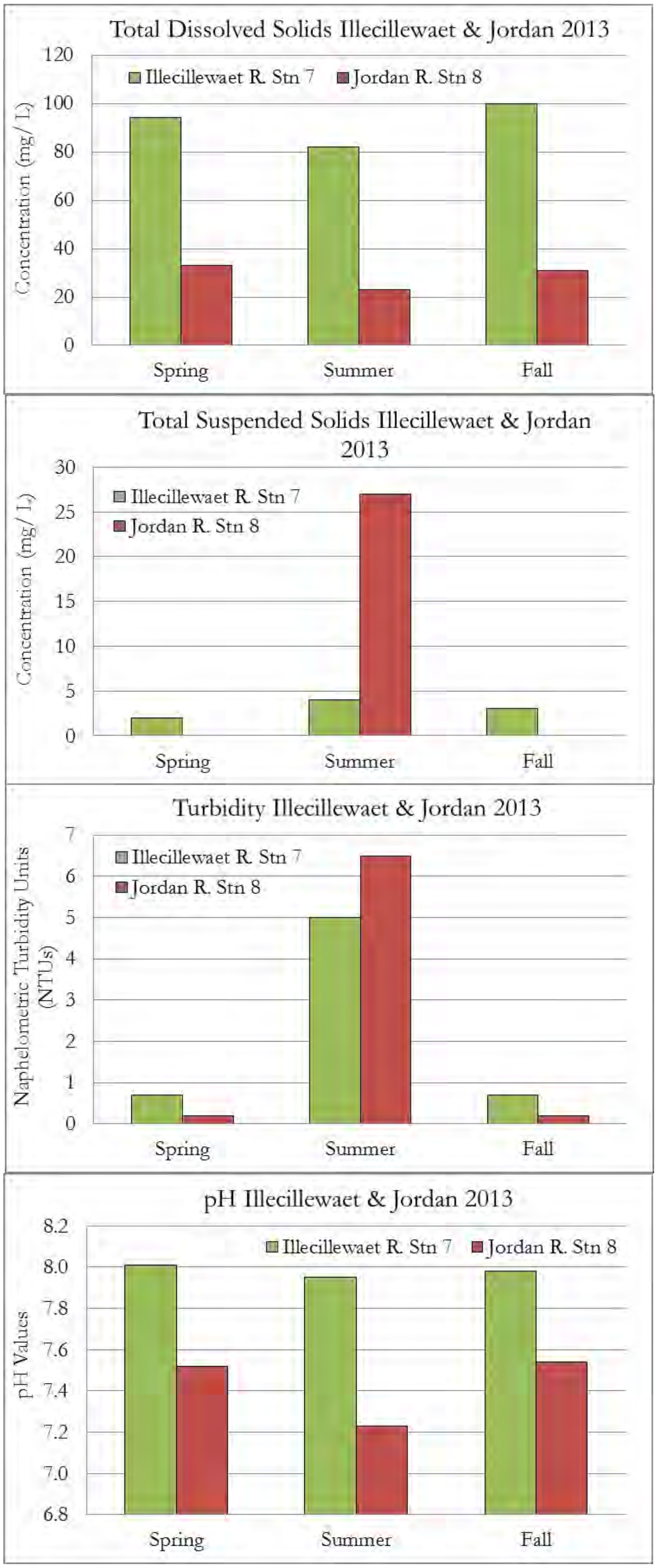

Figure 12 Results for TDS, TSS, turbidity and pH measured in water samples taken at the Illecillewaet and Jordan River index stations in 2013.

6. RECOMMENDATIONS

On February 19, 2014, BC Hydro held a review meeting with all consultants that are working within the Revelstoke Flow Management Plan (RFMP) CLBMON program and solicited suggestions for scope changes to the program for the final 4 years, from 2014 to 2017. As part of CLBMON-15a, stage data collected in the MCR, Illecillewaet and Jordan River index stations over the last seven years have been used to calibrate a HEC-RAS model to predict flows, water depths and wetted width for the MCR Reaches 2–4. Based on this extended calibration phase, it appears that the predictive power of the HEC-RAS model is now highly accurate. It is recommended that the focus of CLBMON-15a should be shifted from *in situ* data collection to calibrate the HEC-RAS model to the application of the HEC-RAS model to produce information for the other programs under the CLBMON-15 umbrella. The following technical changes were suggested at the review meeting:

1. The HEC-RAS model is highly accurate in its prediction of water depth, current velocity and wetted width for the MCR Station 1, the closest index station to REV. This is not surprising since the MCR at this station only receives regulated discharge from REV without any unpredictable tributary contributions. Therefore, no further calibration of the HEC-RAS model output for Station 1 is necessary and the standpipe and anchor stations at Station 1 should be dismantled and removed.
2. Only two annual downloads of the MCR and tributary stations are needed to avoid overloading the memory of the Solinst stage and barologgers and the TidBit temperature loggers. Therefore, we recommend that the number of field trips to download the loggers be reduced from three to two. Funds saved from this reduction in field trips can be applied to produce project-specific HEC-RAS output, as requested at the review meeting.
3. In 2013, the data from Station 3 in Reach 4 of the MCR was not accessible for calibration of the HEC-RAS model. If possible and available, data from Station 3 (the station is serviced and data is downloaded by BC Hydro) should again be used for future runs of the HEC-RAS model.
4. The HEC-RAS model should be used to produce a table and maps that correlate the discharge from REV, MCR tributaries and the stage data for ALR with the wetted width and precise extent of the MCR for the locations of the 234 cross sections in Reaches 1–4. At this time, the HEC-RAS model is used to estimate the total wetted riverbed area for MCR Reaches 1–4 relative to the discharge from REV and its tributaries. This geo-referenced information produced by the HEC-RAS model can be used as input to models that estimate for how long every day an instrument, sampling equipment or fish habitat was submersed throughout the year or a particular sampling season.

7. REFERENCES

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APPENDIX A:
2013 SITE VISIT AND MAINTENANCE DATA

Date mm/dd	Arrival Time (24h)	Location Name	Station #	UTM Zone: 11		Stage Out	Stage Back In	Stage Batt. Left %	Stage Memory Left %	Time Sync.	Baro Out	Baro Back In	Baro Batt %	Baro Memory %	Time Sync.	Tidbit Out	Tidbit Back In	Tidbit Batt %	Tidbit Memory %	Time Sync.	Comments
30-Apr	10:12	MCR Station #6	6	417171	5642074																
30-Apr	12:39	MCR Station #5	5	415490	5645100																
30-Apr	14:21	MCR Station #4	4	414807	5648490																
30-Apr	16:10	MCR Station #1	1	415049	5655566																
30-Apr	16:10	MCR Station #1 Anchor	1AS	415049	5655566																
30-Apr	18:22	MCR Station #2	2	414925	5653213																
30-Apr	18:22	MCR Station #2 Anchor	2AS	414925	5653213																
1-May	9:30	Illicillewaet River Station #7	7	424232	5652102																
1-May	14:12	Jordan River Station #8	8	410904	5655521																
29-Sep	10:00	Jordan River Station #8	8	410904	5655521	10:02	10:36	99	25	+59:30											
29-Sep	13:20	MCR Station #4	4	414807	5648490	13:46	14:18	96	45	+59:32	16:09	16:40	96	45	+59:30						
29-Sep	14:35	MCR Station #5	5	415490	5645100	14:45	15:04	98	45	+59:21											
29-Sep	15:32	MCR Station #6	6	417171	5642074	15:36	15:59	98	45	+59:26											
29-Sep	23:00	MCR Station #2	2	414925	5653213	23:20	23:45	98	45	+59:33	23:01	23:15	100	45	+59:14						
30-Sep	23:00	MCR Station #2 Anchor	2	414925	5653213	0:03	0:34	99	45	+59:30											
30-Sep	1:52	MCR Station #1	1	415049	5655566	1:57	2:28	98	45	+59:20											
30-Sep	1:52	MCR Station #1 Anchor	1AS	415049	5655566																too much rain, surveying at night impossible, no download
30-Sep	15:00	Illicillewaet River Station #7	7	424232	5652102											15:00	16:00	93	72	Yes	S/N 10328108
30-Sep	15:00	Illicillewaet River Station #7	7	424232	5652102											15:00		100		No	S/N 10087358 ,alfunctioned and was removed
30-Sep	15:00	Illicillewaet River Station #7	7	424232	5652102												16:00				was newly installed to replace S/N 10087358
30-Sep	15:00	Illicillewaet River Station #7	7	424232	5652102																S/N 2321302 was downloaded & then removed battery empty, started last 20121025103000
5-Nov	10:11	Jordan River Station #8	8	410904	5655521	12:05		99	95	Yes											
5-Nov	14:35	Illicillewaet River Station #7	7	424232	5652102																
5-Nov	14:35	Illicillewaet River Station #7	7	424232	5652102																
6-Nov	0:36	MCR Station #2	2	414925	5653213	23:53	0:05	98	87	-57.27	23:35	23:47	100		-57:00						
6-Nov	0:36	MCR Station #2 Anchor	2	414925	5653213	0:24	0:36	99	86	-57.27											
6-Nov	1:19	MCR Station #1	1	415049	5655566	2:27	2:44	98	86	-57.25											
6-Nov	1:19	MCR Station #1 Anchor	1AS	415049	5655566	1:58	?	99	31	+2.15											
6-Nov	12:02	MCR Station #4	4	414807	5648490	12:22	12:36	98	86	-57.30	12:06	12:21	98	86	+2.31						
6-Nov	12:57	MCR Station #5	5	415490	5645100	12:53	13:05	98	86	-57.30											
6-Nov	13:20	MCR Station #6	6	417171	5642074	13:18	13:28	98	86	-57.27											

APPENDIX B:
2013 *IN SITU* PHYSICAL WATER QUALITY PARAMETER RESULTS

Date mm/dd	Arrival Time (24h)	Location Name	Station #	UTM Zone: 11		Temperature	Conductivity	Specific Conductivity	Total Dissolved Solids	DO Saturation	DO Total	pH	Turbidity
						°C	µS/cm	µS/cm	mg/L	%	mg/L	pH Units	NTU
30-Apr	10:12	MCR Station #6	6	417171	5642074	3.89	0.161	0.096	0.104	97.8	12.85	7.87	0.6
30-Apr	12:39	MCR Station #5	5	415490	5645100	4.34	0.156	0.095	0.102	99.8	12.97	7.92	0.2
30-Apr	14:21	MCR Station #4	4	414807	5648490	4.24	0.155	0.094	0.101	99.7	12.97	7.94	0.2
30-Apr	16:10	MCR Station #1	1	415049	5655566	3.88	0.162	0.096	0.105	98.6	12.95	7.92	0.2
30-Apr	18:22	MCR Station #2	2	414925	5653213	3.85	0.158	0.094	0.103	99.3	13.05	7.96	0.1
1-May	9:30	Illicillewaet River Station #7	7	424232	5652102	3.2	0.173	0.101	0.112	115.7	15.48	8.06	1.1
1-May	14:12	Jordan River Station #8	8	410904	5655521	6.02	0.043	0.027	0.028	113.7	14.14	7.39	0
29-Sep	10:00	Jordan River Station #8	8	410904	5655521	6.92	0.034	0.022	0.022	102.1	12.44	7.36	0
29-Sep	13:20	MCR Station #4	4	414807	5648490	10.36	0.121	0.087	0.078	102.9	11.52	7.79	
29-Sep	14:35	MCR Station #5	5	415490	5645100	10.4	0.121	0.087	0.078	103.3	11.55	7.86	
29-Sep	15:32	MCR Station #6	6	417171	5642074	10.35	0.12	0.087	0.078	104.2	11.67	7.86	
29-Sep	23:00	MCR Station #2	2	414925	5653213	10.43	0.125	0.091	0.082	101.9	11.38	7.84	
30-Sep	1:52	MCR Station #1	1	415049	5655566	10.15	0.141	0.101	0.092	100.6	11.31	7.8	
30-Sep	15:00	Illicillewaet River Station #7	7	424232	5652102	7.29	0.127	0.084	0.085	108.7	13.1	8.08	
5-Nov	9:58	Jordan River Station #8	8	410904	5655521	1.61	0.058	0.032	0.038	97.3	13.6	7.92	
5-Nov	14:45	Illicillewaet River Station #7	7	424232	5652102	2.3	0.184	0.104	0.119	98.1	13.41	8.04	
6-Nov	0:16	MCR Station #2	2	414925	5653213	9.17	0.136	0.095	0.059	96.2	11.07	7.99	
6-Nov	1:19	MCR Station #1	1	415049	5655566	8.81	0.158	0.109	0.102	95	11.01	8.01	
6-Nov	12:02	MCR Station #4	4	414807	5648490	9.11	0.136	0.095	0.088	97.7	11.26	8.1	
6-Nov	12:57	MCR Station #5	5	415490	5645100	9.13	0.136	0.095	0.088	98.6	11.36	8.08	
6-Nov	13:20	MCR Station #6	6	417171	5642074	9.01	0.136	0.094	0.088	98.7	11.4	8.06	

APPENDIX C:
2013 LABORATORY NUTRIENT AND PHYSICAL PARAMETER RESULTS

Date Sampled	Time Sampled	Station #	Nitrate	Ammonia	Nitrogen, Total	Nitrogen, Total Kjeldahl	Phosphorus, Total	Phosphorus, Total Dissolved	Phosphorus, Dissolved Reactive	Solids, Total Dissolved	Solids, Total Suspended	Turbidity	pH
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	NTU	pH units
30-Apr	16:10	STN1	0.096	0	0.236	0.14	0.028	0.008	0.009	83	0	0.3	7.69
30-Apr	18:22	STN2	0.093	0	0.57	0.48	0.008	0.005	0	75	0	0.5	7.89
30-Apr	14:21	STN4	0.103	0	0.164	0.06	0.006	0.005	0	77	0	0.4	7.93
30-Apr	12:39	STN5	0.101	0	0.39	0.29	0.008	0.007	0	77	0	0.5	7.94
30-Apr	10:12	STN6	0.101	0	0.32	0.22	0.006	0.005	0.006	79	1	0.4	7.95
1-May	9:30	STN7-ILLI	0.402	0	0.688	0.29	0.007	0.006	0.006	94	2	0.7	8.01
1-May	14:12	STN8-JORDAN	0.356	0	0.933	0.58	0.006	0.004	0	33	0	0.2	7.52
30-Sep	1:52	STN1	0.121	0.044	0.121	0	0.035	0.025	0.014	104	0	1.3	7.81
29-Sep	23:00	STN2	0.112	0.026	0.112	0	0.026	0.022	0.009	88	0	1.5	7.83
29-Sep	13:20	STN4	0.115	0	0.115	0	0.024	0.019	0.007	70	1	1.8	7.86
29-Sep	14:35	STN5	0.116	0.022	0.178	0.06	0.023	0.018	0.009	81	0	1.9	7.85
29-Sep	15:32	STN6	0.116	0	0.18	0.06	0.029	0.024	0.007	74	2	2.1	7.88
30-Sep	15:00	STN7-ILLI	0.123	0	0.198	0.08	0.038	0.034	0.006	82	4	5	7.95
29-Sep	10:00	STN8-JORDAN	0.24	0	0.417	0.18	0.047	0.032	0.005	23	27	6.5	7.23
6-Nov	1:19	STN1	0.122	0.052	0.21	0.09	0.005	0.004	0	68	0	0.3	7.81
6-Nov	0:16	STN2	0.11	0.073	0.275	0.16	0.003	0	0	78	0	0.3	7.86
6-Nov	12:02	STN4	0.107	0.044	0.205	0.1	0.006	0.003	0	66	0	0.4	7.87
6-Nov	12:57	STN5	0.107	0.048	0.195	0.09	0.002	0	0	76	0	0.3	7.9
6-Nov	13:20	STN6	0.108	0.058	0.26	0.15	0.003	0.002	0	66	0	0.4	7.91
5-Nov	14:45	STN7-ILLI	0.148	0.059	0.277	0.13	0.004	0.002	0	100	3	0.7	7.98
5-Nov	9:58	STN8-JORDAN	0.19	0.093	0.305	0.12	0.005	0.004	0	31	0	0.2	7.54

APPENDIX D:
GRAPHICAL REPRESENTATION OF THE 2013 MODELLED AND OBSERVED STAGES AT THE MCR STATIONS

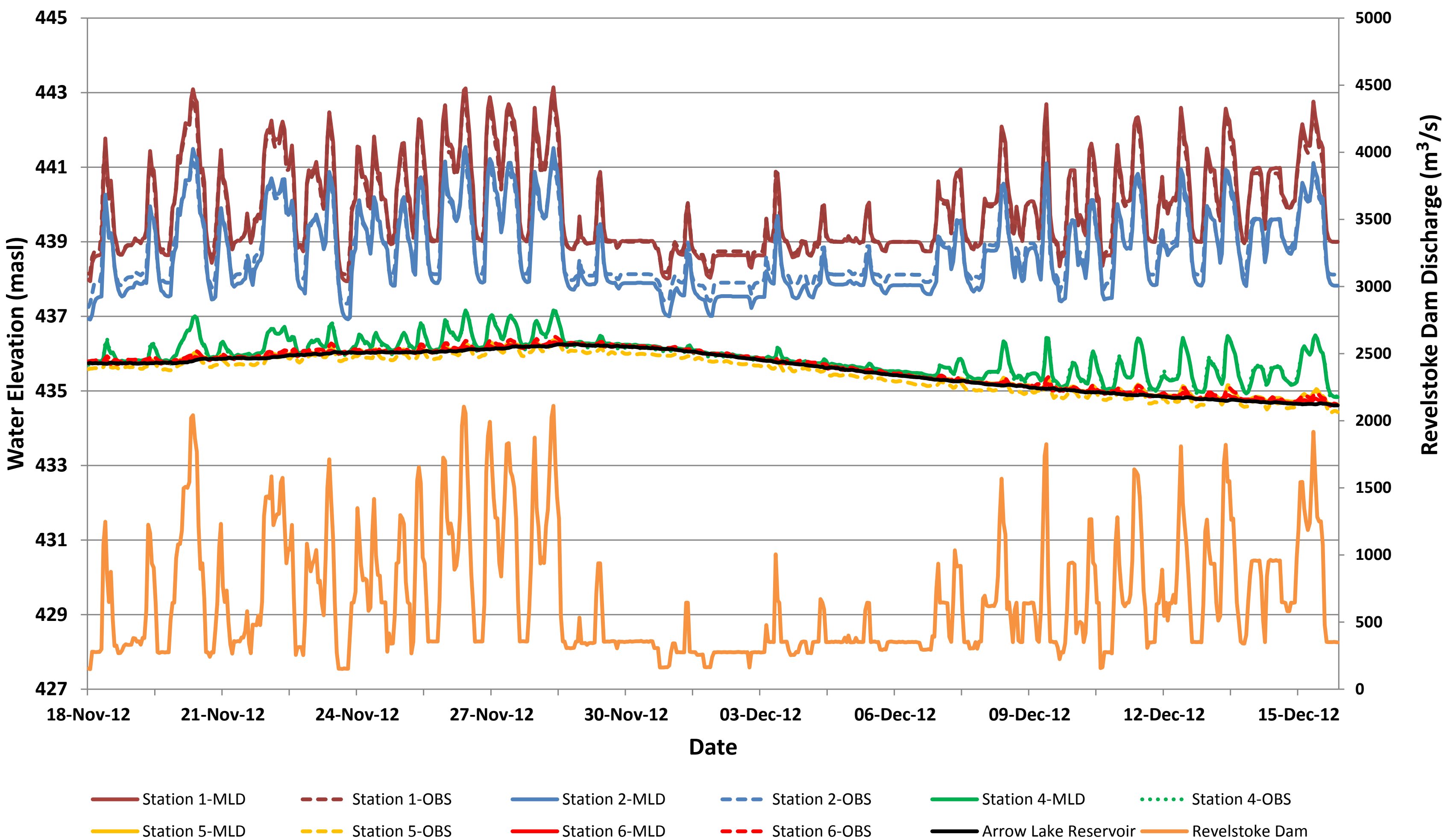


Figure 13 Modelled (MLD) and observed (OBS) stages at the MCR stations for November 18, 2012 to February 10, 2013 (y-axis for water elevations for MCR stations on the left, y-axis only for discharge through Revelstoke Dam on the right).

Figure 13 continued.

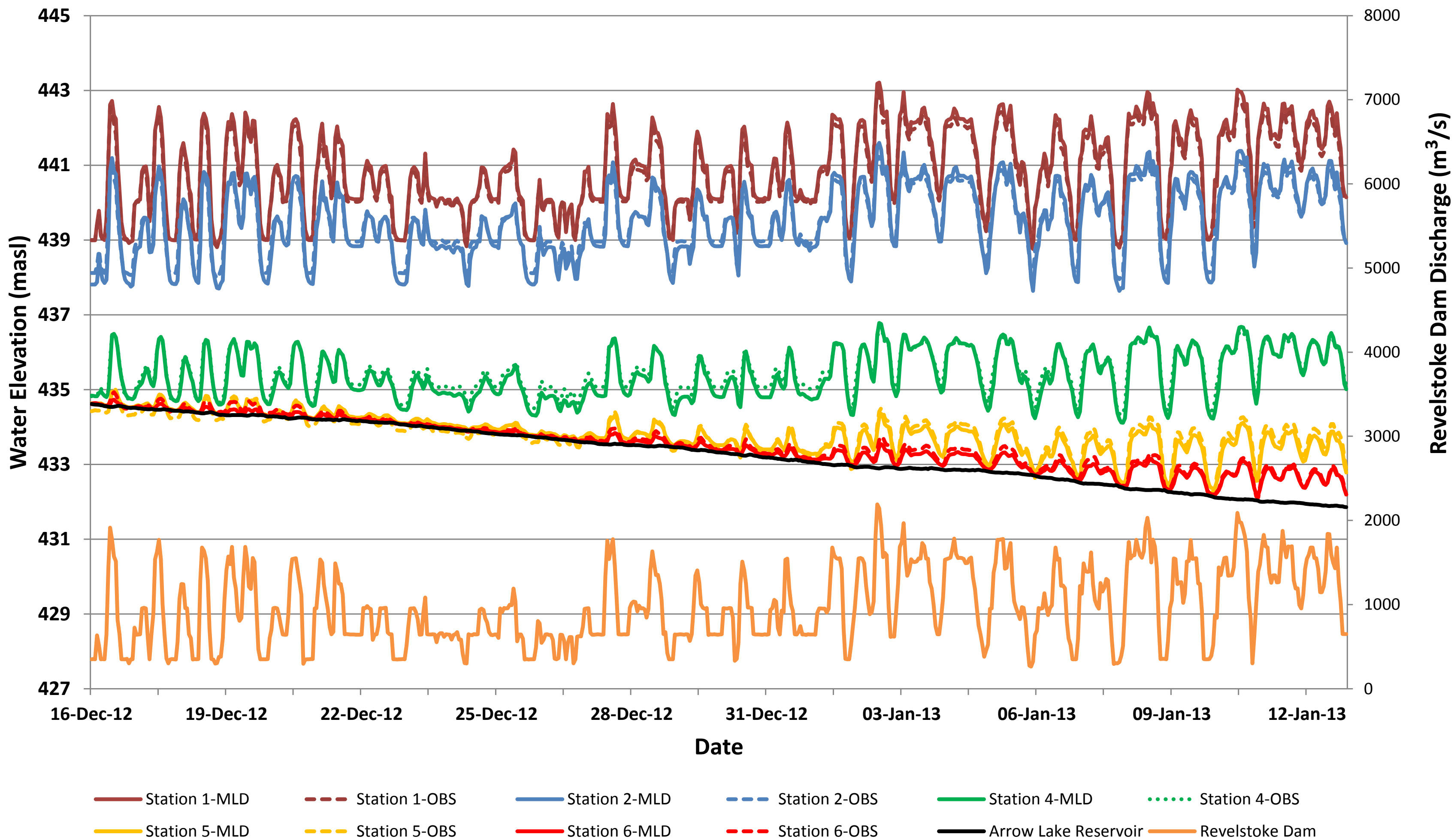
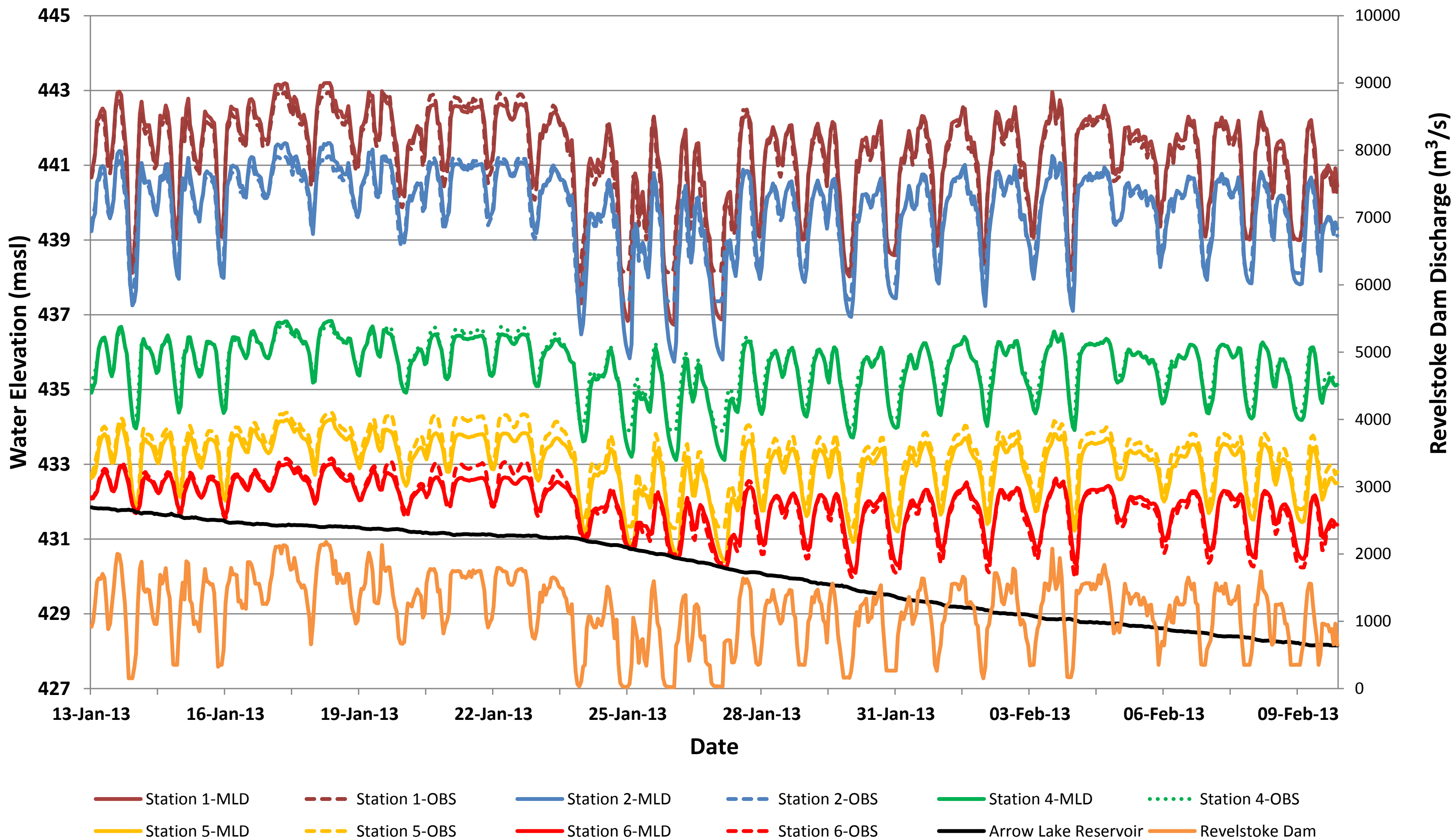


Figure 13 continued.



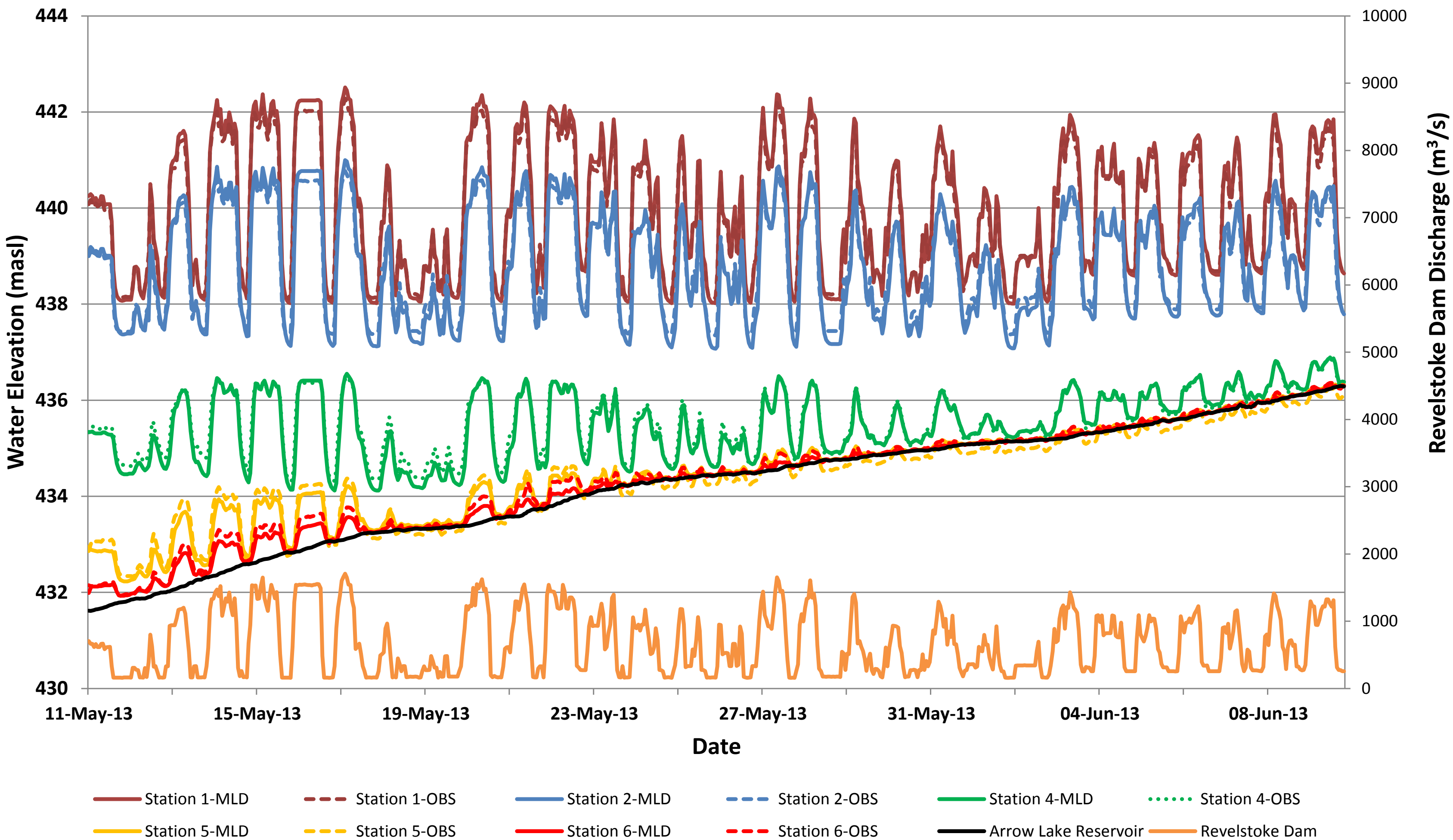


Figure 14 Modelled (MLD) and observed (OBS) stages at the MCR stations for May 11 to November 6, 2013 (y-axis for water elevations for MCR stations on the left, y-axis only for discharge through Revelstoke Dam on the right).

Figure 14 continued.

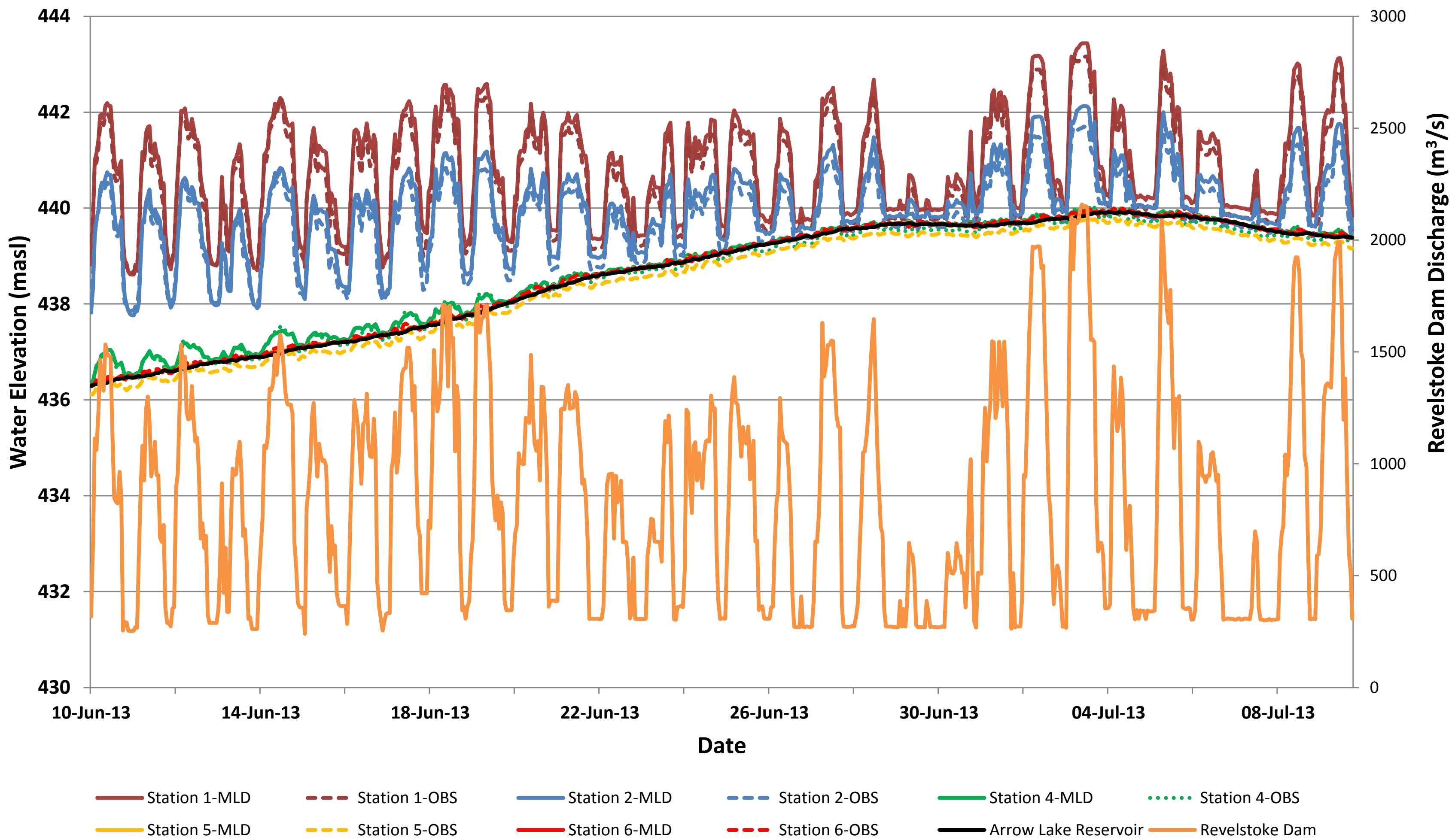


Figure 14 continued.

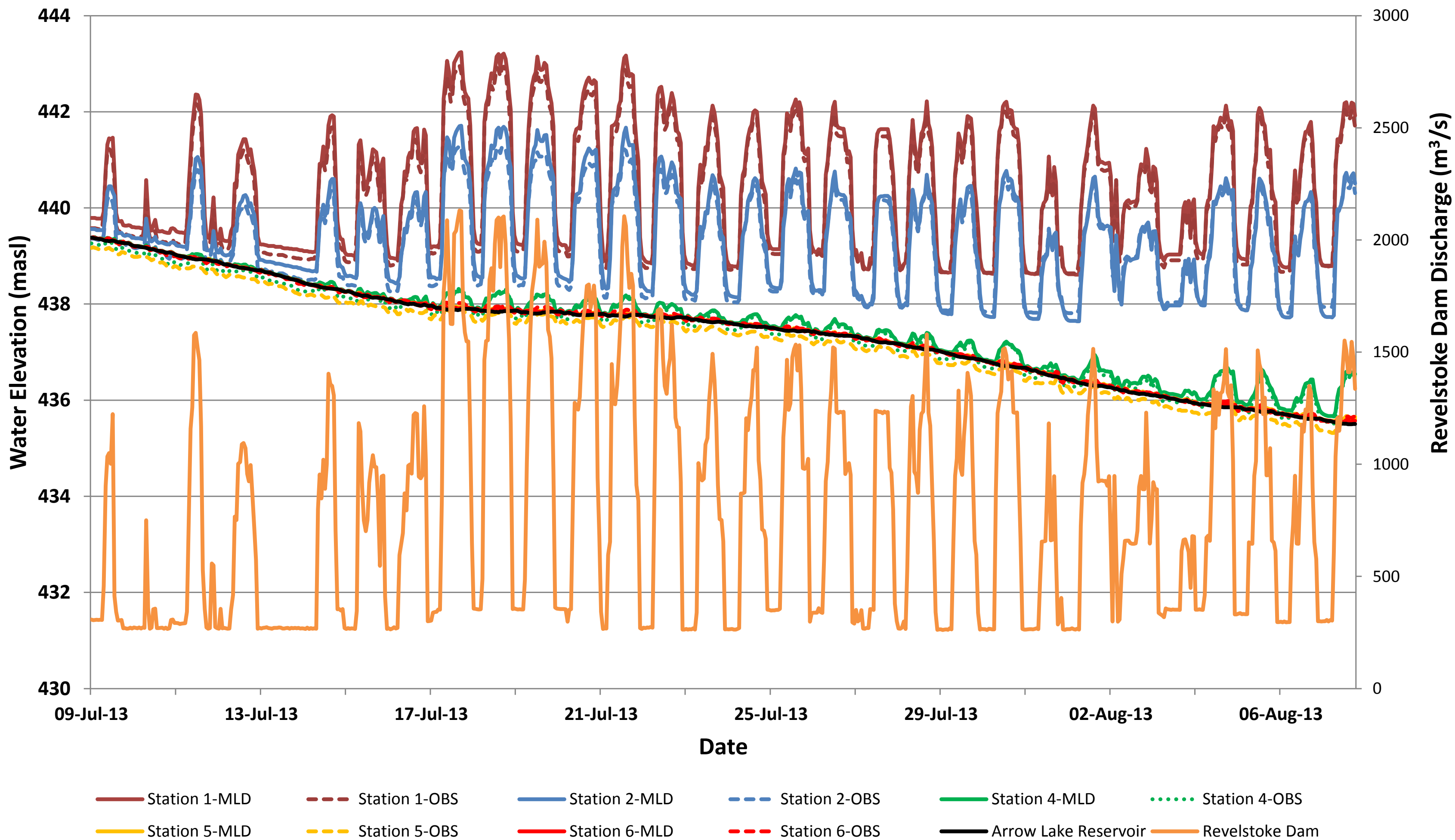


Figure 14 continued.

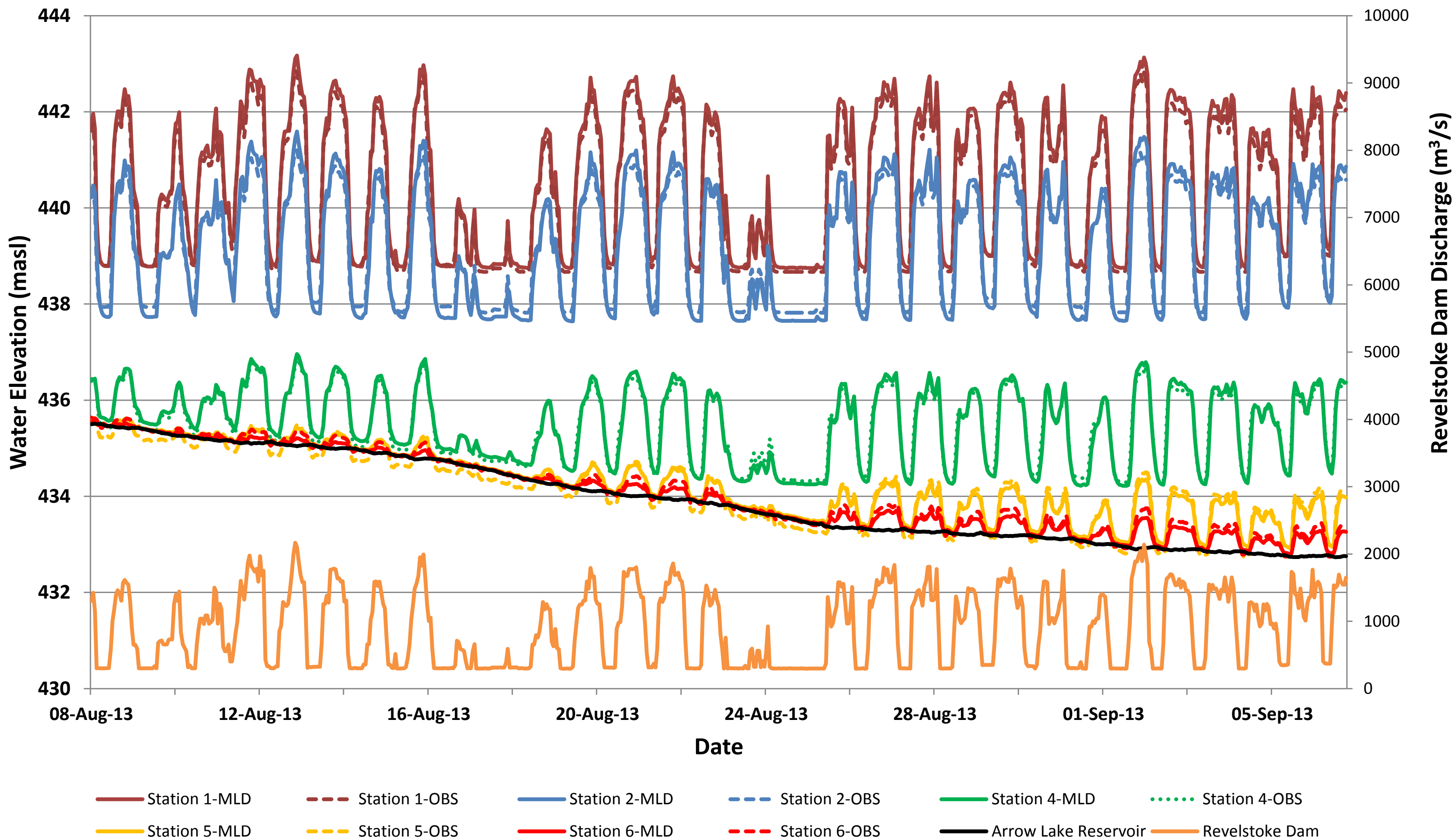


Figure 14 continued.

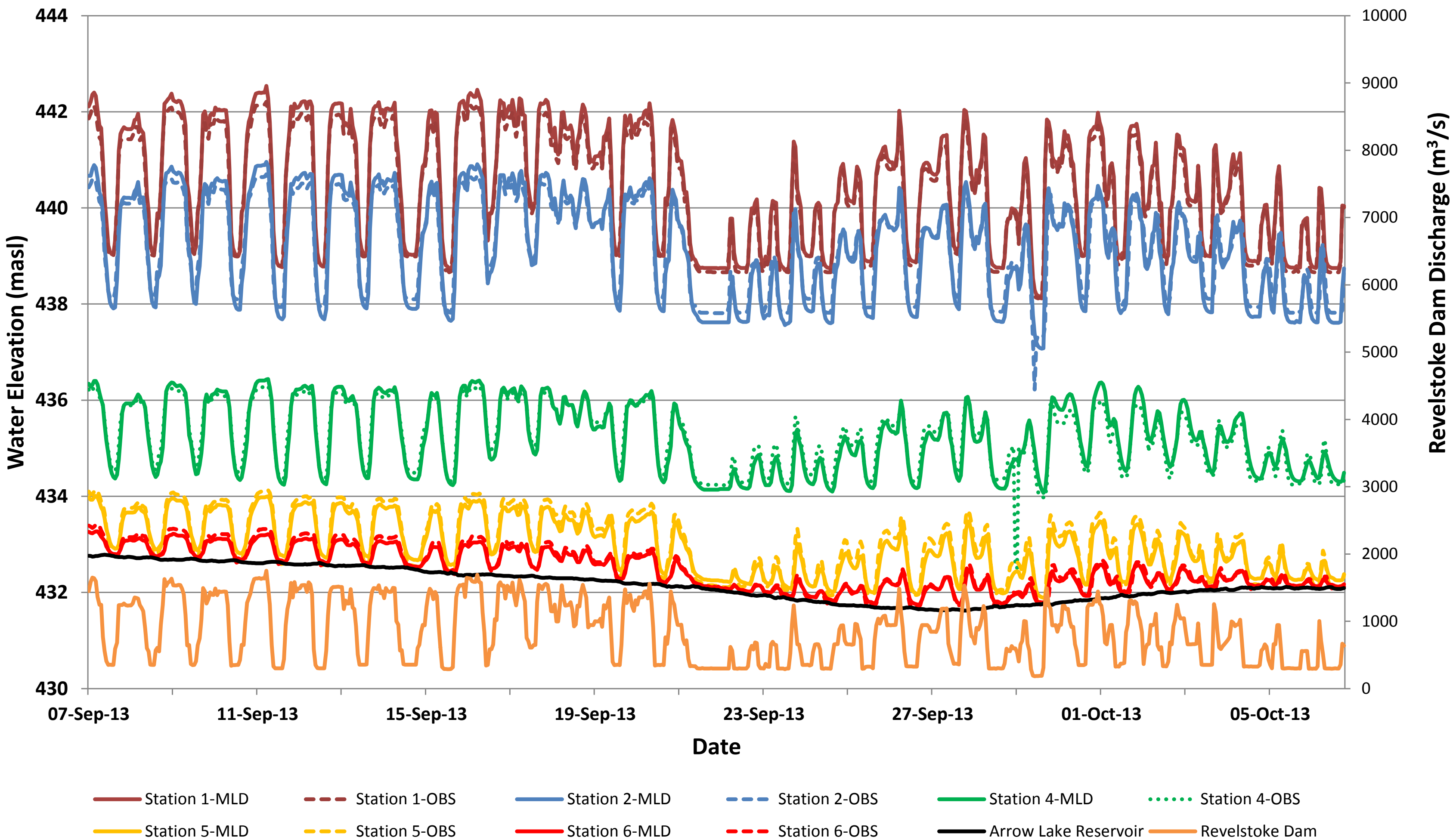
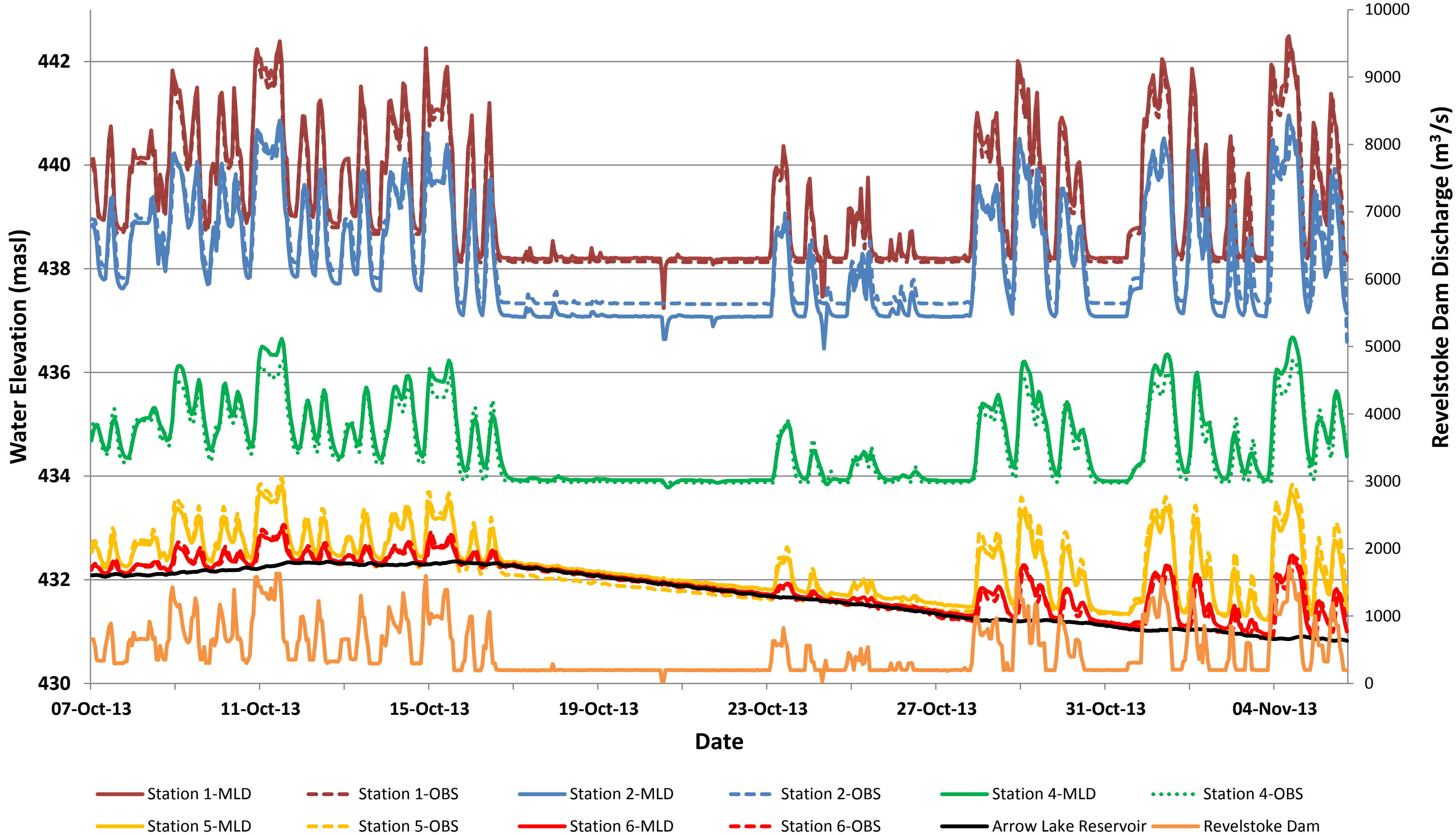


Figure 14 continued.



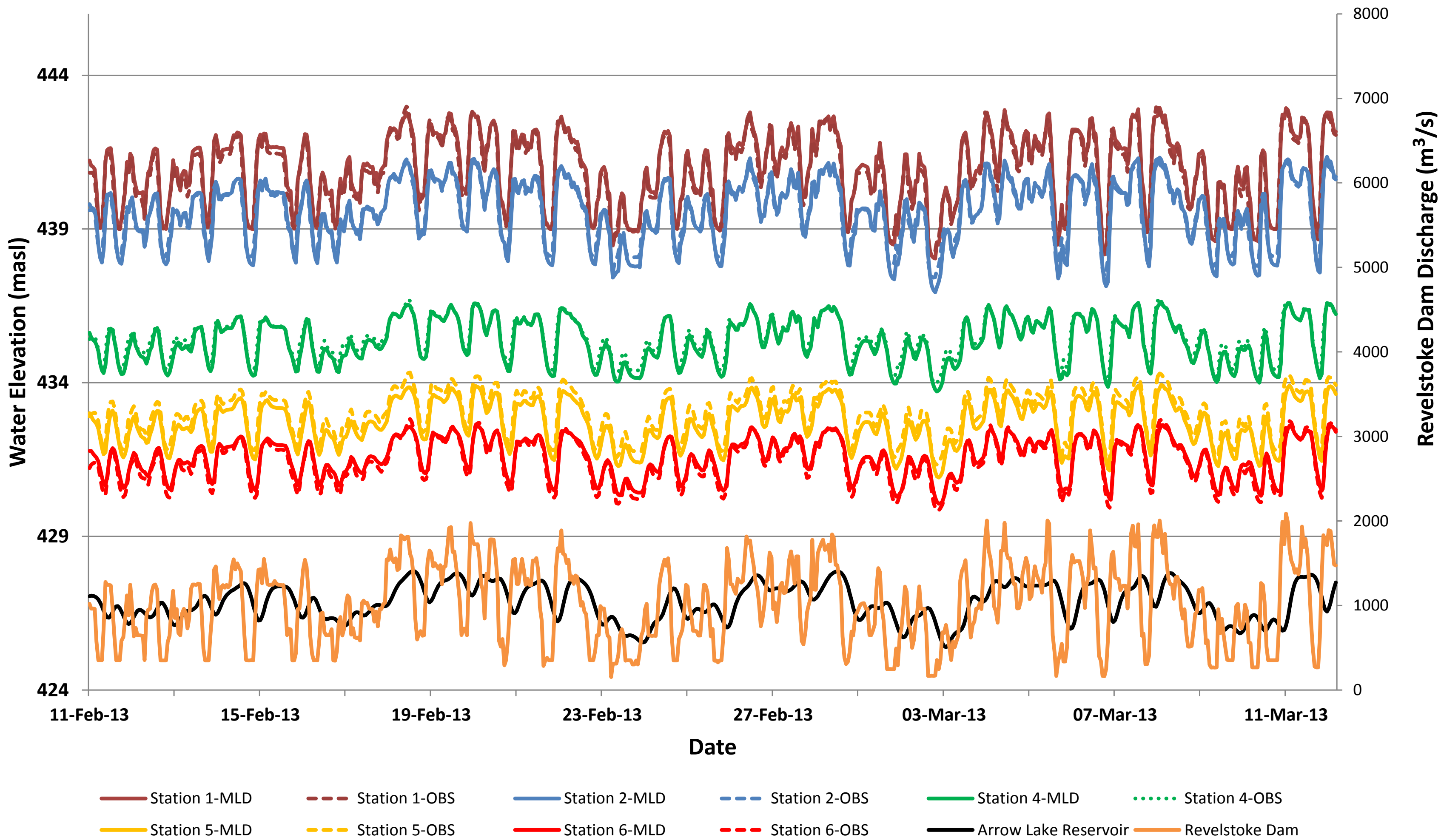


Figure 15 Modelled (MLD) and observed (OBS) stages at the MCR stations for February 11 to May 10, 2013 (y-axis for water elevations for MCR stations on the left, y-axis only for discharge through Revelstoke Dam on the right). Simulated stages are for the first scenario with a uniform-flow depth applied at the downstream boundary.

Figure 15 continued.

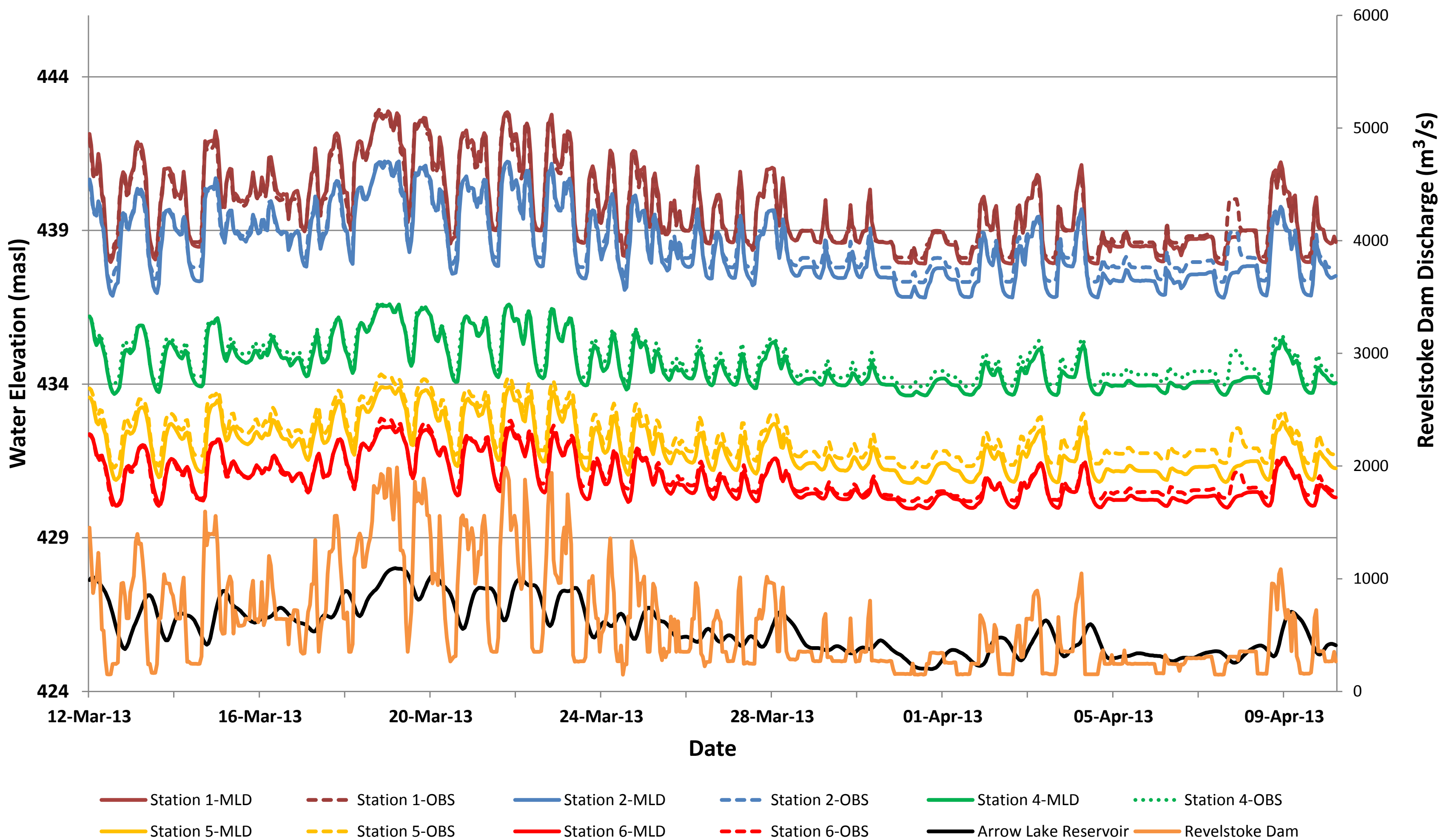
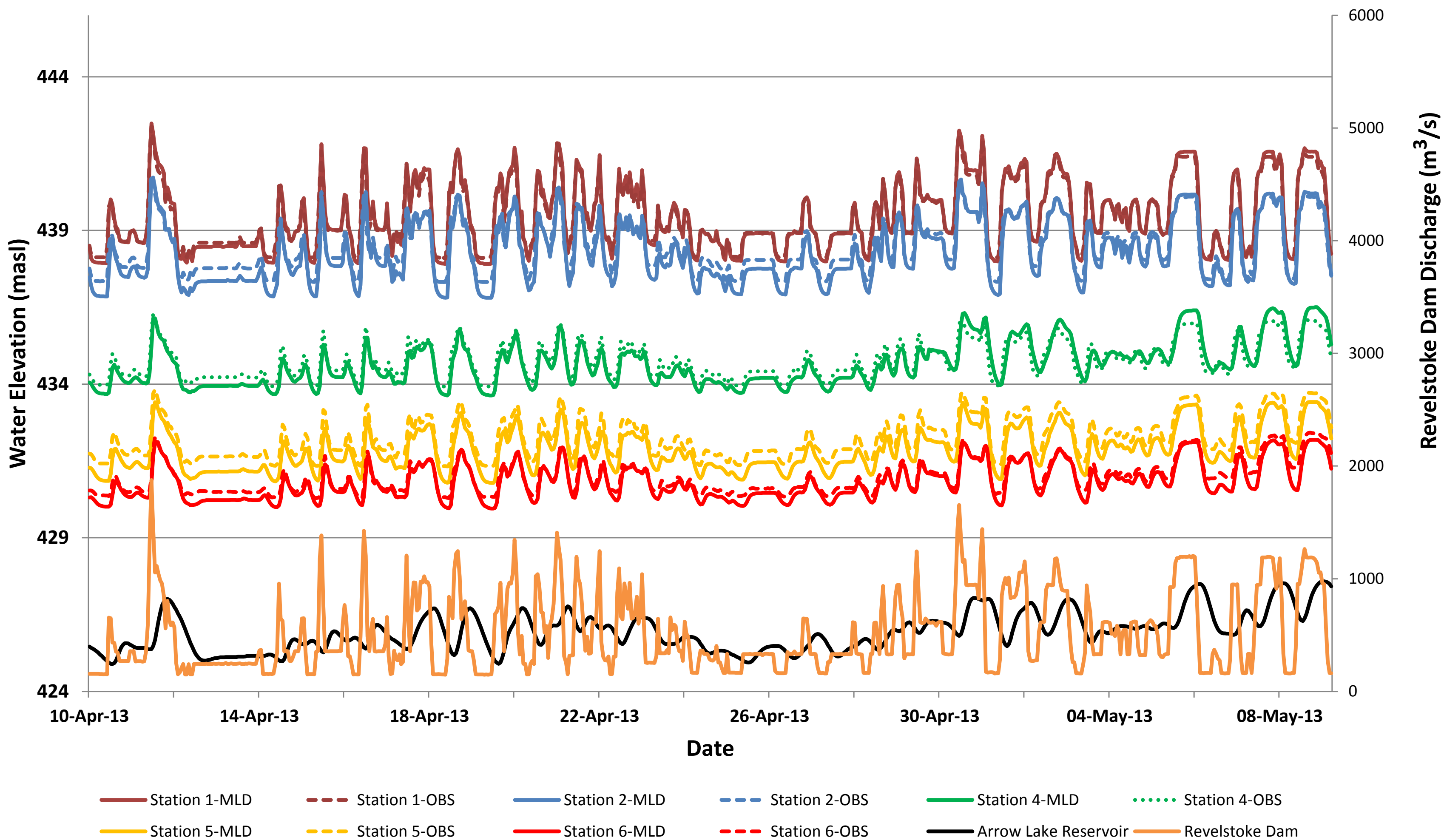


Figure 15 continued.



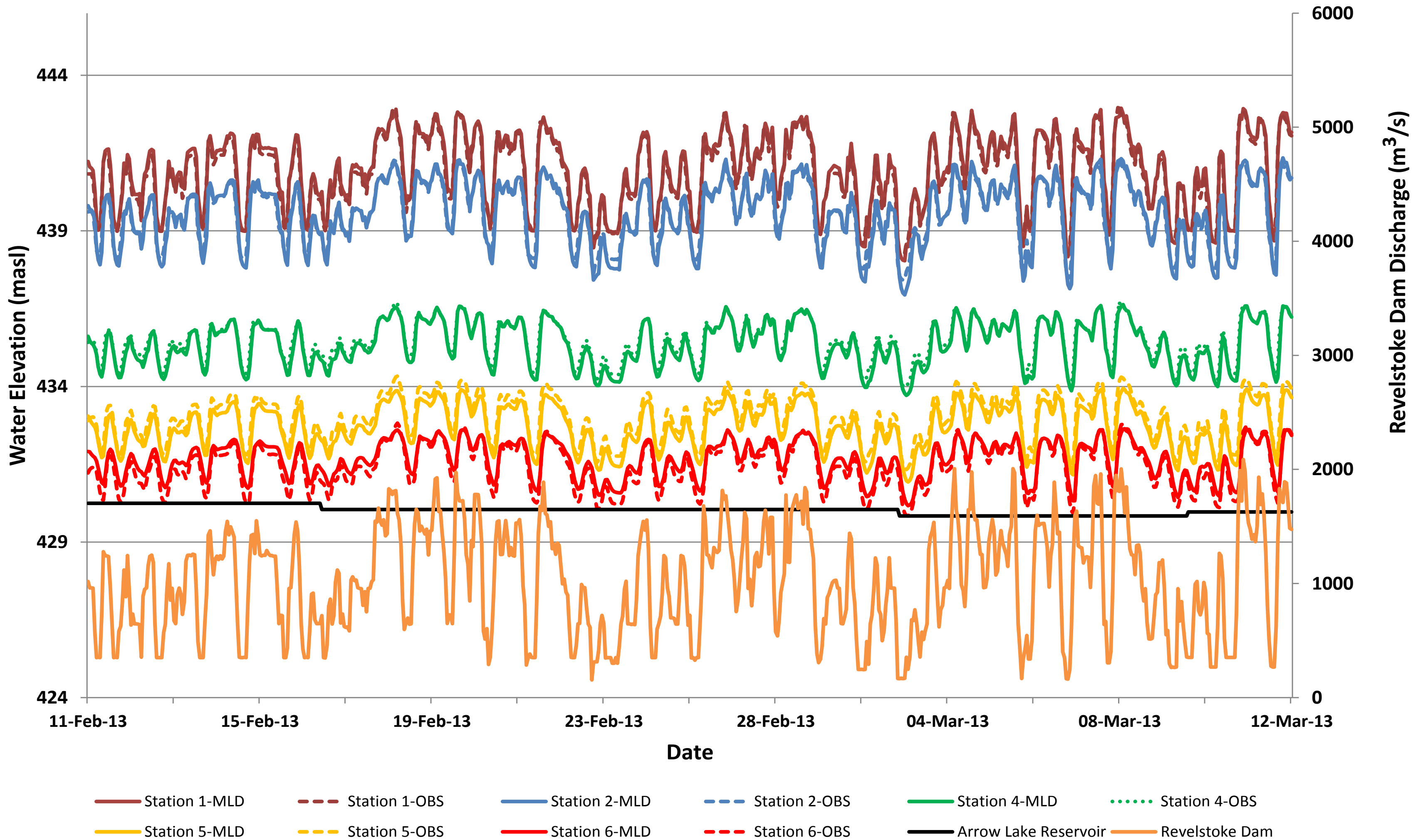


Figure 16 Modelled (MLD) and observed (OBS) stages at the MCR stations for February 11 to May 10, 2013 (y-axis for water elevations for MCR stations on the left, y-axis only for discharge through Revelstoke Dam on the right). Simulated stages are for the second scenario with the weekly-minimum stage for station 6 applied at downstream boundary.

Figure 16 continued.

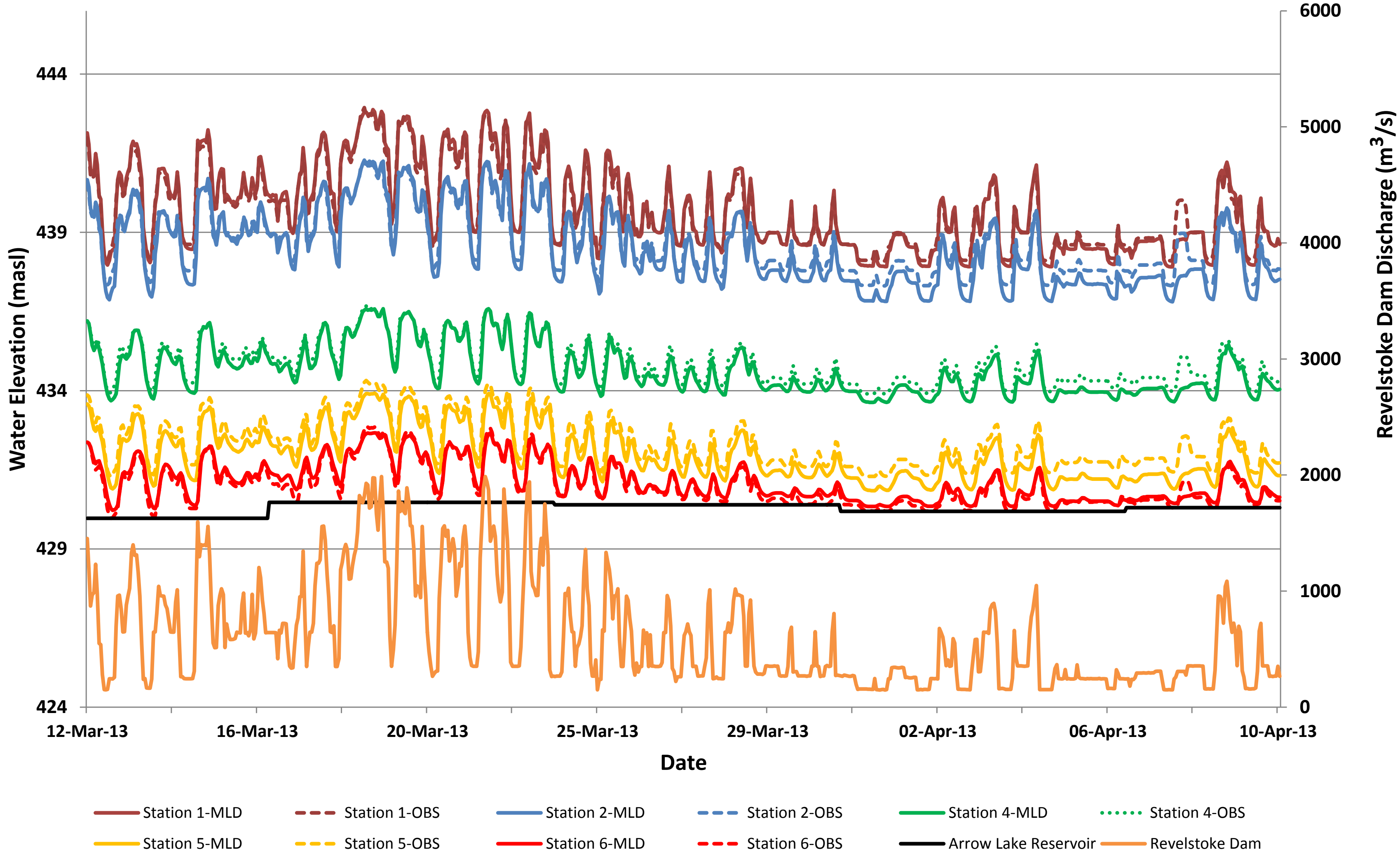
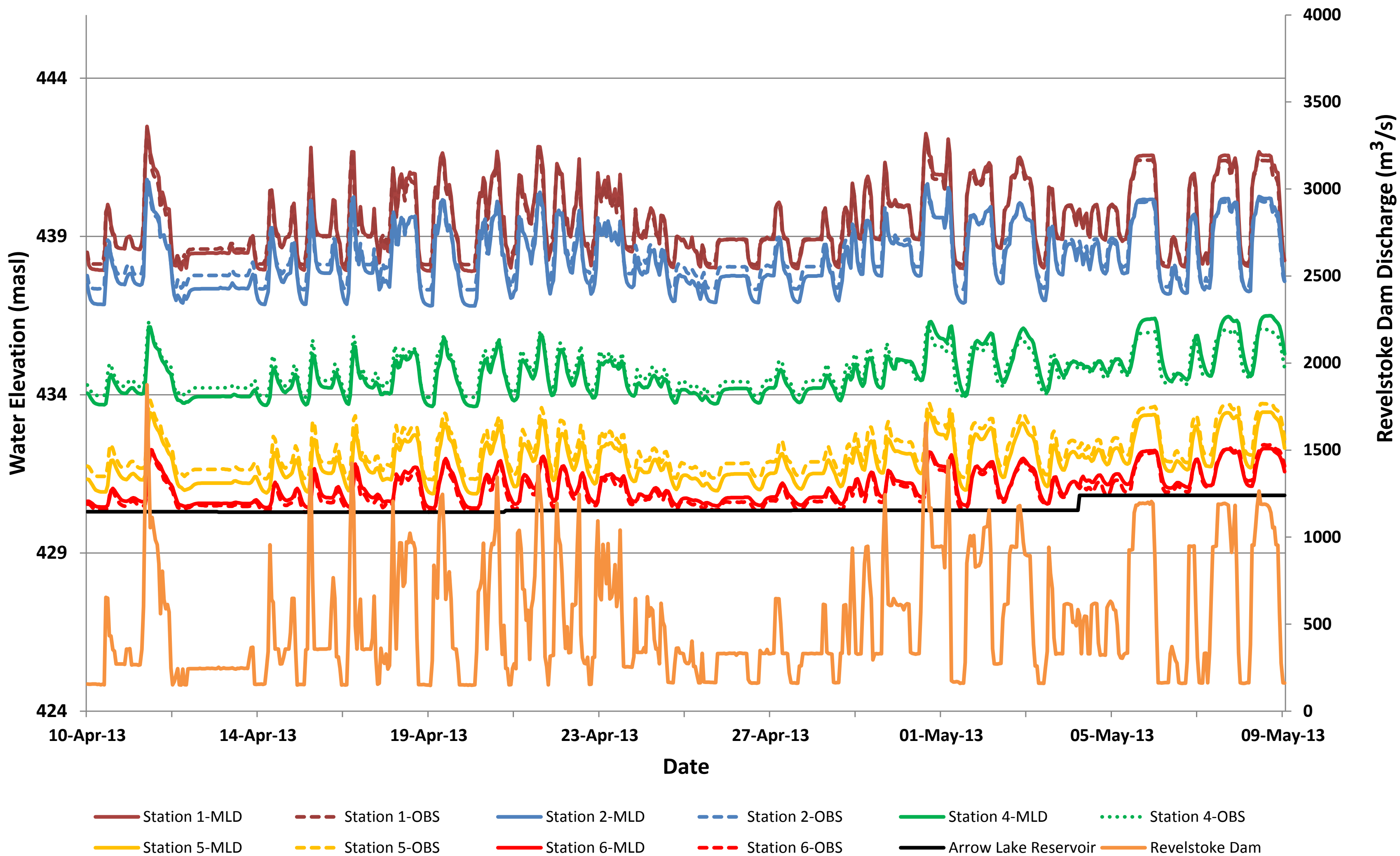


Figure 16 continued.



APPENDIX E: GRAPHICAL REPRESENTATION OF THE 2013 DISCHARGE FROM REV, WATER LEVEL AT DOWNSTREAM BOUNDARY, SIMULATED AVERAGE FLOW DEPTH, SIMULATED AVERAGE FLOW VELOCITY, AND SIMULATED WETTED RIVERBED AREA.

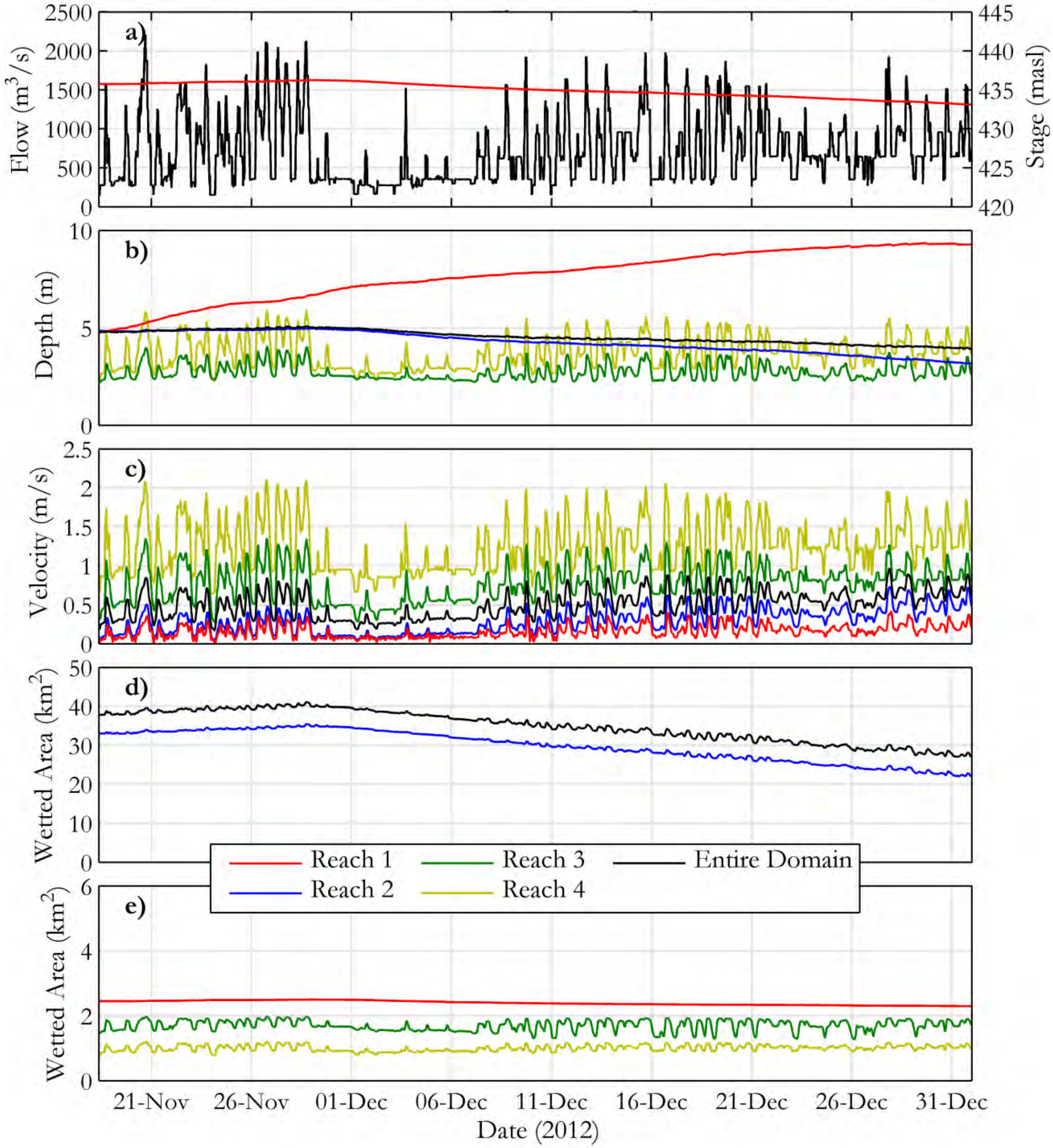


Figure 17 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for November 18 to December 31, 2012.

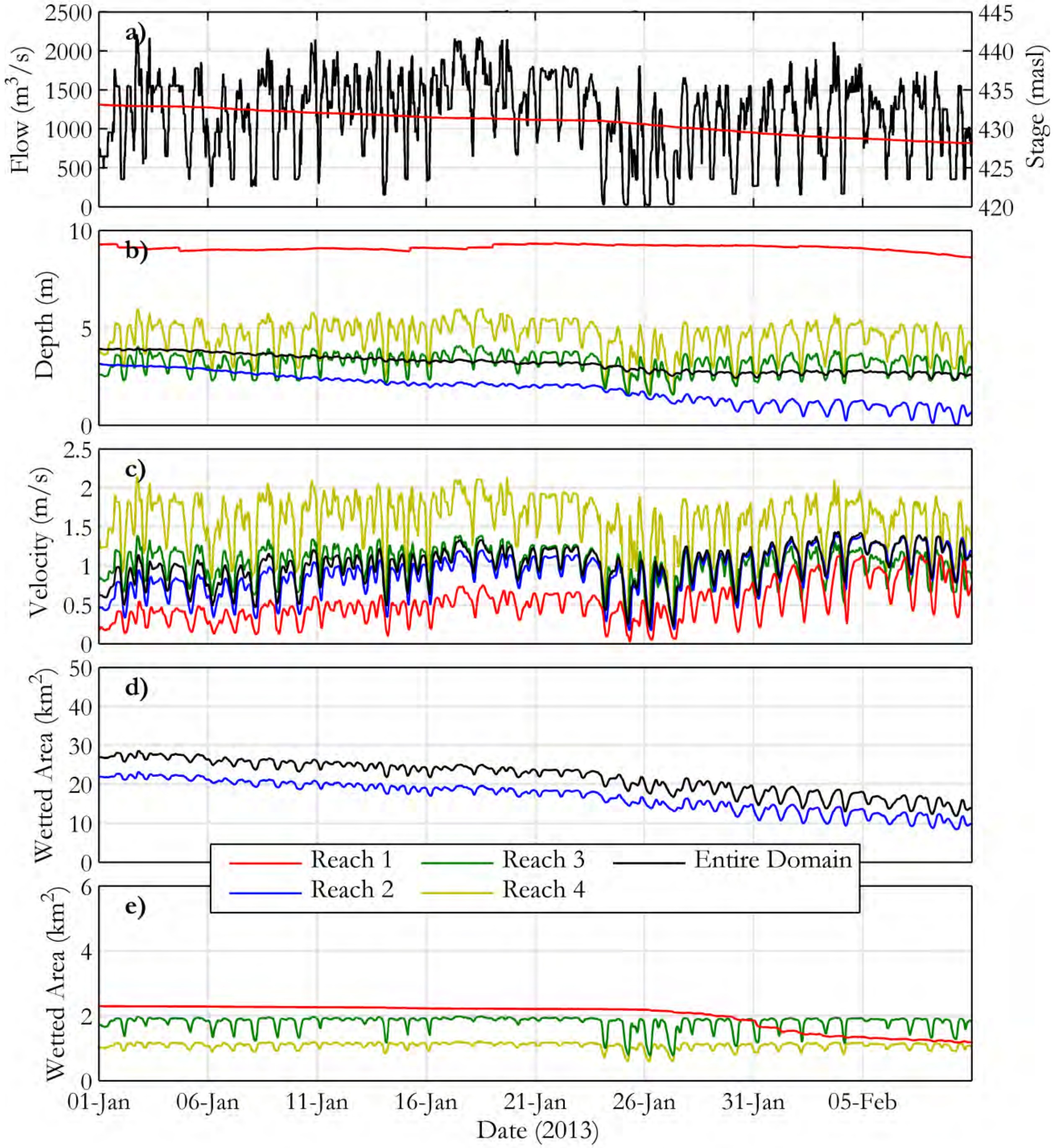


Figure 18 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for January 01 to February 10, 2013.

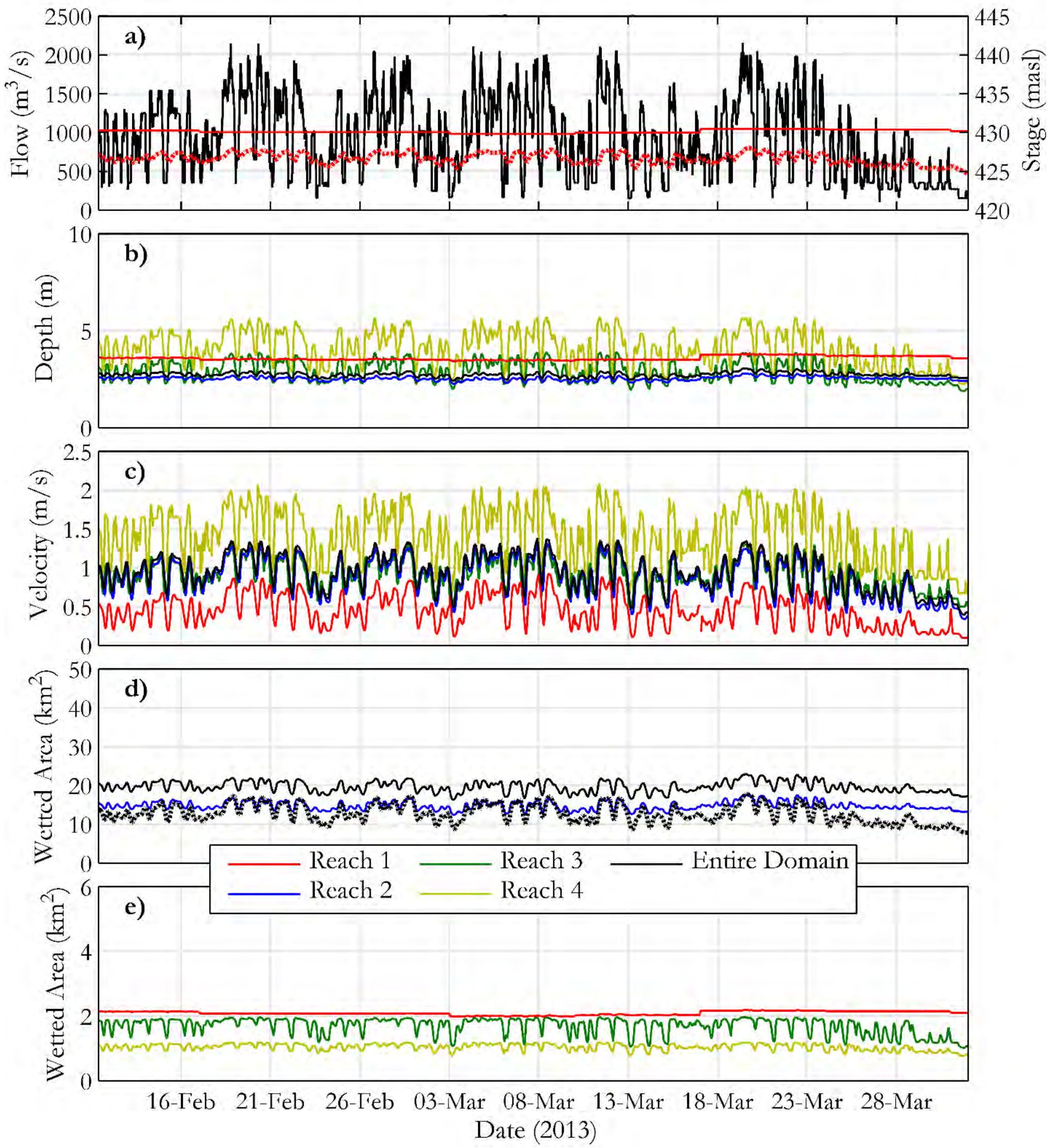


Figure 19 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for February 11 to March 31, 2013. Parameters shown are for two downstream boundary conditions; dashed lines in a) and d) are for uniform-flow depth and solid lines are for the Station 6 weekly-minimum stage.

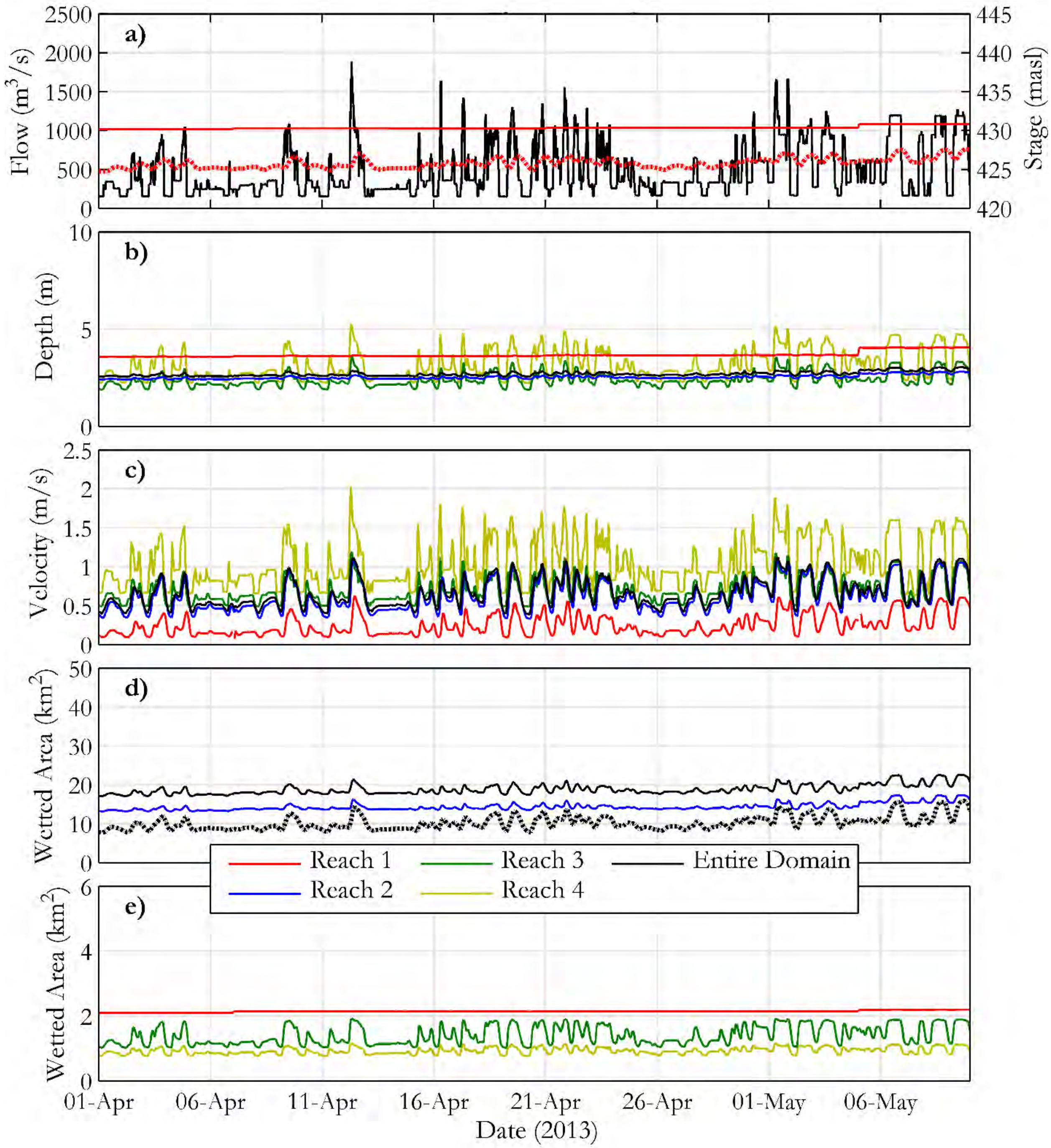


Figure 20 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for April 01 to May 10, 2013. Parameters shown are for two downstream boundary conditions; dashed lines in a) and d) are for uniform-flow depth and solid lines are for the Station 6 weekly-minimum stage

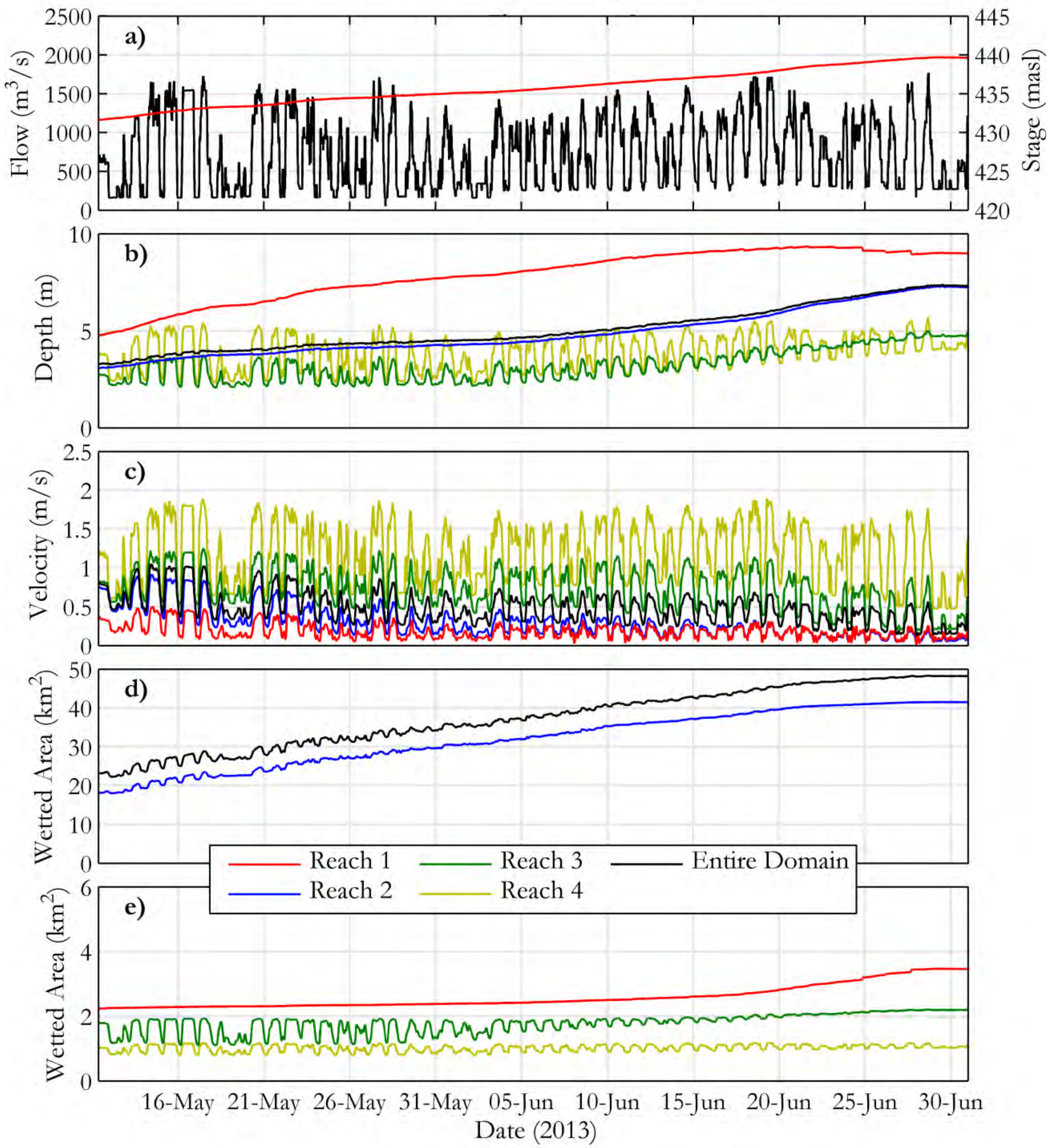


Figure 21 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for May 11 to June 30, 2013.

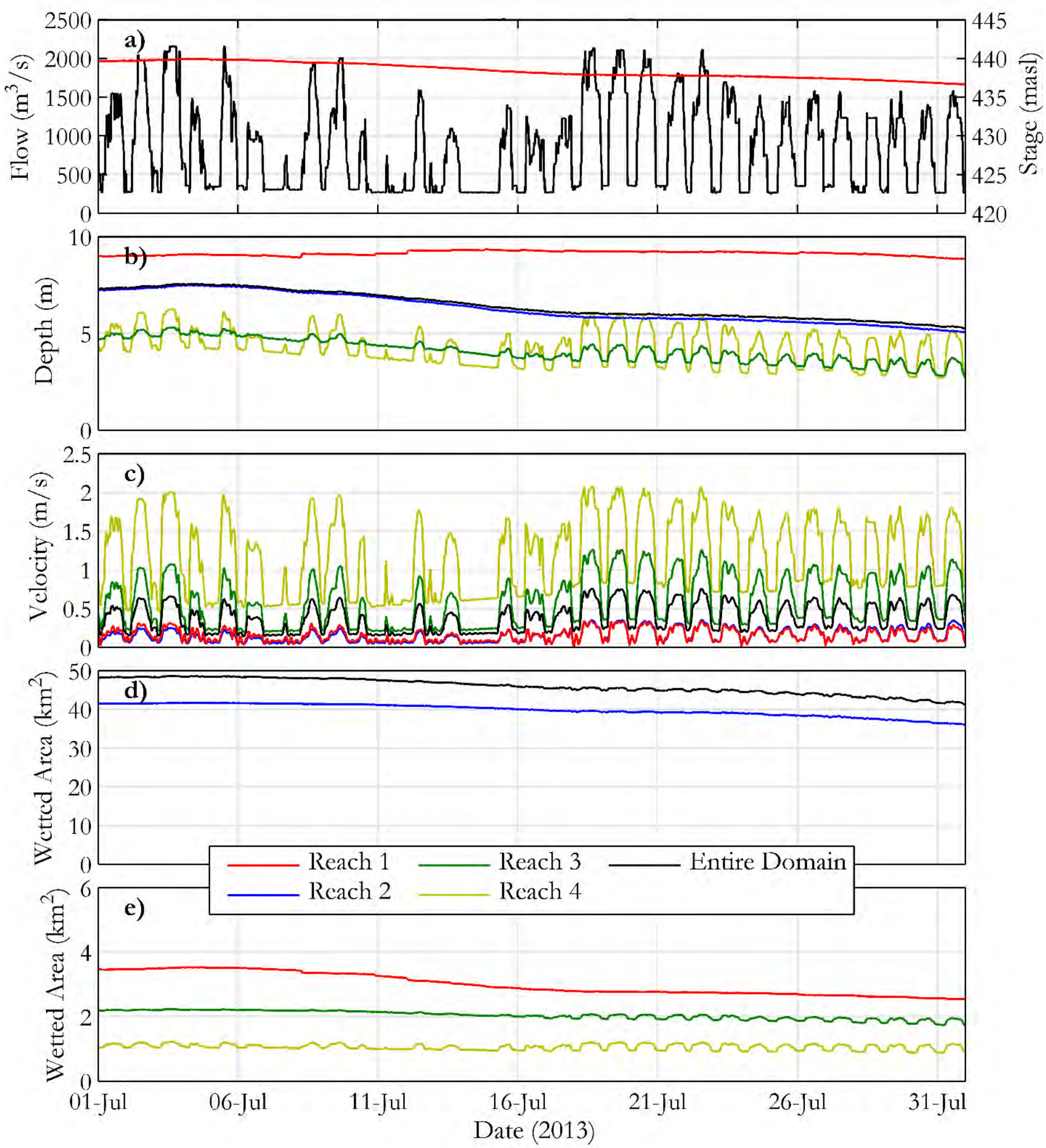


Figure 22 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for July 2013.

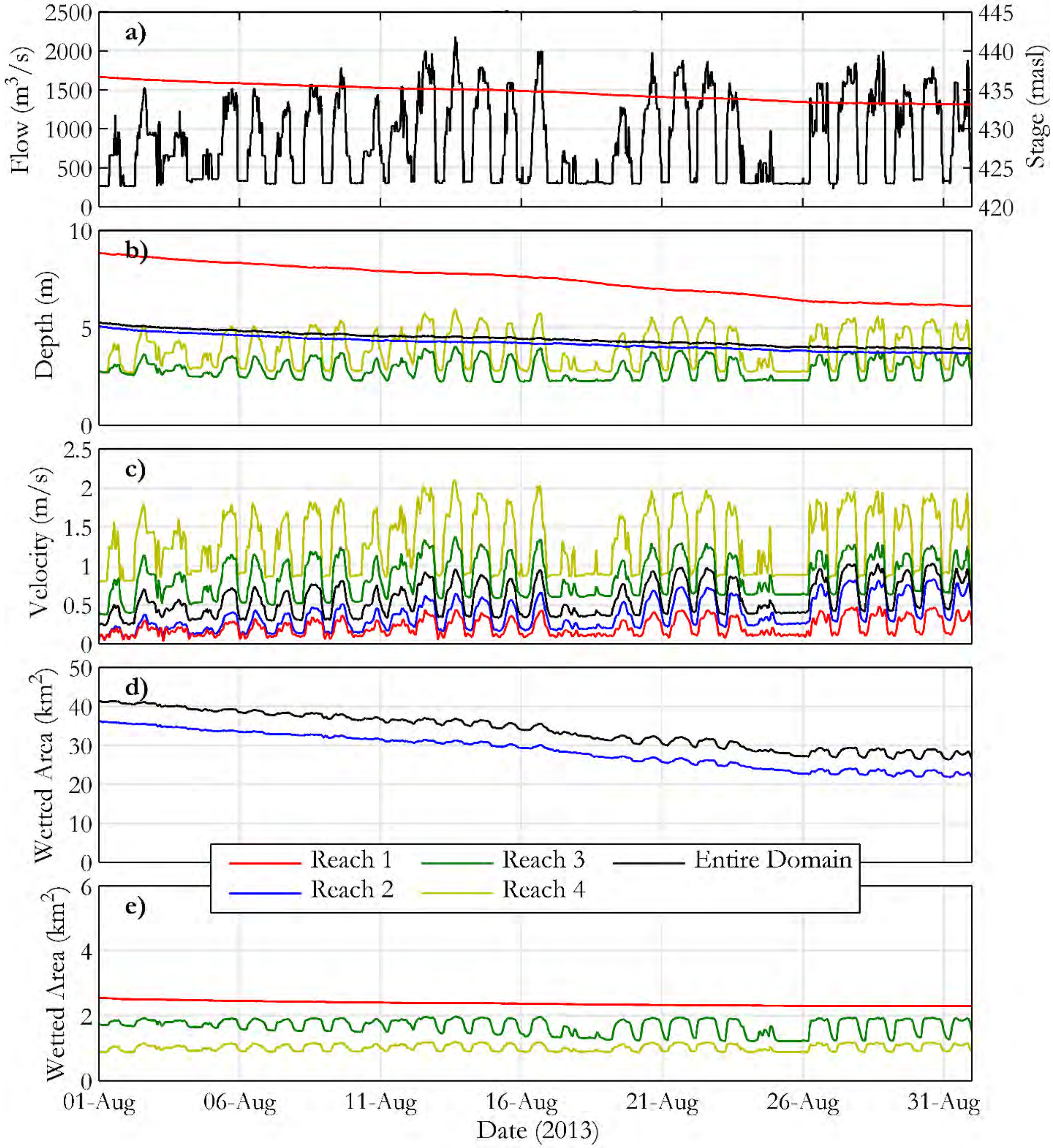


Figure 23 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for August 2013.

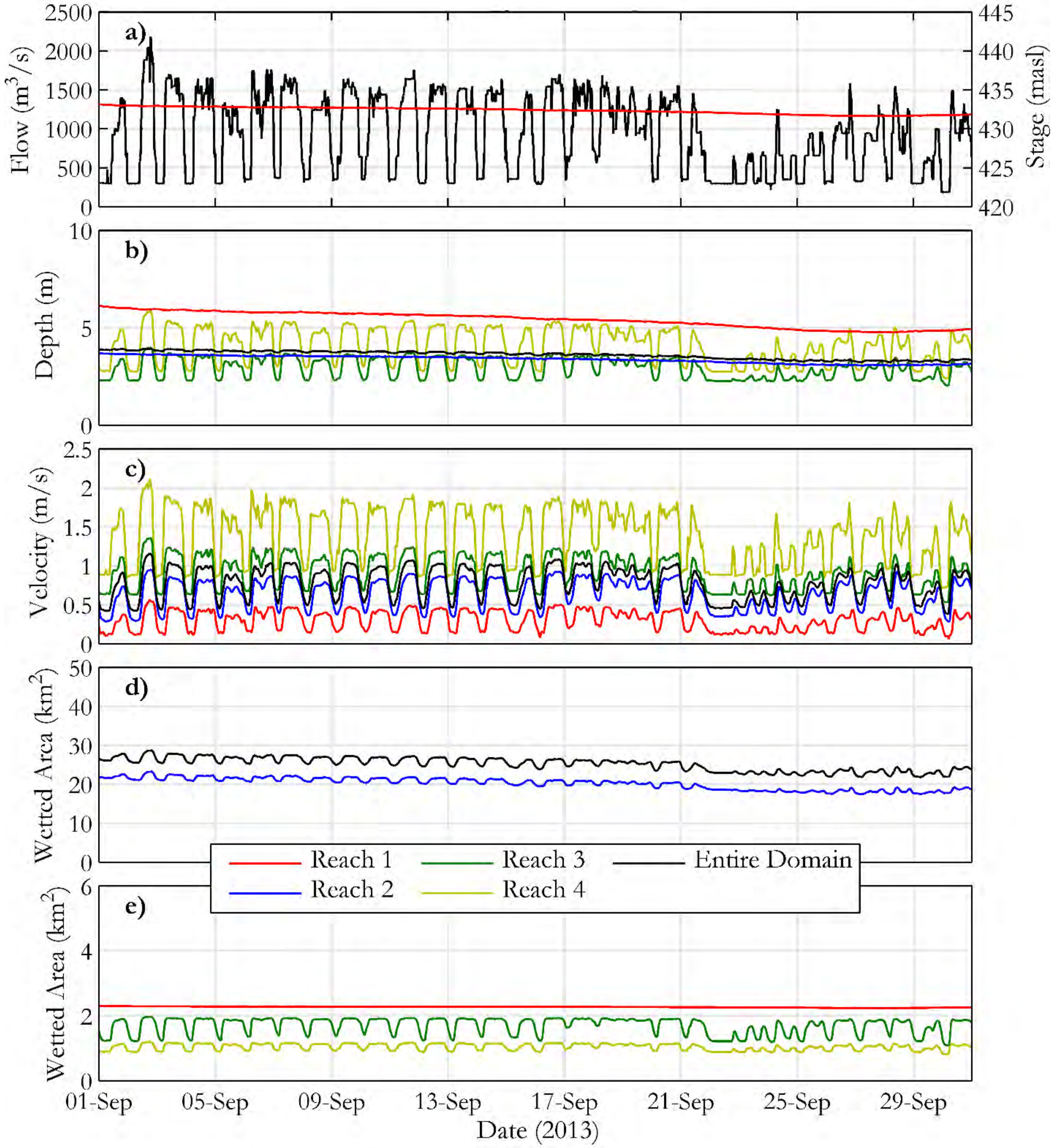


Figure 24 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for September 2013.

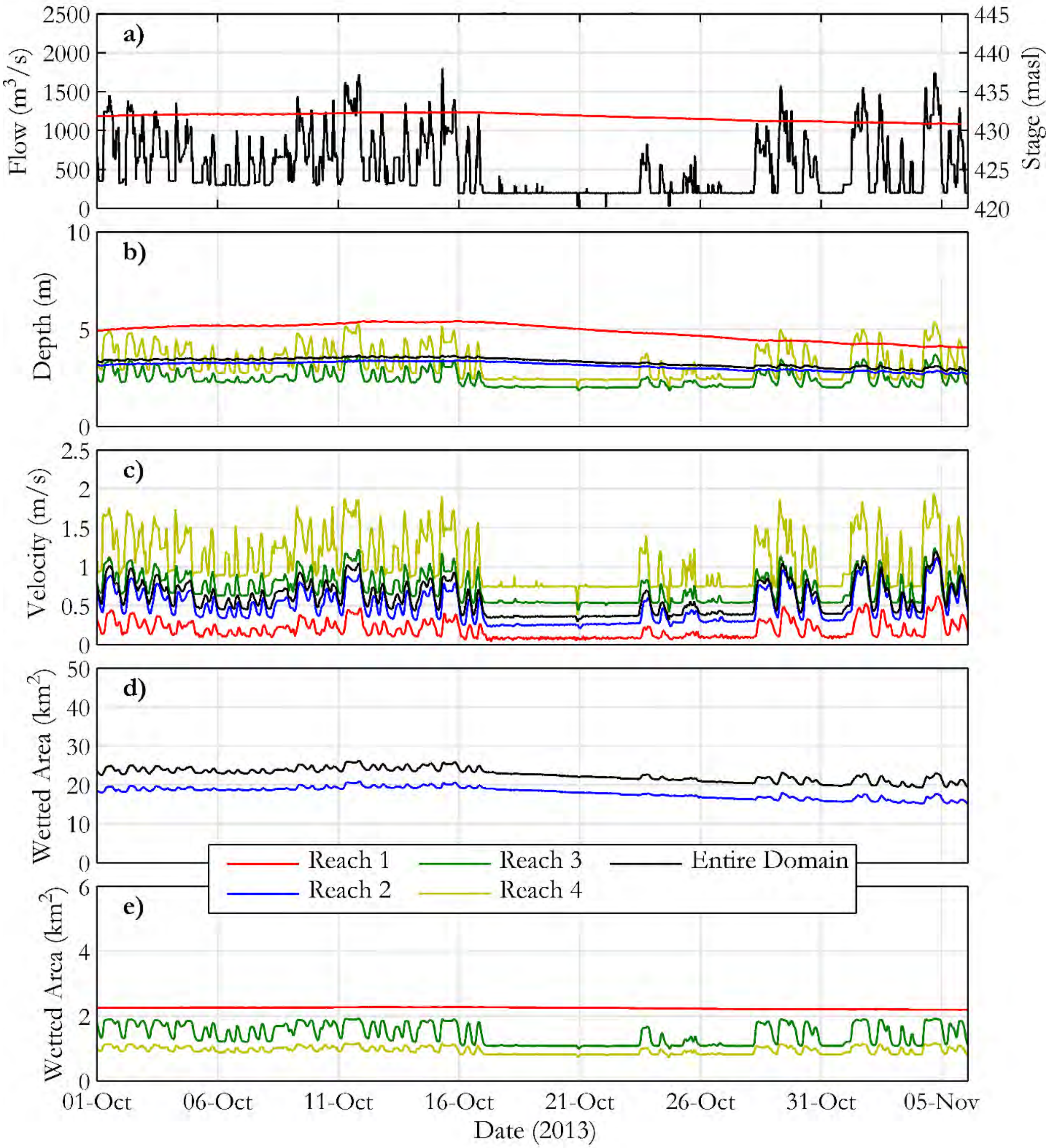


Figure 25 a) Discharge from Revelstoke Dam and water level at downstream boundary of modelled domain; b) simulated average flow depth; c) simulated average flow velocity; and d) & e) simulated wetted riverbed area for October 01 to November 06, 2013.

APPENDIX F: TABULAR REPRESENTATION OF THE 2012-2013 WETTED BED AREA, AVERAGE FLOW DEPTH, AND AVERAGE FLOW VELOCITY FOR THE REACHES OF THE MIDDLE COLUMBIA RIVER BY MONTH

Table 12 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for November 18 to 30, 2012.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	39.33	37.66	41.06	4.8	4.7	5	0.45	0.16	0.85
Reach 4	0.96	0.74	1.14	3.8	2.3	5.9	1.28	0.65	2.12
Reach 3	1.71	1.44	1.91	2.9	2.2	4.1	0.81	0.29	1.46
Reach 2	33.96	32.79	35.31	4.9	4.8	5	0.21	0.03	0.51
Reach 1	2.70	2.66	2.74	6	4.7	7.1	0.14	0.01	0.37

For November 18 to 30, 2012, the average, minimum, and maximum discharges from Revelstoke Dam were 766, 148, and 2,207 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 436, 435.7, and 436.3 m, respectively.

Table 13 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for December, 2012.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	33.16	26.97	39.62	4.3	3.8	4.9	0.39	0.18	0.83
Reach 4	0.95	0.76	1.13	3.7	2.3	5.6	1.09	0.67	2.01
Reach 3	1.64	1.26	1.88	2.7	2.2	3.8	0.71	0.3	1.39
Reach 2	28.01	21.85	34.44	4	3.2	4.9	0.19	0.05	0.54
Reach 1	2.56	2.48	2.73	8.4	7.1	9.4	0.11	0.02	0.36

For December 2012, the average, minimum, and maximum discharges from Revelstoke Dam were 694, 153 and 1,981 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 435, 433, and 436 m, respectively.

Table 14 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for January, 2013.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	23.50	14.55	28.63	3.3	2.4	3.9	0.88	0.47	1.2
Reach 4	1.04	0.56	1.14	4.5	1.5	6	1.61	0.83	2.16
Reach 3	1.75	0.75	1.91	3.2	1.5	4.1	1.15	0.7	1.51
Reach 2	18.34	10.58	23.12	2.1	0.6	3.1	0.73	0.32	1.05
Reach 1	2.37	1.78	2.48	9.1	8.9	9.4	0.36	0.12	0.6

For January 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 1,194, 21 and 2,215 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 431, 429, and 433 m, respectively.

Table 15 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for February 1 to 10, 2013.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	15.88	11.80	19.36	2.7	2.3	2.9	1.19	0.78	1.44
Reach 4	1.03	0.78	1.13	4.4	2.5	5.7	1.54	0.66	2.12
Reach 3	1.75	1.12	1.89	3.1	2.1	3.8	1.1	0.6	1.43
Reach 2	11.65	8.36	14.73	0.9	0	1.4	1.19	0.7	1.4
Reach 1	1.45	1.27	1.78	9	8.6	9.2	0.82	0.26	1.14

For February 1 to 10, 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 1,110, 151, and 2,114 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 428.7, 428.2, and 429.3 m, respectively.

Table 16 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for February 11 to 28, 2013. Values given are for the first scenario with a uniform-flow depth at the downstream boundary.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	13.46	9.31	17.30	2.5	1.9	2.9	1.27	0.89	1.56
Reach 4	1.02	0.81	1.13	4.3	2.6	5.7	1.47	0.66	2.09
Reach 3	1.73	1.19	1.89	3	2.2	3.9	1.06	0.66	1.43
Reach 2	9.61	6.37	13.03	2.2	1.7	2.5	1.31	0.92	1.58
Reach 1	1.09	0.81	1.30	3.1	2.4	3.6	1.15	0.81	1.44

For February 11 to 28, 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 1,026, 152 and 2,149 m^3/s, respectively.

Table 17 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for March, 2013. Values given are for the first scenario with a uniform-flow depth at the downstream boundary.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	12.39	7.75	17.79	2.4	1.6	3	1.24	0.75	1.59
Reach 4	0.98	0.74	1.13	3.9	2.3	5.7	1.44	0.66	2.1
Reach 3	1.61	1.01	1.89	2.8	1.9	3.9	1.04	0.56	1.45
Reach 2	8.78	5.27	13.48	2	1.4	2.5	1.28	0.77	1.6
Reach 1	1.02	0.67	1.33	2.9	2	3.7	1.13	0.69	1.42

For March 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 848, 102 and 2,154 m^3/s, respectively.

Table 18 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for April, 2013. Values given are for the first scenario with a uniform-flow depth at the downstream boundary.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	9.72	7.73	14.37	2	1.6	2.6	0.88	0.68	1.42
Reach 4	0.87	0.73	1.11	3	2.2	5.3	0.92	0.65	2.05
Reach 3	1.32	1.00	1.86	2.3	1.9	3.6	0.72	0.55	1.31
Reach 2	6.69	5.29	10.45	1.7	1.4	2.3	0.95	0.73	1.53
Reach 1	0.84	0.67	1.14	2.4	2	3.3	0.79	0.63	1.22

For April 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 409, 145 and 1,882 m^3/s, respectively.

Table 19 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for May 1 to 10, 2013. Values given are for the first scenario with a uniform-flow depth at the downstream boundary.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	11.97	8.56	15.95	2.3	1.8	2.7	1.13	0.74	1.42
Reach 4	0.94	0.75	1.10	3.6	2.3	5.1	1.19	0.63	1.91
Reach 3	1.56	1.03	1.86	2.7	1.9	3.6	0.9	0.57	1.29
Reach 2	8.46	5.78	11.81	2	1.6	2.3	1.2	0.77	1.51
Reach 1	1.01	0.76	1.24	2.9	2.2	3.5	1.05	0.7	1.34

For May 1 to 10, 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 667, 158 and 1,660 m^3/s, respectively.

Table 20 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for February 11 to 28, 2013. Values given are for the second scenario with the weekly-minimum stage for station 6 applied at the downstream boundary.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	19.91	17.37	21.89	2.8	2.5	3	1.0	0.6	1.4
Reach 4	1.02	0.81	1.13	4.3	2.6	5.7	1.5	0.7	2.1
Reach 3	1.73	1.19	1.89	3	2.2	3.9	1.1	0.7	1.4
Reach 2	14.89	13.08	16.64	2.5	2.4	2.7	1.0	0.5	1.3
Reach 1	2.27	2.24	2.31	3.5	3.5	3.6	0.5	0.2	0.9

For February 11 to 28, 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 1,026, 152 and 2,149 m^3/s, respectively. The average, minimum, and maximum values of the water level assumed for Arrow Lakes Reservoir were 430.1, 430.05, and 430.2 m, respectively.

Table 21 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for March, 2013. Values given are for the second scenario with the weekly-minimum stage for station 6 applied at the downstream boundary.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	19.43	16.31	22.86	2.7	2.4	3.1	0.98	0.47	1.38
Reach 4	0.98	0.74	1.13	3.9	2.3	5.7	1.44	0.66	2.1
Reach 3	1.61	1.01	1.89	2.8	1.9	3.9	1.04	0.56	1.45
Reach 2	14.58	12.30	17.49	2.5	2.3	2.8	0.94	0.4	1.31
Reach 1	2.26	2.15	2.36	3.6	3.4	3.8	0.51	0.11	0.92

For March 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 848, 102 and 2,154 m^3/s, respectively. The average, minimum, and maximum values of the water level assumed for Arrow Lakes Reservoir were 430.2, 429.8, and 430.5 m, respectively.

Table 22 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for April, 2013. Values given are for the second scenario with the weekly-minimum stage for station 6 applied at the downstream boundary

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	18.38	17.08	21.41	2.6	2.5	2.9	0.58	0.4	1.11
Reach 4	0.87	0.73	1.11	3	2.2	5.3	0.92	0.65	2.05
Reach 3	1.32	1.00	1.86	2.3	1.9	3.6	0.72	0.55	1.31
Reach 2	13.89	13.07	16.21	2.5	2.4	2.6	0.53	0.34	1.09
Reach 1	2.30	2.27	2.32	3.6	3.6	3.7	0.19	0.01	0.62

For April 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 409, 145 and 1,882 m^3/s, respectively. The average, minimum, and maximum values of the water level assumed for Arrow Lakes Reservoir were 430.3, 430.2, and 430.35 m, respectively.

Table 23 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for May l to 10, 2013. Values given are for the second scenario with the weekly-minimum stage for station 6 applied at the downstream boundary.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	20.26	17.72	22.56	2.8	2.6	3.1	0.8	0.42	1.12
Reach 4	0.94	0.75	1.10	3.6	2.3	5.1	1.19	0.63	1.91
Reach 3	1.56	1.03	1.86	2.7	1.9	3.6	0.9	0.57	1.29
Reach 2	15.40	13.61	17.28	2.7	2.5	2.8	0.77	0.36	1.08
Reach 1	2.35	2.32	2.38	3.9	3.6	4	0.35	0.01	0.61

For May 01 to 10, 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 667, 158 and 1,660 m^3/s, respectively. The average, minimum, and maximum values of the water level assumed for Arrow Lakes Reservoir were 430.6, 430.3, and 430.8, m respectively.

Table 24 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for May 11 to 31, 2013.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	28.57	22.27	34.74	4	3.2	4.4	0.66	0.33	1.05
Reach 4	0.94	0.76	1.12	3.6	2.3	5.4	1.19	0.61	1.9
Reach 3	1.56	1.09	1.87	2.7	2.1	3.7	0.93	0.59	1.36
Reach 2	23.58	17.89	29.25	3.8	3.1	4.3	0.54	0.23	0.92
Reach 1	2.49	2.42	2.56	6.5	4.8	7.8	0.26	0.07	0.5

For May 11 to 31, 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 681, 52 and 1,727 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 434, 432, and 435 m, respectively.

Table 25 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for June, 2013.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	42.89	34.97	48.32	5.7	4.4	7.3	0.46	0.24	0.74
Reach 4	0.99	0.76	1.13	4	2.3	5.7	1.18	0.65	1.82
Reach 3	1.86	1.26	2.12	3.6	2.1	5	0.81	0.43	1.24
Reach 2	36.97	30.23	41.26	5.6	4.3	7.3	0.24	0.1	0.47
Reach 1	3.07	2.58	3.87	8.8	7.8	9.4	0.16	0.03	0.33

For June 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 746, 156, and 1,166 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 437, 435, and 440 m, respectively.

Table 26 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for July, 2013.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	45.95	41.22	48.62	6.3	5.2	7.5	0.32	0.14	0.65
Reach 4	1.01	0.84	1.16	4.3	2.7	6.3	1.06	0.46	2.02
Reach 3	1.96	1.68	2.14	4.1	2.8	5.3	0.5	0.2	1.11
Reach 2	39.61	35.86	41.43	6.3	5.1	7.5	0.11	0.03	0.25
Reach 1	3.36	2.79	3.93	9.1	8.8	9.4	0.14	0.01	0.31

For July 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 850, 241, and 2,165 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 438, 437, and 440 m, respectively.

Table 27 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for August, 2013.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	33.78	26.31	41.34	4.4	3.8	5.2	0.5	0.23	0.96
Reach 4	0.97	0.84	1.14	3.9	2.7	5.9	1.3	0.8	2.12
Reach 3	1.65	1.21	1.91	2.9	2.2	4.1	0.87	0.39	1.49
Reach 2	28.58	21.73	35.99	4.2	3.7	5.1	0.27	0.07	0.64
Reach 1	2.58	2.48	2.79	7.4	6.1	8.8	0.18	0.03	0.43

For August 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 823, 227, and 2,183 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 435, 433, and 437 m, respectively.

Table 28 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for September, 2013.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	25.17	21.84	28.64	3.6	3.2	3.9	0.8	0.42	1.16
Reach 4	1.00	0.77	1.14	4.1	2.4	5.9	1.48	0.84	2.13
Reach 3	1.66	1.06	1.90	2.9	2	4	1.08	0.71	1.47
Reach 2	20.07	17.32	23.13	3.4	3.1	3.7	0.65	0.28	0.95
Reach 1	2.45	2.42	2.48	5.4	4.7	6.1	0.32	0.1	0.56

For September 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 921, 184, and 2,184 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 432.4, 431.6, and 433 m, respectively.

Table 29 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for October, 2013.

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	22.90	19.77	26.21	3.3	2.9	3.6	0.67	0.45	1.05
Reach 4	0.89	0.68	1.11	3.2	2	5.3	1.23	0.86	1.89
Reach 3	1.38	0.97	1.86	2.4	1.8	3.7	0.91	0.71	1.33
Reach 2	18.20	15.54	20.80	3.2	2.8	3.4	0.55	0.33	0.9
Reach 1	2.43	2.39	2.46	5	4.2	5.4	0.22	0.09	0.47

For October 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 495, 23 and 1,798 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 431.9, 431, and 432.4 m, respectively.

Table 30 Wetted bed area, average flow depth, and average flow velocity for the reaches of the Middle Columbia River for November 01 to 06, 2013

Reach	Wetted Riverbed Area (km^2)			Average Flow Depth (m)			Average Velocity (m/s)		
	Average	Min	Max	Average	Min	Max	Average	Min	Max
All	20.77	19.30	22.96	3	2.8	3.1	0.72	0.41	1.19
Reach 4	0.93	0.77	1.12	3.5	2.4	5.4	1.18	0.73	1.95
Reach 3	1.48	1.06	1.87	2.6	2	3.7	0.88	0.61	1.36
Reach 2	15.98	15.08	17.62	2.8	2.7	2.9	0.64	0.32	1.11
Reach 1	2.38	2.38	2.39	4.1	4	4.2	0.27	0.09	0.62

For November 01 to 06, 2013, the average, minimum, and maximum discharges from Revelstoke Dam were 645, 161, and 1,744 m^3/s, respectively. The average, minimum, and maximum water levels in Arrow Lakes Reservoir were 430.9, 430.8, and 431.1 m, respectively.