# Columbia River Project Water Use Plan

## Lower Columbia River Fish

**Implementation Year 2013**

**Reference: CLBMON#44**

***Lower Columbia River Physical Habitat and Ecological Productivity Monitoring (Year 6)***

**Study Period: 2013**

**Ecoscape Environmental Consultants Ltd.**
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July, 2014

# Lower Columbia River Physical Habitat and Ecological Productivity Monitoring (Year 6)

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ECOSCAPE
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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| µS | microsiemens |
| AICc | Akaike information criterion corrected for small sample sizes |
| ALGS | Arrow Lakes Generating Station |
| BBK | Birchbank |
| BC Hydro | British Columbia Hydro and Power Authority |
| BRD | Combined discharge from Brilliant Dam, including spill and the Brilliant Dam expansion project |
| Caro Labs | Caro Environmental Laboratories (Kelowna, B.C.) |
| Celgar | Zellstoff Celgar Mill |
| CV | Coefficient of variation |
| Didymo | *Didymosphenia geminata* |
| DO | Dissolved oxygen |
| FFF | fall fluctuating flow |
| HLK | Hugh L. Keenleyside |
| QA/QC | Quality assurance, quality control |
| km | kilometer |
| L | litre |
| LCR | Lower Columbia River |
| m | metre |
| m ASL | metres above sea level |
| max | maximum value |
| MCR | Middle Columbia River |
| min | minimum value |
| MWF | Mountain Whitefish |
| N | nitrogen |
| n | sample size |
| NTU | nephelometric turbidity units |
| PCA | principal component analysis |
| POM | particulate organic material |
| RBT | Rainbow Trout |
| SD | standard deviation |
| SRP | soluble reactive phosphorus |
| TDS | total dissolved solids |
| T-P | total phosphorus |
| TSS | total suspended solids |
| WQIS | water quality index station |
| UTM | Universal Transverse Mercator |
| WUP CC | Columbia River Water Use Plan Consultative Committee |

## DEFINITIONS

The following terms are defined as they are used in this report.

| Term | Definition |
|---|---|
| Biplot | An enhanced scatterplot that uses both points and vectors to represent data structure |
| Flow | The instantaneous volume of water flowing at any given time (e.g.1200 $m^3/s$) |
| Freshet | The flood of a river from melted snow in the spring |
| Laminar | Non-turbulent flow of water in parallel layers near a boundary |
| Light attenuation | Reduction of sunlight strength during transmission through water |
| Limitation, nutrient | A nutrient can limit or control the potential growth of organisms e.g. P or N |
| Linear regression model | Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data |
| Macronutrient | The major constituents of cells: nitrogen, phosphorus, carbon, sulphate, H |
| Mainstem | The primary downstream segment of a river, as contrasted to its tributaries |
| Morphology, river | The study of channel pattern and geometry at several points along a river |
| Orthogonal | At right angles |
| Salmonid | Pertaining to the family *Salmonidae*, including the salmons, trouts, chars, and whitefishes. |
| Substrates | Substrate (sediment) is the material (boulder cobble sand silt clay) on the bottom of a stream. |

Suggested Citation

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## EXECUTIVE SUMMARY

This is a multi-year study of physical habitat and ecological productivity on the Lower Columbia River (LCR) between the outflow of the Hugh L. Keenleyside Dam and the Birchbank gauging station. The aim of the study is to address management questions and hypotheses that examine the influence of three different flow periods (Mountain Whitefish (MWF) Jan 1 - Mar 31; Rainbow Trout (RBT) Apr 1 - Jun 30; and fall fluctuating (FFF) Sep 1 - Oct 31) on select physical habitat and ecological productivity measures. Table 1-1 summarizes the management questions, hypotheses and preliminary results. This brief report focuses on 2013 physical data, but also includes historical water temperature, water discharge/elevations and water quality data collected between 2008 and 2012. The reader should refer to Larratt et al. (2013) for the latest ecological productivity findings.

In 2013, 55.1% of LCR flows originated from the Hugh L. Keenleyside Dam and 42.5% from the Brilliant Dam on the Kootenay River. The spring freshet was an above average flow year, with a peak flow of 4,434 $m^3/s$ recorded on July 5th at the Birchbank gauging station. River elevation and discharged data from 2013 were added to the larger dataset prior to the completion of regression modeling. Models of recorded river elevations and flows were used to predict river elevations during pre, post and continuous MWF and RBT flow periods. The river level difference between MWF maximum peak spawning and minimum incubation was greater during pre-MWF flows than with post and continuous flows. Similarly, cumulative elevation drops that occurred during pre-RBT flows were significantly higher than those determined during post and continuous flow periods.

The 2013 LCR water temperatures varied seasonally, ranging from approximately 4 to 19°C, while temperatures in Kootenay River were slightly higher. Regression modeling of cumulative data to date indicated that the influence of flow on water temperature was relatively weak compared to other model predictors such as air temperature, reservoir temperature and reservoir elevation.

Water quality parameters were collected on four occasions in 2013 and indicated good water quality in both Kootenay River and in LCR. Although it was not possible to statistically assess how each flow period affect water quality parameters, we looked at the system from a broader perspective and explored the relationship of seasonal and annual flow on water quality by summarizing water quality data by season and year, and also by employing Principal Component Analysis (PCA). Based on the relationships between annual flow and specific water quality parameters, we then made inferences to whether the implementation of MWF, RBT or FFF alter the availability of biological active nutrients and/or the electrochemistry of the river.

The PCA results supported previous assertions that the influence of the managed flow periods on water quality are subtle compared to the stronger effects of water quality in the flow sources, freshet, anthropogenic nutrient donation groundwater inputs, and even photosynthesis within LCR. We anticipate that fish flows may cause small decreases in electrochemistry parameters through dilution, and may improve particulate and dissolved nutrient delivery under low to moderate flow conditions, but that they are unlikely to have a discernible effect on pH, or on the overall nutrient status of LCR. As others have, we conclude that the effects of the fish flow periods on biologically active nutrients were minor compared to the influences of the major water sources.

**Table 1-1: CLBMON-44 Status of Objectives, Management Questions and Hypotheses After Year 6**

| Management Questions | Management Hypotheses | Year 6 (2013) Preliminary Status |
|---|---|---|
| Physical Habitat Monitoring<br>Q.1.<br><br>How does continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall affect water temperature in LCR? What is the temporal scale (diel, seasonal) of water temperature changes? Are there spatial differences in the pattern of water temperature response? | Ho1phy: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, does not alter the seasonal water temperatures regime of LCR. | Regression modeling of the studies cumulative data to date indicates that the influence of flow on LCR water temperature is relatively low compared to other model predictors. When all seasons and flow periods were considered, LCR water temperatures were most strongly correlated with air temperature and reservoir water temperature, with the strongest relationships observed in the fall and winter, and during MWF and RBT flow periods.<br><br>Flow was positively associated with river temperature during the fall and RBT flow periods, and negatively associated with river temperature during the summer and winter periods. River flows appeared to have no effect during the MWF flow period. Based on this analysis, flow is not an important determinant of river temperature. These findings are consistent with that reported by Scofield et al. (2011) and Larratt et al. (2013) for previous years of the study.<br><br>Given the nominal influence of flow on LCR water temperature, the null hypothesis is preliminarily accepted. |
| Physical Habitat Monitoring<br>Q.2.<br><br>How does continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall affect the seasonal and inter-annual range and variability in river level fluctuation in LCR? | Ho2phy: Continued implementation of MWF and RBT flows does not affect seasonal water levels in LCR. | Regression modeling suggests that river flow is an important determinant of water levels.<br><br>River elevation data at five sites on LCR were regressed with flow data from HLK, BRD, and BBK. Historic flows and the linear relationships were then used to predict elevations during pre, post and continuous MWF and RBT flow periods. The elevation differences during the flow periods were analyzed using permutation ANOVA. At all locations, the river level difference between MWF maximum peak spawning and minimum incubation was greater during pre-MWF flows than with post and continuous flows.<br><br>Similarly, river elevation data from monitoring stations WQIS2 and WQIS3 were regressed with flow data during the RBT flow period. The best fit regression model was used to predict historic elevations. For both stations, the cumulative elevation drops that occurred during pre-RBT flows (1984-1991) were significantly higher than those determined during post (1992-2007) and continuous (2008-2013) flow periods.<br><br>We therefore reject all three null hypotheses. |
| | Ho2Aphy: Continued implementation of MWF flows does not reduce the river level difference between the maximum peak spawning flow (1 Jan to 21 Jan) and the minimum incubation flow (21 Jan to 31 Mar). | |
| | Ho2Bphy: Continued implementation of RBT flows does not maintain constant water level elevations at Norns Creek fan between 1 Apr and 30 Jun. | |
| Physical Habitat Monitoring<br>Q.3.<br><br>How does continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall | Ho3phy: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, does not alter the water quality of LCR. | Water quality parameters that address electrochemistry include: conductivity, TDS, hardness, alkalinity, dissolved metals ions and pH. Biologically active nutrient parameters include: nitrate, ammonia, total P and ortho phosphate (SRP). Based on data collected throughout the study, LCR has good water quality. Parameters rarely exceeded water quality guidelines or objectives. |

| | | |
|---|---|---|
| affect electrochemistry and biologically active nutrients in LCR? | Ho3Aphy: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, does not alter the electrochemistry of LCR.<br><br>Ho3Bphy: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, does not alter the availability of biologically active nutrients of LCR. | We have been unable to statistically test how flows within each flow period affect water quality due to the limited sampling regime. Alternatively, we grouped the seasons from all available years of data to determine if any relationships exist between seasonal and annual flows for specific water quality parameters, and we also used Principal Component Analysis to further understand how flow and water quality are related. The results of these analyses were then used to make inferences about the influence MWF, RBT and FF flow periods on water quality.<br><br>Based on our understanding of the system and the cursory analyses described above, we inferred that the influence of fish flows on water quality is subtle compared to the stronger effects of water quality in the flow sources, freshet, anthropogenic nutrient donation groundwater inputs, and even photosynthesis within LCR. We anticipate that fish flows may cause small decreases in electrochemistry parameters through dilution, and may improve particulate and dissolved nutrient delivery under low to moderate flow conditions, but that they are unlikely to have a discernible effect on pH, or on the overall nutrient status of LCR.<br><br>We therefore preliminary accept the management hypotheses $HO_{3phy,}$ $HO_{3Aphy,}$ and $HO_{3Bphy}$ and assume that fish flows, whether they be MWF, RBT or FF flows, have no effect on the water quality of LCR. |
| Ecological Productivity Monitoring<br>Q.1.<br>What are the composition, abundance, and biomass of epilithic algae and benthic invertebrates in LCR? | Ho1: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, do not affect the biomass, abundance and composition of benthic invertebrates in LCR.<br><br>Ho1Aeco: Continued implementation of MWF does not affect the biomass, abundance and composition of benthic invertebrates in LCR.<br><br>Ho1Beco: Continued implementation of RBT flows does not affect the biomass, abundance and composition of benthic invertebrates in LCR.<br><br>Ho1Ceco: Continued fluctuations of flow during the fall do not affect the biomass, abundance and composition of benthic invertebrates in LCR. | Please refer to Larratt et al. (2013) for the most recent work on the productivity hypotheses. The following progress update was taken verbatim:<br><br>The high seasonal and annual variation observed in the benthic invertebrate data makes it difficult to attribute a causal effect to the MWF, RBT, or FFF periods. It is hypothesized that stable flows during the MWF period may aid in the establishment of Didymo and have subsequent effects on the benthic community, but additional years of data are needed to confirm this association.<br><br>During the RBT flow period, the effects of freshet were greater than potential effects of the flow management regime intended to reduce cumulative drops in river elevation. Despite this, we still hypothesize that the reduction in substrate dewatering during the RBT flow period has acted to stabilize flows and the invertebrate community. During the FFF period, the effects of dewatering likely causes similar biomass loss to those documented in MCR (Schleppe *et al.* 2013), with the most significant influences occurring in areas that are frequently dewatered. However, since LCR sampling only occurred in permanently submerged areas, changes to the peripheral community are difficult to ascertain.<br><br>At this time, we preliminarily reject all four null hypotheses because at minimum, flow management has resulted in changes to the LCR benthic invertebrate community. In future years, we will attempt to elucidate the specific effects of the MWF, RBT, and FFF periods on the benthic community. |

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| Ecological Productivity Monitoring<br><br>Q.2.<br>What is the influence of MWF and RBT flows during winter and spring, and fluctuating flows during fall on the abundance, diversity, and biomass of benthic invertebrates? | Ho2eco: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, do not increase total biomass accrual of periphyton in LCR. | Please refer to Larratt et al. (2013) for the most recent work on the productivity hypotheses. The following progress update was taken verbatim:<br><br>Based on the periphyton data collected thus far, it appears that the management of flows have the potential to alter the periphyton community, with the specific effect dependent on the flow period in question.<br><br>In 2012/13 the low stable MWF flows during the winter enabled extensive Didymo growth which lowered periphyton forage quality, but contributed to very high productivity metrics. We therefore preliminarily reject Ho2Aeco, that MWF flows does not increase total biomass accrual of periphyton. In 2014, periphyton sampling during the MWF flow period will include the collection of weekly Chl-a accrual data, which will provide additional information to more thoroughly address this hypothesis.<br><br>The combination of large spring freshet and RBT flows lowered LCR periphyton productivity in 2012. Lower summer periphyton production metrics compared to the fall are consistent with results reported by Scofield et al. (2011) for years 1-3 of this study. Because we cannot separate the effect of spring freshet from RBT flows, we tentatively accept Ho2Beco, that RBT flows does not increase total biomass accrual of periphyton.<br><br>Mean daily flows during the FFF period were generally quite stable. These moderate flows typically allowed more periphyton growth compared to the spring/summer. We preliminarily accept Ho2Ceco, that FFF do not increase total biomass accrual of periphyton in LCR, since the fall biomass data was typical of large rivers. |
| | Ho2Aeco: Continued implementation of MWF does not increase total biomass accrual of periphyton in LCR. | |
| | Ho2Beco: Continued implementation of RBT flows does not increase total biomass accrual of periphyton in LCR. | |
| | Ho2Ceco: Continued fluctuations of flow during the fall do not increase total biomass accrual of periphyton in LCR. | |
| Ecological Productivity Monitoring<br>Q.3.<br>Are organisms that are used as food by juvenile and adult MWF and RBT in LCR supported by benthic production in LCR? | Ho3eco: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, do not increase the availability of fish food, organisms in LCR | Please refer to Larratt et al. (2013) for the most recent work on productivity hypotheses. The following progress update was taken verbatim:<br>A fish food index (FFI) was used to evaluate the effects of flow management on food for fishes in LCR. The final FFI score for each site represents the abundance of benthic taxon as fish food, the size or biomass availability of benthic taxon as fish food, and the availability of more preferred types of benthic foods. Modeling data suggest that high peak flows during summer periods, as was observed in 2012, had an |
| | Ho3Aeco: Continued implementation of MWF flows does not increase availability of fish food organisms in LCR. | |
| | Ho3Beco: Continued implementation of RBT flows does not increase availability of fish food organisms in LCR. | |

| | | |
|---|---|---|
| | $Ho_{3Ceco}$: Continued fluctuations of flows during the fall do not increase availability of fish food organisms in LCR. | overall negative effect on food for fish. However, during more stable periods, food availability for fish was positively associated with velocity. This suggests that during the RBT flow period, high peak freshet flows reduce food availability for fish, making detection of specific effects associated with the RBT flow regime more difficult. During the fall fluctuating flow period, the availability of food for fish was greatest in areas of higher velocity. Areas of higher velocity were more typical of erosional, cobble banks, which tended to have greater predominance of the more sensitive EPT taxa. Although not specifically modelled, we hypothesize that fish food availability will decrease in the winter due to the establishment of Didymo and less favourable habitat conditions.<br><br>We preliminarily reject all four null hypotheses because at minimum, flows appear to affect the availability of food for fish. In future years we will attempt to better understand the specific effects of the MWF, RBT, and FFF operating regimes on food for fish. |

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## APPENDICES

# 1.0 INTRODUCTION

This is a multi-year study of the physical habitat and ecological productivity on the Lower Columbia River (LCR), between the outflow of the Hugh L. Keenleyside (HLK) Dam and the Birchbank (BBK) gauging station. Over the past decade, BC Hydro and Power Authority (BC Hydro) has altered operations of HLK Dam to minimize the impacts of winter and early summer flows on salmonid spawning and rearing habitats in the LCR.

This study aims to examine the influence of the regulated winter and early summer flow periods, compared to fluctuating flows in the fall, on select physical habitat and ecological productivity measures. This report addresses Year 6 (2013) of the study and only includes historic and 2013 data pertaining to the physical parameters (hydrology, temperature and water quality) of LCR. The reader should refer to Larratt et al (2013) for a summary of the most recent productivity data.

## 1.1 Management Questions

The Columbia River Water Use Plan Consultative Committee (WUP CC) generated a set of management questions and hypotheses that relate to three different flow periods including:

1) Mountain Whitefish (MWF) spawning (Jan 1 – Jan 21) and incubation (Jan 22 – Mar 31). The purpose of the MWF flow period is to reduce the difference between peak flows during spawning and minimum flows during egg incubation;

2) Rainbow Trout (RBT) protection flows (Apr 1 – Jun 30). The purpose of this flow period is to reduce water elevation drops during the RBT spawning period; and

Fall fluctuating flow (FFF) (Sep 1 – Oct 31). This period is used to provide background data outside of regulated RBT and MWF flows

The management questions addressed by the physical habitat and ecological productivity monitoring programs are (BC Hydro 2007):

Physical Habitat Monitoring

1) How does continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall affect water temperature in LCR? What is the temporal scale (diel, seasonal) of water temperature changes? Are there spatial differences in the pattern of water temperature response?
2) How does continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall affect the seasonal and inter-annual range and variability in river level fluctuation in LCR?
3) How does continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall affect electrochemistry and biologically active nutrients in LCR?

Ecological Productivity Monitoring

1) What are the composition, abundance, and biomass of epilithic algae and benthic invertebrates in LCR?

2) What is the influence of the MWF and RBT flows during winter and spring, and fluctuating flows during fall on the abundance, diversity, and biomass of benthic invertebrates?

3) Are organisms that are used as food by juvenile and adult MWF and RBT in LCR supported by benthic production in LCR?

## 1.2 Management Hypotheses

Physical Habitat Monitoring

$HO_{1phy}$: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, does not alter the seasonal water temperatures regime of LCR.

$HO_{2phy}$: Continued implementation of MWF and RBT flows does not affect seasonal water levels in LCR.

$HO_{2Aphy}$: Continued implementation of MWF flows does not reduce the river level difference between the maximum peak spawning flow (1 Jan to 21 Jan) and the minimum incubation flow (21 Jan to 31 Mar).

$HO_{2Bphy}$: Continued implementation of RBT flows does not maintain constant water level elevations at Norns Creek fan between 1 Apr and 30 Jun.

$HO_{3phy}$: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, does not alter the water quality of LCR.

$HO_{3Aphy}$: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, does not alter the electrochemistry of LCR.

$HO_{3Bphy}$: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, does not alter the availability of biologically active nutrients of LCR.

Ecological Productivity Monitoring

$HO_{1eco}$: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, do not affect the biomass, abundance and composition of benthic invertebrates in LCR.

$HO_{1Aeco}$: Continued implementation of MWF does not affect the biomass, abundance and composition of benthic invertebrates in LCR.

$HO_{1Beco}$: Continued implementation of RBT flows does not affect the biomass, abundance and composition of benthic invertebrates in LCR.

$HO_{1Ceco}$: Continued fluctuations of flow during the fall do not affect the biomass, abundance and composition of benthic invertebrates in LCR.

$HO_{2eco}$: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, do not increase total biomass accrual of periphyton in LCR.

$HO_{2Aeco}$: Continued implementation of MWF does not increase total biomass accrual of periphyton in LCR.

$HO_{2Beco}$: Continued implementation of RBT flows does not increase total biomass accrual of periphyton in LCR.

$HO_{2Ceco}$: Continued fluctuations of flow during the fall do not increase total biomass accrual of periphyton in LCR.

$HO_{3eco}$: Continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, do not increase the availability of fish food, organisms in LCR

$HO_{3Aeco}$: Continued implementation of MWF flows does not increase availability of fish food organisms in LCR.

$HO3_{Beco}$: Continued implementation of RBT flows does not increase availability of fish food organisms in LCR.

$HO3_{Ceco}$: Continued fluctuations of flows during the fall do not increase availability of fish food organisms in LCR.

# 2.0 METHODS

## 2.1 Study Area and Sampling Locations

The study area is located in southeast British Columbia on the LCR between HLK Dam and the BBK gauging station (Figure 2-1). Kootenay River is a major tributary to LCR, and there are several smaller tributaries including Norns, Blueberry, China and Champion Creeks. The study area is divided into three reaches: 1) from HLK Dam to Norns Creek; 2) from Norns Creek confluence to the Kootenay River, and 3) from the Kootenay River confluence to BBK gauging station.

Physical parameters including water quality, water temperature and water level were collected at six water quality index stations (WQIS) distributed within the three reaches of LCR and in the Kootenay River (Figure 2-1 and Table 2-1).

**Table 2-1: Monitoring Stations, Sample Types and UTM Coordinates**

| Station Name | Sample Type | UTM Coordinates Zone 11 | |
|---|---|---|---|
| | | Northing | Easting |
| WQIS1 | Physical/chemical/water level | 5,465,742 | 445,693 |
| WQIS2 | Physical/chemical/water level | 5,464,573 | 450,072 |
| WQIS3 | Physical/chemical/water level | 5,464,517 | 452,244 |
| WQIS4 | Physical/chemical/water level | 5,455,332 | 452,653 |
| WQIS5 | Physical/chemical/water level | 5,450,221 | 448,514 |
| WQ C1 (Norns Creek) | Physical/chemical | 5,465,356 | 451,746 |
| WQ C2 (Kootenay) | Physical/chemical/water level | 5,462,911 | 454,114 |

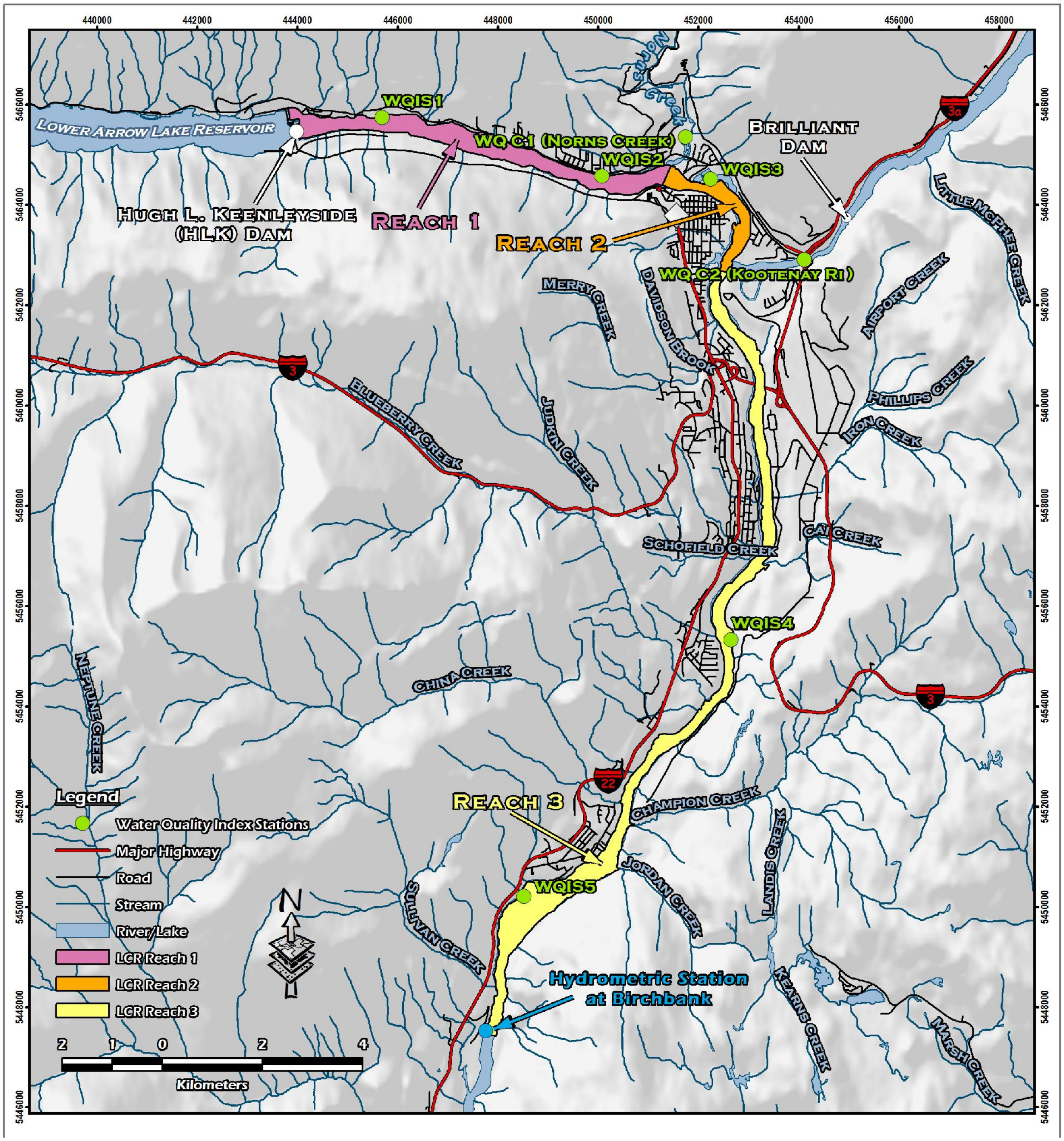


**Figure 2-1: Map of Lower Columbia River Study Area and Water Quality Index Station Sampling Locations**

## 2.2 Hydrology and Water Level

Water level and temperature data were collected at five water quality index stations (WQIS) within the main LCR channel, and at one station on Kootenay River (WQ C2) (Table 2-1).

River flow and discharge data were obtained from Robyn Irvine of Poisson Consulting Ltd. The Columbia River below the HLK Dam consists of flows originating from HLK Dam and the Arrow Lakes Generating Station (ALGS), both of which are managed by BC Hydro. The confluence of the Kootenay tributary is located approximately 10 km downstream of HLK Dam and consists of the combined discharge (BRD) from the Brilliant Dam, the spill from Brilliant Dam, and the Brilliant Dam expansion project; each of which are managed by Fortis BC on behalf of the Columbia Power Corporation. River flows at BBK include water originating from HLK Dam, BRD Dam and all other upstream tributaries. To address the physical monitoring management question #2, river flow and discharge data were obtained for all of 2013, and specific comparisons of the three different flow periods were undertaken.

As previously reported, on July 19, 2011, AquiStar® PT2X Smart Sensors were installed at five water quality index stations (WQIS1 through 5) on LCR and at one station on Kootenay River (WQ C2) (Figure 2-1). Each sensor was placed in a 1.5-inch PVC pipe that was semi-permanently mounted to either a log piling or bedrock. The AquiStar® PT2X Smart Sensors consisted of a combination pressure/temperature sensor and data logger that records data on 15 minute intervals. These sensors remained in place until the summer of 2012, when record high flows inundated the data logger component of the sensors and disabled them[1]. Previously used level loggers were available as backup, and therefore, replacement Onset® Water Level Logger (Model U20) pressure transducers were installed at each of the stations, except Kootenay River (WQ C2)[2], during the week of August 15 -18, 2012. The Onset logger records water levels every 20 minutes, but also requires a barologger (Model U20) to compensate for changes in barometric pressure and to measure air temperature. One barologger was installed at the top end of LCR in Reach 1 and another was installed adjacent to WQIS4 within the upland forest canopy. All pressure readings were compensated for barometric pressure and converted to water depth using HOBOware® software. Water depth was converted to elevation based on the length of the sensor cable and the surveyed elevation of the top of the stilling well.

The elevation survey of each stilling well was completed by Robert Wagner of Ecoscape Environmental Consultants Ltd. on September 21, 2011. The obtained survey data allowed for the direct comparison of sensor locations with LCR elevations. This report includes river stage data collected in 2013.

## 2.3 Physical and Chemical Characteristics

Chemical and physical water quality parameters were collected at seven different sampling locations during 2013 (Table 2-1). The number of water quality sampling locations was reduced from ten to seven, as per a recommendation put forth in Year 4

[1] The data logger component of the sensors were positioned approximately 0.5 - 1 vertical metre above the previously documented high water level. The inundated data loggers were sent to the manufacturer in hopes of recovering lost data, but unfortunately data could not be retrieved and the units were no longer viable.
[2] The replacement sensor at the Kootenay River site could not be installed due to a continuation of high flows. The sensor was successfully mounted on September 13, 2012.

(2011) when flows in Blueberry, China and Champion Creeks were recorded as minimal to nil throughout several of the sampling sessions (Olson-Russello et al. 2012).

Three LCR WQIS are located upstream of the Kootenay River confluence (WQIS1 through 3), and two below (WQIS4 and 5). Three of the five LCR WQIS occur in proximity to noteworthy nutrient sources. WQISI occurs in close proximity to Zellstoff Celgar Mill (Celgar), a pulp processing facility, and WQIS3 and WQIS5 are located close to City of Castlegar outfalls. The City of Castlegar has two separate secondary sewage treatment systems, both authorized under Waste Management Act permits. One of the treatment systems discharges effluent into the Columbia River from the north bank, about 1 km upstream of the Kootenay-LCR confluence. The other system discharges near the west bank, 2 km downstream from the Kootenay-LCR confluence. Available effluent data indicates that discharge levels have remained below permitted maximums (Butcher 1992).

Field trips were conducted on April 3, June 6, September 13, and November 14 during 2013, with all sampling occurring during day-time hours. The following field water quality parameters: temperature, dissolved oxygen (DO), percent dissolved oxygen saturation, pH, conductivity, and total dissolved solids (TDS) were measured with a pre-calibrated Hannah HI 9828 sonde, by lowering the probe 1 m below the water’s surface. Readings were simultaneously recorded in the multi-meter memory and in a field book.

Water quality samples were collected in a low-metals bottle Van Dorn sampler. They were collected from the mid-water column (2-8 m depth) or 1 m below the surface if flows were too high to use the bottle sampler. Water depths were measured with a Lowrance depth sounder. Every mainstem LCR sample was a composite of three subsamples collected from: one third of the river width from left bank, mid river and one third of the river width from right bank. These subsamples were mixed in a triple-rinsed 4L container before decanting into the sample bottles. A composite sample of the river transect was collected because the focus of the sampling effort is to understand the water quality of the river as a whole versus the water quality from the sample points mentioned above.

The sample bottles were provided by Caro Environmental Laboratories (Caro Labs) with the appropriate preservatives pre-measured into the bottles. The non-filtered samples were analyzed for total hardness, ammonia as nitrogen (N), nitrate as N, nitrite as N, total phosphorus, ortho-phosphorus, TDS, total suspended solids (TSS) and turbidity according to Standard Methods. Field-filtered samples were analyzed for low-level soluble reactive phosphorus (SRP) and total dissolved solids (TDS). The filled sample bottles were placed on chipped ice and delivered to Caro Labs in Kelowna, B.C. within 24 hours of collection. One randomly chosen field duplicate and one deionized water travel blank were collected on each field trip. Additional QA/QC protocols were undertaken at Caro Labs.

## 2.4 Statistics Procedures

All statistical analyses and the creation of most figures were conducted in R (R Development Core Team 2013). Prior to carrying out statistical analyses on data across multiple years, 2013 data was combined with datasets from previous years (2008-2012).

### 2.4.1 Water Levels

The mean 2013 water level elevations recorded at WQIS1-5 in LCR and WQ C2 in Kootenay River were compared to the combined water elevation (± SD) during all years. Subsequent analysis of the effects of water level during MWF and RBT flow periods relied on the following key assumptions:

- The channel morphology has not changed substantially since pre-MWF flows (~1984), and;
- The river stage or elevation at any given WQIS can be largely predicted by flows within LCR and that small tributaries or effluent discharges have negligible effects on river elevation.

#### 2.4.1.1 Mountain Whitefish (MWF) Flow Period

To address the sub-hypothesis $HO_{2Aphy}$, that states continued implementation of MWF flows does not reduce the river level difference between the maximum peak spawning flow (Jan 1 to Jan 21) and the minimum incubation flow (Jan 21 to Mar 31), the water elevation difference between the maximum elevation during spawning and minimum elevation observed during incubation at each WQIS was investigated. Because historic river elevation data was not available, predicted elevations were calculated from flow data. Candidate linear regression models of water elevation were constructed for each WQIS, containing all combinations of flows from HLK, BRD, and BBK, and their associated quadratic terms (flow $values^2$) as explanatory variables (Table 2-2). Quadratic terms and appropriate data transformations such as using log scale were considered to account for potential logarithmic or non-linear relationships between flow and elevation. Model selection via Akaike information criterion corrected for small sample sizes (AICc) was used to determine the best fit and other plausible models (Δ AICc<2). In this approach, candidate models were considered and ranked based on their AICc scores. The best fit model exhibited a trade-off between model complexity and optimal fit of regression.

The top model for each site was then used to predict water elevation for periods between pre-implementation of MWF flows (1984 to 1994), post-implementation of MWF flows (1995 to 2007), and continuation of MWF flows (2008-2013). Differences among predicted elevations during each time period were tested using a permutation ANOVA and subsequent post-hoc analysis (Tukey's HSD) to determine groupings. The permutation ANOVA was used in lieu of traditional ANOVA or Student's t tests because it does not require the same assumptions of normality in data (which were not met in several cases), and was preferred to non-parametric methods due to ease of interpretation of results and the ability to conduct post-hoc analyses. Finally, the data were compared to actual elevations measured during 2008 - 2013 to investigate how predicted elevations compared to field collected elevations.

**Table 2-2: Possible flows used in regression modeling for predicting water levels during the MWF flow period**

| Possible Predictor Flows |
|---|
| HLK flow |
| HLK flow + HLK flow $^2$ |
| Brilliant flow |
| Brilliant flow + Brilliant flow $^2$ |
| Birchbank flow |
| Birchbank flow + Birchbank flow $^2$ |

#### 2.4.1.2 Rainbow Trout (RBT) Flow Period

To address sub-hypothesis $HO_{2Bphy}$, that states continued implementation of RBT flows does not maintain constant water level elevations at Norns Creek fan between April 1 and June 30, we used the same analysis procedure described above for sub-hypothesis $HO_{2Aphy}$. To limit the analysis to the Norns Creek fan, the closest two sites, WQIS2 and WQIS3, were included. To evaluate the cumulative elevation differences over the RBT flow period, linear regressions of water elevation were constructed for each site, containing all combinations of flows from HLK, BRD, and BBK, and their associated quadratic terms as explanatory variables. The same model selection process was used to determine the best fit model of all plausible models ($\Delta$ AICc < 2) and subsequently predict elevation during pre-implementation of RBT flows (1984 to1991), implementation of RBT flows (1992 to 2007), and continued RBT flows (2008-2013). Differences among predicted elevations during each time period were again tested using a permutation ANOVA (due to non-normal data in some cases) and subsequent post hoc analysis (Tukey's HSD) to determine groupings. Finally, the data were compared to actual elevations measured in 2008-2013 to investigate how predicted values compared to those collected in the field.

### 2.4.2 Water Temperature

Prior to formal analyses of the effects of environmental and physical variables on LCR water temperature, exploratory analyses and development of explanatory variables were conducted. First, autocorrelation among these explanatory variables were tested using pair-wise correlation coefficients and variance inflation factors following methods outlined by Zuur et al. (2009). All correlation coefficients were below 0.5, and Variance Inflation Factor (VIF) scores were also low, suggesting that autocorrelation among predictors was not a concern. This allowed all possible combinations of explanatory variables to be considered in candidate models. WQIS1 through WQIS3 occur above the confluence of the Kootenay River and only experience flows from HLK whereas, WQIS4 and WQI5 occur downstream and are subject to flows from both HLK and BRD. To account for this, associated explanatory variables were standardized based on location. Flows, reservoir temperature, and water elevation from HLK were used for WQIS1 through WQIS3 sites while BBK flows were used for WQIS4 and WQIS5 sites.

To characterize reservoir temperature as an explanatory variable, values were weighted by associated flows using the following equation:

$$T_{Res.} = \frac{(F_{HLK} \times T_{Arrow}) + (F_{BRD} \times T_{Kootaney})}{(F_{HLK} + F_{BRD})}$$

Where *F* is the flow for either HLK or BRD and *T* is the reservoir temperature for either Arrow Reservoir or Kootenay Lake. This analysis assumed that the final river temperature depends upon the total volume of water and the temperature of the two different water sources only (i.e., there are no other influences), and that all temperature measurements have occurred in a completely mixed solution of the two water sources.

Likewise, reservoir elevation was calculated using the following equation:

$$E_{Res.} = \left(\frac{F_{HLK}}{F_{BBK}} \times E_{Arrow}\right) + \left(\frac{F_{BRD}}{F_{BBK}} \times E_{Kootaney}\right)$$

Where *F* is flow from HLK, BBK, or BRD, and *E* is the water elevation. Temperature data from Kootenay Lake were only available for one to two days in each season. We created a full temperature dataset for this lake to be used in subsequent analyses by predicting daily water temperature from a Generalized Additive Model (GAM) of daily water temperature. This model incorporated both point data from Kootenay Lake and a full dataset from Arrow Reservoir, with day of year (1-365), season, and location (Kootenay Lake or Arrow Reservoir) as explanatory variables.

We used linear mixed-effects modeling (Zuur et al. 2009), model selection via AICc to evaluate the relative effects of water temperature and elevation from above site reservoirs, flow from dams (HLK and BRD), Castlegar air temperature, seasonal flow period, and *a priori* hypothesized interactions between flow periods and dam flows, on LCR water temperatures. In this approach, candidate linear mixed-effects models containing all combinations of the above explanatory variables were constructed with sampling site and year included as random effects to account for the potential lack of independence among measurements from the same year or site. Candidate models were then competed in AICc model selection process described above for elevation and flow period analyses. We also calculated pseudo $R^2$, derived from regressions of observed data versus fitted values (Cox and Snell 1989; Magee 1990; Nagelkerke 1991; and Piñeiro et al. 2008), as a measure of the variation in observed water temperatures explained by a given model. This approach ensured that all plausible explanations for water temperature were equally considered, to better understand the specific effects of flow period on water temperature.

### 2.4.3 Water Quality

Water quality data (2013) was combined with datasets from previous years (2008-2012). Consistent with previous years, if a measurement was non-detectable, it was entered into the database as ½ the lab reportable detection limit.

To illustrate the variation between season and year, boxplots of eight water quality parameters were generated using R. A generalized boxplot is provided in Figure 2-2. The horizontal line in the center of the box depicts the median, with the inter-quartile range (box) representing the 25th and 75th percentiles, the whiskers extend to the highest value that is within 1.5 times the inter-quartile range, and outliers are represented by dots.

Sample number (n) at each LCR site and season ranged from 1 to 14. Winter had the smallest sample number (n=1), spring and fall were intermediate (n=6) and summer had the greatest (n=14).

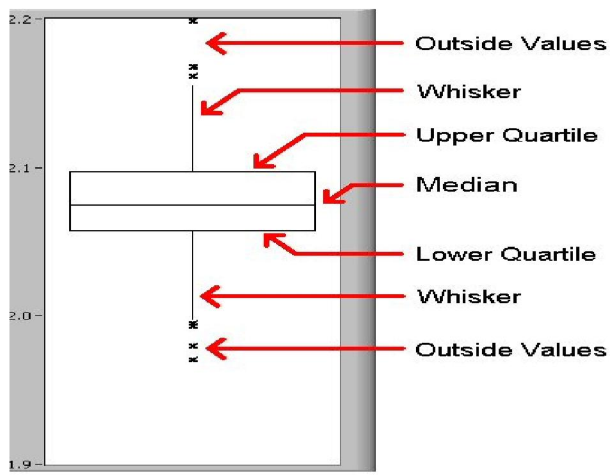


**Figure 2-2: Boxplot Diagram**

The hypothesis $Ho_{3phy}$, states that the continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall does not alter the water quality of LCR. Due to insufficient water quality sample size, it was not possible to directly assess whether the implementation of the flow periods alters water quality parameters. As an alternative, we considered the hypothesis more broadly by looking for relationships between flow (including HLK, BRD and BBK) and select water quality parameters where there was consistent data across years. The parameters that were investigated include TDS, $N0_3$+$N0_2$, $NH_3$ and TP as P, DO, TSS, Turbidity, and Conductivity, encompassing a range of nutrient and electrochemistry data.

Water quality data, collected from the five LCR sites were combined and log transformed and a Principal Component Analysis (PCA) was used to determine if potential relationships exist between any given water quality parameter and flow. Further, this approach also allowed us to understand specific patterns in water quality parameters or flow (e.g., do certain parameters trend together?). The PCA aims to highlight relationships in a dataset of multiple variables and summarize these relationships in as few axes as possible. Eigenvalues are measures of the proportion of the variance in the dataset accounted for by a given axis and can be interpreted as the relative importance of that axis.

# 3.0 RESULTS

## 3.1 Hydrology

### 3.1.1 River Flows

Flow within the study area is dominated by discharges from HLK Dam on the Columbia River and the Brilliant Dam on the Kootenay River. The sum of these flows and of other smaller, local tributaries is recorded at the Birchbank gauging station. In 2013, the mean daily river flows from the Columbia and Kootenay Rivers were 55.1% and 42.5%, respectively, of the total flows at the Birchbank gauging station. This constituted 98% of the total flow, with the remaining 2% originating from smaller tributaries such as Norns Creek and outfalls.

Figure 3-1 depicts the 2013 hydrographs of mean daily river flows from LCR at HLK Dam, Kootenay River from the Brilliant Dam and at the Birchbank gauging station. The mean daily river flows at HLK Dam were greater than those at Brilliant Dam (1209.9 $m^3$/s and 932.7 $m^3$/s, respectively), but Brilliant exhibited a higher peak, with a maximum flow of 2419.7 $m^3$/s recorded on June 21st (Table 3-1).

The highest flow recorded at the Birchbank gauging station in 2013 was 4,434.4 $m^3$/s on July 5th. This is compared to 2011 and 2012 when the peak was 4,155.4 $m^3$/s on July 9th and 6,043.1 $m^3$/s on July 21th, respectively (Larratt et al. 2013; Olson-Russello et al. 2012).

**Table 3-1: Mean Daily River Flows ($m^3$/s) at HLK Dam, Brilliant Dam and the Birchbank Gauging Station in 2013**

| Location | N (days) | Statistic | 2013 |
|---|---|---|---|
| HLK | 365 | Mean | 1209.9 |
| | | Min | 590.7 |
| | | Max | 2145.8 |
| | | SD | 520.5 |
| Brilliant | 365 | Mean | 932.7 |
| | | Min | 448.1 |
| | | Max | 2419.7 |
| | | SD | 612.6 |
| Birchbank | 361 | Mean | 2196.6 |
| | | Min | 1092.5 |
| | | Max | 4434.4 |
| | | SD | 812.0 |

Mean daily flows were separated and summarized for MWF, RBT and FFF periods to more thoroughly understand LCR flows during each of the designated flow periods (Table 3-2). During the MWF flow period (Jan 1 – Mar 31), flows at HLK Dam, Brilliant Dam and the Birchbank gauging station exhibited a different flow pattern compared to earlier years of the study. Previously, the flows originating from HLK and Brilliant Dams during the MWF flow period were fairly consistent from the beginning to the end of the flow period. In

2013, the flows from HLK Dam remained high (~2000 $m^3$/s) throughout January and then showed a substantial drop on February 9th to approximately 800 $m^3$/s (Figure 3-1). HLK flows then remained consistent for the remainder of the flow period. Flows from Brilliant Dam were similar to previous years, exhibiting fairly consistent flows throughout the flow period. The MWF flow period is split into spawning (Jan 1 – Jan 21) and incubation (Jan 22 – Mar 31). At the time of this writing, it is not known whether this drop in flows was sufficient enough to expose MWF eggs.

During the RBT flow period (Apr 1 – Jun 30), flows at Brilliant Dam remained fairly constant until May 5th when they steadily increased over a two week period from about 800 to 2200 $m^3$/s. The flows from Brilliant Dam remained high throughout the remainder of the RBT flow period, and peaked on June 21. The flows at the HLK Dam were generally held stable throughout the RBT flow period and did not begin to increase until the very end of the flow period on June 27. Flows from HLK peaked in early July and remained high through much of the month, while flows from Brilliant Dam steadily decreased during this period.

During the fall fluctuating flow period, a downward trend of mean daily flow for HLK was observed until the second week of October, followed by a gradual increase. Flows from Brilliant Dam were minimal and steady throughout the flow period at approximately 500 $m^3$/s.

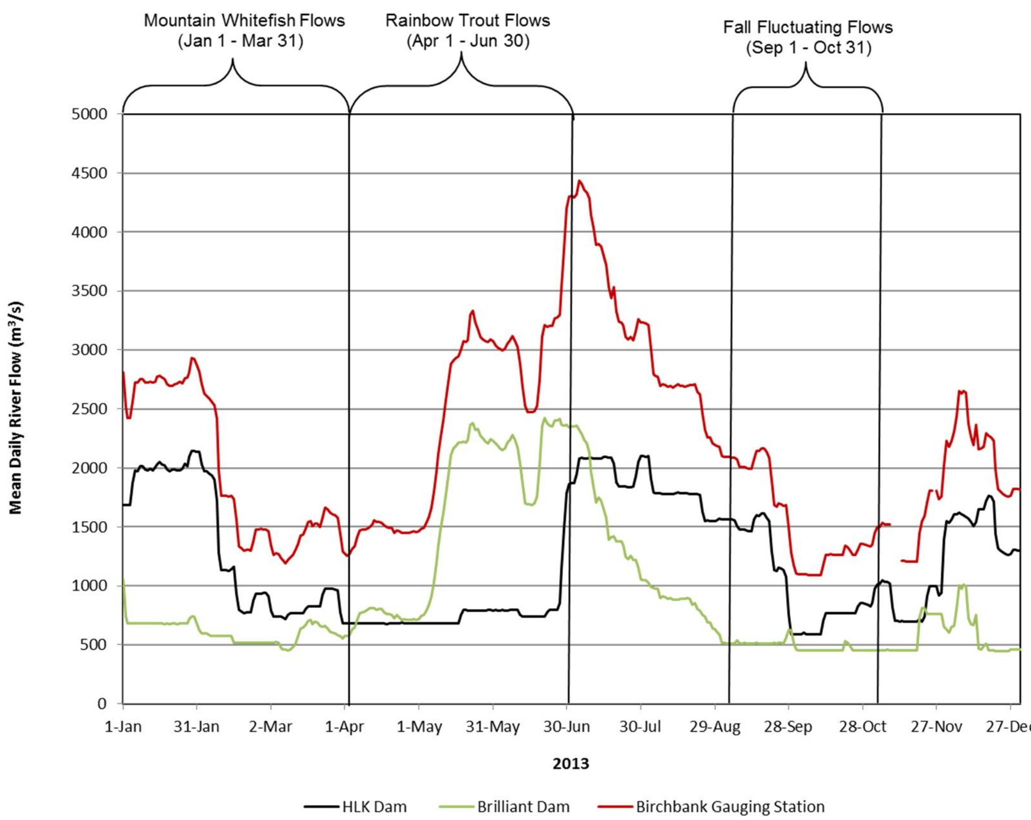


**Figure 3-1: Mean Daily River Flow at HLK Dam (Columbia River), Brilliant Dam (Kootenay River), and Birchbank Gauging Station in 2013**

**Table 3-2: Mean Daily Flows in 2013 by Designated Flow Period ($m^3/s$)**

| Mountain Whitefish Flows (Jan 1 - Mar 31) | | | |
|---|---|---|---|
| **Statistic** | **HLK/ALGS** | **Brilliant** | **Birchbank** |
| N (days) | 90 | 90 | 90 |
| Minimum | 680.8 | 455.8 | 1192.7 |
| Maximum | 2145.8 | 1055.2 | 2929.5 |
| Median | 1127.7 | 605.6 | 1744.1 |
| Arithmetic Mean | 1349.2 | 612.4 | 2002.1 |
| Standard Deviation | 559.5 | 92.3 | 633.9 |
| Coefficient of Variation | 0.41 | 0.15 | 0.32 |
| **Rainbow Trout Flows (Apr 1 to Jun 30)** | | | |
| **Statistic** | **HLK/ALGS** | **Brilliant** | **Birchbank** |
| N (days) | 91 | 91 | 91 |
| Minimum | 676.5 | 571.4 | 1252.1 |
| Maximum | 1787.3 | 2419.7 | 4196.6 |
| Median | 685.3 | 1701.3 | 2523.7 |
| Arithmetic Mean | 751.5 | 1558.5 | 2363.7 |
| Standard Deviation | 150.9 | 712.5 | 800.2 |
| Coefficient of Variation | 0.20 | 0.46 | 0.34 |
| **Fall Fluctuating Flows (Sep 1 to Oct 31)** | | | |
| **Statistic** | **HLK/ALGS** | **Brilliant** | **Birchbank** |
| N (days) | 61 | 61 | 61 |
| Minimum | 590.7 | 451.2 | 1092.5 |
| Maximum | 1612.1 | 626.3 | 2168.6 |
| Median | 836.5 | 507.1 | 1349.8 |
| Arithmetic Mean | 1033.4 | 490.5 | 1564.1 |
| Standard Deviation | 391.2 | 40.1 | 402.1 |
| Coefficient of Variation | 0.38 | 0.08 | 0.26 |

### 3.1.2 Water Levels

Water level sensors collected data at all six sites throughout 2013. At WQIS1, recorded pressure readings and subsequent elevation determinations were not consistent with previous years and this data was removed from the dataset. The pressure sensor at this site had malfunctioned, and has since been repaired by the manufacturer. For this reason, WQIS1 data is only displayed from January through March (Figure 3-2). There was also missing data at WQIS5 during February through March. Data collection at the Kootenay River site (WQ C2) during 2013 was complete, but it was not possible to calculate a SD from January through July since 2013 was the only year of data (Figure 3-2). The sensor was installed during the summer of 2011, but data was not collected during the spring of 2012 due to lost equipment and high flows.

In 2013, recorded water level elevations above the Kootenay River confluence ranged from approximately 419.8 to 424 m asl. Below the confluence (WQIS4 and 5), elevations ranged from 411 to 418 m asl. Index stations 4 and 5 exhibited a higher variation when compared to WQIS1-3, likely due to the combined influence of flows from both HLK and BRD dams.

Upon first glance at Figure 3-2, the mean daily water levels recorded at the six water quality index stations in 2013 appear high compared to other years. At stations 2, 3, 4, and C2, the 2013 elevations were substantially higher than the mean water levels throughout the duration of the study. Unfortunately, this data is misleading because elevation data at each of these stations was lost in 2012 during record high flows. The only station that successfully captured 2012 data was WQIS5. This graph shows 2013 data that is much more aligned with the mean daily water level recorded throughout the duration of the study, and is also within the range of the calculated SD. This suggests that water levels recorded in 2013 were above average, but that it was not a record high flow year. It may be possible to use a GAM model, or other analytical techniques, to estimate the missing 2012 data, and to improve the accuracy of the SD. This was not undertaken for this report, but may be considered in future years.

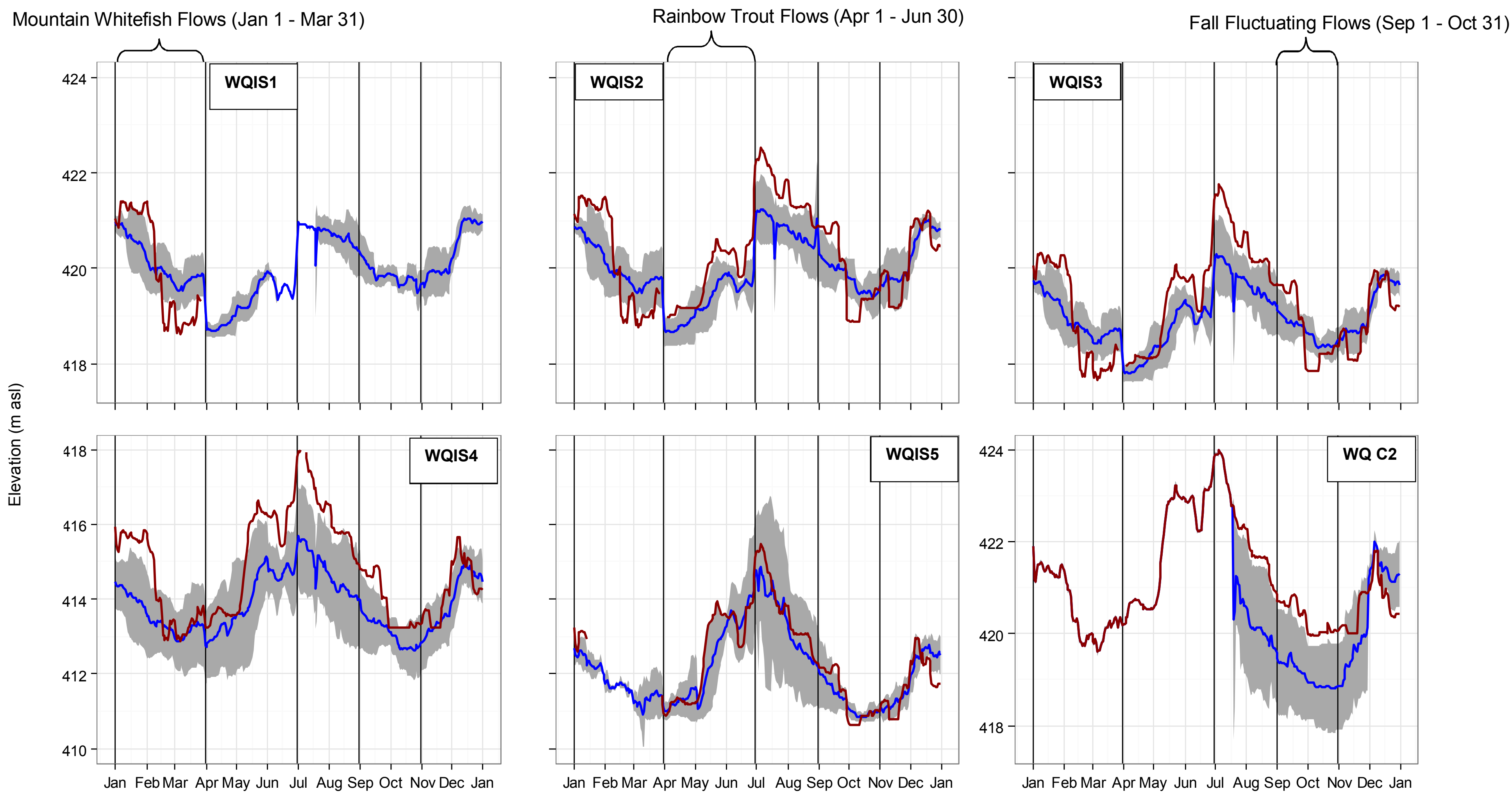


**Figure 3-2: Mean daily water levels recorded at WQIS1 – 5 on LCR and at WQ C2 on Kootenay River.** The red line depicts the mean daily water level recorded at each site in 2013. The blue line is the mean daily water level throughout the duration of the study (2008-13) ± SD (gray shaded area). The SD could not be determined for all months due to gaps in data collection.

#### 3.1.2.1 Mountain Whitefish Flow Period

The following results address sub-hypothesis $HO_{2Aphy}$, which states that continued implementation of MWF flows does not reduce the river level difference between the maximum peak spawning flow (Jan 1 to Jan 21) and the minimum incubation flow (Jan 21 to Mar 31). All relationships between flow and elevation were statistically significant ($p < 0.05$). The best models varied among the five WQIS sites and each contained a different set of explanatory variables. Most of the differences were the result of a site's orientation relative to source flows. Sites above the BRD confluence were best predicted by flows from HLK and sites downstream were more dependent on flows measured at BBK or BRD, possibly suggesting that ramping patterns of BRD have an influence on water elevation downstream (Table 3-3). For all WQIS, the predicted elevation difference during pre-MWF flows (1984-1994) was significantly higher than the predicted elevation difference during post and continuous flow periods (permutation ANOVA, d.f. 2, 27, $p<0.001$) (Figure 3-3). The variance in elevation described by top models was typically very high ($R^2$ range: 0.91-0.97), suggesting that the use of these models for predictive purposes is plausible. The accuracy of the predictive elevations is further supported when the actual elevation differences during the post implementation period are compared to the observed elevations (Figure 3-3).

These results suggest that the implementation of MWF flows has been effective at reducing the difference between maximum flow during MWF spawning and minimum flow during MWF incubation. These results are consistent with findings by Scofield et al. (2011).

**Table 3-3: The Best Fit Models for each Water Quality Index Station that were used to Predict Historic Water Levels during the MWF Flow Period**

| | Site | Best Fit Model (Intercept +Coefficient ( ± SE)) | Adjusted $R^2$ | p-value |
|---|---|---|---|---|
| MWF Analysis | WQIS1 | 4.19e+02 + BBK (-3.66e-03 ± 1.34e-01) + $BBK^2$ (7.46e-07 ± 3.04e-07) + HLK (-6.56e-03 ± 1.27e-03) + $HLK^2$ (-1.50e-06 ± 4.14e-07) | 0.93 | <.0001 |
| | WQIS2 | 4.17e+02 + HLK (3.07e-03 ± 2.88e-04) + $HLK^2$ (-4.89e-07 ± 1.08e-07) | 0.97 | <.0001 |
| | WQIS3 | 4.17e+02 + BBK (-2.83e-03 ± 9.54e-04) + $BBK^2$ (6.54e-07 ± 2.16e-07) HLK (5.26e-03 ± 8.98e-04) + $HLK^2$ (-1.23e-06 ± 2.94e-07) | 0.96 | <.0001 |
| | WQIS4 | 409.0 + BBK (4.19e-03 ± 7.42e-04) | 0.91 | <.0001 |
| | WQIS5 | 409.0 + BBK (1.62e-03 ± 6.04e-05) + BRD (-4.00e-04 ± 1.74e-04) | 0.97 | <.0001 |

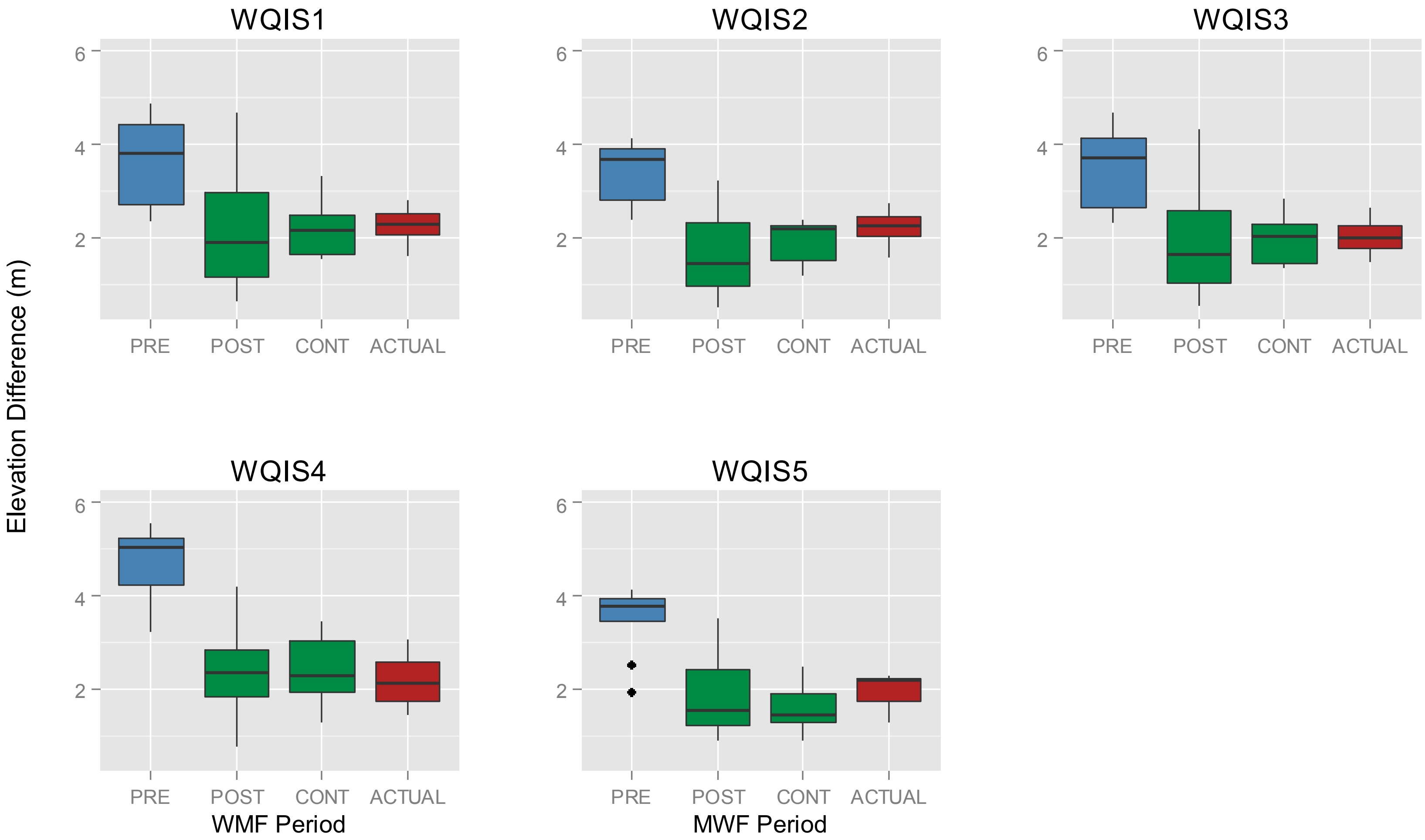


**Figure 3-3: Predicted water level elevation difference between maximum flows during Mountain Whitefish (MWF) spawning (Jan 1 – Jan 21) and minimum flows during MWF egg incubation (Jan 22 – Mar 31) for Pre (1984 – 1994), Post (1995-2007), and Continuous (2008-2013) flow years at each water quality index station.** Different colours indicate statistical significance ($p<0.05$) as determined by a permutation ANOVA. The "actual" dataset was not statistically compared but is included to illustrate variability between predicted CONT values and actual elevation field data collected during 2008-2013.

### 3.1.2.2 Rainbow Trout Flow Period

The following results address sub-hypothesis $HO_{2Bphy}$, which states that continued implementation of RBT flows does not maintain constant water level elevations at Norn's Creek fan between April 1 and June 30 and are derived from analyses described in section 2.5.1.2. The best model differed for two sites; WQIS2 included BBK, BRD and HLK flows, while WQIS3 only included BBK and HLK flows (Table 3-4). In both cases, flow had a strong positive effect on water elevation during the RBT flow periods. It is not fully understood why BRD flows have such a strong effect, given that the sites are upstream of the confluence. However, since our primary objective was to describe elevation as accurately as possible, these explanatory variables were left in the analysis, despite possible concerns of using co-linear explanatory variables.

For both WQIS, the total elevation drop that occurred was significantly higher during pre-implementation of RBT flows (1984-1991) than during post (1992-2007) and continuous (2008-2013) flow periods (perm. ANOVA: WQIS2, d.f. 2, 27, $p<0.001$; WQIS3, d.f. 2, 27, $p=.001$, Figure 3-4). In contrast to the results for MWF, differences in field measured elevations were much more variable and differed markedly from those for predicted elevations. This was particularly true for WQIS3, likely due to higher than typical variability in elevations observed in 2013 compared to other years (Figure 3-2). Although actual observations are more variable than predicted elevations, the data does suggest there is a reasonable confidence in predicted versus observed values.

**Table 3-4: Best Fit Models for WQIS2 and 3 that were used to Predict Historic Water Levels during the RBT Flow Period**

| | Site | Best Fit Model (Coefficient ± SE) | Adjusted $R^2$ | p-value |
|---|---|---|---|---|
| RBT Analysis | WQIS2 | 417.2 + BBK (2.31e-04 ± 6.54e-05) + BRD (5.69e-05 ± 6.27e-05) + $BRD^2$ (1.36e-07 ± 2.07e-08)+ HLK (2.21e-03 ± 1.08e-04) | 0.97 | <.0001 |
| | WQIS3 | 416.9 + BBK (2.19e-04 ± 5.52e-05) + $BBK^2$ (1.70e-07± 1.28e-08)+ HLK (4.97e-07 ± 2.27e-04) + $HLK^2$ (-4.97e-07 ± 1.48e-07) | 0.99 | <.0001 |

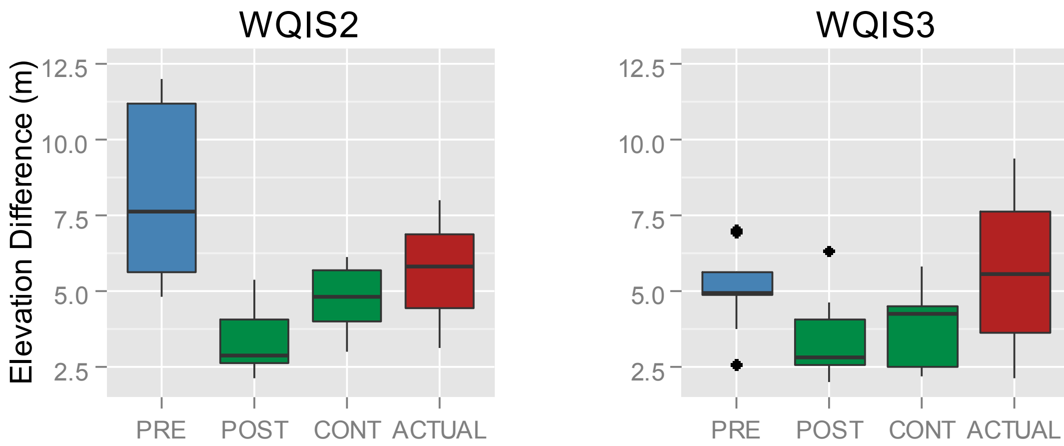


**Figure 3-4: Cumulative sum of elevation drops occurring during the Rainbow Trout Flow period for Pre (1984 – 1991), Post (1992-2007), and Continuous (2008-2013) flow years at each water quality index station.** Different colours within each graph for Pre, Post and Cont datasets indicate statistical significance ($p<0.05$) as determined by a permutation ANOVA. The "Actual" dataset was not statistically compared but is included to illustrate variability between predicted CONT values and actual elevation field data collected during 2008-2013.

## 3.2 Physical and Chemical Characteristics

### 3.2.1 Water Temperature

As with the flow data, 2013 water temperature data also had data gaps, most notably at WQISI (Figure 3-5). Water temperatures during 2013 at the five LCR WQIS varied seasonally, ranging from approximately 4 to 19°C. Temperatures in Kootenay River (WQ C2) were slightly higher, and ranged from approximately 4 to 20.2°C.

The 2013 summer daily temperatures were very similar to the mean temperatures recorded during previous years of the study. Water Quality Index Stations 4 and 5 exhibited a higher variability than sites WQIS1 - 3, likely due to the influx of flows from Kootenay River. Olson-Russello *et al.* (2012) and Larratt et al. (2013) reported slightly higher water temperatures originating from Kootenay River compared to LCR, and it appears that the higher temperatures are responsible for increased variability in temperature observed at downstream sites.

As expected, water temperature followed a seasonal pattern. During MWF flows (Jan 1 – Mar 31), the 2013 water temperatures had very little variation and were typically between 4 and 5 °C. Temperatures during the RBT flow period (Apr 1 – Jun 30) steadily increased from approximately 5 to 13 °C. Finally, the fall fluctuating flow period exhibited the opposite trend with water temperatures declining from approximately 18 to 10 °C.

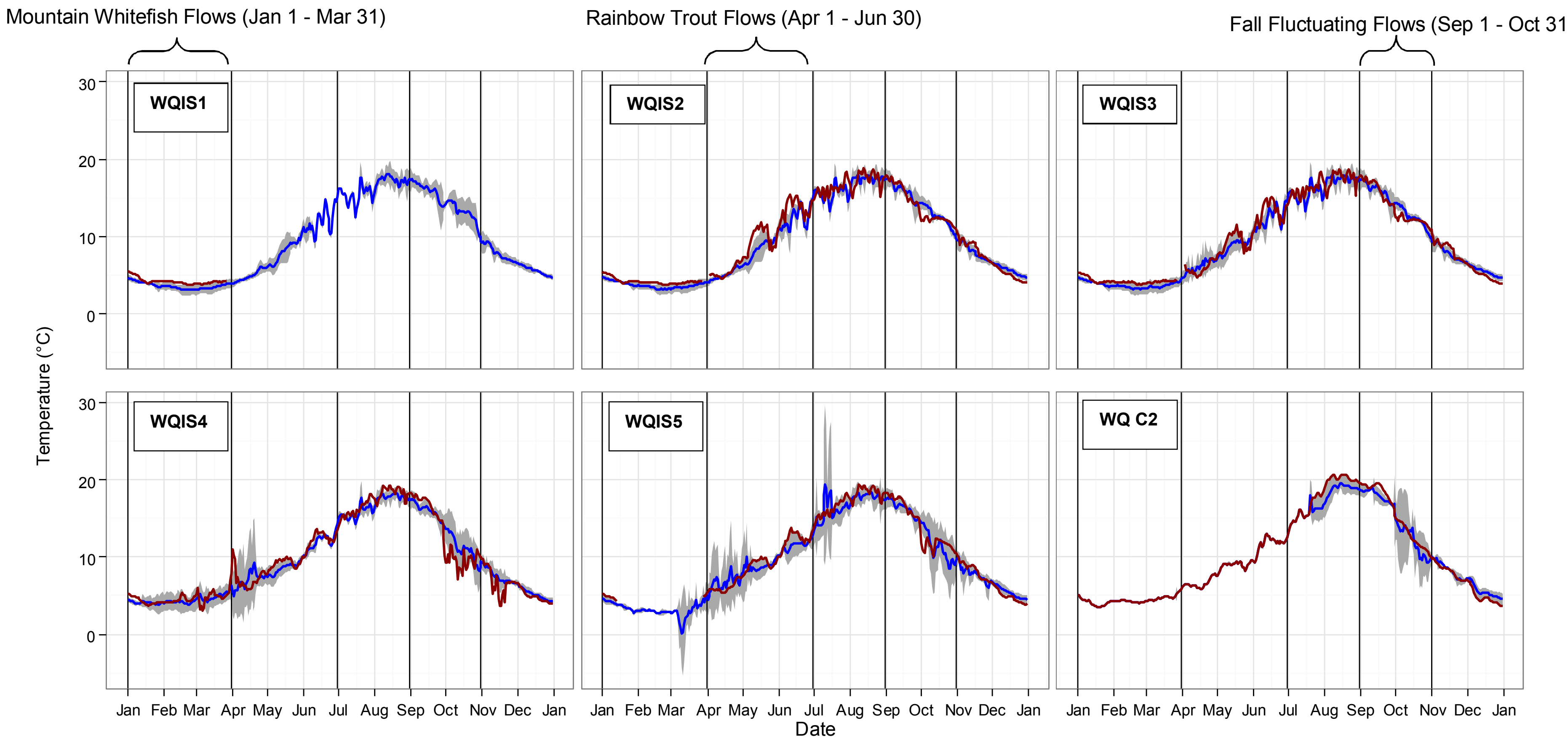


**Figure 3-5: Mean daily water temperatures recorded at WQIS1 – 5 on LCR and at WQ C2 on Kootenay River.** The red line depicts the mean daily water temperature recorded at each site in 2013. The blue line is the mean daily water temperature throughout the duration of the study (2008-13) ± SD (gray shaded area). The vertical lines indicate the beginning and end of each flow period. MWF flows occurred between Jan 1 and Mar 31, RBT flows occurred between Apr 1 and Jun 30 and fall fluctuating flows occurred from Sep 1 to Oct 31.

To test the specific hypotheses that implementation of different flow periods (MWF and RBT) may affect temperature, linear mixed-effects modeling described in Section 2.4.2 of the methods was used. We hypothesized that water temperature may be dependent on the temperature of source waters, air temperature, and the influence of water elevation in upstream reservoirs on thermocline depth, and therefore these datasets were also included in the model. This approach allowed us to rank the relative importance of flow regime with other pertinent parameters that may affect water temperature.

The inclusive temperature model that contained all combinations of explanatory variables and associated interactions was the best model (see Appendix A). Further, this was the only plausible model, with no other models having a $\Delta$ AICc < 2. This model explained a very high proportion of the variance in LCR water temperature ($R^2$ = 0.92). Not surprisingly, LCR water temperatures were most strongly correlated with Castlegar air temperature and reservoir water temperatures when all seasons and flow periods were considered, with the strongest relationships observed in the fall and winter, and during MWF and RBT flow periods (Figures 3-6 and 3-7).

In particular, reservoir elevation had a strong negative effect on LCR water temperature, particularly during fall, winter, and MWF flow periods, where LCR temperatures decreased with increasing reservoir elevation. Overall, reservoir elevation did not appear to have a large effect on LCR water temperature. However, we speculate that the effect of reservoir elevation is greatest during the summer period, when river temperature decreases with increasing reservoir elevation. This is because the water released into LCR comes from deeper cooler reservoir layers[3]. The effect of flow on river temperature was minimal, but positively associated during the fall and RBT flow period, and negatively associated during the summer and winter. River flows appeared to have no effect during the MWF flow period.

Based on this preliminary analysis, flow is not the most important determinant of river temperature. The effects of flows on river temperature were greatest during winter and fall, with a marginal effect of increasing river temperature during the RBT flow period (Figure 3-7).

[3] An interactive effect was previously considered in Larratt et al. (2013). In reviewing this analysis, the graphical representation of the data (i.e., linear trends) differed from the coefficients of the model. This was missed until the analysis was repeated to include 2013 data. Specifically, some of the coefficients presented in Larratt et al. (2013) were inverse to the graphical portrayal of data. Coefficients in this year's analysis were best represented when interactive effects between air temperature, reservoir temperature, and reservoir elevation, and flow period were removed. At this time, we have been unable to resolve the specific reasons for why coefficients were inversed, given the strong graphical representation of the data, and have chosen to present the simplest explanation. It should be noted that our interpretations regarding reservoir elevation have also considered the previous analysis and graphical representation of the data in Larratt et al. (2013) because it provides useful insight about how water temperature is regulated within the LCR.

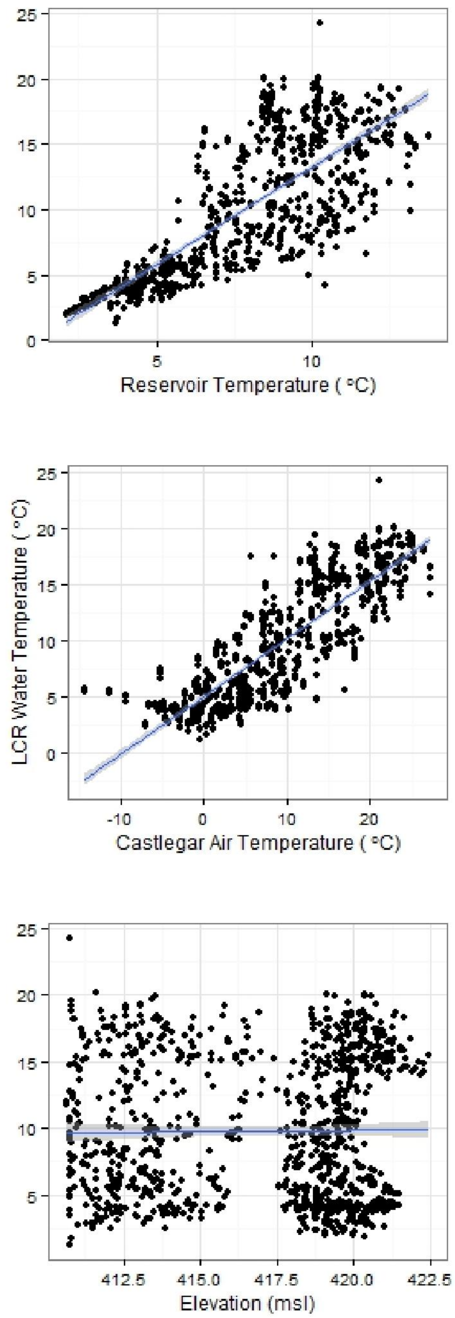


**Figure 3-6: Scatterplots Showing the Relationship of Reservoir Water Temperature, Castlegar Air Temperature, and Reservoir Elevation on LCR Water Temperature.** Plots include individual linear regression lines to show general trends, however, only Castlegar air temperature and reservoir water temperature had significant independent influences on LCR water temperatures (see Appendix A).

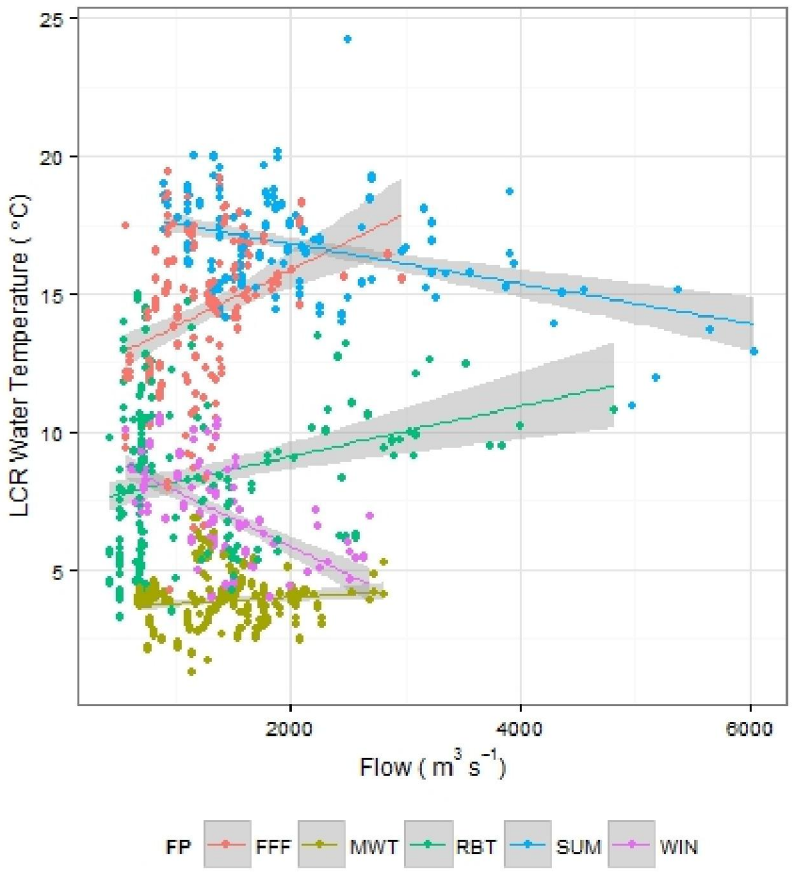


**Figure 3-7: Single Linear Regressions of Flow on LCR Water Temperature in Each Flow Period.** Flow period (FFF = Fall fluctuating flows, MWT = Mountain Whitefish flows, RBT = Rainbow Trout flows, SUM = Summer flows, and WIN = Winter Flows). Plots include individual linear regression lines for each flow period to illustrate how the effect of flow differs among flow periods indicated by the inclusion of the interaction term between these explanatory variables in the top ranked mixed-effects model describing LCR water temperature (Appendix A).

### 3.2.2 Water Quality

Water quality sampling during 2012 and 2013 was modified from the previously collected monthly samples in the June to October growing season to allow sampling to be more disbursed annually and to achieve an overlap with the MWF flow period. Samples were collected on April 3, June 6, September 13, and November 14, 2013. The 2013 results were combined with the entire water quality data set to date. These results are displayed as boxplots according to season: winter (Jan 1 – Apr 5), spring (Apr 6 – Jun 30), summer (Jul 1 – Sep 30), or fall (Oct 1 – Dec 31) (Figures 3-8 to 3-15).

#### 3.2.2.1 Summary of 2013 Water Quality Parameters

##### *3.2.2.1.1 pH*

During 2013, mean LCR pH was 7.77 ± 0.53 (SD) and ranged from 6.34 – 8.93, with the highest values recorded in the winter low flow period (Figure 3-8). The two pH values recorded at WQIS1 and WQIS2 exceeded the LCR upper pH objective limit of 8.5, but were still below the BC MOE guideline of 9.0. Photosynthesis raises pH and usually increases summer pH. The thick mats of *Didymosphenia geminata* present throughout LCR in the winter of 2013 may have contributed to elevated pH in that season, but would not fully explain pH elevated above 8.5. At sites further down the LCR, the observed winter pH's were similar to pH measured in other seasons. The lower pH objective of 6.5 has not been exceeded in this study. In the summer and fall, there appeared to be a modest trend of increasing pH as water moves downstream.

Throughout the study period, Norns Creek exhibited the widest range of pH, likely due to source flows originating from a smaller watershed that has low carbonate buffering capability. Kootenay River showed the narrowest pH range of all the sample sites. Both the Kootenay and Columbia systems show stable pH below their confluence. All LCR pH values met the BC MoE Guideline and fell within LCR Objective range.

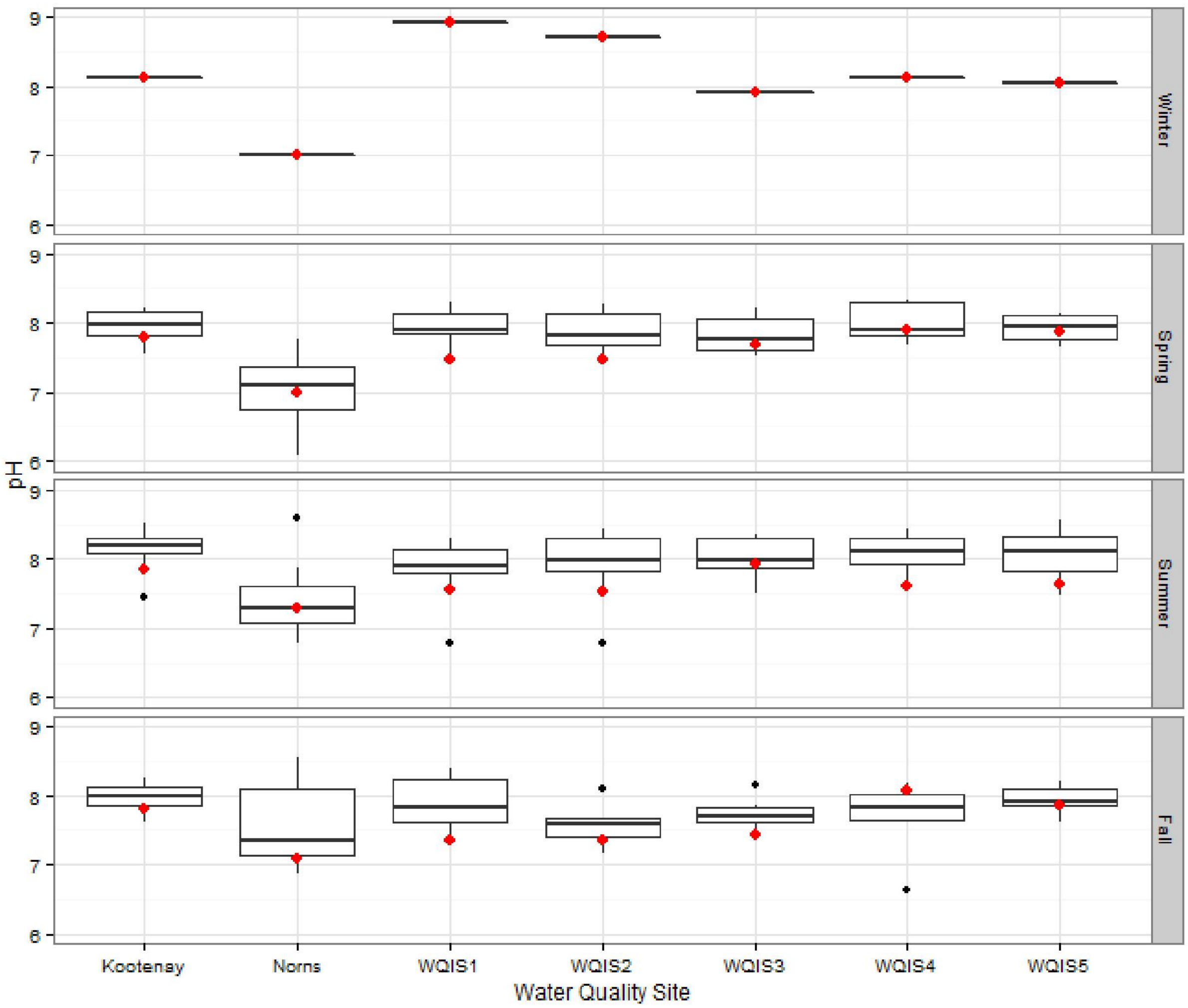


**Figure 3-8: Boxplots of pH from LCR Water Quality Index Sites and Main Tributaries (2008-2013).** 2013 data is shown in red. The LCR lower and upper pH objective limits are 6.5 and 8.5, respectively, and the BC MOE guideline is 9.0.

#### 3.2.2.2.2 Electrochemistry Parameters

Specific conductance, total dissolved solids (TDS), alkalinity and hardness all measure the concentrations of ionized constituents in water and they frequently trend together (Table 3-5). There is some overlap in the measured ions. For example, hardness and conductivity both include calcium. Conductivity and TDS were measured by field meter at every site on all trips. TDS was also analyzed at Caro Labs, while selected samples were submitted for alkalinity and hardness analyses.

**Table 3-5: Ions Contributing to Electrochemistry Parameters**

| Parameter | Equation or Principle Ions Measured |
|---|---|
| Alkalinity | Alkalinity = $[HCO_3^-]_T + 2[CO_3^{-2}]_T + [B(OH)_4^-]_T + [OH^-]_T + 2[PO_4^{-3}]_T + [HPO_4^{-2}]_T + [SiO(OH)_3^-]_T - [H^+]_{sws} - [HSO_4^-]$ |
| Hardness | Mainly contributed by Ca Mg, and also Sr Fe Ba Mn |
| TDS | Soluble salts that yield ions such as: Na+2 Ca+2 Mg+2 HCO3- SO4-2 Cl- NO3- PO4- |
| Conductivity | Mainly contributed by CaCO3; also (H+ Ca+2 Mg+2 K+ !\la+2 Cl- S04-2 N03- HCO-, OH- |

Historically in both LCR and its tributaries, specific conductance showed an inverse relationship with flow. This was not as apparent in 2013 compared to previous years of the study. Conductivity in LCR ranged from 93 – 155 µS/cm, with the lowest values occurring in the fall (Figure 3-9). These 2013 values were comparable to the range of specific conductance measured at Birchbank between 1983 and 1996 (105 – 160 µS/cm) (Holmes and Pommen 1999). On average, the 2013 readings were higher than in 2011 and 2012. The lower conductance observed in those years was probably the result of dilution of base flows during the record freshet years. Conversely, in years with lower dam releases, reduced dilution of base flows including groundwater would result in higher conductivity.

Throughout the study, Kootenay River had consistently higher specific conductance measurements compared to LCR (Figure 3-9). In 2013, it averaged 137 ± 34 µS/cm compared to 120 ± 20 µS/cm in LCR samples. Norns Creek values ranged from a very low 13 µS/cm to 70 uS/cm, consistent with historic values. The low conductance observed at Norns Creek is typical of streams whose source is mostly snowmelt.

Electrochemistry parameters found in LCR are comparatively low and are far below the values where direct harm to fish can occur (Butcher 1992, CCME 2012).

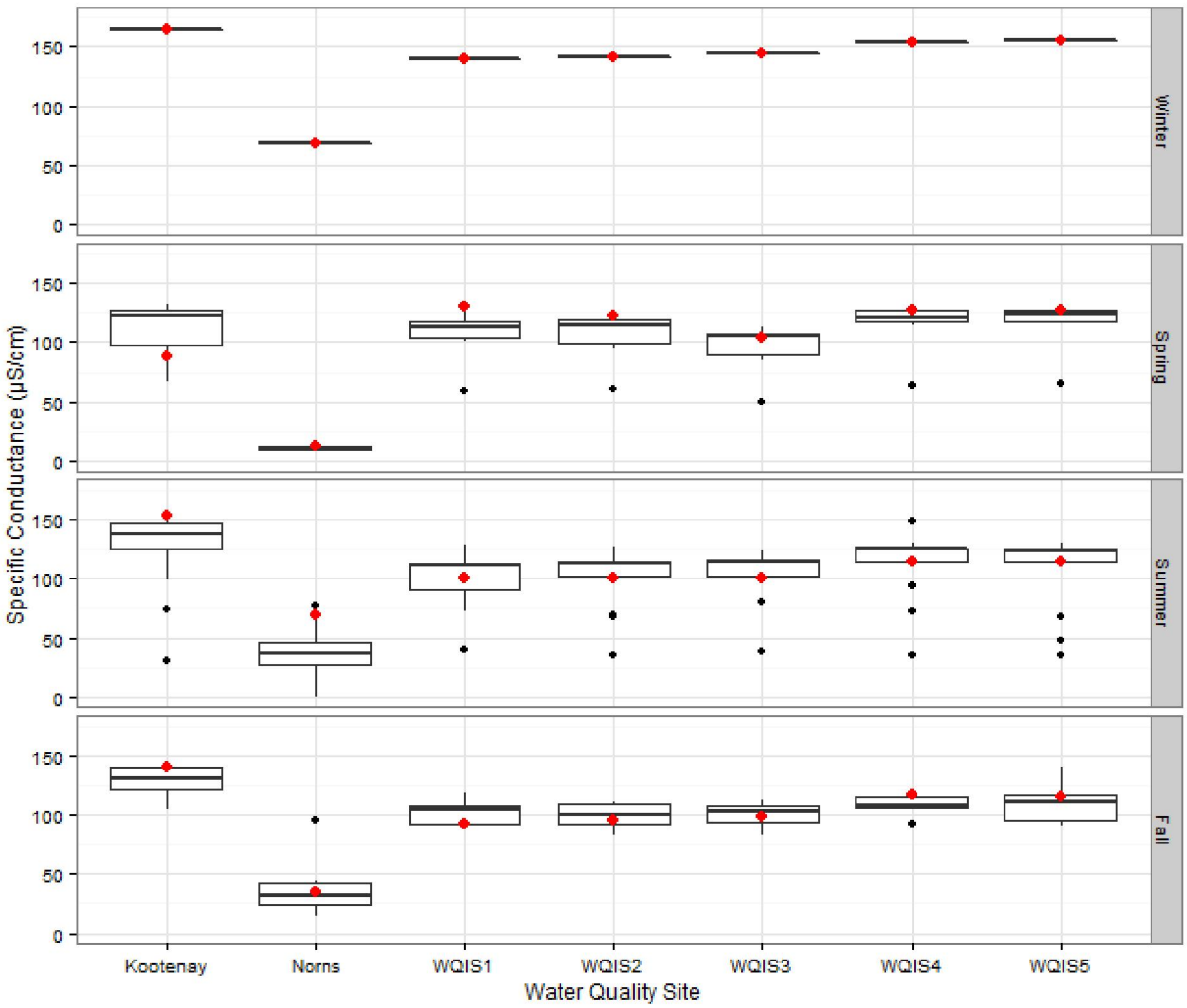


**Figure 3-9: Mean conductivity from LCR Water Quality Index Sites and Main Tributaries (2008-2013).** 2013 data is shown in red. (No guideline or objective available)

Total dissolved solids results from the lab are shown in Figure 3-10. Overall, the 2013 TDS readings were above the means that were previously documented in this study. TDS averaged 72 ± 18 mg/L in LCR during 2013. Like conductivity, TDS tended to increase as water travelled through LCR and was most evident in the fall.

Consistent with previous years of the study, TDS in Kootenay River exceeded that of LCR, and averaged 81 ± 18 mg/L during 2013. The higher TDS observed in Kootenay River was reflected in observed increases in TDS at LCR sites downstream of the confluence. This was particularly evident during the summer and fall where there was the most data from previous years (Figure 3-10).

Norns Creek had consistently lower conductivity and TDS than the mainstem sites, even during very low flow periods such as fall and winter. This indicates that Norns Creek watershed is dominated by granitic geology (non-carbonate).

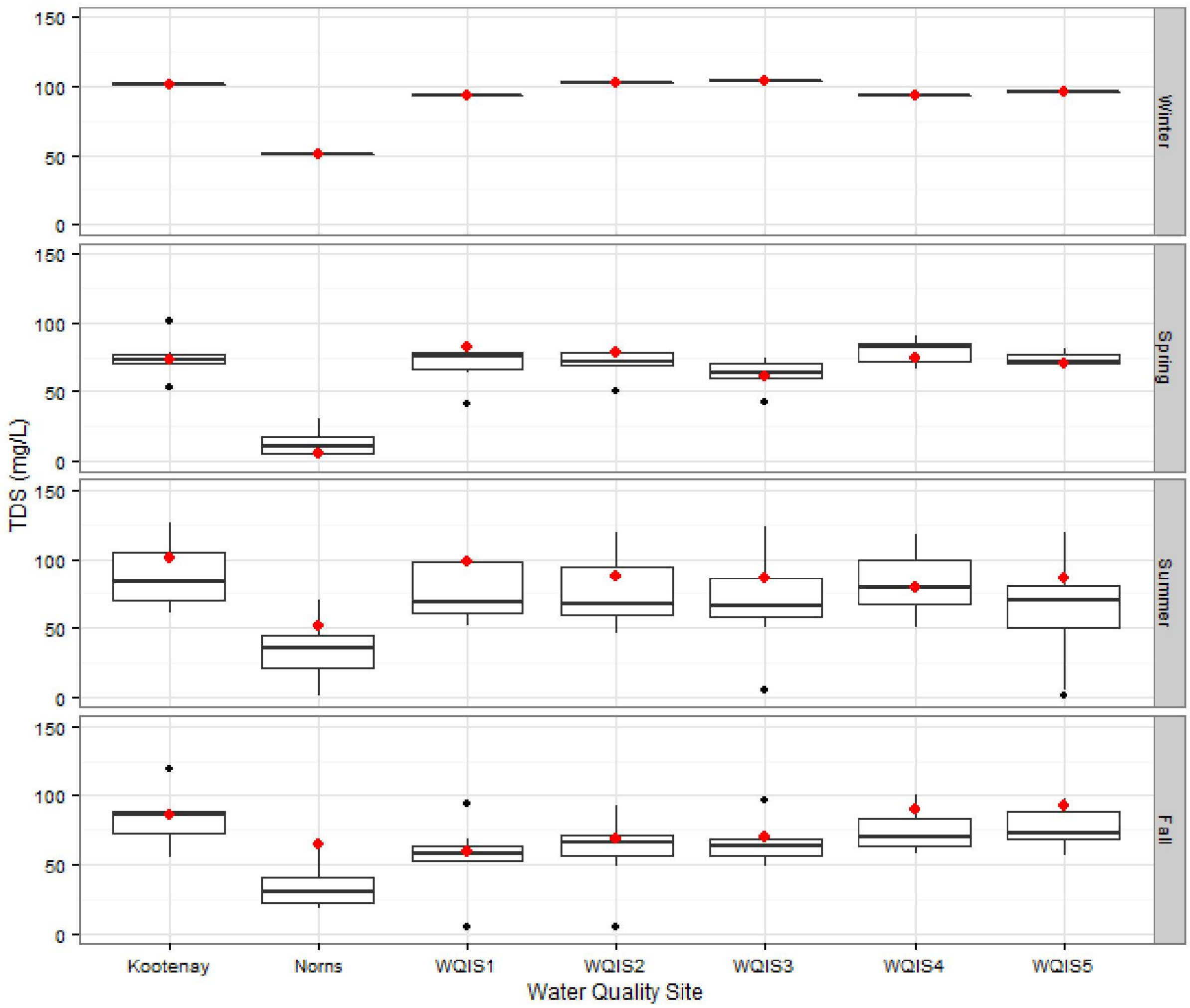


**Figure 3-10: Boxplots of Total Dissolved Solids from LCR Water Quality Index Sites and Main Tributaries (2008-2013).** 2013 data is shown in red. (No guideline or objective available)

#### 3.2.2.2.3 Inorganic Nitrogen

The forms of inorganic nitrogen include nitrate, ammonia and nitrite and these are key macronutrients that are repeatedly consumed, transformed and released as water travels downstream. Throughout the LCR, inorganic nitrogen is dominated by nitrate.

Similar to previous years, ammonia and nitrite were consistently non-detectable in 2013, as is expected in aerobic environments. Nitrate concentrations averaged 0.075 ± 0.01 mg/L $NO_3$ as N in 2013 spring to fall samples, which was 1.5 times higher than the 0.051 mg/L $NO_3$ as N reported for earlier years of this study.

Nitrogen concentrations in the LCR are typically elevated in the summer and fall at sites closest to the dam, possibly the result of the fertilization program on the Arrow Lakes Reservoir (Larratt et al. 2013) because inorganic nitrogen added as fertilizer should theoretically arrive in LCR after July each year (Berube et al. 2012). Other possibilities for this observation include a lower nitrogen concentration in Kootenay River, which dilutes the higher concentration LCR. The highest concentrations of inorganic nitrogen occurred in the winter and averaged 0.127 mg/L $NO_3$ as N. Future winter sampling will determine if these elevated nitrate concentrations are normal or anomalous.

During 2013, the Kootenay River nitrate samples averaged 0.102 ± 0.03 mg/L $NO_3$ as N (Figure 3-11). A fertilization program is also active on Kootenay Lake. Like the LCR, this was 1.5 times higher than the 0.069 mg/L $NO_3$ as N reported in 2012. In 2011 and 2012, Kootenay River had similar nitrate concentrations to LCR during freshet (spring), but declined during the clear flow period (summer and fall). In 2013, the spring concentrations averaged 0.095 ± 0.01 mg/L $NO_3$ as N. Summer and fall nitrate concentrations were lower and averaged 0.057 ± 0.02 mg/L.

As with previous years, nitrate concentrations were much lower in Norns Creek than at the mainstem sites. It had consistently low nitrates but moderate phosphorus concentrations. Agriculture occurs along Norn's lower length, but did not appear to elevate inorganic nitrogen concentrations.

All LCR sites, the Kootenay and Norn's Creek were far below the BCMOE aquatic life nitrogen guidelines of 3 mg/L nitrate and 0.7 mg/L ammonia.

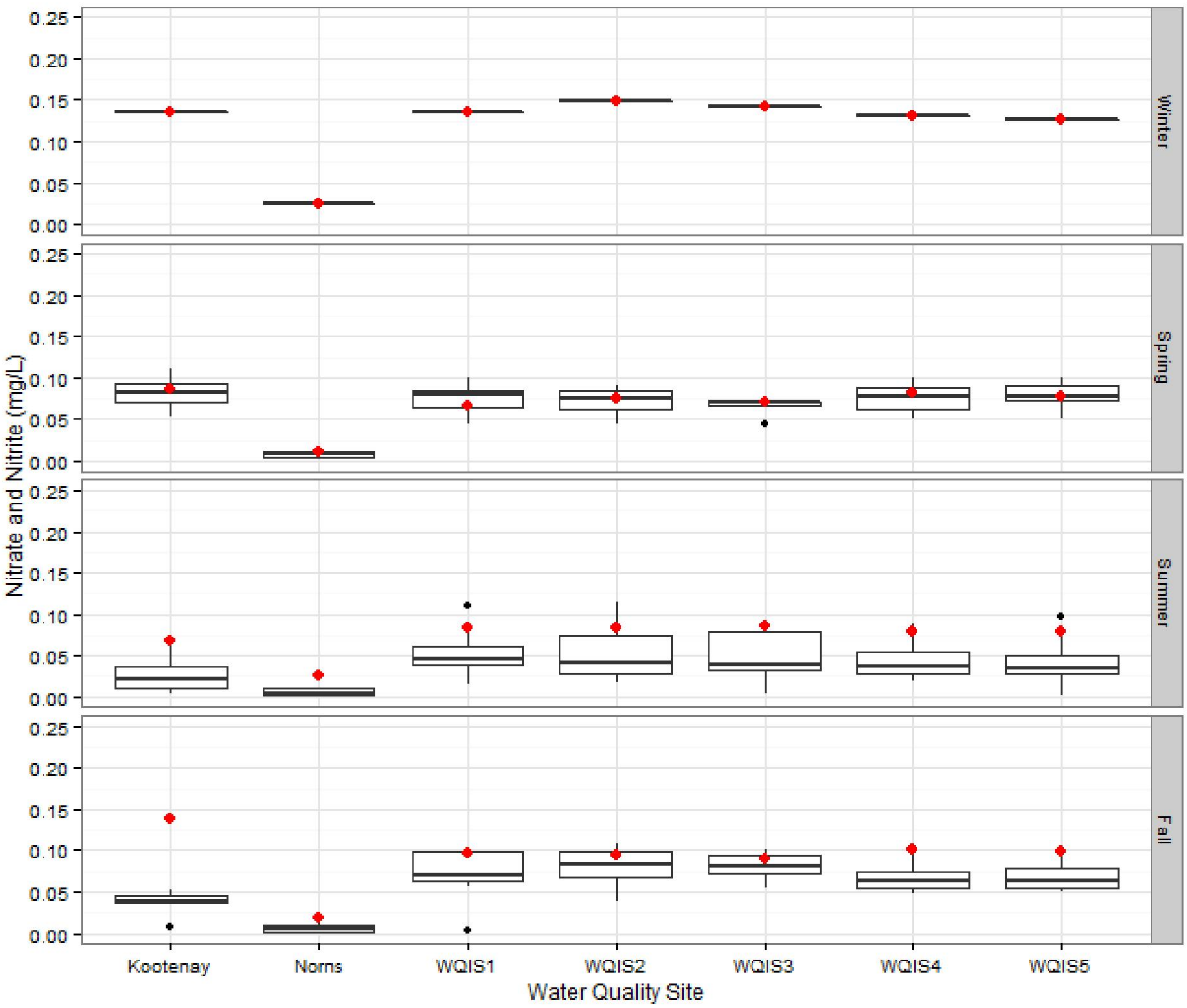


**Figure 3-11: Boxplots of Nitrate and Nitrite from LCR Water Quality Index Sites and Main Tributaries (2008-2013).** 2013 data is shown in red. (BCMOE guideline is 3 mg/L nitrate; 0.7 mg/L ammonia)

### *3.2.2.2.4 Phosphorus*

Total phosphorus (T-P) represents the sum of dissolved and particulate phosphorus in a water sample. In addition to biologically available SRP, total phosphorus can include organic phosphates, P-bearing minerals and P adsorbed onto mixed phases (e.g. clays, organic complexes, metal oxides and hydroxides) (Maher and Woo 1998).

Total phosphorus concentrations in LCR, Kootenay and Norns appeared to be slightly elevated during the summer and fall of 2013, when compared to previous years (Figure 3-12). However, upon further inspection the values were within the range of data observed since 2008. The summer and fall concentrations during previous years of the study (2008-2012) averaged 0.005±0.002 mg/L, compared to 0.004±0.003 mg/L in LCR during 2013.

This was the first year that data was collected in the winter. The concentrations of total phosphorus in the winter in LCR were highly variable between WQIS1 and WQIS3 (Figure 3-12). Operations such as Celgar and / or sewage outflows near these locations may affect the range in values observed during the winter of 2013.

Inorganic ortho-phosphate (or SRP) represents the fraction of T-P that is readily available to periphyton for growth. In 2011 and 2012, SRP never exceeded the detection limit of 0.01 mg/L, except at WQIS4, which is downstream of the Kootenay confluence and several municipal outfalls. SRP never exceeded the detection limit at any sample site during 2013, including Norns Creek and Kootenay River.

The recommended maximum SRP to avoid excessive algae growth in rivers is 0.05 mg/L as P (Bowes et al. 2010) while the maximum recommended total phosphorus concentration is 0.03 mg/L as P (PWQO, 2005). Both ortho-phosphate and T-P concentrations were well below these thresholds in all LCR samples. However, biologically important quantities of SRP are probably still present in the LCR as indicated by its stable, diverse periphyton populations.

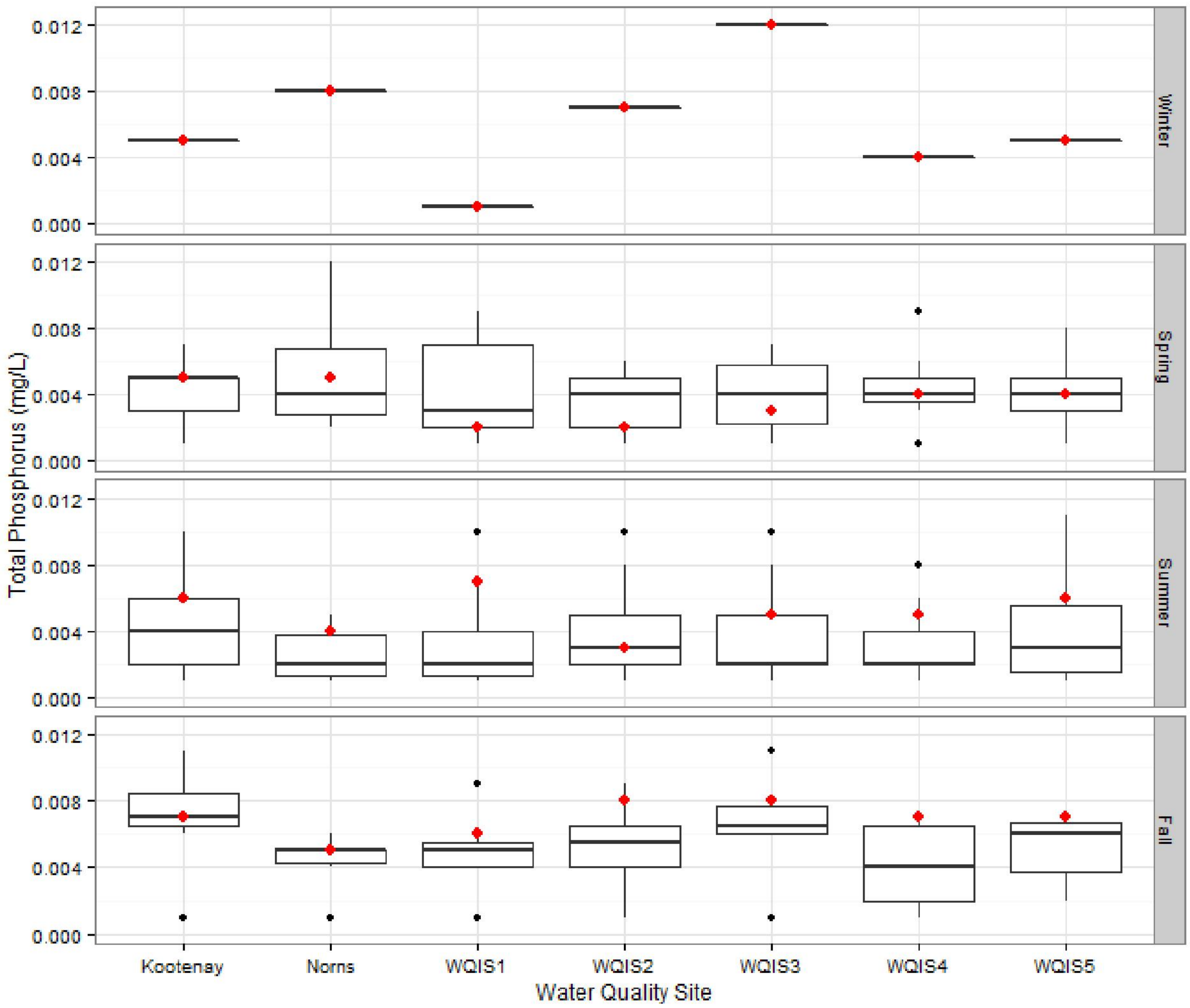


**Figure 3-12: Boxplots of Total Phosphorus from LCR Water Quality Index Sites and Main Tributaries (2008-2013).** 2013 data is shown in red. (tentative guideline = 0.03 mg/L T-P)

#### *3.2.2.2.5 Turbidity*

Turbidity measures how much sediment, organic detritus and organisms suspended in the water decreases its clarity. In LCR, turbidity collected in 2013 was consistent with previous years that ranged from 0.3 to 0.9 NTU (Figure 3-13). The average turbidity in 2013 was 0.44 ± 0.47 NTU. No turbidity spikes of the >7 NTU magnitude seen in past years were observed in 2013. However, it is possible that a freshet turbidity spike was missed since 2013 spring data was collected on June 6$^{th}$, and the freshet peak flows occurred a month later. Turbidity measured at Kootenay River tended to be higher than LCR especially during spring, summer and fall. This in turn would have contributed to slightly higher turbidity at WQIS4 and WQIS5 that occur below the confluence with Kootenay River.

As expected, the turbidity at Norns Creek was consistently higher in the spring compared to Kootenay River and LCR. Because these rivers are fed from reservoirs that allow settling of suspended materials, it logical that the turbidity values would be lower than unregulated Norns Creek.

Turbidity and TSS affect light penetration, particularly into deep water. At the moderate turbidity levels found in LCR, light penetration to the shallow substrates would not have hindered photosynthesis (Caux et al. 1997; ENSR 2001). However, light penetration through water deeper than about 4 m would be reduced enough to influence periphyton production.

Turbidity measured in this study met BC guidelines protective of aquatic life. a turbidity spike would have to exceed background by 2 NTU for a duration of 30 days during clear flows or exceed background by 5 NTU at any time when background is 8 – 50 NTU during high flows (BC MoE 2012). In a low turbidity regulated system like LCR, it is unlikely that these guidelines would be exceeded.

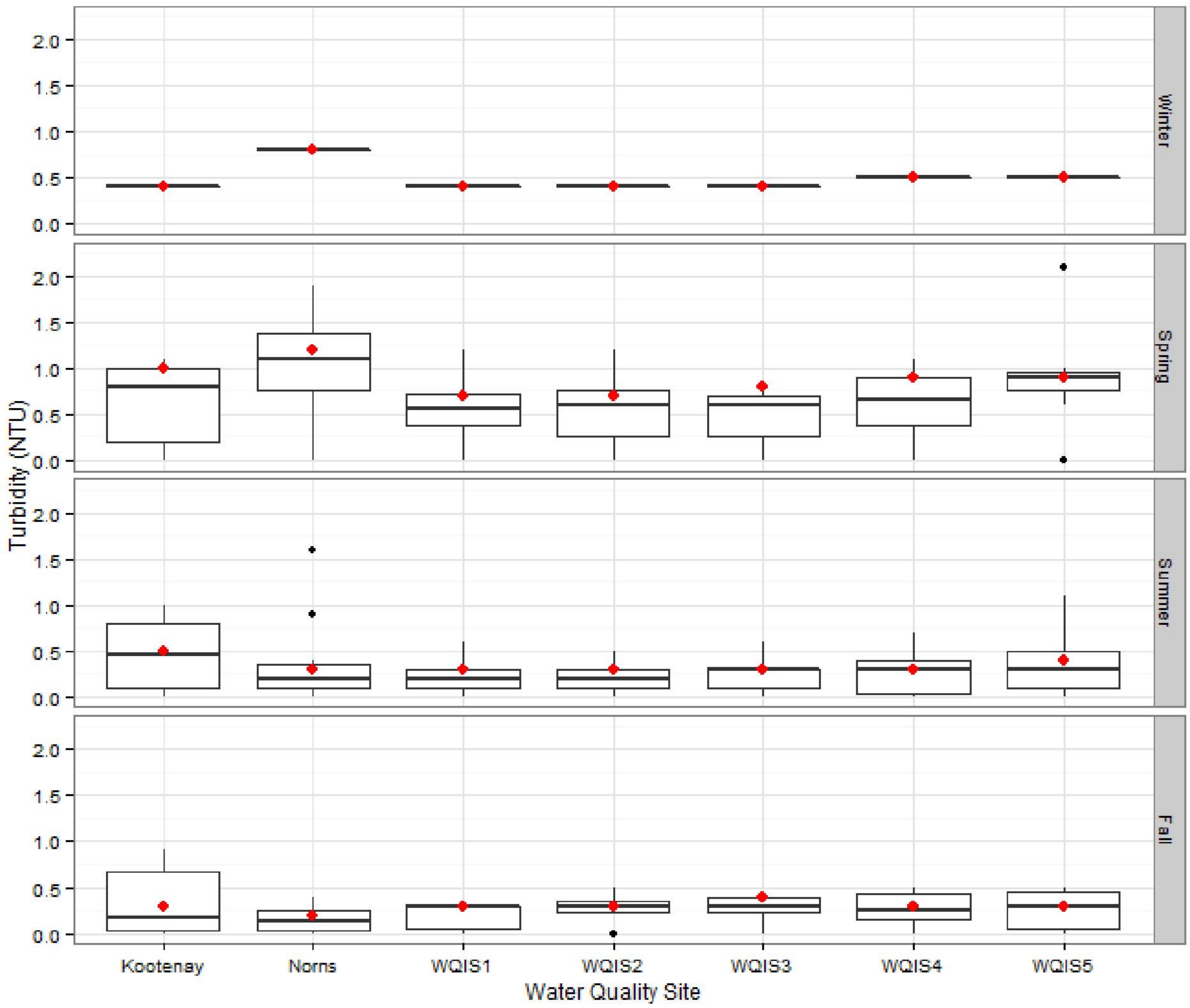


**Figure 3-13: Boxplots of Turbidity from LCR Water Quality Index Sites and Main Tributaries (2008-2013).** 2013 data is shown in red. Outliers from previous years (n=3) were removed to improve plot aesthetics. (aquatic life protection guidelines state maximum 24 hour increase = 8 NTU; maximum clear flow average (30 days) increase = 2 NTU)

#### 3.2.2.2.6 Total Suspended Solids

Total suspended solids (TSS) or non-filterable residue is related to turbidity but this parameter provides an actual weight of the particulate material present in the sample. The relationship between turbidity and TSS depends on the nature of the solids.

Total suspended solids concentrations are typically low in the regulated LCR and Kootenay systems. During the spring of 2013, they were higher in Kootenay River, Norns Creek and at WQIS1, 4 and 5 in LCR. The highest recorded values were 3 and 4 mg/L recorded below the Kootenay confluence at WQIS5 and 4, respectively. (Figure 3-14). Although these values were higher than what was documented in other seasons, they were not necessarily unusual given the higher flow period. As an example, in 2012 the concentration recorded during the spring at Norn's Creek was 15 mg/L.

Higher flows associated with freshet were likely the contributing factor to the variability, but it is interesting that higher values were not recorded at all sites. All 2013 samples from the low flow winter and fall periods were below the 1 mg/L detection limit. Similar trends were documented across years.

Since all mainstem samples consistently had TSS of less than 5 mg/L (Figure 3-14), a TSS spike of 25 mg/L for a duration of 24 h in clear flows, or an increase of 5 mg/L for a duration of 30 days in clear flows, may not occur in LCR. Like turbidity, it seems unlikely that these BC guidelines protective of aquatic life would be exceeded at mainstem sites.

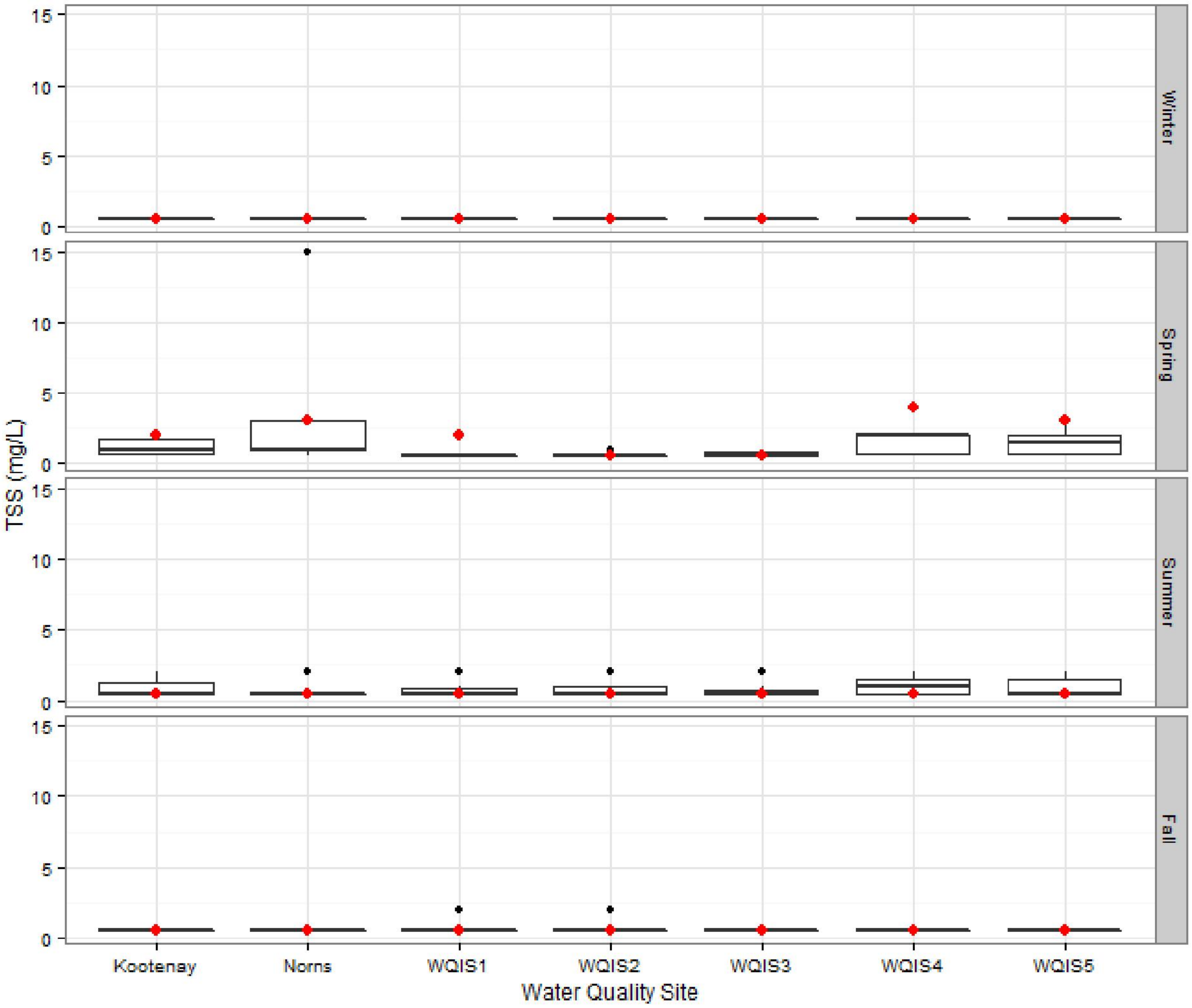


**Figure 3-14: Boxplots of Total Suspended Solids from LCR Water Quality Index Sites and Main Tributaries (2008-2013).** (no objective available).

###### 3.2.2.2.7 Dissolved Oxygen

Dissolved oxygen enters water through turbulent flow, gas exchange and by photosynthesis. The capacity of water to hold dissolved oxygen is a function of its temperature. Dissolved oxygen in LCR ranged from 8.7 – 11.7 mg/L in 2013; a range very similar to previous years. Throughout the study period, dissolved oxygen declined during the summer in response to increased water temperature, but did not fall below the 9.0 mg/L DO Objective at the mainstem sites (Figure 3-15).

Dissolved oxygen saturation ranged from a minimum of 88% in winter to a maximum of 104% in the summer during 2013. Percent saturations above 100% occur naturally when photosynthesis contributes oxygen that super-saturates the water. During this study, dissolved oxygen super-saturation has only been documented in the summer months. The average DO saturation was 99 ± 5%. This was a lower mean than what had been documented in previous years of the study and reflected the shift to sampling during the late fall and winter.

Dissolved oxygen in the Kootenay River during 2013 ranged from 8.4 – 11.5 mg/L, and was comparable to data collected in previous years (Figure 3-15). Norns Creek is the second largest tributary to LCR and in 2013, it measured 8.4 – 11.8 mg/L DO, a range within that previously reported (Larratt et al. 2013; Scofield et al. 2011). Readings were taken from within 1 m of the substrate in Norns Creek and averaged 100% oxygen saturation. The 2013 summer Norns Creek dissolved oxygen sample was below the 9.0 guideline as a result of low, warm flows.

Dissolved oxygen concentrations were adequate for all salmonid life stages throughout this study (BC MoE 2012), and usually exceeded the 10 mg/L DO objective set for LCR (Butcher, 1992).

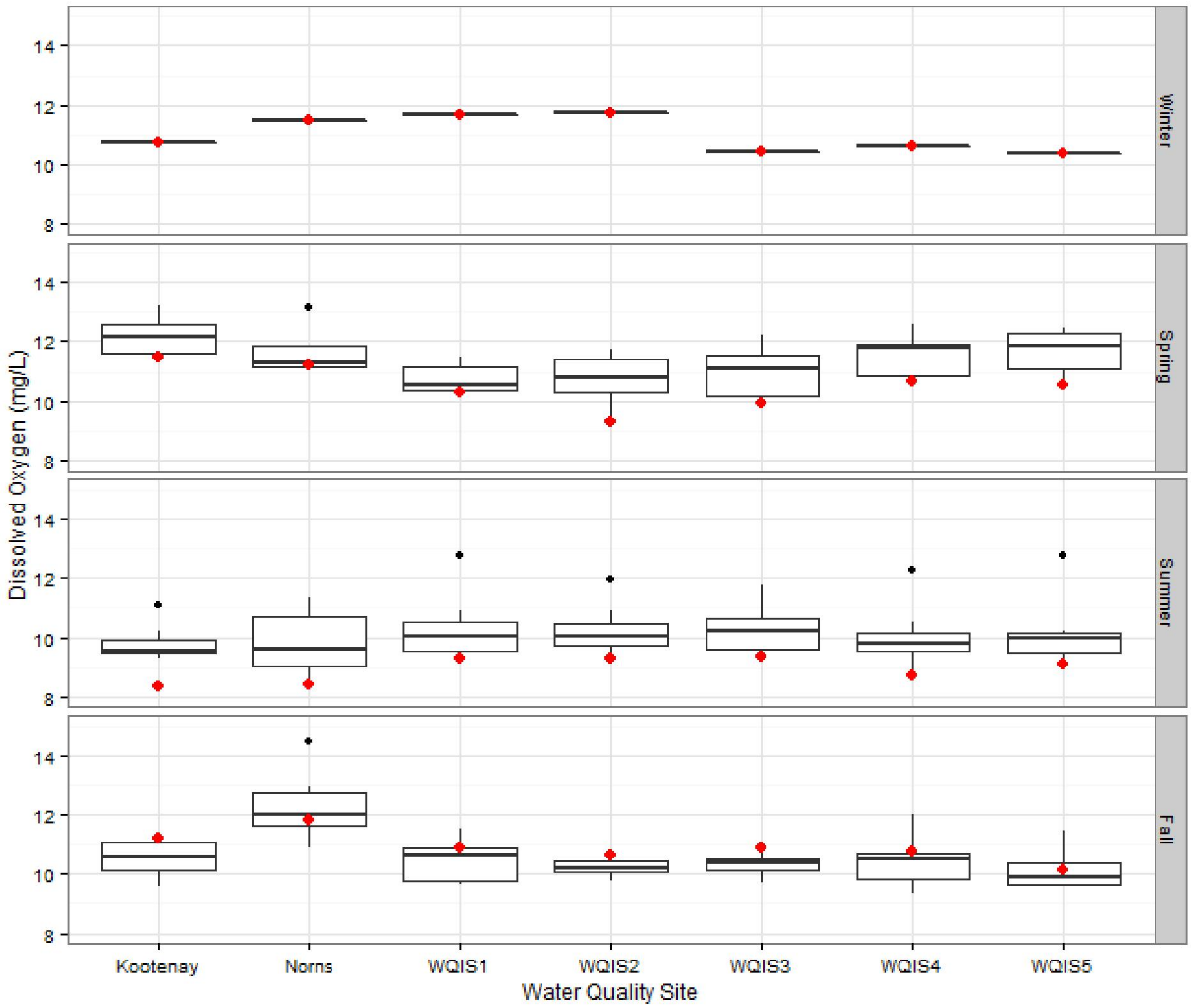


**Figure 3-15: Boxplots of Dissolved Oxygen from LCR Water Quality Index Sites and Main Tributaries (2008-2013).** 2013 data is shown in red. (BC MOE guideline is 9 mg/L; LCR Objective is 10 mg/L).

#### 3.2.2.2 Relationship between Water Quality Parameters and Flow

The proportion of variance accounted for by the first two axes is 0.1734 and 0.1576, or 33% (Table 3-7). Based on this low value we cannot be confident that our interpretation of the first pair of axes extracts all relevant information from the data. The eigenvalues that were generated from the analysis suggest that as many as six of the twelve axes may be informative. We interpret this as suggesting that there is not a strong relationship between flow and water quality parameters. Refer to Appendix B for the loadings (eigenvectors) for the first six axes.

**Table 3-7. Eigenvalues for the first six axes.**

| | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 2.0807 | 1.8917 | 1.5627 | 1.3821 | 1.04824 | 0.94135 |
| Proportion Explained | 0.1734 | 0.1576 | 0.1302 | 0.1152 | 0.08735 | 0.07845 |
| Cumulative Proportion | 0.1734 | 0.331 | 0.4612 | 0.5764 | 0.66378 | 0.74223 |

Figure 3-16 displays the PCA biplots for axes 1 and 2. In the scaling 1 plot, the radius of the circle depicts the length of the vector representing a variable that would contribute equally to all the dimensions of the PCA space. The variables that have vectors longer than the radius of the circle make a higher contribution than average and can be interpreted with confidence. These include flow data from Brilliant and Birchbank, as well as conductivity, TP as P, TDS and $NO_3$+$NO_2$ as N. The scaling 1 biplot shows a gradient from left to right. The group formed by points occurring in the lower left hand quadrant display the highest values of conductivity and $NH_3$ and the lowest values in flow. The points are clustered near the center of the graph and only moderately contribute to axes 1 and 2.

The scaling 2 biplot shows the variables organized into groups. The upper right part of the biplot shows the positive correlation among the three different flows (HLK, BRD and BBK). The biplot also shows a weaker, but positive correlation between flow and most of the water quality parameters, with the exception of conductivity, $NH_3$ and pH. Based on the separation of the variables, flow appears to be most strongly correlated with DO, TSS and turbidity. This result generally corroborates the earlier summary graphs for each of these parameters. The negative relationship between flow and conductivity is also logical given that conductivity has typically displayed an inverse relationship with flow due to dilution. pH displays a shorter arrow, showing that it is less important in this particular ordination plane. Also of note in the scaling 2 plot, are the nearly orthogonal arrows between BBK flow and the various nutrient parameters. An orthogonal separation of arrows indicates a correlation close to 0.

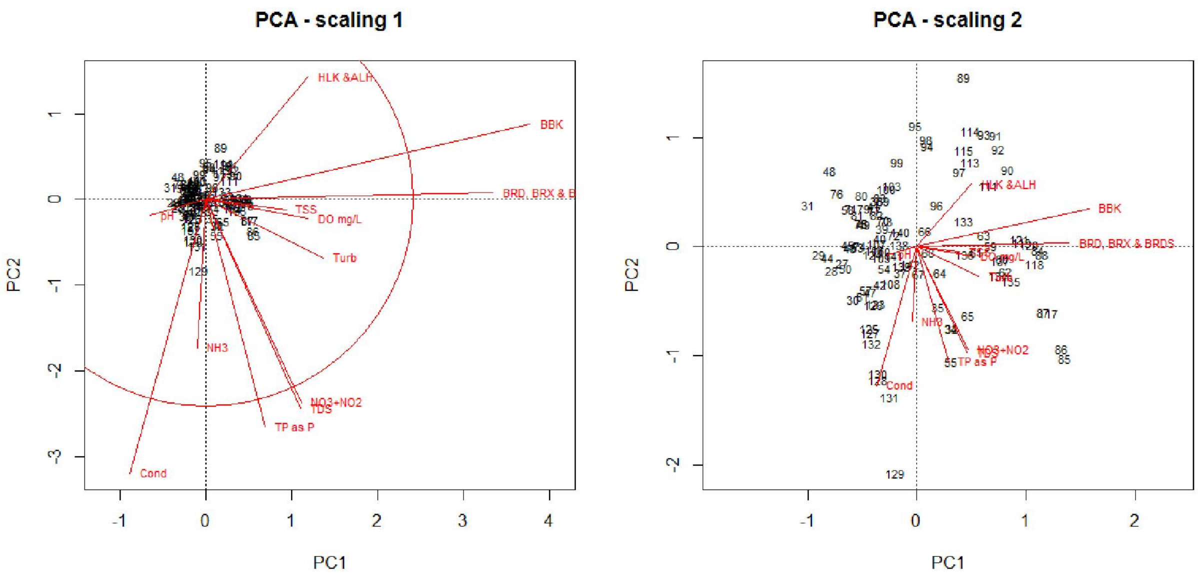


**Figure 3-16: PCA biplots of flow and select water quality parameters**

# 4.0 DISCUSSION

## 4.1 Water Temperature

Water temperatures at the water quality index stations varied seasonally, ranging from approximately 4 to 19°C and were consistent among years. The seasonal patterns observed were similar across all index stations, although the stations below the Kootenay River confluence were slightly warmer during the summer months.

BC Ministry of Environment issues guidelines for water temperature in streams with known fish distributions. The guidelines state that water temperatures should be within ± 1°C of optimum temperature ranges for life history phases of the most sensitive fish species present (BCMOE 2012). The optimum temperature ranges of specific life history stages of species of interest are shown in Table 4-1. These data indicate some inconsistencies with recorded temperatures and the optimal temperature ranges of life history stages. Winter temperatures in LCR are within the optimal range for MWF spawning and incubation, but summer temperatures exceed the 12°C maximum for rearing.

In contrast, LCR temperatures during RBT spawning and incubation periods ranged from about 5 - 15°C, indicating that the temperatures are often lower than the optimal range. Likewise, LCR temperatures during RBT rearing periods are also lower than the 16 - 18°C optimum range. As discussed in Scofield et al. (2011), thermal conditions that are optimal for MWF and RBT rearing would likely be available in other locations in the water column and the fish may move to more optimal habitats. Whereas, lower temperatures during incubation and spawning may result in reduced metabolism and slower growth.

**Table 4-1:** Optimum Temperature Ranges (°C) of Specific Life History Stages of Coldwater Species (modified from BC MOE 2012)

| Species | Incubation | Rearing | Migration | Spawning |
|---|---|---|---|---|
| Rainbow Trout | 10.0 – 12.0 | 16.0 – 18.0 | - | 10.0 – 15.5 |
| Mountain Whitefish | < 6.0 | 9.0 – 12.0 | - | < 6.0 |

LCR water temperatures are most influenced by air temperature, followed by upstream reservoir temperature, and to a much lesser extent, reservoir elevation and river flow. The data suggest that flow does influence water temperatures to some extent, but the specific effects are variable and depend on season. Notably, flow does not appear to influence LCR temperature during the MWF flow period, but does seem to have a small effect during the RBT period when temperature increases with increasing flows. However, this result may also be the result of annual variation in the timing and magnitude of freshet. The statistical model describes a very high proportion of the variance, inferring that the identified factors are key parameters affecting river temperature.

We therefore preliminarily accept null hypothesis $Ho_{1phy}$ which states that continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall, do not alter the seasonal water temperatures regime of LCR. Although flow has the potential to affect river temperature, the data suggest that other parameters such as air temperature, reservoir temperature, and to a lesser extent reservoir elevation are probably more important determinants of river temperature than flow or operating regimes during specific flow periods.

## 4.2 River Flows

The 2013 freshet peaked in the first week of July, with approximately 4,434.4 $m^3/s$ recorded at the Birchbank Gauging Station. For comparison, the maximum mean daily river flows recorded in the first five years of this study (2008 – 2012) were 3,560.0, 2,730.0, 2,761.9, 4,155.4 and 6,043.1 $m^3/s$, respectively. The freshet peak occurred after the RBT protection flow period, which was designed to stabilize or increase flows from the beginning of April to the end of June to reduce redd dewatering and subsequent RBT egg losses (Baxter and Thorley 2010).

Since water elevation data from before the implementation of either the MWF or RBT flow regimes are not available, modeling was used to predict river elevations for historic periods. This approach is appropriate because channel morphology has not changed significantly since 1984 to our knowledge. Channel morphology can affect elevation at any given river cross section. For instance, in wider channels, larger changes in flow are required to obtain the same changes in elevation when compared to narrow channels. For this reason, each elevation station was considered independently in modeling to ensure that site-specific effects and subsequent channel types would be apparent in the analysis.

The modeling data indicate that both of the post-implementation (1995 – 2007) and continued (2007 – 2013) MWF flow periods resulted in smaller changes in water elevation between the spawning and incubation periods than pre-implementation of the flow regime (1984 – 1994). Further, the modelled elevations are very similar to those actually measured in the field corroborating our results. We therefore preliminary reject management sub-hypothesis $HO_{2Aphy}$.

During the Rainbow Trout flow period, the modeling data indicate that both the post-implementation and the continued RBT flow regimes have resulted in a smaller cumulative decrease in river elevation than prior to the implementation of the flow regime. Similar to the MWF flow period analysis, modelled water elevations and those measured in the field were similar. We therefore preliminary reject management sub-hypothesis $HO_{2Aphy}$.

## 4.3 Water Quality

The hypotheses for water quality state that the continued implementation of MWF and RBT flows during winter and spring, and fluctuating flows during fall do not alter electrochemistry and biologically active nutrient concentrations in LCR. The current sampling regime for water quality consists of one sampling event during each season. This is improved over earlier years of the study, when all water quality sampling occurred during the growing season (Jun – Oct). Despite the improvement, the current program still does not provide sufficient data to statistically test the suite of water quality hypotheses ($HO_{3phy}$ $HO_{3Aphy}$ $HO_{3Bphy}$). It may be theoretically desirable to have multiple sampling events within each flow period, but the expenditure required to detect the effect of fish flows would be prohibitive. Although we were unable to directly test how flows within each flow period affect water quality, we were able to group the seasons from all available years of data to determine if any relationships exist between seasonal and annual flows for specific water quality parameters. The results of these analyses were then used to make inferences about the influence MWF, RBT and FF flow periods on water quality.

As we understand it, LCR water quality sampling is intended to provide an understanding of river water chemistry as a whole, and how that water quality influences productivity. The resultant data allows the influences of fish flows to be placed into the broader LCR context. Although the LCR is a regulated system, flows still show marked peaks during the spring and summer months that include annual freshet, while fall and winter exhibit more moderate, stable flows. The overall LCR water chemistry context is set by the chemistry of the HLK and BRD dam releases which together account for 98% of flows. The study data is affected by these interacting influences on LCR, of which fish flows is only one.

Most water quality parameters appeared to vary season and the subsequent seasonal effect on flow (e.g., freshet), with notable variability between years. However, not all water quality parameters demonstrated a strong relationship with flow. For example, both the Kootenay and Columbia systems showed stable pH throughout this study, even during the record 2012 freshet (Larratt al. 2013). Subtle flow changes such as fish flows should therefore have a very minor influence on pH as the strongest effects were due to seasonal and annual variation.

For those parameters that did vary with flow, the effects were frequently in proportion to the flow event. For example, the sediment carrying capacity of flowing water is proportional to its flow velocity (Hei et al. 2009). For this reason, both turbidity and suspended solids were low during winter and fall flows on the regulated Columbia and Kootenay Rivers, with spikes during freshet. The relationship between flow and total suspended solids is well-known and our results are consistent with these known relationships (Giller and Malmqvist 1998; Hem 1985). Like all particulates, the highest loads of organic detritus would occur during the rising leg of freshet. Timing of sampling against peak flows will therefore affect total nutrient results. Total phosphorus concentrations often trend with flow because more particulates are scoured into suspension. However, the relationship is weak in the LCR data.

The positive correlation between flow and dissolved oxygen emerged in the PCA analysis, partly because high flow freshet periods have colder water temperatures. The effect attributable to fish flows for these parameters will be in direct proportion to the contribution of the fish flows to the entire annual flow hydrograph.

For other parameters a direct, inverse relationship was evident between flows in LCR and its electrochemistry. Higher flows in the spring and early summer typically diluted dissolved solids and resulted in lower conductivity readings. All electrochemistry parameters increased following each freshet, when lower summer and fall flows resulted in less dilution with a proportionately greater contribution from groundwater into the base flows (Peterson and Connelly 2001; Tolan et al. 2009; Golder 2010). Therefore, periods where flows are increased for fish should act to lower electrochemical parameters, but the influence of fish flows would be very small compared to larger flow event.

A complex and weak relationship between dissolved nutrients and flow emerged from the LCR data. Nutrient concentrations in LCR are likely influenced by factors including the limnology and nutrient status of Arrow Lakes Reservoir and Kootenay Lake along with their respective fertilization programs, the numerous outfalls that exist on LCR, and other conditions such as tributary inputs from Norn's Creek. In this complex nutrient system, isolating an effect from flow periods is challenging.

During high freshet years, more inorganic nitrogen was observed in the LCR than during years with lower peak flows in the same period. More specifically, the annual average inorganic nitrogen concentrations from 2011 and 2012, when there were record freshets, were approximately double the 2008 – 2010 values (Scofield et al. 2011). Unlike many other rivers, nitrate concentrations have remained elevated during the clear flow period. This was especially evident in 2013. Interestingly, Kootenay River also displayed enhanced inorganic nitrogen during the clear flow period and Kootenay Lake is also fertilized. This could indicate that other factors were in play besides the ALR fertilization. The incorporation of ALR fertilization data, including water quality sampling on ALR, into future LCR water quality analyses may be useful to further understand the relationship of fish flow and water quality.

Unlike flow-induced scour, the anthropogenic phosphorus sources are independent of flows and are therefore more likely to be diluted by higher flows. Throughout this study, ortho-phosphate (or SRP) rarely exceeded the detection limit of 0.01 mg/L in LCR samples. These results are all lower than the historic range recorded for Birchbank, and continue to follow a declining trend over the years (Holmes and Pommen 1999).

Given this context of complex, interacting influences on LCR, detecting subtle influences from fish flows was challenging. 2013 was the 6th year of this study and there was sufficient data to explore additional analyses, beyond simple data summaries. Principal component analyses (PCA) was undertaken to further explore the relationship of flow and water quality. The PCA using flows from HLK, BRD and BBK and specific water quality parameters only explained a small proportion of the variables that were actually affecting water quality parameters. Generally, the findings from the first pair of axes of the PCA corroborated the seasonal trend graphs presented in boxplots. PCA provided further support that there is no strong evidence that fish flows are a dominant factor affecting water quality of LCR.

In summary, and given our understanding of the system and cursory analyses completed, we can infer that the influence of fish flows on water quality is subtle compared to the stronger effects of water quality in the flow sources, freshet, anthropogenic nutrient donation, groundwater inputs, and even photosynthesis within LCR. We anticipate that fish flows may cause small decreases in electrochemistry parameters through dilution, and may improve particulate and dissolved nutrient delivery under low to moderate flow conditions, but that they are unlikely to have a discernible effect on pH, or on the overall nutrient status of LCR. As others have, we conclude that the effects of the fish flow periods on biologically active nutrients were minor compared to the influences of the major water sources. The nutrient status of the Lower Columbia River is heavily influenced by the limnology and nutrients status of the Arrow Lakes Reservoir (Hatfield, 2008) and of Kootenay Lake.

We therefore preliminary accept the management hypotheses $HO_{3phy,}$ $HO_{3Aphy,}$ and $HO_{3Bphy}$ and assume that fish flows, whether they be MWF, RBT or FF flows, have no effect on the water quality of LCR.

## 5.0 RECOMMENDATIONS

1. The current sampling regime for LCR water quality consists of one sampling event during each season at each water quality sampling site. The annual data is therefore limited by sample size. The limited data is not adequate to statistically compare the flow regime effects, and determine if the implementation of the MWF, RBT and FFF periods alter the electrochemistry or nutrients of LCR (Physical Habitat MQ 3). We have attempted to address the hypotheses from a broader perspective by looking at how seasonal and annual flows affect key water quality parameters, and then based on those findings; we have inferred the effects of fish flows. Our data suggests that flow management has a negligible effect on water quality in LCR, with factors such as season (e.g., freshet), upstream reservoir conditions, and annual variation being much more important. A power analysis could be used to determine an appropriate sample size to statistically test the management hypotheses, however to do this, a biologically significant effect size would first need to be determined for each water quality parameter (a lengthy exercise). The data collected thus far suggests that the resultant power analysis sample size would need to be very large and would likely be cost prohibitive. Coupled with this, it is probable that statistical findings would be similar to what we have already speculated using multiple lines of evidence, including the water quality data, and our theoretical understanding of LCR. For these reasons, we recommend the hypotheses associated with Physical Habitat MQ 3 be eliminated or altered, as the current sampling program does not directly test the question and the likelihood of finding an effect of BC Hydro flow management on water quality is low. However, we do recommend that water quality data collection continue, as it provides useful baseline information to identify any irregularities in the electrochemistry and biologically active nutrients that may affect the productivity results.

2. If Arrow Lakes Reservoir fertilization data is available, it should be incorporated into periphyton models to understand its role, if any in LCR productivity. Furthermore, fertilization data may also be useful in further understanding the relationship between fish flows and LCR nutrients.

3. In 2013, the spring water quality sampling event occurred at the beginning of June, approximately one month before peak freshet. The spring water quality sampling date should be pushed back to late June to get closer to peak freshet without the risk of sampling after peak in the falling leg of freshet. This would allow a better understanding of freshet impacts on turbidity, electrochemistry and nutrient concentrations.

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# Appendix A: LCR Water Temperature Linear-Mixed Effects Model Table

**Coefficients, Standard Errors and T Value of Explanatory Variables Included in the Top LCR Water Temperature Linear-Mixed Effects Model.** This model was the inclusive model containing all considered explanatory variables with year (2008-2013) and site (WQIS1 through WQIS5) included as random effects. FPMWT = Mountain Whitefish Flow period; FPRBT = Rainbow Trout Flow Period; FPSUM = Summer Flow Period; FPWIN = Winter Flow Period.

| Variable | Coefficient Estimate | Standard Error | t value |
|---|---|---|---|
| Intercept | 2.4530 | 1.8581 | 1.3200 |
| FPMWT | -5.2526 | 0.4608 | -11.3990 |
| FPRBT | -3.3502 | 0.3847 | -8.7080 |
| FPSUM | 2.5907 | 0.4256 | 6.0880 |
| FPWIN | -1.9135 | 0.4640 | -4.1240 |
| Flow | 0.0007 | 0.0003 | 2.7970 |
| Reservoir Temp. | 0.4835 | 0.0476 | 10.1600 |
| Reservoir Elev. | 0.0060 | 0.0042 | 1.4320 |
| Castlegar Air Temp. | 0.2639 | 0.0123 | 21.4030 |
| FPMWT*Flow | 0.0006 | 0.0003 | 1.8510 |
| FPRBT*Flow | -0.0006 | 0.0003 | -2.5100 |
| FPSUM*Flow | -0.0014 | 0.0003 | -5.3760 |
| FPWIN*Flow | -0.0008 | 0.0004 | -2.1860 |

Appendix B: Principal Component Analysis: Loadings Table

Principal Component Analysis (PCA): Loading scores for the first six principal components for flow and water quality parameters

| Variables | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 |
|---|---|---|---|---|---|---|
| TDS | 1.1004 | -2.43952 | 0.99826 | -0.3934 | 1.4150 | 0.1755 |
| NO3+NO2 | 1.1102 | -2.36604 | -1.64918 | 0.8683 | -0.5451 | -2.0807 |
| NH3 | -0.1081 | -1.7284 | -2.20601 | 1.1796 | -1.4562 | 2.5849 |
| TP as P | 0.6888 | -2.6499 | -1.43526 | -2.2616 | -0.8475 | -1.0576 |
| pH | -0.6498 | -0.18422 | 2.5843 | -0.25 | -3.4343 | 2.201 |
| Cond | -0.889 | -3.19490 | 1.75765 | -1.1124 | -0.3750 | 0.7383 |
| Turb | 1.3607 | -0.68104 | -0.09417 | 0.8402 | 2.9967 | 3.7775 |
| DO mg/L | 1.1855 | -0.22022 | 0.29559 | 3.4181 | -2.4532 | -0.316 |
| TS | 0.9344 | -0.11568 | 3.07687 | -1.4138 | 0.2404 | -0.8509 |
| BBK | 3.7803 | 0.88056 | -0.31049 | -0.8274 | -0.7876 | 0.2796 |
| BRD, BRX & BRDS | 3.3433 | 0.07569 | 1.45191 | 0.9310 | 0.1002 | -0.4739 |
| HLK & ALH | 1.1899 | 1.43177 | -1.72576 | -3.2407 | -1.5483 | 1.4867 |