Analysis of 2017 Water Quality Monitoring: Upper Bulkley River Watershed

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Executive Summary

- This report analyzes the results of the 2017 water quality monitoring data from the Upper Bulkley River watershed to assess current water quality conditions, identify data gaps, and make recommendations to improve monitoring.
- In 2017, water quality monitoring was conducted by the Wet'suwet'en Treaty Office Society and included monthly sampling of physicochemical constituents, total suspended solids, turbidity, major anions and cations, nutrients, total metals, and volatile organic carbons. A total of 67 samples were collected at six sites over 11 months.
- In 2017, overall water quality within the Upper Bulkley River watershed was relatively good at monitored sites, however major parameters of concern include temperature and dissolved oxygen, which exceeded British Columbia Water Quality Guidelines and critical thresholds during important periods of salmon migration, spawning, and egg incubation.
- Turbidity and total suspended solids data collected in 2017 did not suggest excessive entrainment and transport of suspended particulates. However, higher concentrations were observed for parameters often associated with sediments, especially during periods of high flow.
- Nutrient conditions (based on limited available comparative data) were similar at sites monitored in 2017 compared to observations from 1997-2000. However, orthophosphate (ORP) was significantly higher downstream of Upper Bulkley Lake. This suggests that the lake may be a seasonal-source of phosphorus to the Upper Bulkley River.
- From January to April, total ammonium nitrogen (TAN) increased at the Upper Bulkley Road – North Road (UBR North Road) site in comparison to other sites, although total nitrogen (TN) concentrations did not. This suggests additional sources of inorganic nitrogen or organic nitrogen to the Upper Bulkley River during this time period; this may potentially represent nutrient contributions from the area around Houston.
- Total phosphorus (TP) was not included in analysis of 2017 water quality data. As a result, this makes it difficult to determine how phosphorus is influencing nutrient dynamics in the Upper Bulkley River watershed. Future monitoring should include TP.
- Periods of high flow have the potential to increase metal concentrations in surface waters of the Upper Bulkley River. Establishing and maintaining current baseline conditions for total and dissolved metals is important for accommodating potential long-term increases as a result of future extended periods of high flow or future development.
- The role of groundwater and groundwater-surface interactions in the McQuarrie Creek catchment appears to be more prominent than other locations monitored in the Upper Bulkley River watershed. Groundwater inputs to lower McQuarrie Creek may be important for providing colder water of good water quality to the mainstem Upper Bulkley River.
- Buck Creek may be a source of increasing sediment and total metals in the Upper Bulkley River, but a modified study design (i.e., additional sites, parameters) is required to test this hypothesis.
- Of the metals that were detected, Iron (Fe) was the only metal measured across all sites with a subset of concentrations above Water Quality Guidelines. However, values above Water Quality Guidelines were detected for only four samples, and all were collected

during freshet. This is consistent with expectations of higher mobilization of metals during periods of high flows with higher carry capacity for transport of particulate organic matter and sediment. Similar observations have been made on the Upper Bulkley River and its tributaries in past reports, although the importance or impact of high flow events on sediment mobilization or downstream impacts have not been adequately studied.

- No volatile organic compounds (VOCs) were detected in any samples.
- One site, Unnamed Spring, exhibited characteristics more analogous to groundwater than surface water, which distinguishes it from the other sites in the study as an area of particularly high groundwater discharge.
- Future monitoring should aim to improve consistency and cohesiveness surrounding site selection, method, and parameter selection. A comprehensive monitoring plan for assessing water quality limitations and ecosystem condition for salmonids in the Upper Bulkley River should focus on defining specific monitoring goals, incorporating various indicators (e.g., hydrologic, water quality, biological), synchronizing sampling efforts, and expanding collaboration between programs. These strategies will help maximize resources, streamline data collection and interpretation, and establish more cohesive monitoring and management strategies for the future.

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1.0 Introduction

Surface water quality monitoring can help describe ecological conditions, identify questions or sources of concern, and guide priorities or strategies for management. In watersheds with competing demands and pressures, water quality monitoring is also used to establish or enforce environmental criteria to support diverse demands on a watershed. Management of watersheds in British Columbia often requires balancing the needs for species of conservation concern, such as Pacific salmon, with various interests in water use and land development. This poses a particular challenge, as Pacific salmon require particular water quality conditions that are often heavily impacted by water use and land use change.

The Upper Bulkley River is one of the most heavily-modified watersheds in the Skeena River basin of British Columbia. Development over the last century has transformed much of the region into a mosaic of transportation infrastructure, forestry operations, agricultural land, human settlement and mining operations. This legacy of development, as well as ongoing activities, led to persistent environmental impacts. The waterbodies of the Upper Bulkley River are critical habitat for multiple species of Pacific salmon and are currently considered at high risk for degradation (Porter et al., 2013, 2014). Over the past several decades, various studies and professional observations have identified major concerns and pressing water issues including problems related to low flows, high temperatures, sedimentation, changes in catchment hydrology, nutrient enrichment, and mine effluent runoff (e.g., BCCF, 1997; Remington and Donas, 2000; Richter and Kolmes, 2005; Price, 2014). The consensus of previous reports and professional observations is that multiple, cumulative factors may be potentially limiting conditions for salmonids in the Upper Bulkley River.

1.1 Objectives

In 2016, the Upper Bulkley Sockeye and Chinook Habitat Restoration Feasibility Study was initiated to help resource managers and stewardship groups identify and collaboratively address watershed-specific limiting factors for salmonids. In 2016-2017 a number of fish habitat parameters were monitored to identify factors limiting salmonid populations in the Upper Bulkley watershed. As part of this effort, the Wet'suwet'en Treaty Office Society conducted monthly water quality monitoring at various sites across the watershed. There have also been various efforts by DFO to collect additional temperature and flow data throughout the watershed. The objectives of this report are: 1) to analyze the results of recent water quality monitoring data to assess current water quality conditions in the Upper Bulkley River watershed, 2) to compare data with provincial and federal water quality guidelines and historical data, and 3) interpret results to identify potential water quality issues, critical data gaps, and 4) make recommendations to improve monitoring.

1.2 Characteristics of the Upper Bulkley River watershed

Geology

The Upper Bulkley River (UBR)[a] drains a watershed area of 2,315 km^2 over 90 km before its confluence with the Morice River to form the Bulkley River, the largest tributary to the

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[a] The Upper Bulkey River watershed is defined in this report as the catchment area draining the Bulkley River and its tributaries upstream of the Morice River confluence.

Skeena River (Fig. 1). The UBR originates from Bulkley Lake receives flow from numerous tributaries, some of which were monitored as part of this study (e.g., McQuarrie Creek and Buck Creek). The UBR lies within the Stikine terrane of the morphogeological Intermontane Belt and the Nechako Plateau (Gabrielse et al., 1991). The region is characterized by rolling topography; the majority of the UBR watershed is low-gradient (mean gradient < 1.0%) with a mean elevation ~1,100 m (range ~ 570 m - 1,640 m). From the town of Houston to the southeast, the Stikine terrane is unconformably overlain by Early Eocene basalt and pyroclastic rocks of the Endako Group, which are cut by the Topley, Bulkley, Babine, and Nanika plutonic suites. Much of the bedrock was formed by lava flows covering flat-lying, older volcanic and sedimentary rock. The region contains several small volcanic porphyritic intrusions characterized by high concentrations of metal deposits typically of high interest for mineral exploration.[b] Much of the underlying bedrock is obscured by extensive glacial till.

Climate

Climate in this region[c] is characterized by warm summers (mean July temp= 14.7 °C), cold winters (mean Jan temp= -8.5 °C), mean annual temperature of 3.6 °C, and mean annual precipitation of 390 mm (Fig. 2). Less than half of the annual precipitation falls as snow, with typical snow cover from mid-November to mid-April. Historically, the majority of rainfall occurs in fall and early winter, with smaller precipitation events throughout the remainder of the year. The range in discharge for the Water Survey of Canada Station "Bulkley River near Houston" (WSC Station 08EE003) is 0.1 – 321 cms for the period of 1930-2017. The hydrology of the region is dominated by snowmelt, with peak flows occurring during spring freshet (Fig. 3, Fig. 4). Due to the moderate range in elevation for many of the low and medium elevation tributaries, discharge in these systems declines relatively quickly following spring freshet. Rainfall events also contribute a moderate amount of stormflow discharge; large fall precipitation events (including rain-on-snow events) have become increasingly common in recent years. The lowest water levels are observed in August and fish access in some areas can become restricted or impassible (DFO, *pers. comm.*). In addition, beaver dams and channel morphology change annually and both can also influence fish access (B. Wescott, *pers. comm.*). In 2017, maximum mean in-stream temperatures occurred in the Bulkey River at Houston and McQuarrie Creek above Highway 16 in late July – early August (Fig. 4).

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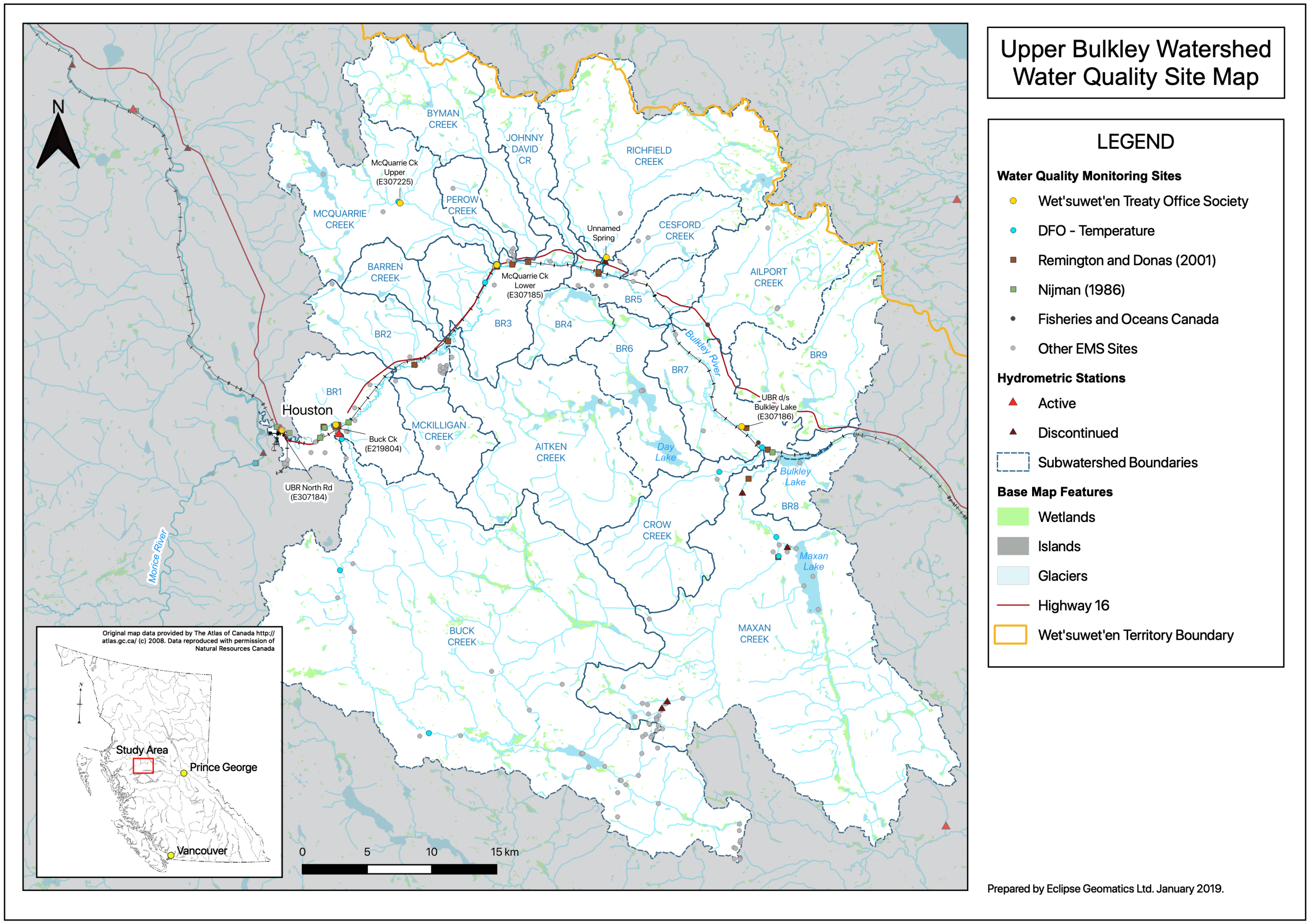
[b] Upper Bulkley 2019 Water Quality Report – MTA tenures: https://maps.skeenasalmon.info/maps/288

[c] Estimated at Houston, B.C. (elevation= 604 m) for 1980-2010 from ClimateBC (www.climatewna.com/ClimateBC_Map.aspx)



Original map data provided by The Atlas of Canada http://atlas.gc.ca/ (c) 2008. Data reproduced with permission of Natural Resources Canada

Prepared by Eclipse Geomatics Ltd. January 2019.

Figure 1. Map of the Upper Bulkley River watershed and locations of hydrometric stations and water quality sampling sites associated with various studies from 1986 - 2017.

Figure 2. Daily mean air temperature and monthly total precipitation for 2017 as measured at Houston, B.C. (Climate ID: 1073615; Lat. 54° 23’47 N, Long. 126° 40’04 W, elevation = 610 m).

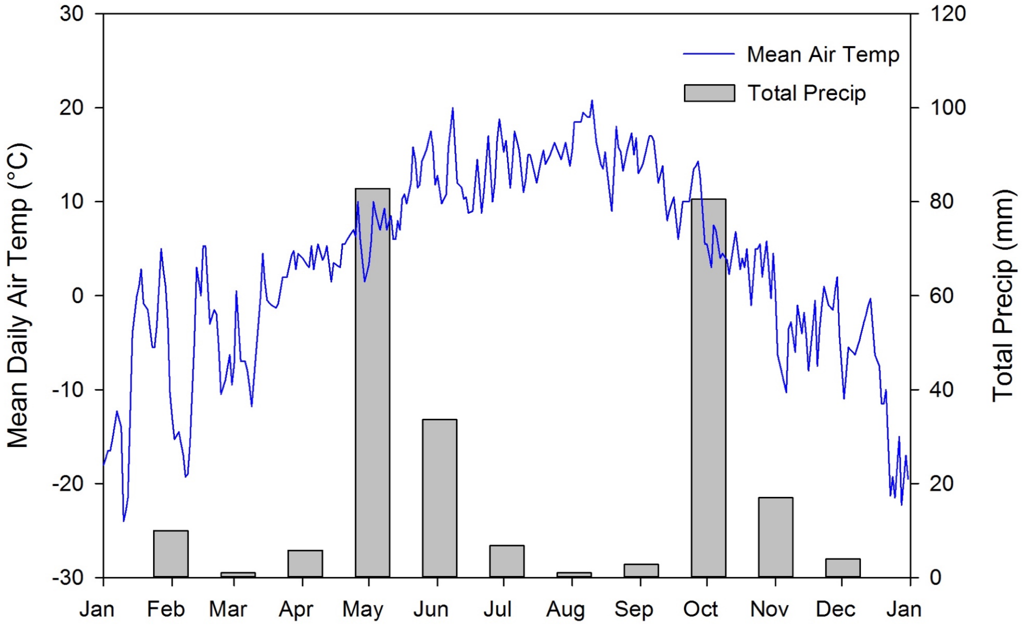
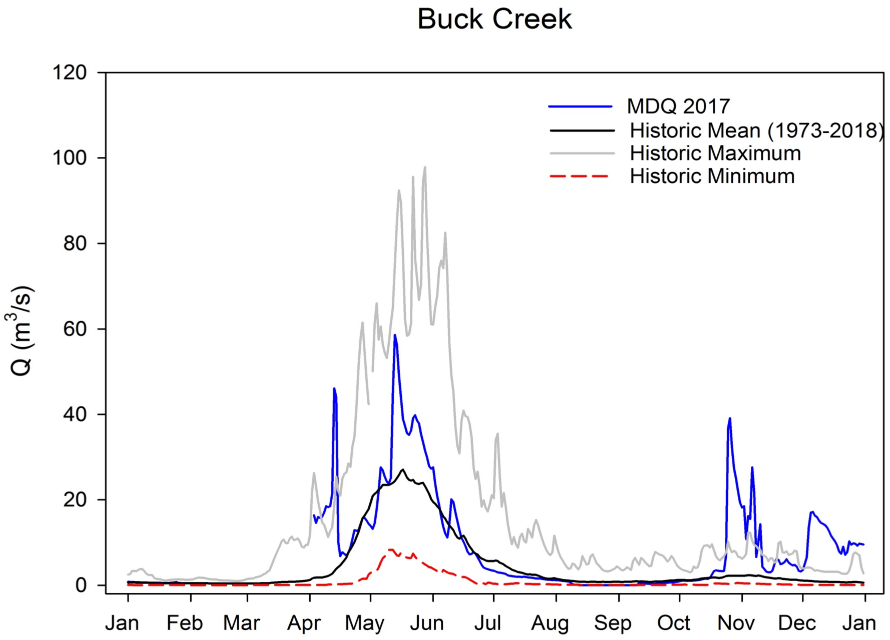


Figure 3. Historic (mean, minimum, and maximum) and 2017 mean annual discharge for 1) Buck Creek (WSC station 08EE013) and 2) Bulkley River at Houston (WSC station 08EE003).


Buck Creek

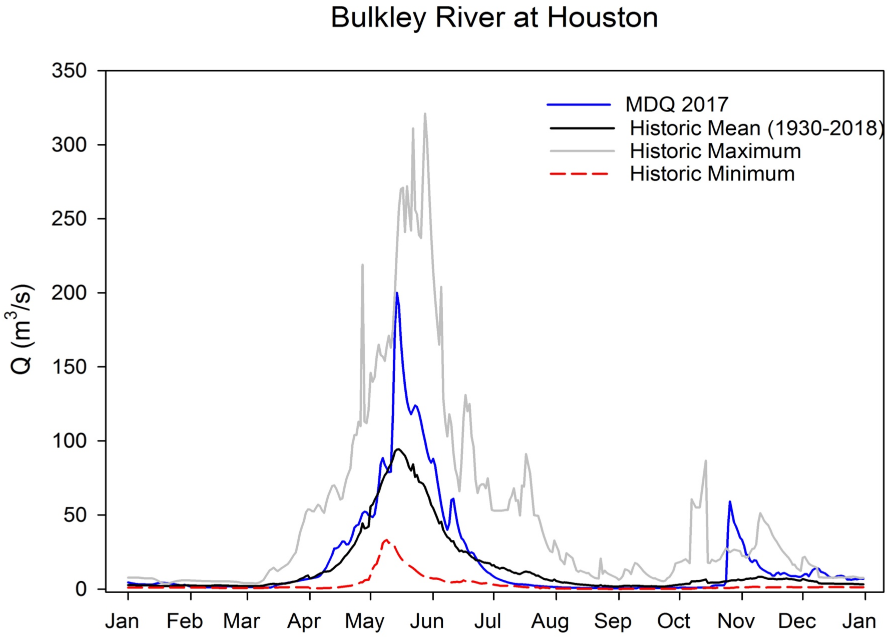
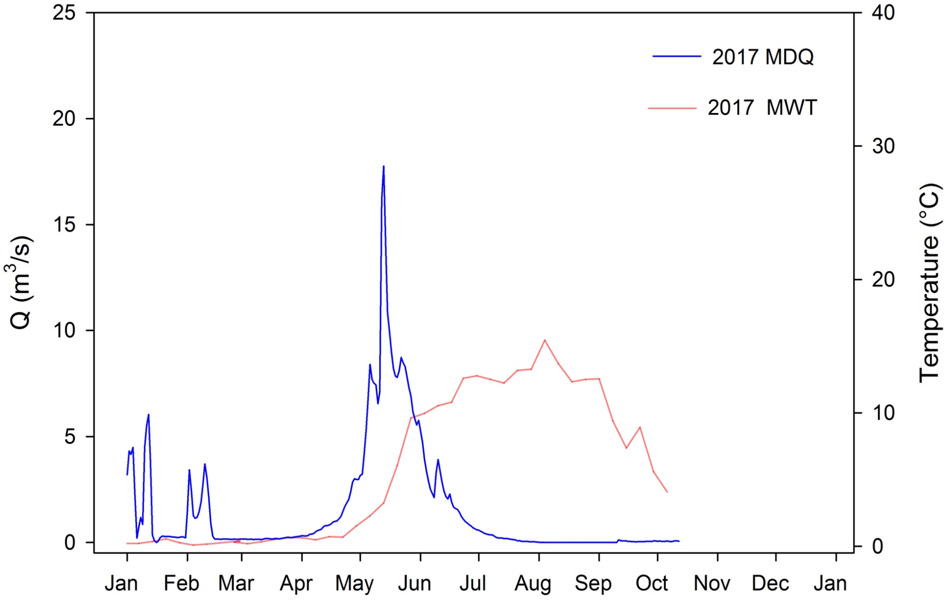
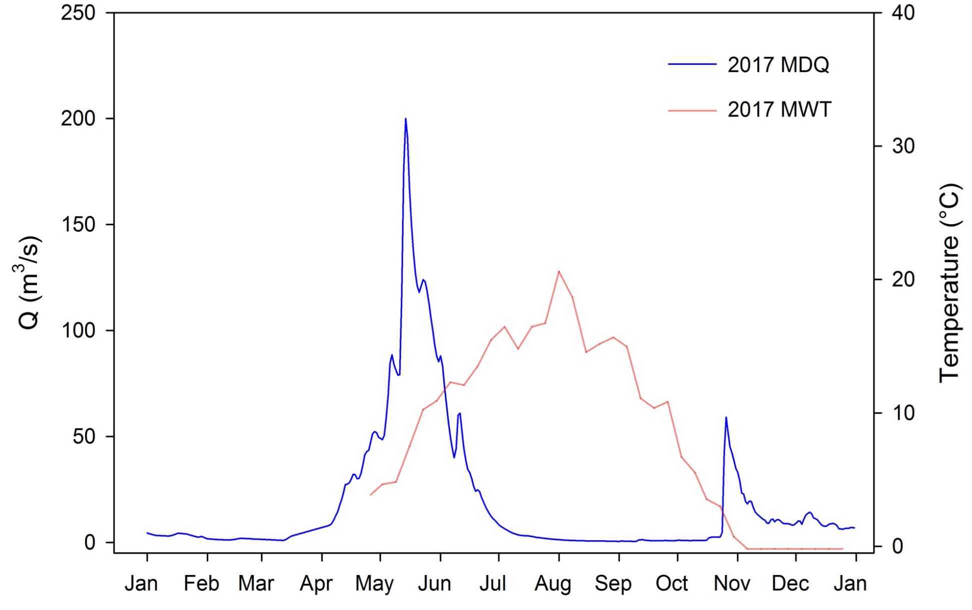

Bulkley River at Houston

Figure 4. Mean daily discharge (MDQ) and mean weekly temperature (MWT) at 1) McQuarrie Ck above Hwy 16 Culvert (BC FLNROD station 08EE002) and, 2) Bulkley River at Houston (WSC station 08EE003). Note that data was not reviewed at the time of publication and should be considered preliminary. For example, it is possible that the location of sensors and/or environmental conditions may be responsible for the variability observed in MDQ at McQuarrie Creek during January and February 2017.

McQuarrie Ck above Hwy 16 Culvert



Bulkley River at Houston



Landcover/Land Use

The majority of land cover in the UBR watershed is coniferous forest, with smaller amounts of deciduous forest along lower elevation slopes and valley bottoms.[d] Major biogeoclimactic ecosystem classification (BEC) zones are Sub-boreal Spruce and Englemann Spruce-Subalpine Fir (Banner et al., 1993). The UBR watershed contains approximately 42 km^2 of lakes and 35 km^2 of wetlands (NWWT, 2018), and the majority of UBR tributary headwaters are influenced to some degree by lakes and/or wetlands.

Public and private land use in the UBR watershed is some of the most intensive in the Skeena River watershed. A large extent of lower elevation land within the UBR watershed has been affected to some degree by humans and major land use includes linear development (e.g., Highway 16, rural roads, railway),[e] agriculture and rangeland,[d] rural settlement, and forestry.[e] Limited mining activity has also occurred at relatively higher elevations. Ranching and hay production are the dominant agricultural activities, along with limited vegetable and dairy operations (RDBN, 2012). Land use activities have resulted in alteration or total removal of extensive riparian habitat, especially on the UBR mainstem (BCCF, 1997).

There are currently 101 surface water withdrawal licenses allocating an annual total withdrawal of 649,708 m^3 within the Upper Bulkley watershed.[f] However, many water withdrawals for irrigation in the UBR watershed are from small, ungauged tributaries, making it challenging to determine total usage. Groundwater withdrawal is also common, and largely unlicensed and unmonitored.

Climate Change

Climate change effects on the region appear to be shifting patterns in seasonal temperature and precipitation. Predictions for the region include increasing temperature and annual precipitation, more precipitation occurring as rain versus snow, decreasing total snowpack, increasing frequency and magnitude of rain events, hotter and drier summers, increasing stream and lake temperatures, among others (Pike et al., 2008a, 2008b). Late summer/early autumn discharge (August-September) appears to have decreased significantly in the Bulkley River over the period of record (1931-2011) (Price, 2014), although the cause of this decrease is likely multifaceted. Hypothesized mechanisms of reduced flows in the UBR include decreased October – April precipitation, water withdrawals, and loss of riparian forests (Price, 2014).

1.3 Water quality concerns for the Upper Bulkley River

In comparison to other river systems in the Skeena River watershed, water quality in the UBR has been relatively well-studied. However, almost two decades have passed since the last comprehensive assessment of water quality (e.g., Remington and Donas, 2000). Previous water quality assessments have focused on establishing patterns in parameters and how they may be affected by human activity, recommending water quality objectives in anticipation of future project development, establishing regional biological monitoring criteria (e.g., CABIN), or evaluating specific impacts such as waste water treatment, mining, or habitat alteration.

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[d] Upper Bulkley 2019 Water Quality Report – Land Cover and Range Tenures: https://maps.skeenasalmon.info/maps/290

[e] Upper Bulkley 2019 Water Quality Report – Forestry and Roads: https://maps.skeenasalmon.info/maps/286
Upper Bulkley 2019 Water Quality Report – Road and Stream Crossing Density: https://maps.skeenasalmon.info/maps/238

[f] Upper Bulkley 2019 Water Quality Report – Water Licenses: https://maps.skeenasalmon.info/maps/289
Northwest Water Tool, accessed online November 1, 2018 at www.bcwatertool.ca/nwwt

Sedimentation

In previous reports, sediment transport is implicated as a potential area of concern for water quality and habitat. Loss of riparian habitat can increase erosion, runoff, and contribution of sediment and nutrients to surface waters. Decades of concern and punctuated periods of inquiry have surrounded the question of whether land use changes may be increasing contributions of nutrients and organic matter to surface and ground waters via both point and non-point sources. Nijman (1986) notes that turbidity exceeds BC's Water Quality Guidelines Criteria for Aquatic Life during freshet, although it is not clear whether this was based on relative change in concentration over time or background concentrations. Various sources also note that sediment inputs from road development and logging practices have historically impacted streams (e.g., Gottesfeld and Rabnett, 2008) although empirical data for the UBR appears limited. Downstream sediment delivery likely also occurred as a result of development and operation of the Equity Silver mine (in operation from 1980-1994), although major impacts appear to have ameliorated since mine closure and implementation of remediation efforts and effects monitoring, downstream monitoring of impacts are ongoing but will not be reviewed here. Monitoring of streambed substrate composition at three UBR sites in 1998 and 1999 indicated that percent fines exceeded the maximum water quality guidelines (WQG) for the <2.0 mm fraction. However interstitial dissolved oxygen at these sites was generally above WQG criteria (AGRA Earth and Environmental Ltd., 2000). The extent to which these sites are representative of effects throughout the watershed is not described.

Nutrient loading and eutrophication

The effects of agriculture, forestry, mining and urban development as sources of nutrient loading (i.e., primarily nitrogen (N) and phosphorus (P)) to waterways is well-described and, due to the prevalence of these activities in the UBR, warrant concern regarding nutrient dynamics and eutrophication. Previous studies observed elevated concentrations of total phosphorus (TP) and orthophosphate (ORP) at UBR sites above the Houston water treatment facility and on several tributaries; these effects were attributed to agriculture and urban development (Wilkes and Lloyd, 1990; Remington, 1991; Portman, 1995). Natural sources of P in the perimeter of the Buck Creek catchment have also been attributed to the Goosly Lake volcanic formation (Remington and Donas, 2000), which has been characterized as relatively high in P (Church and Barakso, 1990) and likely contributes to naturally-elevated background concentrations of P at downstream sites. Other previously-identified nutrient issues (N-species in particular) associated with waste water treatment (Nijman, 1986; Maclean and Diemert, 1987) appear to have been resolved via facility improvement in the early 1990's (Portman, 1995).

Acid rock drainage

Concern has existed for decades over downstream impacts of acid rock drainage (ARD) produced by the Equity Silver mine on multiple waterbodies within the UBR watershed. The Equity Silver mine produced 85 million tonnes of mined waste rock containing pyritic sulphide. Exposure to air and water oxidizes sulphides and produces acid that leaches toxic metals and other deleterious substances. Various efforts have been taken over the years to remediate the effects of ARD and monitor downstream impacts. Although peak ARD rates are believed to have occurred decades ago, models suggest that much lower levels of ARD will last for well beyond 100 years (Knapp et al., 1992), and exceedances of ARD treatment capacity have occurred numerous times since 1981. However, studies on fish and benthic macroinvertebrates from 1984-1989 found fish productivity was within the range of unaffected streams for the area (considered high-quality trout streams). These studies concluded that, at the time, mine operations did not have a serious impact on the fish or benthic macroinvertebrate populations of Foxy or Buck Creek (Bustard, 1984; Bustard, 1989). Similarly, environmental effects monitoring in 2002 and 2006 combined benthic invertebrate abundance and community composition with other chemical parameters and on-site mesocosm experiments to assess the condition of Equity Silver mine drainage streams and concluded that the streams were "not stressed" and that mine remediation was adequate for protecting downstream condition (Perrin, 2007; Perrin et al., 2007).

Low flows and high temperatures

The lowest flows and highest temperatures in the UBR occur in the mid- to late summer and overlap with salmonid migration and spawning, particularly Chinook and sockeye salmon. These conditions are known to influence available fish habitat and impact migration, and are likely further influenced by land use activity in the watershed (Price, 2014). Low flows and high temperatures can also play a role in water quality conditions, contributing to increased algal production or nuisance algal blooms, increased sediment deposition, low dissolved oxygen (hypoxia or anoxia), changes in oxidation-reduction reactions that may influence nutrient and metal cycling, etc. Historic water temperature data exists primarily part of non-temperature focused programs and consists primarily of spot measurements. A list of previous temperature monitoring efforts is found in Wescott (2019). To better understand and adequately quantify temperatures, the Upper Bulkley Water Temperature Monitoring Program was initiated in 2016 as part of the Upper Bulkley Sockeye and Chinook Habitat Restoration Feasibility Study. This program identified baseline conditions and trends for 2016-2018 at 14 sites across the UBR and found that mean weekly maximum temperature exceeds optimum Water Quality Guidelines for Chinook and sockeye, although variation in daily temperature help moderate the most severe effects of maximum daily temperatures (Wescott, 2019). The scope of the temperature program does not include additional investigation of interactions between temperature and other water quality parameters, such as dissolved oxygen.

1.4 Description of Water Quality Parameters

Physicochemical

Physicochemical properties of water quality monitored in 2017 include temperature, pH, specific electrical conductivity (SEC), dissolved oxygen (DO), total hardness, turbidity, and total suspended solids (TSS). Temperature and DO are critical parameters for understanding habitat quality and optimal conditions for aquatic organisms, especially fish, whose various life history stages may be constrained to a range of ideal temperature and DO values. Temperature and DO also plan an important role in chemical reactions that can alter water chemistry (e.g., a lack of oxygen or "anoxia" can cause some compounds or elements to become more water soluble).

Specific electrical conductivity (SEC; also known as specific conductivity, or specific conductance) is a measure of how easily water conducts a charge at 25°C and is used to estimate the concentration of ions in water. SEC can be an early indicator of change in natural waters and is sensitive to processes that change ion concentrations such as runoff, evaporation, flooding, groundwater inputs, and contribution from sources high in salts or minerals. The acidity of water can be defined by pH and is based on the molar concentration of hydrogen ions. The majority of aquatic organisms prefer values of pH from 6.5-9.0. Higher (more acidic) or lower (more basic) pH can affect the solubility and toxicity of chemicals and heavy metals and have lethal effects on aquatic species. A variety of factors affect pH in water, including natural processes such as rock weathering, photosynthesis, organic soils, and precipitation, or anthropogenic activities such as wastewater discharge, mining activities, or increased antropogenic-CO_2 concentrations. Total hardness is the concentration of multivalent metal ions (mostly calcium and magnesium) in water and can also influence the capacity of water to buffer against changes in pH. Most aquatic organisms have a range of tolerance for hardness, values outside of this range can affect osmoregulation and the solubility/toxicity of other metals.

Turbidity and total suspended solids (TSS; particles > 2um) measure water clarity and the concentration of suspended material ("particulates") entrained in a water sample, respectively. The majority of particulates are inorganic materials, but organics, such as algae or bacteria, also contributes to turbidity and TSS. Higher turbidity and TSS suggest higher amounts of entrained material; this reduces light availability to primary producers and can smother benthic habitats. This can lead to redd mortality, as well as changes in benthic communities, productivity, dissolved oxygen concentrations, and biogeochemical processes.

Nutrients – nitrogen and phosphorus

Nitrogen (N) and phosphorus (P) are major nutrients in ecosystems and support food webs by fueling primary productivity. Primary productivity is limited by nutrient availability, and excess nutrients can create excess algal and plant growth, shifts in species composition, and changes in water quality. Both N and P enter surface waters through natural processes such as N-fixation (for N) or rock weathering (more commonly for P, but also N). Human activity can dramatically increase nutrient loading to surface waters and eutrophication is considered a global problem (Smith, 2003; Mekonnen and Hoekstra, 2017). Eutrophication increases biological oxygen demand in water and sediments, alters biogeochemical cycling, shifts community composition of aquatic organisms, and can adversely affect fish growth, spawning and human water use. Major sources of nutrient inputs include runoff from agriculture and ranching, sewage, waste water, and urbanization. Freshwater ecosystems are often co-nutrient limited or P-limited, and excess P can result in shifts in community composition to favour species capable of N-fixation, which in turn further exacerbates nutrient loading. This can have cascading effects for aquatic habitats and water quality conditions (Oliver et al., 2014).

Under normal flows, most P-loading to surface waters occurs via nonpoint sources such as runoff from pasture and cropland, bank erosion, and atmospheric deposition (Riemersma et al., 2006). Although the most readily-available form of P for aquatic organisms is dissolved orthophosphorus (ORP), P is also often found in the particulate form associated with organic matter or soil minerals. P cycles readily between the dissolved and particulate forms, and total phosphorus (TP) is often used to describe the potential amount of P available to aquatic ecosystems. However, the water monitoring conducted in the UBR in 2017 only included analysis of dissolved P (e.g., TDP, ORP) and so estimates of available P in this report are likely conservative.

Major anion and cations

Concentrations of anions such as chloride (Cl^-) and fluoride (F^-) are often used to indicate watershed characteristics including hydrologic flow paths and human impacts. Chloride is considered hydrologically and chemically inert, and therefore a good indicator of catchment throughput. Although Cl^- is naturally occurring, it also finds its way to surface waters through road de-icing products, dust suppressants, and municipal water facilities. Concentrations of Cl^- often relate to watershed characteristics and represent a strong indicator of general human disturbance including extent of urbanization, proportion of agricultural land, and road density (Herlihy et al., 1998; Pinel-Alloul et al., 2002; Dow et al., 2006). In contrast to Cl^-, concentrations of F^- tend to be higher in groundwater than surface water, but rarely exceed 0.2

mg/L[g]. In addition to natural sources, F^- also enters surface waters via industry, agricultural runoff of herbicides and pesticides, and from municipalities with fluorinated drinking water.

Sulfate (SO_4^{2-}) is a major anion in surface waters and concentrations of > 0.5 mg/L are necessary for algal growth. Sulfate occurs naturally but is also contributed to surface waters via anthropogenic sources. Examples of major sources of SO_4^{2-} include sewage treatment, pulp mills, runoff from fertilized agricultural lands, or treatment of mining tailings ponds. Sulfates are not considered toxic to plants or animals under normal conditions, but can be involved in a variety of biogeochemical processes that may affect toxicity (e.g., acid mine runoff can produce highly toxic sulfides under reducing conditions), as well as the solubility of metals or other substances.

Major cation metals in surface waters include calcium (Ca^{2+}) and sodium (Na^+). Both Ca^{2+} and Na^+ exist primarily as salts and occur naturally from rocks and soils, but are also contributed from anthropogenic sources such as road salt, sewage effluent, landfills and industrial sites, and excess leaching of soils high in major cations.

Other total metals

Metals are essential for aquatic life and required, at certain concentrations, for proper organism growth and function. However, at higher concentrations or in different forms (i.e., "species") these same metals can be toxic to aquatic life. Therefore, the evaluation of risk and impact associated with metals can be quite complex and is often based on an optimal concentration range that takes into account minimum concentrations required for growth versus maximum tolerable levels. Factors used to determine these values include metal solubility, physiological function, life stage, previous health of the organism, age, concentration of other water quality parameters such as nutrients, etc. In this report, water quality conditions for total metals are assesed by comparing measured values with available BC Water Quality Guidelines. Water samples collected as part of the Upper Bulkley River water quality sampling in 2017 were only analyzed for total metals, and did not include dissolved metals. Dissolved metals are sometimes thought to be more bioavailable and therefore some water quality guidelines are based only on the dissolved fraction. This report will only look at available guidelines for total metals. Metals can be contributed through a number of natural and anthropogenic processes. Some metals are more prevalent in the natural environment (e.g., potassium, iron, manganese, etc.) and others (e.g., cadmium, mercury, strontium, etc.) are primarily contributed through anthropogenic processes such as mining, industrial activity, and waste water treatment.

Volatile Organic Compounds

Volatile organic compounds (VOCs) are organic carbon compounds that both vaporize in air and dissolve in water. They are derived primarily from anthropogenic activities including fuel tanks, landfills, chlorination of drinking water, fumigants for pest control, wood fibre processing and many other industrial operations. Although VOCs typically volatize from surface water relatively effectively, VOCs can be very persistent in groundwater. VOC's are shown to have a wide range of toxic effects to the environment and to human life.

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[g] In B.C. F^- is typically higher in groundwater than surface water. B.C. Ministry of Environment, accessed online Feb 2, 2019 at: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/fluoride-tech.pdf

2.0 Methods

2.1 Upper Bulkley River watershed surface water monitoring sites – 2017

From January to November, 2017, the Wet'suwet'en Treaty Office Society conducted monthly surface water sampling at six sites (Table 1; Fig. 1). These sites include two locations on the uppermost and lowermost reaches of the mainstem UBR (UBR d/s Bulkley Lake, UBR at North Road), three tributaries to the UBR (McQuarrie Ck Upper, McQuarrie Ck Lower, Buck Ck), and one site of potential groundwater upwelling (Unnamed Spring). Hydrometric data were obtained from stations at Bulkley River near Houston (WSC Station 08EE003), Buck Creek (WSC Station 08EE013)), and McQuarrie Creek above Hwy 16 (FLNROD Station 08EE002) (Appendix, Table A).

Although not included in this report, note that continuous temperature data were also collected at 14 sites as part of the UBR Water Temperature Monitoring Program (Appendix, Table A). Data and results from that program are described in detail in Wescott (2019).

2.2 Surface water sample collection and laboratory analysis

Surface water grab samples were collected monthly at each site from January through November, 2017. Sampling protocols followed those described in the *British Columbia field sampling manual: Part E Ambient Freshwater and Effluent Sampling* (2003). Field water quality parameters (temperature, pH, dissolved oxygen (DO) and specific electrical conductivity (SEC)) were collected using a pre-calibrated YSI Professional Plus hand held meter. Grab samples were collected from a central well-mixed portion the waterbody and capped underwater to eliminate headspace. Samples were stored in the dark on ice and shipped to ALS Environmental (Burnaby, B.C.), following return from the field or the next morning. Additional samples were also sent as QA/QC checks including duplicates, field blanks, and lab blanks. Samples were analyzed using standard protocols approved for ISO/IEC 17025:2005 accredited facilities. Constituents analyzed included basic physicochemical parameters (SEC, pH, total suspended solids (TSS), turbidity, and hardness), nutrients (total nitrogen (TN), total organic nitrogen (TON), total Kjeldahl nitrogen (TKN) nitrate (NO_3^-), nitrite (NO_2^-), total ammonia nitrogen (TAN), total dissolved phosphorus (TDP), and orthophosphate (ORP)), major anions and cations, and total metals. No nutrient data was collected for Unnamed Spring.

2.3 Data analysis

For purposes of analysis, samples with reported values less than the analytical limit of detection (< LOD) were substituted with a single value equivalent of ½ LOD. The single substitution method was selected over generally more robust methods based on data distribution and maximum likelihood estimation because of potential bias associated with low sample size (Helsel, 1990). Constituents with no values > LOD were removed from analysis. Summary statistics were determined by site for each constituent. Comparisons were made between results in 2017 and previous results for water quality studies conducted from 1997-2000 (Remington and Donas, 2000).[h] All data analyses were performed in R (R Core Team, 2017).

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[h] Although data was also collected from 1983-1988 (Wilkes and Lloyd, 1990) at a site relatively comparable to the 2017 site (UBR North Road) the 1983-1988 data at this site is not considered to be reliable for estimating water quality conditions throughout the UBR as this site was affected by wastewater discharges upstream at the Houston sewage treatment plant, and therefore no comparisons were made to 2017.

Table 1. Sites monitored for water quality in the Upper Bulkley River watershed, January – November, 2017.

Site ID	EMS ID	Site description	Latitude (N)	Longitude (W)	Drainage Area (km^2)	Mean Elevation (Min – Max) (m)
Buck Ck	E219804	Buck Creek ~0.5 km u/s confluence with Upper Bulkley River in Houston	54°24'09.3672	126°39'14.3951	467	1,126 (678 – 1,541)
McQuarrie Ck Upper	E307225	McQuarrie Creek, ~13 km u/s confluence with Upper Bulkley River	54°30'50.8716	126°27'49.9062	82	1,124 (914 – 1.551)
McQuarrie Ck Lower	E307185	McQuarrie Creek ~0.1 km u/s confluence with Upper Bulkley River	54°33'22.1940	126°34'46.8687	115	1,091 (728 – 1551)
UBR d/s Bulkley Lake	E307186	Upper Bulkley River ~4.5 km d/s of Bulkley Lake	54°24'11.0484	126°10'14.4142	588	1,019 (743 – 1,573)
UBR North Road	E307184	Upper Bulkley River at North Road ~90 km d/s of Upper Bulkley Lake, and ~ 6.5 km d/s of Buck Creek confluence	54°23'55.1076	126°43'05.4474	2,315	1,106 (612 – 1,573)
Unnamed Spring	NA	Groundwater spring adjacent to Richfield Creek above confluence with Upper Bulkley River	NA	NA	NA	NA

*All sites were also monitored at similar locations for continuous temperature. More information included in report by Wescott (2019).

In British Columbia, approved Water Quality Guidelines (WQGs) are meant to represent safe levels of substances that protect water use for aquatic life, drinking water, agriculture, and recreation. The most stringent of these guidelines in the protection of aquatic life. Because WQGs were designed to be broadly applicable at the provincial scale, they may be over or under-protective for specific sites. In these circumstances, Water Quality Objectives (WQOs) can be developed to more adequately protect existing water quality. To assess current water quality conditions in the UBR watershed, and determine potential need for site-specific WQOs, data were compared with provincial working and approved WQGs for the Protection of Aquatic Life (MECCS, 2018) and recommendation from the Canadian Council of Ministers of the Environment (CCME, 1999).

3.0 Results

In 2017, the Wet'suwet'en Treaty Office Society collected a total of 67 samples (excluding duplicates) at six sites over 11 sampling dates. Summary statistics for water quality parameters are provided in Tables A1-A3, along with corresponding box plots (Fig. A1-A6). Data is also presented as time series (Fig. A7-A13) to elucidate temporal variability and potential seasonal differences in water quality. Results for each constituent are discussed in the following sections. No results are presented for constituents undetected (i.e., all results < LOD) across all samples and includes the following: bromide, select total metals (antimony (Sb), beryllium (Be), boron (B), cadmium (Cd), lead (Pb), lithium (Li), mercury (Hg), molybdenum (Mo), nickel (Ni), potassium (K), selenium (Se), silver (Ag), thallium (Tl), uranium (U), vanadium (V)), all volatile organic compounds (VOCs), all polycyclic aromatic hydrocarbons (PAHs).

3.1 Physicochemical

Physicochemical constituents at sites included in this study are within the natural range of pH and SEC to support good mixed fisheries (pH= 6.5-8.5 and SEC=150-500 uS/cm (EPA, 2012)). With the exception of Unnamed Spring, water hardness at all sites is considered "soft" to "moderately-soft" and therefore surface waters have reduced buffering capacity but are still within the adequate range for protection for aquatic life (Table A1; Fig. A1). The characteristics of water at Unnamed Spring are more indicative of groundwater; SEC is higher at Unnamed Spring than other sites, indicating a higher concentration of dissolved inorganic solids and ions and "hard" with greater buffering capacity. At most sites, pH, SEC, (Fig. A7) and hardness (Fig. A8) indicate some degree of seasonal cycling across most sites, although SEC exhibited almost no temporal variability at Unnamed Spring.

In general, maximum temperatures and minimum DO occurred during July and August, with low DO persisting through September, particularly at UBR d/s Bulkley Lake (Fig. A7). Note that summary statistics are not presented for temperature or dissolved oxygen as substantial diel and daily variability can exist for these parameters and therefore summarizing lower-resolution sampling (e.g., monthly grab samples) conducted at varying times of the day can mislead results. For a more thorough approach to summarizing the high-resolution temperature data collected during this time period, see Wescott (2019).

Sites monitored in 2017 were typically low in turbidity and TSS during baseflow conditions, although the mean and range of variability was higher at UBR North Road, followed by Buck Ck, than other sites (Table A1; Fig. A1). Large increases in turbidity and TSS were apparent during freshet (Fig. A8).

3.2 Anions and cations

Concentrations of Cl^- were relatively low at most of the sites, but slightly elevated at Buck Ck, and significantly higher at UBR North Road (Table A1; Fig. A2). Seasonal patterns suggest an inverse relationship between Cl^- concentration and flow at UBR North Road; concentrations appear diluted during periods of high flow. The remaining sites in this study do not appear to reflect any obvious temporal variability or seasonal trends in Cl^- concentration (Fig. A9).

In 2017, sites on the UBR (UBR d/s Bulkley Lake, UBR North Road) and Unnamed Spring had similar concentrations of F^-, which were higher than concentrations at the two sites in the McQuarrie Creek catchment. In addition, sites on the UBR exhibited temporal variability that suggests seasonality in F^- concentrations, whereas sites on McQuarrie Creek were did not exhibit similar trends (Fig. A9). This pattern was also not observed at Unnamed Spring.

All of the sites monitored in 2017 exhibited SO_4^{2-} concentrations well above the range necessary to sustain algal growth (Table A1; Fig. A2). Concentrations at UBR sites (UBR d/s Bulkley Lake, UBR North Road) were higher and similar at upstream versus downstream sites, but significantly lower than at Buck Ck. Concentrations in SO_4^{2-} at Buck Ck were significantly higher than at other sites. Both McQuarrie Creek sites and Unnamed Spring were lower in SO_4^{2-} throughout the year. In 2017, the degree of temporal variability in SO_4^{2-} varied widely by site but no obvious seasonal trends were observed (Fig. A9).

A summary of results for Ca^{2+} and Na^+ are provided in Appendix B (Table B2). Overall, Ca^{2+} mirrors the pattern seen for hardness (Ca^{2+} is the major contributor to water hardness) and was similar across all sites, but higher at Unnamed Spring. Na^+ was highest at UBR North Road and increased from upstream at UBR d/s Bulkley Lake. There was a large increase in Na^+ from McQuarrie Ck Upper to McQuarrie Ck Lower, reflecting Na^+ contributions from sources accruing downstream in the watershed.

3.3 Nutrients

Nitrogen

In 2017, values for TN were similar across all sites, although means were slightly higher at UBR sites (UBR d/s Bulkley Lake, UBR North Road) than at tributary sites. The greatest differences occurred between UBR sites. Although means were similar between UBR North Road and UBR d/s Bulkley Lake, the range was greater at UBR North Road; the standard deviation in TN concentrations at UBR North Road was twice as high as at UBR d/s Bulkley Lake (Table A2; Fig. A3). On average, 88% (range 35-99%) of the TN pool was comprised of organic nitrogen (TON) and TON covaried with TN. The rank order of sites (from highest to lowest concentration) was maintained for TN and TON across sites and seasons. Overall, seasonal patterns of TN and TON were tightly coupled and showed a positive relationship to discharge (i.e., concentrations increase with increased flow) (Fig. A10). The exception to this was McQuarrie Ck Upper, where higher TN concentrations occurred during summer low flows.

Dissolved inorganic N (“DIN” = NO_3^-+ NO_2^-+ TAN) comprised an average 18% of the TN pool and was primarily composed of NO_3^-. For this report, concentrations of NO_3^- and NO_2^- are reported together (NO_3^- + NO_2^-) as NO_2^- is an intermediary N species produced and consumed rapidly during N-cycling, and so typically present in very low concentrations. At most sites, concentrations of NO_3^- + NO_2^- were relatively similar across all sites (Table A2; Fig. A3). Concentrations of TAN were consistently below detection at tributary sites (notably Buck Creek and McQuarrie Ck Lower) but were on average higher at UBR sites, especially UBR North Road (Table A2; Fig. A3). UBR North Road was the only site where concentrations of TAN were comparable to NO_3^-+NO_2^- on several sampling dates (Jan-April). TAN at UBR North Road was unusually high for the period of Jan-April in comparison to TAN concentrations throughout the watershed and across other times of the year. In contrast to the organic N pool, inorganic N constituents appeared to have a negative relationship with flow; concentrations at most sites increased during periods of low summer and winter flows (Fig. A10). Maximum concentrations of NO_3^-+ NO_2^- occurred at McQuarrie Ck Upper in September during the low summer flow, and maximum concentrations of TAN occurred at UBR North Road in February and March during winter low flow. Unlike TON and TN, there were large differences in temporal variability of DIN between sites; some sites exhibited relatively little or no temporal variability (e.g., TAN at Buck Creek), whereas others exhibited higher variability and more obvious seasonal trends (e.g., NO_3^-+NO_2^- at McQuarrie Creek Lower).

Phosphorus

This study only included collection and analysis of dissolved P (e.g., TDP, ORP), therefore estimates of total available P are likely conservative. Based on TDP concentrations collected in 2017, sites range from ultra-oligotrophic/oligotrophic (McQuarrie Ck Upper and McQuarrie Ck Lower) to mesotrophic-eutrophic (Buck Ck, UBR d/s Bulkley Lake), with UBR North Road exhibiting the largest variability (oligotrophic to mesotrophic). On average, ORP comprised 57% (range = 0-97%) of TDP across all sites (Table A2; Fig. A4). TDP and ORP also covaried across space and time and were strongly positively correlated (Pearson Correlation = 0.986, $p < 0.001$). Sites with the highest average concentrations of TDP and ORP were UBR d/s Bulkley Lake followed by Buck Ck. Average concentrations were lower at UBR North Road, but the highest concentrations were observed at this location at the onset of spring freshet, followed by higher values of TDP and ORP at UBR d/s Bulkley Lake during low both summer and winter low flow (Fig. A11). Temporal variability in P was observed at each site, although the magnitude and direction of the seasonal trend varied between sites. For example, some sites showed a pulse of P delivery at the onset of freshet (UBR North Road, Buck Ck), during fall rain events (Buck Ck), or during summer low flow (UBR d/s Bulkley Lake).

It is important to note that because TP was not measured in this study, N:P ratios are based on total amounts of the most readily-available form of dissolved nutrients (e.g., DIN: ORP). For sites monitored in the UBR during 2017, assumptions regarding N or P nutrient limitation are site-specific. Average N:P was low (N:P < 16) throughout the year at UBR sites (UBR d/s Bulkley Lake, UBR North Road) and Buck Ck, suggesting N-limitation (Fig. A11). In contrast, the two sites on McQuarrie Creek had high N:P (N:P >16) across the majority of samples, suggesting mostly P-limitation, although lower values were measured at these sites in late autumn (November) and late spring/early summer (May/June), suggesting that seasonal shifts in nutrient availability and limitations to productivity or co-limitation may occur during these times.

3.4 Total metals

Only metals with concentrations > LOD are presented in this report (Table A3; Figs. A5-A6, Figs. A12-A13). Total concentrations of chromium (Cr), cobalt (Co) and titanium (Ti) were only detected at concentrations > LOD in a very small subset of samples and summary statistics and figures are provided for those constituents in Appendix B (Table B2). Total metals whose concentrations were < LOD for all samples and are therefore not discussed include: antimony (Sb), beryllium (Be), boron (B), cadmium (Cd), lead (Pb), lithium (Li), mercury (Hg), molybdenum (Mo), nickel (Ni), potassium (K), selenium (Se), silver (Ag), thallium (Tl), uranium (U), and vanadium (V).

For many metals, the mean and range of variability in concentrations were higher at UBR sites (UBR d/s Bulkley Lake, UBR North Road) and Buck Ck than at McQuarrie Ck Upper, McQuarrie Ck Lower, and Unnamed Spring (Table A3; Figs. A5-A6). A few constituents (magnesium (Mg), barium (Ba)) had relatively higher concentrations at Unnamed Spring in comparison to other sites, but overall Unnamed Spring was low in total metals. Major changes in metal concentrations tended to be associated with periods of high flow; most metals show a positive relationship with discharge (i.e., as discharge increases, concentrations of total metals increase) (Figs. A12-A13). Exceptions to this pattern include magnesium (Mg) and potentially manganese (Mn), which appear to decrease in concentration at higher flows. In addition, arsenic (As) may potentially both increase and decrease at high versus low flows, depending on the site, while barium (Ba) remains fairly consistent throughout the year and uninfluenced by flow or seasonality. These patterns were not observed at Unnamed Spring, where concentrations for all metals show minimal temporal variability.

3.5 Volatile organic compounds

No volatile organic compounds (VOCs) were detected at values > LOD for any samples collected in 2017 as part of this water quality monitoring project within the UBR watershed.

3.6 Comparison with Water Quality Guidelines

To evaluate current water quality conditions at sites monitored in 2017 within the UBR watershed, data were compared to existing provincial Water Quality Guidelines (WQG) for the protection of aquatic life (MOECCS, 2018), and Water Quality Objectives (WGO) previously recommended for the UBR (Nijman, 1986). In 2017, a very small number of samples exceeded existing provincial WQG or WGO (Table 2). A total of five WQG exceedances were identified for Fe-Total (WQG = 1 mg/L): three at UBR North Road, one at UBR d/s Upper Bulkley Lake, and one at Buck Ck. All exceedances occurred during freshet. Six WQG exceedances were identified for temperature from July through September, and most were observed at UBR sites (UBR d/s Upper Bulkley Lake, UBR North Road), although one was observed at McQuarrie Ck Lower. In addition, two DO samples exceeded WQO at UBR d/s Upper Bulkley Lake in August and September (WQO = 7.8 mg/L; Nijman, 1986).

Table 2. Water Quality Guideline (WQG) or Water Quality Objective (WQO) exceedances for data collected at UBR water quality sites, January – November, 2017 (n= 11).

	Buck Ck	McQuarrie Ck Upper	McQuarrie Ck Lower	UBR d/s Bulkley Lake	UBR North Road
EMS ID	E219804	E307225	E307185	E307186	E307184
Temperature[*]	0	0	1	2	3
Dissolved Oxygen WQO = 7.8 mg/L	0	0	0	2	0
Total Fe WQG = 1 mg/L	1	0	0	1	3

[*] WQG for temperature are based on species and specific life history stage. For the full table outlining temperature criteria see https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/wqg_summary_aquaticlife_wildlife_agri.pdf or the Appendix B of this report.

3.7 Water quality in 2017 vs. previous studies

Water quality results from 2017 were compared to results collected at the similar sites[i] from 1997-2000 (Remington and Donas, 2000). Unfortunately, the majority of parameters collected in 2017 differed from those in the 1997-2000 dataset, and so only a subset of parameters were comparable. Comparable parameters reflect nutrient concentrations of TAN, NO_3^--NO_2^- (Fig. 5), and ORP (Fig. 6). In addition, comparisons were also made for N:P (as DIN:ORP) (Fig. 6).

Significant differences were detected between 2017 and 1997-2000 for TAN at Buck Ck (decreased in 2017; t(38)= -3.103, p= 0.003), ORP at UBR d/s Bulkley Lake (increased in 2017;

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[i] Because location information was not explicit for all sites included in Remington and Donas (2000), site descriptions were used to ascertain the location of sites included in the historical (2000) report to those included in the recent (2017) study. All paired sites (historic versus 2017) included for comparison are judged to be in relative proximity of each other and reasonable for comparison. Note that McQuarrie Creek samples from 1997-2000 were collected downstream of the highway bridge, whereas samples in 2017 were collected upstream of the bridge.

t(31)= 2.897, p= 0.007), and N:P at McQuarrie Creek Lower (increased in 2017; t(42)= 2.671, p= 0.010). Although not statistically significant, TAN concentrations and range of variability appear to have decreased at all sites between 1997-2000 and 2017, and concentrations of NO_3^-+NO_2^- appear to have increased slightly in range of variability. These differences may represent possible shifts in the composition of the DIN pool, or they may reflect a function of sampling design, including the timing and resolution of sampling between the two studies that reflect differences in natural variability. With the exception of UBR d/s Bulkley Lake, ORP appears to be relatively similar at all sites in 2017 in comparison to 1997-2000. Additional analysis of the total P fraction is required for a more complete understanding of P dynamics, including P-loading and P-availability.

Figure 5. Box and whisker plots of nitrogen data collected from 1997-2000 (Remington and Donas, 2000) versus data collected in 2017 at similar locations. Significant differences between means (Welch's t-test) are indicated with * (for p <0.1) and ** (for p<0.01).

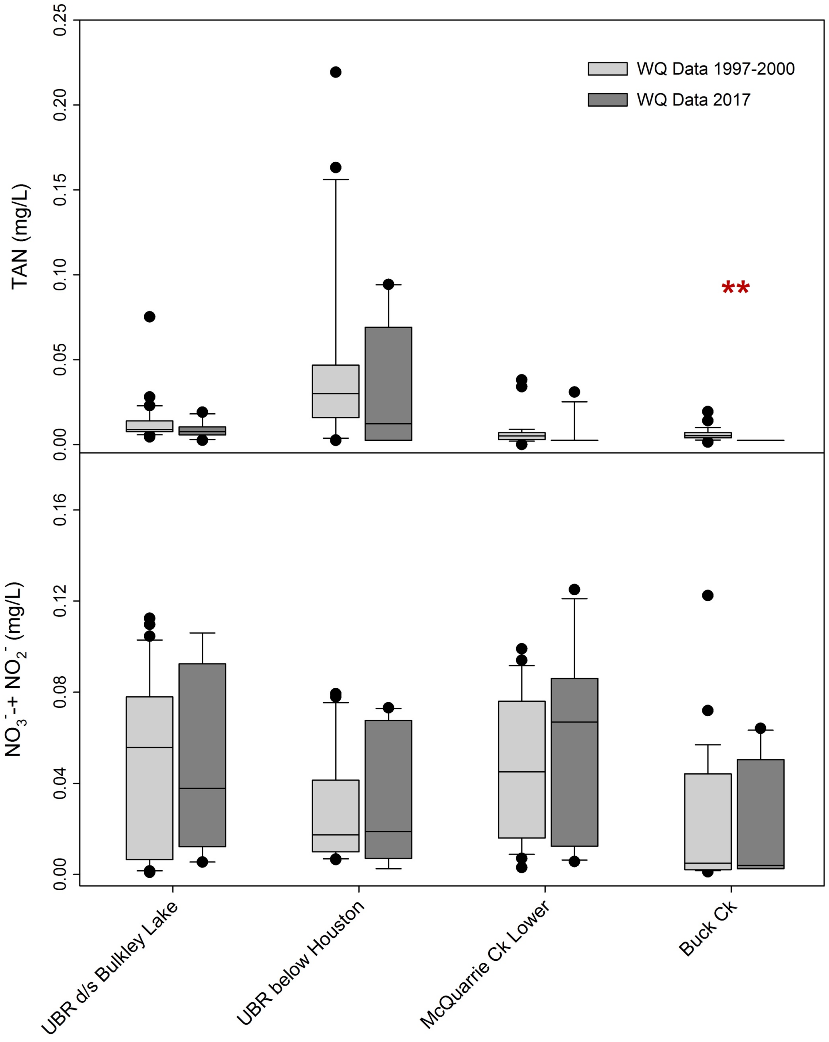
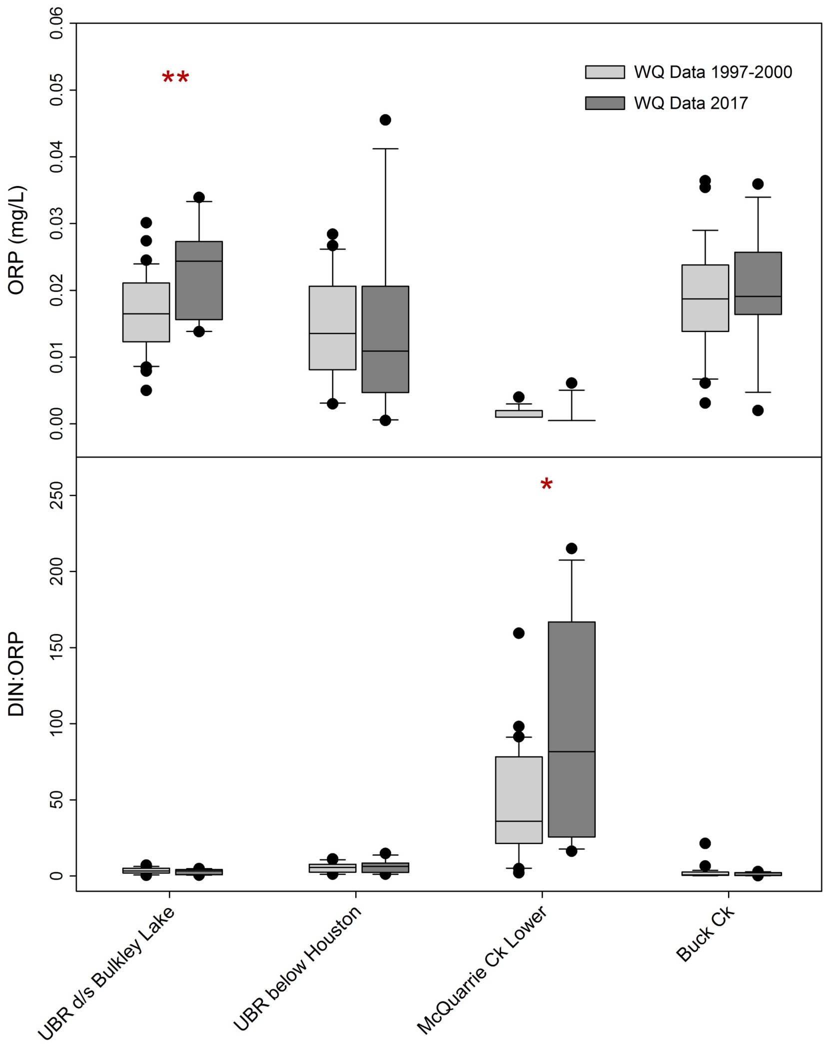


Figure 6. Box and whisker plots of orthophosphate (ORP; but presented as soluble reactive phosphorus (SRP) in earlier data) and N:P (as DIN:ORP) collected from 1997-2000 (Remington and Donas, 2000) versus data collected in 2017 at similar locations. Significant differences between means (Welch's t-test) are indicated with * (for p <0.1) and ** (for p<0.01).



4.0 Discussion

4.1 Water quality of the Upper Bulkley River watershed in 2017

Major water quality concerns – temperature and dissolved oxygen

Despite extensive development and land use change, water quality conditions at sites monitored in 2017 within the UBR watershed are considered relatively good. With respect to fish, the most obvious and pressing water quality issues relate to temperature and dissolved oxygen, which pass critical thresholds during important periods of migration, spawning, and egg incubation. High temperatures and low dissolved oxygen can also affect other water quality parameters, such as encourage reduction of oxidized compounds which may increase the release of toxic compounds or nutrients, etc., with potentially cascading local effects. However, these types of interactions and effects were not monitored in this study and have yet to be empirically observed in the UBR.

It is important to note that exceedance values of temperature and dissolved oxygen warrant further study, as point measurements likely do not capture the highly dynamic nature of these variables. In particular, point measurements likely misrepresent maximum temperatures or minimum DO across various time steps, both critical parameters for the fish and other aquatic organisms. For a more detailed study and analysis of temperature values, exceedances, and implications for salmonids throughout the UBR watershed, please see Wescott (2019).

The role of discharge in water quality – mobilization of materials

Discharge variability and seasonality were important drivers in overall water quality conditions. Changes in constituent concentrations were largely associated with high versus low flow periods. A decrease in concentrations during low water followed by an increase during high water, such as observed for many metals (e.g., Al, Fe, Cu), suggests that low water periods are source-limited, experience higher uptake and immobilization, and/or a relatively higher percent of total discharge contribution from ground water with low solute concentrations. High water events increase runoff surface area and interstitial flows throughout the catchment and therefore increase river connectivity with proximal sources of material. This results in the mobilization of constituents (especially those associated with particulates or soils) and increases concentrations in surface water. Previous observations of metals and sediment mobilization in the UBR are noted by Nijman (1986) and Remington (1996) and are not unique for rivers that experience strong seasonal differences in flow or punctuated periods of snowmelt (i.e., "freshet" or rain-on-snow events). These periods of time contribute the majority of materials that tend to be associated with inorganic or organic particulates, however the fate of these materials and whether they are ultimately removed from the system or settle out downstream and contribute to the overall sediment or nutrient pool is unknown.

Overall, turbidity and TSS data collected in 2017 does not suggest excessive entrainment and transport of suspended materials and sediment, despite various observations suggesting land use and habitat conditions may support sedimentation issues in the UBR. However, the sampling design in this study (i.e., single monthly measures) may not be the most appropriate for adequately identifying sources and mobilization of sediment as these processes are heavily flow-dependent and often more appropriately evaluated by measuring the rate of change over time. Large storm events are more likely to mobilize sediment, however high flow events are underrepresented in the dataset. Alternative methods for investigating potential sedimentation issues should consider stratified sampling approaches to water quality sampling that are based on flow, such as measuring the rate of change and flow-weighted concentrations of turbidity and TSS across the hydrograph and/or above and below suspected sources of sediment. Additional sampling aimed at identifying seasonal patterns would help improve understanding of the sources and drivers of water quality conditions throughout the watershed.

Nutrient conditions – 2017 vs. previous studies

Nitrogen plays an important role in the structure and function of food webs and the process of eutrophication. Both forms of DIN, NO_3^-+NO_2^- and TAN, are available for uptake by algae and plants or readily transformed by microbes and recycling into the available nutrient pool. An interesting observation from 2017 was that concentrations of TAN at UBR North Road appeared elevated from January through April relative to other sites/times of the year. Although TAN disproportionally increased during this time at UBR North Road in comparison to other sites, NO_3^-+NO_2^- also increased with TAN ($r^2 = 0.82$). As total DIN increased during this time, the relative proportion of TN comprised of DIN increased as well, without an overall increase in TN concentration. This suggests either this location is experiencing increased contributions of DIN or increased mineralization and nitrification of organic N are occurring at this location during this time. Lower productivity during winter and early spring months is conducive to reduced algal and plant uptake, and therefore potentially excess production of DIN. However additional investigation is warranted to evaluate the cause of these compositional shifts in the N-pool.

Of the limited number of parameters available for comparative analysis, the majority of data suggested that conditions at sites monitored in 2017 are relatively similar to those observed from 1997-2000. However, there were several differences. The mean value reported for ORP from data collected in 2017 was not significantly different than the mean ORP at the same sites in 1997-2000, with the exception of UBR d/s Bulkley Lake. The distinction of higher ORP at this site is largely driven by higher concentrations during late summer/early fall, which were significantly higher than those measured in 1997-2000. The most likely source of ORP to this site is Bulkley Lake. High ORP concentrations observed at this site correspond to minimum measures of dissolved oxygen. Stratification of Bulkley Lake in late summer and the establishment of an anoxic hypolimnion can result in sediment-release of previously sequestered ORP that is then exported downstream. To understand if and how the lake may be impacting downstream conditions, further information is needed on current limnological conditions and sediment P-loading capacity. Further information is also needed to determine the longitudinal extent of these impacts.

A major gap in this analysis is the lack of data on TP. TP represents the actual amount of P potentially available for production and should be included in future analysis as including only the dissolved-P fraction (TDP) potentially underestimates nutrient availability. It is also likely that periods of high flow increase TP loading in the UBR and may ultimately increase downstream contributions of P to aquatic ecosystems. Overall, nutrient conditions are within the range considered healthy for aquatic organisms such as fish given no additional interaction and complicating factors such as high temperature or anoxia. Interactions of nutrients with other organisms such as periphyton may potentially alter predictions for ecosystem health in respect to fish, however biological metrics were not sampled and are therefore outside the scope of this report.

Only a small number of parameters were available to compare 2017 data with historical data. However, most of these parameters showed no significant change in mean annual concentration over time. Observations of nutrient stoichiometry based on the dissolved, inorganic fraction of N and P (DIN:ORP) indicate that, depending on the site, waters in the UBR watershed are either N- or P-limited and nutrient conditions vary widely, from ultraoligotrophic to eutrophic at select sites during certain times of the year (e.g., late summer/early autumn). Previous reports discuss how nutrients, in particular ORP, in the UBR are relatively high compared to other Skeena River tributaries. At present, there are no comprehensive water quality datasets throughout the Skeena River watershed to accommodate similar broad-scale analysis, however it is worth pointing out that previous interpretations have not taken into consideration differences in total discharge and catchment area. Higher mean concentrations in certain parameters on the UBR may potentially be associated with lower average flows. Without considering flow differences between systems (i.e., "flow-weighting" results) it is difficult to know if concentrations are higher because there are relatively more nutrients contributed from the surrounding watershed, or if nutrients are higher because there is less water within the system and therefore less dilution. In addition, in conjunction with data on periphyton standing crop and benthic macroinvertebrates, previous reports suggest eutrophication was occurring in the reach around the Houston sewage treatment plant and consequently affecting fish populations (Remington, 1996; Remington and Donas, 2000). The 2017 water quality monitoring did not include measures of primary productivity (e.g., chlorophyll *a*) or other parameters that could provide additional biological assessment of nutrient status/eutrophication. Based on water chemistry alone, there are some periods of the year where eutrophic conditions were present, but they were temporally-limited. Additional information is needed to assess whether these effects are widespread, and if they are having negative consequences for the food web, fish survival, and fish reproductive success in these reaches.

Total Metals

Total metals were below British Columbia WQGs for almost every site and sampling occasion, and many total metals were below the LOD for the majority of samples or all samples. Water quality data reviewed by Nijman (1986) noted multiple exceedances of Cu and Zn on the mainstem UBR below Bulkley Lake, and suggested that Cu/Zn mineralization was perhaps common in the watershed. Overall, concentrations of Cu and Zn were highest at Buck Ck, which might be expected given the underlying geology and land use activity within the Buck Creek catchment. However, no exceedances for these metals were identified at UBR d/s Bulkley Lake or Buck Ck sites in 2017, despite the fact that current WQG criteria also represents a lower value than the value applied in the 1986 report.

Total metals are often affiliated with particles, such as organic matter or sediment. Metals can be contributed to surface and ground water through a variety of activities including those that increase erosion and sediment transport, discharge from industrial facilities, contributions of organic matter such as silage, feedlots, or sewage sludge, or acid mine discharge. Monitoring metal concentrations in the UBR, both total and dissolved, especially in the proximity of anthropogenic activities, is important for ensuring maintenance of baseline concentrations. Periods of high flow have potential to increase metal concentrations in surface waters of the UBR, therefore it is important to establish and maintain current baseline conditions in order to accommodate potential long term increases as a result of extended high flow periods.

There has been substantial concern over past decades surrounding downstream effects of the Equity Silver mine and other industrial development. The process of mining can accelerate the erosion, weathering, and mobilization of toxic metals (Bove et al., 2000) with adverse effects that can extend far downstream (Kimball et al., 1995; Church et al., 1997). Metals can remain in bioavailable forms in water and sediments well downstream of mixing zones with potential for bioaccumulation and toxic biological effects on fish and invertebrates (Besser et al., 2001). Discharge from this area drains partly to Buck Ck, the largest tributary to the UBR. Annual monitoring is conducted downstream of the mine and that data is not included in this report. Data collected at Buck Ck in 2017 represents concentrations of total metals and TSS contributed to the UBR. For the majority of constituents, mean concentrations at Buck Ck were not statistically higher than concentrations at other locations, however the range of variability and the maximum values measured at Buck Ck were often higher than other sites with the exception of UBR North Road, located downstream. This may be in part because Buck Creek is a large tributary (the largest to the UBR), but it suggests that Buck Creek is a source of increasing total metals in the UBR. However, this is difficult to determine without samples from the UBR above Buck Creek. In addition, without additional data on longitudinal trends in metal concentrations from Buck Creek, as well as additional information for discerning the complexities of metal biogeochemistry, it is impossible to estimate specific sources of metals within the Buck Creek catchment. One parameter that stood out in samples from Buck Ck is SO_4^{2-}. Concentrations of SO_4^{2-} were significantly higher year-round in Buck Ck in comparison to all other sites. This may represent naturally higher background concentrations due to geological characteristics of the Buck Creek catchment, or but is likely due to activity associated with treatment of the Equity Silver Mine tailings pond. Although SO_4^{2-} concentrations in Buck Creek were significantly higher than other sites monitored in this study, they were still well below maximum concentrations considered safe for aquatic life, drinking water supply, and livestock use (MOE, 2013). Despite high concentrations of SO_4^{2-} from Buck Ck to UBR, concentrations decreased downstream at UBR North Road. This decrease may be a result of dilution, immobilization or removal through microbial processing, or plant and algal uptake.

Spatial trends in water quality across the Upper Bulkley River watershed

Due to the small number of sites monitored in this study, it is not possible to conduct detailed longitudinal spatial analysis, however it is worth discussing some general differences in upstream-downstream water quality. Notable differences between UBR d/s Bulkley Lake and UBR North Road include a decrease in the mean concentration of dissolved P (TDP and ORP), and increases in TAN, hardness, turbidity/TSS, and the majority of total metals. The same upstream-downstream differences were also identified in previous reporting by Nijman (1986). Without more detailed understanding of major tributary inputs and their contributions to mainstem UBR water quality, it is difficult to ascertain the sources influencing upstream-downstream differences. One hypothesis about upstream-downstream decreases in P on UBR mainstem is that dissolved P is converted into particulate form and immobilized via uptake by aquatic organisms or adsorption to minerogenic particles. Therefore, the amount of P within the UBR may not actually be decreasing, but instead converted to a different (particulate) form. In unpolluted rivers with high concentrations of suspended mineral particles (e.g., the UBR during heavy rain events or freshet) basing the total loading of P on measurements of the dissolved P-fraction alone has been shown to underestimate the true loading potential of bioavailable P by more than a factor of two (Muller et al., 2006). The increase in downstream turbidity, TSS, and total metals, particularly during high flow events, also indicates a downstream increase in the contribution of particulates (either inorganic or organic) and further indicates that the total fraction of P may not be well represented in the existing dataset. Based on this, the observation that decreasing upstream-downstream average P concentrations may not be accurate. It also suggests that ORP is being immobilized and either directly contributing to in-stream primary production or adsorbed to mineral particles for potential future availability.

Previous studies on the UBR identified similar concentrations of ORP to those measured in 2017 at various points across the watershed, including higher concentrations in UBR tributaries not monitored in this study. In past studies, tributaries with especially high P concentrations relative to mainstem concentrations were associated with catchments containing either high areas of agricultural land or underlain with volcanic rock comprised of high P-concentration (e.g., Goosly Formation). These reports also associate low N:P ratios with excessive algal growth and high risk of eutrophication (Remington and Donas, 2000; Remington, 1996). In 2017, the observation of increasing upstream-downstream concentrations of solids (e.g., TSS, turbidity) and constituents typically associated with solids, implies the presence of sediment sources along the longitudinal gradient of the UBR. An upstream-downstream increase in TSS and turbidity is a common observation in catchments, especially those with extensive land-use that may exacerbate erosion processes. However, the exact sources of sediment or the downstream length of impact from specific areas of contribution cannot be determined using the data in this study and warrants further investigation.

On McQuarrie Creek, major upstream-downstream changes in water quality between McQuarrie Ck Upper and McQuarrie Ck Lower included increases in SEC, hardness, Ca^{2+}, Na^{+}, F^{-}, and a few metals (e.g., Mg, Ba) but no major changes in solids, nutrients, or the majority of total metals. Most of the aforementioned increases are relatively small, and likely reflect compounding effects of runoff from a increasingly larger catchment area. However, some differences, like differences observed in F^{-} concentrations, suggest the role of groundwater and groundwater-surface interactions in the McQuarrie Creek catchment is different than other locations monitored in the Upper Bulkley River watershed. Groundwater input may become increasingly important at the downstream location; the mean values for water quality parameters at McQuarrie Ck Lower, as well as temperature, tend to shift in the direction of values observed at Unnamed Spring. This suggests that groundwater inputs to McQuarrie Creek Lower may be important for providing colder water of good water quality and low P concentrations to the mainstem UBR. Monitoring groundwater withdrawals and potential activity that could affect groundwater quality may be particularly important in catchments like McQuarrie Creek.

4.2 Past and future water quality monitoring in the Upper Bulkley River watershed

The UBR watershed is arguably one of the most-studied catchments in the Skeena River with respect to water quality. However, despite having almost 50 years of information (the first sampling record appears to be 1972), overall study design and sample collection methodology is relatively inconsistent. Monitoring efforts have lacked long-term and spatial continuality or comprehensive analysis that includes multiple components of hydrology, chemistry, and biology. For example, sampling was conducted above and below the water treatment plant in Houston in various years from 1974-2012 (EMS Sites 400297, 400295). Most years, samples were only collected in July-September. Two years including sampling throughout the year and show that concentrations varied widely depending on the month of sample, and were often much higher during months other than July-September. However, this type of seasonal representation was discontinued in 2000 and no samples have been collected at those locations since 2012. Similarly, other biomonitoring programs such as benthic macroinvertebrate or periphyton monitoring have been applied with limited long-term replication, despite previous recommendations for implementation of a systematic monitoring program. These programs have also included some parameters of water quality monitoring, but rarely incorporate a full suite of indicators (e.g., physical, chemical, biological) at consistent locations. In addition, almost all lack any site-specific measures of hydrology.

Routine water quality monitoring, such as the sampling executed in the 2017 program, is important for developing baseline conditions and for understanding potential change over time. However, it is critical that programs are consistent in their approach, appropriately designed, and sustainable for the necessary period of time required to address objectives. Objectives or questions regarding watershed impacts, limitations to productivity, and change over time should strive to include components of site-specific hydrology, water quality, biological measures, and where appropriate *in-situ* or other approaches to high-resolution sampling (e.g., temperature, dissolved oxygen, turbidity, etc.). It is also paramount that objectives are carefully selected and addressed with the appropriate study design, with consideration for approaches that will allow for comparison between historical data as well as other ongoing projects.

4.3 Recommendations

The 2017 UBR water quality monitoring program provides an important and necessary update to understanding current water quality conditions in the UBR watershed, especially in regards to updating baseline conditions at the five sites included in this program, as well as providing initial insight of current temporal variability. However, various data gaps still exist. The following is a list of recommendations for future work related to understanding potential limiting conditions for salmonids in the UBR. The following recommendations are by no means comprehensive, rather they are meant to help guide or stimulate consideration on directions for future work.

- A high-resolution temperature monitoring program is currently underway to address limitations of temperature to salmonids in the UBR. Additional monitoring could be conducted to discern potential sources and impacts of other habitat-limiting water quality constituents, particularly dissolved oxygen and particulates (sediment, organic matter). Like temperature, dissolved oxygen requires high resolution temporal monitoring to track diel changes, and spot measurements are often inadequate for characterizing limiting conditions as they often underestimate minimum daily values or long-term mean minimums. Transport of particulates is likely to be discharge-dependent and derived from non-point source contributions and therefore requires a carefully researched, appropriate monitoring design. For example, if sedimentation is suspected to be a major issue, study design should include sampling in areas of high risk/concern and appropriate timing of sample collection (e.g., high resolution sampling across the hydrograph during rain/high flow events).
- To establish more a more defensible and robust understanding of baseline conditions and further constrain temporal variability, long-term water quality monitoring should be established at a subset of sites included in this study. It could also be beneficial to add other sites as warranted by specific study questions. Longer-term monitoring should include UBR d/s Bulkley Lake, UBR North Road, Buck Creek, and McQuarrie Creek Lower. Future sampling should also include higher resolution monitoring of certain parameters (as described above) as well as concentrations of total phosphorus (TP) and dissolved organic carbon (DOC).
- If eutrophication continues to be of concern, additional sampling should be conducted on high-risk tributaries, include control sites, and incorporate longitudinal spatial resolution where appropriate. Exploring additional techniques for resolving nutrient sources, such as stable isotope analysis, may also be useful.
- Future water quality monitoring considerations may want to also include site-specific information on hydrology and biology (e.g., benthic macroinvertebrates). However, these parameters are only useful if collected systematically and data appropriately managed

and distributed so that it is readily accessible, shareable, and methodology is transparent. Establishing long-term water quality monitoring stations with routine, seasonally-representative collection of a variety of indicators within a simple and shareable database would provide an excellent foundation for tracking further change over time.

- More information is needed to understand catchment hydrology in the UBR watershed. This includes better understanding of flow variability across the watershed, environmental needs, and empirical data on how flows are being affected by water use.
- Groundwater interactions may be extremely important for influencing surface water quality in the UBR, especially during periods of very low surface flow or during times where local land use activities may affect groundwater quantity and quality. Information on groundwater is extremely important to understanding catchment hydrology in the UBR, including potential groundwater-surface interactions, aquifer mapping and characteristics/status, and how groundwater might be affected by water use.
- Bulkley Lake appears to be a source of limiting conditions in the UBR and is also important rearing habitat for salmonids. Lakes tend to respond as sentinels of land use or climate change and updated limnological information along with possible development of a long-term monitoring program for Bulkley Lake could be useful for as an indicator system for tracking climate conditions in the UBR over time.
- There is new evidence that populations of Chinook co-existing within the same watershed but with different migration timing are genetically-distinct (e.g., Davis et al., 2017; Prince et al., 2017). An outstanding question from this research is whether the early spring run Chinook populations of the Upper Bulkley may be genetically distinct from other populations of Skeena River Chinook. This is critically important because it implies that once these populations have been extirpated they will not return. This has important implications for management, including understanding limitations to productivity, habitat protection, and water use under the Water Sustainability Act. Water quality in the UBR can potentially have the greatest effect on these populations as they hold in the UBR system for long periods of time and must endure the most challenging environmental period (late summer). Further investigation into whether the early spring-run Chinook on the UBR are genetically distinct would help guide future management initiatives and water quality monitoring efforts in this watershed and within the greater Skeena River.

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APPENDIX A

Table A1. Summary statistics for physicochemical and anion data collected at UBR water quality sites, January – November, 2017.

Site		pH	Spc. Conductivity (µS/cm)	Total Hardness (mg/L $CaCO_3$)	Turbidity (NTU)	TSS (mg/L)	Cl^- (mg/L)	F^- (mg/L)	SO_4^{2-} (mg/L)
Buck Ck	Mean ±SD	7.98 ±0.21	176.4 ±46.4	74.1 ±9.4	7.0 ±7.0	9.1 ±10.7	0.93 ±0.64	0.08 ±0.01	30 ±6.7
	Min – Max	7.71 – 8.28	125.3 – 290.8	60.3 – 93.1	0.83 – 25.5	1.5 – 35.6	0.25 – 2.58	0.06 – 0.09	17.6 – 37.4
	95% CI	7.8 – 8.1	147.6 – 205.2	68.6 – 79.7	2.8 – 11.1	2.7 – 15.4	0.55 – 1.30	0.07 – 0.08	25.9 – 34.1
	n	10	10	11	11	11	11	11	10
McQuarrie Ck Upper	Mean ±SD	8.05 ±0.20	100.8 ±26.5	46.8 ±5.1	1.10 ±0.87	2.5 ±1.7	0.25 ±0.00	0.20 ±0.005	2.8 ±0.4
	Min – Max	7.73 – 8.39	70.5 – 174.4	39 – 54.1	0.18 – 2.61	1.5 – 5.7	NA	0.01 – 0.025	2.0 – 3.2
	95% CI	7.93 – 8.16	8.1 – 116.5	43.8 – 49.8	0.59 – 1.61	1.5 – 3.5	NA	0.017 – 0.023	2.6 – 3.1
	n	11	11	11	11	11	11	11	10
McQuarrie Ck Lower	Mean ±SD	8.2 ±0.14	134.4 ±37.0	62.2 ±16.9	1.3 ±1.5	3.9 ±3.6	0.42 ±0.25	0.030 ±0.006	3.4 ±0.9
	Min – Max	7.94 – 8.39	73.1 – 191.0	40.55 – 96.4	0.18 – 4.79	1.5 – 10.9	0.25 – 0.93	0.024 – 0.04	1.5 – 4.7
	95% CI	8.13 – 8.30	112.6 – 156.3	52.2 – 72.2	0.44 – 2.22	1.8 – 6.0	0.27 – 0.56	0.027 – 0.034	2.8 – 4.0
	n	11	11	11	11	11	11	11	9
UBR d/s Bulkley Lake	Mean ±SD	7.96 ±0.29	128.2 ±36.9	53.4 ±9.8	4.9 ±4.4	6.3 ±7.8	0.51 ±0.18	0.078 ±0.012	10.8 ±4.9
	Min – Max	7.38 – 8.38	72 – 214.8	38.1 – 70.9	1.26 – 16.3	1.5 – 26.2	0.25 – 0.67	0.063 – 0.098	2.5 – 18.7
	95% CI	7.53 – 8.30	84.8 – 185.6	41.0 – 69.5	1.3 – 12.2	1.5 – 20.4	0.25 – 0.67	0.064 – 0.097	4.4 – 17.5
	n	11	11	11	10	10	10	10	10
UBR North Road	Mean ±SD	7.82 ±0.22	179.3 ±48.4	76.3 ±17.2	10.2 ±15.0	17.6 ±31.9	3.31 ±1.99	0.070 ±0.010	12.6 ±3.4
	Min – Max	7.50 – 8.31	96.9 – 265.0	50.4 – 100.0	0.68 – 48.8	1.5 – 103	0.81 – 6.66	0.054 – 0.087	5.6 – 17.5
	95% CI	7.57 – 8.16	100.8 – 242.4	51.5 – 97.2	1.0 – 37.8	1.5 – 77.7	0.90 – 6.55	0.056 – 0.084	7.42 – 17.1
	n	11	11	11	11	11	11	11	10
Unnamed Spring	Mean ±SD	7.82 ±0.14	280.1 ±110.5	125.2 ±17.6	1.16 ±1.61			0.069 ±0.006	1.2 ±0.2
	Min – Max	7.58 – 8.04	165.5 – 600	79.1 – 142	0.14 – 4.62		<0.25*	0.055 – 0.076	0.77 – 1.55
	95% CI	7.63 – 8.02	201.7 – 441.8	98.4 – 150.2	0.15 – 3.91			0.060 – 0.075	0.9 – 1.5
	n	11	11	10	10	NA	10	10	10

Table A2. Summary statistics for nutrient parameters collected at UBR water quality sites, January– November, 2017.

Site		TN (mg/L)	TON (mg/L)	$NO_3^- + NO_2^-$ (mg/L)	TAN (mg/L)	TDP (mg/L)	ORP (mg/L)
Buck Ck	Mean ±SD	0.271 ±0.073	0.268 ±0.079	0.021 ±0.026		0.0231 ±0.0087	0.0201 ±0.0085
	Min – Max	0.190 – 0.412	0.175 – 0.381	0.001 – 0.065	<0.0025*	0.0048 – 0.0370	0.0020 – 0.0359
	95% CI	0.228 – 0.314	0.221 – 0.314	0.006 – 0.036		0.0177 – 0.0285	0.0151 – 0.0251
	n	11	11	11	11	10	10
McQuarrie Ck Upper	Mean ±SD	0.272 ±0.054	0.221 ±0.055	0.067 ±0.079	0.0038 ±0.0026	0.0035 ±0.0013	0.0008 ±0.0005
	Min – Max	0.215 – 0.404	0.118 – 0.321	0.003 – 0.263	0.0025*– 0.0026	0.0010 – 0.0048	0.0005*– 0.0018
	95% CI	0.240 – 0.304	0.188 – 0.254	0.021 – 0.114	0.0023 – 0.0053	0.0026 – 0.0043	0.0005*– 0.0011
	n	11	11	11	11	10	11
McQuarrie Ck Lower	Mean ±SD	0.253 ±0.062	0.203 ±0.068	0.057 ±0.041	0.005 ±0.009	0.0028 ±0.0022	0.0010 ±0.0017
	Min – Max	0.170 – 0.372	0.101 – 0.348	0.006 – 0.126	0.0025*– 0.0309	0.0010 – 0.0080	0.0005*– 0.0061
	95% CI	0.216 – 0.290	0.163 – 0.243	0.033 – 0.082	0.0000 – 0.0051	0.0014 – 0.0042	0.0001 – 0.0020
	n	11	11	11	11	10	11
UBR d/s Bulkley Lake	Mean ±SD	0.379 ± 0.070	0.341 ±0.066	0.051 ±0.041	0.0084 ±0.0047	0.0269 ±0.0086	0.0228 ±0.0066
	Min – Max	0.239 – 0.449	0.240 – 0.456	0.006 – 0.107	0.0025*– 0.0190	0.0142 – 0.0395	0.0138 – 0.0339
	95% CI	0.251 – 0.447	0.248 – 0.443	0.006 – 0.106	0.0038 – 0.0166	0.0164 – 0.0395	0.0140 – 0.0312
	n	11	11	11	11	10	10
UBR North Road	Mean ±SD	0.360 ±0.147	0.316 ±0.147	0.032 ±0.028	0.0333 ±0.0375	0.0189 ±0.0160	0.0139 ±0.0131
	Min – Max	0.193 – 0.678	0.179 – 0.631	0.003 – 0.073	0.0025 – 0.0943	0.0032 – 0.0566	0.0005*– 0.0455
	95% CI	0.198 – 0.593	0.001 – 0.035	0.003 – 0.073	0.0025 – 0.0938	0.0039 – 0.0431	0.0008 – 0.0348
	n	11	11	11	11	10	11
Unnamed Spring	Mean ±SD						
	Min – Max			<0.0025*			
	95% CI						
	n	NA	NA	10	NA	NA	NA

Table A3. Summary statistics for select total metals parameters collected at UBR water quality sites, January– November, 2017.

Site		Al (µg/L)	Cu (µg/L)	Fe (µg/L)	Mn (µg/L)	As (µg/L)	Ba (µg/L)	Mg (µg/L)	Zn (µg/L)
Buck Ck	Mean ±SD	399 ±472	2.34 ±1.46	605 ±481	27.2 ±20.3	0.56 ±0.18	15.8 ±8.3	7072 ±862	3.28 ±1.76
	Min – Max	55 – 1710	1.20 – 6.00	129 – 1890	11.0 – 81.0	0.50*– 1.10	10.0*– 35.0	5740 – 8790	2.50*– 7.90
	95% CI	120 – 677	1.47 – 3.20	321 – 890	15.2 – 39.2	0.66 – 0.45	10.9 – 20.7	7581 – 6563	2.25 – 4.32
	n	11	11	11	11	11	11	11	11
McQuarrie Ck Upper	Mean ±SD	69 ±59	0.73 ±0.41	121 ±73	12.5 ±10.2		20.6 ±5.4	2158 ±177	
	Min – Max	12 – 208	0.50*– 1.60	15 – 258	1.0*– 38.0	<0.50*	10.0*– 25.0	1950 – 2430	<2.50*
	95% CI	34 – 104	0.49 – 0.97	77 – 164	6.4 – 18.5		17.4 – 23.8	2053 – 2263	
	n	11	11	11	11	11	11	11	11
McQuarrie Ck Lower	Mean ±SD	68 ±78	0.87 ±0.44	93 ±93	5.6 ±5.9		33.9 ±8.9	3827 ±1024	
	Min – Max	5 – 271	0.50*– 1.55	15 – 316	1.0*– 19.0	<0.50*	23.5 – 52.0	2455 – 5500	<2.50*
	95% CI	21 – 114	0.61 – 1.13	38 – 148	2.1 – 9.1		28.6 – 39.1	3192 – 4461	
	n	11	11	11	11	11	11	11	11
UBR d/s Bulkley Lake	Mean ±SD	254 ±280	1.63 ±0.39	516 ±270	90.9 ±69.4	0.71 ±0.29	<10.0*	4983 ±864	<2.50*
	Min – Max	35 – 1020	1.10 – 2.40	245 – 1250	42.5 – 267.0	0.50 – 1.10		3660 – 6570	
	95% CI	50 – 709	2.30 – 1.15	258 – 934	43.3 – 223.0	0.50 – 1.10	11	3905 – 6420	11
	n	11	11	11	11	11		11	
UBR North Road	Mean ±SD	467 ±707	1.93 ±1.05	792 ±766	90.3 ±41.7	0.65 ±0.33	34.2 ±5.6	6705 ±1405	3.72 ±2.73
	Min – Max	20 – 2300	1.10 – 4.20	157 – 2680	45.0 – 167.0	0.50 – 1.40	25.0 – 44.0	4480 – 8550	2.50– 10.0
	95% CI	39 – 1760	1.10 – 3.85	199 – 2175	47.5 – 150.3	0.50 – 1.30	27.0 – 42.0	4660 – 8385	2.50 – 9.20
	n	11	11	11	11	11	11	11	11
Unnamed Spring	Mean ±SD	15 ±31	0.93 ±1.36	26 ±35	2.7 ±5.4	0.32 ±0.08	55.2 ±5.8	6202 ±734	
	Min – Max	5 – 104	0.50 – 4.80	15 – 126	1.0 – 18.0	0.26 – 0.53	43.0 – 63.0	4600 – 7440	<2.50*
	95% CI	5 – 59	0.50 – 2.87	15 – 76	1.0 – 10.4	0.26 – 0.44	47.1 – 62.6	5194 – 7202	
	n	10	10	10	10	10	10	10	11

Figure A1. Box and whisker plots for physicochemical parameters and solids (Table A1) collected at Upp Bulkley River watershed sites from January – November, 2017. Boxes represent the 25th and 75th percentiles and the middle band represents the 50th percentile (median).

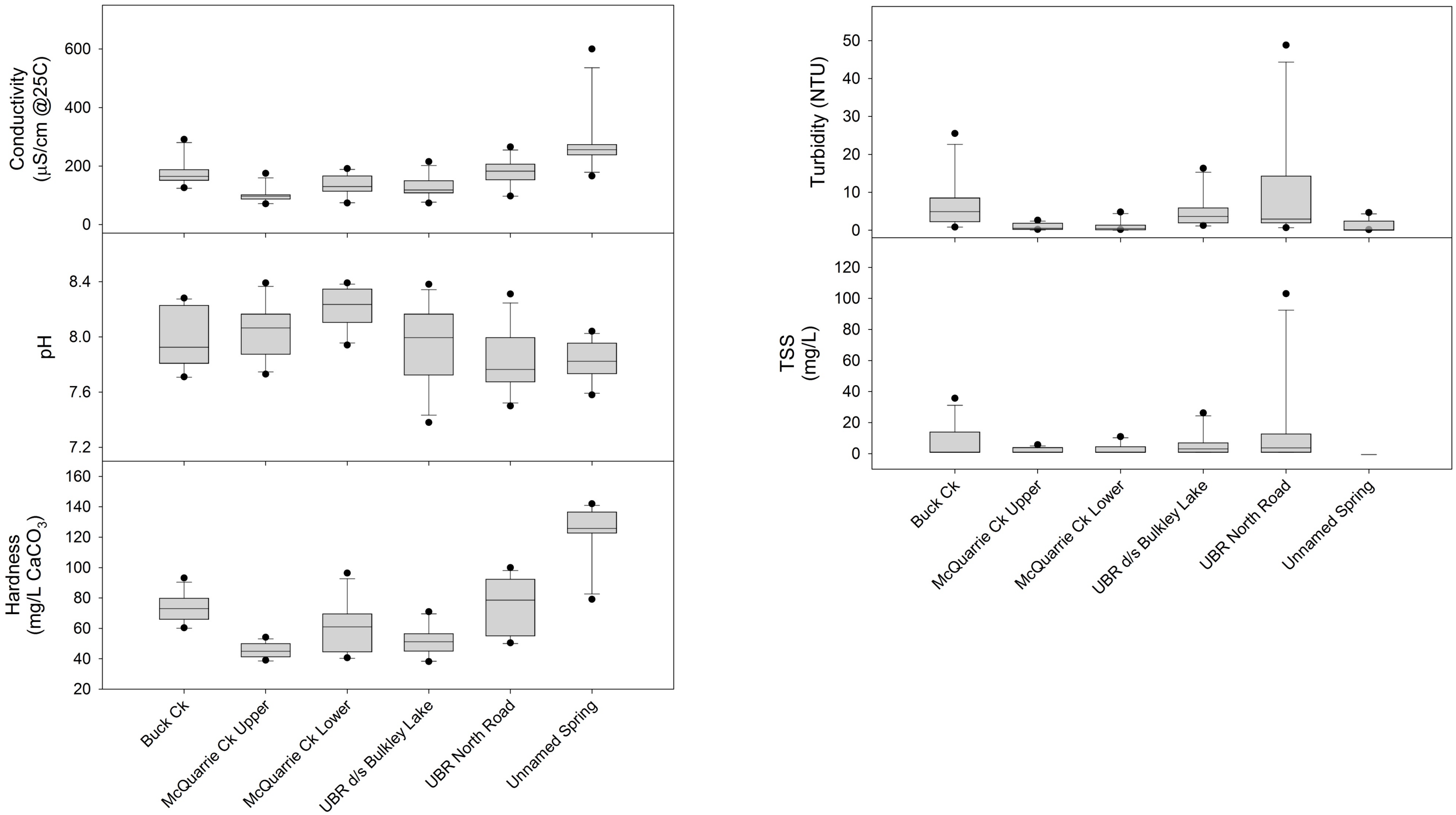


Figure A2. Box and whisker plots for anions (Table 2) collected at Upper Bulkley River watershed sites from January – November, 2017. Boxes represent the 25th and 75th percentiles and the middle band represents the 50th percentile (median).

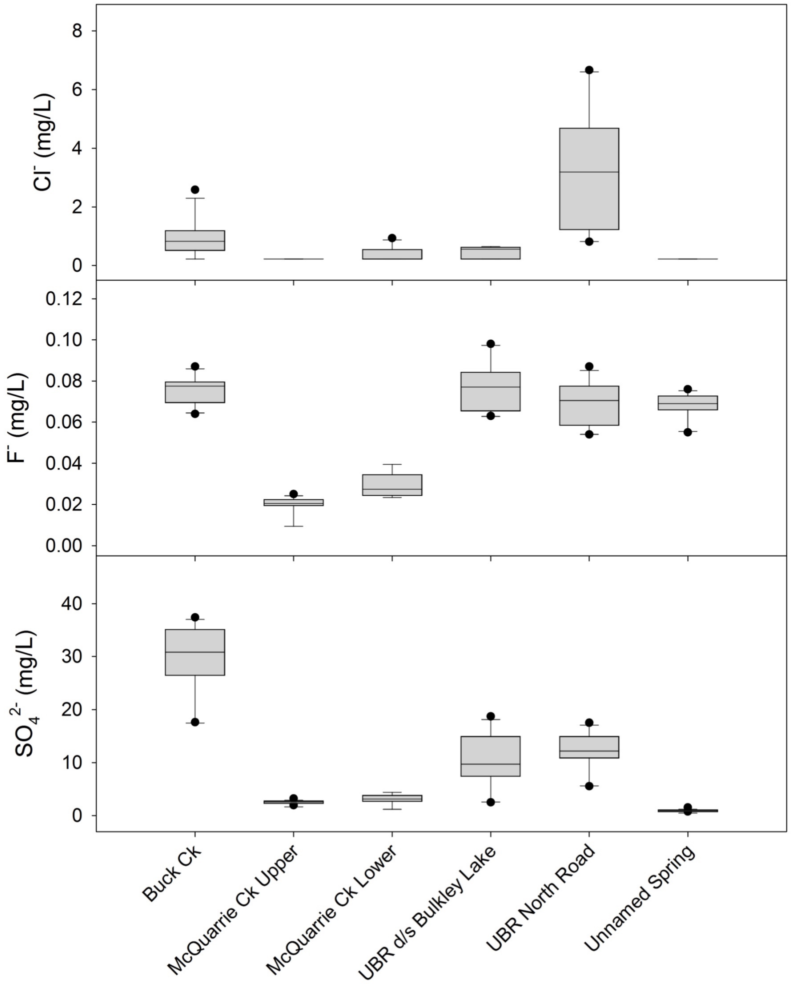


Figure A3. Box and whisker plots for nitrogen (Table 3) collected at Upper Bulkley River watershed sites from January – November, 2017. Boxes represent the 25th and 75th percentiles and the middle band represents the 50th percentile (median).

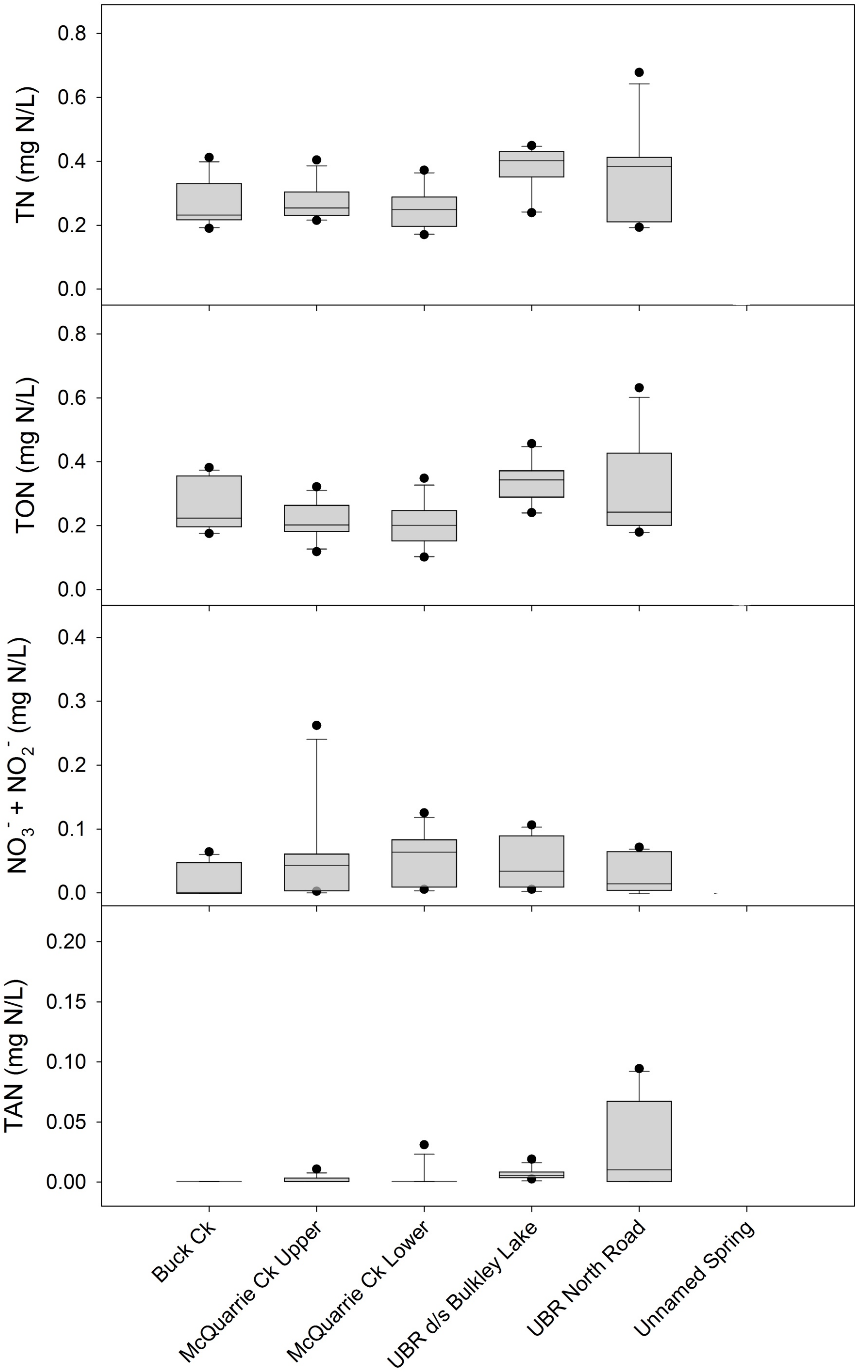


Figure A4. Box and whisker plots for phosphorus (Table 3) collected at Upper Bulkley River watershed sites from January – November, 2017. Boxes represent the 25th and 75th percentiles and the middle band represents the 50th percentile (median).

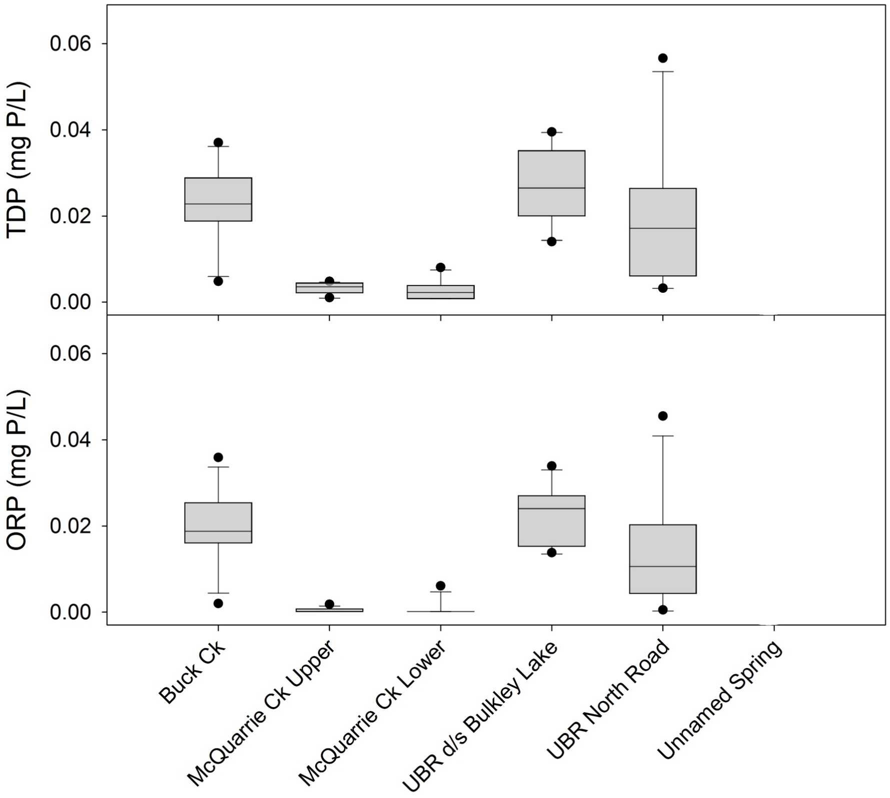


Figure A5. Box and whisker plots for select total metals (Table 4) collected at Upper Bulkley River watershed sites from January – November, 2017. Boxes represent the 25th and 75th percentiles and the middle band represents the 50th percentile (median).

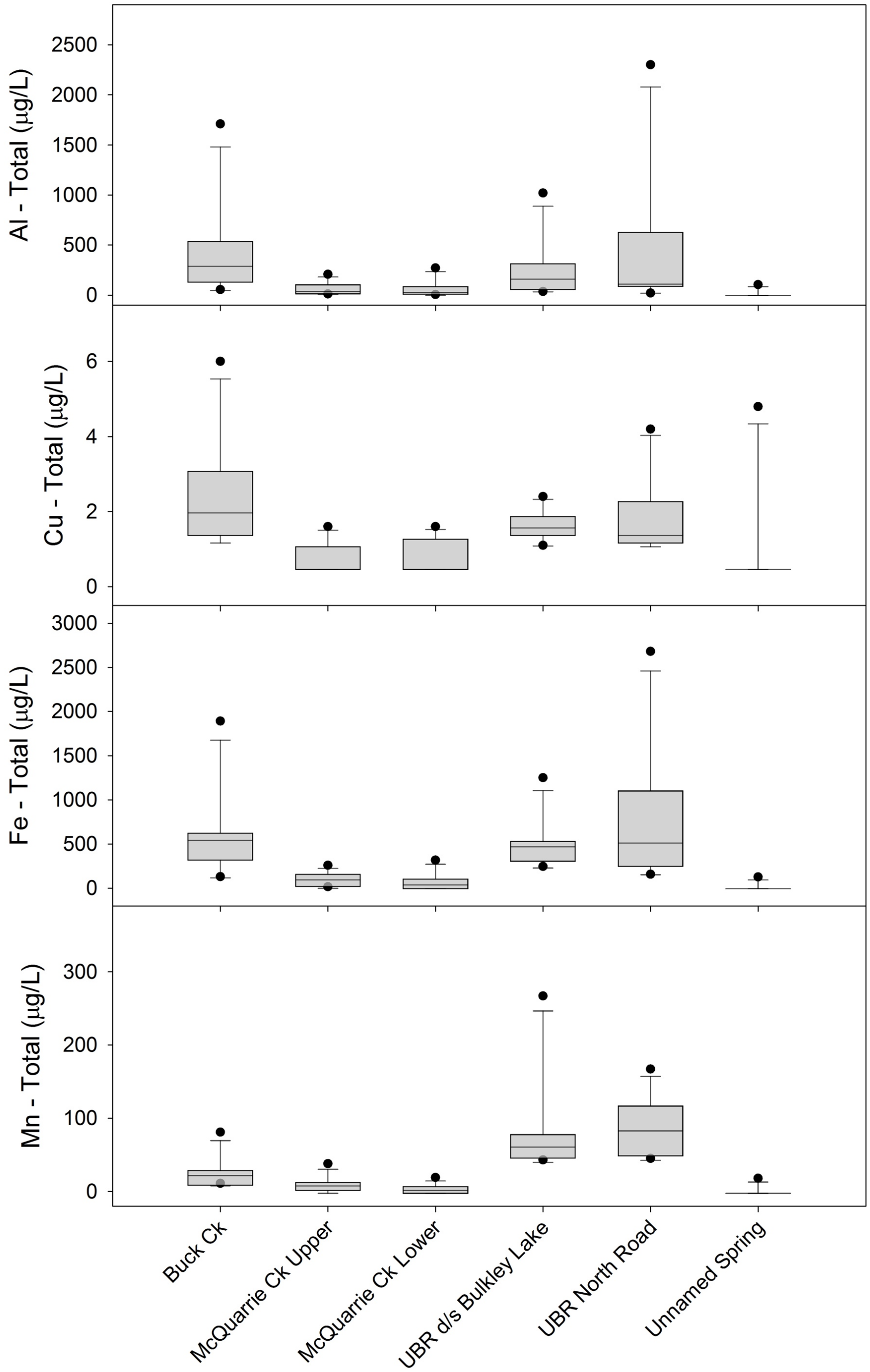


Figure A6. Box and whisker plots for select total metals (Table 4) collected at Upper Bulkley River watershed sites from January – November, 2017. Boxes represent the 25th and 75th percentiles and the middle band represents the 50th percentile (median).

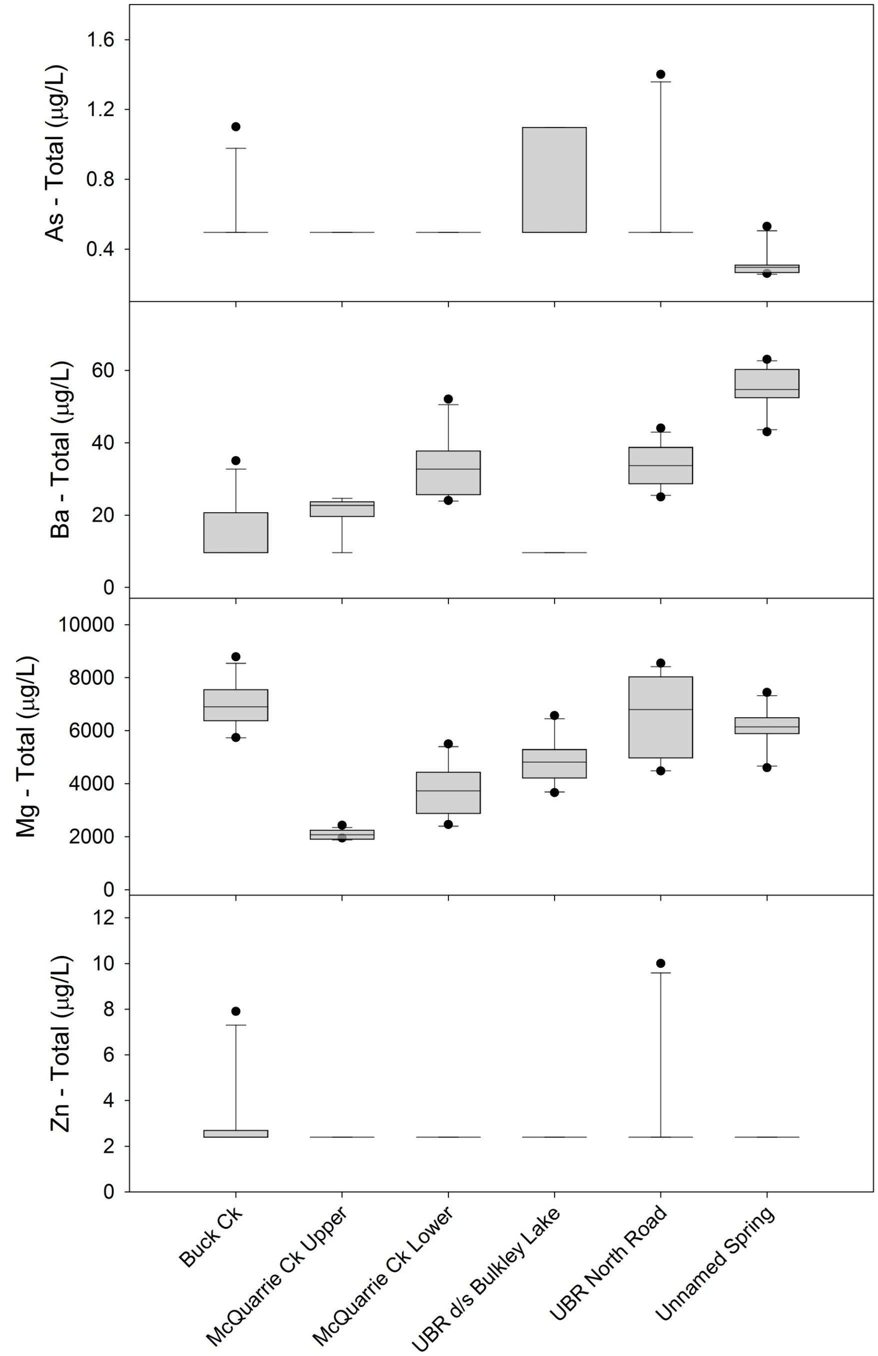


Figure A7. Time series for physicochemical parameters collected at Upper Bulkley River watershed sites from January – November, 2017. The top panel is mean daily discharge at WSC hydrometric stations: 1) Bulkley River near Houston and, 2) Buck Creek.

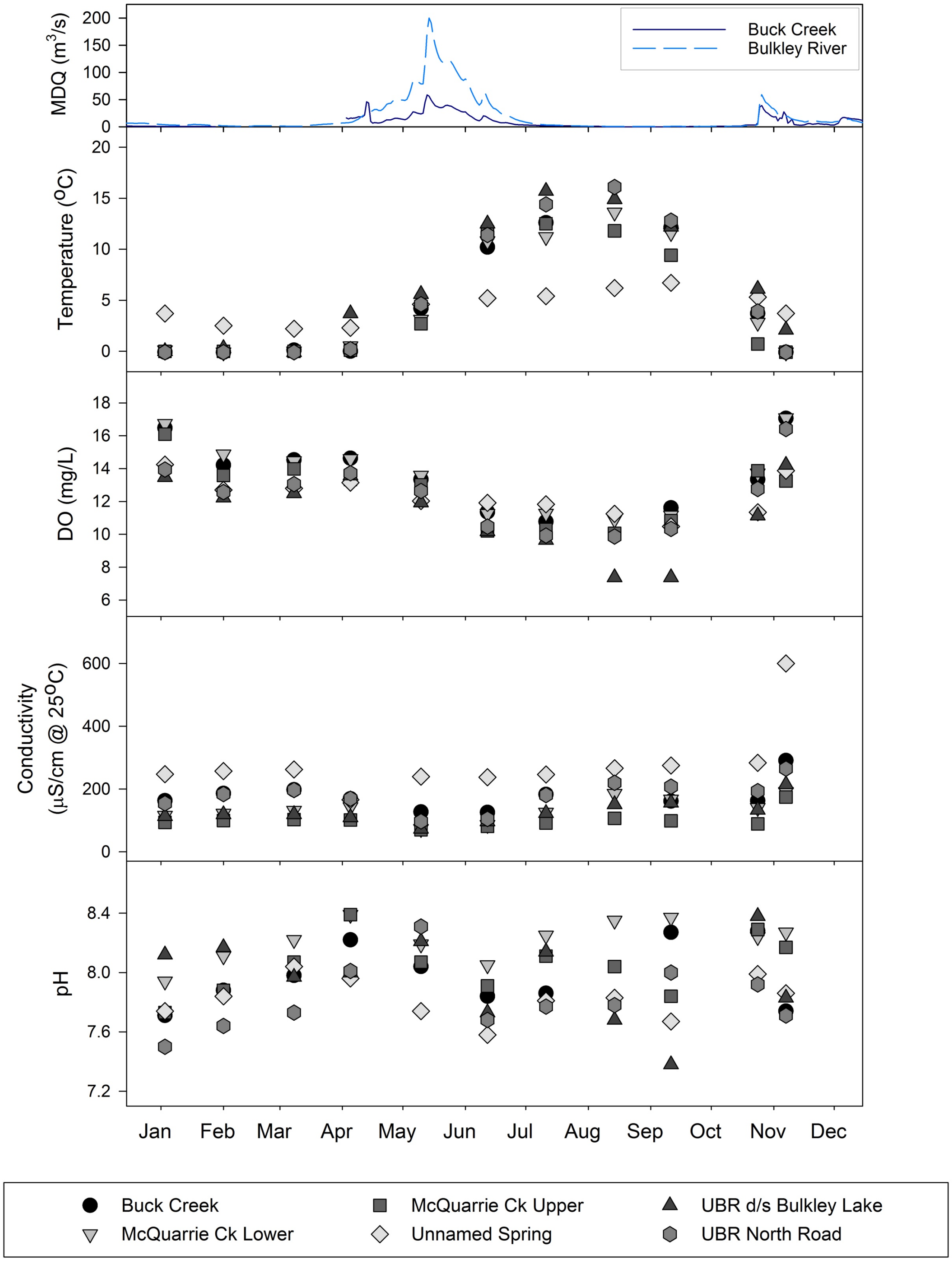


Figure A8. Time series for hardness and solids parameters collected at Upper Bulkley River watershed sites from January – November, 2017. The top panel is mean daily discharge at WSC hydrometric stations: 1) Bulkley River near Houston and, 2) Buck Creek.

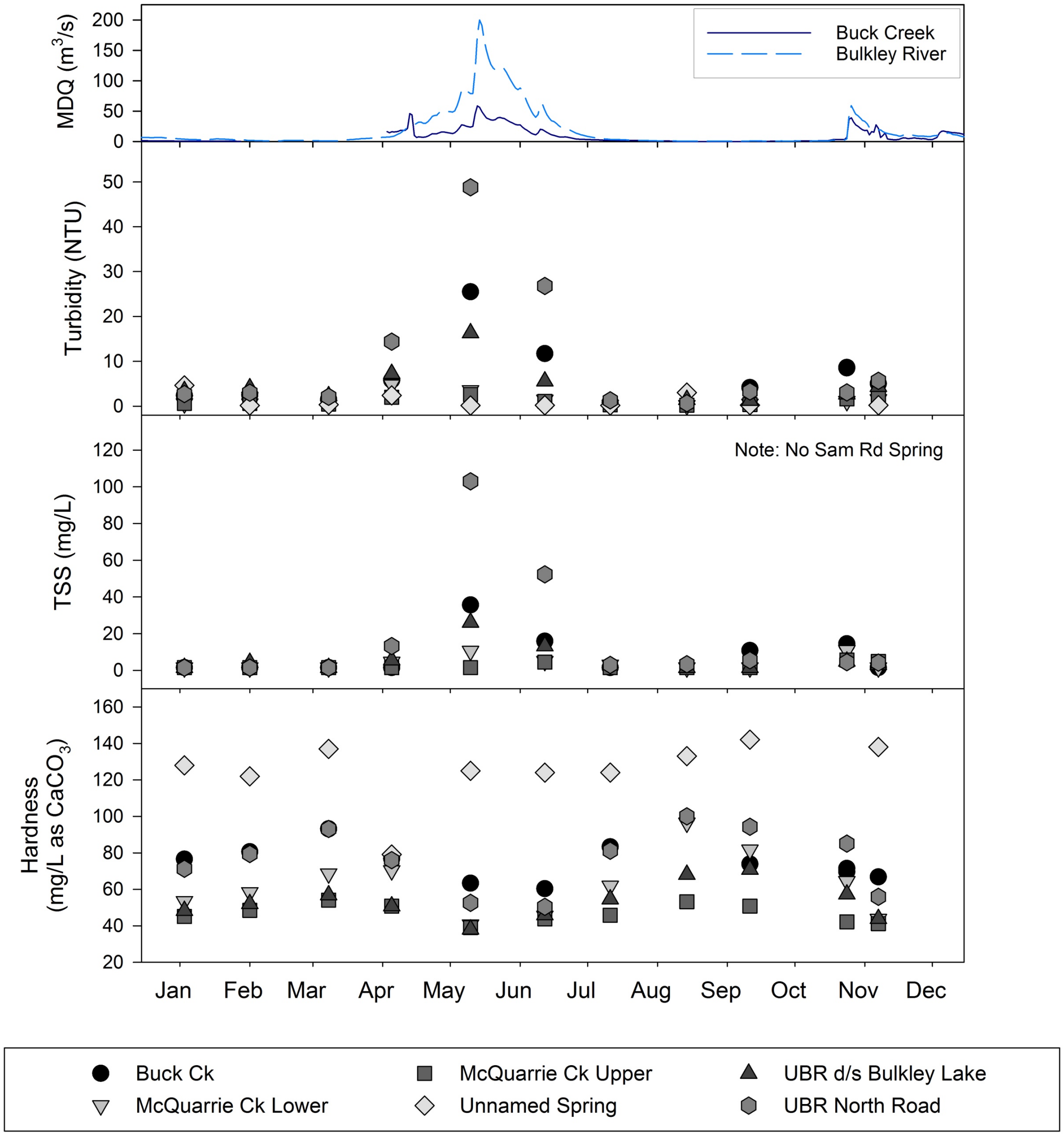


Figure A9. Time series for major anions collected at Upper Bulkley River watershed sites from January – November, 2017. The top panel is mean daily discharge at WSC hydrometric stations: 1) Bulkley River near Houston and, 2) Buck Creek.

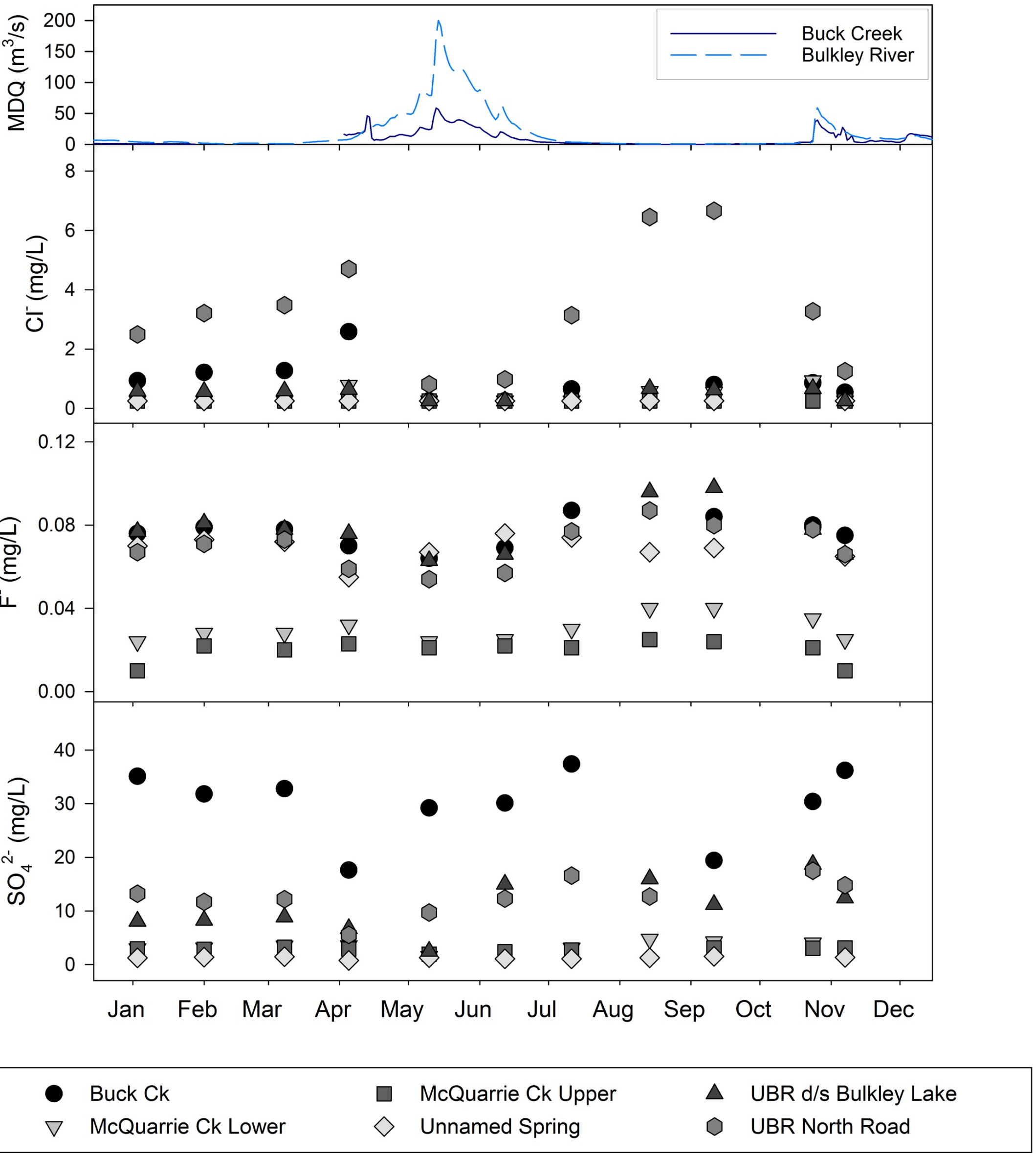


Figure A10. Time series for nitrogen parameters collected at Upper Bulkley River watershed sites from January – November, 2017. The top panel is mean daily discharge at WSC hydrometric stations: 1) Bulkley River near Houston and, 2) Buck Creek.

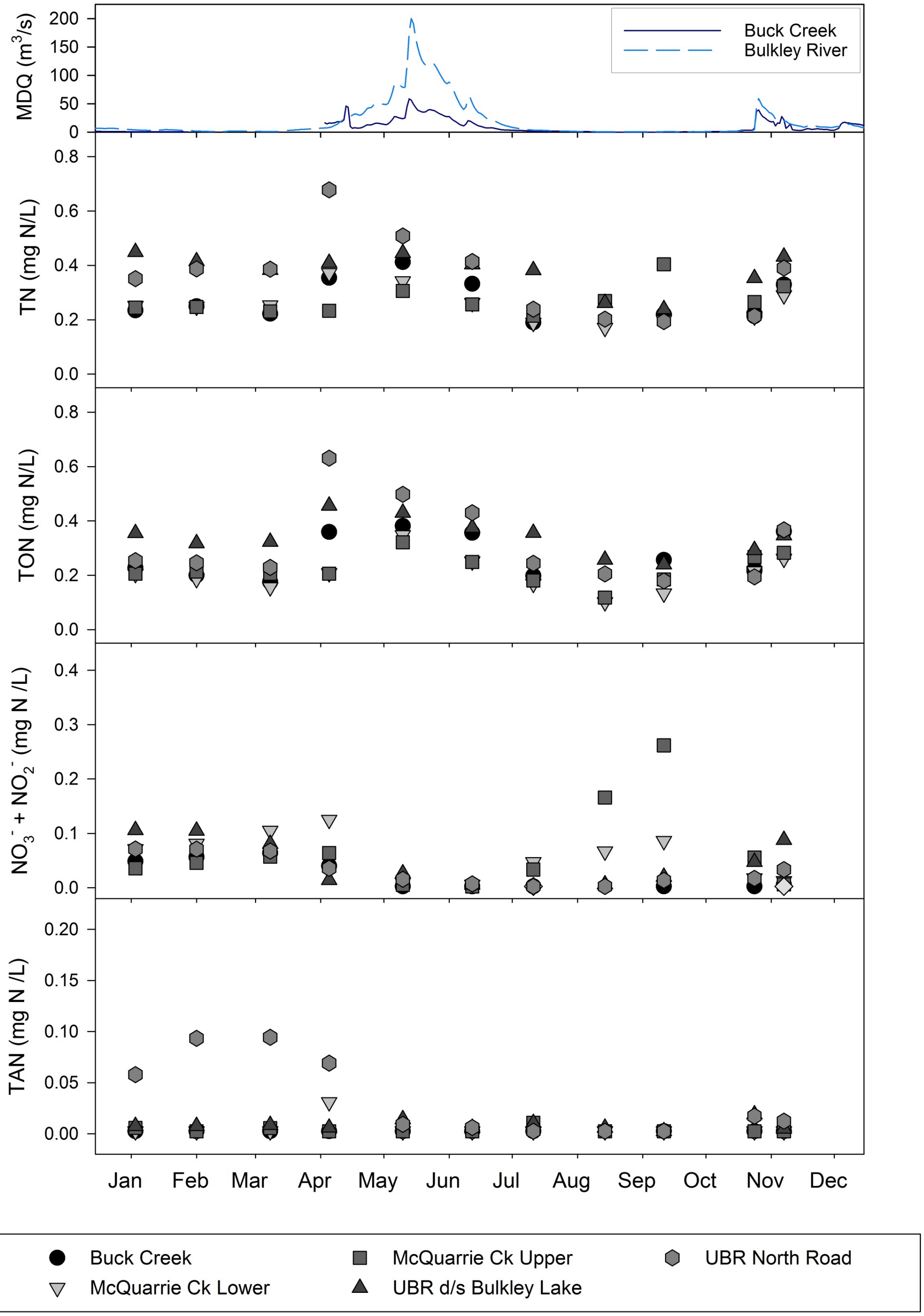


Figure A11. Time series for phosphorus parameters and nutrient ratios collected at Upper Bulkley River watershed sites from January – November, 2017. The top panel is mean daily discharge at WSC hydrometric stations: 1) Bulkley River near Houston and, 2) Buck Creek.

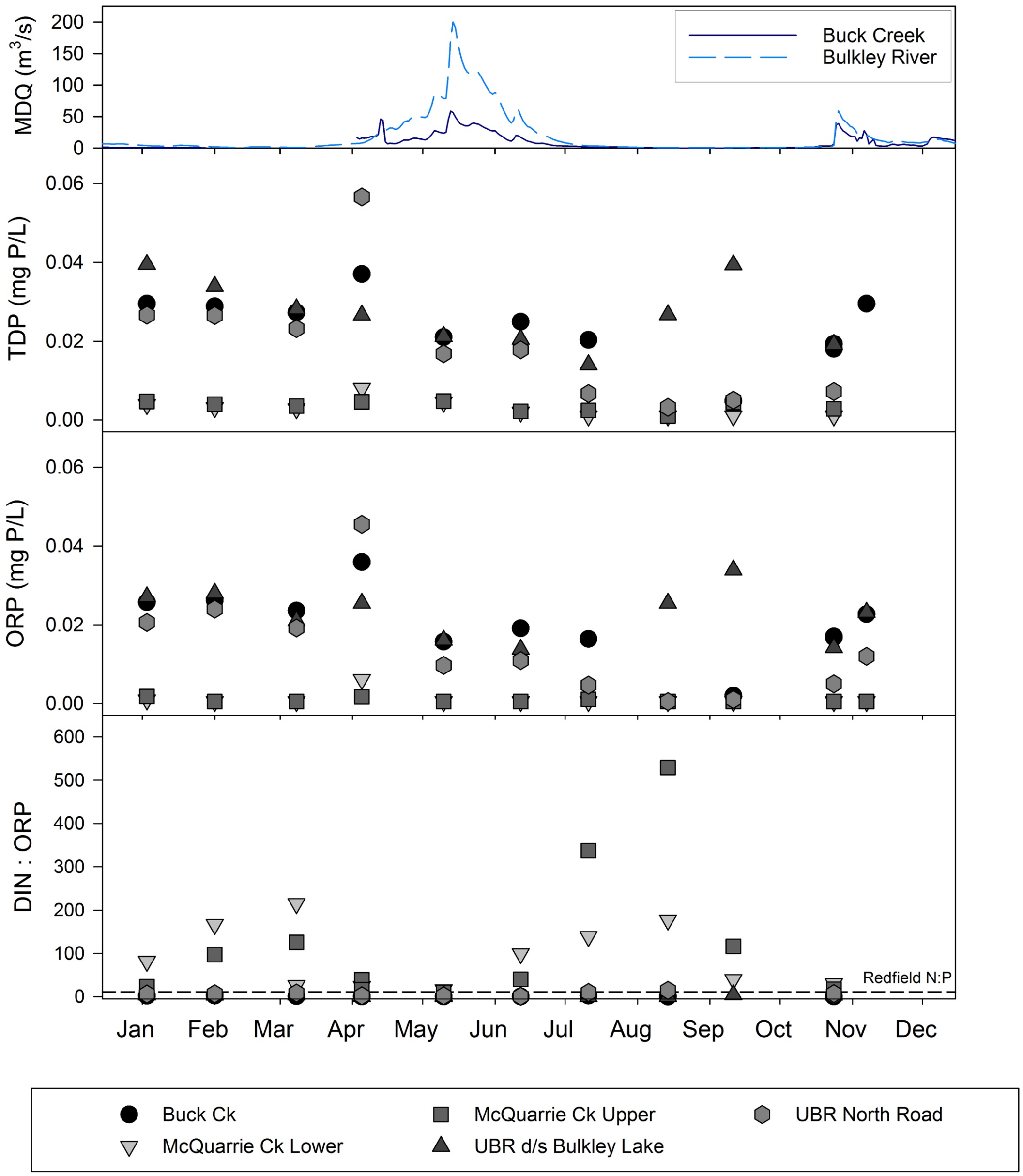


Figure A12. Time series for total metals parameters collected at Upper Bulkley River watershed sites from January – November, 2017. The top panel is mean daily discharge at WSC hydrometric stations: 1) Bulkley River near Houston and, 2) Buck Creek.

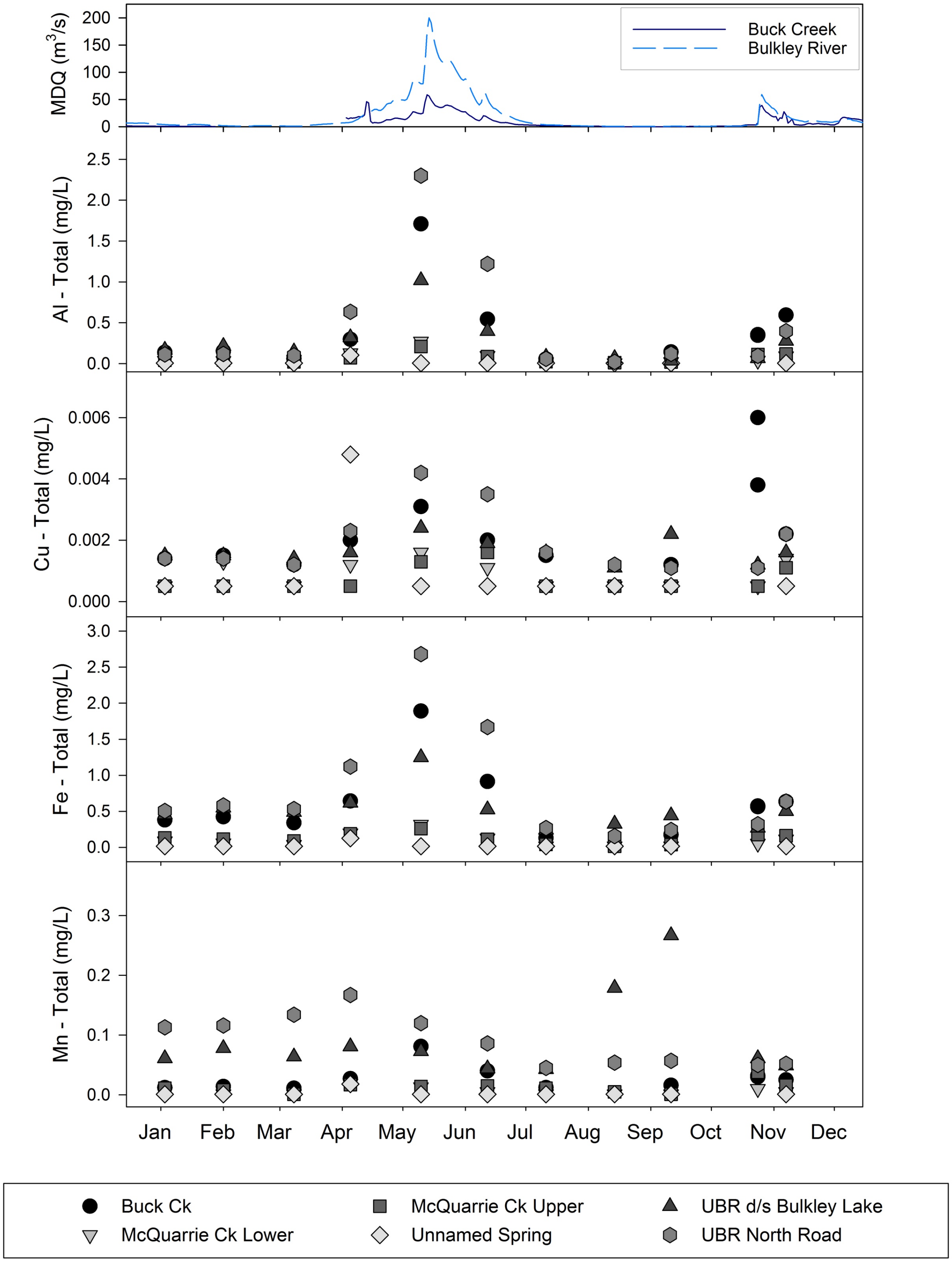
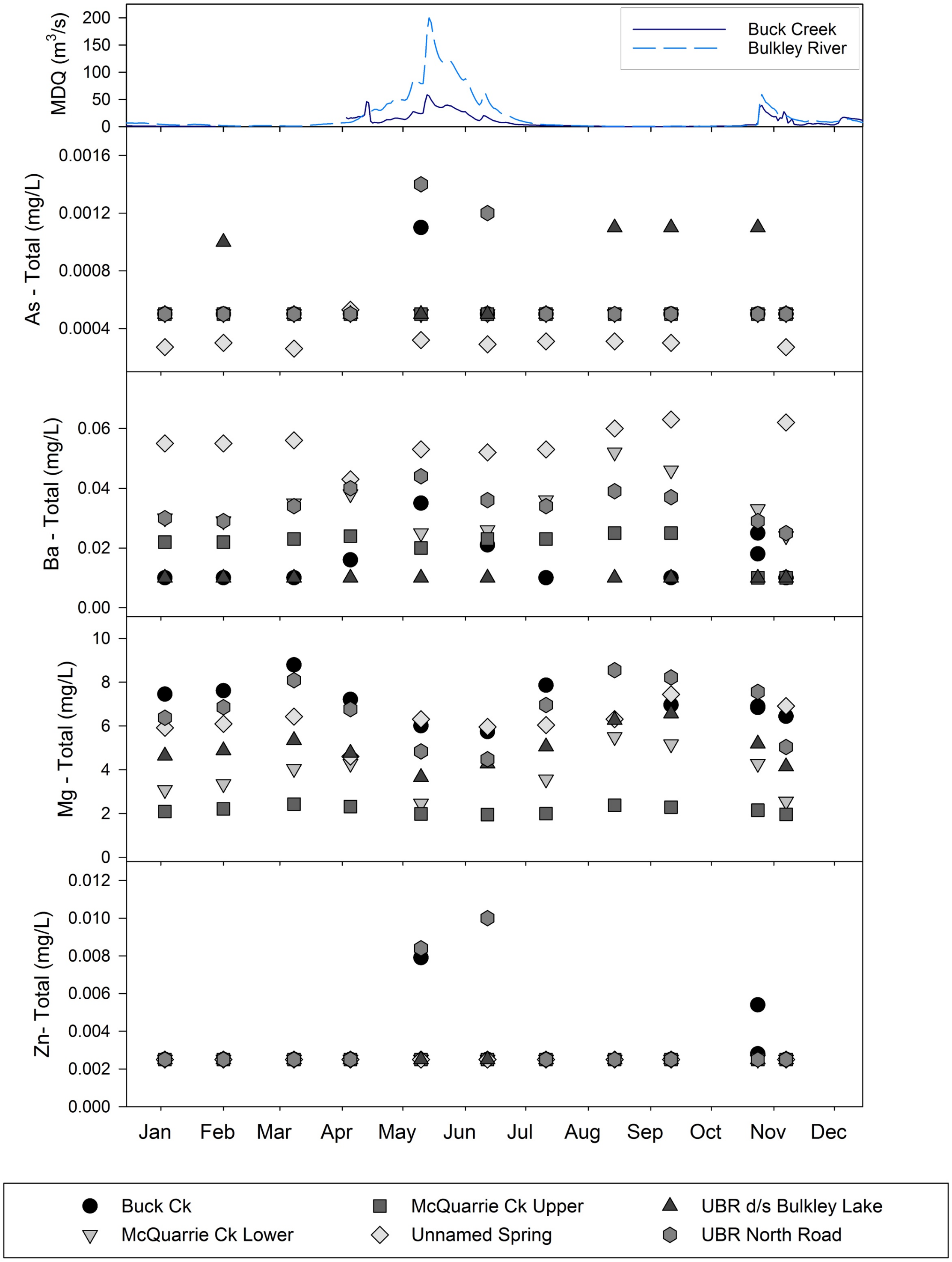


Figure A13. Time series for total metals collected at Upper Bulkley River watershed sites from January – November, 2017.. The top panel is mean daily discharge at WSC hydrometric stations: 1) Bulkley River near Houston and, 2) Buck Creek.



APPENDIX B

Table B1: Hydrometric[a] and continuous temperature monitoring stations[b] in the Upper Bulkley River watershed.

Site	ID	Location	Agency	Parameters	Established
Bulkley River Near Houston[d]	08EE003	54° 23’57” N 126° 43’09” W	Water Survey of Canada	Stage/Discharge, Temperature	Stage: 1930 Temp: 2017
Buck Creek[d]	08EE013	54° 23’45” N 126° 39’00” W	Water Survey of Canada	Stage/Discharge	1973
McQuarrie Creek above Hwy 16[d]	08EE0002	54° 30’56” N 126° 27’57” W	BC FLNROD[c]	Stage/Discharge, Temperature	2016
Bulkley River near Houston[d]		54° 23’57” N 126° 43’09” W	DFO (Wescott, 2019)	Temperature	2016
Bulkley Rr above McQuarrie Ck		54° 30’49” N 126° 27’42” W	DFO (Wescott, 2019)	Temperature	2016
Bulkley Rr below Bulkley Lake[c]		54°23’20” N 126° 08’48” W	DFO (Wescott, 2019)	Temperature	2016
Buck Ck at Houston[d]		54° 23’34” N 126° 38’49” W	DFO (Wescott, 2019)	Temperature	2016
Buck Ck above Bridge 1		54° 18’08” N 126° 38’51” W	DFO (Wescott, 2019)	Temperature	2017
Groundwater Channel[d]		54° 30’06” N 126° 28’39” W	DFO (Wescott, 2019)	Temperature	2016
McQuarrie Ck above Hwy 16[d]		54° 30’53” N 126° 27’51” W	DFO (Wescott, 2019)	Temperature	2016
McQuarrie Ck above North Rd[d]		54° 33’26” N 126° 34’55” W	DFO (Wescott, 2019)	Temperature	2016
Richfield Ck above Hwy 16		54° 30’57” N 126° 20’10” W	DFO (Wescott, 2019)	Temperature	2016
Crow Ck above Maxan FSR		54° 22’18” N 126° 11’52” W	DFO (Wescott, 2019)	Temperature	2017
Maxan Ck below Foxy Ck		54° 19’37” N 126° 07’46” W	DFO (Wescott, 2019)	Temperature	2016
Foxy Ck above Maxan FSR		54° 18’48” N 126° 07’35” W	DFO (Wescott, 2019)	Temperature	2016

[a] The Upper Bulkley River watershed also contains a number of inactive, historical hydrometric stations, however only stations active as of 2017 are included in this table.
[b] Complete description of temperature monitoring stations and program provided in Wescott (2019).
[c] BC FLNROD also established a hydrometric station on Richfield Creek in 2016, however data is not yet available.
[d] Station locations are similar to water quality monitoring sites included in this report

Table B2: Summary statistics for additional parameters (cations, additional metals) collected at UBR water quality sites from January– November, 2017.

Site		Ca (mg/L)	Na (mg/L)	Cr (µg/L)	Co (µg/L)	Ti (µg/L)
Buck Ck	Mean ±SD	18.0 ±2.4	4.2 ±0.7	0.52 ±0.47	0.30 ±0.17	29.2 ±13.9
	Min – Max	14.7 – 22.8	2.9 – 4.9	0.25*– 1.74	0.25*– 0.83	25.0 – 71.0
	95% CI	16.6 – 19.4	3.7 – 4.6	0.25 – 0.80	0.20 – 0.41	21.0 – 37.4
	n	11	11	11	11	11
McQuarrie Ck Upper	Mean ±SD	15.2 ±1.8	<1.0*	<0.25*	<0.25*	<25*
	Min – Max	12.4 – 17.7				
	95% CI	14.2 – 16.2				
	n	11	11	11	11	11
McQuarrie Ck Lower	Mean ±SD	18.8 ±5.1	2.5 ±1.2	<0.25*	<0.25*	<25*
	Min – Max	5.1 – 29.5	1.0*– 4.2			
	95% CI	15.8 – 21.8	1.8 – 3.2			
	n	11	11	11	11	11
UBR d/s Bulkley Lake	Mean ±SD	13.2 ±2.5	3.7 ±0.6	0.54 ±0.52	<0.25*	<25*
	Min – Max	9.22 – 17.6	2.7 – 4.9	0.25*– 1.82		
	95% CI	10.0 – 17.3	2.9 – 4.7	0.25 – 1.52		
	n	11	11	11	11	11
UBR North Road	Mean ±SD	19.5 ±4.6	5.4 ±1.4	0.63 ±0.71	0.37 ±0.28	28.8 ±12.7
	Min – Max	12.8 – 26.1	3.2 – 6.9	0.25*– 2.42	0.25*– 1.09	25.0*– 67.0
	95% CI	13.0 – 25.2	3.3 – 6.9	0.25 – 1.96	0.25 – 0.91	25.0 – 46.0
	n	11	11	11	11	11
Unnamed Spring	Mean ±SD	40.0 ±6.0	3.3 ±0.4	<0.25*		
	Min – Max	24.1 – 44.7	2.2 – 3.8			
	95% CI	30.8 – 44.6	2.6 – 3.7			
	n	10	10	10	NA	NA

Table B3: Optimum temperature ranges of specific life history stages of salmonids for British Columbia water quality guideline application (MOECC, 2018).

	Water Quality Guidelines for Temperature (°C)			
Species	Incubation	Rearing	Migration	Spawning
Chinook	5.0 – 14.0	10.0 – 15.5	3.3 – 19.0	5.6 – 13.9
Chum	4.0 – 13.0	12.0 – 14.0	8.3 – 15.6	7.2 – 12.8
Coho	4.0 – 13.0	9.0 – 16.0	7.2 – 15.6	4.4 – 12.8
Pink	4.0 – 13.0	9.3 – 15.5	7.2 – 15.6	7.2 – 12.8
Sockeye	4.0 – 13.0	10.0 – 15.0	7.2 – 15.6	10.6 – 12.8
Rainbow Trout	10.0 – 12.0	16.0 – 18.0		10.0 – 15.5

Table B4: Fish life history periodicy chart for Bulkley River above Houston. Created 2001 and available from Wayne Duval (wayne.duval@bchydro.com).