Quinsam Coal
Annual Water Quality Monitoring Report 2016-2017

PREPARED BY: QUINSAM COAL CORPORATION

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Glossary & Acronyms

B.C.	British Columbia
CALA	Calibration
CCR	Coarse Coal Reject
COPC	Contaminants of Potential Concern
DL	Detection Limit
DO	Dissolved Oxygen
EMS	Environmental Monitoring Station
EPT	Ephemeroptera, Plecoptera, and Trichoptera
Ha	Hectares
Hp	Horsepower
IDZ	Initial Dilution Zone
km	Kilometer
LLE	Long Lake Entry
LLPTS	Long Lake Seep Passive Treatment System
Masl	Metres above sea level
MDL	Mean Detection Limit
MEM	Ministry of Energy and Mines
MOE	Ministry of Environment
PAG	Potentially Acid Generating
PAH	Polyromantic Hydrocarbons
PEP	Provincial Emergency Program
PNC	Permit Non-compliance
QA/QC	Quality Assurance/Quality Control

QCC	Quinsam Coal Corporation
RPD	Relative Percent Difference
SQO	Sediment Quality Objective for Long Lake
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
VIO	Vancouver Island Objective for phosphorus in streams
WQG	British Columbia Water Quality Guidelines for Protection of Aquatic Life
WQO	Water Quality Objectives for Middle Quinsam Lake Sub-Basin

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Executive Summary

In accordance with Effluent Permit PE-7008 issued under the *Environmental Management Act*, Quinsam Coal Corporation (QCC) operates water management systems designed to mitigate effects of mining activities on the Middle Quinsam Sub-Basin and Iron River watershed(s). This effluent permit provides the framework for the comprehensive monitoring program along with allowable levels of Parameters of Interest (POI) within water released from the permitted management systems. In addition to surface water quality monitoring within management systems and receiving environments, local groundwater, sediment and biological monitoring was conducted at numerous stations for a more comprehensive understanding of effects within the mine footprint.

Following the indefinite suspension of coal production in January 2016, all operations through this monitoring period were defined as "*care and maintenance*" activities. Care and maintenance consisted of fundamental maintenance to core systems, reclamation and protection of assets. In addition, all environmental monitoring obligations as per Effluent Permit 7008 (PE-7008) remained unchanged and were carried out as necessary.

The main objective of this report is to inform governing bodies and stakeholders on the effectiveness of the management systems and compliance with the effluent permit for the 2016-2017 monitoring year including:

- Description of mine-site operations and their respective environmental management systems
- Report on environmental performance along with compliance with the Effluent Permit PE-7008
- Provide updates on receiving environment water, sediment and biological integrity
- Incorporate groundwater monitoring, Long Lake Seep Passive Treatment System (LLST) performance and aggregate loading into Long Lake as part of this report
- Provide insight and recommendations for future monitoring and best environmental practices

Mine discharges released from the permitted locations were within permitted levels for the majority of samples obtained this monitoring period. The only permit limit exceedances encountered were:

- A Dissolved phosphorus exceedance was observed at BDS (applied to discharge limits at SPD of 0.05 mg/L) with a reported result of 0.0608 mg/L. This exceedance was driven by LLST discharges and was determined to be an isolated event with no additional exceedances observed in the year.
- TSS exceedances occurred at 7SSD on two occasions in October (7^{th} and 16^{th}) as significant precipitation was received at the mine site. The exceedances (27.3 and 35.0 mg/L respectively) were marginal but were a direct result on high sediment transport from local drainage.
- Numerous TSS exceedances were observed WD from October to January and were the result of storm events and dewatering the 2-North mine. Although these events were considered the most significant permit non-compliance throughout this monitoring year, TSS levels at the downstream site WC prior to entry of MQL were all within acceptable limits.

Spill reports can be found in Appendix VII including description of the spill, follow up and mitigative techniques.

Numerous water quality guideline (WQG) exceedances across the receiving environment were observed this monitoring year. Majority of the exceedances were anomalous and inconsistent, not attributed to any point source discharges from the mine.

Sulphate concentrations at depth in Long Lake have continued to be a focal point for receiving environment water quality as elevated levels have persisted throughout past monitoring. In 2016, levels increased when compared to previous monitoring years and have saw WQG exceedances through all 5 in 30 monitoring periods averaging 133, 134 and 131 mg/L respectively. The LLST has been effective at reducing sulphate concentrations from mine pool water, however; it is difficult to determine whether this system has a positive effect with respect to sulphate concentrations within Long Lake.

Groundwater monitoring has become increasing important for the understanding of cumulative mine inputs into undisturbed areas and receiving environments. Sulphate, iron, manganese and arsenic (to name a few) are key parameters to monitor as they are most attributed to coal mining operations. Currently, no inputs are known to have significant detrimental effects on receiving environments but future monitoring will be an effective means to identify and determine changes.

The first comprehensive sediment and benthic monitoring program completed internally by Quinsam staff has been completed this monitoring year as required by the effluent permit. This monitoring program evaluated key areas throughout the watershed to determine composition of sediments with respect to mining operations and any effects that may be present within biologic communities that inhabit them along with data from previous studies completed by external consultants. Section 9 through 11 discusses the findings with Appendix I Tables 167 through 254 containing analytical results. Appendix V contains the benthic results, analytical methods and quality control procedures from Cordillera Consulting; Appendix VI describes the study design and Appendix XI Figures 1 through 18 display the sampling locations and parameters of interest compared to previous studies for the lakes.

1.0 INTRODUCTION

The Quinsam Mine is located in the Quinsam River Watershed, approximately 28 kilometers (km) by road southwest of Campbell River. The land reserved by the Quinsam mining operation consists of approximately 283 hectares (ha) and is owned and operated by Quinsam Coal Corporation (QCC). Active mining operations were suspended in mid-January 2016 due to ongoing poor market conditions and a decreased demand for thermal coal. The mine had transitioned into a “Care and Maintenance” program shortly after focusing on maintenance, asset protection and reclamation, specifically the 242 area and the 1 – 4 and 7-South areas. The mine obtained new ownership in June 2017 with the prospect of restarting mine operations in the near future.

The Quinsam Mine produces High Volatile “A” Bituminous thermal coal. Coal is processed at an onsite preparation plant, transported by B-train highway trucks to the Middle Point Barge Terminal north of Campbell River. Coal is then shipped via barge, to local customers and to Texada Island.

Due to the mine’s location, adjacent to Middle Quinsam Lake, the Quinsam River, No Name Lake, and Long Lake, which drain into Lower Quinsam Lake, the operational permits issued by the Ministry of Environment (MOE) and Ministry of Energy and Mines (MEM) established stringent effluent quality standards. Accordingly, QCC has maintained an environmental management system defined by the requirements of Effluent Permit PE-7008 and defined in the C-172 *Mines Act* permit. The mine has collaborated with regulators and stakeholders on key management aspects to minimize mine related effects in the receiving environment.

Sulphate concentrations in surface waters of the receiving environment (e.g. Long Lake) continued to be a focus for the QCC monitoring program. Although PE-7008 lists only one sulphate limit for effluent (500 mg/L at 7SSD), sulphate is routinely monitored at designated sites on the mine site and in the receiving environment. Quinsam continues to assess sources of sulphate and management options to mitigate concentrations in mine related discharge(s).

On-Site Water Quality and Activities

The North, South, and 7-South water management systems represent the cumulative mine related discharges to the Quinsam watershed. As such, strategic operation of management structures is designed for discharge waters to meet permit requirements and be of suitable quality for discharge into the receiving environment. Permit limits for parameters of interest have been established and are closely monitored to ensure environmental protection.

Surface disturbance was limited to the South mining area, close to the 3-South pit, where an engineered outlet channel was constructed (total surface disturbance area of 0.88 ha). The channel will provide a permanent overflow connecting the 3-South sub-aqueous PAG-CCR disposal site to the drainage channel connecting No Name Lake to Long Lake. This will eliminate the need for mechanized pumping to maintain water levels in the 3-South PAG-CCR pit, and is part of the closure plan for the Quinsam Coal Mine Site.

There were no additional surface disturbances during this report period with all efforts focused on reclamation mostly in the 2-3 South areas.

Bioassays

Rainbow Trout 96-hour bioassays were performed on water collected from Settling Ponds #1 and 4 and 7SSD each of these passed with 100% survival. A 7-day *Ceriodaphnia dubia* chronic toxicity test performed on water from collected Stream 1, 7S also passed with 100% survival.

Receiving Water Quality

Water quality attainment in the Middle Quinsam Sub-Basin remains a key management objective at QCC. Comparison to provincial WQGs and Middle Quinsam Sub-Basin water quality objectives (WQOs) is used to evaluate receiving water quality, aquatic health, and overall operational performance.

Monitoring sulphate concentrations continues to act as a essential practice to evaluate mine impacts as it is a key parameter traced back to coal mining. Sulphate concentrations are compared to an average WQG of 128 mg/L, are calculated using a background hardness of 30 mg/L for the Middle Quinsam Sub-Basin. Sulphate results averaged over five weekly samples collected over 30 days (5 in 30) were compared to the WQO. Other parameters of interest for the receiving environment are total arsenic, copper, iron, manganese, and zinc and dissolved iron and aluminum. Elevated dissolved aluminum and total copper, and zinc concentrations are associated with high rainfall events (elevated TSS) and may not be associated with mine related discharges; however, elevated concentrations are considered in the context of aquatic effects.

Monitoring at sites upstream of mine influences (e.g., IR1 in the Iron River) indicates naturally elevated concentrations of dissolved aluminum during high flow events. These metals and other parameters that are higher than WQGs or WQOs are discussed below. Total phosphorous concentrations are compared to the Vancouver Island Objective (VIO) for streams (a maximum of 0.01 mg/L and average of 0.005 mg/L) at sites No Name Lake Outlet, Long Lake Outlet, Middle Quinsam Lake Outlet and 7-South Quinsam River, 7SQR & one wetland Long Lake Entry (LLE).

Groundwater Quality

QCC maintains a comprehensive groundwater monitoring program to characterize water quality associated with mining development. There are a total of 37 groundwater wells including underground sumps located in-situ (disturbance footprint) and ex-situ (outside of mine workings) that are monitored. In the absence of groundwater well samples, underground sump samples are used for comparison. Results for ex-situ wells are compared to Contaminated Sites Regulations Standards for Protection of Aquatic Life (CSR-AW) and those for in-situ wells are and sumps are compared to source terms derived for particular mining areas. Groundwater quality is influenced by bedrock chemistry, an example being the presence of realgar (arsenic sulphide) in the Dunsmuir Sandstone overlying the No. 4 coal zone, resulting in dissolved arsenic in the south area groundwater being naturally higher than the CSR-AW. Parameters of interest for groundwater are those with concentrations higher than the CSR-AW: arsenic, chloride, fluoride, hydrogen sulphide as (H_2S) and sulphate. Overall, in-situ groundwater at Quinsam Coal is generally within the water quality prediction scenarios and ex-situ groundwater typically trends below the CSR-AW guidelines. The two exceptions to the aforementioned is groundwater influenced by host geological formations (e.g. Dunsmuir Member sandstones, Cumberland Member No.1 Coal seam and mudstones) with naturally elevated concentrations of parameters of interest and by weathering processes (i.e. mine wall oxidation and flushing) of disturbed materials within the mine footprint.

Receiving Water Sediment and Biota

QCC conducted a comprehensive biological monitoring program in 2016, as stipulated in Section 4.2.4 and 4.2.7 of the effluent permit. The August through October program involved sediment and benthic invertebrate monitoring at 23 locations in the watershed (at five lakes, one wetland, and three locations on the Quinsam River). In the four lakes exposed to mine influences, samples were collected at inlets, deep sites, seeps, and outlets.

Sediment results were compared to generic Canadian Council of Ministers of Environment (CCME) Interim Sediment Quality Guidelines (ISQG) and Probable Effect Levels (PEL) and to site-specific sediment quality objectives (SQOs) developed for Long Lake that reflect the naturally elevated background levels of some metals. The SQOs were derived from studies completed prior to mining influence in Long Lake (pre-1987). Where background levels are lower than ISQG's, the ISQGs are used for comparison. Primary parameters of interest for sediment are arsenic, iron, manganese and total polycyclic aromatic hydrocarbons (PAH), identified based on concentrations, relative toxicity, and findings in previous reports. Most of the elevated concentrations are related to geology (host rock formations), although mining has contributed inputs.

Water quality in the Middle Quinsam Sub-Basin and Iron River generally meets WQGs and WQOs and is considered suitable for aquatic life. Throughout the monitoring period, Quinsam has demonstrated that mine water management system(s) and procedure(s) are an effective tool in reducing parameters of interest loading in the receiving environment.

Benthic invertebrate samples from lakes and the wetland were analyzed for community metrics (density, taxon richness, diversity, evenness, major taxonomic groups), and for ecologically relevant and statistically significant differences among sites. Quinsam River sites were sampled and analyzed using the Canadian Aquatic Biomonitoring Network (CABIN) method.

Phytoplankton and zooplankton samples collected once per sampling event on all four lakes as a routine requirement of PE-7008s. Samples were analyzed for count, identification and species abundance.

Long Lake Seep Passive Treatment System-

The Long Lake Seep Passive Treatment System (LLST) consists of a series of treatment cells designed to receive mine-water pumped from the 2-South underground workings to reduce Parameters of Interest (POI) concentrations including dissolved sulphate and iron. This system was initiated as part of a remediation plan to limit localized mine-water seepage on the south-side of Long Lake as a result of subsidence caused by mining within close proximity and establishing an evident hydrologic connection.

The Long Lake Passive Treatment System (LLTS) continues to demonstrate reduction in sulphate concentrations throughout the system. Higher reduction is observed during warmer conditions, with reduction efficiencies of upwards of 300 mg/L. The addition of molasses (carbon source) has shown some capability to increase performance within the system.

2.0 WATER MANAGEMENT SYSTEMS AND MONITORING LOCATIONS

Settling ponds, sumps and ditches have been constructed to manage and treat mine contact water to help mitigate any negative effects on the receiving environment. Water management at the Quinsam Mine is divided into three discrete areas: North, South, and 7-South. Appendix XI, Site Map, displays underground mine locations, groundwater wells and surface monitoring sites. Table 1 below describes the within-mine releases monitoring sites and associated initial dilution zones.

Table 1: Description of Monitoring Sites: In-Mine Releases & Initial Dilution Zones

EMS ID #	Monitoring Sites	Station Code	*Type of Water (MW, FW,GW or IDZ)
	North Coal Mining Operation		
E207409	**Settling Pond #4 Decant**	**WD**	**Discharge (MW)**
E207411	Culvert, at Middle Quinsam Lake Road	WC	MW & FW
E283433	2-North Portal Sump (Adit Sump)	2NPS	MW
E207412	2-North Pit Sump CCR Cover	WP	PAG-CCR Water Cover - MW
E292126	South Dyke Sump	SDS	MW
	South Coal Mine		
E218582	**Settling Pond #1 Decant**	**SPD**	**Discharge (MW)**
E217014	Culvert, Downstream End at Access Road	SPC	MW & FW
E217015	South Pit Main Sump Water	3S	PAG-CCR Water Cover (MW & FW)
E292127	2-South Pit In Pit Water Cover (2-South Standpipe)	2S	PAG-CCR Water Cover (MW & FW)
E292128	1977 Bulk Sample Pit	3S77	MW & FW
E292129	Culvert Downstream of 4 South Access Road	4S-Lo	**MW & FW**
	7-South Mining Operation		
E292069	**7-South Surface Decant**	**7SSD**	**Discharge (MW & FW)**
E292110	7-South Adit Sump	7SPS	MW
	Seep Monitoring Sites		
E292131	Long Lake Seeps	LLS & LLSM	MW
	Small seep near the plant (PDS) & groundwater surface near road entering MQL (PDSR)	PDS & PDSR	GW & MW
Long Lake Seep Passive Treatment System			
N/A	Groundwater well (2-South Mine Pool) Influent to the treatment system	QU11-11 (INF-EFF)	MW
N/A	Bio Cell Reactor	BCR-EFF	MW
N/A	Sulphide Polishing Cell	SPC-EFF	MW
N/A	Aeration Lagoon	AL-EFF	MW
N/A	Settling Pond Effluent	SP-EFF	**Discharge MW**
Authorization to Bypass the Works			
N/A	Sampling location 35 m downstream of discharge from the treatment system (SP-EFF) and Settling Pond #1. Discharge is compared to SPD permit limits.	BDS	**Discharge MW**
Initial Dilution Zone (IDZ) Monitoring Sites			
E292130	Long Lake Entrance (South end water entering Long Lake)	LLE	IDZ
E292109	Road Crossing Bridge on Stream 1 above the Lower Wetland (Downstream of 7SSD). The site name is Stream 1, 7S.	7S	IDZ

*** MW= Mine Water, FW= Freshwater, GW =Groundwater IDZ = Intial Dilution Zone**

2.1 MINE RELATED DISCHARGE

2.1.1 *THE NORTH WATER MANAGEMENT SYSTEM*

The north water management system is designed to collect mine related runoff from the north disturbed surface areas and pumped water from the 2-North underground mine operations. This system includes catchment sumps and ditches, pipelines, a subaqueous storage facility for potentially acid generating (PAG) coarse coal reject (CCR) and Settling Pond # 4 (WD) EMS #E207409.

The 2-North subaqueous PAG-CCR facility (WP) EMS #E207412 contains waste rock from 5 South Mine coal processing and is stored with at least 1.50 m of water cover to inhibit acid generation from the stowed material. This water cover is sourced from underground pumps and maintained by QCC personnel.

Based on hydrogeology of the area and mine workings depth, the 2-North mine must be dewatered to allow operations underground. A series of underground pumps move water to surface as needed. The underground dewater wells 1 and 5 Mains are both equipped with 2 X 200 horsepower (HP) surface pumps capable of pumping approximately 1500 gallons per minute collectively. The 6 Mains 2-North dewatering system was decommissioned in June 2016 consists of three pumps also capable of pumping1500 gallons per minute, collectively.

Settling Pond # 4 collects gravity fed water from Brinco Brook, which includes disturbed surface runoff, tailings dam seepage, and underground water collected at 2-North Portal Sump (2NPS) EMS #E283433. The underground dewatering wells 1 and 5 Mains discharge directly into Brinco Brook and mix with the water from 2NPS. Settling Pond # 4 acts as the final collection point before discharge into a meadow/biomass system where it flows into a culvert at Middle Quinsam Lake road sampling location (WC) EMS #E207411, prior to entering another extensive wetland that flows into the inlet of Middle Quinsam Lake.

Settling Pond #4 encompasses approximately 2.4 ha of marshland with an average depth of 1.5 m and a storage capacity of approximately 30,000 m^3. It has been designed to receive a 1 in 10 year flood event and has an emergency spillway to prevent structure failure during extreme flood events. Water from Settling Pond #4 is pumped to the wash plant for use in coal processing.

Used wash plant water is pumped to the tailings dam at the pump site CPP collection ditch, where it filters through the north side of the tailings dam to 2NPS. Water in the 2NPS is used for underground equipment, dust suppression, and emergency firefighting. Excess water in the 2NPS sump is pumped with a 65 HP pump through a 12 inch pipe along the 2-North high wall then discharged into Brinco Brook. South Dyke Sump (SDS) EMS #E292126 collects seepage water from the south side of the tailings dam and pumps it back to the tailings dam (the seepage does not report to the Quinsam River or Middle Quinsam Lake from this location).

Below the wash plant is a natural drainage where groundwater surfaces and flows towards Middle Quinsam Lake. There are two surface monitoring locations here and two nested (deep and shallow) groundwater wells. The plant ditch seep (PDS) is groundwater that surfaces and flows intermittently through the year, drying up in the summer; the water surfaces at the Plant Ditch Seep at the Road (PDSR) prior to entering Middle Quinsam Lake near the inlet end. These sites are monitored monthly when there is flow at surface. Deep and shallow nested groundwater wells MW00-1 (S and D) and MW00-6 (S and D) represent the groundwater below the collection ditch and processing plant. These wells were installed to monitor seepage from the plant site collection ditch. Historically, the plant site collection ditch was used to transport fine tailings from the processing of coal to WP, which was used as a fine tailings settling pond, with excess water pumped into Brinco Brook and gravity feed into Settling Pond # 4.

Figure 1 provides a flow chart describing the flow paths of water in the 2-North Water Management System.

NORTH WATER MANAGEMENT SYSTEM: WATER MOVEMENT

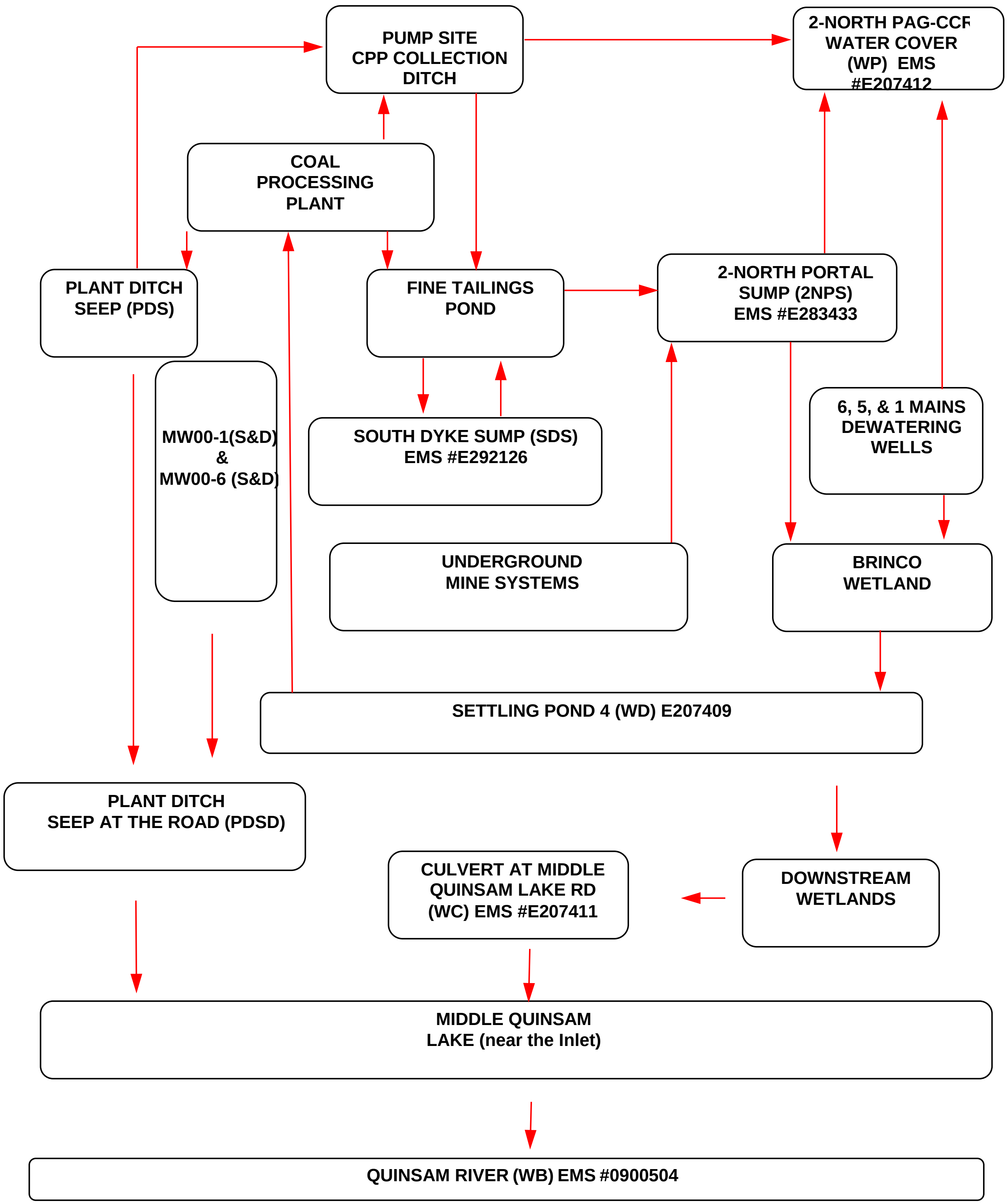

Figure 1: Water Movement and Flow Path in the North Management System

2.1.2 *The South Water Management System*

The South Water Management System is designed to collect mine related runoff from the south disturbed surface areas and manage water in the 2-South (2S) EMS #E292127 and 3-South (3S) EMS #E217015 PAG-CCR containment pits, Long Lake Seep Passive Treatment System (LLTS), and 5-South mine workings.

The two long-term PAG-CCR pits (2-South and 3-South) have been completed as part of the south water management system. Construction of the 2-South PAG-CCR pit was completed in 2014; it includes a clay-bentonite liner to retain water within the pit and a water cover fed by a series of ditches and pipes that collect local catchment water. Surface personnel control valves to direct fresh non-mine impacted water into the PAG-CCR facility or to No Name Lake. A minimum of 1.50 m water cover is required in the 2-South PAG CCR. Excess water from the 2-South PAG-CCR pit overflows a spillway (built in 2015) into a large channel that leads to the 3-South PAG-CCR storage pit. This water is used to provide 1 m deep water cover over 3-South. Excess water in 3-South is pumped via an 88 HP pump capable of pumping 500 gallons per minute directly into the roadside collection ditch that flows into Settling Pond #1.

Settling Pond #1 (SPD) EMS #E218582 is the compliance point for permitted discharges before water enters Long Lake. Settling Pond #1 encompasses 1.8 ha of wetland with an average depth of 1.5 m. An emergency overflow ditch built into the impoundment dam is located on the north end of the pond. A siphon pipeline has been installed from Settling Pond #1 to the 3-South Pond to provide an emergency source of water to maintain the 1 m cover over the 3-South PAG-CCR pond. In 2015, a pumping system was installed in the 5-South workings with discharge into Settling Pond #1 to reduce water levels over the 8-Mains plugs that separate the 5-South and 2-North mines. Water from the 5-South Mine is pumped periodically to Settling Pond #1.

The LLTS is designed to inhibit flow at the Long Lake seep by lowering the 2-South mine-pool through pumping from monitoring well QU11-11, where it is treated on surface. There are four ponds (BCR-EFF, SPC-EFF, AL-EFF & SP-EFF) where water goes through processing. Effluent from this system (SP-EFF) is combined with Settling Pond #1 discharge, then flows 100 m to the location Biocell Downstream (BDS). This effluent channel leads into a series of meadow/biomass systems and combines with the surface and subsurface groundwater.

The 3-South 1977 bulk sample pit (3S77) EMS #E292128 is located upstream of the 4-South Pad and collects groundwater filtering in from the wetland through which Settling Pond #1 flows. The bulk sample pit has a surface discharge that filters into the groundwater and through the connector ditch above the 4-South Mine to the 4-South Fire Pond. The 4-South ditch monitoring location (4S-Lo) EMS #E292129 is a culvert downstream of 4-South Access Road and west of 4S coal pad; it collects runoff from the 4S-pad, groundwater seepage, and surface runoff from the haul road. The monitoring location SPC, EMS #E217014, located downstream of the 4-South Portal and 4S-Lo, does not interact with effluent from 4-South; it captures Settling Pond #1 water downstream of the wetland. The final collection point (EMS #E292130) is at the downstream end of the Long Lake Entrance (LLE) wetland and discharges approximately 50 m upstream of Long Lake. This site is considered the initial dilution zone (IDZ) for Long Lake.

Figure 2 provides a flow chart describing the flow paths of water in the South Water Management System.

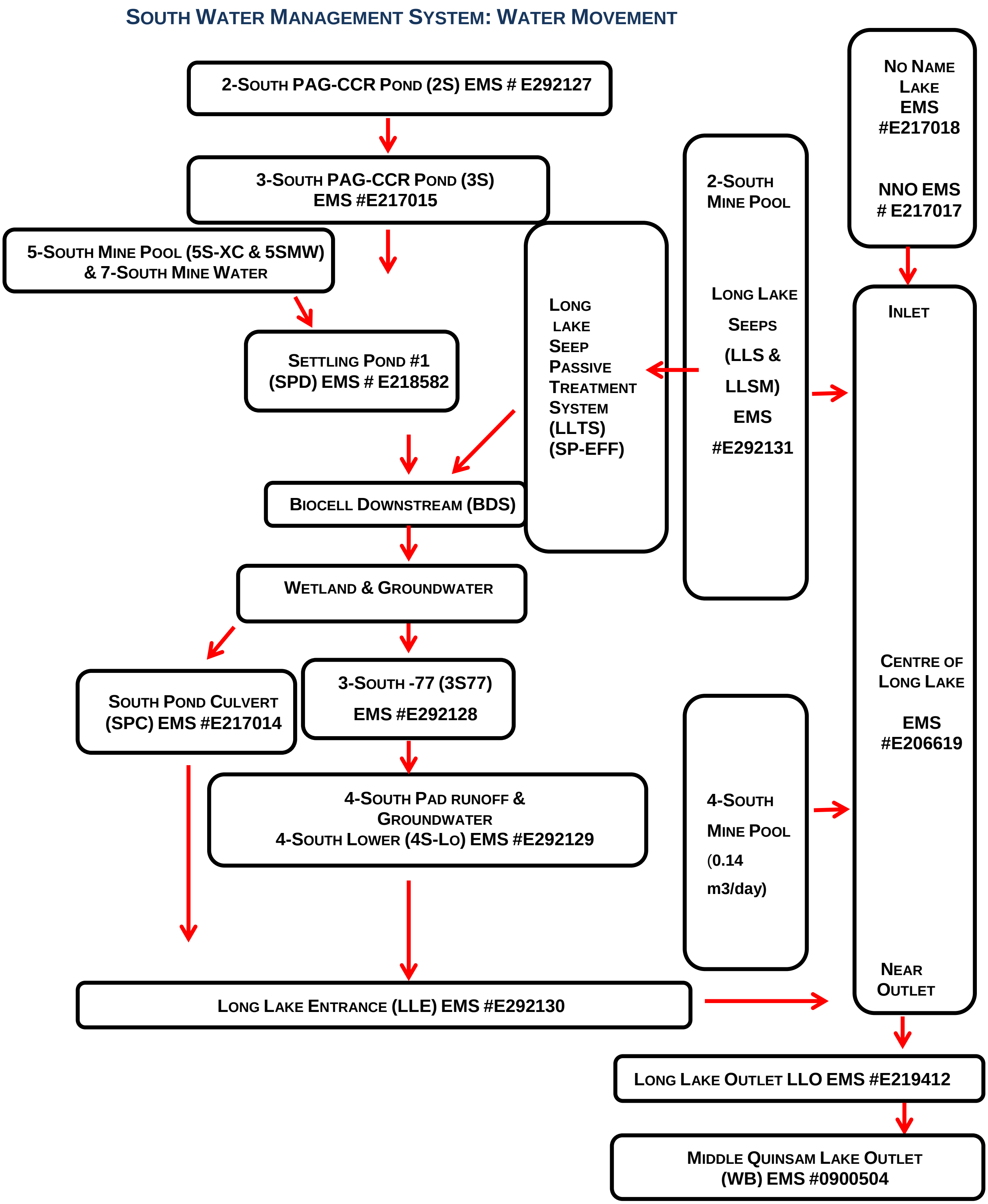

Figure 2: Water Movement & Flow Path in the South Water Management System

2.1.3 *7-South Water Management System*

The 7-South Water Management System includes the 7-South Surface Decant Settling Pond (7SSD) EMS #E292069, 7-South-Adit Sump (7SPS) EMS #E292110, 7-South Containment Pond (7SCP), and receiving environment sites downstream at Stream 1 (7S) EMS #E292109, which flows into the Lower Wetland and monitoring location Lower Wetland Outlet (LWO) EMS #E292112 at the confluence of the Quinsam River. This system is designed to manage excess water from the 7-South catchment area and mitigate environmental impacts from disturbed surface locations affected by mining and underground activity. Water is collected and stored in three main ponds in the 7-South Mine catchment area: 7SPS, 7SCP, and 7SDD.

7SPS contains water that is collected from dewatering processes during mining activity; most of surface water from the coal storage pad is directed into the adit sump. Water is pumped from active mining areas and stored adjacent to the portal entrance to use for dust suppression on mining equipment and for the fire suppression system. Water levels at 7SPS are set up on an automated float system, when water levels rise beyond a desired storage capacity, excess water is pumped underground into the 5-South Mine.

7SCP collects surface runoff from the 7-South surface disturbance area, local groundwater, and infiltration water from the coal pad. This pond allows suspended solids in surface water to settle before the water enters 7SSD. When this pond reaches a certain capacity, it discharges through a culvert into 7SSD. In 2015, the 7SCP was enlarged to accommodate more water. Additional pumps were placed at 7SSD and 7SCP to decrease 7SSD discharge and assist with water management. The revised system pumps water from 7SSD and 7SCP to 7SPS. The pump at 7SCP runs on an automated float system where water levels are kept below the overflow channel into 7SSD. During high precipitation events, a secondary pump can be activated to assist in pumping water to 7SPS. This pump can also be relocated to 7SSD where accumulated water can be diverted into 7SCP. This system does not eliminate discharge from 7SSD but helps reduce the amount discharged, given that 7SSD must discharge during times of heavy precipitation.

7SSD is the permitted discharge location and main water collection pond for the 7-South Mine area, with a cumulative catchment of 3.14 ha. 7SSD is a settling pond that receives water from groundwater infiltrated from the surrounding hillsides and the coal storage pad. This water is monitored for quality and quantity during discharge events. Water is discharged from the pond via a 2 inch discharge line equipped with a valve to allow environmental personal to set the discharge rate based on flow rates measured at the downstream site 7S in Stream 1. An 8:1 ratio (7S:7SSD) was calculated from previous water quality data and modelling conservatively to protect the Stream 1 receiving environment. Water quality downstream in Stream 1 meets applicable guidelines with dilution ratios greater than 8:1.

Discharge from 7SSD forms the headwaters of Stream 1, monitoring location 7S is located on Stream 1 below the confluence with Stream 2 and, for the purposes of the effluent permit, is compared to British Columbia water quality guidelines (WQGs) for protection of aquatic life to evaluate potential effects on aquatic receptors at this location.

Figure 3 provides a flow chart describing the flow paths of water in the 7-South Water Management System.

7-South Water Management Systems: Water Movement

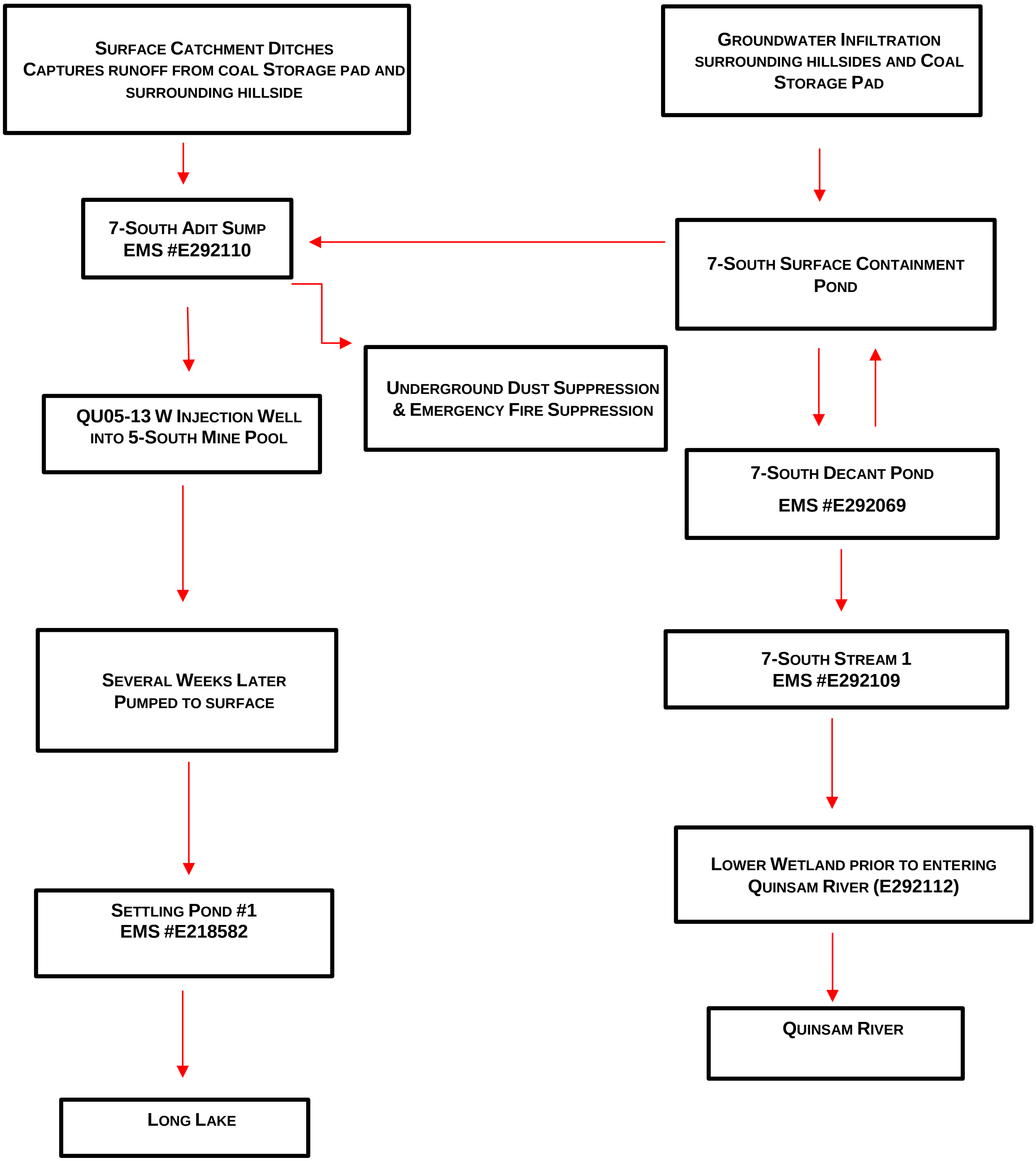

Figure 3: Water Movement and Flow Path at the 7-South Operation

2.2 Receiving Environment Sites

2.2.1 *River, Stream & Lake Monitoring Sites*

Effluent Permit PE-7008 Section 4.2.3 identifies river, stream, and lake monitoring sites that represent the receiving environment for various mine related discharge(s). Most of these sites are monitored on a 5 in 30 sampling frequency (five events in 30 days) during the spring, summer and fall seasons. Table 2 lists the receiving water monitoring sites.

Table 2 : Receiving Water (Stream and Lake) Monitoring Sites

Streams	Lakes
North Mining Operation	
Quinsam River at Argonaut Road (WA) (EMS # 0126402) Outflow from Middle Quinsam Lake (WB) (EMS # 0900504)	Middle Quinsam Lake Centre (EMS # 206618)
South Mining Operation	
Long Lake Outlet (LLO) (EMS # E219412) No Name Lake Outlet (NNO) (EMS # E217017)	Long Lake at Centre (LLM) (EMS #E206619) No Name Lake (NNL) (EMS # E217018)
7-South Mining Operation (Areas 1 to 4)	
Quinsam River upstream of 7 South Mining Operation (QRDS1) (EMS # E286930) Quinsam River downstream of 7 South Mining Operation (7SQR) (EMS # E292113) Lower Wetland Outlet at the confluence of Quinsam River (LWO) (EMS # E292112)	Lower Quinsam Lake (LQL) (EMS #E292118)
7-South Area 5 Mining Operation	
Iron River upstream of mining operations (IR1) (EMS #E297230) Iron River upstream of 7SA5 (IR6) (EMS # E297231) Iron River downstream of 7SA5 and 242 inputs (IR8) (EMS # E297232) Quinsam River downstream of confluence with Iron River (IRQR) (EMS # E299256)	Lower Quinsam Lake (LQL) (EMS # E292118)

River and Stream Sites in the Quinsam River Sub-Basin

- Quinsam River at Argonaut Road (WA) EMS #0126402 – Located upstream of all mine related discharges; represents background (baseline) conditions for water quality comparisons.
- Outflow from Middle Quinsam Lake (WB) EMS #0900504 – Located at the outflow of Middle Quinsam lake; represents combined discharge from North and South water management systems.
- No Name Lake Outlet (NNO) EMS #E217017 – Located at the outflow of No Name Lake; not presently influenced by surface mine related discharge in the South. The groundwater influence from 2-South Pit to No Name Lake near the outlet site was estimated as 50 m^3/day or 10% of the seepage rate.
- Long Lake Outlet (LLO) EMS #E219412 – Located at the outflow to Long Lake; captures all South mine related inputs on surface and a percentage of groundwater (i.e. LLE and Long Lake Seep).
- Quinsam River Downstream Site 1 (QRDS1) EMS #E286930 – This site is located downstream of Middle Quinsam Lake Outflow (WB), the North Mining Operation and upstream of the 7-South Mining Operation; captures changes in water quality before the 7-South Mine and groundwater inputs related to mining.
- Lower Wetland Outlet at the confluence of the Quinsam River (LWO) EMS #E292112 – This site is located downstream of Stream 1 (7S); represents final surface discharge quality prior to combining with the Quinsam River.
- 7-South Quinsam River (7SQR) EMS #E292113 – Quinsam River downstream of QRDS1, LWO, and 7-South Mining Operation; captures incremental changes in water quality that may be attributed to 7-South PAG-CCR storage and flooded mine pool.

Iron River – Proposed 7-South Area 5 (7SA5) Mining Operation

- Iron River Upstream of Mining Operation (IR1) EMS #E297230 – Located upstream of any mine related activity; represents baseline conditions.
- Iron River Upstream of 7SA5 (IR6) EMS #E297231 – Located upstream of any mine related activity (currently); reflects baseline conditions in an area of different geologic formation(s) and baseline water quality influences than IR1 (mainly arsenic concentrations).

- Iron River downstream of 7SA5 and 242 inputs (IR8) EMS #E297232 – Downstream monitoring site on the Iron River; will be used to monitor potential influence of 7-South Area 5 (if developed).
- Quinsam River downstream of the confluence with the Iron River (IRQR) EMS #E299256 –Located downstream of all current and planned (7-South, Area 5) activities; represents the cumulative mine related discharge.

Lake Monitoring Sites

- No Name Lake (NNL) EMS #E217018– Located within the South mine development area.
- Long Lake (LLM) EMS #E206619 – Located within the South mine development area and the monitoring location receives water from No Name Lake, 2-South flooded mine pool as groundwater and surface water (Long Lake Seep). The outlet end receives seepage from 4-South flooded mine pool, estimated at 0.14 m^3/day and south water management discharge (LLE).
- Middle Quinsam Lake (MQL) EMS #E206618 – Located adjacent to the North mine development area and receives all discharge from the North water management system and upstream (non-mine related) inputs. Long Lake flows into Middle Quinsam Lake at the south end near the outlet (WB) via a small tributary stream (LLO).
- Lower Quinsam Lake (LQL) EMS #E292118 – Located well below mine related discharge(s); reflects the combined influences of Quinsam River and Iron River water quality.

2.2.2 *Groundwater Monitoring Sites*

Numerous groundwater observation wells in the vicinity of pits 2N, 1S, 2S, 3S, 4S, 5S, Block 242, and 7S are monitored. The site, location, frequency, and geological details of these wells are listed the *2016-2017 Annual Groundwater Monitoring Report* in Appendix B, Table 1. As an alternative to the 2N, 1S, 2S, 3S, 4S, 5S, and 7S wells, QCC established monitoring sites at underground sumps. During 2016-2017, QCC monitored 37 locations for groundwater. The *"2016-2017 Annual Groundwater Report"* located in Appendix IX outlines sampling methods and analytical results of the monitoring program for groundwater wells and underground sumps. The table below lists groundwater wells monitored in 2016- 2017.

Table 3: Groundwater Wells and Underground Sumps Monitored in 2016-2017

Area	In-Situ Sumps	In-Situ Wells	Ex-Situ Wells	
2-North Ground Water Monitoring	6M2N	1M2N 5M#2 QU10-13 D	QU08-21G S QU10-10 S QU10-11 S	QU08-21G D QU10-10 D QU10-11 D
River Barrier Pillar		QU11-09 M	QU11-05 S QU11-09 S	QU11-05 D
2-North Plant Monitoring Wells			MW00-1 S MW00-6 S	MW00-1 D MW00-6 D
7-South Groundwater Monitoring	1M7S	QU14-10	QU08-10 D QU08-13 B	QU08-13 A
7-South Area 5, 242 Portal Area		242-D		
5-South Monitoring	5SXC	5SMW		
4-South Monitoring Wells		QU11-01 QU78-161	QU10-07 D QU10-09 S	QU10-08 D QU10-09 D
2/3 South Monitoring Wells		QU11-11 MW00-4	MW00-2 MW12-24	MW12-23

2.3 Additional Monitoring Programs

QCC conducts a diverse environmental monitoring program governed largely by the effluent permit PE: 7008. There are also additional baseline water quality monitoring programs and, in 2017, a sediment and benthic invertebrate monitoring program was conducted.

2.3.1 *Baseline Monitoring Programs*

Quinsam conducts additional monitoring to support permit amendment efforts and to provide additional insight into water quality trends and observations. Although this information is not specifically included in this report, the data may be used in future submissions to the MOE. As part of the 7-South Area 5 permit application, baseline monitoring in the Iron River continues to be performed.

Baseline monitoring and characterizing of water quality for future permitting of the 3-South pit continues. An engineered outlet channel was constructed, which will act as a permanent overflow channel connecting the 3-South sub-aqueous PAG-CCR disposal pond to the drainage channel connecting No Name Lake to Long Lake. Monitoring locations include the 2-South Inflow (2SI), 2-South pit near the outflow (2S), 2-South Channel (2SC), and 3-South Pit (3S). Receiving environment monitoring sites are No Name Lake Outlet (NNO) and three locations on the No Name Lake connector channel. The three sites on the connector channel include:

- downstream of the 3S outlet channel (3SDS)
- a tributary to the connector channel (3SDST)
- 100 m downstream of the tributary and the connector channel (3SDS3)

The sites have been monitored on the 5 in 30 schedule during spring, summer, and fall, and more recently on a monthly basis.

2.3.2 *Sediment and Benthic Monitoring*

QCC conducted sediment and benthic monitoring in August through October 2016 to meet condition 4.2.7 (iii) of the amended Permit PE-7008 (dated September 22, 2014). This monitoring program was designed to supplement existing water quality data by evaluating sediment chemistry and benthic biota in waterbodies that receive mine impacted discharges and reference sites with similar characteristics. Appendix VI describes the program, with details provided in Appendix 1, Table 1 (of that report) listing the sampling sites in the five lakes, one wetland, and one river system for a total of 23 sites. Appendix XI, Figures (2-18) display the monitoring site locations and the table below lists the waterbody type, waterbody name and site outlined in the study.

Table 4: Sediment and Benthic Monitoring Sites

Waterbody Type	Waterbody Name	Site
Lakes	No Name Lake (NNL)	No Name Lake Inlet, NNLI (EMS # E224246) No Name Lake Deep, NNLD (EMS # E217018) No Name Lake Near Seep (EMS # E292114) No Name Lake Outlet (EMS # E217017)
	Middle Quinsam Lake (MQL)	Middle Quinsam Lake Inlet (EMS # E206901) Middle Quinsam Lake Deep (EMS # E292115) Middle Quinsam Lake Near Seep (EMS # E292116) Middle Quinsam Lake Outlet (EMS # 0900504)
	Lower Quinsam Lake (LQL)	Lower Quinsam Lake Inlet (EMS # E292117) Lower Quinsam Lake Deep 1 (EMS # E29118) Lower Quinsam Lake Deep 2 (EMS # E292119) Lower Quinsam Lake Outlet (EMS # E292120)
	Long Lake (LL)	Long Lake Inlet (EMS # E292121) Long Lake Deep (EMS # E292122) Long Lake Near Seep (EMS # E292123) Long Lake Outlet (EMS # E219412)
	Gooseneck Lake (GNL)	Middle Gooseneck Lake (EMS # 1132502)
Wetland	Lower Wetland	Lower Wetland Inlet (EMS # E292124) Lower Wetland Middle (EMS # E292125) Lower Wetland Outlet (EMS # E292112)
Quinsam River	at Argonaut Road (WA)	(EMS # 0126402)
	upstream of 7 South Mining Operation (QRDS1)	(EMS # E286930)
	downstream of 7 South Mining Operation (7SQR)	(EMS # E292113)

2.3.3 Long Lake Seep Passive Treatment System & Loading Assessment

Refer to Appendix XII for an annual review of the Long Lake Seep Passive Treatment System and Loading assessment on Long Lake.

2.4 Maintenance & Reclamation Activities

To ensure proper functioning of site wide water management systems, haul roads, roadside ditches, catchment ditches, ponds, culverts, pumps and water lines are maintained on a routine basis. Regular maintenance activities include removal of debris from culverts, replacement of silt fences and straw bales, and removal of sediment build-up from catchment ditches and ponds. Pumps and water lines are inspected daily and maintained as part of the surface inspection.

No operational changes have occurred during the last year, as the Mine has remained in a "*Care and Maintenance"* program since January 2016. Major maintenance of treatment works has not occurred. Composite samplers have been maintained according to the schedule detailed in the *Draft Environmental Procedures Manual*.

Surface disturbance was limited to the South mining area, close to the 3-South pit, where an engineered outlet channel was constructed that will act as a permanent overflow channel connecting the 3-South sub-aqueous PAG-CCR disposal facility to the drainage channel connecting No Name Lake to Long Lake.

The following reclamation and reclamation-related work was completed in 2016 (see the *Annual Reclamation Report for 2016, Mines Act Permit Number C-172* for further details):

- Red Alder seedlings were planted on the 0.78 ha of the 7-South overburden dump upslope of the 7-South settling pond, which had been split into three research plots in 2015 and revegetated with Douglas Fir seedlings +/- Coastal Native Bunchgrass or sodgrass +/- 11-33-11 fertilizer.
- 7-South portal sump slope had top-soil placement and was seeded with Coastal Native Bunchgrass and 11-33-11 fertilizer.
- The 242 mine portal was backfilled with boulder till, with the highwall resloped with till and cover soil and revegetated with Coastal Native Bunchgrass, Sodgrass and an 11-33-11 fertilizer.

- The 3-South outlet channel was constructed, with hydroseed blanketing the disturbed area on both sides of the channel. The hydroseed recipe included Coastal Native Bunchgrass, Coastal Reclamation Mixture seed, and 18-18-18 fertilizer.
- The 3-South east dam construction commenced. The high wall and north dump area was re-contoured and hydroseeded with Coastal Native Bunchgrass, Coastal Reclamation Mixture, and 18-18-18 fertilizer.
- In March 2016, 4-South portals were backfilled and the pad was partially excavated, locating an underground porous culvert, which was subsequently plugged to eliminate water from seeping through the pad. The pad and highwall were resloped with till and cover soil. In April 2016, the area was reforested using Red Alder seedlings, and seeded with Coastal Native Bunchgrass with an 11-33-11 fertilizer.
- The 2-South east highwall was resloped. The resloped highwall and the 2-South west clearing surrounding the weather site was reforested with Red Alder seedlings and seeds, and Coastal Native Bunchgrass with 11-33-11 fertilizer.
- The 1-South sump was infilled and contoured to eliminate water collection, and the surrounding area was hydroseeded with a mixture of Red Alder seed, Coastal Native Bunchgrass, Coastal Reclamation Mixture seed, and 18-18-18 fertilizer.
- 13 exploration drill sites, sumps, and access roads were reclaimed. Reclamation included cementing drillholes, infilling sumps, scarifying drill pads and access roads, and spreading windrowed vegetation back on the drill pads and access roads.
- 25 ha, encompassing the main roads and several soil and till stockpiles were treated with herbicide (targeting Scotch Broom), in accordance with the Quinsam Coal Invasive Plant Management Program.

Reclamation work performed around the 2, 3 & 4 & 7-South areas are expected to substantially improve water quality in the receiving environment by decreasing exposure of weathering waste rock dumps and highwalls

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3.0 Chemical Reagents and Waste Storage

Waste oil and solvents are stored in sealed containers or tidy tanks at secure locations and removed from site for recycling by Terrapure Nanaimo (RS15365). In 2016, 6,300 litres of waste oil was collected and recycled.

Scrap metal at the mine site is collected in designated containers and recycled.

4.0 INCIDENTS - PERMIT LIMIT EXCEEDANCES & PERMIT NON-COMPLIANCES

This section provides a summary of permit limit exceedances and permit non-compliances (PNC) specific to missed samples, parameter analysis, and missing flow data. Appendix 1, Table 2 summarizes permit limit exceedances and non-compliances for 2016/2017. Appendix VII provides the spill reports.

There were 15 reportable total suspended solid (TSS) exceedances and 1 dissolved phosphorous exceedance related to mine discharge during the 2016-2017 reporting period:

- WD: TSS was elevated on 13 occasions correlating to extreme storm events and dewatering of 2-North Mine; spill and non-compliance reports were submitted (DGI 162161, DGI 162328 & DGI 162403 & DGI 163158 & 163326).
- 7SSD: TSS was elevated on two occasions on dates of extreme storm events; the corresponding spill report is DGI 162073.
- Settling Pond #1 at site BDS (under the authorization to bypass the works, E218582) experienced elevated dissolved phosphorous (0.0608 mg/L) above permit limits (0.03 mg/L); the spill report number is DGI 160152.

WD experienced elevated TSS on 13 separate occasions in the Third Quarter (Q3) on October 23rd and November 4th through 13th and again in the Fourth Quarter (Q4) on January 22nd and 30th. The incidents occurred after extreme storm events throughout Q3, which also followed a period of three weeks when there was no dewatering of the 2-North mine pool as the 1-Mains pumping system was down. Once the pumping system was back online, the 2-North, 1-Mains mining section continued to be dewatered. The water levels underground had increased rapidly as a result of precipitation and pump failure and fluctuating water levels may have mobilized local materials and increased TSS levels. PEP was notified upon receipt of results and follow-up action was initiated to ensure the increased TSS levels were localised only; this included additional downstream monitoring and the sample analysis was rushed. Total and dissolved metals were measured in water collected at Settling Pond # 4 and key monitoring locations downstream at WC (which monitors water quality prior to entering Middle Quinsam Lake near the inlet), Middle Quinsam Lake Inlet, and the centre of Middle Quinsam Lake. Initially, the elevated TSS was believed to be associated with elevated iron concentrations, but analytical results indicated concentrations were below the WQG and the permit limit. However, sulphur, sodium, and hardness levels were elevated in the samples. Spill reports were submitted to MoE and MEM.

All other parameters remained below permit limits at Settling Pond # 4 during this monitoring year.

A permit limit exceedance for dissolved phosphorus (P-D) was observed at BDS for one sampling event (April 4, 2016; 0.0608 mg/L). This value exceeded the permit limit of 0.03 mg/L applied to the upstream settling pond, Settling Pond #1 (SPD) E218582 and BDS in accordance with the "*Authorization to Bypass the Works*" letter dated August 25, 2015. A spill report was filed with PEP on April 18. The 24 hour cumulative water volume discharged into Long Lake was 10,722 m^3. Subsequent sampling was performed at upstream sites SPD, SP-EFF, and downstream site Long Lake Entry (LLE); all results were within permit limits.

7SSD experienced elevated TSS levels on two separate events on October 7 and 16, 2016 (27.3 and 35.0 mg/L, respectively). These events occurred after heavy rains.

All PNC incident reports were submitted to the Environmental Compliance website at: environmentalcompliance@gov.bc.ca. These included:

- *Non-compliance PE7008 Missing TSS Equipment Malfunction April 2 - 3rd 2016.* Date submitted April 18, 2016.
- *Non-compliance PE: 7008 Equipment Malfunction May 30 - June 6th, 2016*. Date submitted June 27, 2016.
- *SP4 Non-compliance Equipment Malfunction October 31st through November 20th, 2016.* Date submitted December 1, 2016.
- *Non-compliance PE7008 Missing TSS, Equipment Malfunction October 14, 15, 2016.* Date submitted January 25, 2017.

PNC for continuous discharge occurred intermittently for 29 days out of 365. Discharge was not recorded from May 30 through June 6 and October 31 through November 20, 2016 due to a malfunction in the flow meter. The ISCO Ultra Sonic Flow Meter malfunctioned, erasing continuous flow data. The instrument reset to factory settings while the data was being downloaded to the field laptop. On the second event (October 31 through November 20) field observations and spot measurements were recorded from the flow meter while the new instrument was being shipped to site. A new ISCO signature flow meter with an ultra-sonic level sensor was purchased and installed on November 21, 2016. PNC reports were submitted as required. The instrument has been functioning normally since installation.

As a result of sampler error, no daily composite TSS samples were collected from Settling Pond # 4 on February 21 and 22 and from SPD on February 22, 2017. The composite sampler was functioning normally; however, the samples were not collected, resulting in PNC.

Equipment malfunction occurred at 7SSD on October 14 and 15, resulting in PNC for missed TSS composite samples.

At 7SSD on January 17, 2017 the discharge pipe cracked due to freezing conditions at the discharge line. This damage resulted in a discharge of ponded water for approximately 24 hours (amounting to 25.16245 m^3) and discharged at a rate of 0.29 L/s. Dilution ratios were suitable downstream at 7S during this discharge. As this release of water was not discovered until the next day, a TSS sample was not obtained on the 17^{th}. Throughout the 2016/2017 monitoring year, QCC failed to collect 3 of 21 required composite samples at 7SSD due to equipment malfunction. As a mitigation strategy, the site has had power hard wired to the new composite sampler, which should reduce the risk of equipment failure at this site.

A PNC incident occurred for one sample at SPD on November 9; a daily composite TSS sample was collected but the sample spilled during transit to the laboratory, leaving insufficient volume to analyze for TSS.

A TSS sample was not collected from one monthly sample at WP EMS #E207412 due to the parameter not being included on the chain of custody sent to the analytical laboratory.

Harsh winter conditions (snow and ice) made it unsafe to collect samples on the Iron River and Quinsam River (at IR1, IR6, IR8, 7SQR and IRQR) during February's monthly sampling events.

5.0 MATERIALS AND METHODS: ENVIRONMENTAL MONITORING PROGRAM

Water, sediment, and benthic samples were collected in accordance with methods described in "*The British Columbia Field Sampling Manual for Continuous Monitoring of Air- Emissions, Water, Soil, Sediment, and Biological Samples*" (MOE 2013)[1] and the "*Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators, Version 2, June 2016* (MOE 2016)[2]. This includes following of specified field protocols: use of measures to reduce potential cross-contamination; use of field duplicates, split samples, and method blanks; assessment of within site variability; and checking for transcription errors.

Maxxam Analytics (Burnaby B.C.), a Canadian Association for Laboratory Accreditation (CALA) designated laboratory, conducted the analysis of surface, groundwater, and sediment samples. Phytoplankton samples were analyzed by Stantec Consulting Ltd. (Burnaby B.C.). Zooplankton samples were analyzed by Fraser Environmental (Surrey, B.C.). Benthic samples were analyzed by Cordillera Consulting (Summerland B.C.).

5.1 WATER QUALITY ANALYSIS

PE-7008 identifies the parameters to be analyzed in effluent. Each site has specific requirements for parameters to be analyzed. The following parameters are generally monitored at each station:

- Total suspended solids (TSS) (mg/L)
- Total dissolved solids (TDS) (mg/L)
- pH-Field (standard units)

[1] MOE. 2013. "The British Columbia Field Sampling Manual for Continuous Monitoring of Air- Emissions, Water, Soil, Sediment, and Biological Samples". Available at: http://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/emre/field_sample_man2013.pdf

[2] MOE. 2016. *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators, Version 2, June 2016*. Available at: http://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/water_air_baseline_monitoring.pdf

- Conductivity-Field (uS/cm)
- Alkalinity (mg/L as $CaCO_3$)
- Hardness (mg/L as $CaCO_3$)
- Sulphate (mg/L)
- Ammonia as nitrogen (mg/L)
- Nitrate/nitrite combined as nitrogen (mg/L)
- Dissolved Organic Carbon (mg/L)
- Total phosphorus and dissolved phosphate (mg/L)
- Total and dissolved metals (mg/L)
- Oil and grease (for sites SPD and WD only) (mg/L)
- Rainbow trout bioassays (for sites SPD, WD and 7SSD only)
- 7 Day *Ceriodaphinia dubia* chronic toxicity test (at site 7S only)

The following parameters are specific to lake sampling:

- Dissolved oxygen (mg/L)
- Dissolved oxygen (Percent saturation)
- Temperature (Celsius)
- Light Extinction
- Oxidation reduction potential
- Biological
    - Phytoplankton (chlorophyll “a” and phaeopigment)
    - Phytoplankton (counts and identification to species)
    - Zooplankton (counts and identification to species)
    -

All surface water samples requiring filtering and preserving are collected in 1L plastic bottles and sent to Maxxam as raw water samples; samples were filter and preserved at Maxxam to reduce the risk of cross-contamination on site. Groundwater samples were filtered through a 0.45 µm filter and preserved on site. Maxxam analyzed dissolved and total metals samples using the CCME/BC WQG analytical package to provide suitable detection limits for comparison with guidelines and as per MOE requirements. This included use of conventional and Inductively Coupled Plasma Mass Spectrometry (ICPMS) equipment.

5.2 Environmental Monitoring Equipment

The following equipment was used to conduct the surface monitoring program at Quinsam Coal:

- ISCO 4210 flow meters equipped with a paper chart plotter and datalogger, which are connected to a sonic depth sensor to measure water height above decant (Settling Pond #1) and an ISCO signature flow meter with an ultrasonic sensor (Settling Pond #4). Both instruments use water height to determine discharge by using provided weir/orifice equations. Continuous monitoring is achieved using a datalogger and downloaded using a computer with Flowlink software.
- A Sitrans F M MAG 8000 CT electromagnetic flow meter to record discharge at 7SSD.
- ISCO 12-volt automatic samplers programmed to collect daily composite samples for analysis of TSS deployed at all permitted discharge locations.
- A YSI Exo 1 multiparameter sonde and YSI Pro-Plus, to obtain physical water quality parameters, and calibrated prior to each sampling event following manufacturer specifications for maintenance and handling.
- Two handheld sondes (Eutech PC Tester 35), for routine monitoring of pH and conductivity.
- Levelogger pressure transducers, used to obtain continuous water level measurements at Long Lake Outlet, Middle Quinsam Lake Outlet and the Iron River, with data used to create daily hydrographs.
- A 4 litre Beta sampler, to collect lake water samples; the sampler is constructed with materials to minimize interference cross contamination of metals and the 4 litre volume provides sufficient water for all required analyses in one deployment per depth.
- A Davis Vantage Pro 2 weather site module, to record rain, relative humidly, atmospheric pressure and temperature, with data downloaded via computer.
- A Campbell Scientific weather site, to record temperature, precipitation, wind, humidity, solar intensity, and snow accumulation data (installed next to the 2-South pit in August 2015, became operational in October 2015).
- An Eckman grab sampler, for collection of sediment and benthic invertebrate samples.

Although this list is not exhaustive, it provides an overview of the equipment used for environmental monitoring. Groundwater monitoring equipment is listed in Appendix IX, Section 3 of the Groundwater Report.

5.3 Quality Assurance/Quality Control

Quality Assurance/Quality Control (QA/QC) sampling followed protocols described in MOE (2013, 2016). QA/QC practices were integrated into the water sampling program to maintain the integrity, consistency, and reproducibility of sampling techniques and results of environmental monitoring. Various samples, including field blanks, trip blanks, equipment blanks, and replicates, are used to evaluate methods and identify potential issues related to sampling techniques and equipment. . Each sample type serves a specific purpose:

- Field Blanks – Samples of laboratory-grade, reverse osmosis, deionized water deposited into sample containers in the same location in which a field sample is collected. These samples are carried and treated in the same manner as a field sample to assess any potential cross-contamination that may occur due to sampler technique.
- Trip Blanks – Samples of laboratory-grade, reverse osmosis, deionized water deposited into sample containers in a laboratory setting are transported into field locations with samplers to determine if any cross-contamination occurs due to the handling or storage of sample bottles.
- Equipment Blanks – Samples of laboratory-grade, reverse osmosis, deionized water placed into a piece of equipment at a sampling station to identify potential cross-contamination associated with equipment (e.g., Beta sampler), sampling procedures, or general cleanliness.
- Replicates – Samples collected at the same location and time by the same sampler using the same techniques and equipment. Replicates samples are used to assess precision for each analyte analyzed. Observed variance between replicates identifies uncertainty in sampling, environmental heterogeneity, and laboratory analysis.

Field replicate samples are collected during every sampling event, accounting for approximately 10% of analyses requested from the laboratory. One sampling event may span two or more days. The primary sampling events are:

- Weekly, monthly, and quarterly sampling for all permitted monitoring locations
- 5 in 30 day programs, three times per year for receiving environment sampling for lakes, rivers and streams
- Monthly sampling at Long Lake Treatment System ponds, with a replicate collected quarterly

Relative Percent Difference (RPD) values between replicate samples are calculated using the following formula (MOE 2013):

$$RPD = \frac{(\text{Sample Result - Duplicate Result}) \times 100}{(\text{Sample Result + Duplicate Result}) / 2}$$

The RPD is used to measure variance between replicates and overall integrity and representation of samples. Data quality objectives (DQO) for RPD are set for results where at least one of the duplicates is reported as more than five times the laboratory Method Detection Limit (MDL) and are listed in MOE (2013). Values less than 20% are deemed acceptable; values between 20 and 50% identify a potential problem, and values greater than 50% identify a definite problem. The most likely reason for a high RPD is sample misrepresentation or cross-contamination, heterogeneity of the waterbody, (especially if repeatedly found for a particular site), method or piece of sampling equipment. RPD calculations with values greater than 20% and 50% are presented in Appendix I, Table 64.

During the 2016/2017 monitoring year, 72 replicate surface water samples were collected. Of the 3720 analyzed parameters in these samples, 83 (1.6%) had an RPD greater than 20% while 23 of the 83 (0.6% of total) had an RPD greater than 50%. Duplicate analyses for total copper, dissolved copper, and total aluminum accounted for the most frequent instances of RPD greater than 20%, followed by arsenic, sulphate, iron and manganese. These parameters were above the detection limit in all samples analyzed and typically were more than five times the detection limit, making them more likely to fail than others. Copper accounted for many of the instances of RPD greater than 50%, which might be associated with the low detection limit used. Overall there does not seem to be a parameter displaying enough RPD magnitude to identify a serious problem needing immediate attention. QCC will continue to adhere to sampling practices identified in MOE (2013) and promote best practices at all locations.

All replicates from in-mine release sites had an RPD less than 20% and as a result were not included in this calculation. Of the 83 instances of RPD greater than 20%, 54 were from lake samples and 29 were from river samples (more samples and more replicates were taken from lakes than from rivers). High RPD values were encountered in previous years in lake samples prompting QCC to undertake an internal investigation of lake sampling techniques in 2016. It was concluded that greater cleanliness, care, and storage of lake equipment may increase sampling integrity. The beta sampler was inspected and replaced as small leaks were found near the gaskets that lock the chamber together. A more rigorous cleaning program of the equipment was established in 2016, including the use of hydrochloric acid mixed with deionized water after every lake site to limit cross-contamination and accumulation of any particles. In previous years, between sample locations, the sampler was rinsed three times with deionized water, but not hydrochloric acid. Also, a sonar depth finder was purchased and used to accurately obtain the current bottom depth of each lake sampling location rather than relying on previous data and readings from the sonde's pressure transducer. This reduced the potential for disturbance of water at the sediment interface and introduction of sediment into the sampler. This unit allows greater control of sampling depth and reproducibility of week-to-week sampling elevations for more comparable lake data.

Replicate samples (NNL1, NNL4, NNL9 and WA) saw RPD values for turbidity and TSS (QRSD1) greater than 20% indicating that some metals (total aluminum and copper) associated with those replicates had an RPD greater than 20% suggesting natural heterogeneity within those samples.

The DQO for field blank samples was that concentrations should not be significantly greater nor occur more frequently than for laboratory method blanks (MOE 2013). Results greater than two times the laboratory MDL were identified and investigated to determine potential contamination.

Field blank, trip blank, and equipment blank results of laboratory grade deionized water were within the acceptable range for samples analyzed in 2016/2017 (Appendix I, Table 42). Nine blank samples were analyzed for sulphate and metals; all results met the DQO, indicating acceptable field sample collection and handling.

Results of the 2016/2017 QA/QC review indicate confidence in the ability of QCC to collect and analyze samples that meet required accuracy and precision requirements. Internal performance audits will continue and any identified deficiencies will be investigated to adjust sampling protocol. All employees will be kept up to date with sampling procedures and provided with any training and equipment necessary.

A variance analyses to identify outliers is performed prior to uploading analytical data into the database. Any results outside 95% confidence intervals (within 4 standard deviations) of previous results are investigated, and if needed Maxxam is contacted and the results are rerun and a new report issued that include a review of Maxxam's internal investigation.

Maxxam Analytics laboratory performs internal QA/QC on all sample sets that are analyzed. This is included in the laboratory report provided from Maxxam and reviewed by QCC. The internal QA/QC performed by Maxxam Analytics meets laboratory standards. Maxxam Analytics internal QA/QC involves the following procedures with every sample set analyzed:

- Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.
- Spiked Blank: A blank matrix sample to which a known amount of the analyte, usually from a second source, has been added. Used to evaluate method accuracy.
- Matrix Spike: A sample to which a known amount of the analyte of interest has been added. Used to evaluate sample matrix interference.

6.0 HYDROLOGY

6.1 NORTH WATER MANAGEMENT SYSTEM

6.1.1 *AUTHORIZED DISCHARGE RATES AT SETTLING POND #4 (WD) E207409*

Maximum authorized rates of discharge at WD are 0.32m^3/s (instantaneous) and 0.08m^3/s (annual average) or 2,522,880 m^3 over a period of 365 days. Maximum discharge rates were below 0.32m^3/s in 2016/2017, and were highest (0.236m^3/s) during heavy precipitation events in November and December 2016 and February 2017. Cumulative discharge was 3,401,839 m^3, equivalent to an annual average discharge rate of 0.110m^3/s, which is higher than the authorized average (0.08 m^3/s or 2,522,880 m^3). Figure 4 displays maximum daily discharge and cumulative discharge compared to permit limits.

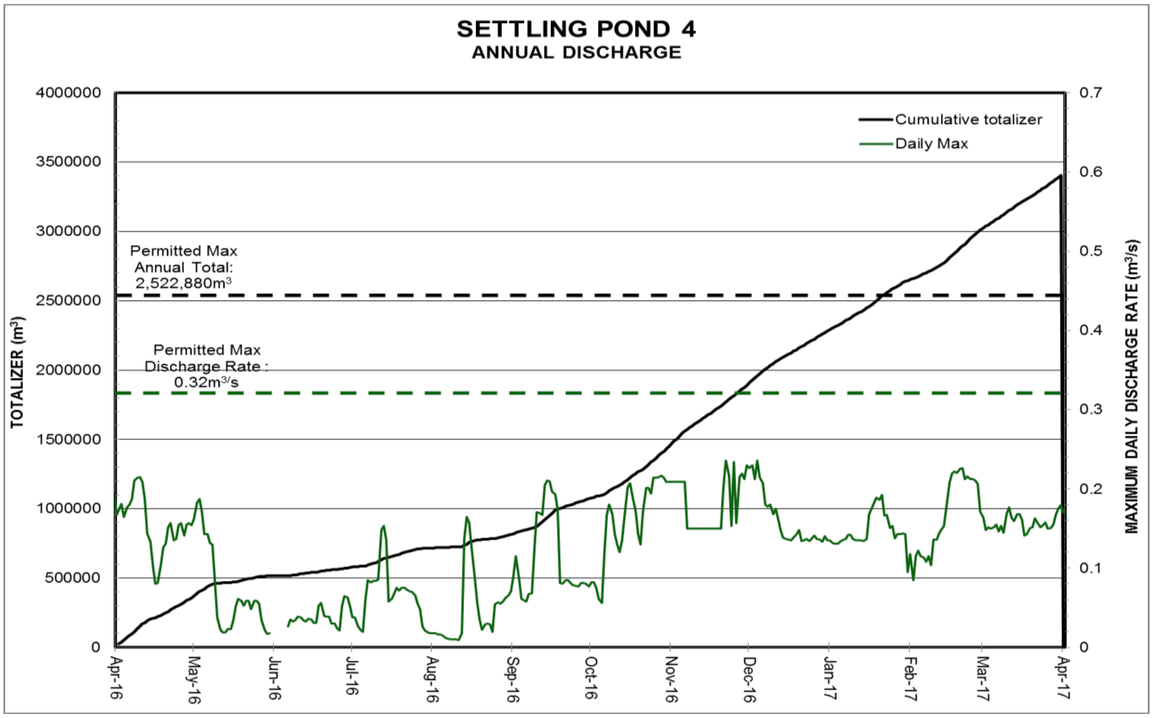

Figure 4: Settling Pond #4 Maximum Daily and Cumulative Discharge, 2016/2017

The annual average flow rate exceeded the maximum permissible value due to elevated discharge rates at WD during spring, fall, and winter coinciding with increased (seasonal) precipitation events. Extreme storm events during the fall and winter seasons increased surface runoff and the rate of underground dewatering to maintain water levels in the 2-North mine. Discharge was higher during the 3rd Quarter (October through December) than in the 4th Quarter (January to March), when conditions were drier and the underground pumping rate was lower.

A summary of discharges from Settling Pond # 4 is displayed in Appendix I, Tables (28-29).

6.2 South Water Management System

6.2.1 *Authorized discharge Rates at Settling Pond #1 (SPD) E218582*

Maximum authorized rates of discharge at SPD are 0.46m^3/s (instantaneous) and 0.10m^3/s (annual average) or 3,153,600m^3 over a period of 365 days. Both annual maximum flow (0.221m^3/s) and annual average flow (0.0290m^3/s) were well below the permitted rates. Figure 5 shows maximum daily discharge and cumulative discharge compared to permit limits.

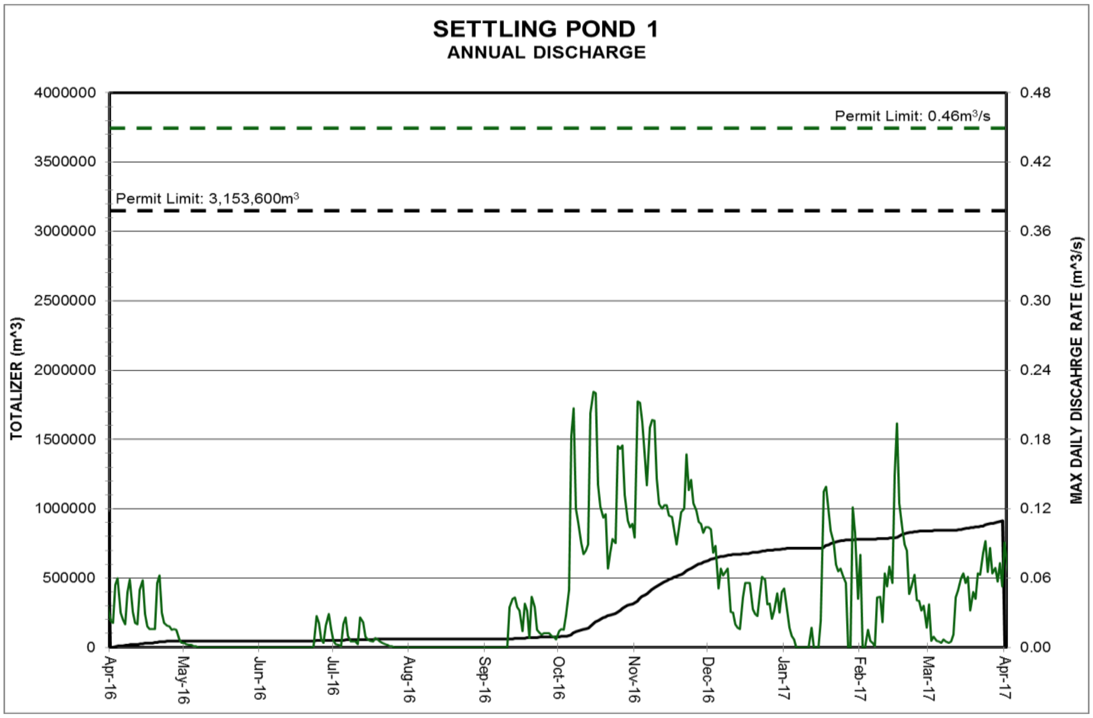

Figure 5: Settling Pond #1 Maximum Daily and Cumulative Discharge, 2016/2017

Daily discharge peaked at SPD several times during October through December and again in February, coinciding with heavy precipitation resulting in increased surface runoff and pumping from the 3-South pit and 5-South underground. The maximum observed rate of discharge was in October 2016. With the low precipitation recorded in spring and summer of 2016, there was no flow recorded from May 7 through June 22 and July 26 through September 10. There was pumping at 3-South pit in summer 2016 with discharge to and out of SPD, due to construction in the pit and surrounding area. Normally the settling pond does not discharge for the entire summer period.

A summary of SPD discharge is displayed in Appendix I, Tables (30-31).

6.2.2 *Initial Dilution zone Monitoring Site, South Water Management System Entrance into Long Lake (LLE) E292130*

Flow monitoring is required weekly at LLE, which discharges near the outlet of Long Lake. Discharge at LLE represents the combined flow from the South water management system (SPD and SPEFF) along with groundwater from the 4-South coal pad area and non-mine related surface water from the upstream wetland and drainage features. As such, this site provides cumulative flow data representing all permitted discharges from the South water management system prior to entering Long Lake near the outlet.

Flow at LLE is well correlated with precipitation events and, historically, experiences a seasonal dry period during summer. However, since commencement of the Long Lake Seep treatment system, a base flow (corresponding with treatment system discharge of 4 L/s) is often present.

Appendix II, Graph 64 displays discharge versus precipitation at LLE.

6.2.3 *Seep Monitoring Sites, Long Lake Seep (LLSM) – E292131*

Manual flow measurements are obtained weekly at the LLSM weir. The flow information is available in Appendix II, Graph 63. The flow recorded at Long Lake Seep indicates a dependency on mine pool (void) water levels as depicted in Figure 6. Mine pool water levels correlate with seasonal precipitation, with highest levels observed in November 2016. As mine pool levels decrease below a certain elevation in late spring, flow at the seep decreases substantially and temporarily stops. In 2016, the seep ceased to flow for four months (May 24 through September 26). It is determined that seep flow is most closely related to water level at the monitoring well MW004 and the threshold level for seep flow is approximately 303.5 - 304 mASL. This trend will continue to be monitored and verified in the future.

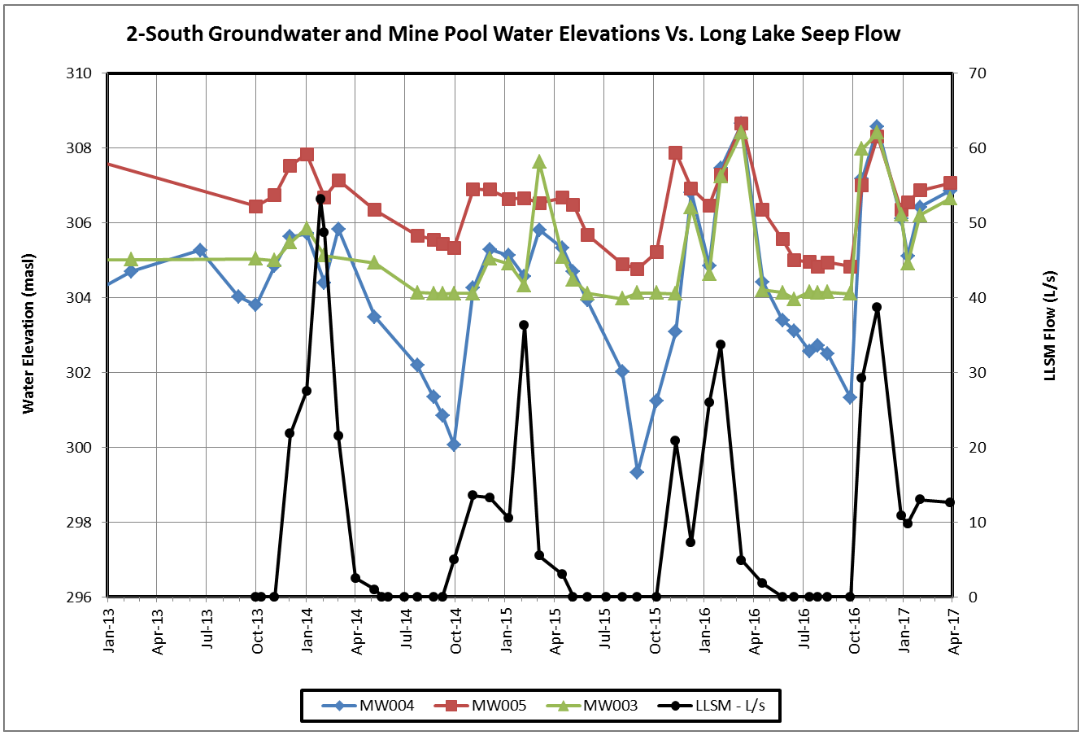

Figure 6: Groundwater and Mine Pool Water Elevations vs. Long Lake Seep Flow, 2016/2017

6.3 7-South Mining Operation Decant (7SSD) - E292069

The maximum authorized discharge from settling pond 7SSD is 0.005m^3/s (5 L/s). However, discharge is dependent on assimilative capacity of Stream 1 (7S) and, therefore, dynamic in nature. To facilitate determination of the appropriate discharge level at 7SSD, a flow rating curve was developed for monitoring site 7S (Figure 7) to allow instantaneous flow levels at 7S to be measured by reading the installed staff gauge.

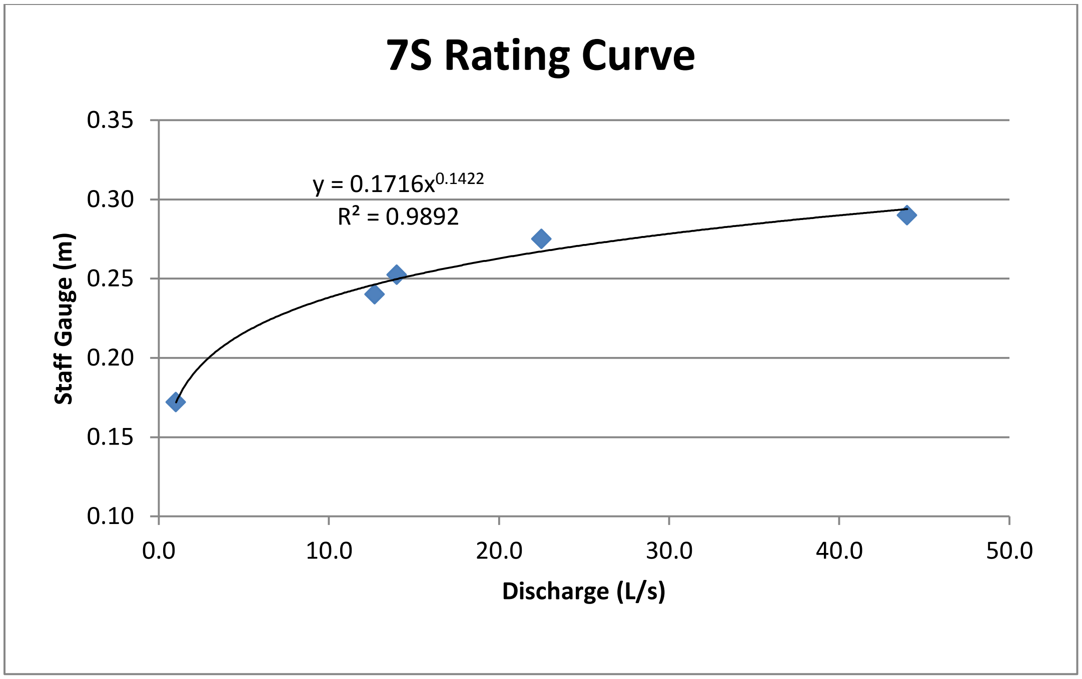

Figure 7: Monitoring Site 7S Stage Discharge Curve

Initially, an 8:1 dilution ratio was identified to maintain desirable water quality in the receiving environment, monitored at downstream site Stream 1 (7S). However, throughout the 7-South operational period, a lower dilution ratio has been shown to allow WQG's to be met in the receiving environment (site 7S). The dynamics of this system are still being monitored and measured; as a longer term dataset is developed, the information will be evaluated to optimize discharge rates, while continuing to protect aquatic life.

In 2015, modifications were made to minimize discharge from 7SSD. The containment pond (7SCP) that delivers water into 7SSD was enlarged to accommodate more water. Additional pumps were placed at 7SSD and 7SCP to decrease 7SSD discharge and assist environmental personnel in water management. The revised system pumps water from 7SSD and 7SCP to 7SPS. The pump at 7SCP runs on an automated float system where water levels are kept below the overflow channel into 7SSD. During high precipitation events, a secondary pump can be activated to assist in pumping water to 7SPS. This pump can also be relocated to 7SSD, where any accumulated water can be diverted into 7SCP. This system does not eliminate all discharge from 7SSD but substantially reduces discharge frequency and aids in management during times of heavy precipitation.

Figure 8 shows 7SSD discharge rates and local precipitation. Discharge rates were substantially reduced during the 2016-2017 monitoring period compared to previous years, which had zero discharge from April to October. Discharge at 7SSD is exclusively influenced by groundwater inputs and precipitation. Appendix I, Table 32, displays cumulative flow measured at 7SSD for 2016/2017. Discharge occurred for 12 days over the year, totaling 731.274 m^3. Maximum discharge rates did not exceed the maximum permitted discharge (5 L/s) and a dilution ratio of >8:1 was maintained at all times. Appendix I, Tables 33-34, provide the 7SSD and 7S dilution ratios for 2016-2017.

Discharge mostly occurred during times of extreme rain events when the inflow volume of water exceeded the pumping capacity.

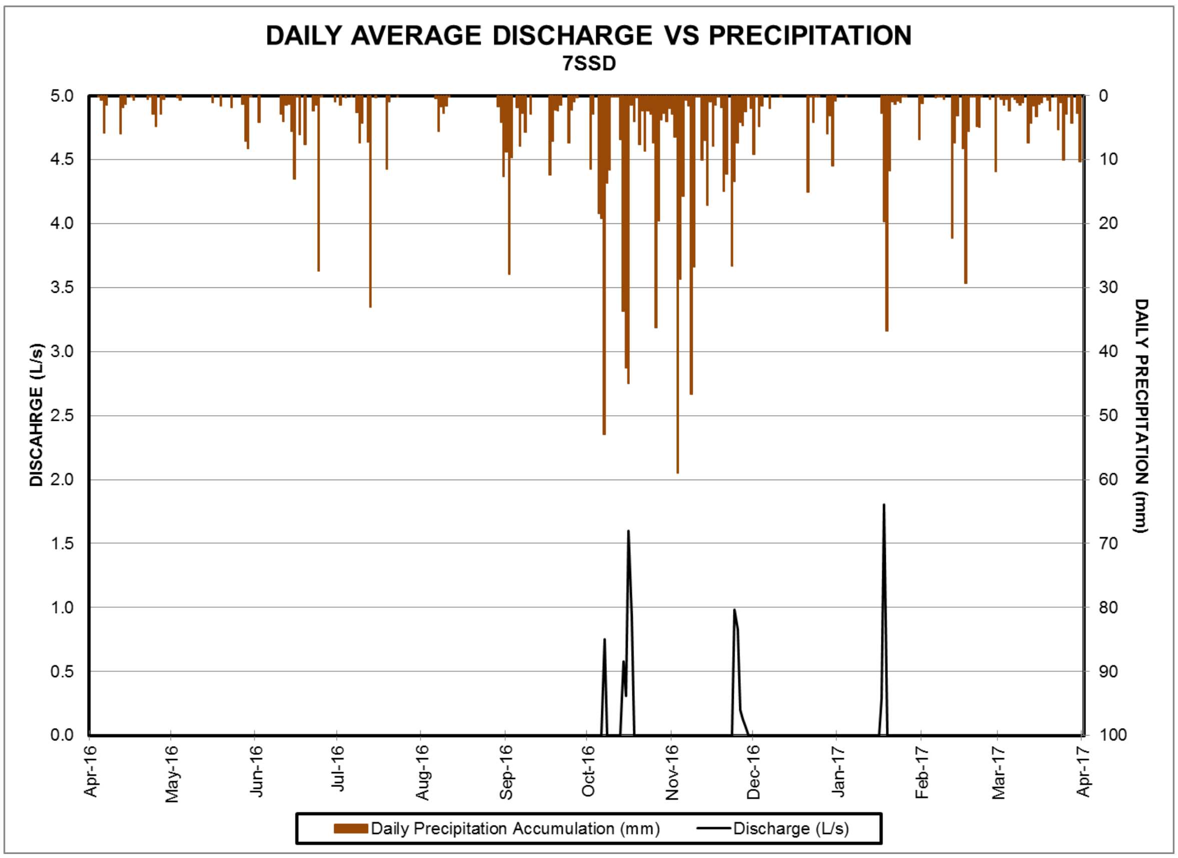

Figure 8: 7SSD Discharge, 2016/2017

6.4 Receiving Environment

Hydrometric stations in the receiving environment monitor hydrological conditions at key locations affected by QCC operations. Stage discharge curves for these stations have been developed using various methods (e.g. staff gauge, pressure transducer, manual measurements) and are periodically updated to ensure that the full range of flow is captured. The information is used to evaluate water quality and, in turn, determine assimilative capacity of the receiving environment with respect to mine related discharge. Moreover, flow is well correlated with lake flushing and turnover events, which directly influence concentrations of certain parameters (e.g. sulphate).

Flow data for WA is obtained from the Environment Canada monitoring station “Quinsam River at the Argonaut Bridge”; the data is currently subject to revision and has not been approved. The flow for WA is controlled upstream by the BC Hydro diversion dam to Gooseneck Lake; therefore, the volume of water diverted for hydro generating purposes influences flows at WA and WB. Accordingly, water levels at these two stations are not as closely correlated with precipitation as they are for other receiving environment stations.

Flow monitoring stations on the Iron River, Stream 1, and Long Lake system(s) are directly influenced by precipitation and the hydrographs typically show a pronounced peak following a precipitation event. This increase generally represents additional dilution and, therefore, assimilative capacity (for most parameters) in the receiving environment.

Appendix II, Graphs (61, 62, 65, 67 and 68) display flows compared to water level measurements and precipitation for the receiving environment hydrometric stations (WA, WB, LLO, 7S and LIR).

7.0 WATER QUALITY: IN-MINE MINE RELEASES & WATER MANAGEMENT SYSTEMS

This section presents results of the 2016/2017 water quality monitoring program for the North, South, and 7-South in-mine releases and water management systems for the major monitoring locations (e.g. settling ponds, discharges) and parameters of interest, to provide context for evaluating receiving environment water quality. The data for all in-mine release water quality monitoring stations are presented in Appendix I, Tables (4 - 27 and 35- 37) with tables (19 and 23) representing the initial dilution zones for the south mine area (LLE) and 7S-South Mine area (7S). Weekly field pH and conductivity results are presented in Appendix I, Tables (38 and 39).

Appendix I, Tables (44 - 74) provide a six year statistical summary (year over year, minimum, maximum, average, median, geometric mean, count, count < detection limit (DL), standard deviation, first quartile, third quartile and standard error) for 27 parameters measured in the Settling Ponds, applicable receiving environment monitoring stations, and ex-situ groundwater wells. Monitoring years 2011-12 to 2016-17 are presented, where data is available. Table 5 below lists the monitoring stations, parameters, and statistics included in this evaluation.

For a summary of permit limit exceedances please refer to Appendix I, Table 2 and Appendix X to review the Annual Status Form prepared for PE-7008.

Table 5: List of Monitoring Stations, Parameters and Statistics

Monitoring Stations		
WA	LLS	
WD	LLSM	QU0813A
MW001D	MW002	QU0813B
MW001S	QU1009D	QU0821GD
MW006D	QU1009S	QU0821GS
MW006S	SPD	QU1010D
WC	LLE	QU1010S
MQL1	LLM1	QU1011D
MQLB	LLMB	QU1011S
NNL1	LLO	QU1105S
NNLB	WB	QU1109S
NNO	7SSD	7SQR
Parameters		
Arsenic (As-T)	Iron (Fe-T)	Lead (Pb-T)
Arsenic (As-D)	Iron (Fe-D)	Lead (Pb-D)
Aluminum (Al-T)	Manganese (Mn-T)	Sulphate (SO4-D)
Aluminum (Al-D)	Manganese (Mn-D)	Zinc (Zn-T)
Alkalinity (Alk-T)	Mercury (Hg-T)	Zinc (Zn-D)
Cadmium (Cd-T)	Mercury (Hg-D)	Phosphorous (P-T)
Cadmium (Cd-D)	Hardness (Hard-T)	Phosphorous (P-D)
Copper (Cu-T)	Nickel (Ni-T)	Nitrate & Nitrite combined (N-NO2,3)
Copper (Cu-D)	Nickel (Ni-D)	Ammonia Nitrate (N-NH3)
Statistics		
Count	Geometric Mean	1st Quartile
Minimum	Count <DL	Median
Maximum	Standard Deviation	3rd Quartile

7.1 North Water Monitoring Sites

The two primary monitoring locations in the North water management system are located at Settling Pond #4, sedimentation pond decant (WD) EMS #E207409 and the final discharge point above Middle Quinsam Lake (WC) EMS #E207411. A discussion for these two sites is presented below. Results for WD and WC including additional monitoring locations in the North mine area are provided in Appendix I, Tables (4 -10 and 37 - 38).

7.1.1 *Settling Pond #4 (WD) EMS #E207409*

Results for the 2016/2017 monitoring program demonstrated that water quality for all permitted parameters (except TSS) were within the permit limits listed in Table 6. Section 4 provides a summary of exceedances and Appendix (VII) provides the submitted Spill Reports. Appendix I, Tables (4, 25, 35 and 38) provide water quality results for Settling Pond #4.

Table 6: Permit Limits Applied to Settling Pond #4

Parameters	Limit	Unit
Total Suspended Solids (daily composite)	25	mg/L
Total Suspended Solids (hourly composite)	35	mg/L
pH	6.0-8.5	mg/L
Ammonia (as N)	1.0	mg/L
Phosphorus (as P)	0.03	mg/L
Oil and Grease (total)	10	mg/L
Aluminum, dissolved	0.5	mg/L
Copper, dissolved	0.02	mg/L
Iron, dissolved	0.3	mg/L
Lead, dissolved	0.05	mg/L
Zinc, dissolved	0.1	mg/L
Rainbow Trout Bioassay (*Oncorhynchus mykiss*)	No mortalities at 100% effluent concentration after 96 hour	96LC50

7.1.2 General Parameters

pH

In 2016/2017, field pH values displayed little variance, ranging from 7.40 to 8.20. Starting in April 2013, field measurements (instead of lab) were used for improved accuracy and reliability. Consequently, a slight decline in reported pH was observed compared to historic results as depicted in Appendix II, Graph 3. Weekly field pH results are provided in Appendix I, Table 38.

Total Suspended Solids (TSS)

There were more TSS exceedances in 2016/2017 than in previous years as extreme storm events led to increased runoff and dewatering of the 2-North underground in quarters three and four. Observations with respect to precipitation, dewatering system operation, pond turbidity, concentrations of TSS and metals will continue to refine best practices and minimize TSS concentrations in WD. Appendix VII presents the information and indicates the situation was attributed to extreme storm events. QCC intends to contact the Director in regards to establishing a maximum level for TSS during extreme storm events, as per Section 2.1.7 of the Effluent Permit, Effluent Characteristics (for Total Suspended Solids). This section states "*Variances may be allowed by the Director for higher discharge rates. The Director may as well, in the future, establish a maximum level for total suspended solids during extreme storm events*".

Hardness and Dissolved Sulphate

Both hardness and sulphate concentrations at WD have displayed marked decreased since 1996; see Graphs 1 and 2 in Appendix II. During 2016/2017, hardness ranged from 292 mg/L to 664 mg/L (averaging 423 mg/L), while sulphate ranged from 320 mg/L to 1170 mg/L (averaging 734 mg/L). Average monthly sulphate concentrations peaked during spring and summer 2016, when discharge rates were lowest signaling minimal mine water dilution and potential evapoconcentration.

As observed in previous years, sulphate concentrations follow a seasonal pattern, with lower concentrations during late winter and early spring and higher concentrations during summer and early fall. Sulphate continues to be the primary parameter of interest from mine related discharges, as it's a common and traceable parameter associated with coal mining.

7.1.2.1 *Dissolved Metals*

Since commencement of underground mining in 1992, dissolved aluminum, copper, iron, lead, and zinc concentrations have remained well below permit limits, with minor, irregular fluctuations noted. In 2016/2017, concentrations measured in samples filtered in the laboratory were typically below detection limits and were well below permit limits. Seasonal trends for parameters of interest were as follows (Appendix II, Graphs 5 through 8):

- Dissolved iron remained below permit limits throughout the monitoring year.
- Dissolved aluminum displayed peak concentrations in October through December, with a maximum of 0.0297 mg/L recorded in November; well below the permit limit of 0.5 mg/L
- Total manganese showed a peak (0.551 mg/L, November 2, 2016) related to high discharge events and TSS exceedances. As there are no permit limits for manganese, concentrations were compared to the WQG of 0.8 mg/L. All results were below the WQG; therefore, adverse effects on the downstream receiving environment would not be expected
- Total iron concentrations have shown an increasing trend since 2006, with concentration variations relating to fluctuating 2-North mine pool water elevations. Concentrations ranged from 0.215 mg/L to 1.33 mg/L in 2016/2017, averaging 0.613 mg/L, with peaks in April 2016 (1.18 mg/L) and December 2016 (1.33 mg/L). The relationship between the mine pool water elevation and elevated total iron concentrations at Settling Pond #4 is believed to be directly related to water flushing the oxidized mine walls and releasing iron into the water column. Appendix II, Graph 8 displays water elevations in the 2-North mine pool (via QU10-13 D) and total iron concentrations at WD

7.1.3 *Culvert into Middle Quinsam Lake (WC) EMS #E207411*

Monitoring station WC represents the cumulative surface water discharge from WD prior to entering Middle Quinsam Lake. Concentrations for parameters of interest are typically slightly lower at WC than at WD, likely attributed to the attenuation that occurs along the WD-WC flow path that includes an expansive wetland. The exception observed is sulphate concentration during summer when discharge and dilution are lowest and evapoconcentration is thought to occur. During 2016/2017, sulphate ranged from 482 mg/L to 1080 mg/L, averaging 691 mg/L at

WC. Metal concentrations are attenuated in the wetland, likely due to uptake by vegetation. This was particularly evident for total iron during times of elevated TSS and iron at WD. Total iron ranged from 0.039 mg/L to 0.147 mg/L averaging 0.309 mg/L. The wetland also provides additional settling and filtration for TSS, which was below the DL (4 mg/L) throughout 2016/2017, even when TSS was elevated at WD (Appendix II, Graph 4). The 2016/2017 results demonstrate the wetland is functioning to reduce TSS before the discharge enters Middle Quinsam Lake. It is important to remember that after passing WC, the discharge water enters another large wetland before entering the inlet of Middle Quinsam Lake approximately 350 m downstream of WC.

7.2 SOUTH WATER MONITORING SITES

The primary monitoring locations in the South water management system are stations that directly influence water quality in Long Lake: Settling Pond #1 decant (SPD) EMS #E218582, Biocell Downstream (BDS), Long Lake Entrance (LLE) EMS #E292130, and Long Lake Seeps (LLS & LLSM) EMS #E292131. The BDS station is an additional location established under the '*Authorization to Bypass the Works*' and is intended to capture the combined discharge of the Long Lake Seep Passive Treatment System Effluent (SPEFF) and SPD. Accordingly, permit limits for SPD have been applied to this site. Please refer to the Long Lake Seep Passive Treatment System and Annual Loading Assessment found in Appendix XII for a full report on loading into Long Lake. This includes point source loading at sites SPD, SPEFF and the Seeps and quantified contributions of dissolved arsenic, iron, sulphate and manganese. The greatest point source contributor of sulphate into Long Lake was SPD with the Seeps contributing the second greatest overall load.

Results for the additional monitoring locations in the South mine area (e.g. SPC) are provided in Appendix I, Tables (11 through 21, 35 through 37 and 39).

7.2.1 *SETTLING POND #1 (SPD) EMS #E218582 AND BIOCELL DOWNSTREAM (BDS)*

These two sites represent the cumulative mine related discharge from the South water management system and are discussed together for ease of comparison. Permit limits applied to SPD and BDS are shown in Table 7. All parameters were below permit limits at SPD and BDS in

2016/2017, except for dissolved phosphorus at BDS on April 4, 2016 (0.0608 mg/L). The corresponding spill report number is DGI 160152.

Table 7: Permit Limits Applied to SPD and BDS

Parameters	Limit	Unit
Total Suspended Solids (daily composite)	25	mg/L
Total Suspended Solids (hourly composite)	35	mg/L
pH	6.0-8.5	mg/L
Ammonia (as N)	1.0	mg/L
Phosphorus (as P)	0.03	mg/L
Oil and Grease (total)	10	mg/L
Aluminum, dissolved	0.5	mg/L
Copper, dissolved	0.02	mg/L
Iron, dissolved	0.5	mg/L
Lead, dissolved	0.05	mg/L
Zinc, dissolved	0.2	mg/L
Rainbow Trout Bioassay (*Oncorhynchus mykiss*)	mortalities at 100% effluent concentration after 96 hour	96LC50

Appendix I, Tables (11, 26 and 35) contain results for SPD water quality while Tables (13, 35 and 39) contain results for BDS. Appendix II, Graphs (9 through 14) display the parameters of interest for SPD.

7.2.1.1 *General Parameters*

pH

All pH readings were within the permit limits at both sites in 2016/2017. Weekly field conductivity and pH are displayed in Appendix I, Table 39. Average field pH was 7.73 at SPD and 7.85 at BDS. Appendix II, Graph 11 indicates peak pH in August and October followed by a decline through fall and winter as discharge commenced, corresponding to pumping from 3-South and 5-South underground.

Nutrients

Dissolved phosphorous exceeded the permit limit of 0.03 mg/L at BDS in April 2016. Ammonia and dissolved phosphorus were below the permit criteria in all other samples from SPD and BDS.

Total Suspended Solids (TSS)

Grab and composite samples for TSS analysis were collected, depending on discharge rates and sampling criteria. TSS ranged from <4.0 mg/L to 15.5 mg/L in 2016/2017 with no permit limit exceedances for SPD or BDS. Most results were less than the detection limit of 4.0 mg/L. During winter, pumping from 5-South underground resulted in TSS concentrations up to 15.5 mg/L. Appendix II, Graph 12 displays the last six years of data for SPD.

Hardness and Dissolved Sulphate

Prior to 2015, the 2 and 3-South pits were the main contributors of sulphate to Settling Pond #1 before dewatering of the 5-South commenced in 2015. As retreat mining was completed in 5-South mine, the workings were isolated from the 2-North mine workings via an engineered bulk head that does not allow in-situ water to interact. Dewatering occurs to maintain water level in the underground workings and alleviate the pressure on the concrete bulk heads that are installed separating 2-North from 5-South. 5-South mine water is transported via pipeline to Settling Pond #1 via a pumping system triggered by increases in water elevation in the 5-South Mine. As water management is now crucial in the 5-South mine pool, excess water is pumped into Settling Pond #1, resulting in increased sulphate concentrations there.

Sulphate concentrations in Settling Pond #1 (and BDS) vary, depending on pumping rates from 5-South underground and 3-South Pit during times of heavy precipitation. Sulphate ranged from 33 mg/L to 632 mg//L and averaged 283 mg/L in 2016/2017. Concentrations were highest from early spring through late summer (low dilution) and lowest during winter (higher flow and high dilution) as shown in Appendix II, Graph 10. Sulphate concentrations will continue to be closely monitored considering the recent flooding of the 2S PAG-CCR facility and dewatering from 5-South.

Typically, there is zero flow at SPD from late spring to early fall as there is minimal pumping from PAG-CCR storage facilities and 5-South. In summer 2016 however, discharge from SPD occurred as dewatering of 3-South was necessary to facilitate equipment access for reclamation activities. There was no discharge from SPD from May 7 through June 22, discharge from June 23 through July 25, and then no discharge from July 26 to September 11. As such, sulphate concentrations measured at BDS are directly related to SPEFF, with 100% of the flow at BDS discharged from the treatment system. Appendix I, Table 35, displays weekly sulphate results at BDS, SPD, and SPEFF.

7.2.1.2 *Dissolved Metals*

Dissolved aluminum, copper, iron, lead, and zinc concentrations at SPD and BDS were below their permit limits during 2016/2017.

7.2.2 *Long Lake Entrance (LLE) EMS #E2922130*

LLE is the most downstream monitoring station in the South Water Management System and represents cumulative mine water discharge into Long Lake (excluding the seeps). This station is located at the outflow of a culvert discharging from a wetland, and effluent flows through an approximately 50 m long channel before entering Long Lake. LLE is not defined as a receiving environment station but rather constitutes the upstream segment of a mixing zone defined as the IDZ in the permit. For observation purposes, results for LLE are compared to WQGs to assess overall water management system performance and influence on Long Lake.

Sulphate and dissolved iron are two main parameters of interest at LLE; both frequently exceeding WQG as displayed in Appendix II, Graphs 22 and 23. In 2016/2017, sulphate ranged from 81 mg/L to 566 mg/L (averaging 283 mg/L) with peak concentrations observed in late summer during the low flow period. Sulphate concentrations exceeded the WQG of 128 mg/L for 50 of 52 weekly samples when applying a five week rolling average. The sulphate WQG varies with hardness (see Table 8) and QCC follows a conservative approach defined in the WQG assuming a background hardness of 30 mg/L (very soft water, measured at WA) to derive a sulphate WQG of 128 mg/L. If the water hardness of 218 mg/L found at LLE was applied, the sulphate WQG would be 429 mg/L resulting in exceedances for only 4 of 52 weeks. If the average hardness in Long Lake (63 mg/L) was applied, the WQG would be 218 mg/L resulting in exceedances for 23 of 52 weeks. These comparisons demonstrate the conservative approach incorporated into the WQG for protection of aquatic life.

Table 8: Approved 30-day Average Water Quality Guideline for Sulphate to Protect Aquatic Life

Water hardness* (mg/L)	Sulphate water quality guideline (mg/L)
Very Soft (0-30)	128
Soft to moderately soft (31-75)	218
Moderately soft/hard to hard (76-180)	309
Very hard (181-250)	429
>250	Need to determine based on site water

Dissolved iron exceeded the WQG maximum of 0.35 mg/L in 2 of 12 monthly sampling events (0.595 mg/L in January and 0.358 mg/L in March 2017). This was mostly likely related to high flow conditions causing the mixing of iron-rich bottom waters of the wetland into surface water discharged at LLE. The high flows may have inhibited the typical redox reactions and iron precipitation processes that reduce dissolved iron to particulate iron. Total iron concentrations were not elevated in 2016/2017.

The Vancouver Island Objective (VIO) for streams defines a maximum suitable concentration for total phosphorous of 0.01 mg/L and an average concentration of 0.005 mg/L applied from May through September. Exceedances occurred for two of the five samples and the 5 month average found at 0.0113 mg/L in August, 0.0182 mg/L in September and an average concentration using of 0.0106 mg/L. As previously stated, LLE is not considered a stream and the VIO is used for general comparison. Nutrients are monitored at LLE to assess loading from the treatment system for potential adverse effects on Long Lake and the downstream receiving environment. The elevated concentrations are most likely attributed to natural biotic processes including assimilation by vegetation, plankton, periphyton, and microorganisms. In wetlands, macrophytes play a significant role in uptake, assimilation and storage of phosphorous. Macrophytes absorb phosphorous directly from the water column and release it shortly after upon vegetation decomposition (R. Reddy, R. H. Kadlec, E. Flaig & P. M. Gale.1999)[3]. Elevated total phosphorus concentrations have been measured since before the treatment system was installed as displayed in the figure below. The measured concentrations are unlikely to result in eutrophication downstream given the low discharge rates from LLE during summer and the absence of a measurable increase in phosphorus in Long Lake where LLE enters the lake.

[3]R. Reddy, R. H. Kadlec, E. Flaig & P. M. Gale .1999. Phosphorus Retention in Streams and Wetlands: A Review, Critical Reviews in Environmental Science and Technology, 29:1, 83-146K

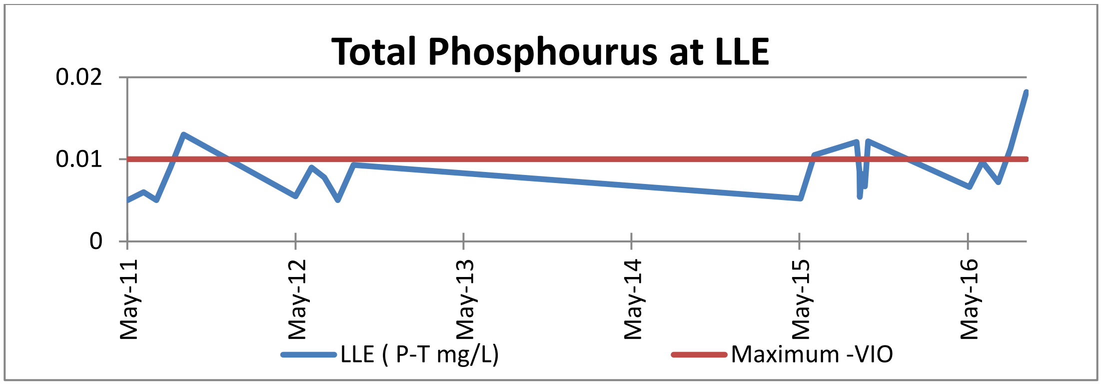

Figure 9: Total Phosphorus at LLE, 2016

Sulphate, iron, and TSS concentrations are influenced by precipitation events and source loading from the multiple disturbance areas within the South mining area. As sulphate and iron were found in high concentrations throughout routine monitoring, Lorax was contracted to perform a loading assessment for LLE to investigate the potential influence from the 4-South portal area. This was followed up with further water quality monitoring at LLE during times of low flow and additional studies. Lorax submitted a study in February 2017 entitled "LLE Wetland Survey and Iron Discharge Study." Quinsam submitted a report in April 2017 entitled "4-South Loading - LLE Water Quality Summary Report (Including Historical Reports)". These studies provide a greater understanding of elevated iron and sulphate concentrations within the LLE wetland.

Lorax (2017) concluded:

> "*The study results indicated that iron introduced into the LLE wetland via 4S-Lo is particulate Fe3+, which is stored within the wetland. Under typical conditions, the particulate Fe3+ settles in the wetland pond and cycles between the wetland substrate and the base of the oxic surface water layer. Water discharging from the wetland and sampled at LLE on August 29th, 2016 had a low concentration of Fe-T, and iron was less than detection limit in all the filtered samples. These data indicate that iron being discharged to Long Lake is present as particulate iron, which has a relatively low bioavailability. Therefore, potential effects from mine-related inputs of iron to Long Lake should be assessed for the Fe-T fraction."*

Water quality has improved following the reclamation work performed on the 4-South Pad as well as the new culvert (at a slightly higher elevation) installation at LLE. In 2016/2017, there were no exceedances for total iron and manganese and only two exceedances for dissolved iron, demonstrating that water quality has improved substantially from previous years.

Appendix I, Tables (19, 36 and 39) provide the full set of data collected at LLE. A statistical summary of the past six years is available in Appendix I, Tables 44 through 74. Appendix II, Graph (66) displays discharge versus precipitation at LLE.

7.2.3 *Long Lake Seep*

The seep into Long Lake is a bedrock groundwater seep delivering water from the 2-South mine pool. This seep is monitored for water quality and quantity to assess overall loading into Long Lake. Long Lake seep water chemistry is influenced by groundwater levels in the 2 and 3-South mining area(s) and is subject to seasonal 'flushing' events due to local precipitation and infiltration.

Two seep sites are monitored on a continuous basis – LLS is the smaller seep and LLSM is the middle seep. LLSM is considered the primary seep, as flows at this site are typically much higher (and variable) than LLS; as such, the hydrology monitoring station is located on this seep.

Overall, water chemistry at both seeps remained consistent with that observed during previous reporting periods. A similar pattern of high flow during winter and no flow through summer and early fall was observed in 2016; however, the dry period (June-October 11) did not extend as long as in 2015 (June through November 23) but was similar to the four month dry period reported for 2014. This was a direct result of the amount of precipitation received at the mine site during 2016-2017. The middle seep ceases to flow when the mine pool water level falls below the elevation of approximately 303.5-304 metres above sea level (mASL) (measured at MW00-4).

Sulphate concentrations at the middle seep (LLSM) are elevated with higher concentrations during winter and lower concentrations through spring. Concentrations at the smaller seep (LLS) are elevated during winter and spring and decrease slightly during summer and early fall. Although results are available for LLS, the cumulative flow at this site was negligible. The increase in sulphate concentrations observed during winter is thought to be attributed to oxidation (and leaching) of the mine void walls as displayed in Appendix II, Graph 24.

Other parameters of interest include arsenic, iron, and total manganese. Both arsenic and iron have exhibited decreasing trends in recent years. Total manganese concentrations have remained fairly stable, although in 2016/2017, they were lower than in previous years. Metals display the same seasonal trend as sulphate, with peak concentrations in the winter. Appendix II, Graphs 25 - 26 displays the concentrations of dissolved arsenic and total manganese since 2011. Concentrations of dissolved arsenic have decreased slightly since 2011, typically remaining below 0.004 mg/L but with one event above 0.005 mg/L in 2012. Total manganese has remained below the WQG of 0.8 mg/L since 2011.

Dissolved iron has decreased substantially and remained stable since mid-2012, when QCC transitioned from field filtering to laboratory filtering of dissolved metals.

During 2016/2017, monthly water quality samples were collected from the seeps with results included in Appendix I, Tables 20-21 and 39.

7.3 7-South Water Monitoring Sites

The 7-South water management system is comprised of a number of structures (Section 2.3) to manage local water in and around the disturbed area, with the most substantial structure being the 7-South settling pond (7SSD). This structure represents the point of discharge for 7-South operations and is regulated under PE-7008. Table 9 outlines the applicable permit limits at 7SSD for each controlled parameter.

Table 9: Permit Limits Applied to 7SSD EMS #E292069

Parameters	Limit	Unit
Total Suspended Solids (daily composite)	25	mg/L
Total Suspended Solids (hourly composite)	35	mg/L
pH	6.0-8.0	mg/L
Sulphate	500	mg/L
Aluminum, dissolved	0.1	mg/L
Cadmium, dissolved	0.000045	mg/L
Copper, dissolved	0.014	mg/L
Iron, dissolved	0.35	mg/L
Selenium, dissolved	0.016	mg/L
Rainbow Trout Bioassay (*Oncorhynchus mykiss*)	No mortalities at 100% effluent concentration after 96 hour	-

7.3.1 *7-South Settling Pond (7SSD) EMS #E292069*

The following discussion highlights parameters of interest at 7SSD EMS #E292069 with respect to discharge water quality and potential influence in the Lower Wetland and Quinsam River receiving environment. A discussion of settling pond performance and validation of actual effluent water quality compared to the water quality prediction model developed for the 7-South water management plan by Lorax follows.

Complete water chemistry datasets can be found in Appendix I, Tables (22- 23, 128, 131-134, 151, and 153-162). Appendix II, Graphs (15 through 21) display the parameters of interest for 7SSD compared to 7S.

7.3.1.1 *General Parameters*

pH

In 2016/2017, pH was generally within the permit limit range (6.0 – 8.0), with weekly measurements ranging from 7.8 to 8.1 (average of 7.81).

Weekly pH and conductivity values for 7SSD are displayed in Appendix I, Table 38.

Total Suspended Solids (TSS)

The TSS ranged from <4.0 mg/L to 35.0 mg/L, with an average of 7.43 mg/L. There were 2 events where TSS was elevated above the permit limit of 25 mg/L (October 7 and 16, 2016) as a result of high surface erosion and low pond retention time during extreme storm events. Improved water management strategies such as revegetation of the surrounding banks and area as well as reduced discharge due to pumping systems have aided greatly in reducing TSS and overall discharge quantities.

Appendix I, Table 27 and Appendix II, Graph 16 display discharge versus daily TSS results at 7SSD.

Dissolved Sulphate

Concentrations of sulphate have decreased substantially since initiation of the management systems as improved practices have been applied. These concentrations have continued to decline into 2017 as improved pumping systems limit the amount of mine impacted water entering the pond. For example, the average sulphate concentration for 2014/2015 was 117.4 mg/L, compared to an average for 2016/2017 of 15.8 mg/L after secondary pumps were installed. Much of the water entering the settling pond is direct rain water and has proven to limit the quantities discharged substantially. These results and observations reflect the effectiveness of improved management measures employed at the 7-South operational footprint to mitigate overall sulphate loading.

7.3.1.2 *Dissolved Metals*

There were no permit limit exceedances for any metals at 7SSD. The settling pond only discharged for 12 days in 2016/2017, with intermittent discharge in October, November, and January. Appendix I, Tables 22 and 32 display the data and discharge quantities, respectively for 7SSD. Tables 9 and 10 display the predicted (expected case and worst case) water quality compared to measured concentrations for parameters of interest at 7SSD and 7S, respectively. Table 9 indicates that dissolved arsenic is the only parameter at 7SSD with a measured concentration at the worst case prediction. Peak arsenic concentrations were measured in summer, resulting from low pond water levels and decreased dilution from precipitation. The pond was not discharging at the time of collection and most samples were collected from the ponded water. When discharge commenced in October, arsenic concentrations were low at both 7SSD and 7S (downstream) as depicted in Appendix II, Graph 18.

Table 10: Water Quality Prediction Model-Best and Worst Case Scenarios Compared to Measured Concentrations at 7SSD

7SSD WQ (2016-17 Averages)				
Parameter	**Expected Case (mg/L)**	**Worst Case (mg/L)**	**Average (mg/L)**	**Result**
Fluoride	0.122-0.134	0.150-0.161	N/A	
Sulphate	56-71	139.3-180.5	15.82	**Below Expected**
Aluminum	0.040-0.041	0.110-0.113	0.009	**Below Expected**
Arsenic	0.001	0.002	0.002	**At Worst Case**
Boron	0.069-0.082	0.152-0.186	0.05	**Below Expected**
Cadmium	0.000012-0.00013	0.000037-0.000040	0.0000037	**Below Expected**
Cobalt	0.00015-0.00017	0.00161-0.00211	0.00048	**Between Expected and Worst**
Copper	0.004	0.006	0.001	**Below Expected**
Iron	0.034	0.130-0.133	0.018	**Below Expected**
Manganese	0.016-0.017	0.054-0.066	0.053	**Between Expected and Worse**
Nickel	0.001	0.003-0.004	0.0005	**Below Expected**
Selenium	0.00193-0.00194	0.00612-0.00632	0.0001	**Below Expected**
Zinc	0.003	0.006	0.0025	**Below Expected**

***When calculating averages, 0.5 of the method detection limit values were used.**

Table 11: Water Quality Prediction Model-Best and Worst Case Scenarios Compared to Measured Concentrations at 7S

7S WQ (2016-17 Averages)				
Parameter	**Expected Case (mg/L)**	**Worst Case (mg/L)**	**Average (mg/L)**	**Result**
Fluoride	N/A	N/A	N/A	
Sulphate	6.49-7.80	15.4-17.8	2.99	**Below Expected**
Aluminum	0.043	0.055-0.056	0.038	**Below Expected**
Arsenic	0.0002	0.0003	0.000086	**Below Expected**
Boron	0.052-0.063	0.061-0.063	0.050	**Below Expected**
Cadmium	0.000010	0.000013	0.000003	**Below Expected**
Cobalt	0.00046-0.00047	0.00062-0.00065	0.00048	**Between Expected and Worse**
Copper	0.001	0.001	0.000394	**Below Expected**
Iron	0.020-0.021	0.030-0.031	0.00975	**Below Expected**
Manganese	0.0026-0.003	0.007	0.00054	**Below Expected**
Nickel	0.001	0.001	0.0005	**Below Expected**
Selenium	0.00028-0.00030	0.00070-0.00075	0.0001	**Below Expected**
Zinc	0.005	0.005	0.0025	**Below Expected**

***When calculating averages, 0.5 of the method detection limit values were used.**

Measured concentrations of sulphate, aluminum, cadmium, copper, iron, nickel, and selenium were below the expected case predictions. Measured concentrations of cobalt and manganese were above the expected predictions but below the worst case predictions at 7SSD. Cobalt was the only parameter observed between expected and worst case at 7S. Of the twelve parameters modelled, the annual average concentrations of nine parameters were below the expected case predictions, two were in-between, and one was at the worst case prediction. This is a marked improvement from previous years. Water quality measured at 7S compared to the model predictions had eleven parameters below the expected predictions and one in-between. This indicates that during 2016-17 monitoring year, measured water quality has improved from previous years, likely due to the adopted management practices over the past few years.

7.4 Middle Point Facility

All water samples collected in 2016/2017 had TSS, pH, and oil and grease concentrations below the permit limits at the Middle Point Facility. Results are presented in Appendix I, Table 75.

7.5 BIOASSAYS

PE-7008 indicates that rainbow trout (*Oncorhynchus mykiss*) LC_{50} bioassays are required once per year (fall flush) at BDS for Settling Pond #1, EMS# E218582 and at Settling Pond #4, EMS# E207409. The bioassays are performed using 100% (non-diluted) discharge water to assess the potential survival of rainbow trout over a period of 96 hours. A successful test sees no mortalities throughout the 96 hour period. Discharge was collected from BDS and Settling Pond 4 on October 20, 2016. On November 22, 2016 an extra rainbow trout LC_{50} bioassay was collected from monitoring site WC, EMS# E207411 to assess water quality downstream of Settling Pond #4 due to repeated TSS permit exceedances.

The permit requires a 96 hour LC_{50} test on *Oncorhynchus mykiss* to be completed using 7SSD EMS# E292069 effluent water and, concurrently, a 7-day *Ceriodaphnia dubia* test from water obtained from 7S, EMS# E292109. This is required twice per year; once during the spring freshet and once during the fall flush. The discharge from 7SSD pond was minimal (11 days) in 2016/2017 and low discharge quantities resulted in omitting the spring freshet sample. The fall flush sample was collected on October 17, 2016 at 7SSD and, concurrently at 7S.

All rainbow trout bioassays and the *Cedriodaphnia dubia* bioassay had 100% survival (Appendix III). This indicated that mine related discharges at BDS, Settling Pond 4, 7SSD, WC and receiving environment monitoring station 7S were compliant, with no acute toxicity in the discharges.

8.0 WATER QUALITY IN THE RECEIVING ENVIRONMENT

<u>Preamble – Water Hardness</u>

For this report, hardness dependent WQGs were derived using background levels of hardness (i.e., monitoring location WA ~30 mg/L) to provide a conservative assessment of receiving environment water quality. Guidelines and objectives do not have legal status but are designed to provide resource managers with direction and comparison for protection of receiving environments with aquatic life.

<u>Guidelines and Objectives:</u> Receiving environment water quality is compared to the British Columbia Ambient WQG for Protection of Aquatic Life for most parameters. The exceptions are hypolimnetic DO (using WQO based on a site specific conditions), total cobalt and total lead

(using more recently established Water Quality Objectives (WQO)[4]), and total phosphorus in streams (using the Vancouver Island objective[5]). Table 11 lists the WQG, WQO and VIO used to screen receiving water quality.

Table 12: Water Quality Guidelines and Objectives Applied to Receiving Environment Stations

Parameter	Lakes (mg/L)		Streams (mg/L)	
	Maximum	5 in 30 day Avg	Maximum	5 in 30 day Avg
Phosphorus - total	0.007 summer avg - Long Lake		0.01	0.005**
	0.006 summer avg - Middle Quinsam L		(May-September)	
Turbidity	n/a	n/a	5.0 NTU	1.0 NTU
Non-filterable residue or TSS	25	5	n/a	n/a
Hypolimnetic DO	3 mg/L minimum during June-August		n/a	n/a
pH	6.5 - 9	n/a	6.5 – 9	n/a
Aluminum (dissolved)	0.1	0.05	0.1	0.05
Arsenic (total)	0.005	n/a	0.005	n/a
*Cadmium (dissolved)	0.00017	0.000088	0.0017	0.000088
Cobalt (total)	0.05	0.004	0.05	0.004
Copper (total)	0.007	0.002	0.007	0.002
Iron (total)	1.0	n/a	1.0	n/a
Iron (dissolved)	0.35	n/a	0.35	n/a
Lead (total)	0.005	0.003	0.005	0.003
Manganese (total)	0.8	0.7	0.8	0.7
Mercury (total)	0.0001	n/a	0.0001	n/a
Nickel (total)	0.025	n/a	0.025	n/a
Silver (total)	0.0001	n/a	0.0001	n/a
Zinc (total)	0.03	n/a	0.03	n/a
*Sulphate dissolved	n/a	128	n/a	128

* Values represent Middle Quinsam sub-basin water quality using WA hardness. Iron River guidelines will be different based on seasonal hardness at IR1

** Average based on monthly samples from May to Sept

[4] Campbell River Area Middle Quinsam Lake Sub-Basin Water Quality Assessment and Objectives. Ministry of Environment. 1989

[5] Guidance Document for Phosphorous Management in Vancouver Island Streams. Ministry of Environment. 2012

Water quality at locations outside of the Middle Quinsam Lake Sub-basin, such as the Iron River and 7-South (7S and LWO), are compared exclusively to the WQG.

8.1 LAKES

The monitoring program for the Middle Quinsam Lake Sub-basin employed a 5 in 30 sampling approach at No Name Lake (NNL), Long Lake (LLM), Middle Quinsam Lake (MQL), and Lower Quinsam Lake (LQL). There are four depths monitored at each lake:

- 1 metre below surface (1 m)
- 4 metres below surface (4 m)
- 9 metres below surface (9 m)
- 1 metre above bottom (1mb)

Monitoring occurred during three separate periods:

- Spring – April/May 2016
- Summer – August 2016
- Fall – October/November 2016

The table below summarizes those parameters above WQG and WQO observed in the lakes for 2016/2017. A summary table is also provided in Appendix I, Table 3. Appendix I, Tables (44 through 75) provide a statistical summary for parameters of interest with Tables (76 through 79), displaying the depth profiles and field results, and Tables (80 through 127) displaying the water chemistry results compared to WQG and WQO. Appendix II, Graphs (27 through 52) illustrate parameter trends at each lake.

Table 13: Summary of Water Quality Guideline Observations at Lake Monitoring Sites

SUMMARY OF WATER QUALITY GUIDELINE OBSERVATIONS AT RECEIVING MONITORING LOCATIONS

EMS ID & Site Name	Site Code & Depth	Parameter	Units	Guideline Limit	Result	Date	Guideline	Sampling Events Exceeding Guideline
E217018 - No Name Lake (NNL)	NNL 7-11 metres	pH-F	pH	6.5	6.16 to 6.47	Apr. 14th, 28th & May 11th	Min	(13/55) Depths profiled during spring
	NNL 7-11 metres				5.79 - 6.49	Summer 5 in 30	Min	(15/58) Depths profiled during summer
	NNL 1-12 metres				5.35 - 6.49	Oct. 27th, Nov. 3rd & 9th	Min	(31/63) Depths profiled during fall
	NNL 1 metre	Al-D	mg/L	0.05	0.0519	Fall 5 in 30	A	Average fall 5 in 30 was exceeded at 1 metre, 4 metre and 9 metre depths
	NNL 4 metre				0.0526			
	NNL 9 metre				0.0511			
E217017 - No Name Lake Outlet (NNO)	NNO	Al-D	mg/L	0.05	0.0521	Fall 5 in 30	A	Fall 5 in 30
E206619- Long Lake Middle (LLM)	LLM 1-20.6 metres	pH-F	pH	6.5	5.83 - 6.44	Oct. 27th, Nov. 3rd & 9th	Min	(68/102) Depths profiled during fall
	LLM 9 metre	SO4-D	mg/L	128	133	Spring 5 in 30	A	Spring 5 in 30 at 9 metres
	LLM 1 metre from bottom (LLMB)				134	Spring 5 in 30	A	Spring 5 in 30 at 1 metre from bottom
					131	Fall 5 in 30	A	Fall 5 in 30 at 1 metre from bottom
	LLMB	Mn-T	mg/L	0.8	0.998 & 1.02	Oct. 27th & Nov. 3rd	M	(2/5) Fall Sampling Events
E206618- Middle Quinsam Lake (MQL)	MQL 13-13.5 metres	Hypolimnetic DO	mg/L	3 mg/L minimum June through August	0.73 & 2.73	Sept. 1st	Min	(2/13.5) depths profiled on Sept. 1st were below 3mg/L. Guideline is from Jun-Aug.
E292118 - Lower Quinsam Lake (LQL)	LQL 15-16.4 metres	pH-F	pH	6.5	6.28 - 6.38	Aug. 31st	Min	(3/16.4) depths profiled on Aug. 31st
	LQL 12-16.4 metres	Hypolimnetic DO	mg/L	3 mg/L minimum June through August	0.00 - 2.81	Summer 5 in 30	Min	(22/81) depths profiled
	LQL 1 metre	Al-D	mg/L	0.05	0.0631	Fall 5 in 30	A	Fall 5 in 30
	LQL 4 metre				0.0625	Fall 5 in 30	A	Fall 5 in 30
	LQL 9 metre				0.0631	Fall 5 in 30	A	Fall 5 in 30
	LQL 1 metre from bottom (LQLB)	Al-D	mg/L	0.05	0.0641	Fall 5 in 30	A	Fall 5 in 30
		Fe-D	mg/L	0.35	0.498, 0.380 & 0.382	Aug. 3rd, 9th & 17th	M	(3/5) Summer Sampling Events
		Fe-T	mg/L	1.00	1.22, 1.15, 1.65 & 1.37	Aug. 3rd, 17th, 25th & 31st	M	(4/5) Summer Sampling Events

8.1.1 *Seasonal Trends*

Spring and fall sampling is timed to cover the times of lake turnover, when water circulates freely in the water column and nutrients become more available for phytoplankton growth (Wetzel 2001)[6]. Water is most dense at 4ºC, and during winter, the surface water (epilimnion) is typically colder than 4ºC and the deeper water (hypolimnion) is at about 4ºC (displaying inverse stratification). Spring turnover occurs when the surface water warms to 4ºC and begins to mix with the deeper water. The lake circulates freely throughout the water column for several days (Wetzel 2001). Through the spring and summer, surface temperatures increase, establishing a thermocline (region of rapid temperature change), with warmer water above and cooler water below. Temperatures cool in late summer, and eventually the thermal stratification breaks down, leading to fall overturn and to mixing of the water column. As surface waters continue to cool, a colder layer overlies the dense bottom water (4ºC) and inverse stratification persists from late fall to spring. During periods with distinct stratification, it has been observed that water chemistry often displays variable concentrations throughout the water column. During overturn, nutrients associated with decomposition of organic matter that has sunk to the bottom are brought into surface waters, where they are available for phytoplankton growth. The timing and duration of spring and fall turnover depend on the size and depth of the lake.

8.1.1.1 *Spring*

The spring sampling program is scheduled to capture the lake turnover that typically occurs in conjunction with warmer temperatures, snowmelt, and increased precipitation. Spring sampling spanned from April 13 through May 11, 2016 during this monitoring year. The sampling regime was triggered after a significant precipitation event and warm temperatures where 300 mm of precipitation was received in March.

In 2016, spring turnover occurred during the last half of the sampling period, when temperatures increased to 4ºC in the upper water column.

[6] Wetzel, R.G. 2001. Limnology, Third Edition. Academic Press, San Diego CA.

Noteworthy observations resulting from the spring lake monitoring program include:

- Spring turnover was observed in all lakes during April as the ambient temperature was unusually warm when lake sampling commenced. Surface temperatures warmed to above 16℃ in all lakes during the fifth week of sampling
- Sulphate remained below the WQG (128 mg/L) in NNL, MQL, and LQL at all depths, and at LLM at 1 and 4 m, however exceeded the WQG at LLM at 9 m and 1 m from bottom
- No Name Lake continued to experience low pH values at depth.

The only parameters of interest that were higher than WQGs during spring sampling were sulphate (deep water at LLM) and pH (deep water at NNL).

8.1.1.2 *Summer*

The summer sampling program is scheduled to capture the period of low flow and lake stratification. In 2016, the summer program ran from August 3 through September 1. The summer program represents the lake's seasonal thermal stratification and a time when deeper lakes naturally develop anoxia in deeper waters. Results from this sampling period represent low dilution conditions when the lakes display minimum assimilative capacity and mine related surface discharges and groundwater infiltration have the greatest influence.

During the summer sampling program, there were high ambient temperatures and low precipitation (177.80 mm accumulated precipitation for June through August), with 78.30 mm in June, 68.9 mm in July, and 30.60 mm in August. This was comparable to summer 2015 (150 mm for June through August).

Noteworthy observations resulting from the summer monitoring program include:

- Sulphate was at or below the WQG (128 mg/L) in NNL, MQL LLM, LQL at all depths, with the maximum (128 mg/L) measures at LLM 1mb

- LLM 1mb had lower average Mn-T concentrations in summer 2016 (0.467mg/L) than in summer 2015 (2.24 mg/L), and were below the WQG average (0.7 mg/L) in 2016 (above the WQG in previous years)
- NNL and LQL had lower pH at depth than in surface waters,
- Hypolimnetic DO was below the site-specific WQG (3 mg/L) in LQL and MQL,
- Total and dissolved iron was elevated above WQG on occasions at 1mb in LQL.

8.1.1.3 *Fall*

The fall sampling program is scheduled to capture the period of elevated precipitation following the summer dry season, representing a 'fall flushing' event that is correlated with elevated surface water metal concentrations resulting from localized weathering and mobilization. The lakes turn over in the fall as the water temperatures decrease and high inflows return. In 2016, the fall monitoring program was initiated on October 27 and ran through November 21 during a time of heavy precipitation (728.70 mm from September 29 through November 21). This was notably higher than fall 2015, when only 285.3 mm of accumulated precipitation was reported for September through November 21.

Noteworthy observations resulting from the fall monitoring program include:

- Precipitation was high, with lake inflows and water levels greater than observed in many years,
- Water quality parameters at most lakes remained below WQGs and WQOs; exceedances occurred at LLM, NNL and LQL.
- All lakes had higher hypolimnetic DO levels compared to fall of previous years, resulting in decreased concentrations of iron and manganese at the sediment water interface (1mb depth),
- Sulphate concentrations were at or below the WQG (128 mg/L) in NNL, MQL, and LQL at all depths, and at LLM at all depths except LLM 1mb (with an average of 131 mg/L) ,
- In LLM, average sulphate concentrations at 1 and 4 m depths were lower in fall 2016 than in fall 2015 and the average concentration at 1 m was the lowest recorded since 5 in 30 sampling began in 2013,
- In MQL average sulphate concentrations for the four depths sampled ranged from 26 mg/L to 31 mg/L
- In LLM, Mn-T concentrations at 1mb in 2016 were the lowest since 2012 (average 0.53 mg/L); two of five samples exceeded the WQG maximum (0.8 mg/L)
- In LQL 1mb, total and dissolved iron concentrations declined below WQG's in fall 2016
- NNL and LLM had lower pH during the first three weeks of sampling below WQG's
- In LQL all depths and NNL 1, 4, and 9 m depths, the average Al-D concentrations were higher than the WQG average (0.05 mg/L).

8.1.1.4 *General Parameters*

pH

Lakes that are deeper and thermally stratified normally have pH that ranges from alkaline on the surface (epilimnion) to slightly acidic at bottom depths (hypolimnion). This trend is typically more pronounced during summer, when the lake is stratified and surface temperatures are elevated.

During 2016, NNL had several occurrences where pH fell below the WQG minimum of 6.5. For the depth profiles, this included 13 of 55 measurements in spring, 15 of 58 measurements in summer, and 31 of 63 measurements in fall.

Factors that may contribute to acidic conditions observed through the water column of NNL include:

- Natural conditions – the western end of the sub-basin is surrounded by a vast wetland; organic wetland soils tend to be acidic
- Limited turnover – temperature gradients are relatively small during spring and NNL is shallow (~12-13 m) compared to Long Lake depth of 20 m and Lower Quinsam Lake depth of 16 -18 m
- Anthropogenic sources – i.e., mining and logging in the area

NNL has a shallow basin (12-13 m) and a large drainage area. Since monitoring began in 2012, slightly acidic conditions have been recorded throughout the water column during spring, summer and fall sampling events, with most of the readings below the WQG of 6.5. Appendix II, Graph (28) displays pH values from 2012 to 2016 at 1 m, 4 m, 9 m, and 1mb. Baseline water quality sampling performed by MoE 1983 and 1984 also indicated pH less than 6.5 at depth. Monitoring will continue at NNL and and No Name Lake Outlet, with trends for pH evaluated.

The sampling location on No Name Lake is considered to be outside of mine related discharge, and low pH values are not believed to be associated with mining activities. No direct surface mine discharge locations to No Name Lake have been identified and the low pH is understood to be naturally occurring.

In Long Lake, pH ranged from 5.83 to 7.44 averaging 6.80 during 2016. In spring and summer 2016, stratification was apparent between 1 m and 4 m depths, where pH ranged from 6.58 to

7.37; pH was lower at 9 m and 1 mb. During fall, pH was below the WQG (in 68 of 102 cumulative depths profiled and is attributed to inflows from No Name Lake and the large amount of precipitation received. In the fall, LLM had pH less than 6.5 through the entire water column during the first three weeks of monitoring; pH was below 6.5 in the hypolimnion (16.0 - 19.8 m) on all five weeks of monitoring. Results are displayed in Appendix I, Table (77) & Appendix II, Graph (33).

Middle Quinsam Lake is generally neutral to slightly basic throughout the spring, summer, and fall and continued for 2016 (all samples above the WQG minimum). Both WA and WC, which enter Middle Quinsam Lake exhibit neutral pH. Results are displayed in Appendix I, Table (29) & Appendix II, Graph (71).

In Lower Quinsam Lake, pH was lower (6.28 to 6.38) than the WQG minimum in the hypolimnetic zone for one event during the summer 2016 sampling period (3 of 16.4 cumulative depth profiles, August 31), but was otherwise in the neutral range averaging 7.15 throughout the water column during the three sampling periods. Results are displayed in Appendix I, Table (79) & Appendix II, Graph (47).

HARDNESS

The WQG for sulphate and several metals varies with hardness. Water is defined as very soft if hardness ranges from 0 - 30 mg/L and soft to moderately soft at 31- 75 mg/L. No Name Lake is considered to have very soft water (average concentration of 13 mg/L in 2016). Lower Quinsam Lake is characterized as very soft to moderately soft (average concentration of 29 mg/L to 31 mg/L in 2016). Since summer of 2014, Middle Quinsam Lake has had soft to moderately soft water (average of 34 mg/L in 2016, similar throughout the water column in all three sampling periods; Appendix II, Graph (39)). Long Lake generally has moderate to hard water (higher hardness in deep water), but the range varies with season and depth. In spring, hardness averaged 82 mg/L at 1 m depth and 123 mg/L at 4 m depth; concentrations were lower in fall, with an average of 25 mg/L at 1 m and 61 mg/L at 4 m. The deeper waters of Long Lake were less variable, with spring to fall averages of 136 mg/L to 106 mg/L at 9 m and 125 mg/L to 134 at 1mb.

In all four lakes, hardness was slightly higher at surface during summer than during fall and spring, indicating flushing and dilution from rain and/or runoff after the summer. During summer, hardness was higher at surface than at depth in No Name and Lower Quinsam lakes, in contrast to Long Lake, which had higher hardness at depth than at surface. This could be an indication of groundwater infiltration to Long Lake or the greater depth of Long Lake (19-20 m), which would have lower flushing in the hypolimnion zone.

SULPHATE

As noted in Section 7.2.2 and Table 7, the sulphate WQG is hardness dependent, but for QCC, it is set at 128 mg/L (applying a background hardness of 30 mg/L from monitoring station WA, upstream of mine influences).

Sulphate concentrations were lower than the WQG of 128 mg/L in No Name, Middle Quinsam, and Lower Quinsam lakes at all depths and in Long Lake at 1 m and 4 m depths during the three sampling periods. It was just above the WQG in Long Lake at 9 m (133 mg/L) and 1mb (134 mg/L) during spring and at 1mb during fall (131 mg/L). If the sulphate WQG was derived using hardness measured in Long Lake (31 to 180 mg/L), it would range from 218 mg/L (1 m and 4 m) to 309 mg/L (9 m and 1mb). Recognizing that hardness and sulphate concentrations in Long Lake reflect the influence of mining discharges, and not baseline conditions, a higher hardness-defined WQG would still be protective of aquatic life, given the protective mechanism provided by hardness (MOE 2013)[7].

Sulphate concentrations increased with depth in LLM, MQL, and NNL and appeared to be correlated with thermal stratification. In LQL, concentrations decreased with depth.

In 2016, sulphate concentrations in Long Lake were greatest during spring at all depths. Average concentrations declined during the summer at 1 m and 4 m depths, but remained high at 9 m and 1mb. Lower concentrations during summer were associated with the limited contribution from the seeps and limited to no surface discharge from Settling Pond #1. There was a large decrease between spring and fall at 1 m (average of 73 mg/L in spring vs. 16.15 mg/L in fall) and 4m (average of 120.6 mg/L in spring vs. 57.7 mg/L in fall). In deep water, the average concentrations were similar in spring and fall (133 mg/L in spring and 103 mg/L in fall at 9 m; 134 mg/L in spring

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[7] Ministry of Environment. 2013. Ambient water quality guidelines for sulphate. Technical Appendix Update. Available at:http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/bc_moe_wqg_sulphate.pd

and 131 mg/L in fall at 1mb). This vertical pattern through the seasons suggests that the deeper water (19 to 20 m depth) does not fully flush.

In Middle Quinsam Lake, the fall 2014 monitoring indicated a decrease in sulphate concentrations at 1 mb from above 128 mg/L to below 20 mg/L after a flushing event. Sulphate concentrations have remained below 52 mg/L since fall 2014. In 2016, the average sulphate concentrations were similar from surface to bottom during the three sampling periods (annual average of 26.9 mg/L). In contrast to previous years, concentrations were highest in surface waters during spring and summer 2016, and decreased slightly in the fall.

No Name Lake and Lower Quinsam lakes continued to have sulphate concentrations well below the WQG in 2016. In Lower Quinsam Lake, peak concentrations were reported during summer at 4 m (average of 22.4 mg/L), and suggested some influence of mining related discharges. In No Name Lake, the average sulphate concentration was below 3 mg/L for all three monitoring periods.

Hypolimnetic Dissolved Oxygen

The hypolimnetic dissolved oxygen (DO) Water Quality Objective of 3 mg/L minimum in June through August was developed for the Water Quality Objectives for Middle Quinsam Lake Sub-basin (MQL and LL) however, Quinsam applies this objective to NNL and LQL. The hypolimnion is the dense, cold bottom layer below the thermocline in a thermally stratified lake. Typically, the hypolimnion is the coldest layer in summer and the warmest layer during winter. Anoxic conditions may develop naturally in deep waters over the summer due to the lack of circulation with upper, oxic water during stratification and consumption of DO by microorganisms and chemical reactions. The reducing environment can cause lake sediments to release iron, manganese, sulfide, and arsenic, all of which could have potential toxicological effects on aquatic receptors.

In 2016, hypolimnetic DO in Long Lake was above 3 mg/L during the summer sampling period but decreased in the fall to less than 3 mg/L. Middle Quinsam and Lower Quinsam Lake exhibited anoxic conditions in the hypolimnion during the summer. On September 1, Middle Quinsam Lake had a DO of 2.73 mg/L at 13 m and 0.73 mg/L at 13.5 m. In Lower Quinsam Lake, water at 12 to 16 m had DO below 3 mg/L for all five weeks of sampling during summer; this lake has a deep basin (17 m) and typically experiences low DO at depth when stratification is pronounced.

8.1.1.5 *Total and Dissolved Metals*

Concentrations of most metals at the four lake monitoring stations were low throughout the spring, summer, and fall sampling periods. Elevated concentrations of dissolved aluminum, total and dissolved iron, and total manganese were observed in some lakes, as discussed below.

Iron and Dissolved Oxygen

Total and dissolved iron (Fe-T and Fe-D) concentrations in the four lakes have displayed similar trends since 2013: low concentrations near surface throughout the year; low concentrations at all depths during spring; and increased concentrations at depth during anoxic conditions during summer and fall. Iron concentrations were well below WQGs for No Name, Long, and Middle Quinsam Lakes (all depths) and at Lower Quinsam Lake (all depths except 1mb).

Lower Quinsam Lake (at 1mb) had elevated Fe-T and Fe-D above the WQGs several times during the summer sampling period. The maximum exceedance for Fe-T resulted in 1.65 mg/L and Fe-D resulted in 0.498 mg/L during fall. This is one of the deepest lakes sampled (17 m depth), and the elevated iron concentrations are directly related to anoxic conditions and associated increase in iron solubility at the sediment/water interface. Appendix II, Graphs (51 and 52) display the inverse relationship between low DO and elevated iron concentrations: when DO decreases below 3 mg/L, iron concentrations increase. Sediment in Lower Quinsam Lake has elevated iron concentrations, higher than sediment quality guidelines in several samples (Appendix I, Tables 221-224).

Manganese and Dissolved Oxygen

A similar relationship exists with manganese (Mn-T) and low dissolved oxygen In Long Lake as observed with iron at LQL. Mn-T concentrations have been found to be inversely proportionate to dissolved oxygen concentrations and are found at highest levels when DO falls below 3 mg/L. In 2016, Mn-T concentrations were lower than in previous years, with fewer WQG exceedances. Total Mn in LL has been found in greatest concentrations at the 9m and 1mb depths where Mn-T has been observed in moderate to elevated concentrations since 2006. Peak concentrations were observed in 2015 at depth when concentrations of DO fell well below 3 mg/L.

Manganese was marginally higher than the WQG maximum (0.8 mg/L) in Long Lake at 1mb during the first two weeks of the fall 2016 sampling period (with a DO of 1.99 mg/L and 1.82 mg/L). At this time, the lake water level was particularly high due to heavy precipitation events and the 1mb samples were taken at 20.3 m and 20.5 m (normally taken at 19 m). The average concentrations did not exceed the WQG average (0.7 mg/L). During the third week of fall sampling, DO continued to decline but Mn-T concentrations declined to <0.5 mg/L; this suggested there may have been a malfunction in the DO probe. Appendix II, Graphs 37 and 38 display the maximum and 5 in 30 average concentrations of total manganese at Long Lake, respectively.

A similar trend of elevated Mn-T with low DO was identified for Lower Quinsam Lake at 1mb during the summer monitoring period. However, concentrations did not exceed the WQG maximum or average during 2016, Appendix II, Graphs 49 and 50 depict these trends.

The Ambient Water Quality Guidelines for Manganese[8] state:

> "*Mn is only slightly to moderately toxic to aquatic organisms in excessive amounts. It is present in almost all organisms and often ameliorates the hazard posed by other metals. Hence jurisdictions in the international arena have not disseminated for Mn guidelines to protect freshwater and marine life. Mn availability and, hence its toxicity in the aquatic environment, can be influenced by many factors including water hardness.*"

In deeper lakes, stratification may result in anoxic conditions in the hypolimnion and the dissolution of the iron and manganese from sediment. Casey (2009)[9] noted:

> "*Iron and manganese are commonly found in groundwater and some surface water such as lakes that have a significant groundwater input. The existence of Fe-D and or Mn-T in groundwater generally infers prior anaerobic conditions with the result that the water is likely to be devoid of oxygen and may also have a high carbon dioxide (CO_2) concentration. As well as being associated with groundwater input the existence of Fe-D and Mn-T in some deep lakes and reservoirs may be due to stratification, resulting in the development of anaerobic conditions in the bottom water zone and the dissolution of the iron and manganese from floor deposits*."

Long Lake has historically been characterized as having very low DO at depth, with levels in September to October below 4 mg/L at depths greater than 15 m (Kangasniemi.1989)[10]. Nordin

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8 Ministry of Environment.2013. Ambient Water Quality Guidelines for Manganese

9 Casey,T.J. 2009. Iron and Manganese in Water Occurrence, Drinking Water Standards and Treatment Options through the Aquavarra Research LMT Water Engineering Papers. Paper 3..

(2006)[11] reported that Long Lake stratifies into hyperlimnion and hypolimnion sections in April and May and remains stratified until October through November. Appendix II Graph 34 displays the inverse relationship between historical DO vs Mn-T reported at 1 mb since 2005 that occurs during late summer and fall when DO levels decline to below 3 mg/L.

SLR (2015)[12] suggested these findings have potential implications for the means by which sediments and Contaminants of Potential Concern (COPC) are distributed in Long Lake. They suggested that the deepest portion of the lake has the greatest potential to accumulate and retain COPC's whose mobility in aquatic systems is affected by oxygen availability in overlying waters and sediments.

It is conceivable that manganese has a greater loading rate from the parent rock and substrate materials, with mobility accelerated by anoxic conditions at depth (SLR.2015); The regional geology of Long Lake is divided in half with the Nanaimo group in the southern half and the Island Plutonic Suite (IPS) in the northern half (SLR.2015); this could have implications for different loading of arsenic and possibly manganese and other metals from parent material (SLR.2015).

The Mn-T concentrations in deep waters of the lakes do not appear to be mine related, as concentrations at most discharge locations remains low; however, the WQG exceedances are of concerns for assessing potential effects in the receiving environment and trends will continue to be monitored in subsequent years.

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[10] Kangasniemi, B.J.1989.Campbell River Area Middle Quinsam Lake Sub-Basin Water Quality Assessment and Objectives. Ministry of Environment, Lands and Parks. Summary.

[11] Nordin, R.N.2006.An Evaluation of the sediment quality and invertebrate benthic communities of Long and Middle Quinsam Lakes with regards to local coal mining activity.

[12]SLR.2015. Sediment Quality, Toxicity, and Bioavailability Review with Background Assessment Based on Current Knowledge of Sediment Dynamics and interpretation or Pre and Post Mining Sediment Concentrations and Distribution.

Arsenic

Arsenic has become a parameter of interest in the Quinsam watershed, particularly for Long Lake, however this parameter is not observed to be elevated in the receiving environment water quality. In the 2016 monitoring programs, arsenic concentrations were well below the WQG (0.005 mg/L), in the four lakes monitored, and so is not a specific concern. Arsenic concentrations in sediment were elevated above guidelines in Long Lake, No Name Lake, and Lower Quinsam Lake (see Section 9.1) and in ex-situ groundwater throughout the site due to the host rock geology (See Appendix IX).The water quality data confirms that arsenic found in the sediment is not transported into the water column, even during times of anoxic conditions.

Aluminum

Aluminum is normally present at concentrations below WQGs but was occasionally elevated above WQGs in 2016. Dissolved aluminum (Al-D) concentrations exceeded the WQG average (0.05 mg/L) during fall in NNL (1 m, 4 m, and 9 m) and at No Name Lake outlet (NNO) as well as LQL (1mb). Al-D was just below the WQG average at LLM (1 m, 4 m, and 9m). Al-D has been naturally elevated above the WQG in background samples taken upstream, associated with runoff and flushing events. During spring and fall sampling on the Iron River upstream monitoring stations (IR1 and IR6) not influenced by mining, also experienced elevated Al-D concentrations.

8.2 River and Stream Sites

The table below summarizes those river and stream sites that were observed to have parameters in excess of the WQG's. This table is also available in Appendix I, Table 3.

Table 14: Summary of Water Quality Guideline Exceedances in the Streams and Rivers

SUMMARY OF WATER QUALITY GUIDELINE OBSERVATIONS AT RECEIVING MONITORING LOCATIONS								
EMS ID & Site Name	**Site Code & Depth**	**Parameter**	**Units**	**Guideline Limit**	**Result**	**Date**	**Guideline**	**Sampling Events Exceeding Guideline**
E286930 - Quinsam River Upstream of 7-South Mining Operation (QRDS1)	QRDS1	Zn-T	mg/L	0.0075	0.0225	Spring 5 in 30	A	Spring 5 in 30 (max. result of 0.0927 mg/L increased average. All other Zn-T results were below detection limits.
				0.033	0.0927	Apr. 12th	M	(1/5) Samples collected during spring. Maximum result may be an outlier.
E292112 - Lower Wetland Outlet at the Confluence of Quinsam River (LWO)	LWO	Al-D	mg/L	0.05	0.1446	Spring 5 in 30	A	Spring 5 in 30
				0.1	0.126, 0.103, 0.153, 0.184 & 0.157	Spring 5 in 30	M	(5/5) Spring Sampling Events
				0.05	0.0799	Summer 5 in 30	A	Summer 5 in 30
				0.1	0.128 & 0.102	Oct. 12 & Oct. 31	M	(2/5) Fall Sampling Events
				0.05	0.0767	Fall 5 in 30	A	Fall 5 in 30
		Cu-T	mg/L	0.002	0.00255	Spring 5 in 30	A	Spring 5 in 30
					0.00233	Summer 5 in 30	A	Summer 5 in 30
		Fe-D	mg/L	0.35	0.494, 0.444, 1.15, 1.640 & 1.25	Spring 5 in 30	M	(5/5) Spring Sampling Events
					0.462, 0.489, 0.536, 0.657 & 0.615	Summer 5 in 30	M	(5/5) Summer Sampling Events
		Fe-T	mg/L	1.00	1.88, 2.91 & 2.06	Apr 27th, May 3rd & 10th	M	(3/5) Spring Sampling Events
					1.110 & 1.100	Summer 5 in 30	M	(2/5) Summer Sampling Events
		TSS	mg/L	5.00	5.6	Summer 5 in 30	A	Summer 5 in 30
E292113 - Quinsam River Downstream of 7-South Mining Operation (7SQR)	7SQR	As-T	mg/L	0.005	0.00558	Aug.11	M	(1/5) Summer Sampling Events
		P-T	mg/L	0.01	0.0117	Aug.11	M	VIO- (1/4) Monthly samples from Jun - Sep
E297230 - Quinsam River Upstream of Mining Operations (IR1)	IR1	Al-D	mg/L	0.05	0.0670	Spring 5 in 30	A	Spring 5 in 30
				0.05	0.0765	Fall 5 in 30	A	Fall 5 in 30
				0.1	0.105	Oct.26	M	(1/5) Fall Sampling Events
E297231 - Iron River Upstream of 7SA5 (IR6)	IR6	Al-D	mg/L	0.05	0.0721	Spring 5 in 30	A	Spring 5 in 30
				0.05	0.109	Fall 5 in 30	A	Fall 5 in 30
				0.1	0.114, 0.147 & 0.113	Oct.18th, 26th & Nov. 10th	M	(3/5) Fall Sampling Events
E297232 - Iron River Downstream of 7SA5 & 242 Inputs (IR8)	IR8	Al-D	mg/L	0.05	0.0725	Spring 5 in 30	A	Spring 5 in 30
				0.05	0.0982	Fall 5 in 30	A	Fall 5 in 30
				0.1	0.133 & 0.101	Oct. 26th & Nov. 10th	M	(2/5) Fall Sampling Events
		As-T	mg/L	0.005	0.00556, 0.00599, 0.00803 & 0.00886	Summer 5 in 30	M	(4/5) Summer Sampling Events
E299256 - Quinsam River Downstream of the Confluence with the Iron River (IRQR)	IRQR	Al-D	mg/L	0.05	0.0587	Fall 5 in 30	A	Fall 5 in 30
For all Middle Quinsam Lake Sub-basin results background hardness of 30 mg/L was used to calculate those parameters that are hardness dependent.								
For Iron River results IR1 average hardness was used to calculate hardness dependent parameters. 5 in 30 average hardness concentrations = 24 mg/L for Spring, 73 mg/L Summer and 30 mg/L for Fall.								

8.2.1 *Middle Quinsam Lake Inflow (WA) EMS #0126402 and Outflow (WB) EMS #0900504*

Comparing Middle Quinsam Lake's inlet (WA) EMS # 0126402 and outlet (WB) EMS #0900504 offers an opportunity to assess potential mine-related effects on Middle Quinsam Lake water quality. Furthermore, water quality results from WA are considered "baseline" for the Middle Quinsam sub-basin receiving environment stations as it is situated upstream of any mine related discharge. Data obtained from WB (outlet of Middle Quinsam Lake) provides information on lake water quality after the addition of discharges from the South water management system, shallow and deep groundwater, Long Lake Outlet (LLO), mine related discharge from Settling Pond #4, and other anthropogenic sources (e.g., logging). Summary statistics for the last six years are provided in Appendix I, Tables 44 and 74 with Tables 128 through 133 presenting water quality data for WA and WB providing a comparison to WQOs and WQGs. Appendix II, Graph (63) displays Middle Quinsam Lake daily inflow obtained at the WA hydrometric station and Graph (64) compares discharge at WB with precipitation. Appendix II, Graphs (53 through 59) display the parameters of interest or those found elevated above guidelines (dissolved sulphate, aluminum, total arsenic and zinc) in the Quinsam Sub-basin.

TSS results at WA and WB remained below detection limits (<4.0 mg/L) throughout all sampling events as reported in previous years, and are expected to continue. Samples for WB are collected below the Coal Main road crossing on the Quinsam River and the low TSS results reflect the efforts made in reducing sediment and erosion at this location.

The pH values were similar at WA and WB. During 2016/2017, pH at WA and WB was weakly alkaline and within the WQG range of 6.5-9.0; pH values averaged 7.68 at WA and 7.71 at WB.

Conductivity at WB reflected the mine influences (elevated conductivity and sulphate are considered signatures of mine influence). For example, average conductivity values in 2016/2017 were 50 µs/cm at WA and 151 µs/cm at WB. Average sulphate concentrations were 1.34 mg/L at WA and 28.6 mg/L at WB, below the WQG at both stations (Appendix II, Graph 55). Like sulphate, annual average hardness concentrations display a moderate increase from WA to WB with average concentrations of 20.4 mg/L to 35.3 mg/L, respectively.

Total metal concentrations displaying a marginal annual average increases between WA and WB include iron (0.021 mg/L at WA to 0.049 mg/L at WB) and manganese (0.00146 mg/l at WA to

0.0072 mg/L at WB) in 2016/2017, likely attributed to mine related discharge. All total and dissolved metals remained below WQGs, and concentrations were similar to previous years.

The VIO maximum for total phosphorous in streams from May through September is 0.01 mg/L; this threshold was not exceeded at WB as the maximum concentration was 0.005 mg/L. Appendix I, Table (166) displays results of nutrient sampling performed during 2016/2017.

8.2.2 *No Name Outlet (NNO) EMS # E217017 and Long Lake Outlet (LLO) EMS # E219412*

Flow from No Name Lake enters the west end of Long Lake and exits Long Lake at the site known as LLO. LLO discharges to Middle Quinsam Lake upstream of Middle Quinsam Lake outlet (WB). Water quality monitoring at NNO and LLO provides information on changes in water chemistry in both Long Lake and the channel connecting the two lakes. The sampling location on No Name Lake is considered to be situated outside of direct mine discharge but could be influenced by groundwater. Therefore, changes in water chemistry between NNO and LLO represent the incremental mine loading into Long Lake from various inputs, including shallow and deep groundwater (e.g. emanating from 2S/3S), Long Lake Seep discharge, mine related discharge from the South water management system, and other anthropogenic sources (e.g., logging).

As shown in Appendix I, Tables 134 through 139, average TSS concentrations for LLO and NNO remained ≤ 4 mg/L during the three monitoring periods in 2016/2017. Both NNO and LLO exhibited similar pH, averaging 7.57 at NNO and 7.63 at LLO, with no WQG exceedances.

Conductivity and sulphate levels increased between NNO and LLO in 2016/2017, reflecting mine influence on Long Lake. Average conductivity was 38 µs/cm at NNO and 184 µs/cm at LLO. Annual average sulphate concentrations were 1.2 mg/L at NNO and 57 mg/L at LLO. Sulphate concentrations at LLO were higher during spring than summer and fall sampling periods, with no values higher than the WQG. Sulphate concentrations at LLO are cyclic with concentrations highs during summer and decreasing concentrations during fall and winter with higher flow rates and increased dilution, Appendix II, Graph (54). Sulphate is monitored weekly at LLO to assess water quality exiting Long Lake. Appendix I, Table (36) displays rolling average values for sulphate, which provide the most appropriate concentration to compare to the WQG.

Dissolved aluminum concentrations were higher than the WQG average (0.05 mg/L) during fall sampling period at many receiving environment sites. At NNO, the average was just above the WQG (0.0521 mg/L) and at downstream locations LLM and LLO the average was just below the WQG resulting in 0.0473 mg/L at LLO during fall. All other total and dissolved metals were below their WQGs, with many below laboratory DLs.

Water quality data for sites LLO and NNO are presented in Appendix I, Tables (134 to 139) with comparison to WQOs and WQGs. Appendix II, Graph 67 compares discharge with precipitation at LLO.

8.2.3 *Stream 1 – (7S) EMS # E292109 and Lower Wetland Outlet (LWO) EMS #E292112*

The headwaters of Stream 1 are formed by the discharge of 7SSD, which combines with Stream 2 above sampling location 7S. Downstream of site 7S, Stream 1 enters the Lower Wetland then flows into the Quinsam River. Given the aquatic values (fish habitat) in the Quinsam River, the 7S station has been defined as the initial dilution zone for 7-South discharge water. This receiving environment site is used to evaluate the influence of 7-South operations on aquatic receptors. The Lower Wetland Outlet station was established to monitor the cumulative water quality in Stream 1, and to understand overall contributions to the Quinsam River. The Lower Wetland Outlet station has not been representative of water quality from 7SSD nor from 7S.

There was discharge from 7SSD for a total of 12 days in 2016/2017 and 43 days in 2015/2016, indicating the limited amount of loading from the 7-South mine discharge to the Lower wetland.

The average sulphate level of 3.00 mg/L at 7S was well below the WQG (128 mg/L) , which was a direct result of diligent control of releases from the 7SSD sedimentation pond (to maintain an 8:1 dilution ratio) and water management measures employed at 7-South operations.

In 2016/2017, all total and dissolved metals were below WQGs and WQOs at 7S. Average Al-D was approaching the WQG average (0.05 mg/L) in fall (0.0489 mg/L).

Downstream site Lower Wetland Outlet (LWO) had elevated concentrations of TSS and metals, with WQG exceedances for TSS, total and dissolved iron, total copper and dissolved aluminum. These results are consistent with baseline measurements collected by Golder Associates [13] in

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[13] Golder Associates. Quinsam 7-South Effluent Technical Assessment Report. 2011

June 2011, which showed WQG exceedances for iron (3.79 mg/L Fe-T and 2.52 mg/L for Fe-D) and aluminum (0.101 mg/L Al-D). Elevated iron and aluminum concentrations at this station are attributed to natural causes as this is a wetland area that most likely has anoxic conditions during low flow. LWO is normally dry during the summer low flow period. The metal source appears to be localized and downstream of 7S, as concentrations were low at 7S throughout 2016/2017 monitoring periods. Water quality data collected during the 2016 late summer early fall sediment and benthic monitoring event also showed elevated Al-D concentrations at the middle and outlet wetland stations. The sediment data showed elevated arsenic, iron and manganese in the middle station but not at the outlet where water quality is collected (Appendix I, Tables 225 - 227). These conditions may be attributed to higher flow conditions during sampling. Refer to Section 9 for a full discussion on sediment results in the Lower Wetland.

All other parameters were below WQGs; results for 7S are displayed in Appendix I, Tables (23 and 24) and Appendix II, Graphs (17 through 21 and 69). Results for LWO are displayed in Appendix I, Tables (143 to 145).

8.2.4 *Quinsam River Downstream Site 1 (QRDS1) EMS # E286930 & 7-South Quinsam River (7SQR) EMS # E292113*

QRDS1 is located approximately 2 km downstream from the MQL outlet (sampling site WB) and upstream of any inputs associated with 7-South operations. QRDS1 was established to monitor groundwater inputs from the underground tailings disposal of 7-South tailings in the 2-North mine and the underground sub-aqueously stored PAG-CCR material in the river barrier pillar. 7SQR is the 7-South Quinsam River monitoring station on the Quinsam River approximately 4 km downstream of QRDS1. 7SQR data are used to evaluate the influence of 7-South mine related discharge to the Quinsam River downstream of the LWO and of groundwater inputs to the Quinsam River from sub-aqueously stored PAG-CCR in the 7-South mine.

The incremental loading associated with discharge from 7-South operation was observed to be negligible in 2016/2017. General parameters were similar for both sites, and TSS values were below the DL in all samples collected.

Sulphate concentrations were similar for the two sites and were well below the WQG (128 mg/L). The annual average sulphate concentration was period was 29 mg/L at both QRDS1 and 7SQR.

Both stations were sampled during the three 5 in 30 sampling periods and 7SQR was also sampled monthly.

Total and dissolved metals concentrations were similar at both stations. At QRDS1, total zinc was higher than the WQG during spring, with a maximum of 0.0927 mg/L (WQG of 0.033 mg/L) and average of 0.0225 mg/L (WQG of 0.0075 mg/L). The maximum of 0.0927 mg/L was considered an outlier as all other results at QRDS1 and 7SQR were below 0.005 mg/L for the entire monitoring period. Arsenic was slightly higher at 7SQR than at QRDS1, with one WQG exceedance observed in August (0.00558 mg/L compared to the maximum-WQG of 0.005 mg/L) at 7SQR.

The VIO maximum for total phosphorous (0.01 mg/L) was exceeded at 7SQR on one sampling event in August (0.0117 mg/L). Appendix I, Table (166) displays nutrient sampling conducted during 2016.

Appendix I, Tables (140 -142 & 146 to 148) and Appendix II, Graphs (55 - 59) display relevant parameters of interest for these sites.

8.2.5 *Iron River*

The Iron River Baseline Summary Report was submitted to the MOE on March 31, 2016. The report reviewed the monitoring data at all sites in the Iron River, summarizing trends and parameters found to be naturally elevated due to the watershed geology and contact with the Benson/Dunsmuir members of the Comox Formation.

As part of the 7-South Area 5 permit application, baseline water quality data were collected at ten stations on the Iron River to gain an understanding of existing water quality and local influences. Additionally, six tributaries were monitored to identify incremental loading.

One year of monthly baseline samples was obtained at all sites to maximize interpretation of seasonal variations and trending on the Iron River. Post-baseline monitoring in 2016/2017 consisted of 5 in 30 and monthly sampling at three stations on the Iron River (IR1, IR6 and IR8) and one station on the Quinsam River, downstream of the confluence of the Iron River (IRQR).

Most general parameters (e.g., TSS, sulphate) had low concentrations at the four stations and remained well below WQGs. Hardness showed seasonal variability, with lower levels in spring and fall (higher flow) than in summer (low flow). As such, the varying hardness levels at IR1 (upstream of mining operations) were used to calculate WQGs that vary with hardness.

Dissolved aluminum and total arsenic were the two primary parameters of interest in the Iron River. In 2016/2017, there were fewer arsenic WQG exceedances than previously reported; IR8 had WQG exceedances in four of the five samples collected during summer (ranging from 0.00556 mg/L to 0.00886 mg/L). The lower incidence of WQG exceedances in 2016/2017 may be related to the generally higher river flows throughout the year compared to previous baseline sampling as displayed in Appendix II, Graph 70. Al-D concentrations were higher than the WQG during multiple sampling events at all four stations during fall and at IR1, IR6, and IR8 during spring. An inverse relationship between As-T and Al-D was identified: Al-D is elevated during periods of higher flow while As-T is elevated at times of low flow (Appendix II, Graphs 60 to 62). In 2015, for example, As-T exceeded the WQG at IR6 and IR8 in most of the samples collected during the summer while Al-D was above the WQG during fall through winter.

All other parameters of interest were below WQGs at IR1, IR6, and IR8 and all except Al-D were below WQGs at IRQR. Therefore, mixing of the Quinsam and Iron rivers continues to provide sufficient dilution to maintain water quality.

Appendix I, Tables (101 -116) and Appendix II, Graphs (101 to 103) display relevant data for all Iron River sites graphed against flow.

9.0 SEDIMENT QUALITY IN THE RECEIVING ENVIRONMENT

Sediment samples were collected from monitoring stations in five lakes, the Lower Wetland, and the Quinsam River in August through October 2016 and analyzed for a variety of parameters. Parameters were chosen based on constituents commonly found in sediment near coal mines and parameters of interest from previous studies completed in this watershed. The analysis chosen were:

- Total Moisture
- Particle Size
- Paste pH
- Total Organic Carbon
- Total Sulphur
- Total Metals
- Polycyclic Aromatic Hydrocarbons (PAHs)

9.1 LAKES

Gooseneck, No Name, Long, Middle Quinsam, and Lower Quinsam lakes were sampled in 2016 (17 stations total) to evaluate sediment chemistry throughout the watershed near mining operations. No Name, Long, Middle Quinsam, and Lower Quinsam lakes were sampled at the inlet, outlet and deep habitats, and all except Lower Quinsam Lake were sampled at seep areas. Gooseneck Lake (the reference lake) was sampled only in deep habitat. Each lake has different physical characteristics and input sources.

The study design followed for the sediment and benthic invertebrate sampling program is contained in Appendix VI Sediment and Benthic Monitoring Program 2016. It followed a modified Spatial Variance Program (Standard) as defined in MOE (2016).

9.1.1 *METHODS*

At each sampling station, three to six replicate samples (subsamples) were collected using an Eckman sampler. Replicate samples were obtained at 5 m equidistant spacing as indicated in (MOE 2016)[14] to provide representation of each location and to minimize the influences of outlier

[14] MOE. 2016. *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators, Version 2, June 2016*. Available at: http://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/water_air_baseline_monitoring.pdf

samples. Sediment was released from the sampler into a mixing bowl and observations (depth sampled, texture, colour, presence of living organisms, debris, biofilm, odour, and sheen) were documented and are described in the results section. Sediment was homogenized, placed in labelled sample jars, placed into a cooler with ice packs, and shipped to Maxxam with a chain-of-custody form.

Split samples were obtained at one site per waterbody and were used to identify the quality and consistency of sample collection and preparation methods. To collect a split sample, sediment was obtained using the Ekman sampler and placed into the mixing bowl like any other sample. The materials were mixed thoroughly and two sets of samples were placed into containers from the mixing bowl. Upon receipt of chemical analysis from the laboratory, reported values were used to calculate an RPD between the samples.

The data was organized by sampling station, with results presented for individual replicate samples and for summary statistics (minimum, maximum, mean, standard deviation, % relative standard deviation, and number of sediment guideline exceedances). The range of values for replicate subsamples reflected natural variability at a station and the average value provided an overall summary of concentrations. PAH and metal results were presented in separate tables for ease of comparison and viewing.

Analytical results for PAHs are presented as raw data and normalized to a 1% total organic carbon (TOC) basis, using TOC concentrations measured within samples. For example, a sample containing 5% TOC would have PAH concentrations divided by 5 to yield the normalized value. As PAHs preferentially bind to organic carbon, it is necessary to account for the varying amounts of TOC that may be present to allow consistent comparisons among replicate samples and stations. Care was taken to use the lowest DLs available at Maxxam, but some samples had elevated DLs (higher than sediment guidelines) due to interference from the sample matrix.

Various guidelines were used to assess sediment quality at the monitoring stations. The Canadian Council of Ministers of Environment (CCME) Interim Sediment Quality Guidelines (ISQG) and Probable Effects Levels (PELs) are generic guidelines for several metals and PAHs (CCME 2017)[15]. B.C. has also developed generic ISQGs and PELs, typically the same as for CCME, but with guidelines for additional parameters (MOE 2017). "The ISQG reflects the concentration below which adverse biological effects are expected to occur rarely. The PEL defines the level above which adverse effects are expected to occur frequently." (CCME 2001)[16] A few generic Ontario Sediment Quality Guidelines were integrated into the list of ISQGs and PELs for parameters than did not have a CCME or BC guideline for comparison. TOC adjusted PAH concentrations were compared to the British Columbia Ambient Sediment Quality Guidelines (BCASQG) (MOE 2017[17]). These standards are dynamic as they change proportionate to the varying amounts of TOC observed in the sediment samples. For ease of comparison and reduced workload, these standards have been kept stationary and the PAH result has been adjusted.

For Long Lake, site-specific sediment quality objectives (SQOs) have been developed that recognize the naturally elevated metal concentrations related to local hydrology and geology (SLR 2015). The SQOs were derived from studies completed prior to mining influence in Long Lake (pre 1987). When the background concentration was lower than the ISQG, the ISQG was used as the SQO.

In Appendix I, Tables for metals, parameters of interest, which are of higher concern due to potential toxicity identified in the present study or previous studies, are colour-coded. Parameters highlighted in blue are of highest interest (arsenic, iron, manganese) and those highlighted in orange (cadmium, chromium, copper, mercury and nickel) are considered of secondary interest.

Tables listing guideline exceedances were compiled separately for metals and PAHs. For PAHs, exceedances for raw concentrations and TOC-normalized concentrations were identified.

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[15] Canadian Council of Ministers of the Environment, Canadian Sediment Quality Guidelines for the Protection of Aquatic Life available at: File:///C:/Users/kar/Downloads/CEQGchemicals%20(2).pdf

[16] Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Introduction. Available at: http://ceqg-rcqe.ccme.ca/download/en/317

[17] British Columbia Ambient Sediment Quality Guidelines

9.1.2 RESULTS

Results for the sediment and benthic sampling stations are provided in Appendix I, Tables 186 to 190 and 193 to 247.

9.1.2.1 *Gooseneck Lake*

Gooseneck Lake (GNL) is situated approximately 3 km northwest of the mine site office, has a maximum depth of approximately 20 m and covers a surface area of 0.78 km^2. This lake does not receive any mine impacted waters but receives the same inflow water that enters Middle Quinsam Lake via a dam controlled by BC Hydro. GNL outflow does not enter the Quinsam Watershed and ultimately enters Lower Campbell Lake via Snakehead and Beavertail Lakes. GNL has been used as a reference lake in historical baseline studies: *"The selection of this lake as a reference lake includes considerations of practicality and geography; however, no two lakes are identical" (*Golder, 2011[18] *).* Use of GNL as a reference lake needs to consider the many differences among the study lakes.

One station was sampled at Gooseneck Lake, (MGNL) which is situated in the southern portion of the lake at the deepest location (15 m) identified by Quinsam staff. The sediment was described as silty and gelatinous with some small debris, and dark brown in colour with a reddish hue. It had a mild anoxic odour and contained various species of aquatic worms. The average moisture for the five samples was 87.8%. The samples were predominantly composed of sand and silt, with a pH of 5.67.

PAHs were present in relatively low concentrations; with a total PAH average of 0.274 mg/kg. Pyrene and dibenz(a,h)anthracene exceeded ISQGs in some samples, but were well below PELs.

Arsenic, iron, and manganese were higher than ISQGs or PELs at MGNL. Arsenic exceeded the PEL in all replicate samples (17.6 to 25 mg/kg, average of 21.4 mg/kg). Iron exceeded the ISQG in all replicate samples (29,500 to 41,400 mg/kg, average of 36,540 mg/kg). Manganese

[18] Golder (Golder Associates Ltd.) 2010. Integrated Long Lake Sediment Assessment.

exceeded the ISQG in all replicate samples, with one sample exceeding the PEL (781 to 1200 mg/kg, average of 987 mg/kg).

Cadmium, copper, mercury, and nickel were present at concentrations above ISQGs but not PELs.

9.1.2.2 *No Name Lake*

No Name Lake (NNL) lies approximately 3 km south of the mine site office in close proximity to historical operations in the South Mining Area. NNL has a maximum depth of approximately 14 m and covers a surface area of approximately 0.2 km^2. There are two major inlets that deliver water from local precipitation and that are not mine impacted.no point source discharges from mining activity. NNL flows into Long Lake via a connector stream and is also known to be a “losing lake” that delivers water to local aquifers. While NNL Lake is not considered a perfect “control” lake, close proximity and supply of water to LLM make it a suitable reference for Long Lake using the Inlet and deep sites. There are groundwater influences from the 2S PAG-CCR disposal pond and possibly the 2-South mine near the outlet and seep sites (seeps are potentially from 2S Pond). Hence the deep, seep, and outlet sites for No Name Lake are considered to be high impact / near field sites

During the 2016 sediment sampling program, four stations were evaluated on NNL: the inlet on the western portion of the lake, the deepest known area near the lake centre, a site near a potential “seep”, and the outlet near the northeast edge. The highest concentrations of primary metals of interest were located at the deep station and the highest concentrations of PAHs were found at the seep station. Secondary metals of interest were generally found in low levels throughout NNL.

No Name Lake Inlet (NNLI)

NNLI is considered not affected by mine water discharges or land disturbance. Located on the western end of the lake, the inlet receives local catchment runoff through a wetland, with flow rates that correlate to seasonal precipitation and weather patterns. Samples were obtained at depths of 3.8 to 5.0 m and were silty and gelatinous, with substantial fresh plant debris and little odour. Sediment was a medium brown colour with many orange streaks and had average moisture content of 92.0% and a paste pH of 5.73.

Total PAHs concentrations were low (average of 0.0252 mg/kg). Concentrations were lower in samples collected in 2003 and 2004 by Nordin and may be due to local variation, sampling practices, or changing analytical techniques. Two of five replicate samples had 2-methylnaphthalene levels marginally higher than the ISQG, but the average was below the ISQG.

Arsenic, iron, and manganese had average concentrations higher than the PELs. Given the lack of mine influence at NNLI, elevated concentrations are assumed to be from natural sources (local geologic formations). Concentrations measured in 2016 were somewhat higher than reported as baseline in the 1980's prior to mining operations (Sneddon & Kelso, 1983); this may be attributed to difference in sampling techniques and exact sampling locale. A relatively small sample size over a long period is not sufficient to describe temporal trends with a high degree of confidence.

Arsenic exceeded the PEL, ranging from 42.8 to 61.2 mg/kg with an average of 52.6 mg/kg. Similar results were reported in 2009 (40.0 mg/kg; Canadian Water Network, 2009) and 2004 (54.1 mg/kg; Nordin, 2004), but lower results were reported in 2003 (34.7 mg/kg Nordin, 2003) and 1983 (12.5 mg/kg; Sneddon & Kelso, 1983). Iron exceeded the PEL, ranging from 59,000 to 80,500 mg/kg, with an average of 67,420 mg/kg. Elevated concentrations have been observed in the past (ranging 29,100 to 50,800 mg/kg) from and are likely naturally occurring, although iron concentrations reported in 2016 were the highest on record. Manganese exceeded the PEL, ranging from 749-3,030 mg/kg with an average of 1,794 mg/kg. Concentrations measured in 2016 were the highest on record, and were approximately twice as high as reported in the 1983 Sneddon and Kelso baseline study.

There were no ISQG exceedances for any of the secondary metals of interest.

No Name Lake Middle (NNLD)

NNLD is situated near the centre of No Name Lake, adjacent to the other major inlet from the south. This station is also used for routine water sampling. Samples were obtained at a depth of 12.0 m and were gelatinous with silt/clay fractions visible. The sediment was dark brown with a red hue, with a mild anoxic odour. The average moisture content was 88.8%, the dried sample was mostly sand (69%) and paste pH was 5.6.

Total PAHs were present in trace concentrations (average total PAH of 0.079 mg/kg), with most of the PAHs below the DLs in the five subsamples. Only 2-methylnapthalene exceeded the ISQG (2/5 subsamples).

Arsenic, iron, and manganese concentrations were higher at NNLD than at any other lake stations monitored in 2016 and exceeded the PELs in all five replicate samples. Such high concentrations were not expected at this station, given that past monitoring results showed much lower values and no mine related discharges enter No Name Lake in this area. There has been substantial logging activity around this lake in recent years, which is known to lead to substantial sediment and particulate metal loading. Also, it is not known how close the sampling locations were for the various studies. It is possible that increases over time are not a result of increased deposition and mainly reflect high variability in chemistry across small distances.

Arsenic concentrations ranged from 106 to 166 mg/kg, with an average of 133.2 mg/kg, about eight times higher than the PEL and over ten times higher than reported in 1983 (10.7 mg/kg; Sneddon & Kelso, 1983). Iron ranged from 125,000 to 218,000 mg/kg, with an average of 173,000 mg/kg, and manganese ranged from 3,890 to 6,820 mg/kg, with an average of 5,528 mg/kg, higher than PELs.

Of the secondary metals of interest, copper (38.8 mg/kg) and mercury (0.219 mg/kg) exceeded ISQG using average concentrations. One of the subsamples saw a PEL exceedance of selenium at 2.01 mg/kg.

No Name Lake Near Seep (NNLS)

NNLS is on the southeastern shoreline, approximately 10 m from shore near a small drainage channel that transports seepage water to the lake from close to the reclaimed 2-South mining operation. Any deposition of materials from this drainage channel is thought to accumulate in and around NNLS. Samples were obtained at a depth of 5.5 m and consisted of silt and clay, with less organic matter than other samples in No Name Lake. The samples had little organic debris, were dark brown with grey portions of clay and had streaks of red.

The highest PAH concentrations in No Name Lake were reported from NNLS, with total PAH ranging from 0.093 to 0.19 mg/kg and averaging 0.133 mg/kg. Concentrations of 2-methylnaphthalene were higher than the ISQG in all five replicate samples (average of 0.043 mg/kg).

Arsenic, iron, and manganese concentrations were higher than PELs in most replicate samples and using average values. Concentrations in 2016 were comparable to those reported in the 2014 sampling program conducted by QCC staff. Manganese concentrations were lower at NNLS than at other stations in No Name Lake in 2016 (range of 770 to 1,400 mg/kg, average of 1,112 mg/kg).

Average concentrations of nickel and copper were just above ISQG (16.1 and 35.9 mg/kg respectively).

No Name Lake Outlet (NNO)

NNO is located approximately 20 m south of the drainage channel that delivers water to Long Lake. Samples had high amounts of fresh and decaying plant debris and were gelatinous and spongy, with high algae content. High moisture content (92 to 94%) resulted in increased DLs for PAHs. This area of the lake is shallow (3 to 4 m depth) and has good exposure to sunlight, which promotes plant growth.

Despite the elevated PAH DLs, total PAH concentrations were low, averaging 0.027 mg/kg.

Arsenic, iron, and manganese concentrations were generally lower at NNO than at other stations in No Name Lake. The average arsenic concentration was below the PEL (13.8 mg/kg with a range of 9.43 to 20.8 mg/kg). Individual and average iron concentrations were below the PEL (ranging from 14,600 to 32,900 mg/kg and averaging 22,040 mg/kg). The average manganese concentration was higher than PEL but lower than at the inlet and deep stations (ranging from 364 to 3,570 mg/kg, indicating more dynamic sediment chemistry at NNO.

Secondary metals of interest concentrations were low throughout subsamples and there were no reported ISQG exceedances using average values.

9.1.2.3 *Long Lake*

Long Lake is a long, narrow lake that receives water from No Name Lake and drains into Middle Quinsam Lake. In addition to inputs from No Name Lake, Long Lake receives local runoff from precipitation, groundwater, and point source discharges from mining operations. A significant fault (appropriately name Long Lake Fault) runs through Long Lake from east to west and acts as the division between sedimentary and volcanic bedrocks. The maximum depth of Long Lake is 20 to 21 m.

Long Lake has been a focus of environmental monitoring for effects of mining activities since the 1990s. Study results have been used to refine best practices for water management and resource management. Sediment has been sampled several times, including in the early 1980s prior to mining. To recognize the naturally elevated background concentrations in Long Lake, SQOs were developed that reflect site conditions (SLR. 2015)

The 2016 sampling program built on the existing dataset by sampling at locations previously identified as of interest. Four sites were sampled: Long Lake Inlet (LLI), on the westernmost portion of Long Lake where water from No Name Lake enters through a wetland; Long Lake Near Seep (LLNS), close to the inputs from the Long Lake Seep; Long Lake Deep, the deepest spot known on the lake and where routine water quality samples are obtained; and Long Lake Outlet (LLO), near the outlet and downstream of all discharges from the South Mining Operations.

Long Lake Inlet (LLI)

LLI is situated upstream of mine-related inputs and is located approximately 10 m from the edge of the wetland where water enters Long Lake. The samples were obtained at a depth of 5 m and were silty and gelatinous, with some decaying plant material and a slight anoxic odour. The top few centimeters were a lighter brown than the remaining layer and contained many small, red aquatic worms. Moisture content averaged 87%, paste pH was 6.50 and the substrate consisted primarily of sand and silt.

Total PAH concentrations were low (average of 0.22 mg/kg). Naphthalene and 2-methylnaphthalene concentrations were higher than their ISQGs but below PELs. Values reported in 2016 were similar to those reported in previous sampling programs.

Arsenic, iron, and manganese concentrations were higher than PELs but not SQOs in all replicate samples. Arsenic concentrations at LLI were similar to those at No Name Lake inlet, with an average of 52.1 mg/kg. Arsenic concentrations at LLI have increased over time (recognizing that some variation in sampling location has also occurred). Average iron concentrations (45,166 mg/kg) were slightly above the PEL and showed little variance among replicate samples. Iron concentrations were slightly higher in 2016 than in previous sampling events. Manganese concentrations were between the ISQG and PEL (average of 728 mg/kg; range of 684-783 mg/kg) in 2016 and were lower than in previous studies.

Cadmium, copper, and nickel had exceedances of ISQGs in some replicate samples. The average copper concentration was below the ISQG. Cadmium exceeded the ISQG in all samples, averaging 0.642 mg/kg, but was well below the SQO. Nickel concentrations were slightly higher than the ISQG in all replicate samples, averaging 17.5 mg/kg. As background nickel concentrations were lower than ISQG, the ISQG was used as the SQO.

Long Lake Near Seep (LLNS)

LLNS is located in the western half of Long Lake slightly downstream from the Long Lake Seep discharges. Situated in the seep IDZ approximately 10 to 15 m from shore, LLNS is situated to evaluate deposition from the seep. The lake is steeply sloped in this area and samples, even though taken close to shore, were obtained at a depth of 15.5 to 16 m. The samples were gelatinous with fine clay, silt and sand, littered with larger debris. The sediment was dark brown with a distinct red surface and contained many red aquatic worms. The average moisture content was 86.3%, paste pH was 6.24 and substrate was composed primarily of sand.

Total PAH concentrations ranged from 0.78 to 1.0 mg/kg, averaged 0.9 mg/kg, and were notably higher than at LLI. Individual PAHs had concentrations higher than the ISQG in some replicate samples and 2-methylnaphthalene was above the PEL in all replicate samples. Comparison with previous sampling programs is challenging because the sampling location has changed over time (Appendix XI, Figure 10).

Arsenic, iron, and manganese concentrations were elevated the five replicate samples, and were higher at LLNS than at other stations in Long Lake, suggesting contributions from the seep. Arsenic ranged from 41.4 to 74.8 mg/kg, averaging 55.4 mg/kg and lower than reported in 2004 and 2010. Iron ranged from 51,000 to 62,000 mg/kg, averaging 55,550 mg/kg and within the range of previous studies. Manganese ranged from 737 to 1,380 mg/kg, averaging 940 mg/kg and higher than some previous studies but lower than in 2004.

Cadmium, chromium, copper, mercury and nickel were higher than ISQGs in some samples; only nickel was above its SQO at LLNS.

Long Lake Deep (LLM)

Long Lake Deep (also referred to as Long Lake Middle or LLM) is located near the centre of the lake at the deepest known portion, and is also used for routine water quality monitoring. Due to its bathymetry, LLM is an ideal location for materials to accumulate in the sediment and has been identified in the past as having high concentrations of parameters of interest. Samples were obtained at a depth of 19.5 m and were silty and sandy, having many fine particles and decaying plant debris. The sediment was a medium brown colour with many orange streaks on the uppermost layer. The average moisture content was 87.3%, paste pH was 5.85, and substrate was composed primarily of sand and silt.

PAH concentrations were higher at LLM than at the other stations in Long Lake and in the other lakes sampled. Total PAH ranged from 2.5 to 2.8 mg/kg, averaging 2.67 mg/kg. Concentrations of some individual PAHs were higher than ISQGs or PELs, including 2-methylnaphthalene (above PEL in all replicate samples, average about five times the PEL) and naphthalene (above PEL in all replicate samples). Naphthalene concentrations normalized to 1% TOC were higher than the BCASQG.

Arsenic, iron, and manganese concentrations were higher at LLM than at the other stations in Long Lake in 2016. Arsenic concentrations averaged 160.3 mg/kg. While somewhat difficult to compare to previous results at this location due to slightly differing GPS coordinates, arsenic concentrations were within the range expected at the seep location, with no sign of an increase over time. Iron concentrations ranged from 104,000 to 119,000 mg/kg, averaging 112,000 mg/kg. While iron was higher at this location that elsewhere in the lake, it did not exceed the SQO and was within the range previously reported. Manganese concentrations were higher than the SQO and averaged 3,240 mg/kg. Maximum manganese concentrations were slightly higher than previously reported at the seep. It is interesting to note that during water sampling at LLM in recent years, manganese concentrations were elevated when DO was low. The assumption is that favorable redox conditions promote dissolution of sediment manganese into the lower levels of the water column.

Copper, chromium, and mercury concentrations were higher than ISQGs, with nickel also higher than the SQO in all subsamples. The source of nickel is not clear, but concentrations have increased over time at LLNS and other stations in Long Lake. Nickel concentrations are about 50% of the PEL.

Long Lake Outlet (LLO)

LLO is downstream of mine inputs into Long Lake, including all discharges from the South Water Management System via LLE. LLO is approximately 75 m upstream from the beginning of the outlet channel. Sediment samples were obtained at depths of 5 to 5.5 m in an area with a high density of floating, decaying logs, rich in plant life, both fresh and decaying. Samples were silty and gelatinous with high amounts of organic material, a mild anoxic odour, and high debris content. The sediment was medium brown in colour and contained many fine, black particles. Moisture content averaged 87%, paste pH was 6.17, and the substrate was composed primarily of silt followed by sand.

Total PAH concentrations were elevated at LLO, ranging from 1.3 to 3.6 mg/kg with an average of 2.18 mg/kg. The maximum value of 3.6 mg/kg was the highest observed at any lake stations sampled in 2016. The average concentration of 2.18 mg/kg was higher than reported in previous studies and indicates an increasing trend. Many individual PAHs were higher than their ISQGs, with 2-methylnaphthalene and naphthalene higher than the PEL (for individual samples and averages). The 1% TOC normalized concentrations of naphthalene also exceeded the BCASQG. Total PAH may be influenced from the amount of floating, decaying logs as wood waste and decaying leaves have been found to contain elevated concentrations of heavy metals and PAH compounds (Meike Nitsche, Nodirjon Nurmatov, Frank Hensgen and Michael Wachendorf.2017).[19]

Arsenic and iron concentrations were higher than the PEL and manganese was just below the PEL, for average and individual samples; levels were below the SQOs. Arsenic concentrations were similar to those reported at LLI in 2016 (average of 47.9 mg/kg) and were in the range reported in previous studies. Iron concentrations were also similar to those reported at LLI in 2016 (average of 53,133 mg/kg), and appear to have increased since 2003. Baseline samples from LLO obtained in 1983 had iron concentrations almost three times higher than reported in 2016 (Sneddon & Kelso, 1983). Manganese concentrations were notably lower at LLO than LLM and were similar to levels seen at LLI in 2016. With an average of 1,034 mg/kg, manganese concentrations were at their lowest since baseline data collection was done and have steadily declined since 2004.

Copper exceeded the ISQG in all replicate samples (average of 50.8 mg/kg) but remained well below the SQO. Nickel concentrations (average of 25.6 mg/kg) were above the SQO and higher than reported for background concentrations.

9.1.2.4 *Middle Quinsam Lake*

Middle Quinsam Lake is part of the Quinsam River system, situated downstream of a BC Hydro diversion dam and just west of the North Mining Operations at Quinsam Coal. The lake receives inputs from the Quinsam River, local groundwater, and precipitation, and is regarded as the

[19]Meike Nitsche, Nodirjon Nurmatov, Frank Hensgen and Michael Wachendorf.2017. Heavy Metals and Polycyclic Aromatic Hydrocarbons in Urban Leaf Litter Designated for Combustion

receiving environment for aggregate discharges from North Mining operations. Flows from Long Lake enter Middle Quinsam Lake near the lower end of the lake, near the outlet to the Quinsam River. The Middle Quinsam Lake outlet is near a bridge close to the mining roads. Middle Quinsam Lake has a maximum depth of approximately 15 m near the lake centre on the southern portion. Four stations were sampled in 2016: the inlet (MQLI), approximately 250 m downstream of the lake inlet; near a potential seep from the coal processing plant (MQLNS); in the deepest area (MQL); and 175 m upstream from the lake outlet and downstream of the channel from Long Lake (MQLO).

Middle Quinsam Lake Inlet (MQLI)

MQLI is in a shallow area approximately 250 m downstream of the inlet. As mine effluent enters a wetland upstream of the defined inlet channel, MQLI is considered affected by mining. Samples were obtained at a depth of 1 to 2 m and were rich in fresh plant material, shells, and debris. Sediment was silty, gelatinous, medium brown colour and rich in organic matter. Moisture content averaged 90%, paste pH was 5.95, and substrate was mainly sand and silt.

Total PAH concentrations were low, ranging from 0.10 to 0.13 mg/kg, with an average of 0.11 mg/kg. 2-methylnaphthalene was marginally higher than the ISQG in all replicate samples, but well below the PEL.

Arsenic, iron, and manganese concentrations were above the ISQGs, but not PELs. The average arsenic concentration of 8.07 mg/kg was lower than at the other three stations in Middle Quinsam Lake. Average concentrations were 30,766 mg/kg for iron and 696 mg/kg for manganese.

Nickel and copper concentrations were higher than ISQGs but well below PELs.

Middle Quinsam Lake Near Seep (MQLNS)

A natural drainage depression originating near the coal processing plant, coupled with surfacing shallow groundwater, discharges water into the lake on the northeastern shoreline. MQLNS was located approximately 30 m offshore of the entry point of this “seep” water to assess whether metals in seep water settle on the lake bottom. Samples were collected at a depth of 1 metre in an area surrounded by wetland rich in fresh plants, shells, benthic invertebrates, and organic debris. The sediment was a medium brown colour and was silty and gelatinous. Moisture content was 94.8%, paste pH was 7.32, and substrate composition was mainly sand.

All PAH concentrations were below DLs.

Arsenic, iron, and manganese concentrations were above ISQGs. Arsenic averaged 9.38 mg/kg; iron averaged 43,840 mg/kg (just above the PEL); and manganese averaged 379.4 mg/kg. Iron was elevated at MQLNS relative to the other stations in the lake and may be associated with elevated iron content measured frequently in the drainage channel discharge.

Middle Quinsam Lake Deep (MQL)

Located in the deepest area of the lake, MQL is a routine water quality monitoring station. Sediment samples came from 13 to 14 m depth and were silty and gelatinous, with numerous red aquatic worms. The samples were medium brown with a green hue, lined with orange streaks and black particles. The moisture content was 92%, paste pH was 6.59 and substrate consisted mainly of sand and silt.

Total PAH concentrations averaged 0.103 mg/kg, similar to other stations in the lake. The only ISQG exceedances observed was 2-methylnaphthalene for two of the three replicate samples collected.

Arsenic and iron concentrations exceeded the ISQG. Average arsenic concentrations were 12.8 mg/kg for arsenic, 36,400 mg/kg for iron, and 354 mg/kg for manganese (lower than the ISQG).

Nickel and mercury concentrations were slightly above ISQGs but well below PELs. Selenium concentrations were higher than the BC alert level of 2 mg/kg in all replicate samples from MQL, with an average of 2.55 mg/kg. While selenium has been observed in trace concentrations throughout the watershed, MQL is the only station with a guideline exceedance. Selenium was present in trace amounts in coal samples analyzed in the past but it is unclear whether this sediment exceedance is directly related to mining discharges.

Middle Quinsam Lake Outlet (MQLO)

MQLO drains into the Quinsam River, conveying water from both Middle Quinsam Lake and Long Lake via an outlet channel near a bridge over the channel that is used for mine traffic. Samples were obtained approximately 100 m downstream of the inlet from Long Lake and 175 m upstream of the bridge. MQLO represents the final deposition area on the lake adjacent to mining activities. Samples were collected in shallow water (1 to 3 m) in an area with high plant debris and numerous crayfish. Samples were silty and gelatinous with minimal odour and a dark brown colour with a green hue. The average moisture content was 93.7%, paste pH was 6.49, and substrate consisted mainly of sand.

All PAH concentrations were below DLs.

Arsenic, iron, and manganese concentrations were higher than ISQGs but not PELs, at concentrations similar to previous studies. Average concentrations were 9.11 mg/kg for arsenic, 26,033 mg/kg for iron, and 722 mg/kg for manganese. These concentrations were similar at the other Middle Quinsam Lake stations so did not reflect additional loading from the Long Lake channel.

Cadmium, copper, and nickel concentrations were above ISQGs but all below PEL. Selenium concentrations were less than half of those observed at MQL.

9.1.2.5 *Lower Quinsam Lake (LQL)*

Lower Quinsam Lake is the furthest downstream monitoring lake for QCC. It is situated approximately 6 km downstream of Middle Quinsam Lake outlet. Lower Quinsam Lake receives all cumulative mine discharges from the three main water management systems at Quinsam Coal. The lake has an area of 1.17 km^2 and a maximum depth of about 21 to 22 m. Sediment chemistry was assessed at four stations: near the inlet (LQLI); the deepest known area (LQL); a second deep area (LQLM); and just upstream of the outlet channel (LQLO). No seeps at Lower Quinsam Lake were identified for sampling.

Lower Quinsam Lake Inlet (LQLI)

LQLI is located 2 km downstream of the Iron River-Quinsam River confluence, at the northern end of the lake. At the inlet, the lake slopes quickly to deep water, and sampling depths were 14 to 17 m only 75 m from the shore. Abundant large woody debris made it difficult for the sampler to penetrate the sediment. Samples were low in organic matter and were predominately composed of sand with little silt and clay. Moisture content was low at 38.7% (likely due to high sand and pebble content) and paste pH was 5.48. The samples contained numerous red aquatic worms along with high amounts of leaves and plant debris on the surface.

Total PAH concentrations were low, with an average of 0.353 mg/kg. Individual PAH compounds, including 2-methylnaphthalene, naphthalene, and phenanthrene had concentrations higher than the ISQGs but well below PELs. Normalized to 1% TOC, only naphthalene was higher than the BCASQG.

Arsenic, iron, and manganese concentrations in Lower Quinsam Lake were lowest at LQLI and increased downstream towards the outlet. At LQLI, arsenic and iron concentrations were higher than PELs averaging 35.7 and 52,160 mg/kg, respectively. Manganese concentrations were higher than the ISQG but lower than the PEL, with an average of 528 mg/kg.

Cadmium, chromium, copper, and nickel concentrations were higher than ISQGs but lower than PELs.

Lower Quinsam Lake Deep 1 (LQL)

LQL is in the northern half of the lake and is used for routine water quality monitoring. Sediment samples were taken at 16 to 17 m depth. The samples had a distinct anoxic odour with a few worms and little to no debris. Samples had distinct layers, with a deep orange colour on the top few millimetres, followed by 2 cm of gray clay and another 7 cm of dark brown sediment. Moisture content averaged 66.8%, paste pH was 5.78, and the substrate was primarily silt with lesser amounts of clay and sand.

Total PAH concentrations were low, with an average of 0.41 mg/kg. There were small exceedances of ISQGs for individual PAH compounds.

Arsenic and iron concentrations at LQL were slightly higher than at LQLI and exceeded the PELs. Average concentrations were 42.2 mg/kg for arsenic and 52,700 mg/kg for iron. Water quality samples from 1 m off the bottom often show elevated iron concentrations when DO levels in deep water are low (Appendix II, 51). Elevated iron concentrations in sediment along with a distinct red tinge at the sediment surface support the theory that iron dissolves and migrates into the water column at times of favorable redox conditions (lower ORP and lower DO). Particulate iron as Fe^{3+} in sediment is reduced to the more soluble Fe^{2+} and migrates into the water column. Although baseline sediment quality is not available, it is inferred that similar conditions occurred prior to any mining activities. High iron concentrations were reported in water during baseline studies in 1983 and 1984 when dissolved oxygen concentrations were low (Norecol, 1983, 1984). These high concentrations of iron in the water quality prior to mining at Quinsam Coal indicate that mine-related inputs are not the cause of high iron concentrations in deep water.

Manganese, cadmium, chromium, copper, and nickel concentrations were higher than ISQGs but not above PELs.

Lower Quinsam Lake Deep 2 (LQLM)

The second deep station LQLM, is about 900 m south of LQL, closer to the lake outlet. There are no additional mine-related inputs between the two deep stations. Samples were taken at depths from 14 to 16 m, and had similar physical characteristics to LQL, including an anoxic odour, minimal debris, and presence of worms. Sediment layering was similar to LQL, but there was an even deeper orange colour on the surface at LQLM. Moisture content averaged 75%, paste pH was 6.12, and substrate was mainly silt but with a higher percentage of sand than at LQL.

Total PAH concentrations were slightly higher at LQLM than at other stations in the lake, averaging 0.50 mg/kg. 2-methylnaphthalene, naphthalene, and phenanthrene concentrations were higher than the ISQGs but not the PELs.

Arsenic, iron, and manganese concentrations were notably higher at LQLM than at LQL and exceeded PELs in all replicate samples. Average concentrations were 87.4 mg/kg for arsenic, 68,020 mg/kg for iron, and 1,338 mg/kg for manganese.

Cadmium, chromium, copper, and nickel concentrations were higher than ISQGs but not PELs.

Lower Quinsam Lake Outlet (LQLO)

LQLO was located 400 m upstream of the defined outlet channel, in an area with high plant debris and many mussels, shells, insects, and eggs. It was necessary to sample here due to increasingly shallow water and high debris closer to the outlet channel. Samples were taken in 1.5 to 3 m depth and were grey and brown in colour, consisting mainly of sand and silt in equal proportions. Moisture content averaged 87.3% and a paste pH was 5.95.

Total PAH concentrations were lower at LQLO than other stations in the lake, with an average concentration of 0.227 mg/kg. 2-methylnaphthalene, naphthalene, and phenanthrene concentrations were higher than the ISQGs but not the PELs.

Arsenic and iron concentrations were slightly lower than at LQLM and averaged 68.0 mg/kg and 64,360 mg/kg respectively. Manganese concentrations were highest in Lower Quinsam Lake at LQLO and exceeded the PEL, averaging 2,082 mg/kg.

Cadmium, chromium, copper, and nickel concentrations exceeded ISQGs but not PELs.

9.2 Lower Wetland

The lower wetland is approximately 350 m in length and is situated downstream of 7-South surface disturbance. It receives water from the 7-South Surface Decant Pond (7SSD) via a seasonal connector stream (Stream 1 - 7S). Stream 1 – 7S receives local catchment runoff from near the disturbed portal area and coal stockpile, but does not receive water from mine pools or from dewatering. Most of the surface water is directed back into the mine using sumps, ditches, and pumps to reduce releases to Stream 1 – 7S. Since early 2015, when a secondary pumping system was installed to further minimize 7SSD effluent flows, discharges to Stream 1 have been minimal. From January 1, 2016 to October 5, 2016, when sediment samples were collected, only 1,001 m^3 of water had been released from 7SSD; the discharge was substantially diluted with rainfall and in.

Sediment was sampled in three locations in the wetland: the inlet where Stream 1 – 7S water enters (LWI); the center of the wetland after mixing (LWM); and just before the outlet to the Quinsam River (LWO). Wetland water levels fluctuate seasonally, and range from almost dry during summer to a pond-like state during the rainy season in mid-autumn. During sample collection in October 2016, the first autumn rains delivered large amounts of water to the wetland.

9.2.1 *Methods*

Samples were collected from the top 2 to 5 cm of substrate in shallow water underneath and around the plentiful plant growth where accessible. Sediment was collected using spoons, placed in labelled jars, then into cooler containing ice packs, and shipped to Maxxam under chain of custody for analysis. Observations (depth sampled, texture, colour and presence of living organisms, debris, biofilm, odour and sheen) were documented and are described in the results section. Three to five replicate samples were collected at each monitoring station. Data were analyzed as discussed in Section 9.1.1.

9.2.2 *Results*

Sediment results for the three wetland sampling stations are provided in Appendix I, 191 and 225 through 227 and 248 to 250.

9.2.2.1 *Lower Wetland Inlet (LWI)*

Located about 25 to 50 m downstream of where Stream 1 enters the wetland, LWI samples were obtained from a small, defined drainage channel within the wetland at a depth of less than 30 cm. The samples were deep brown in colour, had a rich organic odour, and consisted mainly of fine sand and silt with trace amounts of clay. The average moisture content was 89.7% and paste pH was 5.77.

Total PAH concentrations were low (0.0155 mg/kg average) and were lower than at LWM and LWO. No ISQG exceedances were noted for individual PAHs, many of which were below DLs.

Metals concentrations were low in the three samples collected at LWI, with no ISQG exceedances, except for selenium. Selenium concentrations ranged from 1.75 to 2.75 mg/kg (average of 2.10 mg/kg) and exceeded the BC sediment alert level of 2 mg/kg. This was the only wetland station with notable selenium concentrations. Past water sampling in 7SSD indicated selenium concentrations well below the permit limit of 0.016 mg/L.

9.2.2.2 *Lower Wetland Middle (LWM)*

LWM is located approximately 200 m downstream of LWI in a location with slightly deeper water cover. Sediment was collected in an area of less than 30 cm water depth, from a sediment depth of 2 to 5 cm. The samples were deep brown in colour, had a rich organic odour, and consisted mainly of fine sand and silt with trace amounts of clay. The average moisture content was 86.3% and the paste pH was 5.73.

Total PAH concentrations (0.0477 mg/kg average) were higher than at LWI and LWO. Only one ISQG exceedance was noted (2-methylnaphthalene) for one replicate sample; the average was below the ISQG. Most PAH parameters were present at levels below the DLs.

Metals concentrations were low at LWM, with few ISQG exceedances. The only parameter with an average concentration above the ISQG was arsenic (average of 10.0 mg/kg). Iron and manganese concentrations were elevated in some replicate samples but did not exceed PELs.

9.2.2.3 *Lower Wetland Outlet (LWO)*

LWO is located near the outlet to the Quinsam River in a pool of water dammed by beavers and is the final sampling station upstream of the river. Water cover ranged from 0.5 to 1.5 m depth. There were notable amounts of woody debris and plants over the sediment, making sampling somewhat difficult. The sediment was rich in clay, with an even proportion of sand and silt as reported in the laboratory analysis. Moisture content was 76.2% and paste pH was 5.80.

Total PAH concentrations (average of 0.025 mg/kg) were higher than at LWI but lower than at LWM. There were no ISQG exceedances for individual PAHs.

Metals concentrations were below ISQQs in the three replicate samples.

Based on results from LWO, discharges from 7-South have had no appreciable effects on sediment quality to date at this station.

9.3 QUINSAM RIVER

The Quinsam River flows through several lakes in the Quinsam watershed. Upper Quinsam Lake flows into Wokas Lake, the outflow of which forms the start of the Quinsam River. The river flows east about 5 km into Middle Quinsam Lake, then east again about 10 km into Lower Quinsam Lake and then north another 25 km to join the Campbell River, about 3 km from its estuary. The Iron River, a major tributary of the Quinsam River, enters from the south between Middle Quinsam and Lower Quinsam lakes. Sediment was sampled at three stations currently used to monitor water quality on the Quinsam River: WA (upstream of mine-related discharges), QRDS1 (downstream of Middle Quinsam Lake) and 7SQR (downstream of inputs from the 7-South mining activities and upstream of the Iron River confluence).

9.3.1 *METHODS*

Sediment samples were collected using a spoon to remove fine sediment from around boulders and other slow flowing areas. Sediment was placed in labelled jars, placed in a cooler with ice packs, and shipped to Maxxam under chain of custody for analysis. Observations (depth sampled, texture, colour and presence of living organisms, debris, biofilm, odour and sheen) were documented and are described in the results section. Three to six replicate samples were collected at each station.

9.3.2 *RESULTS*

Results for the three river sampling stations are provided in Appendix I, Tables 192 and 228 to 230 and 251 through 253.

9.3.2.1 *WA Station*

WA, located at the Argonaut Bridge, was sampled to evaluate sediment upstream of any mining discharges. This site served as a reference area for the sediment study, given its location upstream of mine influences, although habitat characteristics differed from those of downstream sites. The sampling station was in an area of dense riparian vegetation near a permanent logging road (Argonaut Main). At WA, the river was approximately 10 m wide, with a maximum depth of 1 m, a velocity of 0.62 m/s, and a flow rate of 1.06m^3/s. Large fluctuations in velocities and flow rates are associated with seasonal rainfall events and water release at the BC Hydro diversion dam upstream. Instream habitat was mainly riffles and rapids, with few depositional areas for sediment to accumulate. The dominant substrate types were small cobbles and pebbles, with sandy/silty interstitial material and a relatively low organic content. Sediment had an average moisture content of 21.6%, with 95.2% sand and small amounts of silt and clay. Paste pH was 7.01.

PAHs in sediment were below the DLs for individual parameters.

Arsenic, iron, and manganese had concentrations higher than ISQGs or PELs in one or more replicate samples. Arsenic concentrations were higher than the PEL (average of 17.8 mg/kg and a range of 9.24 to 24.8 mg/kg). Both iron and manganese had concentrations above the PELs for some replicate samples but average concentrations (41,820 mg/kg iron and 898 mg/kg manganese were below PELs.

Average copper and nickel concentrations were higher than the ISQGs but below PELs. One replicate sample had a mercury level ten times higher than the other two samples (0.81 mg/kg) and higher than the PEL; as a result, the average concentration was higher than the ISQG. This measurement was considered an outlier, suspected to be related to analytical error, as concentrations of other parameters in this replicate sample were not unusually elevated.

9.3.2.2 *QRDS1*

QRDS1, approximately 2 km downstream of the outlet of Middle Quinsam Lake, was selected to monitor sediment chemistry downstream of the North and South water management systems. It is assumed that this section of the Quinsam River receives (or will receive in the future) groundwater sourced from the River Barrier Pillar PAG storage area and other mine-affected waters. The station was near exploration roads in the 2-North mining area and had dense riparian vegetation with partial tree cover. The river was approximately 14 m wide, with a maximum depth of 0.5 m and a velocity of 0.64 m/s. This section of river contained small riffles, large boulders and, at the time of sampling, had few depositional areas for sediment to accumulate. The dominant rock types were small and large cobble, with coarse sand and silt interstitial material and a low organic content. Sediment had an average moisture content of 16.0% and contained 95.2% sand with small amounts of silt and clay. Paste pH was neutral at 7.26.

PAH were measurable but low in concentration, with an average total PAH concentration of 0.0412 mg/kg. Some individual PAH compounds were above DLs, with 2-methylnaphthalene, naphthalene, and phenanthrene (as observed in MQL) the most abundant. Concentrations of individual PAHs were lower than ISQGs in the three replicate samples.

Arsenic, iron, and manganese concentrations were higher at QRDS1 than at WA or 7SQR, with average concentrations of arsenic (39.5 mg/kg), iron (59,440 mg/kg) and manganese (1,202 mg/kg) higher than the PELs. Although QRDS1 is close to the mining influence in Middle Quinsam Lake, it is unknown if elevated metal concentrations are due to mining activities or natural conditions.

Average chromium, copper, and nickel concentrations exceeded the ISQGs at QRDS1, with chromium (average 38.6 mg/kg) and nickel (30.9 mg/kg) found in the highest concentrations among the three river stations sampled. Copper concentrations (average 58.3 mg/kg), were lower than at WA and lower again at 7SQR, indicating mining discharge has not contributed to copper loading in the sediment.

9.3.2.3 *7SQR*

7SQR is located just upstream of the Iron River-Quinsam River confluence, about 4 km downstream from QRDS1, and downstream of all mine related discharges, including 7-South. The riverbed was 14 m wide, about 1 m deep, contained a few pools and riffles, and had a slower velocity than WA and QRDS1. The station was partially tree covered, dominated by small shrubs, and contained some aquatic plants and periphyton. The riverbed contained many large boulders and had more abundant silty/sandy interstitial material, making sample collection easier than at upstream stations. The average moisture content was 31.6% and paste pH was 6.26. The samples were mainly composed of sand, with higher concentrations of silt and organic matter than at the upstream stations.

Total PAH concentrations were higher at 7SQR than at upstream stations (average of 0.106 mg/kg, range of 0.015 to 0.25 mg/kg). 2-methylnaphthalene, naphthalene, and phenanthrene concentrations were higher than ISQGs in one or more replicate samples, but only 2-Methylnaphthalene had an average concentration higher than the ISQG.

Arsenic, iron, and manganese concentrations were notably lower than at QRDS1 and were lower than at WA. Only arsenic (average of 17.2 mg/kg) exceeded the PEL, while iron (average of 30,500 mg/kg) exceeded the ISQG and manganese (average of 431 mg/kg) was below the ISQG.

Cadmium concentrations were higher at 7SQR that at upstream stations, with two of the five replicate samples higher than the ISQG and the average concentration (0.465 mg/kg) below the ISQG. Elevated cadmium concentrations have been reported intermittently in discharges from the 7-South mining area since 2012.

10.0 BIOTA MONITORING IN THE RECEIVING ENVIRONMENT

Phytoplankton and zooplankton are monitored every year at one station in each of No Name, Long, Middle Quinsam, and Lower Quinsam lakes. In 2016, benthic invertebrates (and sediment) were also sampled at four locations in each of these four lakes, at an additional reference lake (Gooseneck, one location), at three locations in the Quinsam River, and at three locations in the Lower Wetland, which lies between Middle Quinsam and Lower Quinsam lakes. The sampling sites are shown in Appendix I, Figure 1 and listed in Table 15 with rationale for selection. Reference (control) stations are those upstream of or away from the influence of mine-affected discharges and seepage. Impact stations are those within the influence, and are identified as near field (direct mine influence) and far field (further downstream).

Table 15: Sampling Stations for Biota Monitoring, Quinsam Lakes System, 2016

Habitat Type	Lake	Station	Phyto-plankton	Zoo-plankton	Benthic Invertebrates	Rationale
Lakes	No Name	Inlet			X	reference
		Deep	X	X	X	near field
		Seep			X	near field
		Outlet			X	near field
	Long	Inlet			X	near field
		Deep	X	X	X	near field
		Seep			X	near field
		Outlet			X	near field
	Middle Quinsam	Inlet			X	near field
		Deep	X	X	X	near field
		Seep			X	near field
		Outlet			X	near field
	Lower Quinsam	Inlet			X	far field
		Deep -1	X	X	X	far field
		Deep -2			X	far field
		Outlet			X	far field
	Gooseneck	Deep			X	reference
Rivers	Quinsam	WA			X	reference
		QRDS			X	near field
		7SQ-03			X	far field
Wetlands	Lower Wetland	Inlet			X	far field
		Middle			X	far field
		Outlet			X	far field

This section of the report describes sampling objectives, methods, QA/QC, and results for phytoplankton, zooplankton, and benthic invertebrates. Section 11 discusses results in terms of overall watershed health, related to QCC operations.

10.1 PHYTOPLANKTON

Phytoplanktons are photosynthetic microorganisms that live in lakes at depths to where adequate sunlight can penetrate. They are the main primary producers in lakes, converting sunlight, CO2, and water into organic matter, and are the foundation for the aquatic food web (Wetzel 2001). Phytoplankton includes algae and cyanobacteria, both of which contain at least one form of chlorophyll (chlorophyll *a*), the major photosynthetic pigment. They are sensitive to changes in water quality (Wetzel 2001). Many lakes have a spring and fall phytoplankton bloom (peak growth period) following the seasonal “overturns” or mixing of the water column, which redistribute nutrients through the water column.

Phytoplankton are monitored annually at one station each in No Name, Long, Middle Quinsam, and Lower Quinsam lakes, in the deepest area of the lakes, where routine water quality monitoring is conducted. Since 2013, phytoplankton samples have been collected at the four lakes once each in the spring, summer and fall 5 in 30 day water sampling periods defined in amended Permit PE 7008. From the 1990s to 2012, Permit PE 7008 required sampling at 1, 4, and 9 m depth in April through September at Long Lake and Middle Quinsam Lake, with No Name Lake added in 2012 and Lower Quinsam Lake added in 2013.

10.1.1 *METHODS*

10.1.1.1 *Field Methods*

In 2016, samples were collected from 1 m depth using a 4 L Beta sampler. Chlorophyll a samples were collected as 1 L raw water samples, shipped to Maxxam Analytics (Burnaby B.C.) and laboratory filtered for analysis. A 250 mL sample was preserved with Lugol’s in the field and analyzed for community composition, i.e., counts and identification to lowest practical level (Stantec Consulting Ltd., Burnaby B.C.). Field replicates were collected for QA/QC in April and August 2016.

Laboratory Methods

Organisms were identified to lowest practical level (species where possible) using an inverted microscope. A 27 mL volume of lake water was settled in a chamber. Counts were made at 100X, 400X, and 1000X magnifications, to record the size range of phytoplankton.

Analytical Methods

Statistical tests were conducted to assess the effects of lake (i.e., mine-related effect) and year on the chlorophyll a and total abundance data, using generalized linear mixed effects models (GLMMs). Analysis of variance (ANOVA) was applied to the models to determine the influence of lake and year in the model. GLMMs allow for grouping of variables to account for the repeated measurements during the sampling program and for the resulting variation. The significance of model terms was calculated using the t-statistic and F-statistic. A significant t-statistic indicates the specific level of the variable is significantly different from the intercept. A significant F-statistic indicates that the variable significantly improves the model. Models were fit using R 3.3.1 (R Core Team 2016) 2021 and the R package "lme4" (Bates et al. 2015)[22].

10.1.2 *Results*

10.1.2.1 *Chlorophyll a*

Chlorophyll *a* concentrations provide an indication of overall phytoplankton biomass at any given time and provide a basis for comparing primary production among lakes. Table 16 provides data for samples collected from 1 m depth in 2016 and Appendix IV-1 provides data for 2013 through 2016. Concentrations ranged from below the detection limit of 0.05 µg/L (spring sample from No Name Lake) to 1.51 µg/L (Long Lake, spring) in 2016.

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[21] R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical. Computing, Vienna, Austria. URL https://www.R-project.org/

[22] Bates D, Maechler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67(1): 1-48.

Table 16: Chlorophyll a Concentrations, 1 m Depth, Quinsam Lakes System, 2016

Lake	Chlorophyll *a* (µg/L)		
	Spring (April 13-15)	Summer (Aug. 8-10)	Fall[1] (Nov. 2-4)
No Name	<0.05	0.95	1.14
Long	1.51	0.93	1.05
Middle Quinsam	1.0	0.58	1.14
Lower Quinsam	1.04	0.97	1.02

NOTE:
1. Duplicates pairs taken in Long, Middle Quinsam, and Lower Quinsam Lake had identical values.

Chlorophyll a concentrations varied among lakes and over the three sampling periods. No Name Lake had peak concentrations in summer and fall, Long Lake had peak concentrations in spring, Middle Quinsam Lake had peak concentrations in spring and fall, and Lower Quinsam Lake had no evident peaks. Seasonal trends were as follows in 2016:

- In spring, concentrations were lowest at No Name Lake, intermediate at Middle Quinsam and Lower Quinsam lakes, and highest at Long Lake
- In summer, concentrations were similar at No Name, Long, and Lower Quinsam lakes (0.93 to 0.97 µg/L), and lower at Middle Quinsam Lake (0.58 µg/L).
- In fall, concentrations were similar in the four lakes (1.02 to 1.14 µg/L).

High variability among seasons, years, and lakes was noted between 2013 and 2016 (Figure 10), likely related to variation in timing of spring and fall overturns and in nutrient concentrations.

The chlorophyll *a* concentrations reported for these lakes reflect ultra-oligotrophic conditions (mean concentration less than 1 µg/L, maximum less than 2.5 µg/L), according to the trophic classification system for lakes developed by Vollenweider and Kerekes (1982; cited in Environment Canada 2004)[23]. Permit PE 7008 does not require nutrient analysis for the lakes, and phosphorus, nitrate, and ammonia data were not available to confirm this trophic classification. Chlorophyll *a* results for 2016 are in the range reported from 2013 to 2015 (0.05 to 2.46 µg/L).

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[23] Vollenweider, R. and J. Kerekes. 1982. Eutrophication of Waters. Monitoring Assessment and Control. Organization for Economic Co-operation and Development (OECD) Paris. 156 pp. cited in Environment Canada 2004. Canadian Guidance Framework for the Management of Phosphorus in Freshwater Systems. Report No. 1-8. http://publications.gc.ca/collections/Collection/En1-34-8-2004E.pdf

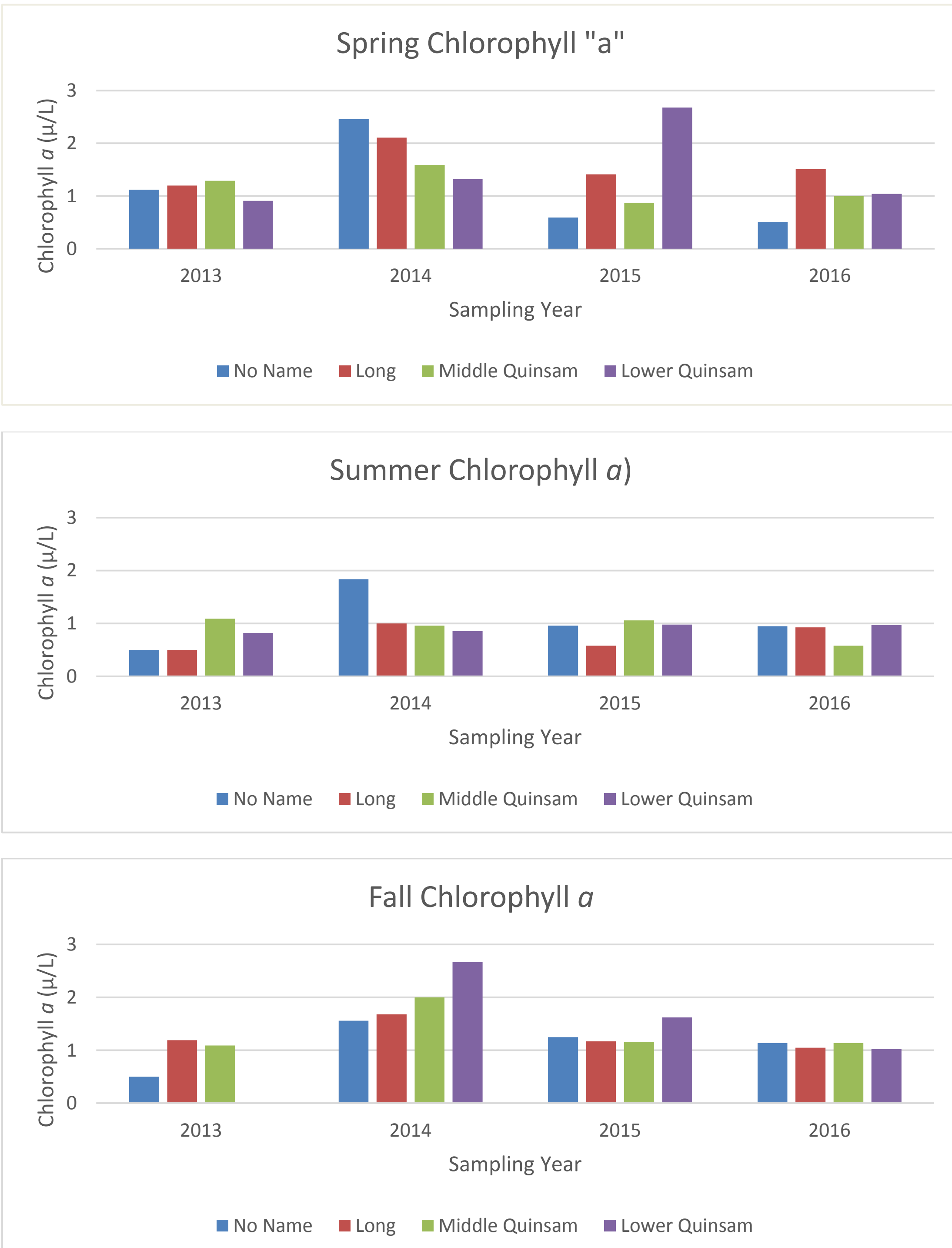

Figure 10: Chlorophyll a (µg/L) at 1 m Depth, Quinsam Lakes System, 2013 – 2016

There were statistically significant differences ($p<0.05$, GLMM, ANOVA) in phytoplankton chlorophyll *a* between years but not between lakes (Table 17), indicating that mine activities do not seem to affect phytoplankton chlorophyll *a*.

Table 17: Result of Statistical Analysis of Differences in Phytoplankton Chlorophyll a by Year and Lake

Variable	Parameter Estimate (SE)	t-value	p of t-stat
Intercept[1]	0.94 (0.21)	4.55	**<0.01**
2014	0.72 (0.17)	4.16	**<0.01**
2015	0.24 (0.17)	1.4	0.17
2016	0.03 (0.17)	0.2	0.84
Lower Quinsam	0.15 (0.17)	0.85	0.4
Middle Quinsam	-0.04 (0.17)	-0.25	0.81
No Name Lake	-0.08 (0.17)	-0.48	0.64
		F-value	**p of f-stat**
Year		7.74	**<0.01**
Lake		0.65	0.59

NOTE:

1. The intercept incorporates both the first levels of Year (2013) and Lake (Long Lake); it is the estimated value of the response variable (abundance) considering both factors.

10.1.2.2 *Phytoplankton Communities*

Phytoplankton taxonomy reports are included in Appendix IV-2 and results are summarized here. Duplicate samples collected for No Name Lake in April and August showed good agreement for the paired samples (within 20% of duplicate samples).

Abundance is summarized in Table 18 as total and by size fraction (identified at 1000X, 400X, and 100X magnifications). Total abundance ranged from 300 to 2,400 cells/mL in 2016. The smallest size fraction (less than 5 μm in size) comprised at least 20% of the total abundance.

Table 18: Phytoplankton Abundance, Quinsam Lake System, 2016

Lake	Month	Abundance (cells/mL) at 1 m depth			
		Total	< 5 µm (1,000 X)	5 to 25 µm (400 X)	> 25 µm (100 X)
No Name	Spring (April)	1,100	864	240	1.8
No Name (replicate)		970	792	180	1.8
Long		1,500	1,300	240	5.5
Middle Quinsam		1,100	882	240	2.8
Lower Quinsam		1,500	1,200	260	5.4
No Name	Summer (August)	1,800	1,200	500	42
No Name (replicate)		1,900	1,280	595	46
Long		1,200	990	140	22
Middle Quinsam		930	810	116	1.5
Lower Quinsam		2,400	1,850	578	1.4
No Name	Fall (November)	650	600	50	0.4
Long		780	640	140	0.5
Middle Quinsam		610	520	90	3.0
Lower Quinsam		300	250	50	0

In 2016, abundance was greatest in spring (Long and Middle Quinsam lakes) or summer (No Name and Lower Quinsam lakes) and lowest in fall. The highest abundance was recorded in summer at Lower Quinsam Lake (2,400 cells/mL) and the lowest was in the fall, also at Lower Quinsam Lake (300 cell/mL). The fall sample from Lower Quinsam Lake contained large amounts of silt, which may have reduced phytoplankton abundance and impaired to the ability to count the algae. Peak abundance and chlorophyll a concentrations did not always coincide, likely related to changes in size of abundant taxa over the sampling periods.

Variation in total abundance among lakes and through the three seasonal sampling periods for 2013 through 2016 is shown in Figure 11. As noted for chlorophyll a, high variability among seasons, years, and lakes between 2013 and 2016 was likely related to variation in timing of spring and fall overturn and nutrient concentrations. Phytoplankton abundance data for 2016 were consistent with those of previous years.

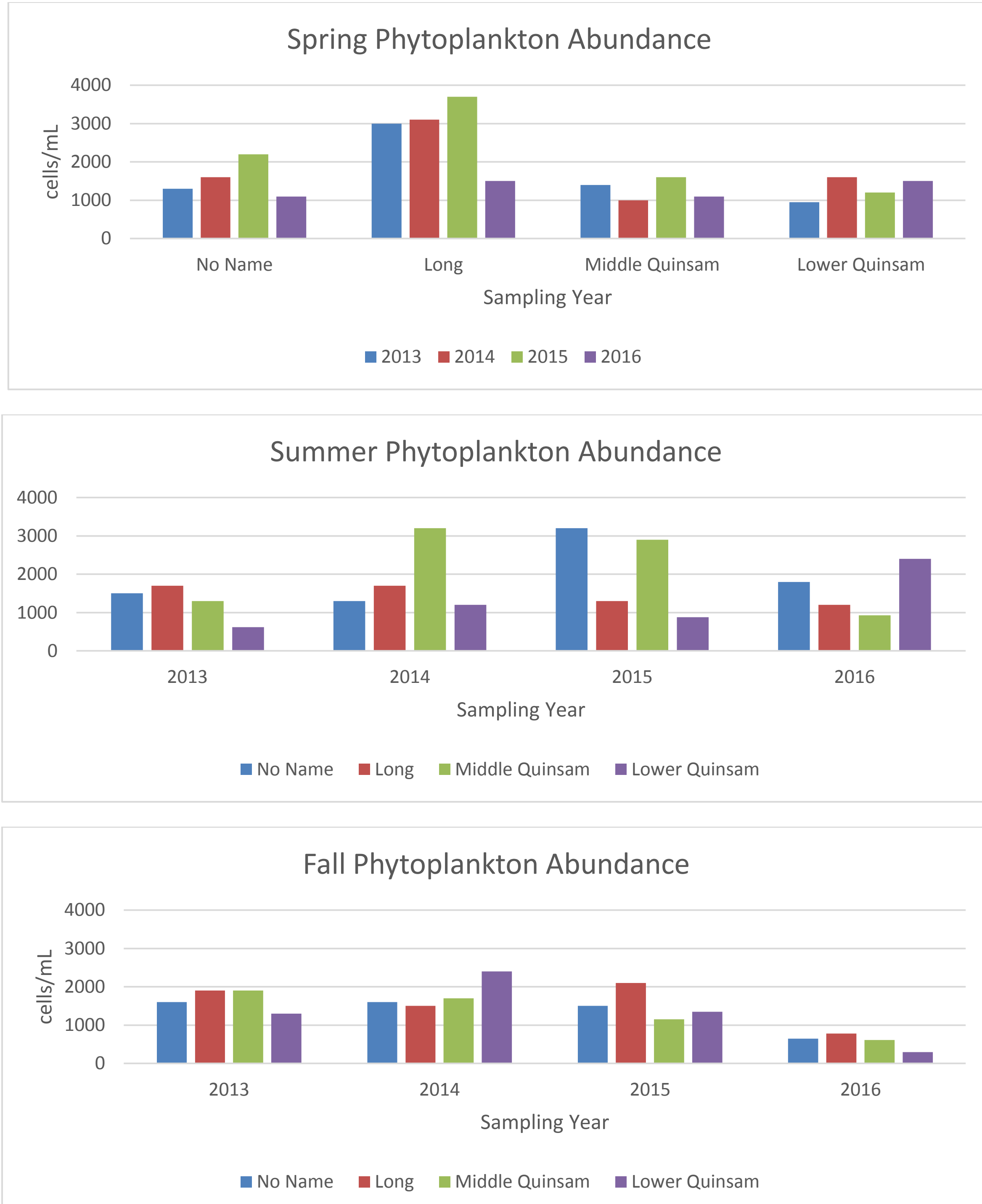

Figure 11: Total Phytoplankton Abundance, 1 m Depth, Quinsam Lakes System, 2013 – 2016

There were statistically significant differences ($p<0.05$, GLMM and ANOVA) in phytoplankton abundance among years but not among lakes (Table 19), indicating that mine activities do not seem to have an effect phytoplankton abundance.

Table 19: Result of Statistical Analysis of Differences in Phytoplankton Abundance by Year and Lake

Variable	Parameter Estimate (SE)	t-value	p of t-stat
Intercept[1]	1885.00 (265.55)	7.1	**<0.01**
2014	285.83 (280.09)	1.02	0.31
2015	384.17 (280.09)	1.37	0.18
2016	-383.33 (280.09)	-1.37	0.18
Lower Quinsam	-648.33 (280.09)	-2.32	**0.03**
Middle Quinsam	-390.83 (280.09)	-1.4	0.17
No Name Lake	-344.17 (280.09)	-1.23	0.23
		F-value	**p of t-statistic**
Year		3.02	**0.04**
Lake		1.81	0.16

NOTE:
1. The intercept incorporates both the first levels of Year (2013) and Lake (Long Lake); it is the estimated value of the response variable (abundance) considering both factors.

Taxon richness (at genus or species level) ranged from 8 (November, Lower Quinsam Lake) to 34 (Lower Quinsam Lake August) in 2016, as shown in Table 20. Richness was highest in either April (No Name and Long lakes) or August (Middle Quinsam and Lower Quinsam lakes) and lowest in November (all lakes).

Table 20: Phytoplankton Taxon Richness, Quinsam Lake System, 2016

Lake	Taxon Richness		
	Spring (April)	**Summer (August)**	**Fall (November)**
No Name	30[a]	27[a]	14
Long	32	28	14
Middle Quinsam	25	32	19
Lower Quinsam	26	34	8

NOTE:
[a] Mean of duplicate samples

Very small (<5 μm) chrysoflagellates (*Ochromonas* spp. and *Chromulina* spp.) were the most abundant phytoplankton in samples from all lakes and all dates in 2016, as has been noted since monitoring began in the 1990s (Appendix IV-2). Although these ultra-nanoplankton were very abundant numerically, they contributed little to algal biomass. Small chrysoflagellates are numerically dominant in many lakes. The predominant and common larger phytoplankton taxa are listed in Table 21 and include:

- Chrysophyta (golden algae; *Ochromonas*, *Dinobryon*)
- Cryptophyta (red-brown algae; *Cryptomonas*, *Rhodomonas*)
- Bacillariophyceae (diatoms; *Melosira italica*)
- Cyanophyceae (blue-green bacteria; *Merismopedia*)

Table 21: Predominant and Common Phytoplankton Taxa, Quinsam Lakes System, 2016

Season	Lake	Predominant	Common
Spring (April)	No Name	*Rhodomonas minuta* larger *Ochromonas* spp.	*Cryptomonas* spp.
	Long	larger *Ochromonas* spp.	*Cryptomonas* spp. *Rhodomonas minuta*
	Middle Quinsam	larger *Ochromonas* spp.	*Rhodomonas minuta* *Dinobryon* sp.
	Lower Quinsam	larger *Ochromonas* spp.	*Rhodomonas minuta*
Summer (August)	No Name	*Merismopedia sp.*	*Dinobryon cylindricum* *Rhodomonas minuta* *Cryptomonas* spp. *Ochromonas* spp.
	Long	larger *Ochromonas* spp.	*Rhodomonas minuta* *Dinobryon cylindricum*
	Middle Quinsam	larger *Ochromonas* spp.	*Cryptomonas* spp.
	Lower Quinsam	larger *Ochromonas* spp.	*Melosira italica*
Fall (November)	No Name	*Rhodomonas minuta* larger *Ochromonas* spp.	
	Long	*Rhodomonas minuta*	*Cryptomonas* spp. larger *Ochromonas* spp
	Middle Quinsam	*Rhodomonas minuta*	larger *Ochromonas* spp.
	Lower Quinsam	larger *Ochromonas* spp.	*Rhodomonas minuta* *Cryptomonas* spp.

10.2 Zooplankton

Zooplankton form the second trophic level in the water column of lakes (secondary producers), grazing on phytoplankton, consuming organic matter, and providing a food source for juvenile fish (Wetzel 2001). Abundance and composition of the zooplankton community vary among lakes due to variation in water chemistry, lake characteristics, and grazing pressures from fish (Wetzel 2001).

Zooplankton are monitored in the Quinsam mine receiving environment annually at one station in each of No Name, Long, Middle Quinsam, and Lower Quinsam lakes. Since 2014, zooplankton samples have been collected once in the spring, summer, and fall during the 5 in 30 water quality sampling periods.

10.2.1 *Methods*

10.2.1.1 *Field Methods*

Zooplankton were collected from No Name, Long, Middle Quinsam, and Lower Quinsam lakes three times in 2016 (once during each 5 in 30 set). Samples were collected using a Wisconsin Plankton Sampler, 63 µm a 10 m vertical tow, with one sample collected per lake. Samples were preserved with ethanol and sent to Fraser Environmental Services (Surrey B.C.) for taxonomic analyses.

10.2.1.2 *Laboratory Methods*

Organisms were counted and identified to lowest practical level.

10.2.1.3 *Analytical Methods*

Statistical tests were conducted to assess the effects of lake (i.e., mine-related effect) and year on zooplankton abundance and taxon richness data, using GLMMs. ANOVA was applied to the models to determine the influence of lake and year in the model. GLMMs allow for grouping of variables to account for the repeated measurements during the sampling program and for the resulting variation. The significance of model terms was calculated using the t-statistic and F-statistic. A significant t-statistic indicates the specific level of the variable is significantly different from the intercept. A significant F-statistic indicates that the variable significantly improves the model. Models were fit using R 3.3.1 (R Core Team 2016) and the R package “lme4” (Bates et al. 2015).

10.2.2 RESULTS

Detailed zooplankton taxonomic composition results are provided in Appendix IV-3 and summarized below.

Zooplankton abundance in samples collected in 2016 is listed in Table 22. Abundance ranged from 30 organisms/sample (Lower Quinsam Lake, November) to 3,656 organisms/sample (Long Lake, April). In No Name, Middle Quinsam, and Lower Quinsam lakes, maximum abundance was reported in the summer, and in Long Lake, the maximum occurred in spring. Abundance tended to be higher in Long Lake and lower in Middle Quinsam Lake compared to the other lakes (except November, when Middle Quinsam and Lower Quinsam lakes had similar abundance).

Table 22: Zooplankton Abundance, Quinsam Lake System, 2016 (vertical tow, 0 to 10 m)

Lake	Month	Abundance (organisms/sample)			
		Total	Copepoda	Cladocera	Rotifera
No Name	Spring (April)	666	395	91	175
Long		3,656	353	83	3,220
Middle Quinsam		213	83	22	108
Lower Quinsam		279	103	38	138
No Name	Summer (August)[1]	1,883	1,236	564	72
Long		3,163	194	1,778	405
Middle Quinsam		1,250	473	772	44
Lower Quinsam		2,707	991	1,569	135
No Name	Fall (November)	288	218	6	64
Long		573	487	49	37
Middle Quinsam		74	32	6	30
Lower Quinsam		30	2	2	26

NOTE:

1. *Chaoborus* (phantom midge) also reported in low numbers in August at Long, Middle Quinsam, and Lower Quinsam lakes

Seasonal and spatial trends are shown in Figure 12 for samples collected in 2014, 2015, and 2016. There has been high variability among lakes, seasons, and years. In general, abundance is highest for the summer samples, following peaks in levels of phytoplankton and organic matter; however, there are exceptions, including low abundance in No Name Lake in summer 2014 and peak abundance in Lower Quinsam Lake in fall 2015. In 2015, abundance was highest in Long Lake during spring and summer and in Lower Quinsam Lake during fall; abundance was lower in No Name and Middle Quinsam lakes than in 2014.

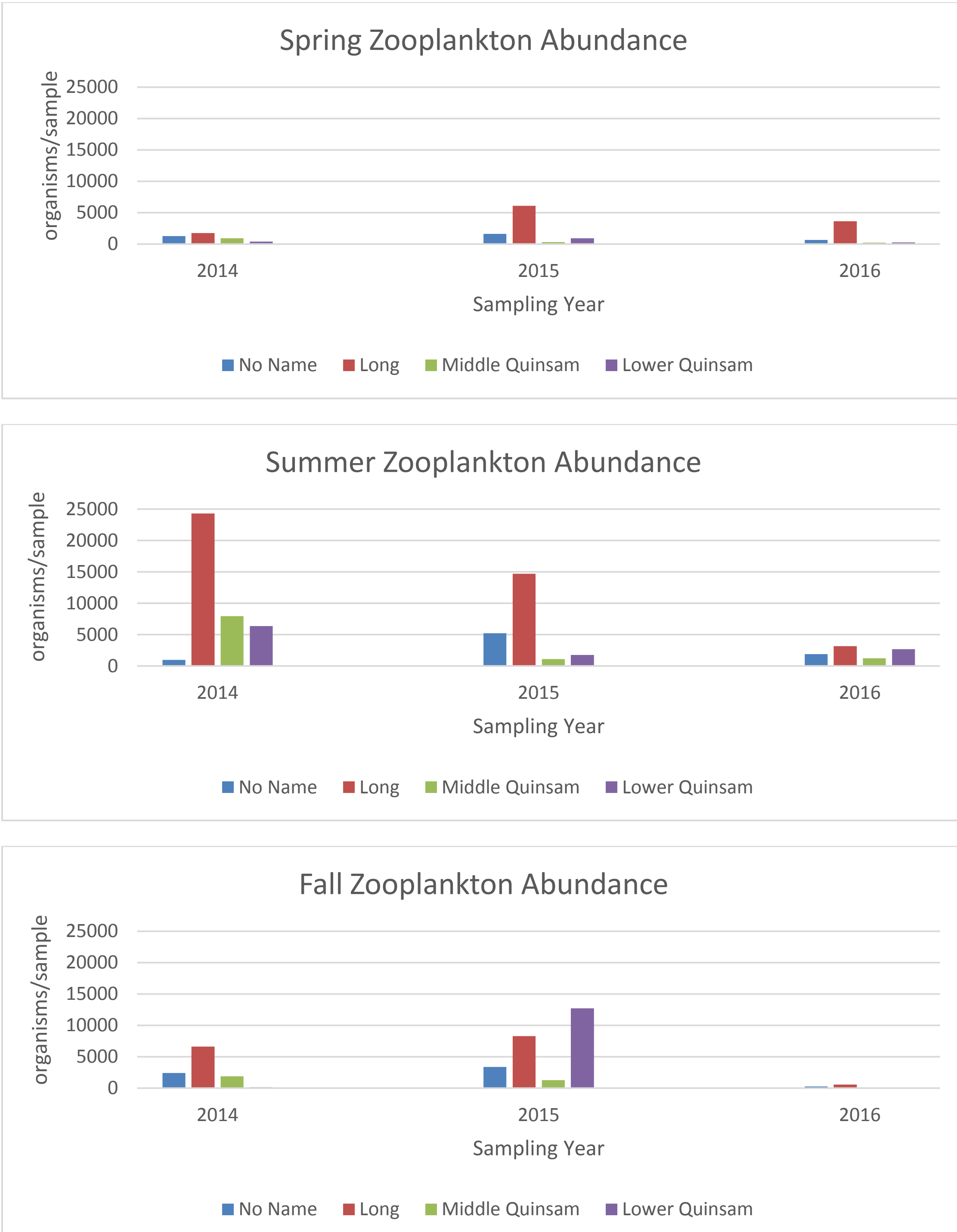

Figure 12: Total Zooplankton Abundance (0 to 10 m Vertical Tows), Quinsam Lakes System, 2014 to 2016

There were statistically significant differences ($p<0.05$, GLMM and ANOVA) in abundance among lakes, but not among years, with highest mean abundance reported for Long Lake, followed by Lower Quinsam Lake, then No Name and Middle Quinsam lakes (Table 23).

Table 23: Result of Statistical Analysis of Differences in Zooplankton Abundance by Year and Lake

Variable	Parameter Estimate (SE)	t-value	p of t-stat
Intercept[1]	8744.83 (1969.18)	4.44	**<0.01**
2015	203.92 (1626.15)	0.12	**<0.01**
2016	-3360.08 (1626.15)	-2.07	**<0.01**
Lower Quinsam	-4878.11 (1877.72)	-2.6	**<0.01**
Middle Quinsam	-6021.33 (1877.72)	-3.21	**<0.01**
No Name Lake	-5712.22 (1877.72)	-3.04	**<0.01**
		F-value	**p of f-stat**
Year		3.03	0.06
Lake		4.48	**0.01**

NOTE:

2. The intercept incorporates both the first levels of Year (2013) and Lake (Long Lake); it is the estimated value of the response variable (abundance) considering both factors.

Taxon richness was calculated at the genus level, omitting unidentified and benthic organisms. In 2016, taxon richness ranged from 6 to 14, and was higher in spring and summer than in fall (Table 24). Taxon richness tended to be highest at No Name and Long lakes.

Table 24: Zooplankton Taxon Richness, Quinsam Lake System, 2016 (vertical tow, 0 to 10 m)

Characteristic	Lake	Spring (April)	Summer (August)	Fall (November)
Number of Genera	No Name	12	10	9
	Long	10	14	6
	Middle Quinsam	9	8	7
	Lower Quinsam	7	10	6
% Juvenile Copepoda and Cladocera in samples	No Name	48%	55%	65%
	Long	6%	24%	77%
	Middle Quinsam	19%	23%	15%
	Lower Quinsam	26%	29%	0%

There were statistically significant differences ($p<0.05$, GLMM and ANOVA) in zooplankton taxon richness among the lakes, but not between years (Table 25), indicating that lake characteristics, including potential mine-related influences, affect the zooplankton abundance.

Table 25: Result of Statistical Analysis of Differences in Zooplankton Taxon Richness by Year and Lake

Variable	Parameter Estimate (SE)	t-value	p of t-stat
Intercept[1]	9.36 (1.00)	9.32	**<0.01**
2015	-1.67 (0.88)	-0.19	0.85
2016	0.08 (0.88)	0.1	0.92
Lower Quinsam	-1.22 (1.01)	-1.2	0.24
Middle Quinsam	-0.56 (1.01)	-0.55	0.59
No Name Lake	1.67 (1.01)	1.64	0.11
		F-value	**p of f-stat**
Year		0.04	0.96
Lake		2.96	**0.05**

NOTE:

1. The intercept incorporates both the first levels of Year (2013) and Lake (Long Lake); it is the estimated value of the response variable (abundance) considering both factors.

Diversity and evenness indices were not calculated because the high proportion of unidentified juvenile Cladocera and Copepoda in the samples (Table 24) would introduce bias into those calculations. Juvenile Cladocera and Copepoda formed a high percentage of samples from No Name Lake on all three sampling dates (48 to 65% of total abundance) and Long Lake in November (77%). Lower proportions (6% to 29%) were reported for Long Lake at other times and for Middle Quinsam and Lower Quinsam lakes on all three dates. The presence of abundant juveniles suggests rapid growth rates.

Zooplankton communities consisted of the larger copepods and cladocerans and the smaller rotifers in 2016 (Figure 13). Composition varied among lakes and seasons:

- No Name Lake – copepods (Cyclopoida and Calanoida) were predominant (over 50% abundance) on all three dates, with rotifers common in April and November and cladocerans common in August; peak abundance occurred in August.
- Long Lake – rotifers were predominant (over 80%) in April, followed by cladocerans in August (approximately 70%) and copepods (over 80%) in November, with peak abundance in April and August.
- Middle Quinsam Lake – rotifers and copepods were predominant in April and November (approximately 40 to 50% each), and cladocerans were predominant in August (approximately 70%) during the peak of zooplankton abundance.
- Lower Quinsam Lake – rotifers and copepods (45 to 50% each) were predominant in April; cladocerans and copepods (40% to 55% each) were predominant in August, during the peak of abundance; rotifers (almost 90%) were predominant in November.

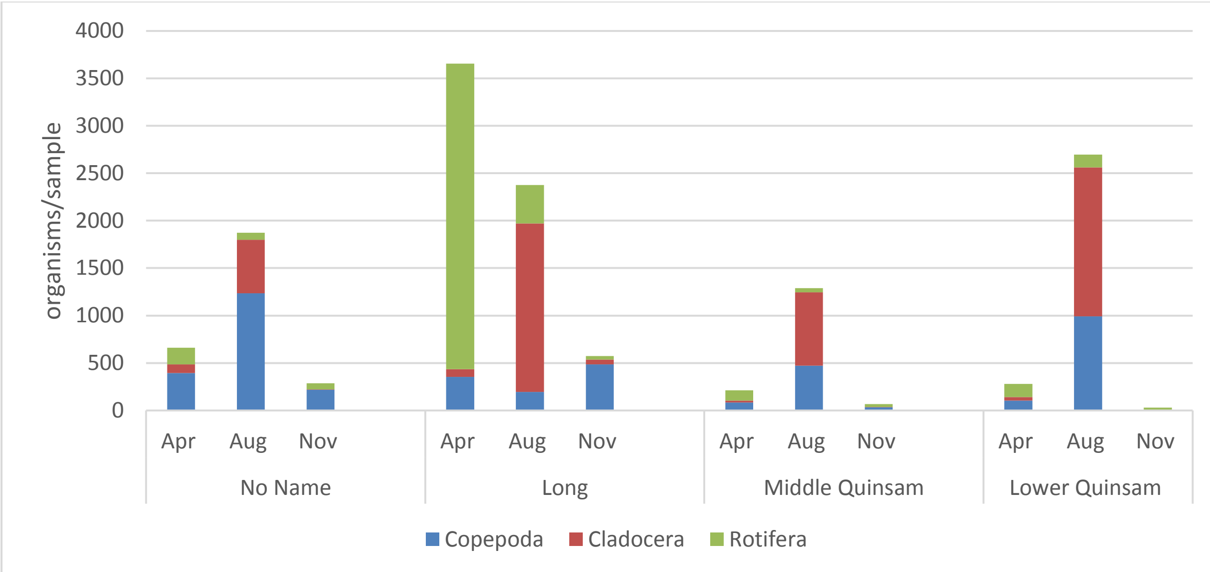

Figure 13: Zooplankton Abundance by Group, Quinsam Lakes System, 2016

Differences in taxonomic composition are related to seasonal conditions, including food supply (phytoplankton and organic matter), and grazing pressures from fish. The larger copepods and cladocerans provide preferred food sources for fish. All four lakes are known to be fish bearing (e.g., salmon and trout species), but there is not enough information about fish populations to estimate grazing pressures on zooplankton.

10.3 Benthic Invertebrates

Benthic invertebrates (benthos) are an important component of both lotic (fast flowing) and lentic (slow flowing) aquatic systems, as they consume smaller animals and plants, aid in decomposition of organic material, and are prey for higher trophic levels such as fish. They are considered important monitoring tools for a range of environmental stresses. Benthic invertebrate communities were sampled to evaluate abundance and community composition (common taxonomic groups, taxonomic richness, diversity, and evenness).

Benthic invertebrates and sediment (Section 9) were sampled at 23 stations in 2016 (Appendix VI Table 1 and Appendix I Figure 1), located in five lakes, one wetland, and the Quinsam River.

Samples were collected in September and October 2016, following standard provincial sampling guidance (BC MOE 2016)24 and the study design provided in Appendix VI.

10.3.1 *Lakes*

10.3.1.1 *Methods*

The design of the benthic invertebrate monitoring program was a modified Spatial Variance Program (Standard), as defined by BC MOE (2016). The four lakes were sampled at Inlet, Deep, and Outlet stations (five replicate samples per station). No Name, Long, and Middle Quinsam lakes were also sampled at Seep stations, where groundwater surfaces and enters the lakes (five or six replicates per station). No seeps had been identified for Lower Quinsam Lake.

Field Methods

Five replicate samples were collected per station, each one a composite of three grabs, at the same locations as the sediment samples (Appendix I Figure 1). Samples were collected with an Eckman sampler. The composite sample was sieved in a sieve bag with a 200 µm mesh to remove fine sediment. Sieve contents were gently transferred to a labeled sample jar, rinsing the sieve to collect all the material. Field filtered water was used for rinsing to avoid introducing zooplankton to the samples. Jars were filled no more than half full and preserved with 10% buffered formalin (filled to top). Samples were stored in a cooler and shipped to the taxonomy laboratory with a chain of custody sheet. Two samples per station were archived and were analyzed later if the first three replicates showed high variability.

Sampling depth varied according to habitat within each lake. Observations (depth sampled; sediment vertical profile, texture and color, and presence of living organisms, debris, biofilms, odor, or oily sheen) were recorded. General habitat information from field surveys and total organic carbon (TOC) and particle size data from the sediment analyses are listed in Appendix I Tables186 to192 and summarized in Table 26.

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[24] British Columbia Ministry of Environment (BC MOE). 2016. Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators, Version 2, 2016 Available: http://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/water_air_baseline_monitoring.pdf Accessed July 2017

Table 26: General Benthic Habitat Characteristics, Quinsam Lakes System, 2016

<table>
<tr><th rowspan="2">Lake</th><th colspan="4">Sampling Site Water Depth (m) and Habitat Characteristics</th></tr>
<tr><th>Inlet</th><th>Deep</th><th>Seep</th><th>Outlet</th></tr>
<tr><td>No Name</td><td>3.8 – 5.0 m
Plant debris
minimal odour
13% TOC
sand>silt>clay</td><td>12 m
Minimal debris
Mild anoxic odour
12% TOC
sand>silt>clay</td><td>5.6 m
Low debris
Mild anoxic odour
11% TOC
sand=silt>clay</td><td>3.0-4.0 m
Coarse organics
Odour of decay
19% TOC
sand>silt>clay</td></tr>
<tr><td>Long</td><td>5.0 m
Some plant debris
Strong anoxic odour
15% TOC
sand>silt>clay</td><td>19.5 m
Minimal debris
Mild anoxic odour
13% TOC
sand>silt>clay</td><td>12.5 – 16.0 m
Some plant debris
Mild anoxic odour
15% TOC
sand>silt>clay</td><td>5.0 – 5.5 m
Wood and plant debris
Mild anoxic odour
11% TOC
silt>sand>clay</td></tr>
<tr><td>Middle Quinsam</td><td>– 2.0 m
Much plant debris
Slight decay odour
12% TOC
sand=silt>clay</td><td>13.0 – 14.0 m
Minimal debris
minimal odour
13% TOC
sand>silt>clay</td><td>1.0 m
Much plant debris
Slight decay odour
17% TOC
sand>silt>clay</td><td>1.0 – 3.0 m
Much plant debris
Mild odour of decay
14% TOC
sand>silt>clay</td></tr>
<tr><td rowspan="2">Lower Quinsam</td><td rowspan="2">14.0 – 17.0 m
Much plant debris
Minimal odour
3.7% TOC
sand>>silt>clay</td><td>16.0 – 17.0 m
Minimal debris
Odour of decay
4.3% TOC
silt>sand>clay</td><td rowspan="2">Not sampled</td><td rowspan="2">1.5 – 3.0 m
Plant debris
Odour of decay
7.4% TOC
sand>silt>clay</td></tr>
<tr><td>14.0 – 16.0 m
Minimal debris
Odour of decay
4.2% TOC
silt>sand>clay</td></tr>
<tr><td>Gooseneck Lake</td><td>Not sampled</td><td>15.0 m
Some fine debris
Medium anoxic odour
13% TOC
sand>silt>clay</td><td>Not sampled</td><td>Not sampled</td></tr>
</table>

Laboratory Methods

Samples were sent to Cordillera Consulting Inc. (Summerland B.C.) for taxonomic analysis. Cordillera was responsible for sample reception, sorting, identification, and QA/QC. Samples were sieved in the laboratory at 200 µm mesh. Cordillera's detailed Methods and QC Report is included in Appendix V-1. Organisms were identified to lowest practical level (typically genus for insect and oligochaete taxa, genus or family for other organisms).

For Inlet, Deep, and Outlet stations, three replicate samples per station were analyzed initially. The additional two samples from Inlet and Outlet stations were subsequently analyzed due to high variability among replicates. All replicate samples from seep stations were analyzed, as were all samples from Gooseneck Lake (only Deep station sampled).

Sorting efficiency was assessed in 9 of 92 samples analyzed (10%; 7 from lakes, 2 from Quinsam River): re-sorted samples had at least 90% (90 to 100%) efficiency. Subsampling efficiency was assessed on 10% (6) of the split samples: the data quality objective (subsample count within 20% of the expected count, i.e., total count divided by number of fractions) was met.

Data Analysis Methods

The benthic community was evaluated in terms of overall community composition (common taxonomic groups and ecological relevance) and standard metrics (density, taxon richness, diversity, and evenness). These standard metrics are commonly used to assess differences among sites (Environment Canada 2012)[25].

Density was calculated as organisms/m2, accounting for sample splitting and area sampled. Richness was calculated as number of taxa at the lowest practical level (genus where possible) within a replicate sample.

Simpson's Diversity Index (D) considers the number of taxa present and their abundance (D ranges from 0 to 1; 1 indicates maximum diversity). This index is calculated as:

$$D = 1 - \sum (p_i)^2$$

where:

p_i is the proportion that taxon i contributes to the total number of invertebrates in a sample.

Simpson's Evenness (E) index indicates the degree to which all taxa of the same level are equal in abundance (E ranges from 0 to 1; 1 indicates maximum evenness). This index is calculated as:

$$E = \frac{\left(1 \big/ \sum (p_i)^2 \right)}{S}$$

[25] Environment Canada. 2012. Metal Mining Technical Guidance for Environmental Effects Monitoring.

where

> p_i is the proportion that taxon i contributes to the total number of invertebrates in a sample and S is the total number of taxa in the sample.

Mean values were graphed using R (R Core Team 2016) for comparison within and among lakes. The graphs show median, 25th and 75th percentiles and 1.5 times the interquartile ranges at each station.

Differences among stations for community metrics were assessed using R, grouping stations by habitat type (i.e., Inlet, Deep, Seep, Outlet). After testing for normality and homogeneity of data distribution, data were log-transformed if indicated, and differences among stations for each habitat type were evaluated using the applicable statistical tests. When data were distributed normally and homogenously, a mixed-effects model was used with raw or log-transformed data. When these assumptions were violated, non-parametric tests (Kruskal-Wallis and Dunn's tests) were used.

To test for a mine-related effect, stations were grouped as low impact (no or negligible influence of mine waste water), medium impact (influence of mine waste water, comparable to a far field station) and high impact (influence of mine waste water, comparable to a near field station), as summarized in Table 27. Rationale for categorizing the stations was as follows:

- Gooseneck Lake was a true reference lake (low impact), outside of mine influences, and sampled only in deep habitat
- No Name Lake was considered a reference or low impact station at the Inlet, as there is no known mine influence in that area, but downstream stations (Deep, Seep, and Outlet) were considered high impact/near field because of groundwater influences from the 2S PAG-CCR disposal pond and possibly the 2-South mine near the Outlet and Seep stations.
- Long Lake was categorized as high impact / near field at all stations (Inlet, Deep, Seep, and Outlet) due to mine influences throughout the lake
- Middle Quinsam Lake was categorized as high impact / near field at all stations (Inlet, Deep, Seep, and Outlet) due to mine influences throughout the lake, although it is noted that mine influence is less at the Inlet
- Lower Quinsam Lake was categorized as medium impact / far field at all stations (Inlet, Deep, and Outlet), given its distance downstream of Middle Quinsam Lake (the Quinsam River enters at the head of Lower Quinsam Lake).

Table 27: Classification of Lakes by Degree of Mine Influence for Statistical Testing

Habitat Type	High Impact/ Near Field	Medium Impact/ Far Field	Low Impact/ Reference
Inlet	Middle Quinsam Long Lake	Lower Quinsam	No Name
Outlet	Middle Quinsam Long Lake No Name	Lower Quinsam	
Deep	Middle Quinsam Long Lake No Name	Lower Quinsam (two sites, 600 m apart)	Gooseneck
Seep	Middle Quinsam Long Lake No Name		

Temporal trends were evaluated for Long Lake by comparison with the 2010 data from Golder (2010)[26].

10.3.2 *Results*

Benthic invertebrate taxonomy data for all samples are provided in Appendix V, with QA/QC reports in Appendix V-1, raw data in Appendix V-2, summary statistics (minimum, maximum, mean, median, standard deviation) for community metrics provided in Appendix V-3, and results of statistical tests provided in Appendix V-4.

Benthic invertebrate communities observed in the five lakes were typical of those found in British Columbia lakes. Taxa included Diptera (chironomid, ceratopogonid, and chaoborid midges), Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), Oligochaeta (aquatic worms), Odonata (dragonflies), Gastropoda (snails and bivalves), and others.

Results are discussed below for general composition first, to provide context for the routine community metrics (abundance, richness, diversity, evenness). Within a given lake, results are presented in order from inlet to outlet. Further discussion of watershed health is provided in Section 11. Because of the diversity of habitat types sampled (Inlet, Seep, Deep, and Outlet), trends are compared statistically among lakes for each habitat type.

[26] Golder Associates 2011. 2010 Integrated Long Lake Sediment Assessment. Report Prepared for Hillsborough Resources Ltd.

The lakes differed in organic content (% TOC) and particle size distribution of sediments (Table 26), which can influence the abundance and composition of benthic invertebrate communities. Lower Quinsam Lake had notably lower % TOC than the other four lakes sampled: average % TOC ranged from 11 to 19% in No Name Lake (highest at Outlet), from 11 to 15% in Long Lake (highest at Inlet and Seep), from 12 to 17% in Middle Quinsam Lake (highest at Seep), 3.7 to 7.4% in Lower Quinsam Lake (highest at Outlet), and 13% in Gooseneck Lake (at Deep). Sediments were generally comprised of sand, followed by silt, and with little clay content; exceptions where silt was predominant or equal to sand content were No Name Lake Seep, Middle Quinsam Lake Inlet, and Lower Quinsam Lake Deep.

Relative Abundance of Taxonomic Groups

The benthic invertebrate communities were characterized by the predominance of Chironomidae (non-biting midges) at most stations, regardless of habitat type. Chaoboridae (phantom midges) were predominant at Middle Quinsam Deep and common at Lower Quinsam Deep 1. The Ephemeroptera, Plecoptera, and Trichoptera (EPT, mayflies, stoneflies, caddisflies) group was more common at Inlet and Outlet than at Deep stations. Pisidiidae (clams) were present in all lakes and did not appear strongly associated with habitat type (e.g., common at No Name Deep and Long Lake Outlet).

The Inlet stations contained mainly Chironomidae, with lower abundance of EPT, Oligochaeta and Pisidiidae (Figure 14). Sampling depths varied and appeared to have a strong influence on community composition and density. No Name Lake was sampled at 3.8 to 5.0 m depth, Long Lake at 5 m, Middle Quinsam Lake at 1.0 to 2.0 m, and Lower Quinsam Lake at 14 to 17 m (Table 26). Substrate was coarser (sand) at Lower Quinsam Lake than at the other lakes (silt). In all four lakes, Chironomidae were predominant; however, overall density was notably lower at the Lower Quinsam Lake Inlet (collected at 14 to 17 m depth due to bathymetry). Oligochaeta were common at No Name and Lower Quinsam Lakes, EPT were common at Middle Quinsam and No Name lakes, and Pisidiidae were common at Long Lake.

Sampling depth appears to have strongly influenced abundance (highest at the shallowest Middle Quinsam and lowest at Lower Quinsam) and composition (more abundant EPT at the shallowest Inlet, Middle Quinsam).

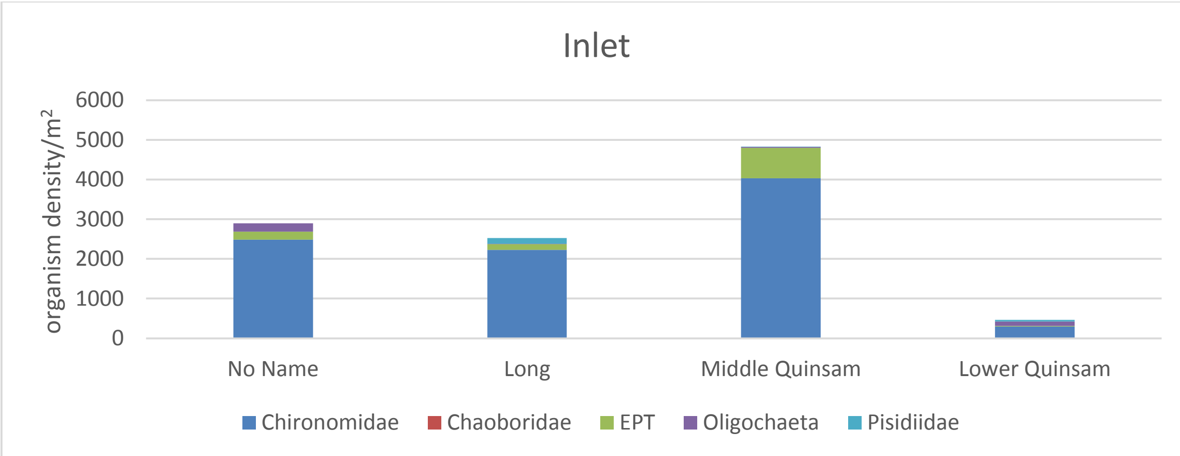

Figure 14: Average Density of Benthic Invertebrate Taxa at Inlet Stations, Quinsam Lakes System, 2016

The six Deep stations varied in composition (Figure 15) and depths sampled. Deep samples were collected at 12 m in No Name Lake, 19.5 m in Long Lake, 13 to 14 m in Middle Quinsam Lake, 16 to 17 m in Lower Quinsam Lake, and 15 m in Gooseneck Lake (Table 26). No Name Lake contained mainly Chironomidae and Pisidiidae, with some Chaoboridae. Long Lake, with lower total density, contained mainly Chironomidae with some Chaoboridae. Middle Quinsam Lake, also with low total density, contained mainly Chaoboridae with some Chironomidae. Lower Quinsam Lake contained Chaoboridae and Chironomidae, with some Oligochaeta. Gooseneck Lake contained mainly Chironomidae. Pisidiidae were common in No Name Lake, which was the shallowest depth sampled in Deep habitat.

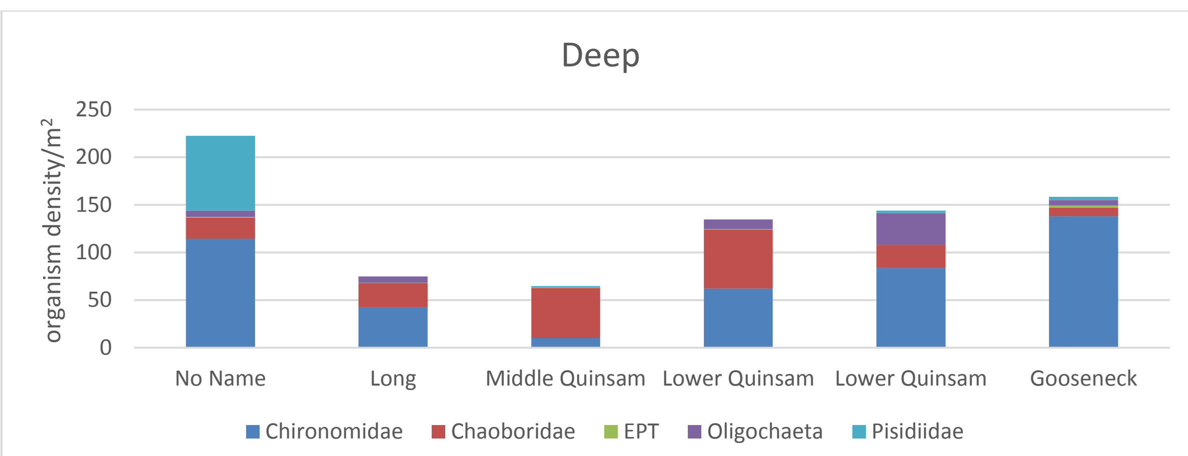

Figure 15: Average Density of Benthic Invertebrate Taxa at Deep Stations

Dissolved oxygen (DO) levels in deep water (hypolimnion) appears to be a major factor in composition of the Deep communities. The phantom midge *Chaoborus* (family Chaoboridae) is tolerant of low DO, and its high abundance in Middle Quinsam and Lower Quinsam lakes corresponds to minimum DO concentrations of 3.0 mg/L and 0 mg/L, respectively during the summer 5 in 30 day sampling period (Appendix 1, Tables 78 and 79). In contrast, the minimum DO in Long Lake was 3.4 mg/L and in No Name Lake was 5.8 mg/L (Appendix 1, Tables 76 and 77). Chaoboridae migrate between oxygenated areas at night to lower oxygen areas during the day (Hillsenoff 2011)[27].

The three Seep stations varied in composition (Figure 16) and depths sampled (Table 26). No Name Lake, sampled at 5.6 m off shore from where a channel conveying surfaced groundwater and other mine contact water enters the lake, consisted mainly of Chironomidae with some Oligochaeta and Pisidiidae common. Density at No Name Seep was lower than at Long and Middle Quinsam Seeps. Long Lake Seep, sampled at 12.5 to 16 m depth in an area with subsurface seepage, contained mainly Chironomidae, with Chaoboridae and Oligochaeta common. Middle Quinsam Seep, sampled at 1.0 m depth near a potential seep from the coal processing plant area, contained mainly EPT and Chironomidae, with some Pisidiidae. The presence of Chaoboridae at the Long Lake Seep was consistent with its presence at the Long Lake Deep station and the low DO levels in deeper water during summer.

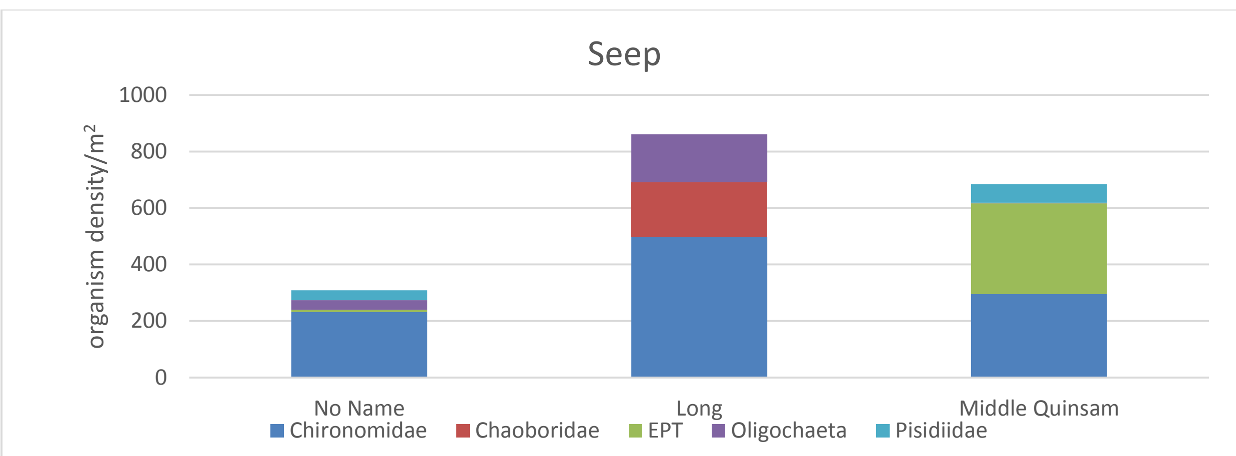

Figure 16: Average Density of Benthic Invertebrate Taxa at Seep Stations

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27 Hillsenhoff, W. 2001. Diversity and Classification of Insects and Collembola. Chapter 17. In: J. Thorp and A. Covich (editors). Ecology and Classification of North American Freshwater Invertebrates. Second Edition. Academic Press, San Diego CA.

Outlet stations varied in composition (Figure 17) and in depths sampled (Table 26). Inlet and Outlet sampling depths within a lake were consistent in No Name, Long, and Middle Quinsam lakes, but not in Lower Quinsam Lake. For Outlets, No Name Lake was sampled at 3.0 to 4.0 m, Long Lake at 5.0 to 5.5 m, Middle Quinsam Lake at 1.0 to 3.0 m, and Lower Quinsam Lake at 1.5 to 3.0 m. Chironomidae and EPT were the most abundant taxa at Outlet stations. In No Name Lake, EPT and Chironomidae were predominant, and in Long, Middle, and Lower Quinsam lakes, Chironomidae were predominant and EPT were common, along with Pisidiidae in Long Lake, and Oligochaeta in No Name, Middle Quinsam, and Lower Quinsam lakes. Density was notably higher at the shallow Middle Quinsam Lake station than at deeper No Name and Long lakes and shallow Lower Quinsam Lake station.

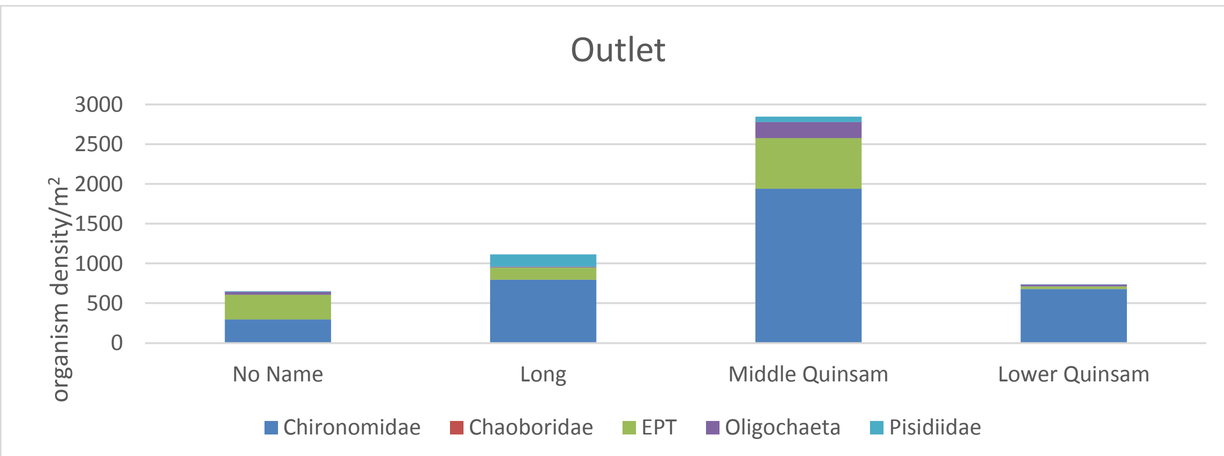

Figure 17: Average Density of Benthic Invertebrate Taxa at Outlet Stations

Density

Density showed a consistent pattern within each lake; highest at the Inlet, considerably lower at the Deep and Seep, and intermediate at the Outlet stations. Higher density at lake inlets and outlets generally occurs due to their shallow water, high DO, coarse substrate, and complex habitat, which supports higher abundance than in deep habitat (low DO, fine substrates). Habitat conditions in the Quinsam lakes generally followed this trend (Table 26).

Mean density ranged from 948 organisms/m^2 (Middle Quinsam Lake Deep) to 87,200 organisms/m^2 (Middle Quinsam Lake Inlet). There was high variability among replicates within a given station, particularly for Inlet and Outlet stations (Figure 18). Spatial trends for mean density were as follows:

- At Inlet stations, range of 14,522 (Lower Quinsam Lake) to 87,200 organisms/m^2 (Middle Quinsam Lake), with 57,900 and 53,100 organisms/m^2 at No Name and Long lakes, respectively
- At Deep stations, range of 950 organisms/m^2 (Middle Quinsam Lake) to 3,200 organisms/m^2 (No Name), with 1,100 organisms/m2 at Long Lake and 2,100 and 2,400 organisms/m^2 at the two Lower Quinsam Lakes stations and 2,400 organisms/m^2 at the Gooseneck Lake reference station
- At Seep stations, range of 1,900 organisms/m^2 (Long Lake) to 11,800 organisms/m^2 (Middle Quinsam Lake), with 5,483 organisms/m^2 at No Name Lake
- At Outlet stations, range of 14,500 organisms/m^2 (Lower Quinsam Lake) to 47,600 organisms/m^2 (Middle Quinsam Lake), with 22,600 organisms/m^2 at Long Lake and 23,600 organisms/m^2 at No Name Lake.

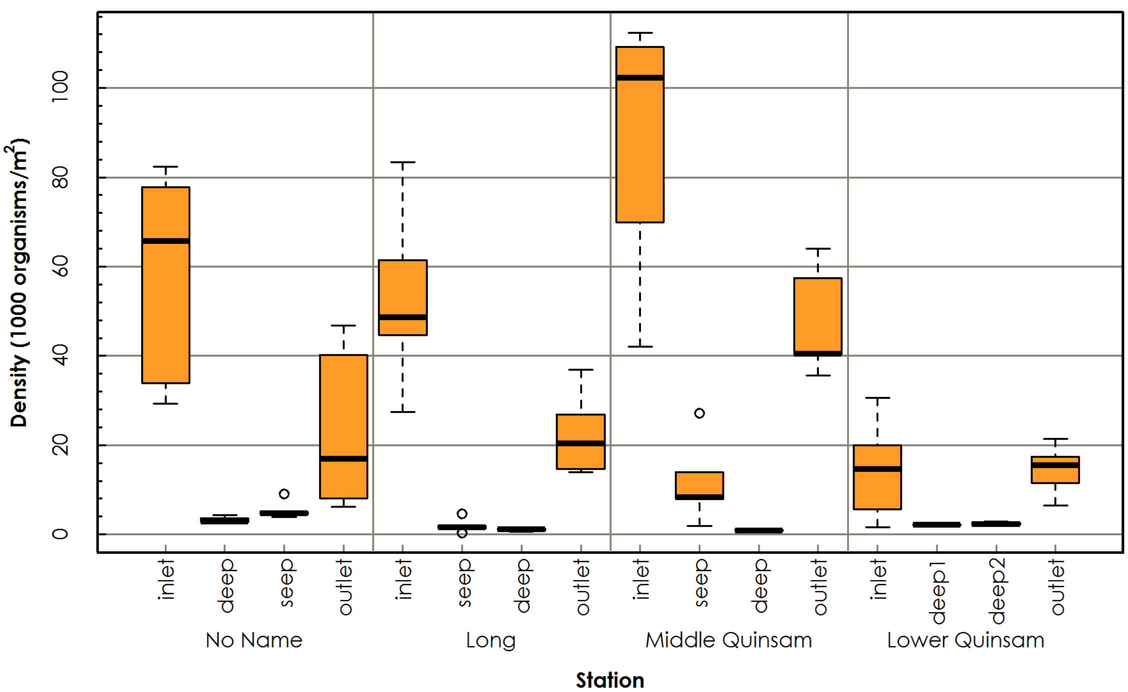

Figure 18: Benthic Invertebrate Density in Lakes, 2016

(Black bars indicate the median, boxes indicate the 25th and 75th percentiles, whiskers indicate the range within 1.5 times the interquartile range, and circles indicate outliers)

There were statistically significant differences in density ($p<0.05$, GLMM or non-parametric test; Appendix V-4), as follows:

- For Inlet stations, density differed between high impact (Long and Middle Quinsam) and low impact (No Name) or medium impact (Lower Quinsam) stations, but differences between pairs were small

- For Deep stations, density differed between high impact (Long, Middle Quinsam, and No Name) and medium (Lower Quinsam) or low impact (Gooseneck) stations, with lower density at high impact stations
- For Seep stations, the comparisons were significant for deep seeps (No Name and Long Lake) compared to Deep stations but not for shallow seeps (Middle Quinsam) compared to shallower stations (Lower Quinsam Outlet.
- For Outlet stations, there were no significant differences among lakes.

Taxon Richness

Mean taxon richness at the lowest practical level ranged from 7 to 36. Within a lake, taxon richness was generally similar at Inlet and Outlet stations, lower at Seep, and consistently lowest at Deep stations (Figure 19). As noted for density, habitat conditions at lake inlets and outlets typically support higher taxa richness than at deeper areas. Among lakes, richness was generally highest at No Name and Long lakes, and lower at Middle and Lower Quinsam lakes. Spatial trends for mean taxon richness were as follows:

- At Inlet stations, range of 22 to 36, highest at Long Lake, intermediate at No Name Lake and lowest at Middle Quinsam and Lower Quinsam lakes
- At Deep stations, range of 8 to 14, higher at No Name than Long, Middle Quinsam, and Lower Quinsam lakes, and higher again at the reference lake (Gooseneck Lake: 18 taxa)
- At Seep stations, range of 7 to 27, highest at No Name Lake, intermediate at Middle Quinsam Lake, and lowest at Long Lake
- At Outlet stations, range of 29 to 32, similar for the four lakes.

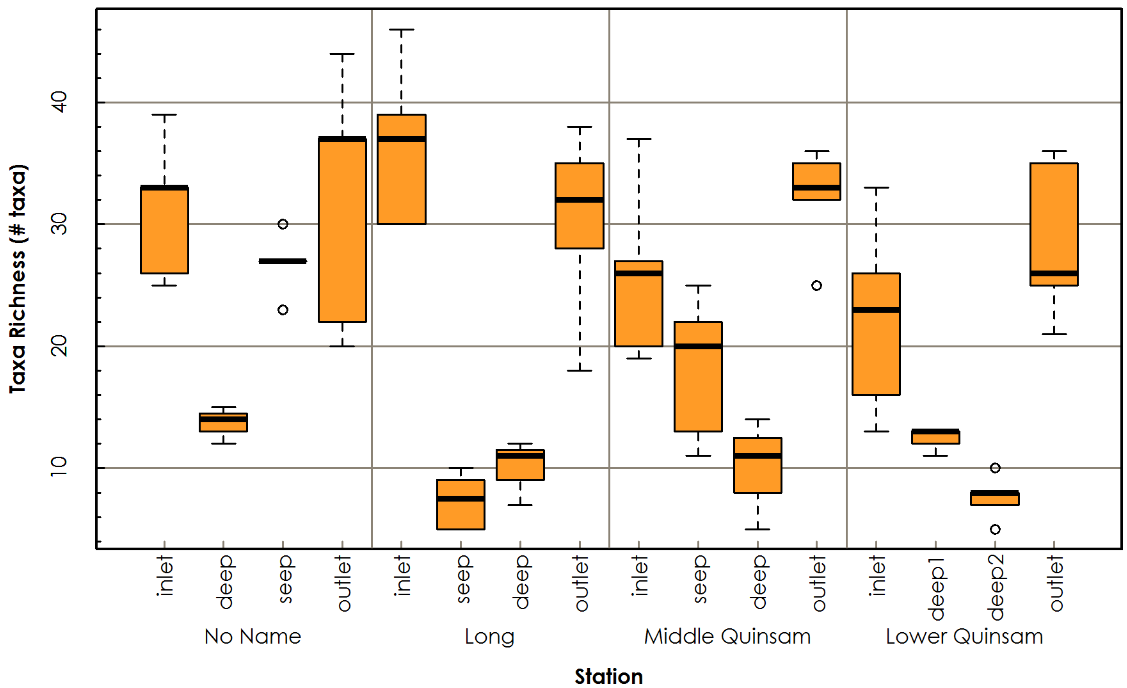

Figure 19: Benthic Invertebrate Taxa Richness in Lakes, 2016

(Black bars indicate the median, boxes indicate the 25th and 75th percentiles, whiskers indicate the range within 1.5 times the interquartile range, and circles indicate outliers)

There were statistically significant differences in richness ($p<0.05$, GLMM or non-parametric test; Appendix V-4) for Deep stations (low impact Gooseneck higher than the medium and high impact stations), but not for Inlet, Seep, and Outlet stations.

Diversity

Diversity (Simpson's Index of Diversity) showed a similar pattern to density and richness; generally highest at Inlet and Outlet, lower at Seep, and lowest at Deep stations (Figure 20). Mean diversity ranged from 0.57 to 0.91. A value of 1.0 indicates maximum diversity. Spatial trends were as follows:

- At Inlets, range of 0.84 to 0.91, higher at No Name Lake than at the other three lakes
- At Deeps, range of 0.57 to 0.82, highest at Gooseneck and No Name lakes, intermediate at Long and Lower Quinsam lakes, and lowest at Middle Quinsam Lake
- At Seeps, range of 0.71 to 0.87, higher at No Name than Long and Middle Quinsam lakes
- At Outlet sites, range of 0.82 to 0.90, similar among the four lakes.

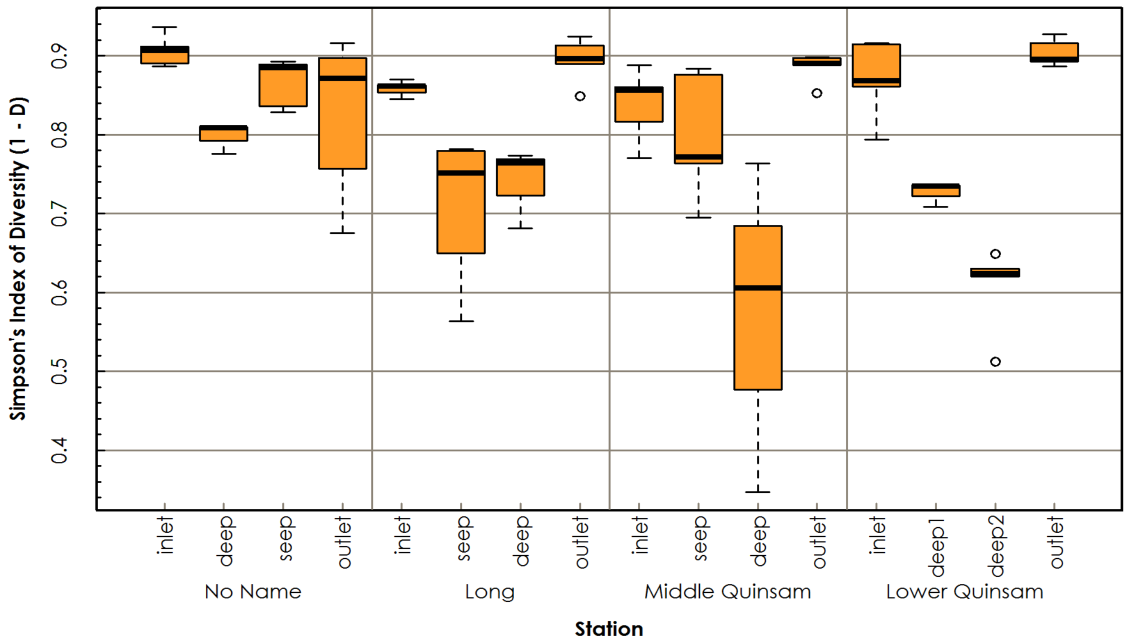

Figure 20: Benthic Invertebrate Diversity in Lakes, 2016

(Black bars indicate the median, boxes indicate the 25th and 75th percentiles, whiskers indicate the range within 1.5 times the interquartile range, and circles indicate outliers)

There were statistically significant differences in diversity ($p<0.05$, GLMM or non-parametric test; Appendix V-4) among stations for Inlets (high differed from low but not medium impact), Deep (low differed from medium and high impact), and Seep versus Shallow sites (medium differed from low and high impact). There were no significant differences among Outlet stations or for deep Seeps compared to Deep stations.

Evenness

Mean Simpson's Evenness ranged from 0.20 to 0.55, with no consistent pattern or association with habitat type. A value of 1.0 reflects maximum evenness. Within a lake, mean evenness was highest in No Name Lake at the Deep station, in Long Lake and Middle Quinsam Lake at the Seep stations, and in Lower Quinsam Lake at the Outlet station (Figure 21).

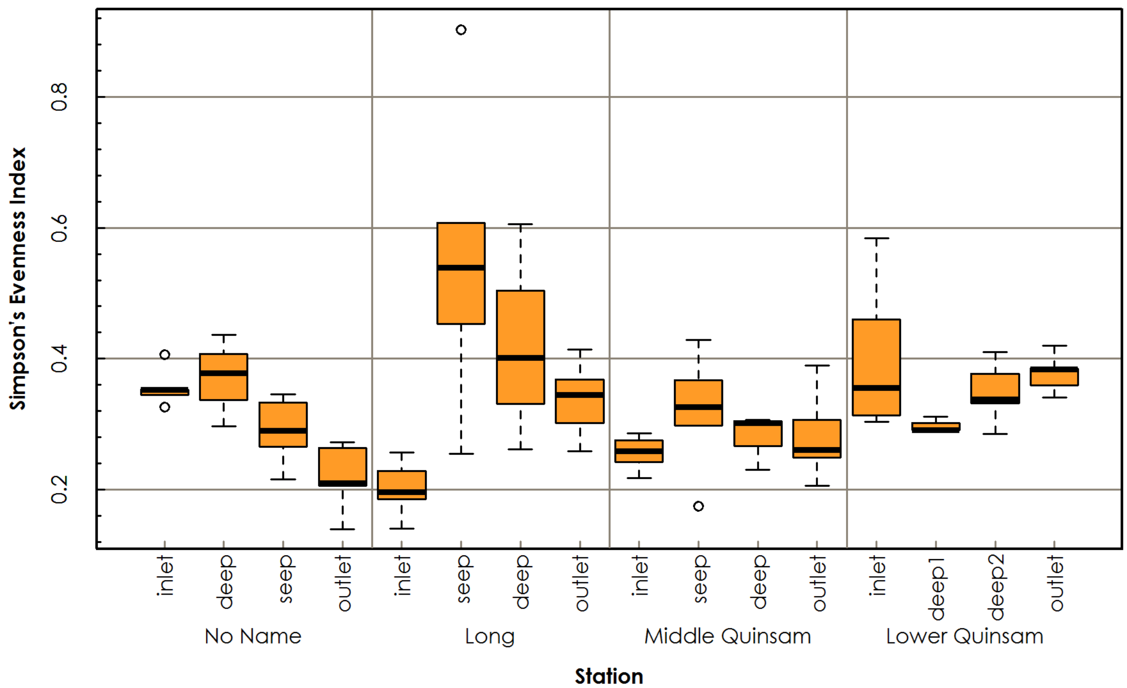

Figure 21: Benthic Invertebrate Evenness in Lakes, 2016

(Black bars indicate the median, boxes indicate the 25th and 75th percentiles, whiskers indicate the range within 1.5 times the interquartile range, and circles indicate outliers)

There were statistically significant differences ($p<0.05$, GLMM or non-parametric test; Appendix V-4) in diversity among stations for Inlets (high impact differed from low and medium) and Seep versus deep stations (high impact differed from low impact). There were no significant differences among Deep or Outlet stations or for Seeps compared to shallow stations.

Summary for 2016 Lake Data

The benthic invertebrate communities recorded are typical for the habitats sampled. Chironomidae and Chaoboridae are commonly found in fine-grained sediment of shallow and deep areas of lakes and Chaoboridae and some Chironomidae favour low oxygen conditions. EPT are commonly associated with coarser substrate, shallower water, and higher dissolved oxygen levels, which are usually found at lake inlets and outlets (Wetzel 2001). Community composition did not show obvious evidence of mine influence. The high impact Inlet stations (Middle Quinsam and Long Lake), did not have distinctly different community composition compared to the medium impact (Lower Quinsam Lake), or low impact Inlet (No Name Lake) stations. The same was true for the Outlet stations. Composition varied among the high impact

Deep stations, but the medium impact site (Lower Quinsam Lake) had similar composition to the high impact Deep station (Long Lake). The reference lake, Gooseneck Lake, supported similar community composition to the Deep stations in the mine-influenced lakes, with Chironomidae pre-dominant and small proportions of Oligochaeta, and EPT present.

There were statistically significant differences for some endpoints and habitat types ($p<0.05$; mixed effects model, non-parametric tests):

- Inlet stations had significant differences for density, diversity, and evenness (high impact stations Long and Middle Quinsam differed from medium impact Lower Quinsam Lake and low impact No Name Lake. There were no significant differences among lakes for taxon richness. Inlet samples from Lower Quinsam Lake were taken substantially deeper than at the other lakes, which resulted in lower density and taxon richness at this medium impact station. Density was lowest at the medium impact station (Lower Quinsam) and diversity and evenness were lowest at high impact lakes.
- Deep stations had significant differences for density (high differed from medium and low impact stations) and for taxon richness and diversity (high and medium differed from low impact), typically lower at high impact (Long and Middle Quinsam) than medium (No Name) and low (Gooseneck) impact stations and similar to the medium impact (Lower Quinsam) station, with evenness showing no significant differences among stations.
- For Seep stations, trends among sites were challenging to identify, given the variation in water depths and mine influence at the stations sampled and the lack of a low or medium impact Seep station. Density and evenness were highest at the deep (12 to 16 m) Long Lake, intermediate at the shallow Middle Quinsam (1.0 m) and lowest at the shallowest (5.6 m) No Name Seep stations. Taxon richness and diversity were highest at medium depth No Name, intermediate at shallow Middle Quinsam, and lowest at deep Long Lake stations. Seeps compared to Deep stations had a significant difference for density (high differed from low but not medium impact stations). Seeps compared to shallow stations had a significant difference for diversity (medium impact differed from both high and low impact stations).
- Outlets had no significant differences for any of the metrics tested.

Among these differences, the ones that could be statistically significant and ecologically relevant (i.e., related to the mine influence and not to habitat differences among lakes) are those for Deep stations, given the stability of these stations and distance from confounding influences such as inlet and outlet depths. Density was significantly lower at Long and Middle Quinsam stations (high impact), compared to No Name, Lower Quinsam, and Gooseneck stations. Taxon richness and diversity were significantly lower at Long and Middle Quinsam stations than at No Name and Gooseneck stations.

In addition to potential mine-related effects on the benthic community, the lower abundance recorded at all habitat stations in Lower Quinsam Lake compared to the other lakes may reflect overall lower productivity, as seen in the lower %TOC content of sediment at Lower Quinsam (3.7 to 7.4%) compared to the other lakes (11 to 19%). The lakes with higher sediment organic content are those with greater wetland development in the vicinity, which also likely moderate the flow responses from rainfall events into the lakes.

Comparison to Previous Studies

Nordin (2006)[28] studied water, sediment, and benthic invertebrate communities of No Name, Long, Middle Quinsam, and Upper Quinsam lakes in 2003 and 2004. Lake inlets and outlets were sampled in littoral habitat. Results for the benthic communities indicated no differences in density and diversity or in relative proportions of EPTs and chironomids between inlets and outlets of each lake, although some localized changes were identified that could reflect mine influence.

Golder Associates (2011) conducted an integrated sediment study of Long Lake in 2010, which included assessment of sediment and porewater chemistry, laboratory toxicity tests, and the benthic invertebrate community to assess effects of mine-related discharges, particularly the seep on the south shore of the lake and a discharge channel. Samples were collected from 17 nearshore stations, four deep stations, inlet, and outlet of Long Lake, and from two deep stations in Gooseneck Lake. Five stations sampled in 2010 corresponded to the Inlet, Deep, Seep, and Outlet stations in Long Lake and one of the Deep stations sampled in Gooseneck Lake for this 2016 study. The 2010 samples were collected in early April, whereas the 2016 samples were collected in late September.

Results from 2010 generally were similar to those from the 2016 studies: in 2010, abundance and taxon richness were higher at Inlet and Outlet stations than at Deep and Seep stations, and at many near shore stations on the south shore close to the Seep or the north shore downstream of the Seep. The most abundant taxa in 2010 were nematodes, chironomids, oligochaetes, molluscs and amphipods in near shore stations, and nematodes, chironomids, and oligochaetes in deep stations (along with a few Chaoboridae). This was similar to results for 2016 samples, except that nematodes were rare at all stations and Chaeoboridae were common at the Deep station in 2016 samples (possibly related to different sampling times of the studies). Taxon richness values were

[28] Nordin, R. 2006. An evaluation of the sediment quality and invertebrate benthic communities of Long and Middle Quinsam Lakes with regard to local coal mining activity. Prepared for BC. Ministry of Environment.

similar in the two studies (Golder reported an average of 30 for Inlet, 35 for Outlet, 2 to 7 for Deep, 10 for Seep in Long Lake and 10 to 16 for Deep in Gooseneck Lake).

10.3.3 *Quinsam River*

Benthic invertebrate samples were collected from three stations within riffle habitat on the Quinsam River (Appendix I Figure 1):

- WA: 1.32 km upstream of Middle Quinsam Lake, and upstream of Quinsam Mine influences, in an area of mainly cobble and pebble substrate and forested riparian area
- QRDS1: 2.4 km downstream of Middle Quinsam Lake (which receives inputs from the North Mine Site and from Long Lake but does not include 7 South Mining discharges), in an area of mainly cobble and pebble substrate and forested riparian area
- 7SQR: 5.25 km downstream of QRDS1 and downstream of all discharges from Quinsam Mine to the Quinsam River, in an area of large boulder and cobble substrates and forested riparian area.

10.3.3.1 *Methods*

Benthic invertebrate samples were collected from stream sites using a kick net, following Environment Canada's Canadian Aquatics Biomonitoring Network (CABIN) protocol (Reynoldson et al. 2001)[29] and analyzed using the Reference Condition Approach (RCA). Habitat data including channel morphology, canopy cover, substrate, water velocity and canopy cover were collected at each site following CABIN protocols (Appendix V-5).

Field Methods

Samples were collected on September 14 through 16, 2016. At each station, the riffle habitat for sampling was defined and substrates were kicked for three minutes, with flow carrying invertebrates into the kicknet. Large and deeply embedded rocks were rubbed by hand to loosen organisms. The area was traversed in a zigzag pattern from bank to bank. The net was removed from the water, and the sample rinsed carefully into a container, taking care to remove organisms

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[29] Reynoldson, T.B., C. Logan, T. Pascoe, and S.P. Thompson. 2001a. CABIN Invertebrate Biomonitoring Field and Laboratory Manual. National Water Research Institute, Environment Canada. Burlington, ON. 53 p. http://cabin.cciw.ca/intro.asp

clinging to the net (using forceps). Samples were preserved with 10% buffered Formalin in a 1:3 ratio (Formalin:sample). Samples were labelled inside and outside with site code, sampling date, and the number of jars (i.e. 1 of 3, 2 of 3, etc.). Sampling information (the person kicking, typical depth of kicked area, sampling time, number of sample jars required to contain the sample) was recorded on field sheets.

Laboratory Methods

Samples were sent to Cordillera Consulting for taxonomic analysis. Cordillera was responsible for sample reception, sorting, identification, and QA/QC (sorting and sub-sampling efficiency). The detailed Methods and QC Report from Cordillera (2016) is included in Appendix V-1. Organisms were identified to lowest practical level (typically genus for insect and oligochaete taxa, genus or family for other organisms). Samples were split, if required, with a minimum of 300 organisms counted and identified.

Sorting efficiency was assessed in 9 of 92 samples analyzed (10% of samples, 7 from lakes and 2 from the Quinsam River). All re-sorted samples had at least 90% (90 to 100%) efficiency. Subsampling efficiency was measured on 10% of the samples that were subsampled (five lake samples). The five samples met the data quality objective (a subsample count should be within 20% of the expected count, i.e., total count divided by number of fractions).

Data Analysis Methods

Taxonomic data were analyzed at the family level, as per the CABIN protocol, and using the 2010 BC Coastal RCA model. Data were also summarized for taxa richness, EPT taxa richness, Simpson's Index of Diversity, and Simpson's Evenness, as described in Section 10.3.1.1.

10.3.4 *Results*

Habitat

CABIN field sheets are presented in Appendix V-5. Key habitat data are summarized in Table 28. In situ water quality data collected at the time of sampling are presented in Appendix I, Tables 184 to 185. Station WA is considered a reference station, QRDS1 a near-field station and 7SQR a far-field station.

Water depth, water velocity, and substrate composition were similar at WA and QRDS. The most downstream station, 7SQR, was deeper, with lower velocity water and higher boulder content than at the upstream sites. Temperature, pH, and dissolved oxygen levels were similar at the three sites. However, conductivity increased from upstream (47.8 µS/cm2 at WA) to downstream of Middle Quinsam Lake at QRDS1 (145.6 µS/cm^2) and 7SQR (135.5 µS/cm^2), reflecting the influence of mine drainage on the Quinsam River.

Table 28: Habitat Characteristics of Benthic Invertebrate Stations, Quinsam River, 2016

Station	Channel Width (m)	Wetted Width (m)	Mean Velocity (m/s)	Mean Depth (m)	Substrate (% composition)			
					Boulder	Cobble	Gravel	Pebble
WA	11.7	11.3	0.62	0.34	3	53	11	33
QRDS1 [a]	18.7	13.9	0.64	0.34	2	54	10	36
7SQR	25.4	14.4	0.18	0.60	35	51	3	11

Note:
[a] also 8% sand

Table 29: In Situ Water Quality at Benthic Invertebrate Stations, Quinsam River, 2016

Station	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Water temperature (°C)
WA	7.09	7.5	47.9	16
QRDS1	7.82	7.8	145.6	17
7SQR	7.83	7.3	135.5	15

Sediment particle size in samples collected for chemical analysis was mainly sand at WA and QRDS1 and sand with greater silt content at 7SQR. The % TOC in sediment was notably lower than in the lake stations, and the average ranged from 2.9% (7SQR) to 3.2% (QRDS1).

Benthic Invertebrate Community

Full taxonomic results are provided in Appendix V-2. Table 30 presents a summary of community indices at the family level for benthic invertebrate at the river stations:

- Abundance was highest at WA, the upstream station (1,525 organisms/sample), intermediate at QRDS (798 organisms/sample), and lowest at 7SQR, the most downstream station (338 organisms/sample. Low abundance at 7SQR was likely attributable to predominance of boulders at 7SQR; cobble, gravel, and pebble substrates typically support higher invertebrate abundance than boulder substrate.
- Family-level richness varied little across sites, from 20 families at WA to 23 families at 7SQR.

- EPT richness at the genus level was similar at the three stations (16 to 17 taxa)
- Simpson's Diversity Index was high, ranging from 0.79 (WA) to 0.87 (7SQR), with a value of 1.0 reflecting maximum diversity.
- Simpson's Evenness Index was low, ranging from 0.24 (WA) to 0.33 (7SQR), with a value of 1.0 reflecting maximum evenness.

The higher richness, diversity, and evenness found at 7SQR compared to upstream stations indicate mine-related discharges are not adversely affecting the benthic community.

Table 30: Benthic Invertebrate Community Family-Level Indices, Quinsam River, 2016

Index	WA	QRDS1	7SQR
Abundance (organisms/sample)	1,525	798	338
Family Richness	20	22	23
EPT Richness (genus level)	16	17	16
Simpson's Diversity Index	0.79	0.84	0.87
Simpson's Evenness Index	0.24	0.29	0.33

Table 31 shows community composition at the Quinsam River stations. EPT were predominant at all three stations, with notably higher abundance at WA and QRDS (62% and 69%, respectively) than at 7SQR, downstream (38%), likely associated with differences in substrate composition. Ephemeroptera (notably Baetidae, Heptageniidae, and Leptophlebiidae) were more abundant that Plecoptera or Trichoptera. True flies (Diptera, including Chironomidae) were common at the three sites (9% to 28%) and Oligochaeta (aquatic worms) were common at QRDS and 7SQR (13% and 15%, respectively).

In general, EPT organisms are associated with clean water (coarse substrates, well oxygenated, low organic enrichment) and Oligochaeta and Chironomidae are considered tolerant of fine sediments, organic enrichment and lower DO (which can be due to polluted conditions), although there are exceptions (Barbour et al. 1999)[30].

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30 Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. U.S. Environmental Protection Agency; Office of Water; Washington, D.C. EPA 841-B-99-002.

Table 31: Benthic Invertebrate Community Composition, Quinsam River, 2016

Taxon	WA	QRDS1	7SQR
EPT	62%	69%	38%
Diptera	28%	9%	26%
Oligochaeta	6%	13%	15%
Other	4%	9%	21%

The benthic invertebrate community data were evaluated using the 2010 BC Coastal RCA model. The predictor variables used for the RCA model were: average depth, bankfull width, number of national parks in the watershed, and percent alpine area in the watershed. Based on environmental characteristics at the Quinsam River sampling sites, the three sampling sites were predicted using reference group three.

Table 32 provides a summary of how the Quinsam River benthic invertebrate communities at the three sampling stations sit in relation to the three vectors in reference group 3 ordination space. Figures 22 through 24 illustrate the location of the stations in reference group 3 ordination space for the first two vectors. All three Quinsam River stations fall outside of the 90% probability ellipse on at least one occasion and are classified overall as mildly divergent from the reference condition or “potentially stressed” category (Table 32).

Table 32: Table 32: Quinsam River 2016 Assessments Based on Reference Condition Approach

Station	Reference Group	Probability of Site in Group	Vector 1 vs 2	Vector 1 vs 3	Vector 2 vs 3	Overall
WA	3	0.75	Mildly Divergent	Similar to Reference	Mildly Divergent	Mildly Divergent
QRDS1	3	0.57	Similar to Reference	Mildly Divergent	Similar to Reference	Mildly Divergent
7SQR	3	0.95	Similar to Reference	Mildly Divergent	Mildly Divergent	Mildly Divergent

Since 10% of stations that are similar to the reference condition are expected to fall outside the 90% probability ellipse, the invertebrate community at the Quinsam River sampling sites was compared to the reference group community for further evaluation.

The invertebrate community at station WA was mildly divergent from reference group 3 primarily due to total invertebrate abundance, number of EPT individuals, % Ephemoptera that are Baetidae, and % Plecoptera. In 2016, site WA had greater total invertebrate abundance than the reference group 3 mean (1,445 vs 732), greater number of EPT individuals (950 vs 567) than the reference group 3 mean and greater % Ephemeoptera that are Baetidae (83 vs 28), while the reference group 3 mean had a greater % Plecoptera (24 vs 4) (Table 33). This benthic invertebrate community composition is indicative of Quinsam River conditions upstream of the Quinsam Mine.

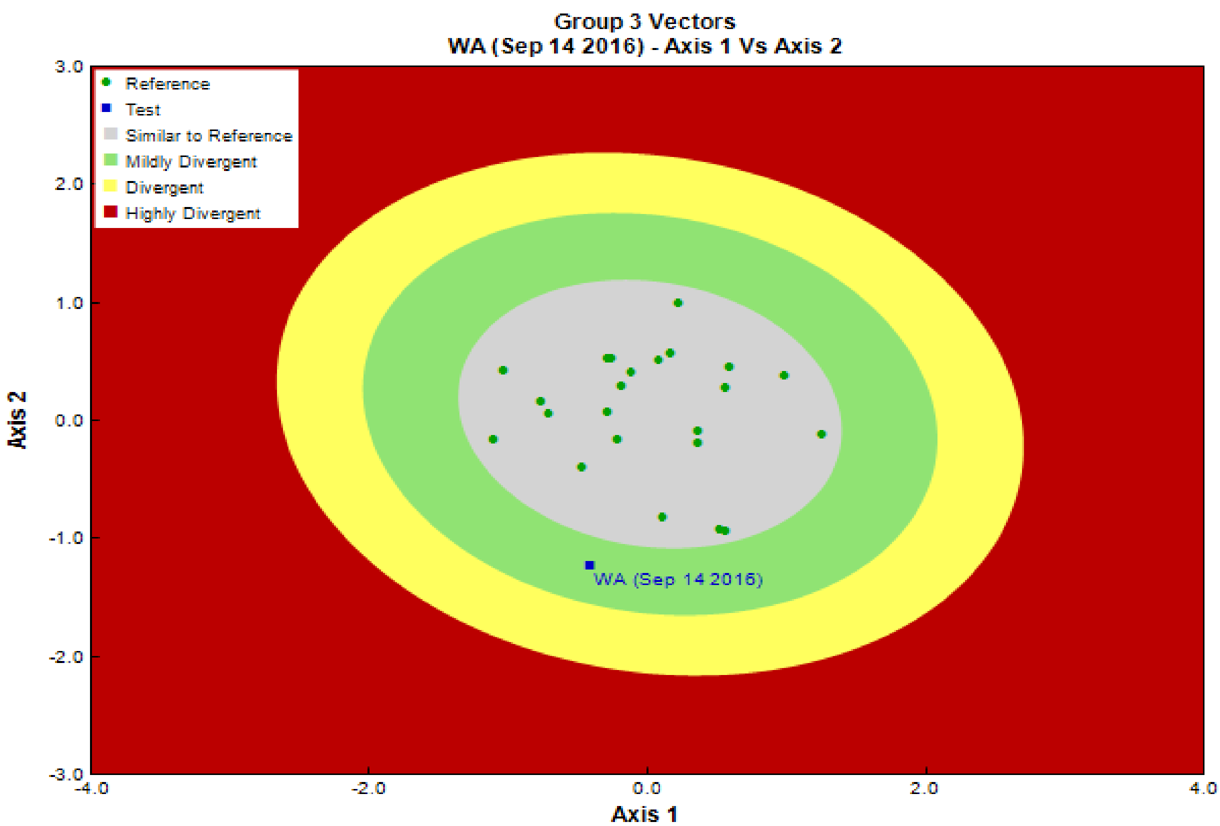

Figure 22: Benthic Invertebrate Community at WA Compared to the Reference Condition

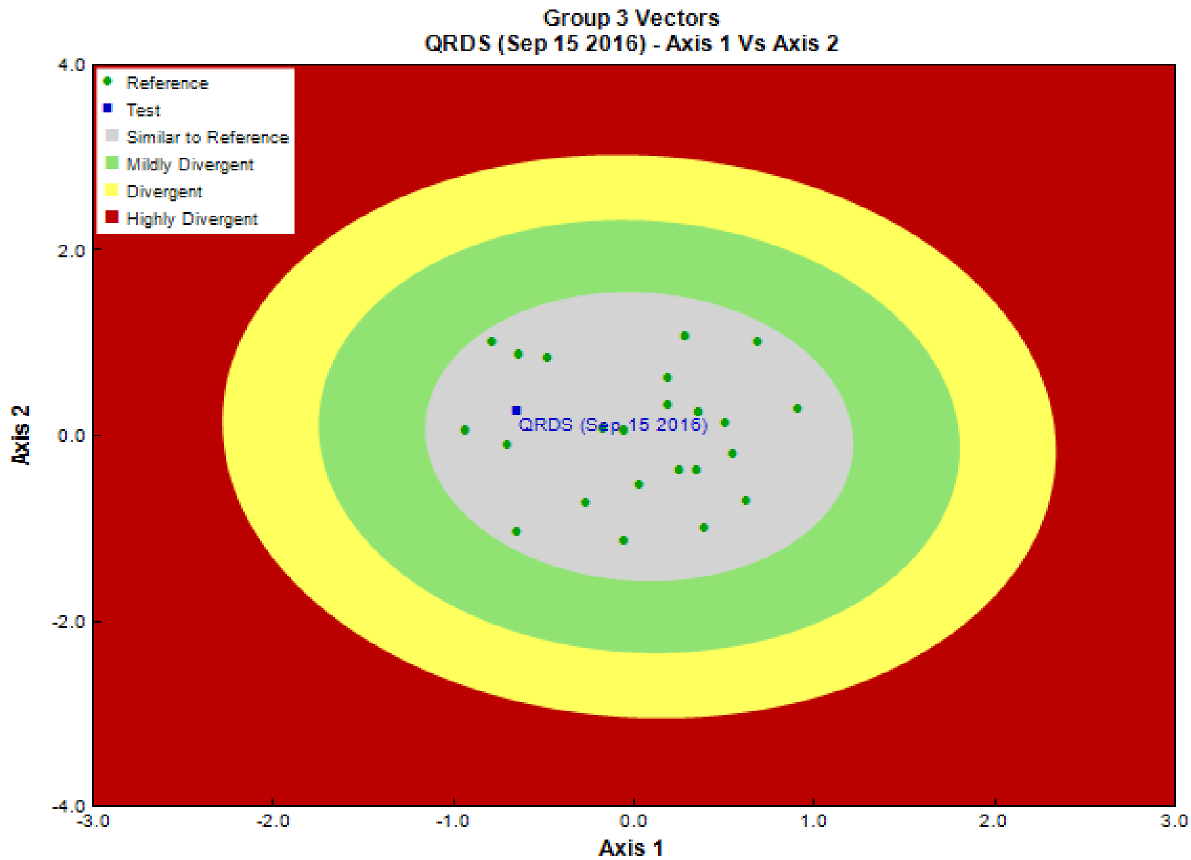

Figure 23: Benthic Invertebrate Community at QRDS1 Compared to the Reference Condition

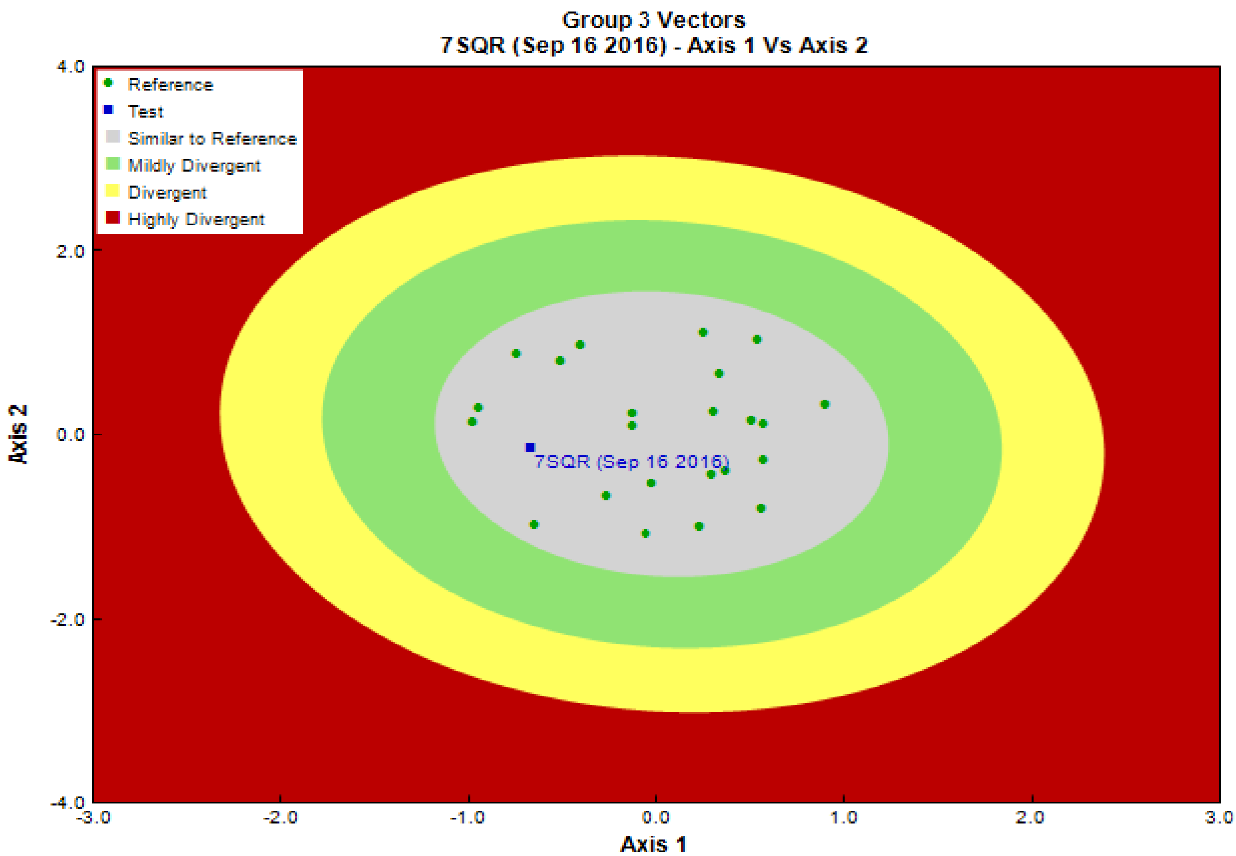

Figure 24: Benthic Invertebrate Community at 7SQR Compared to the Reference Condition

The invertebrate community at station QRDS was mildly divergent from the reference group 3 primarily due to a greater % Ephemeroptera (62% vs 40%), greater % Ephemeroptera that are Baetidae (41 vs 28), and the presence of Coleoptera (9% vs 0.2%) at QRDS, while the reference group 3 mean has a greater % Chironomidae (15% vs 3%)s and % Plecoptera (24% vs 6%) (Table 33). The similarity of the benthic community at site QRDS to the reference condition, the community at WA, and abundance of Ephemeoptera and Coleoptera at QRDS indicates good quality aquatic habitat and water quality and that mining activities in the watershed do not appear to adversely affect the benthic invertebrate community at QRDS1.

The invertebrate community at station 7SQR was mildly divergent from the reference group 3. This was due to the reference group 3 mean having greater % EPT individuals (71 vs 41), greater EPT individuals (567 vs 130), and higher % Plecoptera (24 vs 4) and station 7SQR haing greater % Ephemeroptera that are Baetidae (59% vs 28%) and the presence of Odonata taxa (Table 33). The difference in % Ephemeroptera that are Baetidae and % Plecoptera between the reference group mean and site 7SQR is also found at the other two Quinsam River stations and therefore is not indicative of a disturbed site. Station 7SQR has a greater depth than the reference group 3 average (60 cm vs 23 cm) and greater bankfull width (25 m vs 15 m) and is dominated by boulder substrates. The differences in the benthic invertebrate community between 7SQR and the reference group 3 may be due to differences in habitat more than to mining influences. Station 7SQR also had Odonata and Oligochaeta, two taxa that are found in slow water with fine substrates, indicating that an area with slow water was included in the benthic sampling area.

Table 33: Benthic Invertebrate Metrics for the Quinsam River Sampling Sites and the BC Coastal Model Reference Group 3 Mean

Metric	Quinsam River Stations			Reference Group 3 Mean	Standard Deviation
	WA	QRDS 1	7SQR		
Total Abundance	1445	798	338	732	638
Total No. of Taxa	18	21	23	19	4
Shannon-Wiener Diversity	2	2	2	2	0
Simpson's Diversity	1	1	1	1	0
Pielou's Evenness	1	1	1	1	0
% EPT Individuals	66	69	41	71	22
% Ephemeroptera	53	62	25	40	20
% Ephemeroptera that are Baetidae	83	41	59	28	26
% Plecoptera	4	6	4	24	16
% Tricoptera	9	1	11	7	8
% Coleoptera	0	9	0	0	1
EPT Individuals (Sum)	950	550	130	567	533
EPT taxa (no)	9	10	9	11	2
Ephemeroptera taxa	4	4	3	4	1
No. EPT individuals/Chironomids+EPT Individuals	1	1	1	1	0
Plecoptera taxa	2	3	2	4	1
Trichoptera taxa	3	3	4	3	1
Coleoptera taxa	1	1	0	0	0
Chironomidae taxa (genus level only)	1	1	1	1	0
Diptera taxa	4	5	4	3	1
Odonata taxa	0	0	2	0	0
% of 2 dominant taxa	58	49	42	54	12
% of 5 dominant taxa	77	79	77	79	9
% of dominant taxa	44	26	26	37	14
No. Clinger Taxa	15	17	15	15	3

10.4 SUMMARY FOR RIVER STATIONS

The RCA model results (mildly divergent from the reference condition) and individual metrics (family richness, EPT richness, EPT predominance) indicate that the three sampling stations on the Quinsam River do not show signs of adverse effects from mine-related discharges. The Quinsam River supports a variety of insect taxa that indicate clean water conditions and provide abundant prey for fish.

10.4.1 *COMPARISON TO HISTORICAL DATA*

Environment Canada sampled the Quinsam River at sites upstream and downstream of Middle Quinsam Lake using the CABIN protocol as part of an overall study of the Quinsam watershed (Strachan et al. 2010)31. The upstream station (close to WA) was sampled in 2003, 2005, and 2006; the downstream station (close to QRDS) was sampled in 2006; and sites lower in the watershed were also sampled. The results for the upstream station varied, with a category of “potentially stressed” assigned in 2003 and 2006 and a category of “not stressed” assigned in 2005 (classification terms in use at that time). Results for the downstream station indicated a category of “not stressed” in 2006. The sampling sites appear to be similar in location to stations WA and QRDS, sampled in 2016, and the results are similar to those obtained in 2016. The “not stressed” category indicates healthy communities that are equivalent to reference conditions.

10.4.2 *WETLAND SITES*

Three areas in the Lower Wetland lying between Middle Quinsam and Lower Quinsam lakes were sampled in fall 2016 for benthic invertebrate communities: Inlet, Middle, and Outlet (Appendix XI, Figure 1). The Lower Wetland is approximately 350 m long, is situated downstream of 7-South surface disturbance, and receives inputs from the 7-South Surface Decant Pond via Stream 1. The wetland water levels fluctuate through the year (Section 9.2).

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[31] Strachan, S., A. Ryan, H. McDermott, and C. MacKinlay. 2010. Benthic Invertebrate and Water Quality Assessment of the Quinsam River Watershed in British Columbia 2001-2006. GBAP Report #EC/GB/07/85.

10.4.2.1 *Methods*

Field Methods

Although water levels were low prior to sampling, rainfall prior to the October 2016 sampling trip had raised water levels in the wetland. Samples were collected from areas considered to be wetted throughout the year:

- Inlet station was sampled 25 to 50 m downstream of where Stream 1 enters the wetland, at a water depth of less than 30 cm; samples had a rich organic odour and consisted mainly of fine sand and silt
- Middle station was sampled approximately 200 m downstream of the Inlet station, in water less than 30 cm deep; samples had a rich organic odour and consisted mainly of fine sand and silt
- Outlet station was sampled near the outlet to the Quinsam River in an area dammed by beavers, in 0.5 to 1.5 m of water; samples were rich in clay, with sand and silt.

Field methods for wetland samples were the same as for lakes (Section 10.3.1.1). Five replicate samples were collected per station, each one a composite of three grabs, at the same locations as the sediment samples (Appendix I, Figure 1). Observations (depth sampled; sediment vertical profile, texture and color, and presence of living organisms, debris, biofilms, odor, or oily sheen) were recorded. The composite sample was sieved in a sieve bag with a 200 µm mesh size to remove excess sediment. The sieve contents were gently transferred to a labeled sample jar, rinsing the sieve with water to collect all the material. Jars were filled no more than half full and preserved with 10% buffered formalin (filled to top). Samples were stored in a cooler and shipped to the taxonomy laboratory with a chain of custody sheet.

Laboratory Methods

Samples were sent to Cordillera Consulting for taxonomic analysis. Cordillera was responsible for sample reception, sorting, identification, and QA/QC of sorting and sub-sampling efficiency. Five replicate samples were analyzed at the Outlet station (given high variation noted for the first three samples analyzed) and three replicate samples were analyzed at each of the Inlet and Middle stations. The detailed Methods and QC Report from Cordillera (2016) is provided in Appendix V-1. Organisms were identified to lowest practical level (typically genus for insect and oligochaete taxa, genus or family for other organisms).

Sorting efficiency was assessed in 9 of 92 samples analyzed (10% of samples, 7 from lakes and 2 from the Quinsam River): all re-sorted samples had at least 90% (90 to 100%) efficiency.

Subsampling efficiency was measured on 10% of the samples that were subsampled (six samples): the data quality objective (a subsample count should be within 20% of the expected count, i.e., total count divided by number of fractions) was met for the six samples.

Data Analysis

Data were analyzed as described for lake samples (Section 10.3.1.1). Community composition by major taxonomic group was summarized. Density, richness, EPT richness, Simpson's Index of Diversity, and Simpson's Evenness indices were calculated. Results were graphed to show differences among stations.

Statistical significance of differences among stations were tested using ANOVA and the non-parametric Kruskal Wallis Test. However, due to the unbalanced study design and the inability to meet assumptions of normality and homogenous variances, the results are not presented.

10.4.3 *Results*

Results are discussed below for general benthic invertebrate community composition, and for individual metrics (abundance, richness, diversity, evenness). Further interpretation of results in terms of watershed health is provided in Section 11.

Sediments at the Inlet and Middle wetland stations were mainly sand with some silt and at the Outlet station was approximately equal proportions of silt and sand (Appendix I Table 191). The average % TOC was 31% at the Inlet, 18% at the Middle, and 7% at the Outlet (Appendix I Table 182), where water depth was notably higher than at upstream stations.

Community Composition

Benthic invertebrate taxonomic composition varied widely among the three wetland stations (Figure 25). Oligochaeta were predominant and Mollusca were common at the Inlet and Middle stations. Chironomidae, Oligochaeta, and Mollusca were predominant at the Outlet station, in roughly equal proportions. These taxa are common in areas of slow flowing water, fine sediment, and abundant organic matter (Barbour et al. 1999).

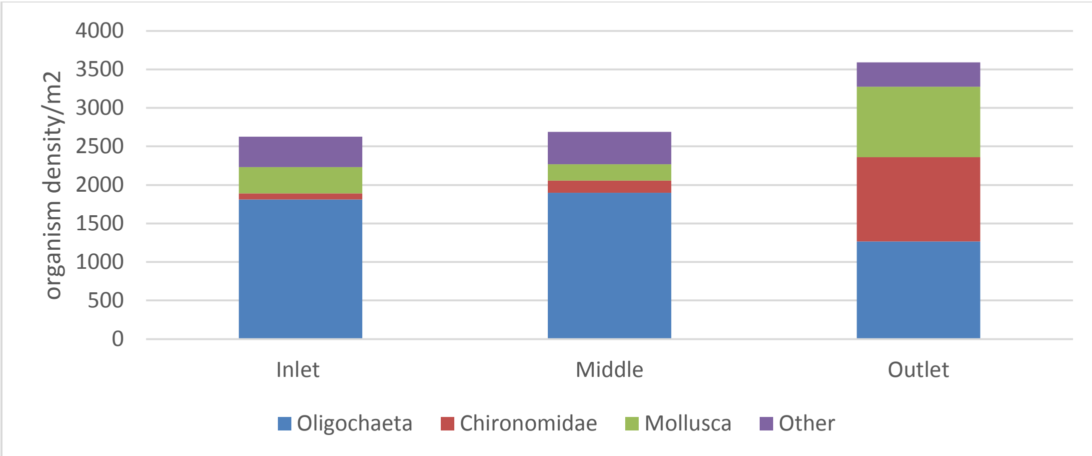

Figure 25: Average Density of Common Taxa in the Lower Wetland, 2016

The most common taxa were Diptera (mainly non-biting midges of the family Chironomidae, including *Polypedilum* and *Tanytarsus*), Oligochaeta (aquatic worms, mainly Lumbriculidae and Tubifinae), and Mollusca (mainly freshwater clams of the family Pisidiidae, including *Sphaerium* and *Pisidium*).

Density

Density of benthic invertebrates in the Lower Wetland samples ranged from 981 to 6,984 organisms/m^2, with mean values ranging from 2,626 to 3,521 organisms/m^2 (Table 34). Mean density was higher at the Outlet than at Inlet and Middle stations. Variability was higher at the Outlet (five replicate samples) than at the Inlet (three replicates) and Middle (three replicates). Five replicates were analyzed at the Outlet due to high observed variability in the first three replicates analyzed.

Table 34: Benthic Invertebrate Density in the Lower Wetland, 2016

Station	Number of Samples	Density (organisms/m^2)			
		Minimum	Maximum	Mean	Standard Deviation
Inlet	3	1,847	3,117	2,626	47
Middle	3	2,309	3,117	2,636	29
Outlet	5	981	6,984	3,521	193

Taxon Richness

Taxon richness was calculated at the lowest practical level (genus where possible) and ranged from 5 to 18 per sample, with a mean of 10 to 12 taxa per station (Table 35). Mean taxon richness was lowest at the Inlet, intermediate at the Middle, and highest at the Outlet station. Taxon richness calculated as total number of taxa per site (Table 35) increased downstream, from 19 (Inlet), to 28 (Middle), to 37 (Outlet). The increase in richness with distance downstream may be due to habitat differences among stations or to recruitment with distance downstream.

Table 35: Taxon Richness in the Lower Wetland, 2016

Station	Number of Samples	Taxon Richness (organisms/sample)				Total Taxa per Site
		Minimum	Maximum	Mean	Standard Deviation	
Inlet	3	5	13	10	4	19
Middle	3	9	18	14	5	28
Outlet	5	7	18	12	4	37

Diversity

Simpson's Diversity Index was calculated at the lowest practical level (genus where possible). Mean diversity ranged from 0.52 to 0.75 (Table 36). A value of 1 indicates maximum diversity. Diversity was lowest at the Middle (0.52) and highest at the Outlet (0.75).

Table 36: Simpsons Diversity Index in the Lower Wetland, 2016

Station	Number of Samples	Diversity			
		Minimum	Maximum	Mean	Standard Deviation
Inlet	3	0.37	0.77	0.63	0.22
Middle	3	0.37	0.74	0.52	0.20
Outlet	5	0.63	0.84	0.75	0.08

Evenness

Simpson's Evenness Index was calculated at the lowest practical level (genus where possible). Evenness ranges from 0 to 1, with a low value indicating predominance of one or a few species and high values indicating relatively equal numbers of individuals belonging to each species. Evenness ranged from 0.09 to 0.64, with mean values of 0.32 at the Inlet, 0.18 at the Middle, and

0.39 at the Outlet sites (Table 37). This reflects the predominance of a few taxa at each station, particularly for the Middle station.

Table 37: Simpsons Evenness Index in the Lower Wetland, 2016

Station	Number of Samples	Evenness			
		Minimum	Maximum	Mean	Standard Deviation
Inlet	3	0.31	0.33	0.32	0.01
Middle	3	0.09	0.25	0.18	0.08
Outlet	5	0.21	0.64	0.39	0.17

10.5 Summary for Wetland Stations

Benthic Invertebrate samples from the Lower Wetland contained a range of organisms typical of slow flowing water and fine sediment (Barbour et al. 1999), with Chironomidae, Oligochaeta, and Mollusca most abundant. The wetland sites were similar in overall composition, aside from greater abundance of Chironomidae and Mollusca and lower abundance of Oligochaeta at the deeper Outlet station compared to the shallower Inlet and Middle stations. The differences in density, taxon richness, evenness and diversity were not assessed statistically, given the differences in replicate samples analyzed per station, but results suggest that mine water is not adversely affecting benthic communities. General conditions (water depth, % TOC) differed notably for the Outlet compared to the Inlet and Middle stations and likely contributed to the differences in benthic communities among stations.

11.0 Summary and Watershed Health Evaluation

The Quinsam River is the major watercourse in the watershed. It flows into and out of Middle Quinsam Lake and into and out of Lower Quinsam Lake (Appendix XI, Figure 1). The Iron River, a large tributary, enters the Quinsam River upstream of Lower Quinsam Lake. The main human activities in the watershed are the Quinsam Coal mine, logging, water diversion for hydro-electric generation, and, near the mouth, a federal salmon hatchery. Several salmonid species occur throughout the watershed.

The study lakes (Appendix XI, Figure 1) varied in their exposure to mine-related discharges: Gooseneck Lake is the reference lake; No Name Lake is upstream of most of the mine discharges, but receives some inputs; Long Lake and Middle Quinsam Lake receive surface water discharges and groundwater seepage; and Lower Quinsam Lake is downstream of mine discharges.

The study lakes differ notably in physical characteristics, which make distinguishing natural vs. mine-related influences on the aquatic communities challenging:

- No Name Lake is relatively shallow (maximum depth of 14 m) and has a surface area of 0.2 km^2. It is fed by water that has travelled through an extensive wetland area upstream of the inlet; sediment is typically sand with silt and little clay, with TOC levels of 11 to 19%.While close to historical mine activities in the South Mine area, the lake is mainly unaffected by mine discharges; pH is often naturally lower than the BC WQG of 6.5.
- Long Lake is deep (maximum depth of 20 to 21 m), long (surface area of 0.15 km^2), receives inputs from No Name Lake, and has a residence time of 72 to 178 days (Kangasniemi 1989)[32]. The Long Lake outlet flows through a stream into Middle Quinsam Lake. Sediment is typically sand with silt and little clay, and with 11 to 15% TOC. Hypolimnetic waters often become anoxic during summer and early fall. A geological fault through the middle of Long Lake is a divide between sedimentary and volcanic bedrocks. The lake receives mine-related inputs from sediment pond discharges and groundwater seeps.
- Middle Quinsam Lake has a maximum depth of 15 m with a surface area of 0.76 km^2, receives inputs from the upper Quinsam River at its inlet and from Long Lake near its outlet, and has a residence time of 17 to 38 days (Kangasniemi 1989). Sediment is typically sand with silt and little clay, and with 12 to 17% TOC. Hypolimnetic waters often become anoxic during summer and early fall. The lake receives mine-related inputs from sediment pond discharges and groundwater seeps.
- Lower Quinsam is deep (maximum depth of 21 to 22 m), large (surface area of 1.17 km^2), and approximately 10 km downstream from Middle Quinsam Lake. Sediment is typically sand with silt and little clay, and TOC ranges from 4 to 7% TOC, lower than No Name, Long, Middle Quinsam, and Gooseneck lakes (11 to 19% TOC).
- Gooseneck Lake, used as a reference lake, is deep (maximum depth of 20 m) and has a surface area of 0.78 km^2. It drains into the Campbell River watershed. Sediment consists of sand with silt and little clay, with 13% TOC.

Effluent Permit PE-7008 requires routine monitoring of effluent, groundwater, and surface water quality, and phytoplankton and zooplankton communities in the receiving environment. There is also a requirement to monitor sediment and benthic invertebrates and to bring together results of the programs into an overall assessment of health of the Quinsam River watershed near the Quinsam Mine. Each monitoring component provides evidence that can be used to assess

[32] Kangasniemi, B. 1989. Campbell River area Middle Quinsam Lake sub-basin water quality assessment and objectives. Technical Appendix. Water Management Branch, MOE.

whether, and to what degree, discharges from the Quinsam Mine currently affects health of aquatic organisms in the lakes, Lower Wetland, and Quinsam River.

Concerns about effects of Quinsam Mine discharges on water and sediment quality in receiving environment lakes were identified in previous studies, including Nordin (2006)[33], Cullen et al. (2010)[34], Cullen and Reimer (2010)[35], Golder (2011)[36], and SLR Consultants (2015)[37]. Pre-mining conditions were described in Kangasniemi (1989). These previous studies focused on Long Lake, particularly sediment. Long Lake receives large inputs of mine-affected discharges and sediments have a greater frequency of guideline exceedances compared to lake water. Most recently, MOE retained SLR to review previous studies, assess sediment quality and potential aquatic effects in Long Lake, and develop site-specific sediment quality objectives (SQOs) for Long Lake that reflect background (pre-mining) metal concentrations (SLR 2015). The SLR study described nine metals considered chemicals of potential concern (above CCME sediment quality guidelines) for Long Lake: arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, and selenium; and developed background concentrations for these metals. PAHs were also identified as a chemical of potential concern.

The review of Long Lake sediment chemistry from prior to onset of mining (pre-1987) to 2014 identified spatial variation in concentrations of some metals: arsenic and lead increased between the inlet and outlet and arsenic, cadmium, mercury, and selenium concentrations were significantly higher in deep (more than 9.1 m depth) than shallow (less than 9.1 m depth)

[33] Nordin, R. 2006. An evaluation of the sediment quality and invertebrate benthic communities of Long and Middle Quinsam Lakes with regard to local coal mining activity.

[34] Cullen et al. 2010. An environmental investigation of the Quinsam watershed. Prepared for Canadian Water Network

[35] Cullen, W. and D. Riemer. 2010. Interim report to the Quinsam Coal Environmental Technical Review Committee: Update on three studies: Long Lake seep sampling, Long term mussel monitoring program and cage mussel experiment.

[36] Golder Associates. 2011. 2010 integrated Long Lake sediment assessment, interpretive report. Prepared for Hillsborough Resources Limited by Golder Associates.

[37] SLR Consulting Ltd. 2015. Sediment quality, toxicity, and bioavailability review with background assessment based on current knowledge of sediment dynamics and interpretation of pre and post mining sediment concentrations and distribution. Long Lake at Quinsam Coal Mine, Campbell River BC. Prepared for BC Ministry of Environment by SLR, Vancouver BC.

sediments (SLR 2015). Based on the studies reviewed, SLR concluded the following for Long Lake:

- Background concentrations (and SQOs) are higher than CCME PELs for arsenic, iron, and manganese; higher than ISQGs for cadmium, chromium, and copper; and lower than ISQGs for lead and nickel. Background concentrations were not determined for mercury due to potential for cross-contamination in samples, or for selenium due to lack of baseline data.
- Coal mining activities have not resulted in increased concentrations of cadmium, chromium, copper, iron, lead, and mercury in Long Lake sediments.
- Concentrations have increased over time for nickel (throughout the lake), manganese (middle part of the lake), and arsenic (eastern part of the middle lake).
- The naturally occurring anoxic or low DO conditions in the hypolimnion of Long Lake from summer into fall result in a change in redox conditions at the sediment-water interface, often resulting in increased concentrations of iron, manganese, and arsenic in deep waters of the lake.
- Laboratory sediment toxicity test results from Golder (2011), indicated some toxicity, but this could not be attributed to a particular location or “effect gradient” within Long Lake, so could not be used to distinguish whether effects were due to natural conditions or mining activities. The exception was sites downstream of the Seep, which had elevated iron and arsenic concentrations, and presented a more obvious source of toxicity.
- Benthic invertebrate community assessments at inlet, outlet, north, and south shorelines, seeps, and deep habitats (Golder 2011) also could not confirm whether observed differences in abundance and taxon richness were associated with mining activities.
- Fish tissue data (rainbow and cutthroat trout collected by MOE in 2007) in No Name, Long, Middle Quinsam, and Upper Quinsam lakes indicated elevated mercury levels in fish from all four lakes (unrelated to mining) and arsenic, manganese, and lead concentrations two times higher in Long Lake than in the other three lakes. Note: there are no tissue consumption guidelines for these metals.

Arsenic levels, sources (natural vs. anthropogenic) and bioavailability in the Quinsam watershed, including Long Lake, were examined by Cullen et al. (2010) and Cullen and Reimer (2010). The authors determined that Long Lake sediment composition did not resemble potential sources of arsenic at Quinsam Mine (settling ponds, drainage channels, coal). They concluded that arsenic in Long Lake did not come from waste rock piles or coal handling but that the Seep and possibly other groundwater sources could be major sources of arsenic in lake sediments, along with weathering and oxidation of arsenic in rock formations in the watershed (including waste rock at the mine). Groundwater monitoring programs conducted by QCC indicate elevated dissolved arsenic levels in wells placed in ‘shallower’ Dunsmuir Member sandstones, particularly in the area of the #4 coal zone in the North and 7-South mining areas, associated with natural geological sources (QCC 2017[38] and Lorax 2011[39]). Monitoring of the Long Lake Seep indicates arsenic and iron levels have decreased since 2011and arsenic and manganese levels in seep water have been below WQGs since 2011 (Section 7.2.3), indicating this previously identified metal source is not currently of concern.

Cullen (2010) assessed arsenic bioavailability in lake sediments using physiologically based metal extraction. The tests mimic extraction of arsenic in the human gastrointestinal system. The results indicated that arsenic bioavailability is similar among the lakes in the Quinsam watershed (Cullen 2010). However, the SLR (2015) review suggested that it would have been more relevant to extract arsenic using acids and enzymes more typical of sediments and benthic invertebrates. As a result, SLR (2015) concluded the Cullen (2010) test results did not provide a good measure of arsenic bioavailability to benthic invertebrates.

The previous studies and monitoring conducted by QCC for Permit PE 7008, have found elevated concentrations of sulphate and various metals in Long Lake water and elevated metals in the sediment of Long Lake and other lakes in the area. However, the previous studies have not been able to establish cause and effect relationships between mining activities, metal concentrations and effects on the aquatic communities (Golder 2011, SLR 2015). The current study provides further investigation into potential influence of mine operations on environmental conditions in the Quinsam River watershed.

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[38] Quinsam Coal 2016-2017 Annual Groundwater Monitoring Report. Submitted to Ministry of Energy and Mines and Ministry of Environment

[39] Lorax Environmental and Enterprise Geoscience Services Ltd. (2011). Appendix I 4 South Mine Groundwater Evaluation. In Mine Permit (C-172) Amendment Appendices K-N (Vol. Volume 4, pp. 4-1, 4-12, 4-13, 4-13, 4-35, 5.3,6-47, 6-55). Burnaby, B.C.

11.1 Summary of Water Quality Results for Receiving Environment

Water samples were collected from No Name, Long, Middle Quinsam, and Lower Quinsam lakes in three 5 in 30 day sampling periods at 1 m, 4 m, 9 m, and 1 mb (Section 8). Samples were also collected according to this schedule at three stations in the Quinsam River. Conductivity and sulphate are indicators of mine-affected discharges and increased between the inlets and outlets of Long Lake and Middle Quinsam Lakes (Section 8.2.2).

In the three sampling periods in 2016, water quality in the lakes generally met BC WQGs (Appendix I, Table 3):

- In spring, the only WQG exceedances were:
    - Sulphate in Long Lake deep water (9 m and 1 mb), with a maximum just above the WQG of 128 mg/L
    - pH in No Name Lake deep water (9 m and 1 mb), just below the WQG of 6.5
- In summer, the following WQG exceedances were reported:
    - DO in deep water below the site specific WQO of 3 mg/L in Middle Quinsam and Lower Quinsam lakes (low in all four lakes)
    - Sulphate at or below the WQG (highest at Long Lake at 1 mb)
    - Total and dissolved iron above WQGs in deep water of Lower Quinsam Lake
- In fall, the following WQG exceedances were reported:
    - Sulphate in Long Lake at 1 mb (average of 131 mg/L), just above the WQO
    - Manganese in Long Lake (just above the WQG on two occasions, maximum of 1 mg/L compared to WQG of 0.8 mg/L)
    - Dissolved aluminum in No Name Lake and Lower Quinsam Lake (just above the WQG of 0.05 mg/L) at various depths.

Water monitoring results indicate generally good water quality in the lakes, with sulphate the main parameter associated with mine discharges, and present just above the WQG in deep water of Long Lake. The sulphate WQO was derived conservatively for the Quinsam Lake system, as defined in the permit, using hardness at the upstream river station WA (notably lower than in Long Lake). Sulphate concentrations in Long Lake do not suggest potential for adverse effects to aquatic life. The low magnitude exceedances of WQGs for other parameters (e.g., pH, dissolved aluminum, total and dissolved iron, and manganese) are typically associated with natural conditions and do not suggest potential for adverse effects on aquatic life.

Long, Middle Quinsam, and Lower Quinsam lakes naturally develop low DO levels in deep water (hypolimnion) during the summer, and the low DO levels extend into the fall sampling period. In fall of 2016, DO levels in deep water of Long Lake were higher and concentrations of iron and manganese at the sediment-water interface (1 mb depth) were lower than in previous years. This was likely influenced by the unusually high precipitation and water levels in fall 2016. As noted by SLR (2015) and earlier studies, low oxygen levels near the sediment-water interface can result in increased mobilization of iron, manganese and arsenic, which are sensitive to fluctuations in reducing and oxidizing (redox) conditions. In 2016, however, there were only rare, low magnitude exceedances of WQGs for iron and manganese in deep water of Long Lake and none for arsenic. In Long Lake, sediment arsenic levels were elevated above PELs but in 2016, concentrations in water were at least ten times lower than the WQG of 0.005 mg/L at all depths sampled.

The 2016 water quality results for the four sampled lakes were consistent with those reported in recent years (Quinsam Coal 2016 and earlier reports)[40] and reflect the high level of compliance with permit conditions for sediment ponds and discharges at mine infrastructure. There was a higher number of permit exceedances at mine site monitoring stations in 2016, related to elevated TSS during times of high precipitation events (Section 7).

At the three Quinsam River sites upstream and downstream of Quinsam Mine, sulphate and conductivity were indicators of mine-related inputs. For example, mean sulphate increased from 1.33 mg/L at WA (upstream of Middle Quinsam Lake and mine related inputs) to 28.6 mg/L at WB and 29.0 mg/L at QRDS (downstream of Middle Quinsam Lake and mine related inputs), and remained at 29.0 mg/L at 7SQR (further downstream of mine influences). Conductivity and total metals concentrations showed similar spatial trends. However, there were only infrequent exceedances of WQGs (Appendix I, Table 3): arsenic at 7SQR (one date during summer) and zinc at QRDS (one occasion during spring, considered an outlier).

The water quality monitoring results for lakes, Quinsam River, and at the mine site indicate overall compliance with permit requirements and do not suggest a current source of concern for aquatic biota in the receiving environment.

11.2 SUMMARY OF SEDIMENT QUALITY RESULTS FOR RECEIVING ENVIRONMENT

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[40] Quinsam Coal. 2016. Quinsam Coal Annual Water Quality Monitoring Report 2015-2016. Report prepared by Quinsam Coal

Sediment samples were collected in fall 2016 from Inlet, Deep, and Outlet stations in No Name, Long, Middle Quinsam, and Lower Quinsam lakes, Seep stations in No Name, Long, and Middle Quinsam lakes, and one Deep station in Gooseneck Lake (Section 9). Sediment in the lakes consisted mainly of sand and silt. TOC levels were high (11 to 19%) in all lakes except Lower Quinsam (4 to 7%). Sampling depths varied among stations and reflected bathymetry at each location (e.g., inlet sampling depth ranged from 1 to 2 m in Middle Quinsam Lake to 14 to 17 m in Lower Quinsam Lake). Many samples from deep waters contained visible signs of iron deposits (red or orange streaks or hue) and a mild anoxic odour, indicating reducing conditions.

PAH concentrations were measured in the sediment samples and compared to guidelines for total PAH and individual PAH parameters. Mean total PAH concentrations were below the BC sediment guideline of 4.0 mg/kg; levels were low in Gooseneck (0.27 mg/kg), No Name (up to 0.03 mg/kg), Middle Quinsam (up to 0.11 mg/kg), and Lower Quinsam Lake (up to 0.41 mg/kg) and higher in Long Lake (up to 2.8 mg/kg in Deep and Seep samples). There were exceedances of ISQGs for 2-methylnaphalene, naphthalene, and phenanthrene in samples from all five lakes. Total PAH levels reflected an association with Quinsam Mine operations in Long Lake, but not Middle Quinsam Lake, although the maximum total PAH and individual PAH concentrations would not be expected to result in adverse effects on aquatic biota.

Metal concentrations were compared to CCME ISQGs and PELs (CCME 2017[41]) and to SQOs developed for Long Lake (SLR 2015). "The ISQG reflects the concentration below which adverse biological effects are expected to occur rarely. The PEL defines the level above which adverse effects are expected to occur frequently." (CCME 2001). However, site-specific conditions should be considered in evaluating these generic guidelines as background concentrations may be elevated, particularly in mining areas, and organisms may be adapted to existing conditions. The SQOs provide this site-specific context for metals with concentrations higher than the generic guidelines.

There were numerous guideline exceedances both in lakes unaffected by mine activities (i.e., background or baseline conditions) and in mine-affected lakes. Cadmium, chromium, copper, mercury, and nickel were present at concentrations above ISQGs but below PELs at many stations. While cadmium, chromium, copper, and mercury concentrations did not appear to be

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[41] Canadian Council of Ministers of Environment (CCME). 2017. Canadian Environmental Quality Guidelines. Available at: http://ceqg-rcqe.ccme.ca/en/index.html

related to mine activities, nickel concentrations have increased over time in Long Lake and Middle Quinsam Lake. As noted by SLR (2015) and considering the small magnitude guideline exceedances and conservatism in the guidelines, concentrations of all these metals are below levels that suggest a toxicity concern for aquatic biota.

The main metals of concern are arsenic, iron, and manganese. Concentrations of these metals were higher than PELs at stations in four of the lakes, and as a result, suggest a potential risk of adverse effects to aquatic biota. Sediment concentrations of these metals in 2016 were generally in the previously reported range (summarized in SLR 2015). The exception is No Name Lake Deep samples, which had notably higher concentrations of all three metals than previously reported (SLR 2015).

Mean arsenic concentrations were higher than the PEL of 17 mg/kg in all stations from, Long, Lower Quinsam, and Gooseneck lakes, in all stations from No Name Lake except the outlet and were higher than the ISQG of 5.9 mg/kg but below the PEL at all stations in Middle Quinsam Lake and the outlet of No Name Lake (Figure 26). Mean concentrations ranged up to 160 mg/kg, highest at Long Lake Deep, and were also elevated at No Name Deep. Samples from Long Lake were lower than the SQO of 927 mg/kg developed by SLR (2015). Arsenic concentrations were lowest in Middle Quinsam Lake (above the ISQG but not the PEL).

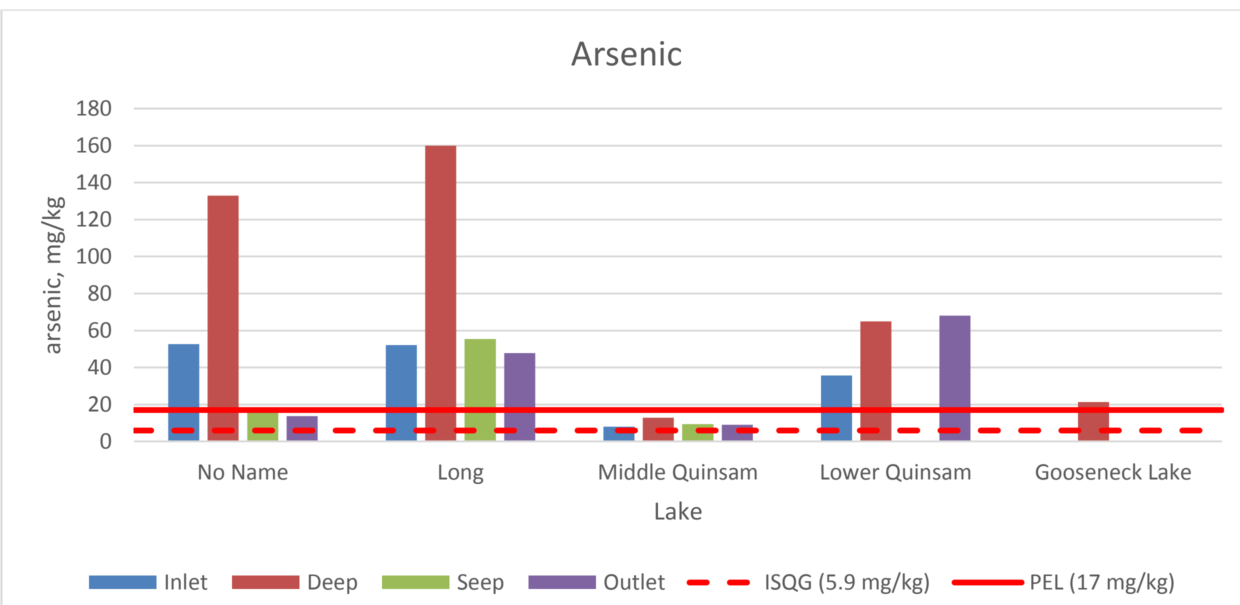

Figure 26: Mean Arsenic Concentrations in Sediment, Quinsam Lakes System, 2016 (Long Lake SQO = 927 mg/kg for whole lake, 89 mg/kg in west lake, and 1046 in east lake)

Mean iron concentrations were higher than the PEL of 43 766, mg/kg at the Inlet and Deep stations from No Name, at all stations except the Inlet from Long Lake and all stations from, Lower Quinsam Lake. All stations in Middle Quinsam and Gooseneck Lakes had concentrations higher than the ISQG of 21,200 mg/kg but below the PEL (Figure 27). Mean concentrations ranged up to 173,000 mg/kg, highest at No Name Lake Deep, and were also elevated in Long Lake Deep. Samples from Long Lake stations were lower than the SQO of 155,000 mg/kg developed by SLR (2015). Iron concentrations were lowest in Middle Quinsam and Gooseneck lakes (above the ISQG but not the PEL).

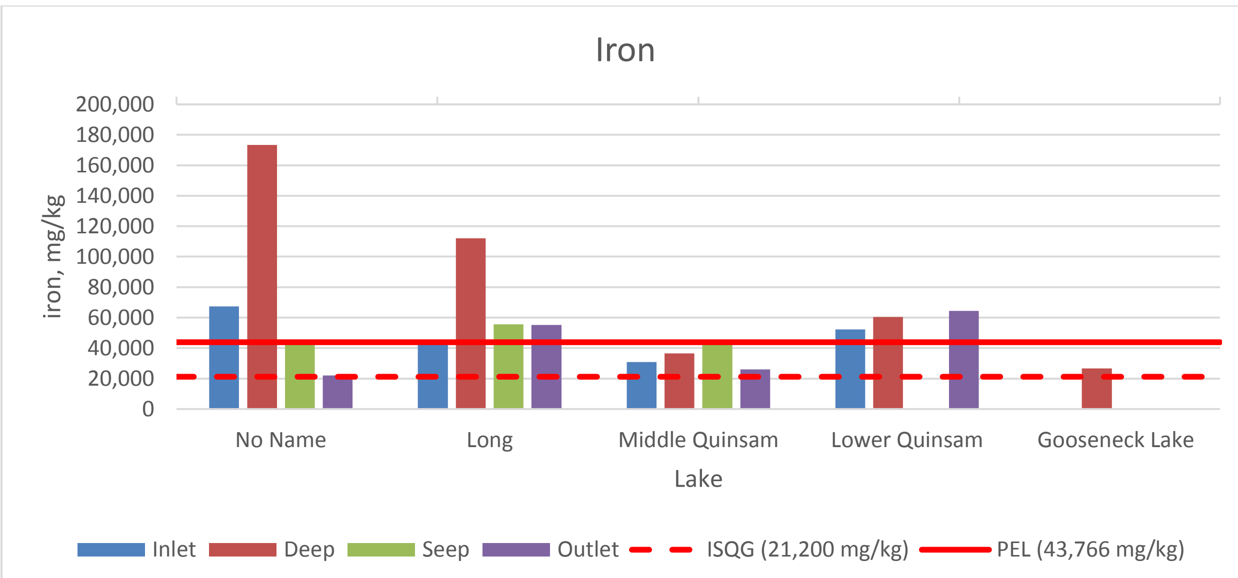

Figure 27: Mean Iron Concentrations in Sediment, Quinsam Lakes System, 2016 (Long Lake SQO = 155,000 mg/kg

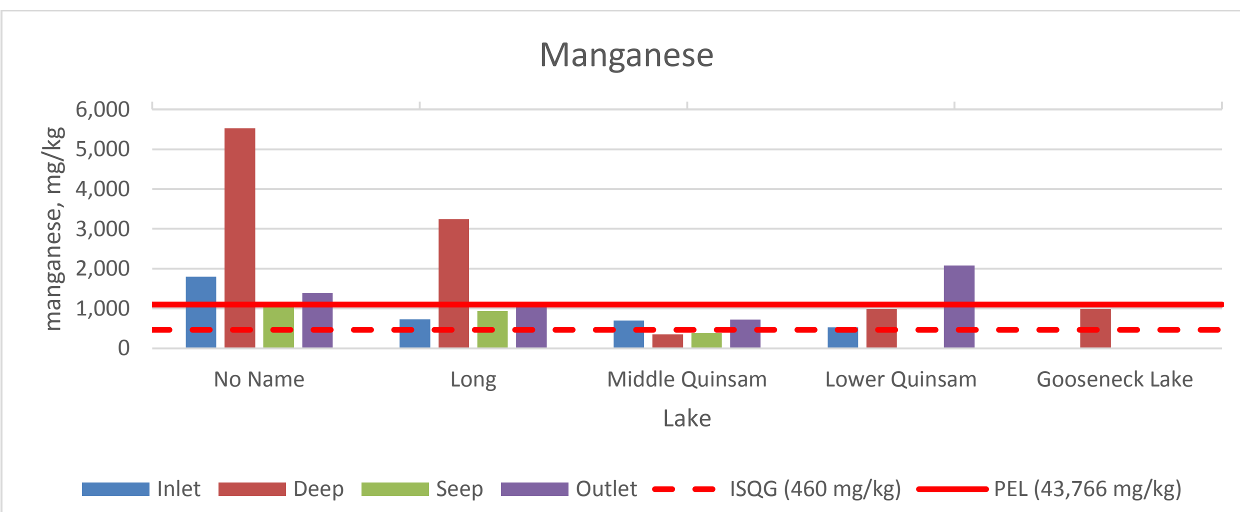

Figure 28: Mean Manganese Concentrations in Sediment, Quinsam Lakes System, 2016 (Long Lake SQO = 2,040 mg/kg)

Mean manganese concentrations were higher than the PEL of 1,100 mg/kg in three stations from No Name Lake (Inlet, Deep and Seep), Long Deep and Lower Quinsam Outlet, and were higher than the ISQG of 460 mg/kg but below the PEL at all stations in Middle Quinsam, Long Lake Inlet Seep and Outlet, Lower Quinsam Inlet and Deep, and Gooseneck Deep (Figure 28). Mean concentrations ranged up to 5,528 mg/kg, highest at No Name Lake Deep, and were also elevated in Long Lake Deep. Samples from Long Lake Deep were above the SQO of 2040 mg/kg developed by SLR (2015). Manganese concentrations tended to be lowest and near or below the ISQG in Middle Quinsam Lake.

With concentrations of arsenic, iron, and manganese higher than PELs at several stations, these metals are of potential concern for adverse effects on aquatic biota. However, in many cases, the concentrations cannot be directly attributed to discharges and seepage from Quinsam operations. Additional considerations are the naturally elevated levels measured in Long Lake prior to mining (current levels are below the SQOs for arsenic and iron, but not manganese), No Name, Lower Quinsam, and Gooseneck lakes, and the lower concentrations in Middle Quinsam Lake, which does receive mine inputs.

SLR (2015) concluded that the elevated iron concentrations in sediment, along with a distinct red tinge at the sediment surface of several lakes, support the theory that iron dissolves and migrates into the water column at times of favourable redox conditions (lower oxidative-reductive potential and lower DO). During times of favourable redox conditions, particulate iron as Fe^{3+} in sediment is reduced to the more soluble Fe^{2+} and migrates into the water column.

11.3 Summary of Phytoplankton Results for Lakes

Phytoplankton were sampled at 1 m depth three times a year (spring, summer, fall) in No Name, Long, Middle Quinsam, and Lower Quinsam lakes (Section 10.1). This sampling approach has been used consistently since 2013. Chlorophyll *a* and total phytoplankton abundance data collected between 2013 and 2016 were statistically similar among the four lakes but differed among sampling years ($p<0.05$, GLMM, ANOVA), indicating year to year variability (Section 10.2).

The low chlorophyll *a* levels measured in all four lakes in 2016 and historically reflect ultra-oligotrophic conditions (mean concentrations less than 1 µg/L, maximum less than 2.5 µg/L) of these lakes (Vollenweider and Kerekes 1982).

The phytoplankton communities in all four lakes have a small bloom in the spring and fall and have a predominance of small flagellates (chrysophytes and cryptophytes) throughout the year. The blue-green bacterium *Merismopedia* sp. was common in No Name Lake during summer 2016, as noted since sampling began in that lake in 2013. The presence of *Merismopedia* in No Name Lake but not the other lakes may be associated with runoff from the surrounding wetland areas. This is the main difference in composition of surface water samples noted since 2013.

In 2016, taxon richness was similar among the four lakes, and was higher in spring and summer (25 to 34 taxa) than in fall (8 to 19 taxa).

Phytoplankton results for 2016 were consistent with those of previous years, and do not suggest adverse effects on phytoplankton communities in Long or Middle Quinsam lakes, both of which receive direct inputs of mine-affected water.

11.4 SUMMARY OF ZOOPLANKTON RESULTS FOR LAKES

Zooplankton are sampled in a vertical tow from surface to 10 m depth three times a year (spring, summer, fall) in No Name, Long, Middle Quinsam, and Lower Quinsam lakes (Section 10.2). This approach has been used consistently since 2014.

In 2016, zooplankton abundance was highest in the spring (Long Lake) or summer (No Name, Middle Quinsam, Lower Quinsam) and lowest in the fall. Abundance tended to be highest in Long Lake, intermediate in No Name and Lower Quinsam Lake, and lowest in Middle Quinsam Lake during spring and summer. Taxon richness was also higher in the spring and summer than in the fall, ranging from 6 to 14 taxa per sample.

Zooplankton abundance and community composition has varied among lakes and seasonally from 2014 through 2016. In general, zooplankton abundance is highest for summer samples following peaks in phytoplankton and organic matter. However, there are exceptions, when numbers peak in spring or fall. There were statistically significant differences ($p<0.05$, GLMM and ANOVA) in abundance among lakes, but not among years, with highest mean abundance reported for Long Lake, followed by Lower Quinsam Lake, then No Name and Middle Quinsam lakes. Similarly, there were statistically significant differences ($p<0.05$, GLMM and ANOVA) in taxon richness among lakes, but not between years (higher mean richness at No Name Lake than at Long, Middle Quinsam, and Lower Quinsam lakes).

The zooplankton communities consisted of larger Cladocera and Copepoda, which are common prey for small fish, and smaller Rotifera, which are important recyclers of organic matter in lakes (Wetzel 2001). Predominant taxa varied among lakes. During times of peak abundance in 2016, No Name contained mainly Copepoda and Cladocera (summer peak); Long Lake contained mainly Rotifera (spring peak) and Cladocera (summer peak); and Middle Quinsam and Lower Quinsam lakes contained mainly Cladocera and Copepoda (summer peaks).

The differences in abundance, taxon richness, and composition indicate that general lake characteristics (e.g., grazing by fish, timing of phytoplankton blooms) affect the zooplankton community. There was no evidence of adverse effects of mine-related discharges on the zooplankton of Long and Middle Quinsam lakes, given that maximum abundance is typically reported in Long Lake, typical zooplankton taxa are present in all four lakes, and taxa that provide prey for fish are abundant.

11.5 Summary of Benthic Invertebrate Results for Lakes

Benthic invertebrate communities are commonly used to monitor aquatic environments, due to their sensitivity to environmental stressors and ability to reflect site conditions over a long period of time (Barbour et al. 1999; Environment Canada 2012). In the current study, benthic invertebrates are particularly useful for evaluating watershed health and ecological relevance of the observed elevated arsenic, iron, and manganese concentrations in sediment.

Benthic invertebrate samples were collected in fall 2016 from Inlet, Deep, and Outlet stations in No Name, Long, Middle Quinsam, and Lower Quinsam lakes, Seep stations in No Name, Long, and Middle Quinsam lakes, and one Deep station in Gooseneck Lake (Section 10.3.1). Sediment samples were also collected and analyzed at these sites.

As noted in the introduction to Section 11, habitat characteristics that influence benthic communities (substrate composition, TOC, sampling depth, anoxic conditions in deep water) varied among the lakes, and were related to differences in large morphology (bathymetry, hydrology) and the surrounding landscape. For example, sampling depth varied among lakes for a given habitat type (inlet sampling depth ranged from 1 to 2 m in Middle Quinsam Lake to 14 to 17 m in Lower Quinsam Lake). Substrate in all four lakes tended to be mainly sand with silt and with high TOC levels (11 to 19%), except in Lower Quinsam (4 to 7%). The lakes varied in their exposure to mine-related discharges: Gooseneck Lake is the reference lake; No Name Lake is upstream of most but not all mine discharges; Long Lake and Middle Quinsam Lake receive surface water discharges and groundwater seepage; and Lower Quinsam Lake is downstream of mine discharges.

Benthic invertebrate communities were typical of British Columbia lakes. Taxa included Diptera (chironomid, ceratopogonid, and chaoborid midges), Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), Oligochaeta (aquatic worms), Odonata (dragonflies), Gastropoda (snails and bivalves), and others. Chironomidae (non-biting midges) were predominant at most stations. Chaoboridae (phantom midges), which tolerate very low DO levels, were predominant or common at Middle Quinsam and Lower Quinsam Deep stations. Ephemeroptera, Plecoptera, and Trichoptera (EPT) were most common at Inlet and Outlet stations, where habitat is more diverse than at Deep stations. Pisidiidae (clams) were present in all lakes and did not appear strongly associated with particular habitat types. Table 38 provides a summary of differences among lakes and habitat types.

Table 38: Summary of Lake Benthic Community Metrics

Habitat Type	Community Metric			
	Density	**Taxon Richness**	**Evenness**	**Diversity**
Inlet	High impact (Long and Middle Quinsam) differed from low impact (No Name) and medium impact (Lower Quinsam), but differences between pairs were small	No significant differences among lakes.	High impact (Long and Middle Quinsam) differed from low impact (No Name) but not medium impact (Lower Quinsam),	Diversity lower at high impact (Long and Middle Quinsam) than at low (No Name) and medium (Lower Quinsam).
	Middle Quinsam > No Name and Long > Lower Quinsam	Long > No Name, Middle Quinsam and Lower Quinsam	No Name and Lower Quinsam > Long and Middle Quinsam	No Name > Long, Middle Quinsam and Lower Quinsam
Deep	Differed between high impact (Long, Middle Quinsam, No Name) and medium (Lower Quinsam)/low impact (Gooseneck),	Higher for low impact Gooseneck Lake (mean of 18) than medium and high impact lakes (mean of 8 to 14)	Low impact (Gooseneck) differed from medium and high impact lakes	No significant differences among lakes
	No Name > Lower Quinsam and Gooseneck > Long and Middle Quinsam	Gooseneck > No Name > Long and Middle Quinsam > Lower Quinsam	Long and No Name > Gooseneck, Lower Quinsam and Middle Quinsam	Gooseneck and No Name > Long > Middle Quinsam > Middle Quinsam
Seep	No significant difference for shallow seeps (Middle Quinsam) compared to shallower stations (Lower Quinsam Outlet). Significant differences for deep seeps (No Name and Long) compared to Deep stations	No significant differences among lakes	Significant difference for Seep versus Shallow sites (medium differed from low and high impact). No significant differences for deep Seeps (Long and No Name) compared to Deep stations	No significant differences for Seep vs. Shallow stations. Significant difference for Seep versus deep stations (high impact differed from low impact).
	Long > Middle Quinsam > No Name	No Name > Middle Quinsam > Long	Long > Middle Quinsam and No Name	No Name > Middle Quinsam > Long
Outlet	No significant differences among lakes	No significant differences among lakes	No significant differences among lakes	No significant differences among lakes
	Middle Quinsam > Long > No Name and Lower Quinsam	Middle Quinsam > Lower Quinsam > No Name and Long	Lower Quinsam and Long > Middle Quinsam and No Name	Lower Quinsam, Long, and Middle Quinsam > No Name

NOTE:

Statistical significance ($p<0.05$) determined using GLMM or non-parametric tests (Appendix V-5).

Inlet stations had significant differences between lakes for density, diversity, and evenness (high impact Long and Middle Quinsam differed from medium impact Lower Quinsam Lake and low impact No Name Lake) but not for taxon richness. The Lower Quinsam Inlet station was deeper than at the other lakes, had lower density and taxon richness, and resembled Deep stations rather than other Inlet stations. The Middle Quinsam Inlet was shallower than at the other lakes, and had higher invertebrate density than the other Inlet stations. With the large differences in habitat conditions (sampling depth, % TOC), and varying trends for community metrics, it was not possible to distinguish whether sediment metal concentrations or mine discharges are having an adverse effect on benthic communities of Long and Middle Quinsam Lakes at the Inlet stations.

For Seep stations, trends among sites were challenging to identify, given the variation in water depths, mine influence, and the lack of a low or medium impact Seep stations for comparison (all Seep stations were considered high impact). Benthic invertebrate density and evenness were highest at the 12 to 16 m deep Long Lake station, intermediate at the 1.0 m deep Middle Quinsam station, and lowest at the 5.6 m deep No Name station. Taxon richness and diversity had the opposite trend, and were highest at No Name, intermediate at Middle Quinsam, and lowest at Long Lake stations. As noted in Section 7.2.3, arsenic, manganese and iron concentrations at the Long Lake Seep have decreased in recent years, with many concentrations below the WQGs.

Seep invertebrate communities compared to those at Deep station had a significant difference in density (high differed from low but not medium impact stations). Seep invertebrate communities compared to those at shallow stations had a significant difference in diversity (medium impact differed from both high and low impact stations). Long Lake Seep had lower invertebrate richness and diversity than other Seep stations and then Long Lake Deep. However, the Long Lake Seep benthic community did not appear adversely affected by groundwater seepage, given that density was higher than other Seep stations and Long Lake Seep had similar taxonomic composition to Long Lake Deep. For the shallow Middle Quinsam Seep, there were few significant differences when compared to other shallow sites (only for evenness). The Middle Quinsam Seep community composition was similar to Inlet and Outlet stations in Middle Quinsam Lake and there was a high proportion of pollution sensitive EPT taxa at the Seep. These are indications of a lack of adverse effect at the Seep.

Outlets had no significant differences among the lakes for benthic invertebrate density, taxon richness, evenness, or diversity. Indicating that overall mine influences within a lake are not adversely affecting the invertebrate communities at the Outlets.

Of the four types of habitat sampled, Deep habitats are less influenced by the differences in morphology (bathymetry, wetland influence) that were found at the Inlet, Outlet, and Seep stations. Deep sediments are also less disturbed by annual flushing of the lakes, and may provide a more stable, long-term repository for metals.

Benthic invertebrate communities at the Deep stations had statistically significant differences in density (lower at high impact Long and Middle Quinsam than medium and low impact No Name, Lower Quinsam, and Gooseneck stations), taxon richness and diversity (lower at high and medium than low impact stations), with evenness showing no significant differences among stations. These invertebrate community characteristics in Long and Middle Quinsam Deep stations suggest adverse effects or stresses on the benthic communities. The results do not indicate the stress is mine-related, given that arsenic, iron, and manganese concentrations in sediment are among the highest reported for the study lakes in Long Lake but are not elevated in Middle Quinsam Lake, and that the metals concentrations in Long Lake sediment are naturally elevated.

11.5.1 *Summary of Benthic Invertebrate Results for Quinsam River*

Benthic invertebrate communities in rivers are commonly used to monitor aquatic effects, given their sensitivity to environmental conditions and ability to reflect site conditions over a long period of time (Barbour et al. 1999; Environment Canada 2012). In the current study, they are particularly useful for evaluating watershed health and ecological relevance of differences in water and sediment chemistry observed in the Quinsam River. The use of the reference condition approach (RCA) to biomonitoring allows comparison of benthic invertebrate communities both within the Quinsam River watershed and to other watercourses in the 2010 BC Coastal RCA dataset.

The Quinsam River was sampled at three locations in September 2016: WA upstream of Middle Quinsam Lake (reference), QRDS1 downstream of Middle Quinsam Lake, and 7SQR, downstream of all mine influences and upstream of Lower Quinsam Lake. Results presented in Section 10.3.2 indicate that the three stations support typical riffle communities of benthic invertebrates, including predominance of organisms that require clean, high DO water (EPT taxa) and similar taxon richness and high diversity at the three stations.

The RCA model results for the three Quinsam River sampling sites (mildly divergent from the reference condition) and individual metrics (family richness, EPT richness, EPT predominance) indicate that the three sampling stations do not show signs of adverse effects from mine-related discharges. The Quinsam River supports a variety of insect taxa that indicate clean water conditions and provide abundant prey for fish.

11.6 Conclusion

Water in lakes of the Quinsam River watershed near Quinsam Mine and in the Quinsam River itself is generally of good quality, meeting WQGs and WQOs on most sampling dates. Sulphate remains slightly higher than the WQO in deep water (9 m and 1 mb) of Long Lake. Low DO levels in deep waters are common during summer and early fall in all four lakes and the reference Gooseneck Lake, which can result in mobilization of arsenic, iron, and manganese. Concentrations of these metals in deep water were lower in 2016 than in earlier years. No Name, Long, Middle Quinsam, and Lower Quinsam lakes support phytoplankton communities typical of ultra-oligotrophic conditions and distinct zooplankton communities in each lake that provide typical prey for fish. There were no indications of adverse effects of mine discharges on the plankton communities of lakes (density, taxonomic richness, composition).

Sediment in the study lakes contains elevated levels of several metals. Arsenic, iron, and manganese concentrations are higher than PELs in Long Lake, which is affected by mine discharges, and in some areas of No Name and Lower Quinsam lakes, which have notably lower mine influence than Long Lake. However, concentrations of these metals are lower than the PELs (albeit higher than ISQGs) in sediment of Middle Quinsam Lake, which receives the majority of mine discharges. The sediment data for these lakes indicate the influence of limnological conditions (morphology, residence time of water), localized geology and groundwater quality on concentrations of arsenic, iron, and manganese. The results of this 2016 study and earlier reports (summarized in SLR 2015) illustrate the challenges attributing the elevated arsenic, iron, and manganese concentrations in lake sediments to Quinsam Mine operations. There are naturally elevated concentrations in the reference Gooseneck Lake, in relatively unaffected No Name and Lower Quinsam lakes, and in the pre-mining database for Long Lake. Currently, arsenic, iron, and manganese levels in Long Lake sediment are below the SQOs developed to reflect pre-mining background conditions (SLR 2015), suggesting current levels in Long Lake do not reflect a mine influence.

While levels of arsenic, iron, and manganese are low in discharges from the mine, they can be elevated in groundwater seeps entering Long Lake (Golder 2011, Cullen 2011, SLR 2015). However, seep monitoring conducted since 2011 has shown a notable decline in concentrations of these metals (Section 7.2.3), and groundwater monitoring indicates naturally elevated concentrations in wells established in the Dunsmuir rock formation. The presence of anoxic or suboxic conditions in lake deep waters during the summer and early fall (which develop naturally in the study lakes) leads to conditions where metals that are sensitive to changes in the redox environment can be mobilized and enter the deep waters of the lakes. The amount of mobilization varies from year to year: in 2016, there were only rare and low magnitude WQG exceedances for iron in Long Lake. However, in earlier years, the concentrations of iron and manganese were higher in Long Lake and Lower Quinsam Lake. Results of this 2016 study and earlier studies, summarized in SLR (2015) cannot conclusively identify a mine-related source for these metals in Long Lake, aside from possible localized sources from seeps, in addition to naturally elevated levels observed in other lakes in the watershed.

With concentrations of arsenic, iron, and manganese above the PELs in some lakes, there is a concern for potential aquatic toxicity, particularly for benthic invertebrates that inhabit the sediment, regardless of whether the metals come from natural or mine-related sources. Effects on benthic invertebrate communities were evaluated through sediment toxicity tests (Golder 2011) and benthic invertebrate community assessments (Nordin 2006, Golder 2011, the 2016 study).

Results of standard laboratory toxicity tests of Long Lake sediment on growth of the amphipod *Hyalella azteca* and chironomid larva *Chironomus tentans* did not identify consistent trends for toxicity results, except in localized areas around the seep(s), an effluent discharge location on the shore of Long Lake, and in two of four samples of deep sediment (Golder 2011). Taken together, the samples from inlet, outlet, near shore and deep areas of Long Lake showed no obvious relationship between contaminant concentration and survival and growth of the test species, aside from the localized effects noted above (Golder 2011).

Results of the 2016 lake benthic invertebrate community study were generally similar to previous studies (Nordin 2006, Golder 2011). The inlets and outlets of No Name, Long, Middle Quinsam, and Lower Quinsam lakes supported diverse communities of benthic invertebrates and showed some lake-specific trends related to bathymetry, morphology, and surrounding land characteristics (e.g., presence of wetlands). Differences among the lakes appeared to be related more to these differences in habitat than to differences in water or sediment quality and mine influences. Benthic invertebrate communities in deep habitats had lower density, taxon richness, and diversity in Long and Middle Quinsam lakes (greater mine influence) than in No Name, Lower Quinsam, and Gooseneck lakes (lesser mine influence lakes and reference lake). Although a link with mine operations cannot be ruled out, there was no consistent relationship between metal levels in sediment and effects on benthic communities (high metals in Long, No Name, and Lower Quinsam lake vs. low levels in Middle Quinsam Lake), especially because sediment concentrations are naturally elevated in these lakes.

The benthic invertebrate community sampling in the Quinsam River, conducted using the CABIN protocols and assessed using the reference condition approach, also did not provide signs of adverse effects from mine-related discharges. The stations upstream (WA) and downstream (QRDS1 and 7SQR) were ranked similarly as mildly divergent from the reference condition (undisturbed coastal BC rivers and streams) and contained mainly insect taxa that indicate clean water conditions and provide abundant prey for fish (mayflies, stoneflies, and caddisflies).

In conclusion, the 2016 benthic invertebrate and sediment quality study conducted for Quinsam Mine added to the body of knowledge about the watershed. Results of the lake surveys indicated no adverse effects on phytoplankton and zooplankton communities in Long and Middle Quinsam Lakes. Results for benthic communities were less conclusive, indicating reduced abundance and diversity in Deep habitats of Long and Middle Quinsam lakes, but it was not possible to attribute this to a mine-related effect; interpretation of results was confounded by the influence of naturally elevated background levels of sediment metals and the challenges finding sampling areas with similar habitat characteristics in all five lakes. Differences among lakes for either Inlet or Outlet habitats were minor, suggesting overall effects on lake benthic communities are limited and localized. The river sampling program provided the most definitive information about watershed health, with the three sampling stations upstream and downstream of the mine showing similar results (mildly divergent from the reference conditions), and not indicating a mine-related effect downstream of the Quinsam Mine. In lakes and the Quinsam River, benthic invertebrate organisms typical of the habitats sampled were present, and would provide prey sources for fish.

11.7 Recommendations

The following recommendations for future monitoring programs are made:

- Add analysis of nutrients (total and dissolved phosphorus, ortho-phosphate, nitrate, nitrite, ammonia, total Kjeldahl nitrogen) to the lake water monitoring program, to support evaluation of the oligotrophic status of the lakes and to provide background data should changes in arsenic loadings to the lakes occur in the future (relationship between arsenic mobilization in sediment/water interface, DO levels in deep water, and increase in trophic status and organic matter loading to sediments).
- Consider additional monitoring of seep areas in Long Lake to assess success of mitigation measures implemented in recent years. Further characterize habitat, and, sediment water quality conditions at the No Name and Middle Quinsam Seeps.

12.0 Closing

Water quality in the Middle Quinsam Sub-Basin remained consistent with previous years and is considered to be in good condition with little appreciable impacts associated with coal mining. The majority of parameters of concern were below Provincial guideline and objective levels indicating minimal health risk to sensitive aquatic receptors. For example, sulphate concentrations were recorded below its respective guideline during all sampling events in three out of four lakes sampled; this trend signifies water management features and controls at the mine site are effective.

This year, Quinsam experienced permit limit exceedances for TSS in the North and at 7-South mostly attributed to precipitation events. However, during all events TSS levels recorded were not detectable at downstream monitoring sites and, therefore, not considered detrimental to the receiving environment. Quinsam was diligent in monitoring the downstream receiving environment and the results demonstrated that the risk to aquatic receptors was minimal.

Faulty equipment causing missing discharge data was replaced and remedial measures were developed and implemented to mitigate future occurrences and ensure compliance with effluent permit conditions. These include:

- A new ISCO automated composite sample was purchased for 7SSD
- Hard power was brought to 7SSD and Settling Pond #4 ensuring power at all times
- A new Signature flow meter was purchased for Settling #4 discharge
- Frequent site inspections
- Reduced pumping and discharging at 7SSD

It is anticipated that these efforts will assist in reducing permit limit exceedances & data gaps throughout out 2017-18 monitoring year.

Parameters of interest and those displaying elevated concentrations in the lakes include total and dissolved iron (LQL 1mb) & total manganese (LLM 1mb) both of which are associated with anoxic concentrations at depth. Dissolved aluminum displayed elevated concentrations as a result of the flush in some lakes (NNL & LQL).

The relationship between low DO and elevated manganese in Long Lake 1 metre from bottom sample has been demonstrated in Appendix II, Graph (34). This pattern of elevated manganese at depth has become more evident since the initiation of the 5 in 30 monitoring in 2013. Previously there were occasional exceedances occurring during monthly sampling over summer and fall and all events were associated with low DO.

When surface water quality emanating from the South Water Management System is examined there does not appear to be a correlation between mine related discharge and Long Lake manganese concentrations. The only surface sampling location displaying elevated manganese is the 4-South Lower ditch (4SLO) displaying elevated but stable manganese concentrations throughout the year averaging 1.48 mg/L. Total manganese concentrations at monitoring site LLE remained well below guideline levels with an average concentration of 0.0521mg/L for the reporting year (Although, it is questionable if discharge at LLE actually impacts the LLM sampling location). The Long Lake Seeps (LLS & LLSM) had an average concertation of 0.244 mg/L with no individual monthly samples exceeding the guidelines.

However, manganese concentrations (dissolved fraction) in the historical mining zones (e.g. 2-South & 4-South) within close proximity to Long Lake were thought to be contributing to elevated manganese influencing water column concentrations through both shallow and deep groundwater in the lake. Monitoring well MW00-2 situated next to the 3S pit sampled on quarterly basis, was the only well that displayed elevated dissolved manganese concentrations averaging 2.546 mg/L. The 2-South mine pool groundwater well MW00-4 situated on the southern side of Long Lake does not display elevated manganese with average concentrations resulting in 0.005 mg/L.

Nested (deep and shallow) groundwater wells (QU10-09 D & S) situated across from the 4-South mine and developed to capture any seepage emanating from the mine are low as well, averaging 0.092 mg/L and 0.398 mg/L for deep and shallow, respectively. The host rock formations and anoxic conditions are believed to be cause of the elevated manganese in Long Lake. Sediment results displayed elevated concentrations collected from the deep sampling location on Long Lake averaging 3,240 mg/kg. In comparison No Name Lake deep site manganese sediment concentrations averaged 5,520 mg/kg but water quality in the deep sampling site does not show elevated concentrations. This is likely because the lake does not experience anoxic conditions and does not readily leach from the sediment.

Quinsam anticipates that the efforts invested into the reclamation projects will continue to contribute to improved water quality in Long Lake. This will be determined over the next few years as vegetation starts to become established within the area and concentrations of parameter loading start to decline.

Once again depth profiling has resulted in low pH conditions exceeding lower water quality guidelines of 6.0 observed in No Name Lake during all seasons and Long Lake during fall. However, there is little concern as the slightly acidic conditions are likely naturally occurring.

The Iron River was added to the receiving environment monitoring program during the 2014/2015 monitoring period as a result of the 7-South Area 5 mine approval. This development has been postponed until the demand for thermal coal increases. This system experiences naturally elevated concentrations (above water quality guidelines) of aluminum and arsenic; aluminum is present throughout the system (i.e. from IR1 through IR8) whereas arsenic is primarily detected below the sandstone unit of the Dunsmuir member contact represented by monitoring location IR6. These parameters have continued to be observed throughout 2016-17 monitoring in this system with less frequent exceedances of arsenic during low flow sampling. The main intention is to develop water quality objectives reflective of baseline conditions.

Quinsam Coal will continue to focus on site wide water management with a target of mitigating parameter of interest concentrations in the receiving environment. To date, Quinsam has demonstrated that the existing mine related controls and features implemented have been effective at reducing concentrations of certain parameters (e.g. sulphate). This trend is expected to persist and will be highlighted by future monitoring programs.

In closing, Quinsam trusts the information herein addresses the environmental responsibilities and provisions applicable to effluent permit PE: 7008 specifically section 4.2.7 iii).

This report has been reviewed by an appropriate qualified professional as signed below. Should you have any questions or concerns please contact the undersigned at Quinsam Coal Environmental Department 250-286-3224 Ext 225.

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