Teck Trail Operations

Lower Columbia River
Aquatic Effects Monitoring Program

2018 Data Collection and Interpretation Report

Prepared By:
Ecoscape Environmental Consultants Ltd.

Prepared For:
Teck Trail Operations
Trail, B.C.

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Prepared For:

TECK TRAIL OPERATIONS
PO Box 1000
25 Aldridge Avenue
Trail, BC
V1R 4L8

Prepared By:

ECOSCAPE ENVIRONMENTAL CONSULTANTS LTD.
102 - 450 Neave Court
Kelowna, BC
V1V 2M2
Phone: 250 491-7337
Fax: 250 491-7772
ecoscape@ecoscapeltd.com

&

LARRATT AQUATIC CONSULTING LTD.
2605 Campbell Rd
West Kelowna, BC
V1Z 1T1
Phone: 250-769-5444
Fax: 250-769-3233
heather@larratt.net

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The report team contributors were:

Project Lead:
Kyle Hawes

Data Management:
Rachel Plewes
Luke Crevier

Statistical Analysis:
Rachel Plewes
Luke Crevier

Authors:
Heather Larratt
Rachel Plewes
Kyle Hawes

LIST OF ACRONYMS

µS	microSiemens
AFDW	Ash Free Dry Weight (Volatile Solids)
Al	Aluminum
AEMP	Aquatic Effects Monitoring Program (formerly Aquatic Receiving Environment Monitoring Program; AREMP)
AOI	Area of Interest represents the Lower Columbia River from the confluence of the Kootenay River downstream to Waneta – including both reference and exposure areas (downstream of the smelter) assessed within the AREMP.
ALS	ALS Environmental Laboratories, Burnaby BC
As	Arsenic
BIR	Birchbank
BC Hydro	British Columbia Hydro and Power Authority
BC ENV	British Columbia Ministry of Environment and Climate Change Strategy
BOD_5	5-day Biological Oxygen Demand
Ca	Calcium
CABIN	Canadian Aquatic Biomonitoring Network
Caro Labs	Caro Environmental Laboratories (Kelowna, BC)
CCME	Canadian Council of Ministers of the Environment
CII	Teck Metals Ltd. Trail Smelter combined effluent Outfall II
CIII	Teck Metals Ltd. Trail Smelter combined effluent Outfall III
CIV	Teck Metals Ltd. Trail Smelter combined effluent Outfall IV (fertilizer outfall on right bank at Stony Creek)
Cl	Chlorine
Cd	Cadmium
CRIEMP	Columbia River Integrated Environmental Monitoring Program
Chl-a	Chlorophyll-a
Co	Cobalt
CRH	Torrent Sculpin (*Cottus rhotheus*)
CSR	Contaminated Sites Regulations
Cu	Copper
DDI	Double Deionized Water
DEP	Depositional area sample site
DEP-EXP	Depositional area sample site situated downstream of the smelter
DEP-REF	Depositional area sample site situated upstream of the smelter
Didymo	*Didymosphenia geminata*
DO	Dissolved Oxygen
EPT	Ephemeroptera, Plecoptera, Tricoptera
ER	Exposure Ratio
ERA	Ecological Risk Assessment
ERO	Erosional area sample site
ERO-EXP	Erosional exposure area sample site situated downstream of the smelter
ERO-REF	Erosional reference area sample site situated upstream of the smelter
EXP	Indicates sample sites/areas situated downstream of the smelter. These represent exposure area samples.
Fe	Iron
g	Gram
GIS	Geographic Information Systems
GPS	Global Positioning System
GSI	Gonadosomatic Index
HBI	Hilsenhoff Biotic Index

Hg	Mercury
HLK	Hugh L. Keenleyside
HSD	Honest Significant Difference
HSI	Hepatosomatic Index
ICP-MS	Inductively-Coupled Mass Spectrometry
IDZ	Initial dilution (mixing) zone of effluent receiving waters extending downstream from the TML Trail Smelter to Old Bridge.
ISQG	Interim Sediment Quality Guideline
K	Potassium
k	Fulton’s Condition Factor
kcfs	Thousands of Cubic Feet Per Second
kg	Kilogram
km	Kilometer
L	Liter
LCR	Lower Columbia River
m ASL	Meters Above Sea Level
m	Meter
max	Maximum Value
MCR	Middle Columbia River from below the Revelstoke Reservoir downstream to Upper Arrow Lake
Mg	Magnesium
mg	Milligram
min	Minimum Value
mm	Millimeter
Mn	Manganese
Mo	Molybdenum
MW	Mountain Whitefish (*Prosopium williamsoni*)
N	Nitrogen
n	Sample Size
Na	Sodium
NaCl	Sodium Chloride
NMDS	Non-metric Multidimensional Scaling
NTU	Nephelometric Turbidity Units
Pb	Lead
PCA	Principal Component Analysis
PCOC (PMOC)	Potential Contaminant of Concern (equates to Potential Metal of Concern herein)
PEL	Probable Effects Level (lower limit usually associated with the potential for adverse effects)
POM	Particulate Organic Material
ppm	Parts per Million
QA/QC	Quality Assurance and Quality Control
RB	Rainbow Trout (*Oncorhynchus mykiss*)
REF	Indicates sample sites/areas situated upstream of the smelter. These represent reference area samples.
SALM	Strong Acid Leachable Metals
SD	Standard Deviation
Se	Selenium
Si	Silicon
SO_4	Sulphate
TDS	Total Dissolved Solids
Tl	Thallium

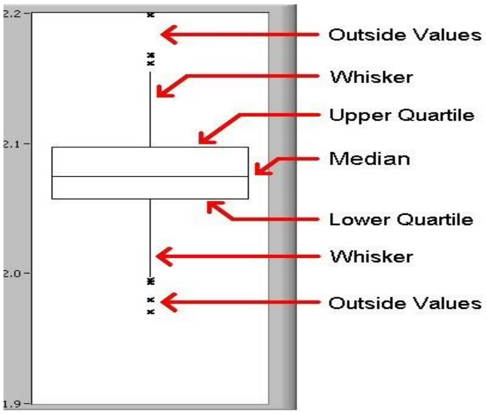
T-P	Total Phosphorus
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TML	Teck Metals Limited
TOC	Total Organic Carbon
TRO	Tissue Residue Objectives
TSS	Total Suspended Solids
TTS	Teck Trail Smelter
UBC	University of British Columbia
USEPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
VIF	Variance Inflation Factors
WP	Walleye (*Sander vitreus*)
WQIS	Water Quality Index Station
WUP CC	Columbia River Water Use Plan Consultative Committee
Zn	Zinc

DEFINITIONS

The following terms are briefly defined as they are used in this report. For a fuller explanation, please refer to scientific literature.

Term	Definition
Anoxic	Devoid of oxygen.
Benthic	Organisms that dwell in or are associated with the sediments.
Benthic production	The production within the benthos originating from both periphyton and benthic invertebrates.
Bioaccumulation	Removal of materials from solution by organisms via adsorption, metabolism.
Bioavailable	Available for use by plants or animals.
Biomagnification	A marked increase in a material of interest through successively higher levels of a food chain.
Catastrophic flow	Flow events that have aquatic population-level consequences of >50% mortality.
Cyanobacteria	Bacteria-like algae having cyanochrome as the main photosynthetic pigment.
Diatoms	Algae that have hard, silica-based "shells" frustules.
Effective Dilution	Ratio of the effluent concentration to the plume concentration
Eutrophic	Nutrient-rich, biologically productive water body.
Exposure Area	The Columbia River within the Initial Dilution Zone and areas downstream of the smelter effluent discharges (to Waneta).
Flow	The instantaneous volume of water flowing at any given time (e.g., 1200 m^3/s).
Functional Feeding group	(FFG) Benthic invertebrates can be classified by mechanism by which they forage, referred to as functional feeding or foraging groups.
Inflow plume	An inflow seeks the layer of matching relative density in the receiving water, diffusing as it travels; High TSS, TDS and low temperature increase water density.
Left Bank	Left bank (river left) when looking downstream.
Light attenuation	Reduction of sunlight strength during transmission through water.
Limitation, nutrient	A nutrient can limit or control the potential growth of organisms e.g., P or N.
Macronutrient	The major constituents of cells: nitrogen, phosphorus, carbon, sulphate, H.
Metal of Interest	In previous studies/reports metals of interest were referred to as Potential Contaminants of Concern (PCOC).
Micronutrient	Small amounts are required for growth; Si, Mn, Fe, Co, Zn, Cu, Mo etc.
Microflora	The sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms.
Myxotrophic	Organisms that can be photosynthetic or can absorb organic materials directly from the environment as needed.
Nano plankton	Minute algae that are less than 5 microns in their largest dimension.
Near-field	Near field mixing is the immediate mixing upon release from the diffuser and its interaction with ambient river water.
Pico plankton	Minute algae that are less than 2 microns in their largest dimension.
PPB or µg/L	1 part per billion (e.g., 1/6th of an aspirin tablet in 1 rail car of water (16,000 gal).
Peak biomass	The highest density, biovolume or chl-a attained in a set time on a substrate.
Periphyton	Microflora that are attached to aquatic plants or solid substrates.
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes.
Redox	The reduction (-ve) or oxidation (+ve) potential of a solution.
Reducing environment	Devoid of oxygen with reducing conditions (-ve redox) e.g., water-covered organic sediments. Negative redox is usually driven by bacterial activity.
Reference Area	The Columbia River within the AOI upstream of Stoney Creek and smelter effluent discharges.
Right Bank	Right bank (river right) when looking downstream.
Riparian	The interface between land and a stream or lake.
Zooplankton	Minute animals that graze algae, bacteria and detritus from a water column.

HOW TO INTERPRET A BOXPLOT



The lower (first) quartile (Q_1) is defined as the middle number between the smallest number and the median *of the data set. The second quartile (Q_2) is the median of the data. The upper (third) quartile (Q_3) is the middle value between the median and the highest value of the data set.*

An outlier (outside) value is generally defined as any value that is 1.5 times the lower (Q1) and upper (Q3) quartile values (i.e., the whiskers on the above figure). Outlier values can be due to real variability in the sample population, heavy-tailed distributions, or due to errors in sampling equipment or transcription.

WATER QUALITY, SEDIMENT AND TISSUE GUIDELINES

Generalized Water Quality Guidelines and Objectives

Selected Analytes	Units	LCR Water Quality Objectives		BC	
Water Quality General		Short-term	Long-term	Short-term acute	Long-term chronic
pH		6.5 - 8.5	-	6.5 - 9.0	-
Dissolved oxygen	mg/L	5.5 - 9.5	-	5 - 9 (min)	8 - 11 (min)
Total organic carbon	mg/L	-	-	-	± 20% of 30-day median background concentration
Suspended solids	mg/L	-	-	± 25	± 5
Turbidity	NTU	-	-	± 8	± 2
Metals					
Aluminum – dissolved	mg/L	-	-	0.1	0.05
Arsenic – total	mg/L	-	0.005	0.005	-
Cadmium – dissolved	mg/L	-	-	Cd calc	Cd calc
Chromium – total	mg/L	-	0.001	-	-
Chromium III ion	mg/L	-	-	-	0.0089
Chromium VI ion	mg/L	-	-	-	0.001 (working)
Copper – total	mg/L	0.00717	0.002	BLM Model	BLM Model
Iron – total	mg/L	-	-	1.0	-
Iron – dissolved	mg/L	-	-	0.35	-
Lead – total	mg/L	0.0379	0.0048	Pb calc	Pb calc
Mercury – total inorganic	mg/L	-	-	0.0001	0.00002
Nickel – total	mg/L	0.0025 - 0.150	-	-	Ni calc (working)
Selenium – total	mg/L	-	-	0.002	0.001
Sodium – total	mg/L	-	-	-	-
Silver – total	mg/L	-	-	(0.0001 if hardness <100mg/L) - 0.003	0.00005 (hard <100 mg/L) - 0.0015
Thallium – total	mg/L	-	0.0008	-	0.0008 (working)
Zinc – total	mg/L	0.033	0.0075	Zn calc	Zn calc
Nutrients					
Ammonia as N	mg/L	-	0.102 - 2.08 temp/pH table	0.752 - 27.7 temp/pH table	0.102 - 2.08 temp/pH table
Nitrate-N as N	mg/L	-	-	32.8	3.0
Nitrite-N as N	mg/L	-	-	0.06	0.02
Total phosphorus as P	mg/L	-	-	0.005 - 0.015 for lakes	-
Sulphate	mg/L	-	-		218 (hardness of 70 mg/L)

Parameter/Analyte mg/L	Calculation
Cd short-term (dissolved)	$e^{1.03 * (\ln(Hss) - 5.274)}/1000$
Cd long-term (dissolved)	$e^{0.736 * (\ln(Hss) - 4.943}/1000$
Cu total	BC Biological Ligand Model (2019)
Ni long-term	When hardness >60 to <180 mg/L = $e^{(0.76[\ln(Hss)]+1.06)}/1000$
Pb short-term	$e^{1.273 * (\ln(Hss)-1.46)}/1000$
Pb long-term	$3.31 + e^{(1.273 \ln(\text{mean hardness}) - 4.705)}/1000$
SO_4 (proposed 2013)	Hardness(mg/L) soft (0-30)=128 mg/L SO_4 | moderate (31-75)=218 mg/L SO_4 | hard(76-180) =309 mg/L SO_4 | very hard(181-250)=429 mg/L SO_4
Zn short-term	(33+0.75(hardness-90))/1000
Zn long-term	(7.5+0.75(hardness-90))/1000

Water Quality Guideline References

LCR Objectives: Lower Columbia River from Birchbank to the International Border: Water quality Assessment and Recommended Objectives, MacDonald Envi Services Ltd. 1997

LCR Objectives: Ambient Water Quality Assessment and Objectives for the Lower Columbia River – Birchbank to the US Border. Overview Report. 2000.

BC Water Quality Guidelines. 2019. https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines

Sediment quality guidelines

		LCR Sediment	BC Working Guidelines 2006		CCME	
Total Metals	**Units (Dry wt.)**	**Objective**	**ISQG**	**PEL**	**ISQG**	**PEL**
Arsenic	mg/kg	5.7	5.9	17	5.9	17
Cadmium	mg/kg	0.6	0.6	3.5	0.6	3.5
Chromium	mg/kg	36.4	37.3	90	37.3	90
Copper	mg/kg	35.1	35.7	197	35.7	197
Iron	mg/kg	-	21,200 (2%)	43,766 (4%)	-	-
Lead	mg/kg	33.4	35	91.3	35	91.3
Manganese	mg/kg	-	460	1100	-	-
Mercury	mg/kg	0.16	0.174	0.486	0.17	0.486
Nickel	mg/kg	-	16	75	-	-
Selenium	mg/kg	-	2	-	-	-
Silver	mg/kg	-	0.5 (Ontario)	-	-	-
Thallium	mg/kg	-	-	-	-	-
Zinc	mg/kg	120	123	315	123	315

ISQG = interim sediment quality guideline (mg/kg = µg/g)

PEL = probable effects level

NOTE: the Objectives cited here are more stringent than the Contaminated Sites Regulations (CSR) Schedule 9 standards for sediment

According to the 2009 BC Lab Manual for sediment samples, the < 2 mm fraction is analyzed.

Sediment Guideline References

LCR Objectives: Lower Columbia River from Birchbank to the International Border: Water quality Assessment and Recommended Objectives, MacDonald Envi Services Ltd. 1997

BC Sediment Quality Guidelines https://www.for.gov.bc.ca/hfd/library/ffip/Nagpal_NK2001.pdf

CCME Canadian Council of Ministers of the Environment http://www.ccme.ca/

Tissue metals guidelines for consumers of fish

	Human Health[1]	**Wildlife[2]**	**CCME[4]**	**BCMOE**
Analyte	µg/g	µg/g	µg/g	µg/g
Arsenic	3.5	0.47		
Cadmium		0.9		
Chromium		0.94		
Lead	0.5	0.16		0.08
Mercury	0.5	0.1	0.033	
Selenium[3]	High intake = 1.8 (ww) Moderate intake = 3.6 (ww) Low intake = 18.7 (ww)	1		Egg/ovary = 11 (dw) Whole body = 4 (dw) Muscle/fillet = 4 (dw)

[1] Canadian guidelines for chemical contaminants and toxins in fish and fish products. Based on fish protein (mussel) concentration (Ammend.no.11, 2011). (Can.Food.Insp.Agency 2011)

[2] LCR tissue residue objectives (TRO): Lower Columbia River from Birchbank to the International Border: Water quality Assessment and Recommended Objectives (MacDonald Envi Services Ltd. 1997)

[3] BCMOE. 2014. Ambient water quality guidelines for Selenium Technical Report Update. Water Protection and Sustainability Branch Environmental Sustainability and Strategic Policy Division British Columbia Ministry of Environment. 270pp.

[4] CCME tissue guideline is for methyl mercury and based on the most stringent avian receptor.

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EXECUTIVE SUMMARY

INTRODUCTION

Ecoscape Environmental Consultants Ltd. (Ecoscape) was retained by Teck Metals Limited, Trail Operations (Teck) to carry out an aquatic effects monitoring program (AEMP) on the Lower Columbia River (LCR) as per part 3.2 of Effluent Permit PE02753. The purpose of this program is to conduct effluent receiving environment monitoring in the LCR. A secondary purpose of the work is to provide information to Teck to facilitate management decisions for smelter operations.

The Trail smelter has three permitted outfalls (CII, CIII, and CIV). The requirement to carry out an AEMP was delegated to Teck by BC ENV in 2011. Methods for the AEMP data collection and interpretation adapt the Proposed Study Design for Teck Trail Smelter AREMP (Golder 2012a).

This report follows the third data collection cycle (2018) and includes evaluation of water quality, sediment quality, periphyton communities and benthic invertebrate communities. Small and large-bodied fish were not collected in the 2018 data collection cycle since the sampling frequency was extended from a 3-year cycle to a 6-year cycle to reduce population burdens associated with lethal sampling for tissue analysis and condition metrics, and to align with other LCR studies.

The primary study area is the lower Columbia River from Stoney Creek to Old Bridge, as this area receives the permitted effluent from the smelter at three locations along the right bank. This is referred as the initial dilution zone (IDZ). Downstream of the smelter, sampling extends from Old Bridge to Waneta just upstream of the confluence with the Pend Oreille River and north of the international border at Waneta. Reference study areas include the lower Columbia River, beginning from the Hugh L Keenleyside Dam and the Brilliant Dam on the Kootenay River, extending downstream to Stoney Creek.

BACKGROUND

The influence of the smelter effluent discharge on the aquatic receiving environment was monitored initially by Teck and then through the Columbia River Integrated Environmental Monitoring Program (CRIEMP) which implemented a Lower Columbia River Water Quality Objectives Monitoring Program from 1997-2005 (Hatfield 2008).

Teck conducted a large-scale Ecological Risk Assessment (ERA) of the Trail Smelter operations from 2000 to 2007 (Golder 2007; Golder 2012a). The aquatic ERA Area of Interest (AOI) encompassed the lower Columbia River and its tributaries from downstream of the Hugh L Keenleyside Dam, and the Brilliant Dam on the Kootenay River to Waneta. The ERA concluded that risk management objectives were being met for fish, but that additional evaluation was required with respect to periphyton and benthic invertebrates at specific sites downstream where non-smelter related stressors are also present. Tributary systems did not have strong evidence for smelter-related risks.

In addition to the smelter outfalls, smelter-related influences include Stoney Creek, which discharges just upstream of the smelter and contributes metals to the LCR (Teck Cominco 1998), and historically impacted groundwater discharges to the LCR in the vicinity of the smelter (Golder 2012).

Non-smelter-related stressors include urban stormwater and the Regional wastewater treatment facility, as well as elevated metals in tributaries resulting from other anthropogenic sources such as forestry, historical mining and run-off from agricultural and urban areas (Golder 2007).

BC Hydro dam flow regulation from the Hugh L. Keenleyside (HLK) and Brilliant Dams is a key determinant of LCR condition. River flow is an important driver of benthic community development in all flowing waters. In addition to determining dilution, flow affects a range of co-variate parameters including substrate submergence or stranding, velocity, turbulence, sediment transport, and light penetration.

Sources other than permitted smelter discharges have a potential influence on the health of the aquatic receiving environment. Due to the integrating nature of the LCR, any impacts from these sources could not be assessed separately from the effluent discharge, and the AEMP will measure parameters as a result of all influences on the river, not just the Trail Smelter effluent discharge.

WATER QUALITY

The water quality program is a long-term monitoring program designed to evaluate potential effects of Teck's permitting effluent discharges on the LCR. Water quality samples are collected in spring, summer, and fall. The spring and fall sampling sessions are designed to target a low flow period where metal concentrations in the water column should be the least diluted. However, the LCR is a regulated river and flows were higher during some of the sampling events and years.

Water quality monitoring sites include:

- Birchbank – upstream Reference Site (9.7 km upstream of smelter).
- Stoney Creek – 100 m downstream of Stoney Creek confluence and CIV outfall (within the IDZ near upstream end)
- New Trail Bridge – Beneath or as close to the Bailey Street bridge as safely practicable, within the IDZ (250 m downstream of the CII effluent outfall).
- Old Trail Bridge – 20 m upstream of the Old Bridge. The Old Bridge marks the end of IDZ (1.1 km downstream of CII effluent outfall), so this sample location is within the IDZ at the downstream end.
- Maglios – 4.2 km downstream of the IDZ. This site was added in the 2014 sampling program to demonstrate near to full mixing of the effluent plume by this location as opposed to Waneta, which is 10 km further downstream.
- Waneta – 15.8 km downstream of smelter, above Pend Oreille River confluence.

Water quality data were compared to applicable BC long-term and short-term Water Quality Guidelines and LCR Water Quality Objectives. The long-term average concentration was determined by calculating the mean from 5 samples collected within 30 days from right bank shallow locations (R-sh) during spring low flow. The R-sh locations were used because the effluent plume hugs the right bank and diffuses outward moving downstream.

The variations in river flow between sampling events make it difficult to compare annual differences and trends in metal concentrations. Therefore, the effect of river flow on metal concentrations associated with smelter effluent was tested by multiple linear regression with analyte concentrations (mg/L) at New Bridge R-sh.

Trend Analysis using Mann-Kendall was conducted with flow-weighted mean concentrations of the five spring R-sh samples from 2012-2018. The FWMC represents the total load for the time period divided by the total river discharge for the time period.

Only selenium and cadmium had significant trends out of the 95 assessed parameters. These trends were influenced by sources upstream of the smelter since similar trends were observed at Birchbank. The flow-weighted concentrations of total selenium increased from 2012-2018 at Waneta and at the reference Birchbank site. Other sites had the highest flow-weighted selenium concentrations in 2016. The flow-weighted dissolved cadmium concentrations increased from 2012-2018 at Stoney Creek, particularly in 2016-2018 and at the reference Birchbank site in 2016-2017.

Management Question 1. Are Provincial Water Quality Objectives attained at the downstream end of the IDZ during low flows (less than 40 kfcs) as per long term trend monitoring (e.g., CRIEMP)?

2012	Provincial Water Quality Objectives are attained at the downstream end of the IDZ, or Old Bridge Site, during low flows. The exceptions were mercury and cadmium, which exceeded the objectives or guidelines at some of the reference sites upstream of the smelter as well as below the IDZ. All nutrients were within respective water quality objectives or guidelines throughout the LCR.
2015	No metal exceedances attributable to the smelter were detected in 2015-2016 samples below the IDZ. Provincial Water Quality Objectives were attained at the downstream end of the IDZ, or Old Bridge Site, even during low flows during all 2015 and 2016 sampling events. Nutrient concentrations in the LCR below the IDZ were not significantly altered by the effluent discharges.
2018	No metal exceedances attributable to the smelter were detected in 2018 samples below the IDZ. Provincial Water Quality Objectives were attained at the downstream end of the IDZ, or Old Bridge Site, even during low flows during all 2017 and 2018 sampling events. Total organic

	carbon exceedances occurred throughout the study area outside the IDZ, but not within it, and its concentrations followed a declining trend in the LCR. The total increase in nitrogen was ~ 5% between Birchbank and Waneta and that included other inputs as well as smelter effluent.
Summary	To date, no metal or nutrient exceedances attributable to the smelter were detected below the IDZ. Nutrient concentrations in the LCR below the IDZ were not significantly altered by the effluent discharges.
Management Question 2. Does water quality in the study area vary spatially (various locations in the Columbia River including point source, reference sites (both horizontal and vertical), and temporally (between seasons and years) as a result of Teck's point source effluent discharges and if so, describe the variances?	
2012	Yes, the plume stays on the right bank (~1/3 channel width) to the end of the IDZ. Transect water sampling showed that water quality varies in the river cross-section in both horizontal and vertical stations within the IDZ, but not at Waneta. Upstream to downstream trends were detected for many metals including As, Cd, Cr, Cu, Pb, Ni, Se, Tl, and Zn. Within the IDZ, metal sources likely include effluent and groundwater discharges, and Stoney and Trail creeks. Other potential sources of metals of interest to the LCR downstream of the smelter include stormwater, historical mining and milling, municipal effluent and naturally high metals in tributaries. An effluent plume delineation model was developed for the three permitted outfalls and Stoney Creek in 2012 (Golder 2012) and subsequently evaluated by water quality sampling and spatial analysis (Hawes and Larratt 2014). At New Bridge, the measured dilution was less than predicted by the model, ranging from about 2% (As/Se) to over 20% (Cd). This apparent reduced dilution is likely influenced by impacted groundwater (Hawes and Larratt 2014) that upwells to the river adjacent to the smelter (Golder 2010). At the downstream limit of the IDZ, the effluent plume measured about 60 m wide, as opposed to the predicted 35 m wide, and the percent dilution was greater than the model predicted -1% dilution with a mixing ratio of about 200:1 (0.5% dilution) (Hawes and Larratt 2014).
2015	The AREMP transect water quality sampling showed spatial variation in water quality within the IDZ. The effluent plume stays on the right bank (~1/3 channel width or approximately 60 m) through to the downstream end of the initial dilution zone. Transect sampling at Waneta indicated the plume was completely diffused/mixed across the channel as demonstrated by homogeneity of most metal concentrations across the channel. Water sampling at Maglios (at the Bear Creek confluence, near Rock Island), indicated that the plume was nearly diffused across the channel about 4.2 km downstream of the IDZ. Between this station and the smelter outfalls, the plume follows the right bank, and all metals of interest were within the LCR and BC guidelines by the downstream end of the IDZ. Complete mixing of the plume occurred between Maglios and Waneta.
2018	Water quality sampled during seasonal low flows varied in the river cross-section at both horizontal and vertical stations within the IDZ due to the effluent plume (stayed on right bank, ~1/3 channel width or approximately 60 m) and the influence of impacted groundwater not captured by the remediation system. Effective mixing of the effluent plume was attained about 4.2 km downstream of the IDZ. Water quality trend analysis showed statistically significant trends for only TOC, T-Zn and D-Cd and only at Old Bridge and Stoney Creek. The apparent lack of water quality trends reflects the importance of flows (available dilution) at the time of sampling. Variable LCR flows made detecting improvements in smelter water treatment difficult.
Summary	Water quality in the study area varied spatially and temporally but variation was not caused solely by Teck's point source effluent discharges. Spatial variation was also influenced by impacted groundwater and other discharges not related to the smelter, and temporal variation was largely determined by flows at the time of sampling.

Management Question 3. Are water quality parameters that are analyzed for the AREMP stations appropriate?	
2012	Yes. The overall AREMP water quality study design meets the goals of assessing potential smelter impacts. It focusses on lower flow periods where mixing and dilution are reduced, and water quality impacts are expected to be greatest.
2015	Yes. The AREMP water quality monitoring study conducted in 2015-2016 met all requirements. The existing parameters and their reportable detection limits are appropriate for this study.
2018	Yes. The existing program met all requirements at the time it was conducted. Note, however, that ENV introduced a new biotic ligand copper guideline in fall 2019 that requires the addition of DOC analyses which was added to the analytical schedule as of 2020.
Summary	The AEMP water quality monitoring study conducted in 2012-2018 met all requirements of assessing potential smelter-related impacts. It focusses on lower flow periods where mixing and dilution are reduced, and water quality impacts are expected to be greatest. Existing parameters and their reportable detection limits are appropriate for this study. DOC analyses will be conducted for calculation of the biotic ligand model for copper, introduced by BC ENV in fall 2019.

DEPOSITIONAL HABITAT

The AEMP depositional habitat component is designed to assess potential effects of Teck Trail Operations permitted effluent discharges on depositional communities by comparing benthic invertebrate structure and composition between areas upstream (reference) and downstream (exposure) of the smelter. Hydrodynamics of the Columbia River in the AOI create conditions where long-term depositional zones are rare (Golder 2003). Depositional habitat was estimated at 0.1% of the total sediment habitat within the AOI (Golder 2007a). Therefore, the relative importance of these diverse depositional areas is restricted by their small contribution to the overall LCR habitat.

Sediment and benthic invertebrates were collected at 10 depositional sites originally identified through a sediment quality triad assessment performed as part of the aquatic ecological risk assessment (Golder 2007):

- Three reference areas at Kootenay Eddy (DEP-REF- 1), Genelle Eddy (DEP-REF-2), and Birchbank Eddy (DEP-REF-3).
- Seven exposure sample sites were established at Korpak (DEP-EXP-1), Maglios (DEP-EXP-2), Casino (DEP-EXP-3), Airport Bar (DEP-EXP-4), Trimac (DEP-EXP-5), Fort Shephard Eddy (DEP-EXP-6), and Waneta (DEP-EXP-7).

Depositional areas of the LCR will reflect the influences of historical sources as well as current smelter discharges and other non-smelter inputs. Tributary creek sediments from Blueberry, Murphy, Hanna and Topping creeks have concentrations comparable to depositional sites downstream of the smelter for lead, copper, arsenic and cadmium (Reyes, 2004). Thus, elevated metal concentrations in sediments downstream of the smelter cannot be attributed to past or present smelter activity alone. Depositional sites are dynamic, and each site has its own character in contrast to the comparatively uniform erosional habitats. The character of individual sites can change over time, and this must be considered when interpreting sediment and benthic community results collected in this study.

The 2012, 2015, and 2018 AEMP data show that metal concentrations in depositional sediments downstream of the smelter (exposure sites) were higher than reference sites. This is consistent with the results of earlier studies (Golder 2007, Hatfield 2008). Distance from the smelter was a factor in sediment metal distribution but had a non-linear relationship. None of the sediment metals of interest consistently decreased with distance from smelter in 2018. The non-linear pattern of sediment exceedances as distance from the smelter increases suggests there are site-specific effects which may include influences of river flow dynamics along with other sources of metals such as naturally occurring metal concentrations, historical mining and milling, municipal effluent and/or stormwater. Estimates of percent slag in this study were lower in recent years than in earlier studies (Golder 2003; 2007).

Sediment metals that exceeded guideline PEL concentrations in 2018 were limited to Zn, Pb, Hg, and Cu in the <2mm fraction. Sediment metals concentrations in 2018 were higher than in 2015 at several sites, but were similar to 2012 levels. This is interpreted to reflect inter-annual variability due to the transient nature of the smaller depositional sites.

Sediment metal concentrations in exposure areas have varied throughout the years due to the dynamic and mobile nature of LCR sediments. Varying flow regimes and water levels, continual sediment influx from upstream sources, and scouring to downstream mainstem sites causes variable results from year to year. Fines that accumulated during low flows are frequently scoured and re-sorted during high flows (Parametrix et al. 2010). In 2018, the historical Maglios, Airport Bar and Birchbank sites had been scoured by high flows and were no longer depositional habitat. As a result, new depositional sample sites were located in the vicinity of the original sites and the 2018 data from these sites is not directly comparable to the historical data at these sites.

Sediment metal concentrations remained relatively steady in the 2012 to 2018 data, both in terms of concentration and number of guideline exceedances (Table 4-12). In 2018, metals concentrations were higher than 2015 at several sites but were similar to 2012 levels. Some decline in concentrations is evident when the 2012-2018 data is compared to 2003. In 2018, sediment metals concentrations in a smaller grain size fraction (<63um) were also analyzed. The <63 µm samples had higher concentrations of metals than the <2mm fraction, interpreted to result from metals adsorption on organics which are proportionately higher in the <63um fraction. Metals in both sediment fractions followed similar distribution patterns at the sample sites.

In addition to physical and chemical characteristics of the sediment, a critical part of the depositional habitat component is assessment of benthic community structure to evaluate whether elevated metals in sediment result in impairment of the benthic communities and their role as nutrition for higher trophic level consumers. Abundance, species diversity, and species composition are measured and differences between exposure and references sites are assessed graphically and statistically. Physical elements of the habitat formed an important component of this assessment. While variations in habitat between deposition sites are evident, the differences did not indicate detectable impacts from sediment metal concentrations or from current effluent discharges on depositional periphyton or benthic invertebrate community structure.

Management Question 1. What is sediment quality in the depositional areas upstream and downstream of the smelter?	
2012	Sediment metals in downstream depositional areas that exceeded two standard deviations of results from reference sites were Cu, Pb and Zn. In 2012 data, the list of metals exceeding PEL concentrations downstream of the smelter was As, Cu, Pb, and Zn.
2015	Most metals of interest in depositional exposure sites exceeded two standard deviations of results from reference sites in all years of study. Every depositional sediment metal concentration metric available show decreasing concentrations of all metals of interest from 2003 to 2012, and from 2012 to 2015. In every exposure site, the number of sediment metal exceedances and the magnitude of those exceedances decreased from 2003 to 2015. In 2015 data, the list of metals exceeding PEL concentrations or sensitive species concentrations was smaller than in earlier years and only included Cu, Pb, and Zn.
2018	Sediment metals in the small, dynamic depositional sites downstream of the smelter were elevated above the upstream control sites, with the highest concentrations at adjacent sites and the lowest at downstream Waneta. Sediment metal concentrations remained relatively steady in the 2012 to 2018 data, both in terms of concentration and number of guideline exceedances. In 2018, metals concentrations were higher than 2015 at several sites but were similar to 2012 levels. Some decline in concentrations is evident when the 2012-2018 data is compared to 2003.
Summary	Sediment metal concentrations in depositional exposure areas vary spatially and temporally due to the dynamic and mobile nature of LCR sediments; however, the overall pattern appears to be one of relative stability and not indicative of significant changes in inputs of metals from 2012 to 2018, with most metal concentrations lower than in 2003. (Table 4-12) presents the concentrations of metals of interest in sediment sampled since 2003.

<u>Management Question 2.</u> Are benthic invertebrate communities in depositional sediments downstream of the smelter different from upstream communities in terms of abundance, species diversity and species composition?

2012	A community analysis (NMDS) detected no change in invertebrate community structure between samples collected from depositional sites upstream and downstream of the smelter. However, increasing distance downstream from the smelter and sediment zinc and copper concentrations were negatively correlated with invertebrate abundance, species richness, and percent Chironomidae in depositional habitats.
2015	A small difference in overall species composition was detected between reference and exposure areas in 2015, as there was in 2012. However, community structure differed significantly between years (2012 and 2015). Reference areas had higher abundance and biomass than exposure areas. Maglios (DEP-EXP-2) had the highest sampled species richness as well as the highest mean species richness across the five samples.
2018	No detectable impact of sediment metal concentrations or current effluent discharges was detected on depositional periphyton community structure or standing crop. Invertebrate communities continue to illustrate natural annual variability across all sites. Annual variation (year) in the 2012, 2015 and 2018 invertebrate samples explained 18% of the invertebrate community variation. However invertebrate community variation between reference and exposure areas were not significantly different in any sampled year to date.
Summary	Depositional habitats account for only about 0.1% of the LCR Area of Interest. While variations between deposition sites are evident, the differences did not indicate detectable impacts from sediment metal concentrations or from current effluent discharges on depositional periphyton or benthic invertebrate community structure.

<u>Management Question 3.</u> If differences in benthic communities exist, do these differences suggest adverse effects (i.e., impairment of benthic communities such that they provide poor habitat to upper trophic consumers) and is this linked to current permitted effluent discharges?

2012	No change was detected in benthic communities in reference and exposure areas. The depositional habitats at Maglios and Waneta were more similar in community structure to other sites assessed (upstream and downstream of the smelter) than documented in previous studies. This result may be due to annual variation in benthic community production or to variability in habitat quality as it relates to substrate size and stability and other natural physical variables. Since no significant difference in communities was observed in erosional habitats (including those in the IDZ) it is unlikely that the differences in depositional habitat benthic invertebrate community metrics were linked to current permitted effluent discharge.
2015	Community structure differed significantly between sites and years (2012 and 2015), highlighting natural seasonal and annual variability that can occur in benthic communities. Total invertebrate abundance at reference and exposure sites was not significantly different in depositional habitats. Similarly, percent EPT, percent Chironomidae and effective number of species were not significantly different between reference and exposure sites. The four benthic invertebrate metrics did not differ significantly by year sampled. The differences in depositional habitat benthic invertebrate community metrics are unlikely to be linked to current permitted effluent discharge.
2018	Community structure differed significantly between sites and years (2012, 2015, and 2018), which continues to highlight the natural seasonal and annual variability that can occur in benthic communities. No significant difference in the total abundance, %chironomid composition, was detected when reference and exposure 2018 data were grouped and compared by year. Community diversity

	expressed by effective species differed significantly between year, however, no significant difference between reference and exposure areas was detected. In 2018, total abundance was highest at the Genelle reference area, while biomass was highest in the Airport exposure area. Species richness was greatest at the Korpak exposure area, while effective species number (diversity) and Chironomid relative abundance was greatest in Casino Eddy samples.
Summary	Depositional habitats account for only about 0.1% of the LCR Area of Interest. While variations between deposition sites are evident, invertebrate community variation, assessed using NMDS, was not significantly different between reference and exposure areas. Thus, impaired conditions or adverse smelter-related effects were not detected.

EROSIONAL HABITAT

The primary objectives of the erosional habitat sampling components are to assess effects of effluent discharges on benthic invertebrate and periphyton communities in these habitats. Two study areas were in upstream reference areas identified as Reference Area 1 (ERO-REF-1) (left bank opposite Stoney Creek and CIV outfall) and Reference Area 2 (ERO-REF-2) (Birchbank). Five downstream exposure areas were sampled at sites identified as downstream Exposure Area 1 through Exposure Area 5 (ERO-EXP-1 to ERO-EXP-5).

- ERO-EXP-1 occurs exclusively along the right bank of the river extending about 1,300 m downstream from Stoney Creek and the CIV effluent outfall.
- ERO-EXP-2 occurs in the right bank side channel downstream of the CIII effluent outfall, entirely within the CIII plume. The total length of this area is only about 315 m.
- ERO-EXP-3 was identified in the original study design as a single area that spans the width of the river beginning just below the right bank side channel, next to the smelter, and extending downstream about 3,000 m. As the understanding of both the effluent plume and groundwater plume has improved over the years, sampling within ERO-EXP-3 was further stratified into left and right bank subsamples such that future analysis can begin to evaluate the left and right bank communities separately. The left bank is sampled at ERO-EXP-3 to assess the potential for groundwater plume effects in this area. Flowing downstream through ERO-EXP-3, the effluent plume diffuses outward from the CII outfall and the right bank and is diluted to about 0.5% of the initial CII outfall concentrations (Hawes and Larratt 2014) by Old Bridge (Schedule A).
- ERO-EXP-4 encompasses both the left and right bank of the river downstream beyond the effluent plume where diffusal and mixing is becoming more complete. The total length of this area is about 2,500 m.
- ERO-EXP-5 encompasses both the left and right bank of the river beginning downstream of the Rock Islands and Bear Creek confluence where full mixing of the plume has occurred. ERO-EXP-5 extends to the Pend d'Oreille river Confluence and is about 12,000 m in length.

Relative effects of metals concentrations and habitat on periphyton and benthic communities in the LCR were assessed using various response variables.

Management Question 1. What is the difference in periphyton communities in erosional habitat downstream of the smelter compared to the upstream communities in terms of periphyton community structure, composition, and standing crop biomass?

2012	All metrics and statistical analyses did not detect any differences between periphyton communities in erosional habitats upstream and downstream of the smelter. Diatoms are the most prevalent type of algae in erosional river biofilms. The dominant species lists did not indicate measurable change between the reference and downstream erosional areas. Within the IDZ, where warmer water and comparatively nutrient-rich groundwater can infiltrate the river, a shift to increased concentrations of cyanobacteria and filamentous green algae was detected. This shift did not appear to be in response to metal concentrations.

2015	Periphyton data demonstrated natural variance in abundance within and between sites, including reference and exposure sites. All metrics and statistical analyses conducted on the 2015 data did not detect any smelter-related impact on erosional periphyton community structure. Diatoms are the most prevalent type of algae in erosional river biofilms and have accounted for an increasing percentage of periphyton production within the IDZ which is now similar to typical LCR results. The dominant species lists did not indicate measurable change between the erosional reference and exposure sites. Within the IDZ where warm effluent and warm, comparatively nutrient-rich groundwater can infiltrate the river, a shift to increased concentrations of cyanobacteria and filamentous green algae were detected in the past but was subtle in 2015 and did not appear to be in response to metal concentrations. Major driving forces on LCR periphyton communities include flows and localized water velocity, irradiance, nutrient concentrations, algae settling from upstream reservoirs and grazing pressure. Near-field taxonomic results from 2015 confirm the erosional productivity metrics, suggesting that the influence of the smelter on the AOI is diminishing as reclamation treatment proceeds.
2018	There was little indication of a spatial trend in the distribution of algae classes with distance upstream or downstream of the smelter in the 2018 data. Although productivity metrics, including abundance, biovolume and chl-a, varied significantly between periphyton erosional sites, no adverse impacts on erosional periphyton community structure attributable to the smelter was detected. The side-channel receiving CIII effluent developed a distinctive cyanobacteria periphyton in all years including 2018. The enhanced near-field productivity does not approach nuisance proportions but can be a benefit to benthic invertebrates. The cyanobacteria detected are not harmful from a habitat perspective, only different. The causation of different periphyton community structure in the side-channel is difficult to determine, but appears to be more linked to physical habitat attributes (e.g., higher water temperature and velocity) than effluent constituents.
Summary	Periphyton community metrics did not differ significantly between reference and exposure sites in 2012, 2015 or 2018. Over the course of 2003-2018 periphyton studies, productivity metrics within the IDZ and near-field have been trending lower toward more typical LCR levels. LCR periphyton dynamics were dominated by flow-related factors (Larratt et al. 2013).
<u>Management Question 2.</u> What is the difference in the benthic invertebrate communities in erosional habitat downstream of the smelter compared to the upstream communities in terms of community structure and composition? If differences in benthic communities exist, do these differences suggest adverse effects (i.e., impairment of benthic communities such that they provide poor habitat to upper trophic consumers) and is this linked to current permitted effluent discharges?	
2012	Overall species richness and diversity did not differ between reference and downstream areas. The mean EPT richness and mean %EPT were both higher in downstream areas and mean Hilsenhoff Biotic Index score was less than reference sites - indicating a greater predominance of pollution sensitive species downstream of the smelter. Erosional habitats in exposure areas had higher mean invertebrate abundance compared to reference samples. Invertebrate abundance was greatest in near-field exposure area samples located just downstream of smelter Outfall CIII. No shifts in community composition between reference and exposure areas were documented. Based on comparison with reference sites, benthic invertebrate community health was similar in erosional habitats downstream of the smelter. Water velocity was the most important covariate influencing invertebrate abundance, EPT richness, percent EPT, and diversity in LCR erosional habitats.
2015	Statistical tests of benthic macroinvertebrate community structure between erosional reference and exposure habitats did not detect statistical differences.

	EPT taxa were the predominant organisms across all Reference and Exposure areas. Exposure Area 2, situated just downstream of the CIII outfall, had the highest mean abundance, biomass, EPT richness, and % EPT. ERO-EXP-2 site 3 had the lowest measured HBI score. Hilsenhoff Biotic Index scores and EPT richness were both significantly different between reference and exposure areas. Exposure areas had higher EPT richness and lower HBI scores corroborating one another indicating a greater abundance of metal and pollution sensitive species in sites downstream of the smelter. Water velocity and substrate size were the most important variables influencing communities in erosional habitats. Velocity was an important variable for explaining benthic macroinvertebrate abundance, %EPT, and HBI scores. Sites with higher water velocity had higher abundance and %EPT while having lower HBI scores. Exposure Area 2, within the side channel downstream of the CIII outfall, had the highest mean velocity of all areas followed by Exposure Area 5 and Exposure Area 3.
2018	In 2018, no significant difference in benthic invertebrate total abundance was detected between the reference areas and any of the exposure areas. However, total abundance was highest in ERO-EXP-2, the side channel into which the Combined III outfall discharges. Similarly, 2018 data showed no significant difference in total invertebrate biomass, species richness, or effective species numbers between any other pairings of reference and exposure areas. Hilsenhoff Biotic Index values were lower in the exposure areas of the initial dilution zone than the two upstream reference areas and exposure areas further downstream. This corroborates the results of both the 2012 and 2015 data collection and interpretation.
Summary	No significant difference in the structure of benthic macroinvertebrate communities was detected between reference and exposure erosional habitats. Additionally, no significant differences in other community metrics including total abundance, biomass, species richness, and diversity were detected between any other reference and exposure areas. In comparison with reference sites, benthic invertebrate community health was similar in erosional habitats downstream of the smelter. Mixed effects models demonstrated that water velocity was the most important variable influencing benthic macroinvertebrate community diversity in erosional habitats. Erosional sites with higher velocities had greater benthic invertebrate abundance and were dominated by EPT taxa.
Management Question 3. On the basis of qualitative review, is there a trend in periphyton and benthic metrics over time?	
2012	Insufficient data was available to qualitatively assess whether changes in benthic invertebrate community metrics were occurring. Other studies on the Columbia River upstream of the smelter documented high annual and seasonal variation in invertebrate community metrics (Larratt et al 2013). Additional sampling in subsequent years (as outlined in the AREMP study plan (Golder 2012a) may help to support a qualitative observation of trends.
2015	Community structure differed significantly between years (2012 and 2015 AREMP data) for both erosional and depositional habitats. However, the Columbia River is known to have high natural annual and seasonal variation in invertebrate community metrics (Larratt et al 2013). Based on this, insufficient data were available to assess trends in benthic invertebrate metrics over time.
2018	Adding 2018 data corroborates previous AEMP cycle results and further strengthens the review that the smelter is not having an adverse effect on periphyton and benthic community composition. Although some differences within sites were observed, they were driven mostly by physical variables, namely current velocity, and associated substrate size. Sites with higher velocities had greater benthic macroinvertebrate abundance and were dominated by EPT taxa and thus had lower HBI scores.

Summary	The three years of data suggest that the smelter did not have an adverse effect on periphyton and benthic community composition. Although some differences within sites were observed, these differences were driven mostly by physical variable such as current velocity and associated substrate size. Additional data collection cycles will strengthen analysis of trends.

SMALL-BODIED FISH (not collected in 2018 reporting cycle)

The small-bodied fish program was developed by Ecoscape (2013) after the original AEMP study design. Data collection occurred in the spring following the other community sampling components and was carried out in 2013 and 2016. Small and large-bodied fish sampling program frequency was extended to a 6-year cycle from a 3-year cycle to reduce population burdens associated with lethal sampling and therefore were not sampled in 2018. The adjustment of these programs was discussed between Teck representatives and the Ministry of Environment during the review of the 2015/2016 interpretation report. Small-bodied fish will be evaluated as part of the 2021 data collection cycle.

Management Question 1. Is there a difference in tissue metals composition and concentration in small-bodied fish between reference areas and exposure areas downstream of the smelter?

2013	Differences in concentrations between sculpin collected in reference and exposure areas were relatively low, yet statistically significant in all cases. Fish sampled from exposure areas downstream of the smelter generally had higher lead concentrations than the other metals.
2016	Sculpin tissue Pb, Tl, As and Cd concentrations at near-field sites were significantly different than at reference sites, while the remaining metals of interest were not different.

Management Question 2. Do tissue metal concentrations decrease in small-bodied fish as the distance from the smelter effluent discharge increases?

2013	Sculpins sampled in the IDZ downstream of the Combined III outfall had higher tissue metals concentrations than those captured upstream of this location. Tissue metals concentrations decreased in sculpins sampled further downstream from the smelter beyond the IDZ.
2016	Sculpins sampled in the IDZ downstream of the Combined III outfall had higher tissue metals concentrations than those captured upstream of this location. Tissue metals concentrations decreased in sculpins sampled further downstream from the smelter beyond the IDZ. This gradient in response at exposure sites may correlate with progressive dilution moving downstream away from the smelter. In 2016 sculpin samples, tissue concentrations for most metals of interest were below the wildlife TRO guidelines in both the reference and the exposure sites. There was one exceedance of both the arsenic wildlife TRO (0.47 mg/kg ww) and cadmium wildlife TRO (0.9 mg/kg ww) from ERO-EXP-3-1. Whole body lead concentrations exceeded the TRO (0.16 µg/g wet weight) for wildlife in 258 sculpins. All sculpins collected from within and downstream the IDZ had lead concentrations that exceeded the TRO for wildlife and 37 sculpins from Reference sites had lead concentrations that exceeded the TRO. Concentrations drop markedly with increasing distance downstream from New Bridge. Sculpins collected from the right bank adjacent downtown Trail (ERO-EXP-3-2-R) had average lead concentrations that were 3.5 times lower than fish collected just 300 m further upstream from ERO-EXP-3-1-R.

Management Question 3. Is there a difference in the length, weight, liver weight, gonad weight and condition of fish collected upstream of the smelter and downstream of the smelter?

2013	There was no significant difference in various condition responses between upstream and downstream areas.
2016	There was no significant difference in condition responses between reference and exposure areas.

Management Question 4. What is the relationship between the distance from the effluent discharge and tissue metals, condition factor, liver weight (liversomatic index) and gonad weight (gonadosomatic index)?

2013	There was no statistically significant relationship between distance from the smelter effluent discharges and the evaluated condition metrics.
2016	The hepatosomatic and gonadosomatic indices showed no significant difference with distance from the smelter.

LARGE BODIED FISH TISSUE (not collected in 2018 reporting cycle)

The primary objectives of this component are to assess potential effects of effluent discharges, particularly metals concentrations, on large-bodied fish tissues (measured in fillets, whole fish samples, and gut contents). Species used for this component of the AEMP included Mountain Whitefish, Rainbow Trout, and Walleye.

Data collection occurred in the fall of 2012 and 2015. Fish were not collected in 2018 since the small and large-bodied fish sampling program frequency was extended to a 6-year cycle from a 3-year cycle to reduce population burdens. This frequency was also to be adapted into other monitoring programs on the LCR including Celgar, from which data sharing and other synergies could be realized. The adjustment of these programs was discussed between Teck representatives and the Ministry of Environment during the review of the 2015/2016 interpretation report. Large-bodied fish will be evaluated as part of the 2021 data collection cycle.

Management Question 1. How do concentrations of total metals in the tissues of large-bodied fish species in the lower Columbia in 2012 compare to concentrations since 2000?

2012	Since 2000, declining trends were evident for arsenic, cadmium, and lead concentrations in fillets of mountain whitefish, Rainbow Trout, and Walleye. No trend was detected for chromium and mercury with the current data. Fish tissue data from previous years was insufficient to assess potential trends of other metals of interest.
2015	Declining trends were measured for arsenic, cadmium, and lead. Increased detection capabilities for cadmium since 2004 demonstrate the declining trend in 2005 for Walleye, and in 2012 and 2016 for all three species. However, no trend was apparent for chromium and mercury.

Management Question 2. Do fish tissue concentrations exceed relevant human consumption guidelines?

2012	Concentrations of metals in fish fillets were within the published Canadian guidelines for chemical contaminants and toxins in fish for consumption.
2015	Concentrations of arsenic, chromium, cadmium, lead and selenium in fish fillets were below human consumption guidelines (Canadian Food Inspection Agency 2011). Most muscle and whole fish samples were below the wildlife TRO guidelines. Whole fish concentrations of mercury in Walleye from both reference and exposure areas exceeded the TRO. None of the muscle tissue or whole fish had arsenic, cadmium, or chromium concentrations above the TRO wildlife guideline. Only one Rainbow Trout caught in 2016 had a whole-body concentration of lead above the TRO. The mercury TRO was exceeded in Walleye whole fish concentrations from both reference and exposure areas, and in one Mountain Whitefish from a reference area. The TRO guidance specifically states that the values should be compared to a composite sample or average of 6-10 fish, not single samples.

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APPENDICES

1.0 INTRODUCTION

Ecoscape Environmental Consultants Ltd. (Ecoscape) was retained by Teck Metals Limited, Trail Operations (Teck) to carry out an aquatic effects monitoring program (AEMP) on the Lower Columbia River (LCR) as per 3.2 of Effluent Permit PE02753. This report follows the third data collection cycle (2018). The program title was previously an Aquatic Receiving Environment Monitoring Program (AREMP). Following review of the 2015 interpretation report, the BC Ministry of Environmental (ENV) requested that the program be renamed to an Aquatic Effects Monitoring Program (AEMP). The purpose of this work is to conduct effluent receiving environment monitoring in the LCR. A secondary purpose is to provide information to facilitate management decisions for smelter operations.

Teck Trail Smelter is located adjacent to the right bank looking downstream of the lower Columbia River in Trail, BC, about 11 km due north of the International Border with the United States. The streamline distance from the smelter down to the border is about 18 km (Schedule A).

The primary study area is the lower Columbia River from Stoney Creek to Old Bridge, as this area receives the permitted effluent from the smelter at three locations along the right bank. Downstream of the smelter, sampling extends from Old Bridge to Waneta just upstream of the confluence with the Pend Oreille River just north of the border. Reference study areas include the lower Columbia River, beginning from the Hugh L Keenleyside Dam and the Brilliant Dam on the Kootenay River, extending downstream to Stoney Creek (Schedule A).

There are several sources of metals in the study area, including:

- Smelter emissions, for which an Aquatic Ecological Risk Assessment study has been conducted (Golder 2007);
- Groundwater discharge, for which a hydraulic interception and treatment system was commissioned in 2017 and is currently operating;
- Stoney Creek, which is currently under assessment and remediation;
- Sediment in the Columbia River foreshore area adjacent to downtown Trail, which is currently under investigation;
- Trail Creek, which is currently under investigation in the Annable area of Warfield;
- Non-smelter influences including old mine workings and mills, storm sewer discharge, pulp mill effluent and municipal sewage effluent; and
- Naturally occurring metals.

Sources other than permitted smelter discharges described further below, have a potential influence on the health of the aquatic receiving environment, but the evaluation of such influences is outside the scope of this AEMP. Due to the integrating nature of the LCR, any impacts from these sources could not be assessed separately from the effluent discharge anyway; it is therefore acknowledged that the AEMP will measure parameters as a result of all influences on the river, not just the Trail Smelter effluent discharge.

The structure of this report is based on the Proposed Study Design for Teck Trail Smelter AREMP (Golder 2012a) and on Recommendations to AREMP, 2015-2017 (Hawes et al. 2015). The requirement to carry out an AEMP was delegated to Teck by BC ENV in 2011. AEMP studies involve monitoring of water quality, sediment quality, periphyton communities, benthic invertebrate communities, small-bodied fish, and large-bodied fish. The following report describes project objectives and methods, and outlines management questions.

1.1 Background Information

The LCR aquatic environment in Canada has been extensively studied, with data collected over the years by various organizations. Teck has commissioned numerous studies and reports on a wide range of potential effects of past and current smelter operations. These efforts provide historical data and context for this study.

Teck conducted a large-scale Ecological Risk Assessment (ERA) of the Trail Smelter operations from 2000 to 2007 (Golder 2007; Golder 2012a). The aquatic ERA Area of Interest (AOI) encompassed the lower Columbia River and its tributaries from downstream of the Hugh L Keenleyside Dam, and the Brilliant Dam on the Kootenay River to the International Border.

Tributaries

Cadmium, silver, and zinc concentrations exceeded criteria at both reference and exposure sites within tributaries to the lower Columbia River. The ERA (Golder 2007) hypothesized that some elevated metals concentrations in tributaries may be explained by other anthropogenic sources, such as forestry, highway run-off, erosion from power and gas rights of way, old mining works and run-off from agricultural and urban areas (the later especially true for reference tributaries (Golder 2006)).

Sediment metals in tributaries were elevated from upstream reference sites downstream to Murphy Creek, with variable metals concentrations between the smelter and Beaver Creek, and high metals concentrations farther downstream at Sheppard Creek (Golder 2006).

Algal biovolume in tributaries was low at most sites, and the degree of variability between reference and exposure sites was within the standard error (Golder 2006). Golder (2012) concluded there was low risk to tributary systems from smelter discharges

Differences in benthic invertebrate community composition were reported for the tributaries studied in the area of influence (AOI) (Golder 2012). These differences reflected environmental variation relating to water quality and habitat (Golder 2006), with the variability in natural habitat features being the primary determinants of periphyton and benthic community composition (Golder 2012).

Lower Columbia River

The Aquatic ERA (Golder 2007) AOI included 56 km of the lower Columbia River from the Hugh L Keenleyside Dam, and the Brilliant Dam on the Kootenay River downstream to Waneta at the International Border. Assessment endpoints were defined for periphyton community composition, benthic invertebrate community composition, fish population and condition metrics as well as habitat quality.

The sequential assessment of lines of evidence (SALE) of the ERA indicated that the risk management objectives were being met for Mountain Whitefish and Prickly Sculpin. Therefore, an evaluation of risk management options was not required for these large and small-bodied fish (Golder 2012). The SALE analysis indicated that risk management objectives were not being met for periphyton in near-field areas at New Bridge within about 250 m downstream of the smelter's combined II outfall along the right bank. In addition, the SALE indicated that risk management objectives were not being met for depositional habitat benthic invertebrates at Maglios and Waneta sites. However, given that the area of depositional habitat in the AOI is only about 0.1%, the spatial extent of impacted sediment quality was small relative to the context of the entire AOI (Golder 2007).

Effluent Plume Overview

A plume delineation model was developed for Trail smelter effluent in 2012 (Golder 2012) and subsequently evaluated by water quality sampling and spatial analysis (Hawes and Larratt 2014). Daily effluent flow and total metals concentrations for each outfall were provided by Teck. Effluent flow (m^3/s) and concentration data (mg/L) were compared with transect water quality data on corresponding days to assess the percent assimilation and spatial attributes of the discharges. Results were compared with the modeled effective dilution.

During spring LCR low flows, the average combined effluent discharge from all three plumes is approximately 0.14% of LCR flows (Hawes and Larratt 2014). A groundwater plume, characterized by elevated nitrogen, sulphate, fluoride, total dissolved solids, arsenic, cadmium, iron, lead, manganese, and zinc (Golder 2012), is present beneath the smelter and discharges to the LCR adjacent to the smelter. This groundwater plume confounds effluent plume modeling because its constituents are also components of the smelter outfalls.

At New Bridge, the measured dilution was less than predicted by the model, ranging from about 2% (As/Se) to over 20% (Cd). This apparent reduced dilution may be explained by the groundwater plume (Hawes and Larratt

2014). At Old Bridge, the downstream limit of the initial dilution zone, the plume measured about 60 m wide, as opposed to the predicted 35 m wide, and the percent dilution exceeded the model-predicted 1% dilution with a mixing ratio of about 200:1 (0.5% dilution) (Hawes and Larratt 2014).

Operational Improvements

Teck has undertaken a series of facility improvements that have had a positive effect within the receiving environment. These include:

- 1981: effluent treatment plant
- 1981: stripped zinc electrolyte was routed to fertilizer plant instead of river discharge
- 1982: mercury removal plant constructed
- 1991: construction of a drainage control system to route wash water and stormwater to the effluent treatment plant
- 1993: Heat exchanger installed in lead smelter
- 1994: Phosphate-based fertilizer production was terminated
- 1995: cessation of slag discharge to the LCR
- 1997-98: installation completed and operation of KIVCET flash lead smelter commenced
- 1997-98: seepage collection system along Stoney Creek
- 2003: a closed industrial landfill adjacent to Stoney Creek was capped with an engineered membrane
- 2005: arsenic-containing wastes adjacent to Stoney Creek were consolidated in a permanent storage facility.
- 2013-2014: removal of metals-impacted sediment from a former iron-ore roaster residue discharge area on the LCR south of Stoney Creek.
- 2015: mitigation of metals-impacted sediment on a 90 m section of Stoney Creek downstream of Highway 22.
- 2016 Mitigation on Haley Creek to control sediment transport to Trail Creek
- 2016-present: construction and commissioning of Phase 1 of a groundwater remediation system to intercept and treat the groundwater plume beneath the smelter arising from historical practices.

The Aquatic Ecological Risk Assessment study (Golder 2007c) concluded that there was no compelling evidence of smelter-related risks or impacts on fish, aquatic plants, or insects in LCR. Subsequent improvements at the smelter have made further improvements in the receiving environment.

1.2 Potential Metal or other PCOC Sources to the LCR Area of Interest

Potential metals of concern identified in earlier studies of the LCR included:

- **Surface water**: arsenic, cadmium, chromium, copper, lead, zinc, mercury, thallium
- **Groundwater:** Total Dissolved Solids (TDS), ammonia, nitrate, nitrite, sulphate, fluoride, chloride, dissolved metals/metalloids (antimony, arsenic, cadmium, cobalt, copper, iron, lead, manganese, magnesium, selenium, sodium, thallium, uranium, and zinc)
- **Sediment:** arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, thallium, zinc
- **Fish tissue:** zinc, copper

There are many influences on water quality in the LCR. The Aquatic ERA identified non-smelter-related stressors in the vicinity of New Bridge (adjacent downtown Trail) and the Maglios sites (at the confluence with Bear Creek and the Regional wastewater treatment facility; Golder 2007) (Table 1-1) summarizes permitted effluent discharges to the Lower Columbia River as of 2019.

Table 1-1: Active Permitted Effluent Discharges to the Lower Columbia River (updated 2019).

Location	Permit #	Discharge Description	Approximate Discharge (m^3/day)
LCR – between HLK dam and Castlegar, BC	PE 1272	Zellstoff-Celgar Ltd Partnership - final industrial kraft pulpmill low rate activated sludge effluent	177,000
	PE 7622	Lion's Head Inn -private 2° treated domestic via small package tmt plant with extended aeration effluent	20
	PE 80	City of Castlegar – 2° treated effluent via aerated stabilization ponds, polishing lagoons, chlorination	2,728
	PE 4008	City of Castlegar - treated domestic effluent via activated sludge tmt plant, UV disinfection, sludge lagoons	1,600
	PE 141	Selkirk College- 2° treated domestic effluent via silver recovery system, rotating biochemical disk tmt plant	536
LCR – Trail, BC	PE 02753	Teck Smelter - industrial effluents, cooling water via various tmts including lime, Hg cleaning area, groundwater recapture	296,000
LCR – downstream of Trail, BC	PE 274	Kootenay Regional District - 2° treated effluent via bar screening, grit removal, sedimentation, sludge digestion, chlorination	13,600
	PE 71	Village of Montrose - 2° treated effluent	640
Beaver Creek	PE 133	Village of Fruitvale - 2° treated effluent	910
	PE 2500	Village of Salmo - 2 ° treated effluent including infiltration	455

Source: BC ENV Nelson, 2006 (After Golder 2007); Opus Dayton Knight 2016, BC ENV Discharge website

Additionally, stormwater runoff is discharged into the LCR at numerous locations. Urban stormwater from Trail, Rossland, and Warfield discharges to the LCR via Trail Creek (Golder, 2007c). An unknown volume of runoff from highways, roads, railways, mine works, mills and transmission lines may also affect the LCR. Furthermore, other industries and agricultural developments can impact the LCR.

The focus of this study is to determine potential metals of concern associated with the smelter that may affect the LCR. Metal sources influenced by the smelter are outlined in the following sections.

1.2.1.1 Outfalls

The Trail smelter has three permitted outfalls (CII, CIII, and CIV). Distribution of effluent is governed by fluid dynamics. A CORMIX model (Golder 2012) predicted that metal concentrations in outfall plumes would be diluted to near background concentrations within the distances outlined in Table 1-2. The model also predicted that outfall plumes may mix with the groundwater plume that upwells between CII and CIII along the western bank of the river (Golder 2010).

A Rhodamine-B dye tracer study during low flows in April 1997 and a study by Hawes et al. (2015) both showed faster attainment of 1% dilution than the CORMIX model predicted, indicating that the CORMIX model results were conservative. At the Old Bridge, the model predicted CII and CIII discharges would be diluted to about 1% (100:1 mixing ratio), and that the plume width would measure about 35 m. Water quality data from 2011-2013 detected metals concentrations over background levels along the right bank as well as in shallow and deep sites collected 60 m offshore from the right bank. Thus, the CII effluent plume at low flows was approximately 60 m wide as opposed to the predicted 35 m width. With increased plume diffusion, field measurements indicated a mixing ratio of about 200:1 (0.5% effective dilution) (Hawes et al. 2015).

Table 1-2: Teck Trail smelter estimated effluent plume dimensions during Columbia River low flow periods (Golder 2012b).

Discharge Name	Discharge Type under normal LCR Flows	Monitoring Parameters	CORMIX predicted plume dimensions at Low Flow 1% dilution
Combined CII	Multi-port diffuser	Cd, Cu, Hg, Pb, Zn, pH	1300 m long x 35 m wide
Combined CIII	Multi-port diffuser	TSS, Zn, As, Pb, Cd, Hg, Cu, Tl, pH	1700 m long x 20 m wide
Combined CIV	Multi-port diffuser	Hg, NH_3, Zn, pH	25 m long x 9 m wide
Stony Creek	Surface Discharge		130 m long x 8 m wide
Groundwater	Sub-surface plume		near CII and CIII discharges (see Schedule A for maps)

1.2.1.2 Stoney Creek

Stoney Creek discharges just upstream of the smelter and contributes metals to the LCR (Teck Cominco 1998). The Stoney Creek watershed is affected by historical waste disposal and storage activities that contribute to metal drainage from seepage and surface runoff. The stream also receives runoff from an urban area and a historical municipal landfill. An assessment undertaken in Lower Stoney Creek as per the Final Remediation Plan (Golder 2012c) identified metals-impacted soil and sediment. A channel rehabilitation project was completed for a 90 m section of the creek bed to restore degraded areas, reduce transport of metals-impacted soils from the slopes and to minimize downstream transport of metals-impacted sediment (SNC Lavalin, 2015). Additional investigation to evaluate residual dissolved metals input to surface water is currently underway.

1.2.1.3 Groundwater

Hydrogeological investigations have been conducted beneath the smelter and surrounding area over a period of more than 15 years and have led to the identification of an area of impacted groundwater beneath the smelter site. The main impacted groundwater plume flows toward the south-southeast with a minor flow component toward the south beneath the fertilizer plant. Shallow portions of the main plume discharges to the LCR adjacent to the smelter; its shallow to intermediate portions upwell across the entire width of the river; and its deeper portions migrate beneath the LCR through the East Trail Aquifer before discharging into riverbed sediments along the left bank from around the Old Bridge to about 1.3 km downstream (Golder, 2012c). This scenario was supported by left bank water samples for As, NH_3, Cu, and Pb collected during the AEMP at New Bridge, (Hawes et al. 2014) and in subsequent data collection in 2015-2016 (Hawes et al. 2019) and again in 2017 and 2018.

Groundwater discharge to the river depends on river stage but is influenced more by the rate of change in stage rather than by absolute river level (Golder 2010). Falling river levels result in groundwater upwelling to the river whereas rising river levels contribute to recharge of the aquifer. Phase 1 of a hydraulic interception and treatment system to address the main groundwater plume as per the 2012 Final Remediation Plan (Golder 2012c) was commissioned in 2017.

1.2.1.4 Sediment - Historical Slag Discharge

Slag is a granulated by-product of the smelting process. It is a particle consisting primarily of silica, calcium, and iron, that contains small amounts of base metals including zinc, lead, copper, and cadmium (Golder 2007b). Although grain size is similar to sand (DeBrito and Saikia 2013), slag has a density of >2.9 g/cm^3 (Cox et al. 2005), while coarse sand is lighter, with an average density of 2.65 g/cm^3. Discharge of slag from the Trail Smelter to the river began in the early 1920s and was discontinued in 1995. The amount of discernable slag in depositional areas is progressively declining, based on field and microscope examination.

1.2.2 Flow Regulation

Flow regulation by BC Hydro from the Hugh L. Keenleyside (HLK) and Brilliant Dams is a key determinant of LCR condition. River flow is an important driver of benthic community development in all running waters. In addition to determining dilution, flow affects a range of co-variate parameters including substrate submergence or stranding, velocity, turbulence, sediment transport, and light penetration, all of which were considered in the previous AREMP reports (Hawes et al., 2014 and Hawes et al., 2019), and further investigated herein.

2.0 PROJECT SCOPE AND MANAGEMENT QUESTIONS

Methods for the AEMP data collection and interpretation adapt the Proposed Study Design for Teck Trail Smelter AREMP (Golder 2012a) with data collection beginning in fall 2012. Changes to the program recommended in 2014 were subsequently implemented. This 2018 AEMP consists of six components plus data management (Table 2-1).

Table 2-1: Components of the Teck Aquatic Effects Monitoring Program.
Water Quality
Depositional Habitat – physical parameters, periphyton, benthic invertebrates
Erosional Habitat – physical parameters, periphyton, benthic invertebrates
Large-bodied (adult sport fish) fish tissue metals
Small-bodied (sculpin) fish condition and tissue metals
Aquatic wildlife health monitoring

2.1 Water Quality

The water quality program is a long-term monitoring program designed to evaluate potential effects of Teck's permitted effluent discharges on the LCR. The Columbia River Integrated Environmental Monitoring Program (CRIEMP) implemented a Lower Columbia River Water Quality Objectives Monitoring Program from 1997-2005 (Hatfield 2008). This program and the Aquatic ERA (Golder 2007) collected significant water quality data, and together with the AEMP, these efforts document the complex history of the smelter and changing water quality objectives or guidelines, and water sample collection and analytical techniques.

Key water quality questions posed in Golder (2012a) and to be answered by the AEMP are:

Q1. Are Provincial Water Quality Objectives attained at the downstream end of the Initial Dilution Zone during low flows (less than 40 kfcs/1133 m^3/sec) as per long-term trend monitoring (e.g., CRIEMP, BC ENV)?

Q2. Does water quality in the study area vary spatially between locations in the LCR including point source and reference sites (both horizontal and vertical), and temporally between seasons and years as a result of Teck's point source effluent discharges and if so, describe the variances?

Q3. Are water quality parameters that are analyzed at the AEMP sites appropriate?

The AEMP study design recommended that water samples be collected near the shoreline as well as within the water column at specified transect locations, and. throughout different seasons within years and events between years. To help assess potential effects of smelter discharges, control sites upstream of any influences of the smelter effluent outfalls (e.g., Birchbank) were also included.

2.2 Depositional Habitats

The objective of the AEMP depositional habitat component is to assess potential effects of Teck Trail Operations' permitted effluent discharges on depositional benthic communities by comparing benthic invertebrate structure and composition between areas upstream (reference) and downstream (exposure) of the smelter. It is acknowledged that depositional areas may be affected by other metal sources in the LCR. Specific study questions for this component include:

Q1. What is the sediment quality in the depositional areas upstream and downstream of the smelter?

Q2. Are the benthic invertebrate communities in depositional sediments downstream of the smelter different from the upstream communities in terms of abundance, species diversity and/or species composition?

Q3. If differences in benthic communities exist, do these differences suggest adverse effects (i.e., impairment of benthic communities such that they provide poor habitat to upper trophic consumers) and is this linked to current permitted effluent discharges?

For purposes of this study, adverse effects were defined as statistically significant differences in abundance, species diversity and species composition to values outside the normal range such that benthic communities may be impaired and provide poor nutrition to upper trophic consumers. The normal range was calculated as the variation among reference upstream sites plus/minus two standard deviations of the mean of multiple reference areas. Values outside of this normal range are, for purposes of this report, considered outside the range of natural variability and therefore indicative of potential effects on benthic communities. This definition of adverse effects aligns with earlier work (Golder 2012a).

Sediment quality for benthic invertebrates is a key component of this work program. Assessments of sediment quality at three reference and seven exposure sites were assessed.

Metals are known to have the potential to influence biological communities in riverine ecosystems (Jones and Bennett 1986; Solomon 2008, Luoma et al. 1997). Benthic invertebrates are often used as indicator species because their community structure and diversity are affected by substrate, water quality, velocity, desiccation/drying on regulated systems like the Columbia, distance downstream of a point discharge, etc.

2.3 Erosional Habitat

The primary objectives of the erosional habitat sampling are to assess effects of effluent discharges on benthic invertebrate and periphyton communities in these habitats. Specific study questions are:

Q1. What is the difference in periphyton communities in erosional habitats downstream of the smelter compared to the upstream communities in terms of periphyton community structure, composition, and standing crop biomass?

Q2. What is the difference in the benthic invertebrate communities in erosional habitats downstream of the smelter compared to the upstream communities in terms of community structure and composition?

Q3. On the basis of qualitative review, is there a trend in periphyton and benthic metrics over time?

This aspect of the work program is similar to the depositional habitat program and focuses on identifying potential impacts of effluent discharges by looking for observed changes in community structure and diversity in periphyton and benthic communities.

2.4 Small-bodied Fish Tissue Monitoring

The small and large-bodied fish sampling program frequency was extended to a 6-year cycle from a 3-year cycle to reduce population burdens associated with lethal sampling for tissue analysis and condition metrics. Fish data was not scheduled for collection in 2016-18. The next collection year will be 2021. The small-bodied fish program was developed by Ecoscape (2013) after the original AEMP study design. The following are the key questions and a brief summary of how the AEMP addresses them:

Q1. Is there a difference in tissue metals concentration in small-bodied fish between reference sites and exposure sites downstream of the smelter?

Q2. Do tissue metal concentrations decrease in small-bodied fish as the distance from the smelter effluent discharge increases?

Q3. Is there a difference in the length, weight, liver weight, gonad weight and condition of fish collected upstream of the smelter and downstream of the smelter?

Q4. What is the relationship between the distance from the effluent discharge and tissue metals, condition factor, liver weight (liversomatic index) and gonad weight (gonadosomatic index).

The study attempts to address differences in metal accumulation in small fish tissue based on species with short home ranges. Sample sites coincided with previous metals analysis work completed for the smelter including benthic analysis, water quality, and large bodied fish tissue analysis.

Age, sex, total length, and weight, and liver and gonad weight are documented for each fish caught.

2.5 Large-bodied Fish Tissue Monitoring

The small and large-bodied fish sampling program frequency was extended to a 6-year cycle from a 3-year cycle to reduce population burdens associated with lethal sampling for tissue analysis and condition metrics. Primary objectives of this component are to assess potential effects of effluent discharges, particularly metals concentrations, on fish tissues (measured in fillets, whole fish samples, and gut contents).

Specific study questions are:

Q1. How do the concentrations of total metals in the tissues of Mountain Whitefish, Rainbow Trout, and Walleye in the lower Columbia in 2012 and 2015 compare to the concentrations since 2000?

Q2. Do fish tissue concentrations exceed relevant human consumption guidelines?

The tissue sampling program is intended to investigate whether accumulations of metals occur in fish as a result of smelter effluent discharges. Fish aging and condition assessments are a key component of this work program and were completed as part of the Lower Columbia River Fish Indexing Program (Ford and Thorley, 2011).

3.0 METHODS

The study design (Golder 2012a) identified seven areas within the AEMP Study Area: Reference Area 1, Reference Area 2, and Exposure Areas 1 through 5. Sample sites were identified within these larger areas. The location of all study areas and sample sites in the LCR area of interest for water quality, sediment quality, periphyton and benthic invertebrate sampling, small-bodied fish, etc., are illustrated on Map Sheets (Schedule A).

3.1 Water Quality

Study areas and sample sites in the LCR area of interest for water quality are illustrated in Figure 3-1.

The study area for the water quality sampling component of the AEMP includes the mainstem Lower Columbia River from Birchbank to the Waneta monitoring station just upstream of the Pend Oreille River confluence. Monitoring sites are shown in Figure 3-1 and are consistent with previous monitoring programs (Hawes et al. 2014). The water quality program was developed to evaluate the effects of the permitted effluent discharges by the smelter on the LCR. For this reason, sampling efforts are concentrated in the spring low flow period to gather data when dilution of effluents is minimized. This effort allows a worst-case analysis.

Permitted effluent discharges from Teck Trail Operations are continuous and the site operates every day for 24 hours a day. All sampling activities occur when effluent is being discharged.

Water quality monitoring sites include:

Birchbank – upstream Reference Site (9.7 km upstream of smelter).

Stoney Creek – 100 m downstream of Stoney Creek confluence and CIV outfall (within the IDZ near upstream end).

New Trail Bridge – Beneath or as close to the Bailey Street bridge as safely practicable, within the IDZ (0.25 km downstream of the CII effluent outfall).

Old Trail Bridge – 1.1 km downstream of CII outfall, marks the end of the IDZ (Note that the monitoring site is 20 m upstream of the Old Bridge and therefore still within the IDZ).

Maglios – 4.2 km downstream of the IDZ. This site was added in the 2014 sampling program to demonstrate near to full mixing of the effluent plume by this location as opposed to Waneta, which is 10 km further downstream.

Waneta – 15.8 km downstream of smelter, above Pend Oreille River confluence.

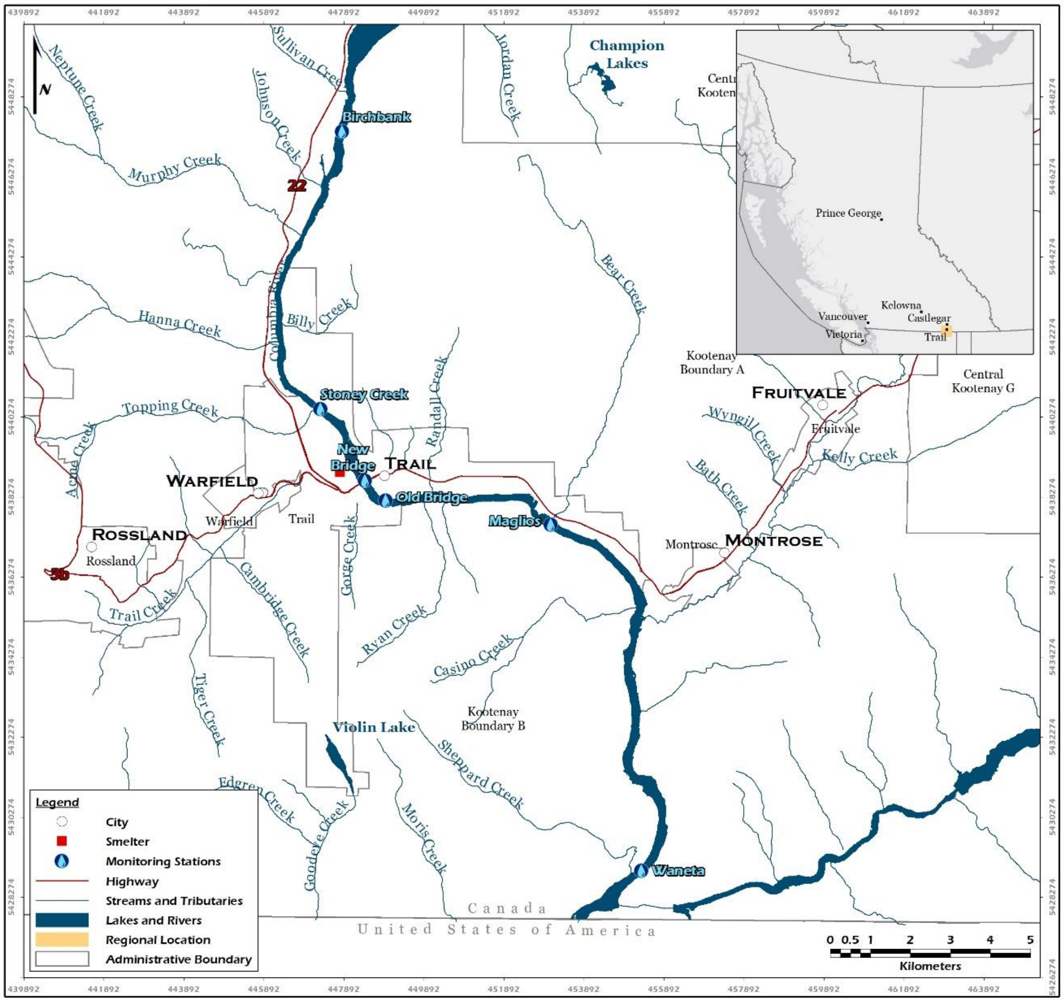


Figure 3-1: Study Area and Sample Sites - Surface Water Quality.

All water samples were collected using a Van Dorn bottle - Type Beta Plus designed for sampling trace metals and organics. There were two water quality sampling level intensities: transect and right shallow grab. The purpose of the transect sampling was to evaluate spatial heterogeneity across the river channel. For transect sampling, a series of six samples was collected with two near-shore grab samples, and four mid-channel samples (Figure 3-2). A composite sample at Waneta was collected over the six separate samples since analysis (Hawes et al. 2014) indicated concentration homogeneity across the river channel at this location. The Waneta composite was obtained by combining 3 samples collected evenly across the channel at ½ the wetted depth. For transect sampling, a total of 30 samples plus 3 samples for quality assurance and quality control (QA/QC) were collected during each sampling event. Grab sample events involved the collection of a single sample from the right bank in a wetted depth of about 1 m.

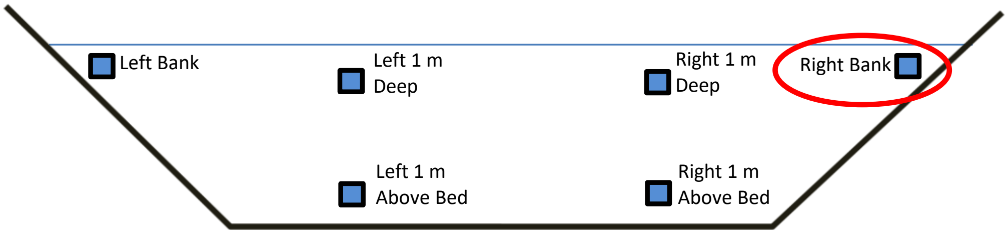


Figure 3-2: Schematic of transect water sample locations across the Columbia River channel (Perspective: Looking downstream). Transects were completed at Birchbank (reference site), Stony Creek, New Bridge, Old Bridge, Maglios, and Waneta. Grab sample events collected a sample from the right bank position (circled red). The short forms for the channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

Water quality sampling was conducted from March to October each year. Grab samples from the right bank shallow location (R-sh Figure 3-2) were collected on March 21-22, April 4-5, April 18-19 in 2018.

Transect samples, including the right bank shallow location, were collected during the fall low flow period on October 3-5, 2018. During the July high flow period, transect samples were collected on July 17, 2018. Figure 3-3 illustrates the LCR hydrograph by year from 2011-2018 to highlight the variability in flows along with the water sample dates in each season and year of monitoring.

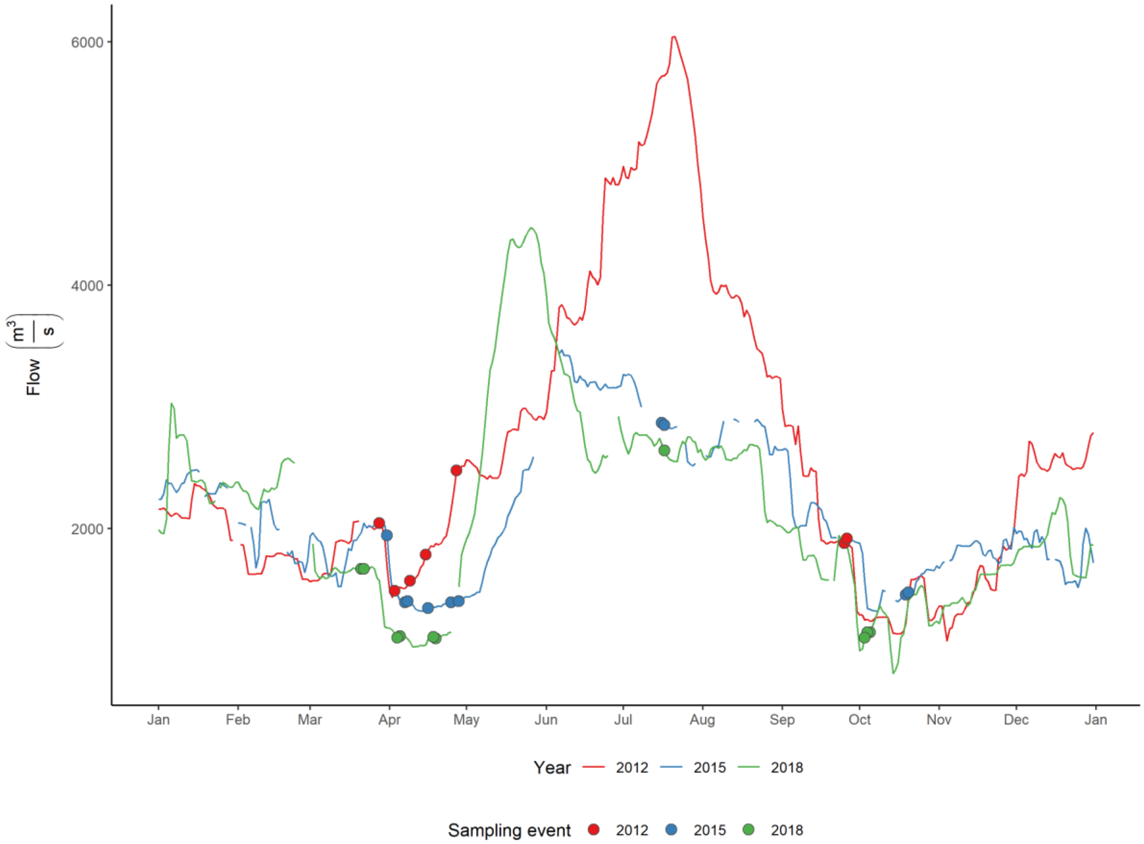


Figure 3-3: Lower Columbia River flows and the spring, summer and fall AEMP water sampling periods (denoted as points above) for 2012, 2015 and 2018. Flow data are based on Birchbank Station (08NE049) from Water Survey of Canada.

3.1.1 Water Quality Field Parameters and Laboratory Analyses

Water quality field parameters were measured with a pre-calibrated Hanna HI 9828 (2015) and a YSI Pro DSS multimeter (2016 -2018) by lowering the sonde to the prescribed depth upstream of the sample site, then allowing the boat to drift until the sonde cable was vertical and on-site before the reading was recorded in the meter memory. Parameters included: GPS location, temperature, dissolved oxygen, percent dissolved oxygen saturation, pH, conductivity, total dissolved solids, and salinity. Data were downloaded from the meter computer to a stand-alone computer at the end of every sample collection session. Water depths were measured with a boat-mounted Lowrance HDS 7 chartplotter. Back-up field meters included a Hanna HI 9025C multi-meter, a Eutech Instruments pHTestr-20 for pH verification, and a Hanna conductivity meter.

Water quality samples were collected and submitted to a certified analytical lab and is a critical component of this monitoring program.

Lab parameters included:

1. Specific conductivity, total alkalinity, hardness, pH, TSS, TDS, BOD_5, TOC, turbidity;
2. Major ions Ca, Mg, K, Na, Br, Cl, F, SO_4;
3. Nutrients including ammonia, nitrate, nitrite, TKN, total phosphorus, dissolved phosphorus;
4. Total (not filtered) and dissolved (field-filtered) ultra-low metals scans with method detection limits 5 times lower than the BC ENV water quality guideline for the protection of aquatic life - using Inductively-Coupled Mass Spectrometry (ICP-MS).

3.1.2 Water Quality Data Analysis

Water quality data were evaluated using a variety of techniques that aligned with methods used in earlier reports (Hawes et al. 2014; Hawes et al. 2019). Data exploration with descriptive statistics (mean, minimum, maximum, standard deviation, etc.) were used to compare reference sites to exposure sites. Data from 2018 were plotted to illustrate the range of measured parameter concentrations at each site relative to established Water Quality Objectives and Guidelines. Box plots were then prepared from the data sampled during low flow periods (March, April, and October) and data sampled during the July high flow period and each was displayed as points.

Water quality data were compared to applicable guidelines and LCR Water Quality Objectives in the Reference areas (Birchbank), the IDZ (Stoney Creek, New Bridge, and Old Bridge), and the downstream areas (Maglios and Waneta). Exceedances of the BC long-term chronic (average) water quality guidelines were determined by calculating the mean from 5 samples collected (within 30 days of each other) from right shallow (R-sh) locations and comparing the mean to the applicable BC long-term chronic water quality guidelines. Spatial and temporal variations were subsequently described. Non-detectable results are common in metal detection samples. When calculating the average concentrations, non-detectable results were treated as half of the detection limit as per Huston and Juarez-Colunga (2009) and Technical Guidance 4; Environmental Management Act Authorizations (January 2016).

River flows during each of the water quality sample events was highly variable. This variability can affect the concentration of metals and nutrients. Therefore, the effect of river flow on metal concentrations associated with smelter effluent was tested by multiple linear regression with analyte concentrations (mg/L) at New Bridge R-sh as the response variable, as predicted by the product discharge at Birchbank and the sum of loadings from all for effluent outflows. The sum of daily loadings from CIV, Stoney Creek, CIII, and CII was calculated for each analyte of interest (Ag, Al, As, Cd, Cu, Fe, Hg, K, NH_3, Ni, NO_2, NO_3, P, Pb, Se, SO_4, TKN, Tl, TOC, Zn).

Trend Analysis was conducted on the flow-weighted mean concentrations (FWMC) of the five spring R-sh samples from 2012-2018; 2011 data were not included in the analysis because detection limits were higher.

The FWMC was calculated as:

$$FWMC = \frac{\sum_{1}^{n}(c_i * t_i * q_i)}{\sum_{1}^{n}(t_i * q_i)}$$

With this equation, the concentration in each sample (c_i = collected from the right shallow location) was weighted by both the time (t_i = 24h) and the flow (q_i = average daily LCR flow measured at Birchbank) that accompanied it. The FWMC represents the total load for the time period divided by the total discharge for the time period.

Mann-Kendall tests were used to determine if water quality parameters had trends from 2012-2018. Tests were performed using the “Kendall” package version 2.2 in R (McLeod, 2011). Detailed model formulae for all analyses are overly complex to include in report text, but are presented in Appendix M.

3.1.3 Quality Assurance / Quality Control for Water Samples

Quality assurance is a critical aspect of any monitoring program on trace metals because the ultra-low analyte concentrations make them susceptible to contamination. QA/QC reports from the labs can be found in Appendix C with the water quality data.

3.1.3.1 Field Quality Assurance

Prior to transect sampling, sample bottles were pre-labeled and stored in large resealable plastic bags, organized by site. The sampling boat and associated gear were pressure-washed prior to launching at Trail to remove road grime that could affect sampling, and to limit the potential for accidental transport of invasive species. Sampling began at reference sites and progressed downstream. Samples were collected from prescribed depths and sites in a cleaned, low metals Van Dorn bottle sampler. Sample bottles were provided by ALS Environmental Laboratories (ALS) and with the appropriate preservatives pre-measured in vials. Sample bottle caps, syringes and filters were triple-rinsed as needed with sample water to minimize contamination from atmospheric deposition. Metals sample bottles were triple-rinsed and immediately field-filtered using rinsed, prescribed syringe filters. All field sample preservation methods prescribed by ALS were observed. Clear un-powdered vinyl gloves were worn for all sample handling except Hg samples, when nitrile gloves were worn. Filled sample bottles were immediately placed on chipped ice and couriered to ALS Labs in Burnaby, B.C. within 48 hours of collection.

Duplicate instruments were used for field parameters where calibration is prone to drift such as pH. Where agreement was within instrument tolerances, the Hanna multi-meter data were taken as correct. When agreement was not within tolerances, the multi-meter was re-calibrated. Data were downloaded from the multi-meter computer to a stand-alone computer at the end of every sample collection session**.**

3.1.3.2 Lab Quality Assurance

Standard water quality sampling methods were employed (BC ENV 2013), as well as all instructions from ALS, Vancouver.

Every sampling event QA/QC involved 1 travel blank (lab double de-ionized water (DDI) travels unopened), 1 field blank (Lab DDI water handled as sample water) and up to 3 duplicate samples (labels did not tell the lab which samples they duplicate). The minimum number of QA/QC samples was 3 per transect sampling event (10% of samples). Lab reports were checked on receipt of data and queries or requests for sample re-analysis were sent as soon as possible and within sample hold times. Requests for re-analysis were based on differences between sample duplicates that exceeded accepted tolerances, generally 20 - 50% difference due to the ultra-low concentrations, or an outlier result that exceeded the range of standard deviation for the applicable results to date. The lab was also directed to retain samples until they were notified that they could dispose of them or until the hold times specified in Standard Methods had expired.

The lab was asked to report the data electronically in Microsoft Excel and portable document format.

3.2 Sediment Quality Monitoring

Sediment samples and supporting parameters were collected at 10 depositional sites (Schedule A: Maps 1-10). Each of the sites were identified in the sediment quality triad (Golder 2007). All samples were collected following sampling procedures outlined in Clarke (2003) and other standardized, acceptable scientific techniques (Cavanagh et al. N.D.). Sample sites included:

1. Three reference areas at Kootenay Eddy (DEP-REF- 1), Genelle Eddy (DEP-REF-2), and Birchbank Eddy (DEP-REF-3).
2. Seven exposure sample sites were established at Korpac (DEP-EXP-1), Maglios (DEP-EXP-2), Casino (DEP-EXP-3), Airport Bar (DEP-EXP-4), Trimac (DEP-EXP-5), Fort Shephard Eddy (DEP-EXP-6), and Waneta (DEP-EXP-7).

At depositional sites, coarser consolidated substrates were often encountered below 20 – 50 cm of surficial substrates. Deep sediments were immobile and less likely to interact with river ecosystems and therefore were of less interest than the surficial sediments that were sampled as described below.

Sediment samples were collected by pushing 4.35 cm diameter clear acrylic corers into the substrate to a depth of 15 cm and the 200 cm^3 core was transferred to a large resealable plastic bag. Five cores were added to each bag to create a composite sample from a variety of sub-sample locations within the designated sample site. The sediment sample was mixed thoroughly and a 500 cm^3 sediment subsample was retained and stored in a cooler on ice and delivered to Caro Analytical Labs, Kelowna for processing.

Supporting data collected at each sediment sample site included:

1. Substrates were assessed using a GIS approach at all 10 sediment sites. Each habitat unit sampled was mapped in GIS. The percentage cover of each type of substrate was developed. This GIS approach allows long-term tracking of sediment erosion and deposition in the river and facilitates documentation of habitat change over time.
2. Water velocity, channel morphology (run, riffle pool, etc.), bankfull width, and sample depth was collected at each site. Velocity at each sample site was collected using a Marsh McBirny or a Swoffer flow meter depending upon water depth. Velocity was collected at the 40% column depth.
3. The percentage of cover of aquatic macrophyte was estimated visually at each sample site.
4. The distance from the point of discharge was determined using GIS as measured from the centerline of the channel to the sample site. This data was useful in assessing potential gradients that may exist from the point of smelter discharge.

Data were collected in a spatial framework using GIS and stored in standard data formats (e.g., Microsoft Excel).

In the Larratt Aquatic lab, both wet and dry sediment samples were examined for presence of slag in white sorting trays and photographed with a macro lens. Sediment samples were compared to slag samples obtained from the smelter. The samples were mixed with distilled water and reviewed under 400 power on an inverted microscope fitted with a second high-intensity lamp as a side light. Several microscope photographs were taken from each sample as an archived record to corroborate observations. Records were kept of: dark silt, possible slag, organic debris, protozoa, small invertebrates, bacteria, fungi, Didymo tubes, algae, vascular debris, pollen, etc.

In the Caro Analytical lab, the strong acid leachable metals (SALM) soil procedure was followed, according to the British Columbia Environmental Laboratory Manual 2015 procedure for total sediment metals. Sub-sampling was done using approximately 50 g of sample for drying. According to the 2015 BC Lab Manual method, the sample was dried, then disaggregated and split into two subsamples. One sample was sieved to <2 mm (BC ENV, 2015) and the second was sieved to <63 µm. Slag was identified as an interest in the Aquatic ERA (Golder 2007). Stones, rocks, debris, and possibly large slag particles exceeding the 2 mm sieve size were excluded from the analyzed samples, per the sample preparation procedure for the analysis of total metals, as referenced within the BC Contaminated Sites Regulations and BC Environmental Lab Manual. The SALM method achieves near-complete recoveries of some important metals, but many others are only partially recovered, such as aluminum, barium, beryllium, chromium, strontium, titanium, thallium, and vanadium. Metals not dissolved with this method are unlikely to be of environmental consequence (British Columbia Environmental Laboratory Manual: 2015). The SALM method is applicable to the following total metals and parameters:

> Aluminum Al, Iron Fe, Silver Ag, Antimony Sb, Lead Pb, Sodium Na, Arsenic As, Lithium Li, Strontium Sr, Barium Ba, Magnesium Mg, Sulfur S, Beryllium Be, Manganese Mn, Thallium Tl, Boron B, Mercury Hg, Thorium Th, Cadmium Cd, Molybdenum Mo, Tin Sn, Calcium Ca, Nickel Ni, Titanium Ti, Chromium Cr, Phosphorus T, Uranium U, Cobalt Co, Potassium K, Vanadium V, Copper Cu, Selenium Se, and Zinc Zn.

Duplicate samples of the entire 2018 sediment sample set were analysed from the <63 µm fraction and evaluated as above. Differences in sediment metal concentrations between the <63 µm fraction and the <2 mm fraction were determined using a paired Wilcoxon signed-rank test.

Correlations between sediment metal concentrations were determined using Pearson's correlation coefficient and Principal Component Analysis. Pearson's correlation coefficient were calculated for pairs of sediment metal concentrations at exposure sites for 2012, 2015 and 2018 data. In addition, Pearson's correlation coefficient were also calculated separately for the 2018 sediment metal concentration in the <63 µm fraction and <2 mm fraction.

Principal Component Analysis (PCA) was used to help understand potential variation in sediment concentrations between sites and years (Appendix P). Highly correlated sediment metal concentrations of As, Cd, Cr, Cu, Pb, Hg, Se, Tl and Zn from the <2 mm fraction 2012, 2015 and 2018 samples were included in the PCA. Cd was log10-transformed, and Cr was square root transformed to satisfy model assumptions. All sediment metal concentrations were standardized by converting concentrations to z-scores. Sample sites were displayed in a plot using the two principal component axes Appendix P).

Statistical analysis of variable sediment data was restricted because there was only one composite sampled from each depositional area collected and three years of sampling. Data analysis relied on comparison to guidelines and to historical values using percent difference. Where statistics were used (for example Pearson's correlation coefficient), ½ of the detection limit was used where concentrations were below the method detection limit.

3.3 Periphyton Monitoring

3.3.1 Depositional Habitats

Objectives of this assessment were to determine effects of effluent discharges on depositional habitat, and periphyton community structure and diversity. Periphyton samples were collected from the same ten depositional sites that were used in the depositional sediment sampling component (highlighted in Section 3.2).

Depositional areas having approximately 20-40 cm of water cover were sampled for periphyton using the petri dish sampling method outlined in Barbour et al. (1999). Briefly, sand or silt substrate samples are collected by inverting a large 8.85 cm diameter petri dish, sliding a flat spatula under the dish, and lifting the surface sediment sample. The 55.4 cm^3 sample was agitated in a plastic sample bottle with 500 mL of 0.45 micron filtered river water, and a 250 mL sample promptly decanted into a pre-labeled sample jar. This was repeated three times to get three replicate samples from each depositional area.

For periphyton taxonomy, each 250 mL sample was transferred to a triple-rinsed 600 mL beaker and agitated with a stick blender for 30 seconds before a 10 mL subsample was extracted and allowed to settle in a 22 cm^2 settling chamber for 24 hours (periphyton identification description, section 3.3.5) at the LAC lab.

3.3.2 Erosional Habitats

Cobble-size substrates were selected using stratified random techniques (Schachter, N.D.; CCME 2011) from undisturbed sample areas that had been continuously submerged for at least 10 weeks so that they had well developed periphyton communities. The 10-week minimum period of inundation prior to sampling has been based on our understanding of the time required for periphyton to attain peak biomass in the LCR (Larratt et al. 2013). The LCR hydrograph was closely monitored prior to the initiation of fall data collection to ensure that sampling occurred only after the prominent decline in discharge such that LCR flows had not been lower since May or earlier. This would mean the substrates being sampled had been inundated for at least 20 weeks. Although sampling in the spring prior to the increasing freshet hydrograph was historically sampled (Golder 2012a), fall sampling was selected. This period was chosen as it is the optimal time for sampling benthic macroinvertebrates since most taxa are in an aquatic life stage at that time of year and are in a later stage of development to permit taxonomic resolution required. In addition, fall sampling is synchronized to occur when LCR flows drop to a level that permits sampling of stable substrates and benthic communities that are permanently wetted. Thus, the periphyton program was aligned with the benthic monitoring program.

Sample areas were selected that had similar water depth, flow, velocity, substrate size, macrophyte cover and shading. Adapting the Generalized Random Tessellation Stratified Spatially-Balanced Survey Design (Stevens and Olsen 2004), five randomly chosen near-shore cobbles were obtained from wadeable areas within each of the five exposed sample sites and two upstream reference sites for a total of 35 samples. Additional 'oversamples' were also collected if required.

Each sample was composed of five subsamples collected from the top of each cobble surface. To minimize natural variation, samples were collected from the apex surface (parallel to the water surface) of smooth cobbles 20-50 cm in diameter. This process was repeated to collect three individual replicate samples, using methods found in the USEPA Rapid Bioassessment Protocol for Periphyton (Barbour et al. 1999).

Fifteen smooth cobbles (100-200 mm in diameter) were selected and placed on 3 plastic trays (5 rocks/tray) at the river's edge to minimize drying. Each tray was sampled separately for replicate samples from each site. A standard 2" ABS cylinder (inside diameter 50.8 mm) was fitted with a flexible rubber gasket and held firmly on the top of the cobble (Figure 3-4). A scalpel, modified toothbrush, and a squirt bottle filled with filtered river water were used to remove all the periphyton within the sampler diameter (20.26 cm^2). The rock and funnel were rinsed into a beaker to a total volume of 100 ml. Coarser sand and predators were noted but not added to the sample. This was repeated for all 5 rocks of a given sample to give a final volume of 500 mL per replicate. Samples were chilled with ice to 2˚C prior to shipping.

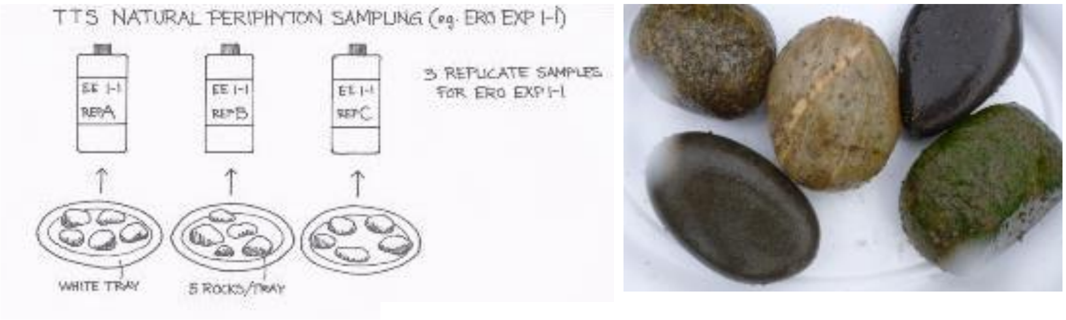


Figure 3-4a

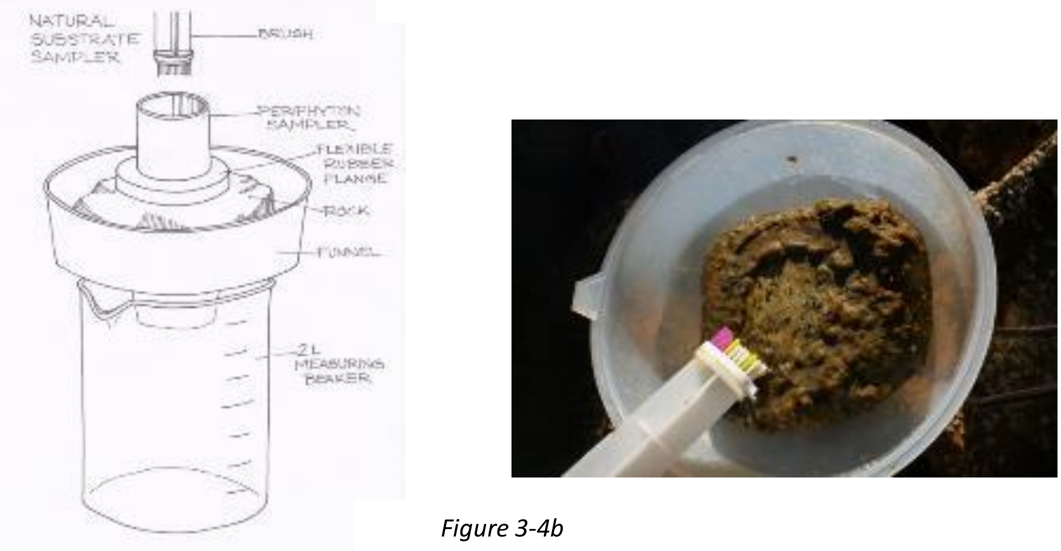


Figure 3-4b

Figure 3-4: Illustration of natural cobble substrate periphyton sampling in the LCR.

In the Larratt Aquatic algae lab, each replicate was agitated, and 200 mL subsampled to a glass jar and preserved with 0.2+ mL of Lugol's preservative. Preserved samples were refrigerated to await taxonomic analysis. The remaining sample water (300 mL x 3) was batched in a triple-rinsed 1 L brewers flask shielded with aluminum foil to exclude light. A 500 mL chl-a sample was cut, refrigerated, and kept dark until delivery to Caro Labs Kelowna within 24 hours. A total of 35 chl-a samples plus 3 field duplicates were submitted to Caro Analytical.

For taxonomy, each 200 mL sample was transferred to a triple-rinsed 600 mL beaker and agitated with a stick blender for 30 seconds before a 10 mL subsample was extracted and allowed to settle in a 5.3 cm diameter settling chamber for 24 hours (periphyton identification description, section 3.3.5).

3.3.3 Periphyton Identification, Enumeration and Measurements

Periphyton sorting and identification methods are consistent with those currently used in similar studies of the Mid and Lower Columbia River for BC

Hydro, to allow comparison of Columbia River periphyton studies (e.g., Olson-Russello et al. 2014).

1. Samples were settled in counting chambers for 24 hours. Cells were counted along mid-section transects examined at 400× - 800× magnification under a phase contrast inverted microscope.
2. Intact cells containing cytoplasm were counted as live, and cells without cytoplasm were counted as dead.
3. Counts continued until 300-500 cells were counted and taxa relative abundance stabilized (no new taxa encountered, dominant taxa stable at +-20% of count, (Barbour et al. 1999, Chpt 6). Counting continued if taxa relative abundance had not stabilized. Vigorous shaking of the sample did not always break up algae clumps before the subsample was withdrawn, allowing a clumped distribution of large taxa to persist. Cells of filamentous and colonial taxa were separated from counts of unicellular taxa because of their clumped distribution.
4. Microscope photographs of typical assemblages were taken from each sample and archived.
5. Algae cell dimensions were measured to allow for the calculation of biovolumes. Algal cell biovolumes were calculated using published geometric formulae (Hildebrandt et al., 1999; Diaina, et al., 2006). Twenty specimens from each taxa were measured to the nearest 0.1-micron using ScopePhoto 3.0 image processing software. Median measurements were used to calculate cell biovolumes. Calculated biovolumes were compared to the range of sizes reported in published literature as a QA/QC step.
6. All parts of microflora were evaluated from the settled samples, noting prevalence of detritus, vascular debris, bacteria, fungi, yeasts, and micro-grazers (protozoa) to estimate productivity.
7. While diatoms usually dominate LCR periphyton, the inclusion of very small members of the periphyton biofilm in the taxa counts, including nano-periphyton (<2 – 20 microns), and pico-periphyton (>0.2 – 2 microns) bacteria and fungi facilitates estimates of productivity as they usually form a significant component of the overall periphyton community (Stockner 1991; Wetzel, 2001). High power (600 – 900×) magnification was used for visual identification of species. Dr. J. Stockner's (formerly of UBC) verified the taxonomy of these small, difficult to identify species.
8. All data were recorded in Microsoft Excel spreadsheets.
9. In lieu of preserved diatom reference samples that have short shelf life, microscope photographs of typical LCR periphyton assemblages were archived from each taxonomic sample. These photos provide a record

that is usable at least to the genus level and includes non-diatom components of the periphyton.

10. About 20% of these samples were selected for taxonomic verification by Dr. J. Stockner. Dr. Stockner used a variety of microscopes to verify identifications, particularly for the nano- and pico-periphyton. Any taxonomic corrections/ nomenclature variations from existing data were clearly identified. All other taxonomic evaluations were performed by H. Larratt, Larratt Aquatic Consulting Ltd.

Phycologist Dr. J. Stockner also compiled a master species list for the Columbia System using current taxonomic nomenclature. In addition to his master-list, keys used during this work include:

References:

- Patrick and Reimer; The Diatoms of the United States
- Wehr and Sheath Freshwater Algae of North America
- Canter-Lund and Lund Freshwater Algae; Their Microscopic World Explored
- Prescott; Algae of the Western Great Lakes
- Cyanobacteria Image Gallery; http://www-cyanosite.bio.purdue.edu/images/images.html
- River Diatoms: a multi-access key; http://craticula.ncl.ac.uk/EADiatomKey/html/taxa.html
- Academy of Natural Sciences ANSP Algae Image Database; http://diatom.ansp.org/AlgaeImage/SearchCriteria.asp

Periphyton data were entered in Microsoft Excel spreadsheets and continuously backed up to an off-site server. Replicate preserved samples were refrigerated at Larratt Aquatic's office as back-up samples and discarded after six months.

3.3.4 Environmental Impact Prevention

Didymo (*Didymosphenia geminata)* is present in the LCR and can spread readily through transport of sampling gear. Nuisance blooms have been reported in rivers worldwide (BBC 2014). However, evidence indicates that blooms are probably not caused by introductions but, rather, by environmental conditions that promote excessive stalk production (Bothwell et al. 2014).

Regardless of factors affecting the spread and proliferation of Didymo, all wader boots used by Ecoscape were soaked for 1 minute in a salt solution containing 70 g NaCl/L and dried in the sun for several days or frozen for a week (Matheson et al. 2007).

3.3.5 Periphyton Quality Assurance/Quality Control

H. Larratt performed taxonomic investigations on all samples, with about 20% of periphyton samples going out to Dr. J. Stockner for taxonomic verification in 2012 as part of our QA/QC program. The following four steps were incorporated in taxonomic investigations for this AEMP:

1. Documenting live:dead ratios of diatoms prevents an overestimation of the standing crop and provide insights into the nutritional value of the periphyton.
2. Inclusion of very small members of periphyton biofilm in the taxa count, including nano-periphyton (<2 – 20 microns), pico-periphyton (>0.2 – 2 microns) bacteria and fungi prevents a significant under-estimate of productivity. Generation time of these small simple forms is a matter of hours, and they are usually a significant component of the overall periphyton community (Stockner 1991; Wetzel, 2001).
3. Algae cell dimensions were measured to allow for the calculation of biovolumes. Biovolume accounts for the difference in cell size among algae types and allows the estimation of standing crop.
4. A microscope photo of a typical field was archived from each sample for future reference.

3.4 Benthic Invertebrate Monitoring

The benthic invertebrate monitoring program was focused on assessing impacts of permitted effluent discharges on the quality of benthic habitats, together with the resultant benthic communities. Physical elements of the habitat formed an important component of this assessment.

3.4.1 Depositional Habitat Sampling

A total of five benthic invertebrate samples were collected from each of thirteen depositional areas using an Eckman dredge (sample area = 0.0225 m^2). Dredge sampling positions were randomly selected by blind deployment of the apparatus such that substrates and bottom conditions were not visibly assessed prior to deployment. Previous assessments determined that a sample size of 5 is sufficient to describe variability (Golder, 2007c). Samples were sieved in a wash bucket with 400-micron mesh (Env.Can. 2012) and transferred into a labeled sample bottle. The five dredge samples were not combined but rather represented replicates for that area.

Some depositional areas in the river are more dynamic than others because they are less sheltered by prominent landforms and/or bedrock. As a result, he depositional areas of Birchbank Reference Area, Maglios Exposure Area and Airport Bar Exposure Area previously sampled in 2012 and 2015 were not sampled in 2018 and were replaced by other depositional habitats identified nearby (See Map sheets). New depositional areas were chosen as those containing suitable depositional attributes (i.e., fine depositional substrates) and occurred as close as possible (upstream or downstream) to the areas being replaced/omitted from 2018 sampling.

The Birchbank Reference Area (DEP-REF-3) sampled in previous years was exclusively medium to coarse-grained sand substrates and not a representative depositional habitat. The new DEP-REF-3 was relocated about 675 m downstream on the left bank. The Maglios Exposure Area (DEP-EXP-2) occurred in a backwater area just downstream of the Bear Creek fan on the left bank of the Columbia River. This depositional area was isolated by a gravel bar from river surface waters and nearly dry during the 2018 data collection. This area was therefore not sampled in 2018 and DEP-EXP-2 was moved downstream about 1,200 m to the right bank of the river. Airport Bar (DEP-EXP-4) was also relocated about 1,200 m downstream on the left bank since the medium to coarse-grained sandy substrates of the original site were not representative of the predominantly silty substrates of other backwaters and eddies.

3.4.2 Erosional Habitat Sampling

Sampling was carried out in upstream reference and downstream exposure areas as outlined in the AEMP study plan (Golder 2012a), and an attempt was made to standardize field conditions at each site, including substrate size, water velocity, etc. Study areas and sample sites are shown in Map sheets 1-10 (Schedule A). All benthic invertebrate sampling was completed in natural substrates at wadable depths during low flows.

Two of the study areas were in upstream reference areas identified as Reference Area 1 (ERO-REF-1) (left bank opposite Stoney Creek and CIV outfall) and Reference Area 2 (ERO-REF-2) (Birchbank).

Five downstream exposure areas were sampled at sites identified as downstream Exposure Area 1 through Exposure Area 5 (ERO-EXP-1 to ERO-EXP-5). Sites within each of the upstream and downstream areas were randomly chosen using ArcGIS spatial tools. No additional sample sites were added as oversamples because all designated areas were effectively sampled. The exposure area sample sites are summarized as follows:

- ERO-EXP-1 occurs exclusively along the right bank of the river extending about 1,300 m downstream from Stoney Creek and the CIV effluent outfall.
- ERO-EXP-2 occurs in the right bank side channel downstream of the CIII effluent outfall, entirely within the CIII plume. The total length of this area is only about 315 m.

- ERO-EXP-3 was identified in the original study design as a single area that spans the width of the river beginning just below the right bank side channel, next to the smelter, and extending downstream about 3,000 m. As the understanding of both the effluent plume and groundwater plume has improved over the years, sampling within Ero-Exp-3 was further stratified into left and right bank subsamples such that future analysis can begin to evaluate the left and right bank communities separately. The left bank is sampled at ERO-EXP-3 to assess the potential for groundwater plume effects in this area. Flowing downstream through ERO-EXP-3, the effluent plume diffuses outward from the CII outfall and the right bank and is diluted to about 0.5% of the initial CII outfall concentrations (Hawes and Larratt 2014) by Old Bridge (Schedule A).
- ERO-EXP-4 encompasses both the left and right bank of the river downstream beyond the effluent plume where diffusal and mixing is becoming more complete. The total length of this area is about 2,500 m.
- ERO-EXP-5 encompasses both the left and right bank of the river beginning downstream of the Rock Islands and Bear Creek confluence where full mixing of the plume has occurred. ERO-EXP-5 extends to the Pend d'Oreille river Confluence and is about 12,000 m in length.

At each sample site, a series of 5 area-based samples (Figure 3-5) were collected from undisturbed riverbed while moving upstream. All benthic sampling was completed in permanently wetted natural substrates at wadable depths during low flows. The sample net had a mesh size of 400 microns in accordance with standard CABIN protocols (Env.Can. 2012). The 5 samples were combined to form one composite sample. The sampler quadrat was 0.56 m^2. Thus, once combined, the total area sampled at each site was 2.8 m^2. Biophysical field information recorded for each site included:

- Substrate composition (general) – percent composition of each substrate type (e.g., boulder, cobble, gravel, sand etc.).
- Water velocity - velocity measurements were collected (using a Swoffer 2100 flow meter or Marsh-McBirney Flo-Mate) at the 40% column depth.
- Sample depth and broader channel morphology (run, riffle pool, etc.).
- In situ water quality – Using an YSI Pro DSS (temperature, dissolved oxygen, total dissolved solids, turbidity, pH, specific conductivity, salinity, redox).
- Distance from smelter effluent outfalls (CII, CIII, and CIV) was determined using GIS as measured from the centerline of the channel to the sample site.

Figure 3-5: Sampling benthic invertebrates using an area-based approach with a modified surber/CABIN kicknet sampler (devised for area-based sampling in large river system with coarse substrates). The area shown is in Ero-Exp-3 situated on the right bank within the initial dilution zone.

3.4.2.1 Substrate Characteristics

The composition of stream bed material characterizes the type of habitat available to aquatic organisms. In addition, substrate composition is integral to understanding hydrological characteristics of that site.

The standard CABIN (Env.Can. 2012) pebble count was used to characterize substrate size and composition at each sample site. Substrate measurements within a sampling area were taken once all other sampling components were complete. While zigzagging through the sample area, substrates (i.e., boulder, cobble, pebble, gravel) were randomly selected every two steps following CABIN (Env.Can. 2012). If possible, the substrate material was extracted from the water and its intermediate axis (diameter perpendicular to the longest axis) was measured. If the substrate could not be dislodged, it was measured in place. The fraction of embeddedness for all rocks measured was also recorded.

3.5 Benthic Taxonomy

Benthic invertebrate samples were field-processed by filtering samples and storing them in 70% ethanol. Fixed benthic invertebrate samples were transported to Cordillera Consulting in Summerland BC. Samples were sorted and identified to the genus-species level where possible. Benthic invertebrate identification and biomass calculations followed standard procedures. Field samples had organic portions removed and rough estimates of invertebrate density calculated to determine if sub-sampling was required. After samples were sorted, macro-invertebrates were identified to species and all micro portions were identified following the Standard Taxonomic Effort lists compiled by the Xerces Society for Invertebrate Conservation for the Pacific Northwest. A reference sample was kept for each representative taxon found.

A sampling efficiency of 95% was used for benthic invertebrate identification and was determined through independent sampling.

Numerous metrics of benthic community structure including diversity, richness, community representation, and foraging guild were compiled (Appendix J).

3.5.1 Quality Assurance / Quality Control for Benthic Invertebrates

Lab reports on sediment and benthic samples were reviewed within two working days of receipt, and requests for re-analysis made if results were outside the 99th percentile without apparent cause. Lab reports were compared to all relevant standards and guidelines, with unusual results flagged.

3.6 Analysis of Periphyton and Benthic Invertebrate Community Response

The response of periphyton and benthic invertebrate communities to measured chemical (i.e., water and sediment quality), geographical, and physical variables were analysed using multiple approaches. These are summarized in the following subsections.

3.6.1 Response Variables

Relative effects of metals concentrations and habitat on periphyton and benthic communities in the LCR were assessed using response variables. Periphyton response variables included: 1) abundance, 2) biovolume, 3) effective number of species, 4) Shannon evenness, 5) species richness, and 6) chlorophyll-a production. Benthic invertebrate response variables included: 1) richness of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT richness), 2) abundance, 3) % of samples made up of EPT taxa (% EPT), 4) % of sample made up of Chironomid taxa (% Chironomidae), 5) effective number of species, 6) Shannon Evenness, 7) Hilsenhoff biotic index, and 8) Total Biomass.

Explanatory variables included habitat type (i.e., depositional and erosional), treatment (i.e., reference or exposure), distance from effluent outfall (CIII outflow used as point of reference), water temperature, water velocity, and substrate size (D50). The substrate metric D50 is the median substrate diameter, 50th percentile. The final set of explanatory variables was selected based on variance inflation factors (VIF) <5 and correlation coefficients (< 0.7).

3.6.2 Depositional and Erosional Site Analysis Methods

Productivity metrics associated with periphyton analyses, and community metrics associated with invertebrate analyses from depositional and erosional sites from 2012, 2015 and 2018 were included in linear mixed-effects models that used maximum likelihood fitting (Zuur et al. 2009). The fixed effects for all models included velocity, water temperature, substrate size (D50), treatment (exposure and reference), and year. In the periphyton biovolume model, the interaction term of year and reference was included.

Periphyton productivity metrics and benthic community metrics are expected to be correlated within the same erosional area and year, and as such they represent pseudo-replicates. However, the size of the erosional areas was highly variable, and some erosional areas may have independent samples and not be pseudo-replicates. Random effects of erosional area (e.g., ERO-EXP-2) and year were tested for each productivity and community composition model.

For depositional areas, periphyton and benthic metrics were calculated by summing all five samples that were collected at each site. Due to the use of pseudo-replicates, analysis of depositional community data solely collected in 2018 could not be completed.

Candidate models were compared through Akaike Information Criterion corrected for small sample size (AICc) based on Δ AICc values and AICc weights (w_i) which ranks models based upon the principal of parsimony, balancing model fit with complexity, in which the best models have the lowest Δ AICc and highest W_i. In this approach the overall relative model performance was determined, rather than assessing the significance of individual parameters or models through p-values. Because numerous models performed similarly based on these criteria, we also assessed the relative support for the effects of different explanatory variables using multi-model averaging (Burnham and Anderson 2002; Anderson 2008). In this latter approach, model averaged parameter estimates with 95% confidence intervals (direction, variability, and size of effects) and relative variable importance (RVI: sum of W_i for all models containing a variable of interest) were calculated for each explanatory variable from 95% confidence sets of models (Burnham and Anderson 2002; Grueber et al. 2011).

Variables with 95% confidence intervals that did not span zero, and with RVI values >0.5, were viewed as important in describing variation in response variables (e.g., Burnham and Anderson 2002). We also calculated pseudo R^2 for high-ranking models (derived from regressions of the observed data versus fitted values), which gives an indication of the proportion of the variance in response variables explained by an individual model (see Cox and Snell 1989; Magee 1990; Nagelkerke 1991; Piñeiro et al. 2008 for details).

To interpret and compare parameters which varied widely in scale, we conducted analyses after standardizing continuous explanatory variables by subtracting global means from each value (centering) and dividing by two times the SD (scaling) (Gelman 2008). Total abundance for both periphyton and benthic invertebrates, total biomass, and total biovolume in erosional and depositional sites were also log transformed to meet model assumption of normality.

3.6.2.1 Depositional Periphyton and Benthic Invertebrate Models

For the depositional sites, invertebrate and periphyton metrics were calculated by summing all five samples collected at each site. To determine if elevated copper (a well-known algicide) concentration in sediment had adverse effects on periphyton, the correlation between periphyton metrics and sediment concentrations of copper at exposure depositional sites was tested using Pearson’s correlation coefficient. Periphyton metrics of effective number of species, total abundance and total biovolume were compared using a two-way ANOVA with year (2012, 2015 and 2018) and treatment (reference and exposure) along with the interaction term. Mixed-effects modeling of depositional communities was not undertaken due to the small size of sites and the fact that true replication was not possible, therefore violating the model assumptions. Total biovolume and abundance were log transformed. Benthic invertebrate metrics of total abundance, percent EPT, percent chironomids and effective species numbers were compared with year and treatment without an interaction term. Total abundance, percent Chironomidae and percent EPT were log transformed to meet model assumption of normality.

3.6.2.2 Erosional Periphyton and Benthic Invertebrate Models

Linear mixed-effects modeling of periphyton and benthic communities (Appendix I and Appendix L) were done in the lmer package, and competed and averaged using the MuMIn package version 1.43.6 (Barton, 2019), both implemented in R. While these models generally followed assumptions of multiple linear mixed-effects models, and many performed well, individual relationships among response and explanatory variables were not always linear based on scatter plots of the data. Therefore, interpretations of effects should be limited to general direction and size, but not shape of relationships. Following this, these models are not appropriate for predictive use.

For Erosional Areas, site was the random effect and the fixed effects included velocity, water temperature, substrate size (D90), treatment (exposure and reference) and distance to Hugh Keenleyside Dam. Distance to Hugh Keenleyside Dam is a surrogate for distance from the smelter since it provides a continuous variable with no negative values.

3.6.2.2.1 Erosional Periphyton Models

Five linear mixed-effect models and model averaging was used to assess periphyton metrics. Erosional area was used as the random effect for log-transformed total periphyton abundance and the effective species number. The combination of erosional area and year was used as the random effect for log-transformed total periphyton biovolume and Shannon’s Equitability (E_H).

Erosional area and the combination of erosional area and year were used as the random effects for log-transformed chlorophyll-a (μg/L).

3.6.2.2.2 Erosional Benthic Invertebrate Models

Six linear mixed-effect models and model averaging was used to assess benthic metrics. Erosional area was used as the random effect for log-transformed total abundance, the Hilsenhoff Biotic Index (HBI), and percent EPT composition. The combination of erosional area and year was used as the random effect for the effective species number, EPT species richness, and the percent Chironomidae composition. Additionally, we used one linear model to assess Shannon's Evenness (E_H) for benthic species using water temperature, substrate size, velocity, site type (reference or exposure), and year as predictors. Invertebrate biomass was not modelled because invertebrate biomass was only sampled in 2015 and 2018.

3.6.3 Community Composition

Non-metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity was used to explore variation in periphyton and benthic invertebrate community composition. Often in ecological research, we are interested not only in comparing univariate descriptors of communities, but also in how the constituent species—or the composition—changes from one community to the next. One common tool used to understand and visualize community composition is NMDS. The goal of NMDS is to collapse information from multiple dimensions (e.g., multiple species abundance or habitat values) into fewer dimensions so that they can be visualized and interpreted. Unlike other ordination techniques that rely on (primarily) Euclidean distances, such as Principal Coordinates Analysis, NMDS uses rank orders, and thus is an extremely flexible technique that can accommodate a variety of different kinds of data (Leftcheck 2018).

The NMDS for periphyton used Bray Curtis transformed periphyton and benthic invertebrate abundances. A separate NMDS analysis was conducted for erosional and depositional sites. Separating erosional from depositional sites allowed taxonomic differences within a given habitat type to be tested. To eliminate effects of rare taxa, taxa that occurred at less than 5% of all sites were removed from analysis. A PERMANOVA was used to determine if groups (Year, Reference vs. Mine Influenced Sites) were significantly different in community composition. NMDS was performed at genus taxonomic levels for both periphyton and benthic invertebrates to investigate effects of small- and large-scale taxonomic community differences. Finally, species were related to the community differences by fitting them to ordination plot as factors using Envfit (Oksanen, 2016). Only species that were significant ($p<0.05$) were considered. These species describe most of the observed variation between sites. All community analysis used the R package vegan version 2.5-5 (Oksanen, 2019).

An ANOVA was used to compare periphyton and invertebrate metrics among areas sampled in 2018 and all metrics were log transformed to better meet model assumptions. Levene's test was performed to determine if sites had periphyton metrics with equal variances. If the ANOVA determined there were significant differences among areas, the Tukey's Honest Significant Difference (HSD) test was used to identify key areas that had different periphyton productivity or community composition.

3.7 Small and Large-bodied Fish Monitoring

The small and large-bodied fish sampling program frequency was extended to a 6-year cycle from a 3-year cycle to reduce population burdens associated with lethal sampling for tissue analysis and condition metrics, and to align with other LCR studies. The adjustment of these programs, with data collection now occurring every six years, was discussed between Teck representatives and the Ministry of Environment during the review of the 2015/2016 interpretation report. Accordingly, fish were not collected in the 2018 data collection. These programs will resume in the 2021 data collection cycle.

4.0 RESULTS AND DISCUSSION

4.1 Water Quality

The following section presents water quality data collected during the 2018 sampling years and compares values to relevant LCR Water Quality Objectives/Guidelines and previous years (2011-2017).

4.1.1 General Water Quality Parameters

Field-measured parameters that were slightly elevated within the IDZ included conductivity, salinity and pH (Table 4-1). These water quality parameters were still within the typical range for the LCR both upstream and downstream of the IDZ (Larratt et al. 2013). In both the IDZ and the entire AOI, none of the general water quality parameters exceeded LCR Water Quality Objectives in the 2018 data.

Turbidity in samples collected in 2018 ranged between 0.50 – 3.54 NTU, and average turbidity of 1.00 ± 0.50 NTU. Similarly, TSS concentrations in samples collected in 2018 were below the 3.0 mg/L lab detection limit and below the field meter detection limit.

There are no approved BC guidelines for the protection of aquatic life or LCR Objectives for specific conductivity or TDS. ERO-EXP-2-2 and ERO-EXP-2-3 had elevated TDS (114, 116 mg/L) compared to TDS measured at upstream reference sites (70, 73 mg/L). TDS levels returned to reference levels by ERO-EXP-3-1. Similarly, water temperature was elevated by more than 2°C at ERO-EXP-2-2 and ERO-EXP-2-3 compared to upstream reference sites in 2018 field data (Table 4-1, 4-2). Although the mean water temperature at ERO-EXP-2 was 15°C, the maximum individual sample site temperatures at ERO-EXP-2-2 and ERO-EXP-2-3 were 16°C which exceeded the BC maximum daily temperature guideline of 15°C for watercourses with Bull Trout (BC ENV 2001). The exceedance of the daily temperature guideline for Bull Trout were restricted to small areas isolated along the shallow margin of the right bank of the river in the side channel just downstream of the CIII outfall and downstream of the CII outfall. While Bull Trout may frequent these areas of the river, risks to individuals from exposure to elevated temperatures would be negligible. These wasters are quickly mixed. In addition, behavioural avoidance by Bull Trout would be simple during periods when water temperatures in ERO-EXP-2 and the upstream right bank margin of ERO-EXP-3 exceeded background temperatures that were approaching the 15°C threshold.

Table 4-1: Averaged Erosional Site Field Measurements, 2018.

	Reference Sites		Exposure Sites				
Parameter	Ero Ref 1 Birchbank	Ero Ref 2 u/s Stoney	Ero Exp 1 CIV-Stoney	Ero Exp 2 CIII	Ero Exp 3 CIII-Korpac	Ero Exp 4 Kor-Mag	Ero Exp 5 Mag-Wan
Sample size	5	5	5	5	5	5	5
Conductance µS/cm	109	108	111	144	117	117	113
Salinity PSU units	0.05	0.05	0.05	0.068	0.052	0.052	0.05
pH	7.44	7.47	7.38	8.34	7.56	7.8	NA
Water temperature ºC	13.7	13.6	13.3	15	12.8	12.4	12.8
Dissolved oxygen mg/L	10.7	10.7	10.6	10.6	10.6	10.7	10.7
Dissolved oxygen % sat.	103	103	102	105	100	100	101

Table 4-2: Depositional Site Field Measurements, October 2018.

	Reference Sites			Exposure Sites						
Parameter	Dep Ref 1 Kootenay Eddy	Dep Ref 2 Genelle Eddy	Dep Ref 3 Birchbank Eddy	Dep Exp 1 Korpac	Dep Exp 2 Maglios	Dep Exp 3 Casino	Dep Exp 4 Airport Bar	Dep Exp 5 Trimac	Dep Exp 6 Ft Shepherd	Dep Exp 7 Waneta
Sample size	1	1	1	1	1	1	1	-	1	1
Conductance µS/cm	127.8	117.2	107.6	114.5	113.2	156.4	113.8	-	112.9	117.8
pH	7.17	7.71	7.35	8.07	8.07	8.17	8.06	-	NA	NA
Water temp. ºC	14.78	13.67	14	13.06	12.83	10.44	12.72	-	12.83	13.44
Dissolved oxygen mg/L	10.81	11.56	10.81	10.87	10.77	10.2	10.81	-	10.84	11.69
Dissolved oxygen % sat	106.7	111.3	104.9	103.4	101.8	91.3	101.9	-	112	106.7

* Meter failed to read correctly at Trimac

4.1.2 Nutrients

4.1.2.1 Inorganic Nitrogen

There are numerous sources of inorganic nitrogen within the LCR, including municipal effluents, lake fertilization programs in upstream reservoirs, and stormwater inflows (MacDonald 1997; Can-BC 2008). Nitrate and ammonia are key nutrients that are consumed, transformed, and released in a cycle as water travels downstream. Ammonia and nitrate account for most of the total nitrogen concentrations in the LCR AOI, with very low nitrite concentrations (Figure 4-1).

None of the 2011-2017 or 2018 samples approached inorganic nitrogen guidelines for aquatic life (3.0 mg/L nitrate as a long-term average; 0.02 mg/L nitrite; 0.7 mg/L ammonia) (Figure 4-1). In the LCR, the distribution of inorganic nitrogen species has been stable through the years (Olson-Russello et al. 2014). Inorganic nitrogen averages 86% nitrate and 14% ammonia. Nitrate concentrations are related to transport during high flows and ammonia concentrations are primarily donated by groundwater throughout the river, with increased donation during low flows (Larratt et al. 2013).

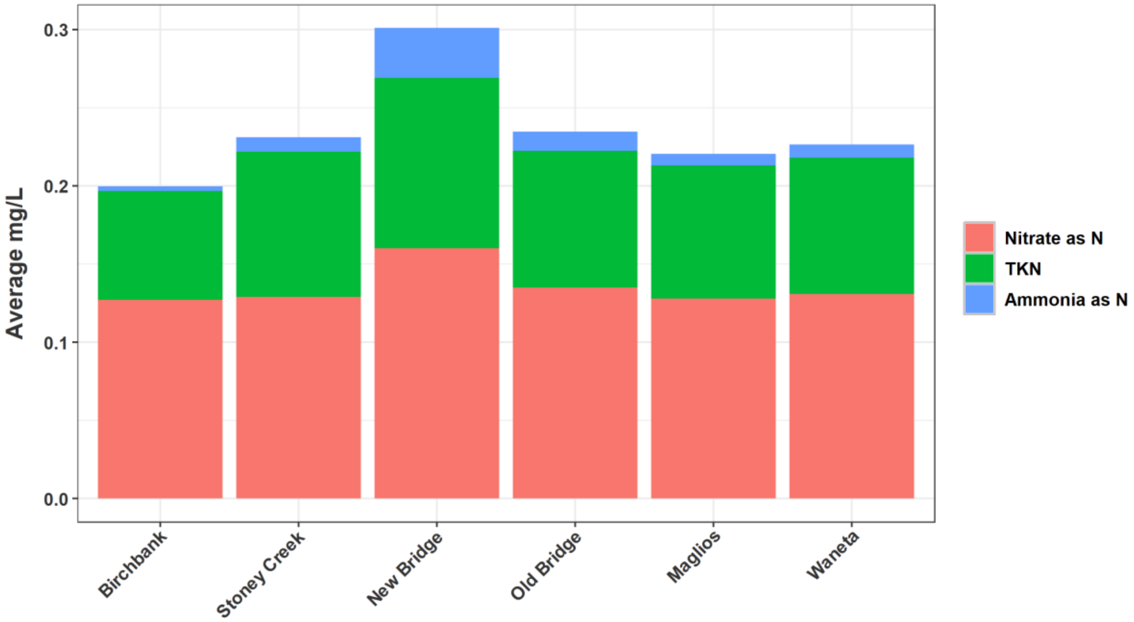


Figure 4-1: Average concentration of nitrogen forms for samples collected along the right bank shallow site of the LCR in 2018 during spring low flows.

Nitrate concentrations were uniform throughout the AOI in 2018 and all samples were above the standard detection limit. For example, the long-term average of nitrate from the right shallow samples at the reference site (Birchbank) was 0.142 mg/L and at the downstream Maglios site was 0.150 mg/L. During fall low flow transect sampling, there was a small increase (0.261 mg/L) in nitrate measured within the IDZ at New Bridge R-sh that was not evident downstream at Maglios (Figure 4-1).

Nitrite is a transient form of inorganic nitrogen, explaining why 64% of the nitrite concentrations were below standard detection limits in 2018. During the fall 2018 low flow transect sampling, nitrite concentrations from sites downstream of the smelter were elevated above the Birchbank reference samples. However, none of the concentrations were close to the short or long-term guidelines. Small variations in nitrite concentrations seen across transects may be associated with groundwater discharge areas (Figure A33).

In all transects including the reference site, shallow samples had more ammonia than the balance of transect samples (Figure 4-1). Elevated ammonia concentrations occurred within the IDZ in shallow samples from both banks (Table 4-3, Figure 4-1) which may be a result of groundwater influence and/or CIII effluent discharge.

Ammonia concentrations in shallow samples declined downstream of the IDZ, with a faster rate of decline in R-sh than L-sh. Transect ammonia samples were equivalent across the river at Maglios (Appendix A; Hawes et al. 2019). Ammonia guidelines were not exceeded at any sample sites and eighteen percent of 2018 water quality samples were below the limit of detection for ammonia (Table 4-3). It is important to note that effluent from the groundwater treatment plant does not contribute to any ammonia concentrations because the treatment process converts groundwater ammonia to nitrate.

Contributions made by organic forms of nitrogen measured since 2014 have been small (Figure 4-2). They were measured as TKN that also includes ammonia. Elevated TKN in R-sh and L-sh low flow samples may be related to groundwater influence, likely in the ammonia component of TKN (Appendix A19; Hawes et al. 2019). Organic nitrogen increased in the IDZ and remained elevated downstream, but the net change was small and unlikely to exert a secondary influence on water chemistry.

Average total nitrogen concentrations at New Bridge R-sh were elevated above the reference Birchbank R-sh site by about 91% or 0.044 mg/L in 2018. However, total nitrogen declined downstream of the IDZ. The increase in total nitrogen between Birchbank and Waneta was about 5%.

Table 4-3: Nutrient Concentrations at LCR Sample Sites, right bank shallow sample (2018).

	BC Guideline or LCR Objective mg/L	Results (mg/L)	Birchbank	Stoney Creek	New Bridge	Old Bridge	Maglios	Waneta
Nitrate	32.8 (max)	Average	0.127	0.129	0.16	0.135	0.128	0.14
(as N)	3.0 (average)	Long-term Average	0.144	0.145	0.173	0.151	0.148	0.146
Nitrite	0.06	Average	0.000568	7.00E-04	0.00084	0.000646	0.000618	0.000518
(as N)	0.02 (average)	Long-term Average	<0.001	0.000582	0.000524	0.000563	<0.001	<0.001
Ammonia	0.681 – 27.7	Average	0.0029	0.00938	0.0319	0.0123	0.00749	0.00811
(as N)	0.102 – 2.08	Long-term Average	0.0025	0.00823	0.0309	0.0119	0.00679	0.00779
TKN	--	Average	0.0697	0.0928	0.109	0.0874	0.0851	0.0773
(as N)	--	Long-term Average	0.0627	0.0941	0.103	0.0825	0.079	0.077
Phosphorus	--	Average	0.00342	0.00386	0.00391	0.00362	0.00312	0.00425
(as P)	--	Long-term Average	0.00328	0.00378	0.00374	0.00351	0.00294	0.00424
Potassium	--	Average	0.59	0.593	0.644	0.602	0.629	0.565
	--	Long-term Average	0.58	0.59	0.639	0.597	0.635	0.558
Sulphate	--	Average	11.3	11.5	16.9	12.5	11.7	11.8
	218	Long-term Average	11.8	11.8	17.3	12.9	12.2	12
TOC	--	Average	1.42	1.34	1.32	1.29	1.28	1.26
	--	Long-term Average	1.47	1.39	1.35	1.33	1.31	1.29

ǂ long term average based on the average of 5 samples collected within 30 days during spring low-flow sampling (Mar-Apr).

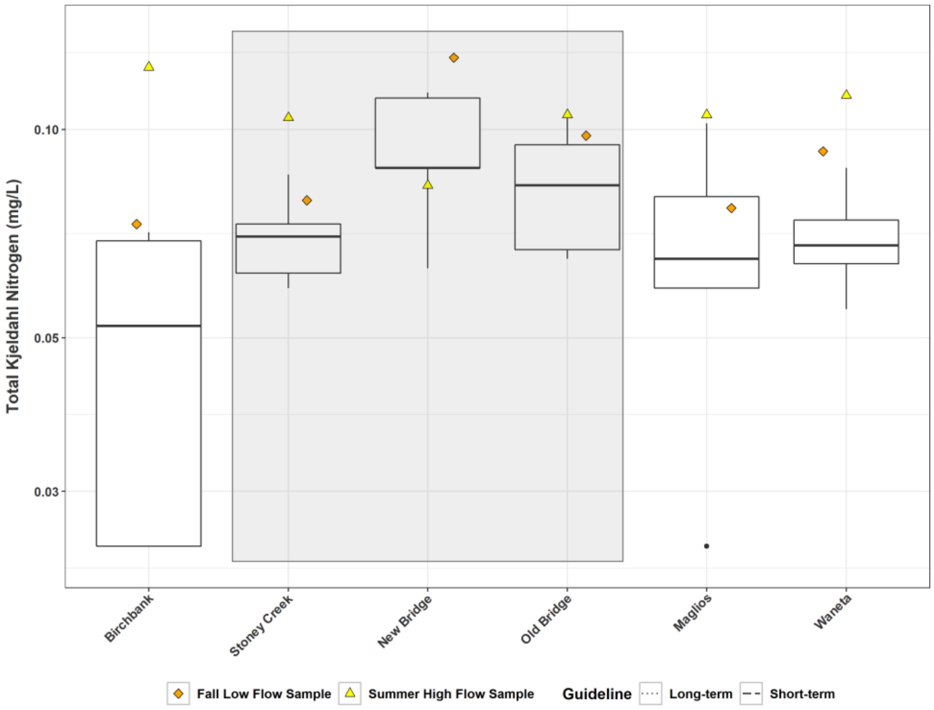


Figure 4-2: Box plots of TKN organic nitrogen measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. One percent of the samples were below the limit of detection for TKN. There are no BC water quality guidelines or LCR water quality objectives for TKN.

Note: See page vi for explanation of boxplots and guide for interpretation.

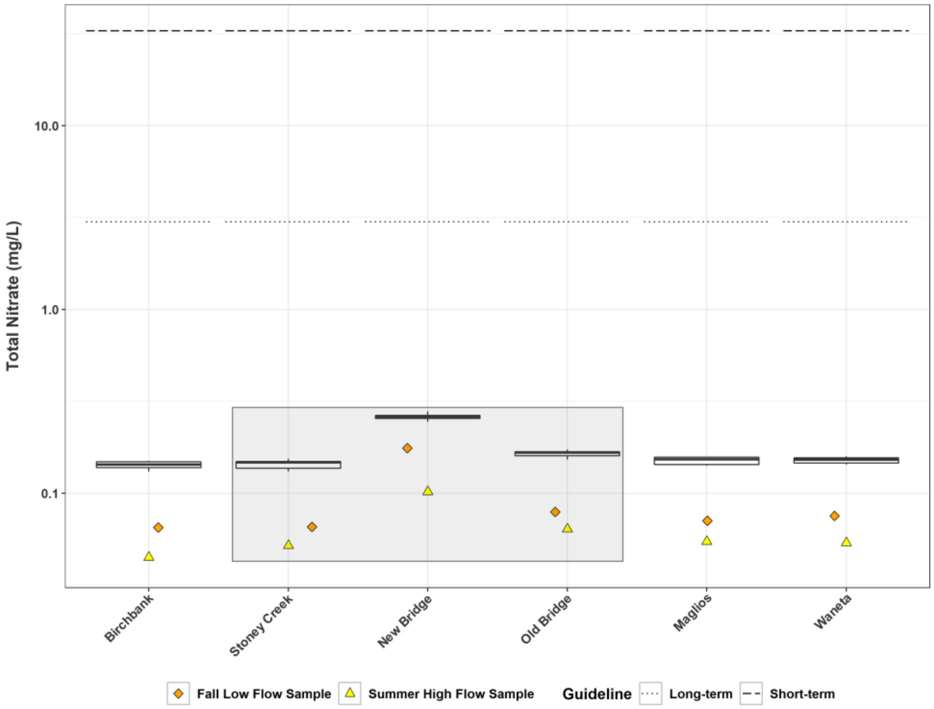


Figure 4-3: Box plots of total nitrate (as N) measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. No samples were below the limit of detection for nitrate.

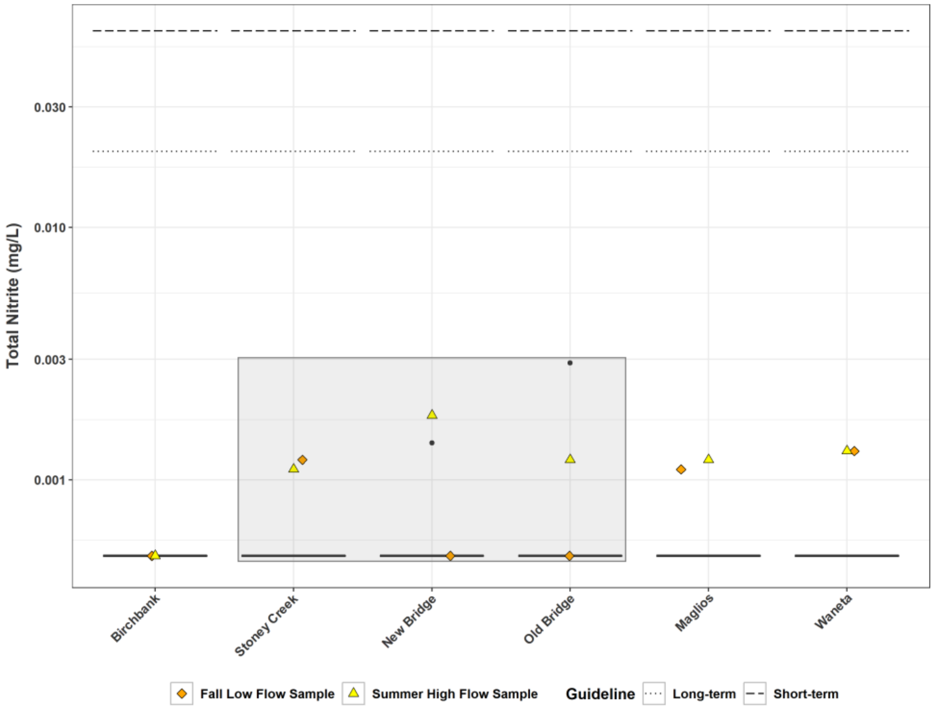


Figure 4-4: Box plots of total nitrite (as N) measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. 64 percent of samples were below the limit of detection for nitrite.

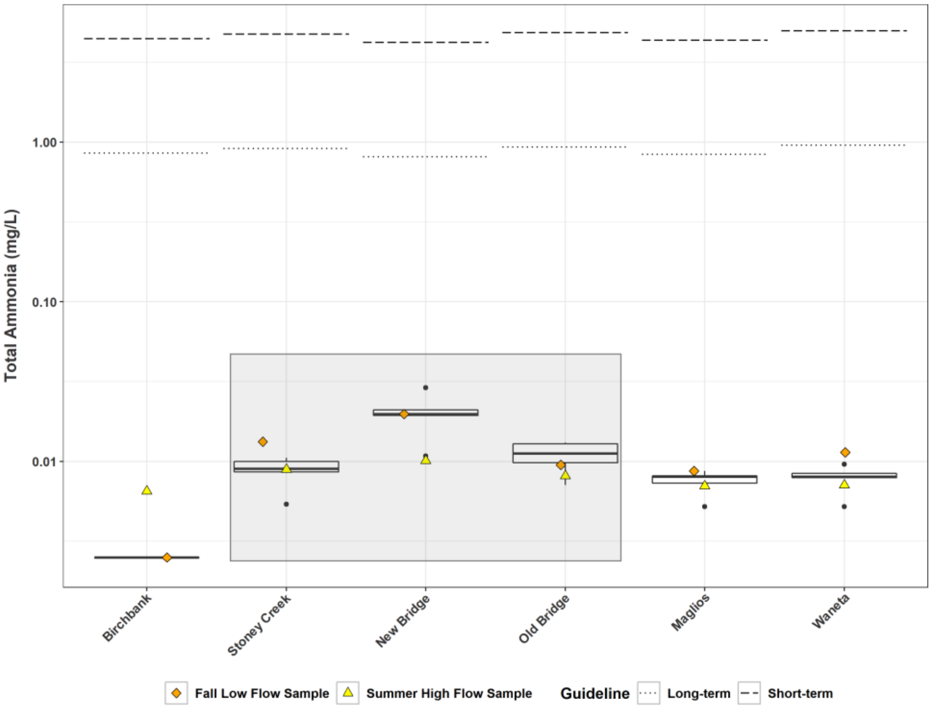


Figure 4-5: Box plots of ammonia (as N) measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. 18 percent of samples were below the limit of detection for ammonia. Guideline is a calculation based on pH and water temperature.

4.1.2.2 Phosphorus

Phosphorus is a key nutrient that usually controls aquatic productivity. Total phosphorus (T-P) concentrations measured throughout the LCR follow a declining trend over the years, particularly during 1968 – 1978 (Holmes and Pommen 1999; Can.-BC 2008) as outfall water treatment improved throughout the LCR. Phosphorus is added annually as part of lake fertilization programs in upstream Hydro reservoirs.

There is no phosphorus objective set for the LCR, and no provincial guideline for total phosphorus concentrations in rivers. The guideline value for lakes was therefore considered as a qualitative reference point, although it has not been empirically verified as being suitable for rivers. Total phosphorous concentrations exceeded the BC total phosphorous guideline for lakes minimum guideline (0.005-0.015 mg/L) in 4 of 30 spring low flow samples collected in 2018 and were measured at Waneta and New Bridge (Figure 4-6). In the fall low flow samples, all right bank samples exceeded the guideline including the Birchbank reference site. Based on these data, the smelter does not appear to affect phosphorus concentrations. No net change in total phosphorus concentrations was detected between Birchbank and Waneta in most years; however, the 2018 data shows increased P between Maglios and Waneta relative to Birchbank measurements (Figure 4-6). This is unlikely to be related to Teck Trail Operations. The highest P value in the fall 2018 low flow transect sampling occurred at Old Bridge L-1m deep, suggesting a potential groundwater influence (Figure A34). Phosphorus is not a contaminant of concern in the groundwater plume migrating from Trail Operations, however, there may be other influences on groundwater along the left side of the river.

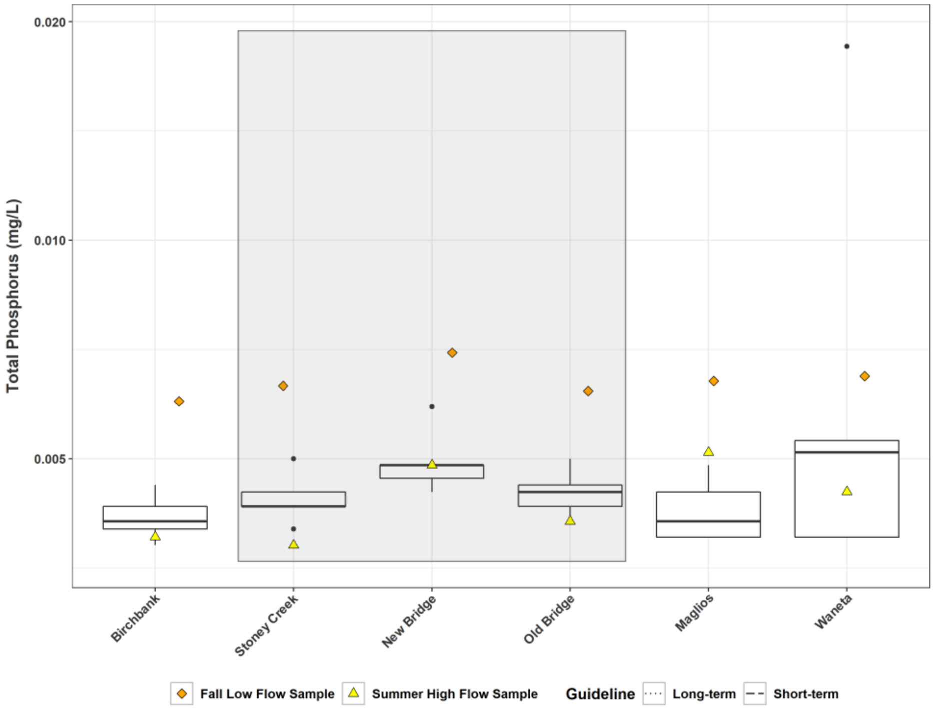


Figure 4-6: Box plot of total phosphorus concentrations measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. No samples were below the limit of detection for total phosphorus.

4.1.2.3 Minor Nutrients

Potassium concentrations were elevated at New Bridge R-sh and L-sh and may reflect a groundwater contribution (Appendix A14; Hawes et al. 2019). There are no BC Guidelines or LCR Objectives established for potassium. Potassium samples from the end of the IDZ were similar to background reference concentrations. Stormwater and sewage effluent discharged below the smelter would also contribute to the continuing increase in potassium observed in Maglios and Waneta samples.

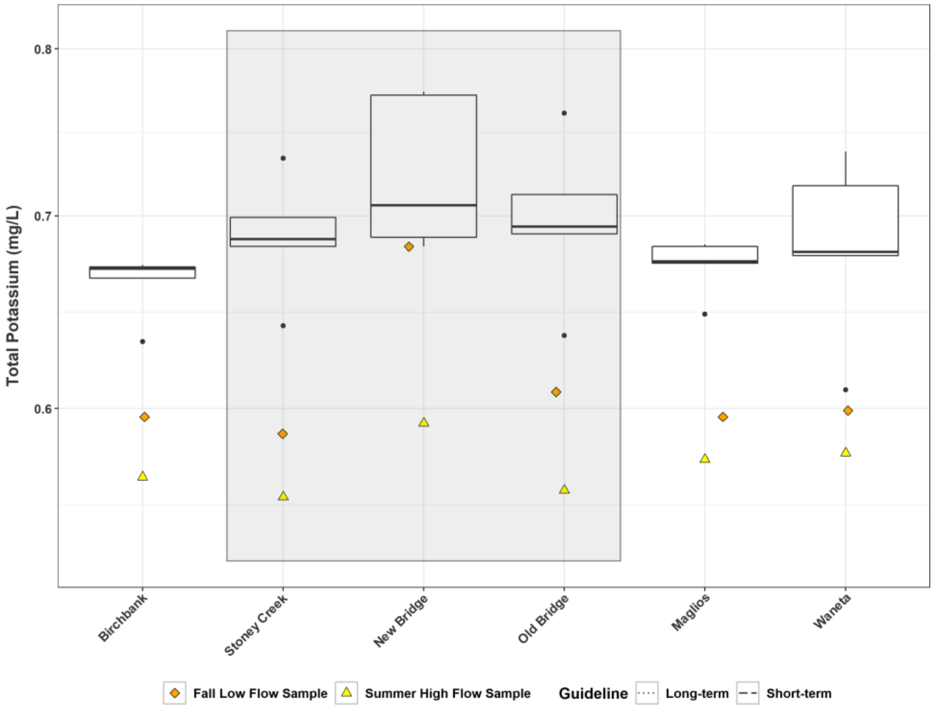


Figure 4-7: Box plots of potassium measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. No samples were below the limit of detection for potassium.

Sulphate is utilized by some algae and bacteria in the periphyton (Wetzel 2001). Sulphate was the dominant anion in the AOI (Hawes et al. 2014) and is a major component of the groundwater plume beneath the smelter (Golder 2010). The 30-day average guideline for the protection of aquatic life is 218 mg/L SO_4, in soft to moderately soft waters (31-75 mg/L as $CaCO_3$) typical of the lower Columbia River (Meays and Nordin 2013). This guideline was not exceeded in any 2015-2018 samples, including the fall 2018 transect sampling (Appendix A17). Sulphate 30-day average concentrations increased at New Bridge along the right bank (avg. 18.02 ±0.80 mg/L SO_4). Sulphate concentrations returned to within 3.8% of Birchbank reference concentrations by Maglios (Figure 4-8). Sulphate results were similar to 2011–2017 results.

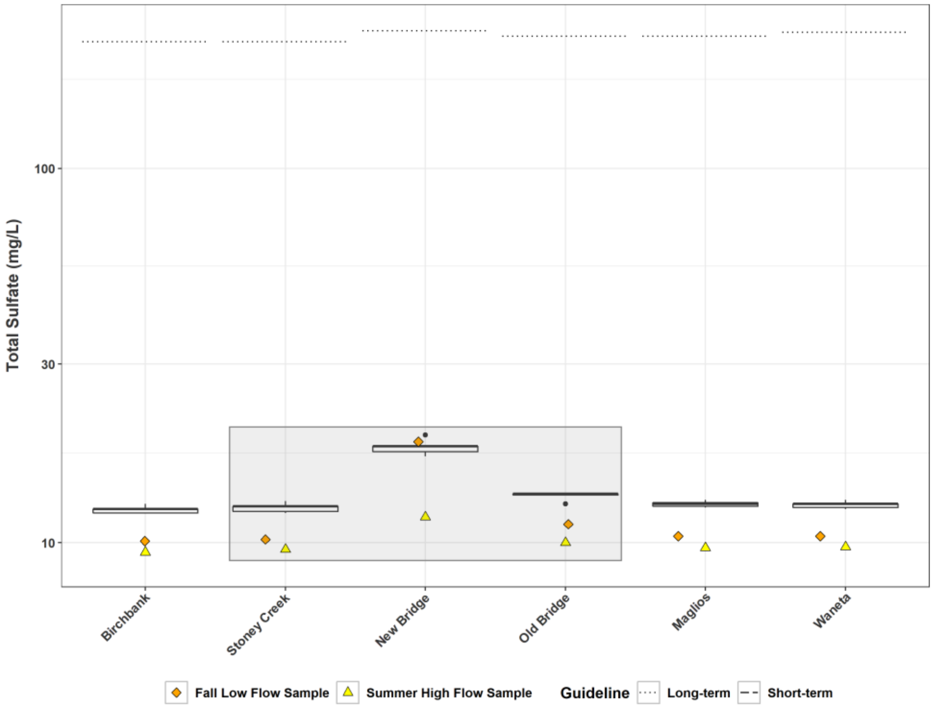


Figure 4-8: Box plots of sulphate concentrations measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. No samples were below the limit of detection for sulphate.

Total organic carbon (TOC) provides an indication of organic material available for invertebrate food, and for sequestering metals. TOC is generally low in the LCR. The BC WQG prescribes a 30-day median within ±20% of the median background TOC concentration (MWLAP 2001), which was 1.38 mg/L at Birchbank. Based on this, the upper guideline concentration was 1.66 mg/L and the lower guideline concentration was 1.1 mg/L.

The spring 30-day median values at all sites were within the BC WQG (Figure 4-9; Appendix A20). TOC was not elevated in the effluent plume of the smelter, nor in the IDZ compared to sites outside the IDZ. TOC sources are greater upstream of the Birchbank reference site than they are near or below the smelter, resulting in a declining trend through the area of interest (Hawes et al. 2019).

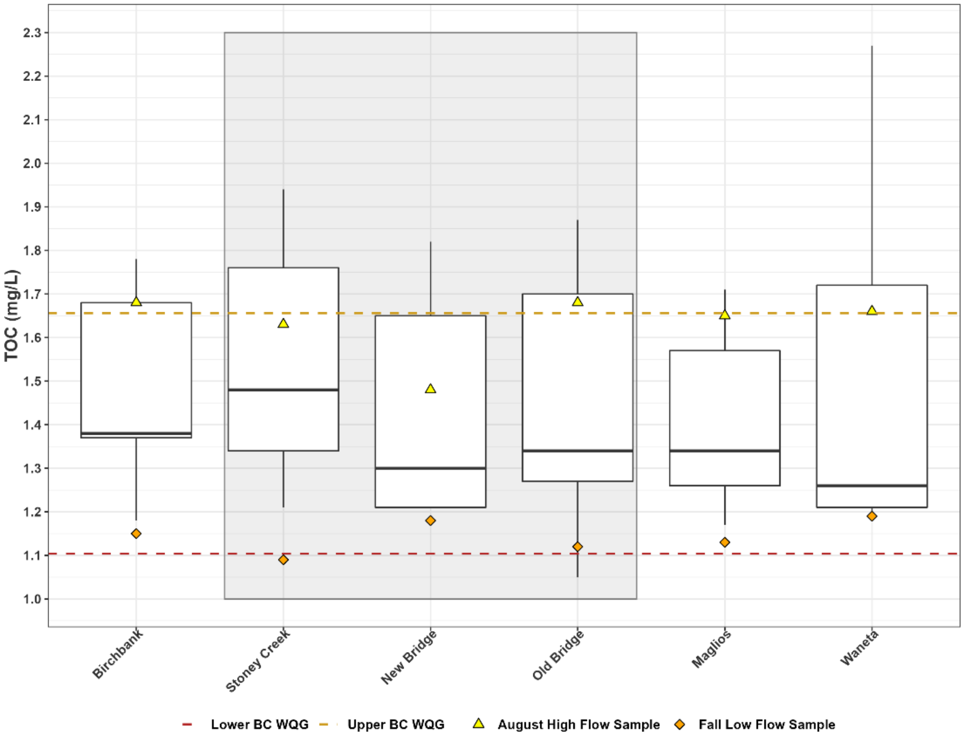


Figure 4-9: Box plots of TOC concentrations measured in R-sh position during 2018 March-April. Points correspond to 2018 summer and fall R-sh samples. The grey box represents the Initial Dilution Zone. The red and orange dashed lines represent the calculated BC WQG based on the Birchbank spring sampling data. No samples were below the limit of detection for TOC.

4.1.3 Total and Dissolved Metal Concentrations

Three sampling programs were employed in the LCR in 2018:

- Transect sampling across the river at each sample site during fall low flows monitors the spatial extents of the plume and aligns with the aquatic community sampling program.
- Grab samples from the right bank are also conducted during summer high flows.
- Sampling during the spring was intended to target low flow periods when there is a higher probability of BC Water Quality Guideline exceedances. This sampling allowed the calculation of 30-day averages from five weekly grab samples from the right bank sites and allowed comparison to BC WQG.

Both BC WQG and LCR Objectives were used to evaluate water quality in this report. Guidelines are set at levels designed to result in negligible risk to biota, their functions, or any interactions that are integral to sustaining the health of ecosystems and the designated resource uses they support (CCME 2013; BC ENV 2019). Similarly, objectives are specific criterion adapted to protect the most sensitive designated water use at a specific location with an adequate degree of safety, taking local circumstances into account (BC ENV 2017). An exceedance of a water quality guideline or objective does not necessarily mean that there will be effects on aquatic species.

The following discussion of dissolved and total metals is focussed on metals of interest. These metals were selected based on previous reports, and on significant differences between near-field and reference sites over the study years (Table 4-4).

Table 4-4: Matrix for Determining Water Quality Metals of Interest.

Metal	Metals of interest identified in previous reports	Near-field sites >> reference sites in earlier work (2011-14)	Near-field sites >> reference sites in recent 2015-16 work	Guideline exceedance during past 10 years in LCR AOI
Aluminum				✓
Arsenic	✓	✓		✓
Cadmium	✓	✓	✓	✓
Chromium	✓			✓
Copper	✓	✓		✓
Lead	✓	✓	✓	✓
Mercury	✓	✓	✓	✓
Nickel	✓			✓
Selenium		✓	✓	✓
Silver	✓			
Thallium	✓	✓	✓	
Zinc	✓	✓		✓

(Previous reports: Golder 2003, Hatfield 2008, Golder 2010)
>> signifies a difference of >50% this table uses new cadmium guideline

Most figures in this report depict total metal concentrations (as opposed to dissolved metals) to align with BC WQG and LCR objectives; however, metals occurring mainly in particulate phases can frequently have lower potential toxicity. Numerous metals occurred predominantly in the dissolved form throughout the LCR (Table 4-5). Within the IDZ, cadmium, lead, and thallium and had an increased proportion of total concentrations in the dissolved phase.

Table 4-5: Percent of total analyte concentration accounted for by dissolved phase metals in the LCR 2011-2018.

	Average % dissolved metals					
Metal/Site	BB	SC	NB	OB	MA	WA
Aluminum	49%	48%	41%	38%	38%	48%
Arsenic	99%	96%	89%	94%	94%	92%
Cadmium	75%	79%	84%	80%	71%	86%
Copper	96%	90%	85%	84%	85%	85%
Lead	25%	25%	38%	28%	26%	33%
Mercury			29%			
Selenium	98%	91%	88%	86%	87%	87%
Silver	97%	94%	98%	92%	98%	92%
Thallium	79%	85%	97%	98%	100%	97%
Zinc	90%	88%	90%	87%	92%	87%

Legend: BB = Birchbank; SC = Stoney Creek; NB = New Bridge; OB = Old Bridge; MA = Maglios;
WA = Waneta

No exceedances of the short-term acute or long-term chronic Water Quality Guidelines or LCR Objectives occurred for any metals of interest downstream of the IDZ in 2018. Within the IDZ, the spring 2018 30-day average cadmium and selenium concentrations exceeded the long-term WQG at New Bridge r-sh (Table 4-6). As these elevated concentrations were within the IDZ, they do not constitute non-attainment.

Table 4-6: Observed exceedances in the LCR 2018 water quality data.

		Exceedances	
Metals	**Units**	**Within the Initial Dilution Zone**	**Downstream of the Initial Dilution Zone**
Cadmium – dissolved	mg/L	Yes	No
Selenium – total	mg/L	Yes	No

4.1.3.1 Comparison of total, dissolved and BLM metal guidelines

Implementation of metals criteria is complex due to the site-specific nature of metals toxicity and variable metal behavior. Canadian guidelines frequently use total metals, which is the sum of dissolved ions and metals associated with particulates or minerals, while the US EPA frequently uses dissolved metals. Studies have indicated that particulate metals appear to contribute to overall metal toxicity, but their contribution is substantially less than that of dissolved metals (US EPA MoU 1993).

The following section focuses on the results of 2018 sampling for total metals of interest and discusses historical data and trends. Complete water quality data are available in Appendix C accompanied by QA/QC outputs in Appendix D. The box plots below present 2018 low flow sampling data.

4.1.4 Aluminum (Al)

Spring low flow dissolved Al concentrations did not exceed the BC long term average allowable concentration at any of the six sample sites (Figure 4-10). Similarly, no Al exceedances were detected in the 2018 fall transect sampling (Figure A22). All samples were above the limit of detection for D-Al.

A declining trend in Al concentrations has been detected throughout the LCR in data collected from 1983-2005 at Birchbank (Can. BC 2008), although a significant declining trend was not apparent in the 2012-2018 R-sh spring low flow data. The highest Al concentration during the spring low flow sampling occurred at the Birchbank upstream reference site, and the lowest at Waneta.

The highest aluminum concentrations were documented during the July high river flow periods. This is likely a result of increased aluminum being carried downstream by freshet flows in tributaries associated with increased erosion, channel scour, turbidity, and TDS. No influence of the smelter was detected in the 2011-2018 water quality data.

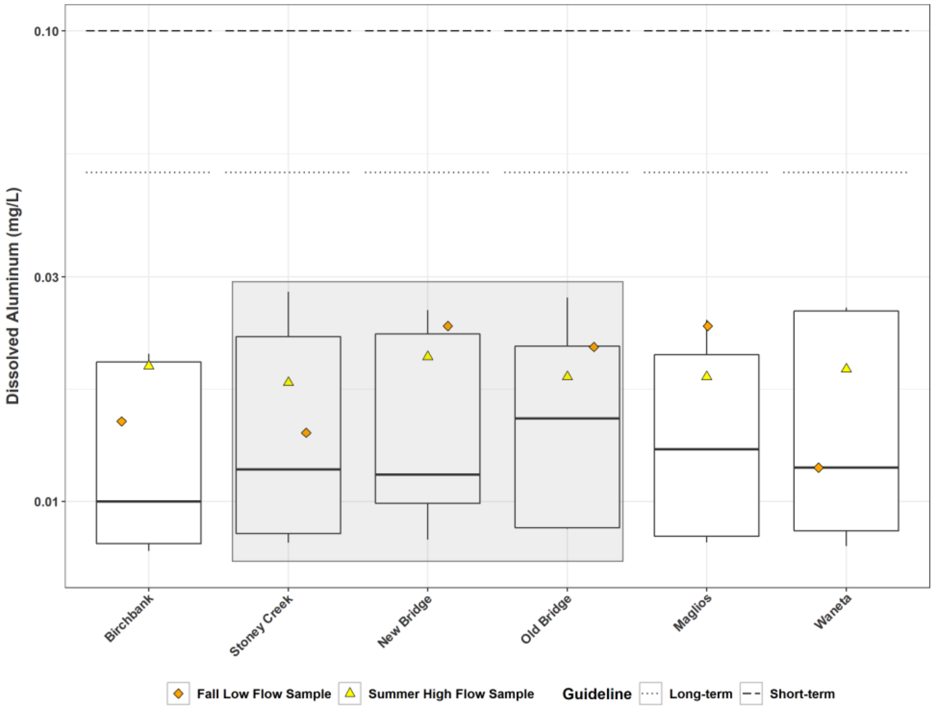


Figure 4-10: Box plots of D-Al measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. All samples were above the limit of detection for D-Al.

4.1.5 Arsenic (As)

Both the 30-day average LCR Objective and the BC WQG short-term maximum concentration of arsenic has been set at 0.005 mg/L (5 µg/L) T-As to protect fish and aquatic life (BC ENV 2005). T-As within the IDZ, notably at the R-sh sites, was elevated above background concentrations and was attributable to smelter effluents and possibly groundwater inflows. No 2018 samples exceeded the Objective, even within the IDZ, as has been observed in previous years (Figure 4-11; Figure A24; Hawes et al. 2019). Arsenic concentrations were highest in the Stoney Creek right shallow samples in 2012-2015 and 2017-2018. In 2018, arsenic concentrations noted within the IDZ were fully mixed by Waneta and were within 11.2% of the average right shallow reference site concentrations by Maglios.

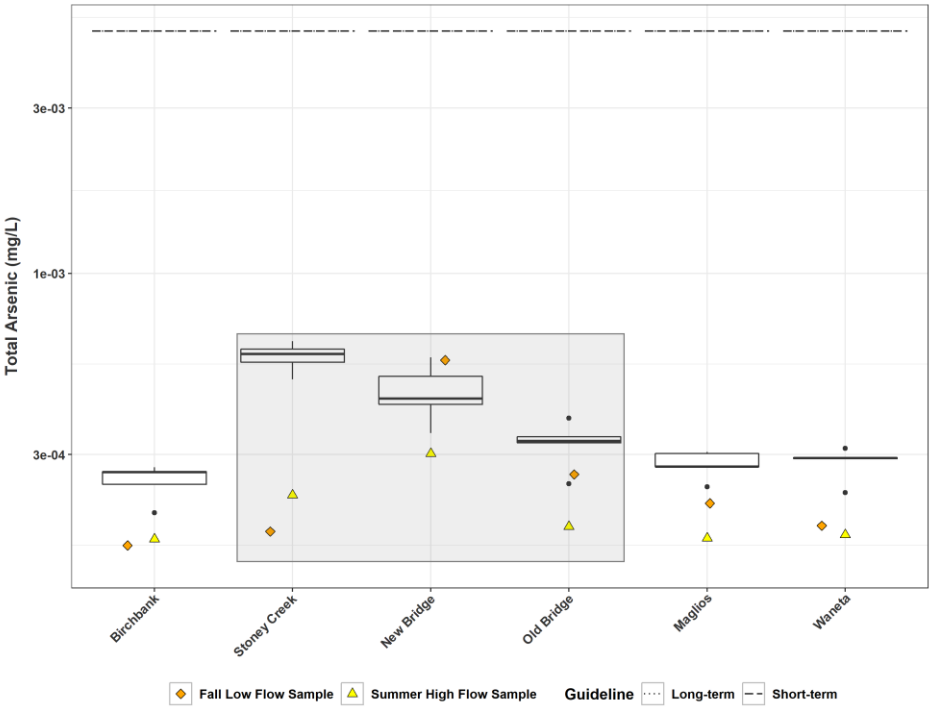


Figure 4-11: Box plots of T-As measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. All samples were above the limit of detection for T-As. The dashed line displays the BC short-term maximum concentration of 0.005 mg/L for total As, which is also the 30-day average allowable LCR Objective.

4.1.6 Cadmium (Cd)

The formula-based dissolved cadmium (D-Cd) Guidelines (BC ENV 2015) were applied to 2018 water quality data (Figure 4-12). These formulae use measured total hardness to calculate the site-specific short and long-term D-Cd Guidelines. Since 2011, the measured total hardness at Birchbank (background) has averaged about 66 mg/L as $CaCO_3$. Applying this value, the long-term chronic guideline would be 1.56 E-04 mg/L and the short-term maximum would be 3.84 E-04 mg/L.

All New Bridge R-sh samples collected during 2018 spring and fall low flows exceeded the BC long-term chronic concentration for dissolved Cd. However, no samples exceeded the BC short-term maximum Guideline. During summer high flows, the New Bridge R-sh sample was below the long-term guideline. There were no sample exceedances of the short or long-term Guidelines at Old Bridge or further downstream beyond the IDZ.

As in the 2011-2017 data, 2018 data showed the highest dissolved Cd concentrations in New and Old Bridge right bank (R-sh) samples, that are within the IDZ (Figure A25). These R-sh samples are depicted in Figure 4-12.

In both the 2011-2014 and the 2015-2016 data sets, elevated dissolved cadmium concentrations from the IDZ remained elevated along the right bank at Maglios, but not by Waneta (Hawes et al. 2019). However, in 2018 spring low-flow samples, D-Cd remained elevated above the reference Birchbank site concentrations at both Maglios and Waneta. Transect studies indicated that the mixing through the channel was close to, but not fully complete at the Maglios site while complete mixing was evident at Waneta (Hawes et al. 2019). Reasons for the slightly elevated D-Cd concentration at Waneta are not known at this time.

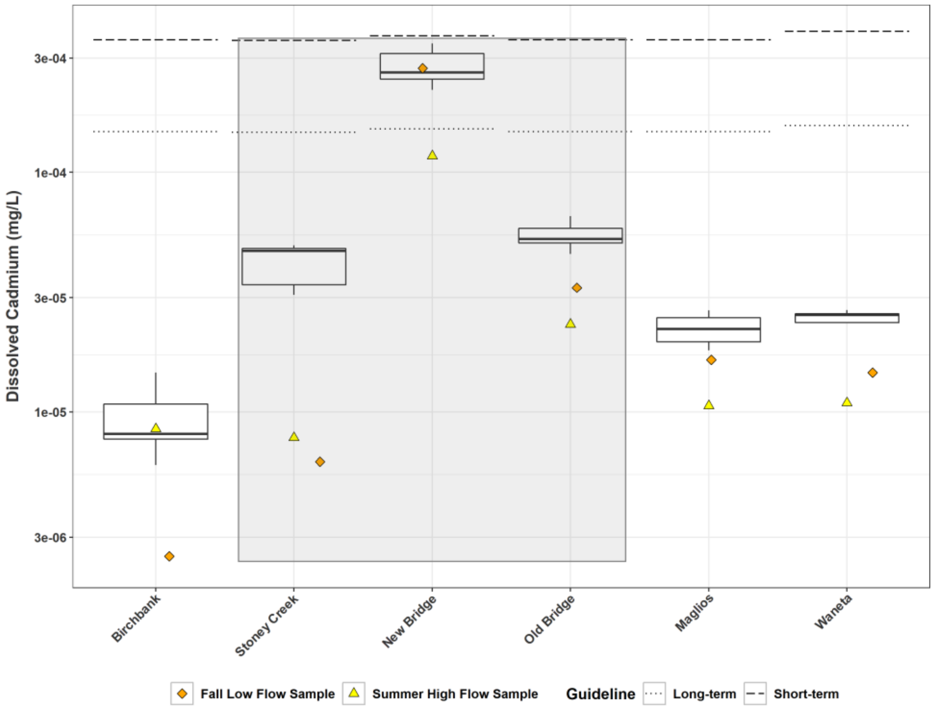


Figure 4-12: Box plots of D-Cd measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. 15 percent of samples were below the limit of detection for Cd. Dashed lines represent calculated guideline values.

4.1.7 Chromium (Cr)

Like 2011-2017 data, only 4% of the 2018 water quality data was above the limit of detection for chromium. No exceedances of the Water Quality Guidelines for Cr occurred in any samples collected in the AEMP from 2011-2014, and the only exceedance in the 2015-2016 data occurred mid-channel at the Birchbank reference site in July 2016 (Hawes et al. 2019).

A 30-day average LCR objective of 0.001 mg/L (1.0 µg/L) for total chromium was set for the protection of fish and aquatic life. No short-term water quality objective was established for Cr (BC ENV 1997). As shown in Figure 4-13, concentrations of total Cr at all 6 sites did not exceed the 30-day average LCR objective for total Cr. Similarly, no fall 2018 transect T-Cr samples approached the Cr guideline (Figure A26). Thus, no influence from the smelter was detected in the Cr data from 2011 - 2018.

Total chromium concentrations have declined in BC ENV data collected at Birchbank between 1983 and 2005 (Can.-BC 2008). Current Waneta T-Cr concentrations were lower than historical concentrations and were mostly below the limit of ultra-low metal detection of 0.0001 mg/L.

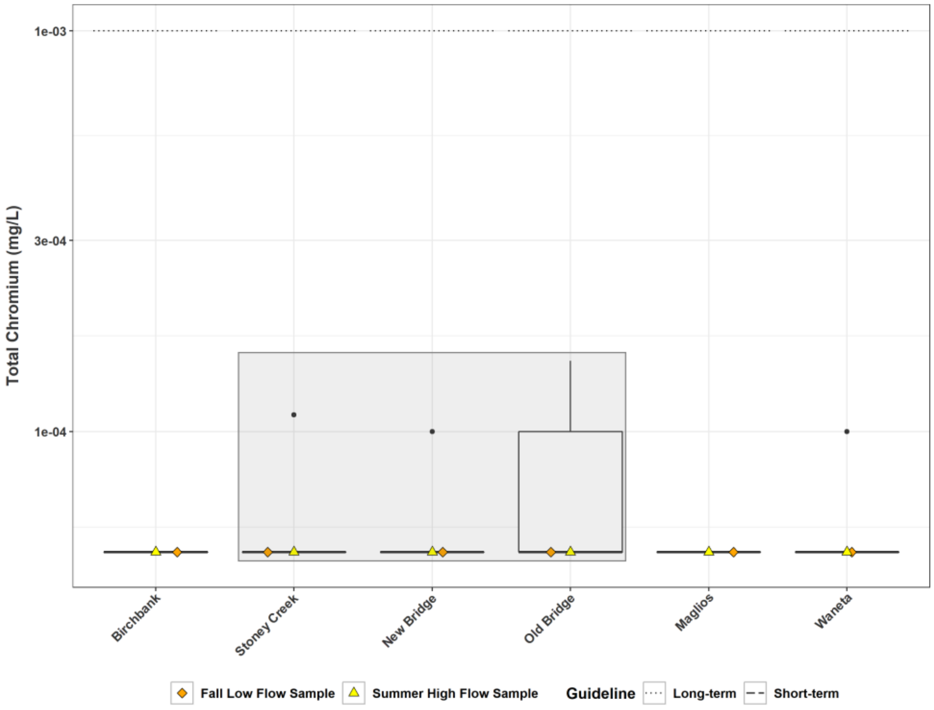


Figure 4-13: Box plots of T-Cr measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. 93 percent of samples were below the ultra-low limit of detection for T-Cr. Dashed lines represent calculated guideline values.

4.1.8 Copper (Cu) and Future Use of Biotic Ligand Model

ENV changed the model used for deriving acute and chronic guidelines for aquatic exposure to copper on August 15 2019. The old model, established in 1987, used a formula to calculate a total copper guideline based on water hardness. The new 2019 copper guideline uses the Biotic Ligand Model (BLM) to define metal toxicity over a range of water chemistry by defining when the metal-biotic ligand complex reaches a critical concentration. The Biotic Ligand Model (BLM) uses recent research to derive site-specific and sample-specific dissolved copper guidelines for many species found in BC. The BLM model is calibrated to work within specific ranges for the various parameters. These ranges are typical for most natural waters. The BLM software generates a lowest effect level (LEL) concentration for numerous species found in BC. According to the guidance documents, the proposed guideline should be ½ of the lowest LEL concentration. This method ensures that even the most sensitive species are protected.

The BLM model requires dissolved organic carbon analyses (DOC), but this parameter was not analyzed in samples collected to date. DOC data will be collected in future AEMP sampling programs. This report therefore uses the previous T-Cu guideline.

Both above and below the smelter, copper occurs primarily in the dissolved form. Elevated copper concentrations have been measured on both sides of the river in the IDZ at New Bridge suggesting groundwater influence in addition to smelter effluents (Hawes et al. 2019).

A 30-day (long-term) Water Quality Objective of 0.002 mg/L (2.0 µg/L) and short-term of 0.00717 mg/L T-Cu (7.17 µg/L) was set in 1997 for the protection of fish and aquatic life in the LCR (BC MoE 1997). Even within the IDZ, the average long-term T-Cu concentrations have not exceeded the 30-day Objective since 2011 (Figure 4-14).

Using the old T-Cu guideline, no exceedances occurred within or outside the IDZ in 2011 – 2018 sampling (Figure 4-14). The 2018 copper distribution across the channel was similar to earlier AEMP sampling, where values downstream at Maglios R-sh were within 23.4% of background levels measured at Birchbank. The highest value found in the Fall 2018 samples was New Bridge R-sh (Figure A27).

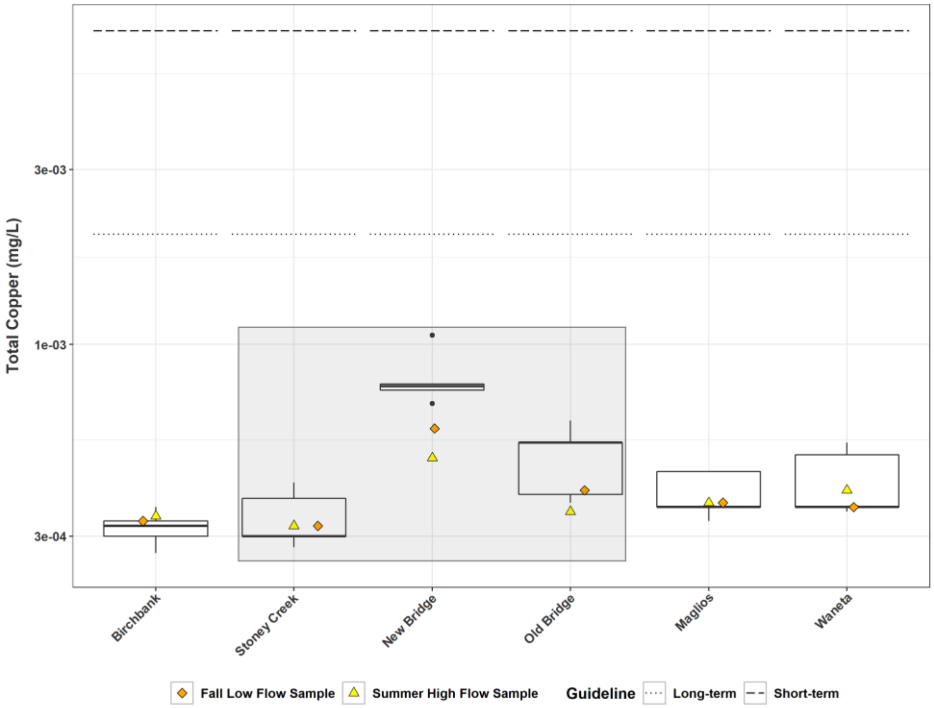


Figure 4-14: Box plots of T-Cu measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. No samples were below the ultra-low limit of detection for T-Cu. Dashed lines represent calculated guideline values.

4.1.9 Lead (Pb)

No samples exceeded either the short-term or the long-term Water Quality Objective for total lead (T-Pb) in the 2018 data. Elevated T-Pb concentrations above background were measured at Stoney Creek, New Bridge, and Old Bridge in 2018 and in earlier datasets (Hawes et al. 2019).

Water Quality Objectives for the LCR set a short-term allowable concentration of total lead at 0.0379 mg/L (37.9 μg/L) to protect fish and aquatic life. The long-term T-Pb Objective is 0.0048 mg/L. All AEMP water sampling to date (2011–2018) indicated the highest average lead concentrations occurred within the IDZ in right bank samples (Figure 4-15). Most of this lead occurred in the less bio-available particulate form.

Unlike historical data, no samples exceeded the calculated BC WQGs for short-term or long-term average for lead or the LCR Water Quality Objectives in AEMP studies. Consistent with 2011-2017 observations (Hawes et al. 2014; Hawes et al, 2019), average lead concentrations remained slightly elevated at Waneta compared to the Birchbank reference site in 2018 (Figure A29).

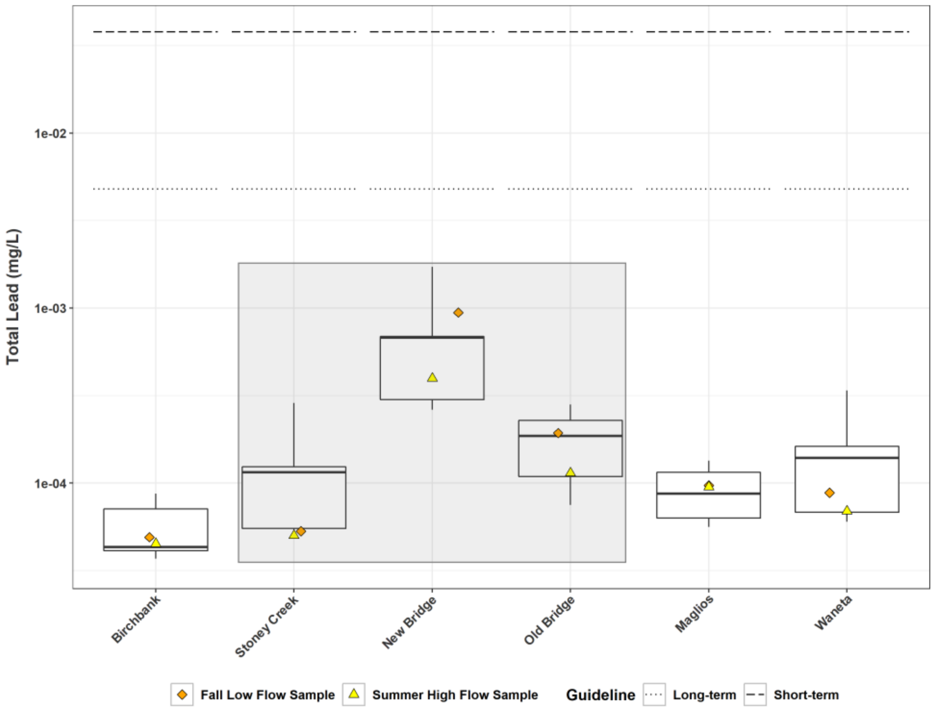


Figure 4-15: Box plots of T-Pb measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. No samples were below the ultra-low limit of detection for T-Pb. Dashed lines represent calculated guideline values.

4.1.10 Mercury (Hg)

There were no exceedances of the short-term guideline for total mercury (T-Hg) at any sites and no exceedances of the long-term guidelines either within or outside of the IDZ (Figure 4-16). The 2017 BC short-term WQG for total mercury was set at 0.0001 mg/L (0.1 µg/L), with a long-term guideline of 0.00002 mg/L T-Hg (0.02 µg/L) when methylated Hg (MeHg) = 0.5% of T-Hg. Further analysis needs to be performed to confirm percentage of MeHg in water samples. Like aluminum, historical mercury concentrations occasionally exceeded the BC short-term Guideline both above and below the smelter (Hawes et al. 2014; Hawes et al. 2019), while in the 2018 data, there were no exceedances. Similar to 2011-2017 data, 2018 total mercury concentrations were elevated above reference levels inside the IDZ but returned to near background levels by Maglios (Figure 4-16; Figure A30). 76% of 2018 samples had non-detectable (<0.0005 µg/L) T-Hg concentrations, even with the ultra-low metal analyses.

No Water Quality Objective for mercury was set for the LCR.

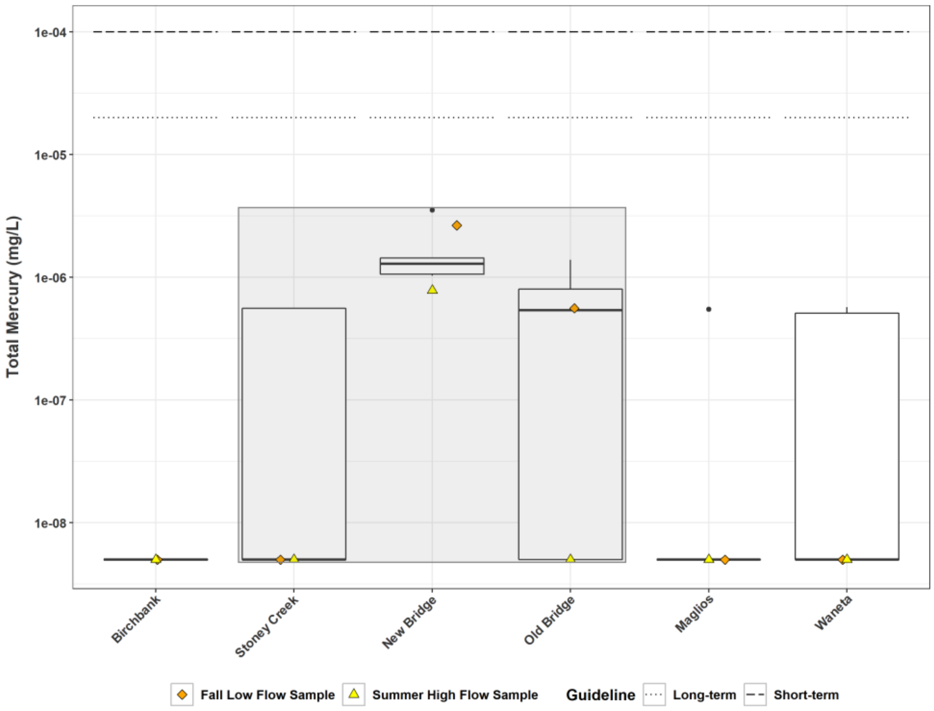


Figure 4-16: Box plots of T-Hg measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. 76% of 2018 samples were below the ultra-low limit of detection for T-Hg. The dashed line displays the BC short-term allowable concentration of 0.0001 mg/L and the dotted line displays the BC long-term allowable concentration of 0.00002 mg/L for total Hg.

4.1.11 Nickel (Ni)

No exceedances were detected in any 2011–2017 or 2018 samples collected above or below the smelter in the LCR area of interest including within the IDZ (Figure 4-17). The nickel short-term maximum LCR Objective was established for the protection of fish and aquatic life and ranges between 0.0025 - 0.150 mg/L T-Ni. The BC long-term WQG is a hardness-based calculation and is shown in (Figure 4-17).

Total nickel concentrations at Maglios were within 1.6% of the reference Birchbank site in 2018, similar to earlier years of study. Most of the nickel in LCR samples is present in the dissolved form. Differences between nickel samples along the fall 2018 low flow river transect at every site were small (Figure A31).

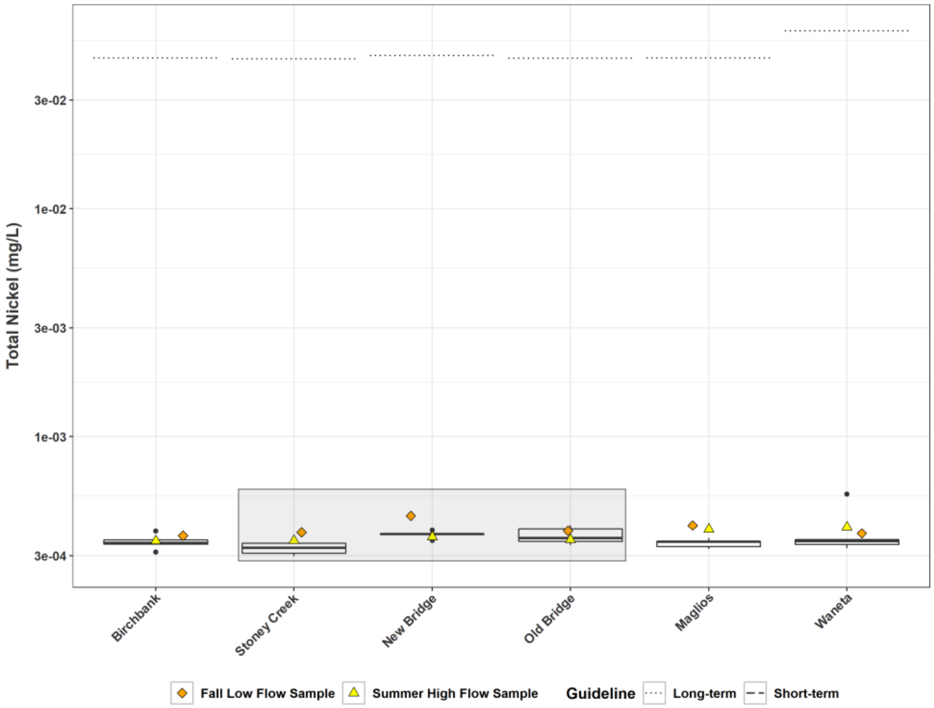


Figure 4-17: Box plots of T-Ni measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. None of the 2018 samples were below the ultra-low limit of detection for T-Hg.

4.1.12 Selenium (Se)

The water quality guideline for the protection of aquatic life set the short-term guideline for Se at 0.002 mg/L T-Se (2 µg/L) and an alert level at the long-term average of 0.001 mg/L T-Se (1 µg/L) (BC MOE 2014).

In 2018, exceedances of the T-Se short-term acute guideline occurred only within the IDZ at the New Bridge R-sh site, on April 18th and 19th (Figure 4-18) (Figure A36). Elevated Se within the IDZ does not constitute a permit exceedance.

The BC ENV long-term chronic T-Se Guideline was exceeded in 2018 and 2015 at the New Bridge right bank shallow (r-sh) site, and in 2016 at both the New Bridge and Old Bridge r-sh sites. At New Bridge and throughout the LCR, Se occurred mainly in the dissolved form.

T-Se remained far below the short-term guideline outside of the IDZ in 2018. At Waneta, where complete mixing of the effluent plume is achieved, T-Se averaged 0.079 ug/L (27% higher than Birchbank). No exceedances of T-Se occurred outside the IDZ in sampling to date.

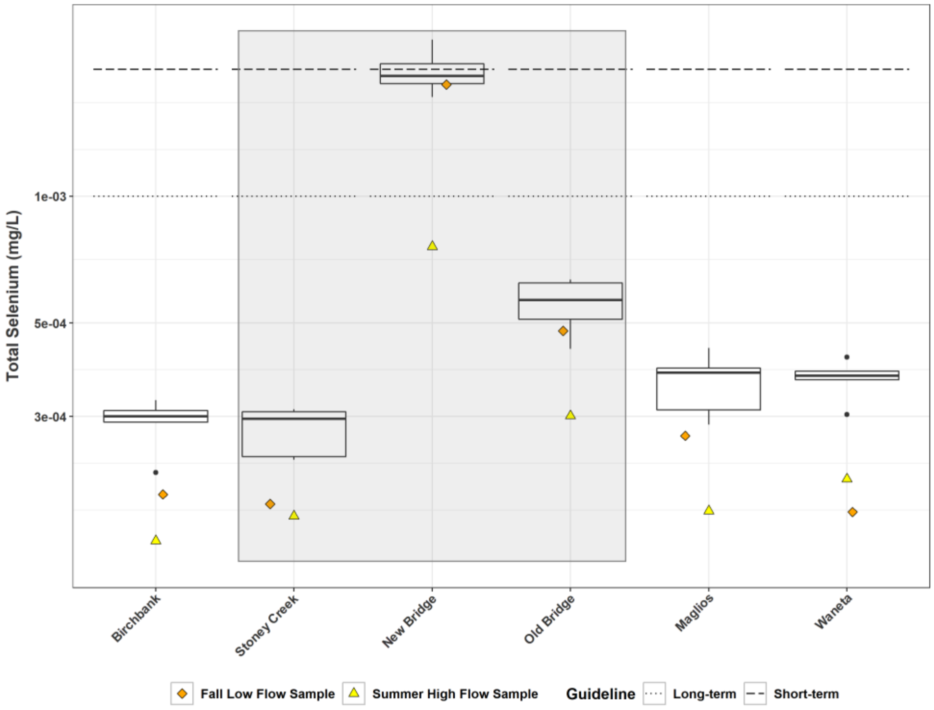


Figure 4-18: Box plots of T-Se measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. None of the 2018 samples were below the ultra-low limit of detection for T-Se. Recent revisions have set the short-term acute water quality guideline for Se at 0.002 mg/L T-Se (2 µg/L) and an alert level at the long-term average of 0.001 mg/L T-Se (1 µg/L) for the protection of aquatic life (BC ENV 2014).

4.1.13 Silver (Ag)

Like previous years, only 2% of samples gave measurable silver (T-Ag) results even when analyzed using ultra-low metal analyses. No samples collected from 2011-2018 have exceeded either short-term or long-term Water Quality Guidelines for silver with one exception. The fall Birchbank upstream reference transect samples exceeded the BC short-term allowable concentration for total Ag at R-sh, R-1m above bottom and L-sh (Figure A37). The concentration of dissolved Ag for these Birchbank fall 2018 samples was below the limit of detection.

The BC WQG for total silver is hardness-dependent. For waters with hardness <100 mg [$CaCO_3$]/L, a short-term guideline of 0.0001 mg/L T-Ag (0.1 µg/L), and a long-term (30-day mean) of 0.00005 T-Ag (0.05 µg/L) was recommended by BC ENV (2017) for the protection of freshwater fish and aquatic life.

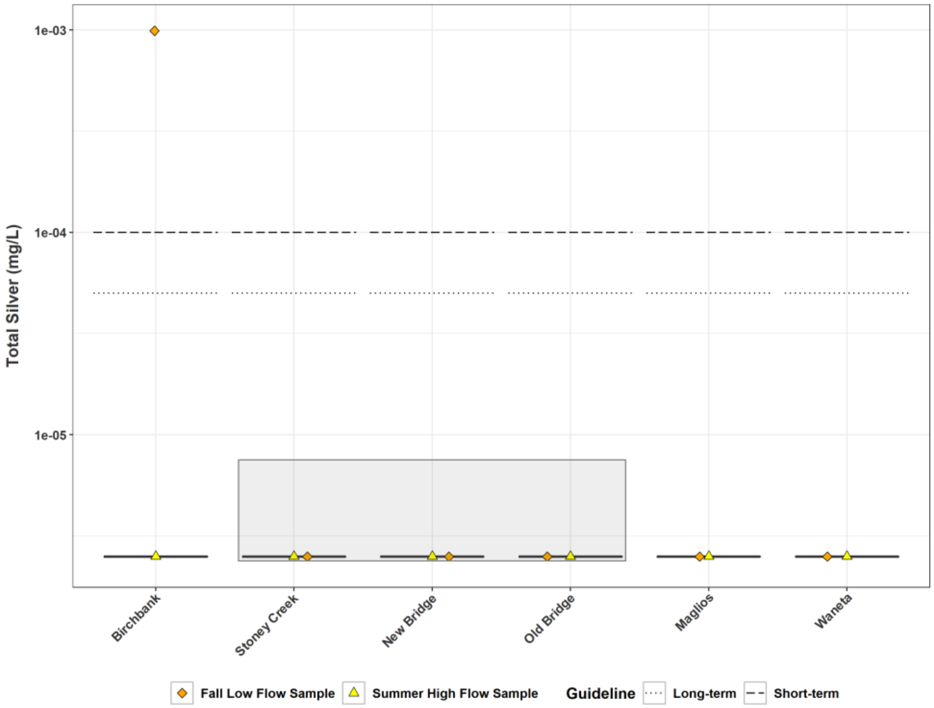


Figure 4-19: Box plots of T-Ag measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. 96% of the 2018 samples were below the ultra-low limit of detection for T-Ag.

4.1.14 Thallium (Tl)

There were no exceedances of the long-term Objective for total thallium (T-Tl) outside the IDZ during 2018. The provisional long-term LCR Water Quality Objective for total thallium of 0.0008 mg/L (0.8 µg/L) was recommended by BC ENV (1997) for the protection of fish and aquatic life. There is no short-term acute Objective for thallium.

The spring 2018 30-day average concentration at New Bridge R-sh met the long-term chronic Objective. Some individual sample concentrations at New Bridge r-sh were above the Objective in 2018, but only the 30-day average is comparable to the Objective (Figure 4-20).

Similar to 2011-2017 data, elevated T-Tl concentrations were measured at New Bridge and Old Bridge in 2018. These studies have not shown exceedances of the long-term Objective for T-Tl outside the IDZ (Figure A39). Tl was predominantly in the dissolved form.

The distribution of thallium concentrations across transects was similar in the 2011-2017 data and the 2018 data. These results all showed increased Tl in the effluent plume path, and effective but incomplete mixing by Maglios, and full mixing by Waneta.

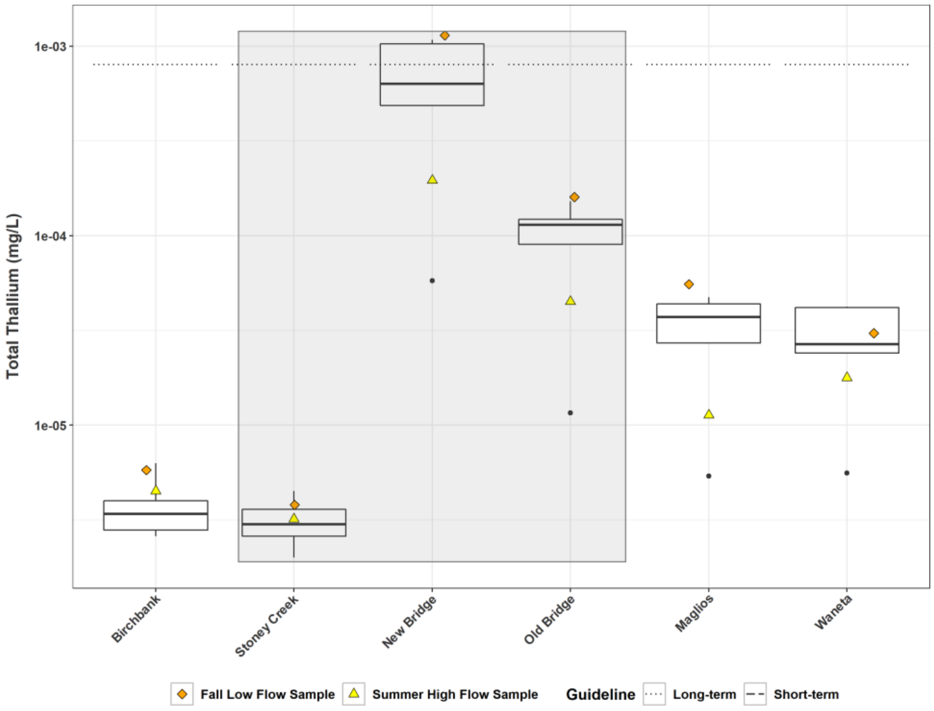


Figure 4-20: Box plots of total Tl measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. No samples were below the limit of detection for Tl. The dotted line displays the working BC and LCR long-term allowable concentration of 0.0008 mg/L for total Tl.

4.1.15 Zinc (Zn)

No zinc exceedances occurred at any site outside the IDZ in Spring or Fall low flow samples collected from 2011-2018. Elevated T-Zn concentrations were consistently measured along both the right bank and to a lesser extent, the left bank at New Bridge and Old Bridge. However, none of the values measured have exceeded the LCR long-term chronic, or the LCR short-term maximum concentration for total Zn. Within the IDZ, samples at New Bridge exceeded the BC long-term guideline but does not represent non-attainment of the Permit (Figure 4-21; Figure A42). Maglios Fall 2018 low flow samples indicate thorough T-Zn mixing, and the Waneta samples were 51% above the reference Birchbank site (Figure A42).

Water Quality Objectives for the LCR, set the short-term maximum concentration of total zinc (T-Zn) at 0.033 mg/L (33 µg/L) to protect fish and aquatic life and other water uses (BC ENV 2005). The long-term chronic Guideline is 0.0075 mg/L T-Zn. Throughout the LCR area of interest, zinc occurs primarily in the dissolved form.

In the 2011-2017 Fall low flow data, the R-sh samples showed elevated zinc at the upstream Birchbank site (Hawes et al. 2019). Within the IDZ, the main source of T-Zn is smelter effluent.

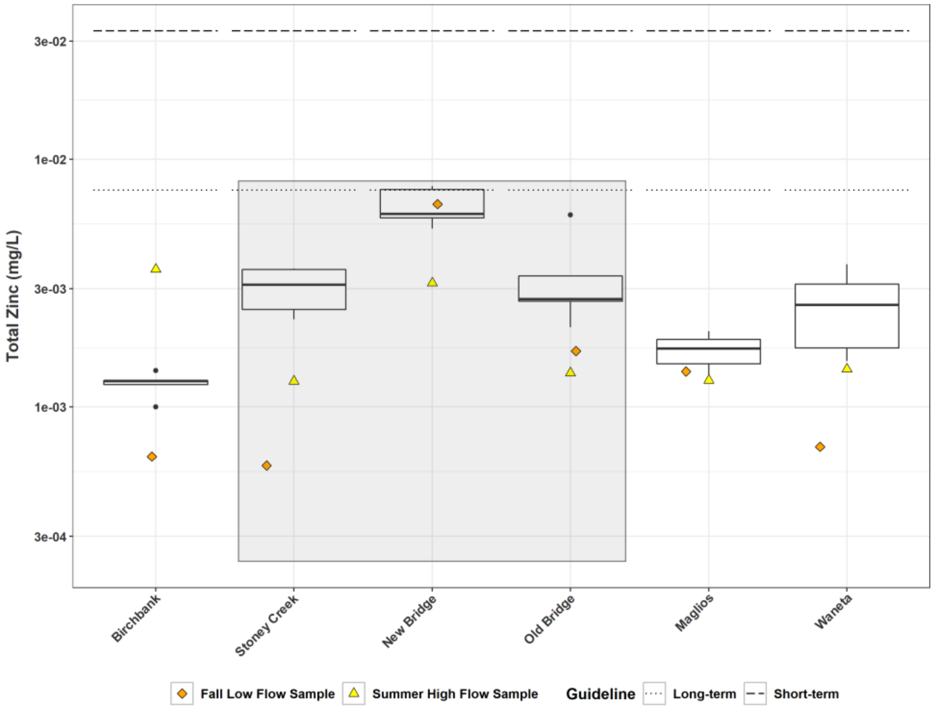


Figure 4-21: Box plots of T-Zn measured in R-sh position during 2018 March-April. Points correspond to 2018 fall and summer R-sh samples. The grey box represents the Initial Dilution Zone. 1% of the 2018 samples were below the ultra-low limit of detection for T-Zn.

4.1.16 Annual Variability and Trend Analysis

The spring sampling sessions are designed to target a low flow period where metal concentrations in the water column should be the least diluted. However, the LCR is a regulated river and flows were higher during some of the sampling events and years. For example, all the 2017 spring sampling events occurred on days that had a mean daily discharge of >2000 m^3/s (Table 4-7). Spring sampling events during higher discharges can influence metal concentrations. Variations in discharge between sampling events make it difficult to compare annual differences and trends in spring metal concentrations.

Table 4-7: Birchbank flow summary for spring water quality sampling events (2012-2018).

Year	Mean ± Standard Deviation of Flow (m^3/s)
2012	1874 ± 400.3
2013	1540 ± 58.42
2014	1635 ± 271.7
2015	1523 ± 281.8
2016	1108 ± 78.46
2017	2185 ± 95.87
2018	1108 ± 8.304

Multiple linear regression models were used to evaluate the relationship between water quality parameters and flow at New Bridge R-sh. Concentrations of ammonia, nitrate, sulfate, As, Cd, Cu, Se and Tl at New Bridge R-sh were lower at higher flows (Figure A16-Figure A20). There were no observed relationships between concentrations of Fe, Pb, Hg and Zn and mean daily flow at Birchbank (Table A43).

The highest number of BC long-term WQG exceedances was in 2016, including a long-term exceedance of dissolved selenium at Old Bridge R-sh (Hawes et al. 2019; Figure 4-22). The spring 2016 and 2018 sampling events had the lowest mean flows compared to other years (Table 4-7). Despite having similar flows, spring 2018 had less water quality exceedances than spring 2016. However, T-Ni concentrations were elevated in all 2018 right bank shallow samples compared to 2012-2017 right bank shallow samples, including the Birchbank reference site (Figure 4-23). At New Bridge, Old Bridge and Waneta, 2018 T-Tl concentrations were elevated in 2018 right bank shallow samples compared to 2012-2017 samples from those sites (Figure 4-23). Unlike T-Ni, T-Tl was not elevated at the reference site in 2018 samples. Although T-Tl was elevated at exposure sites, it only exceeded BC water quality guidelines within the IDZ at New Bridge.

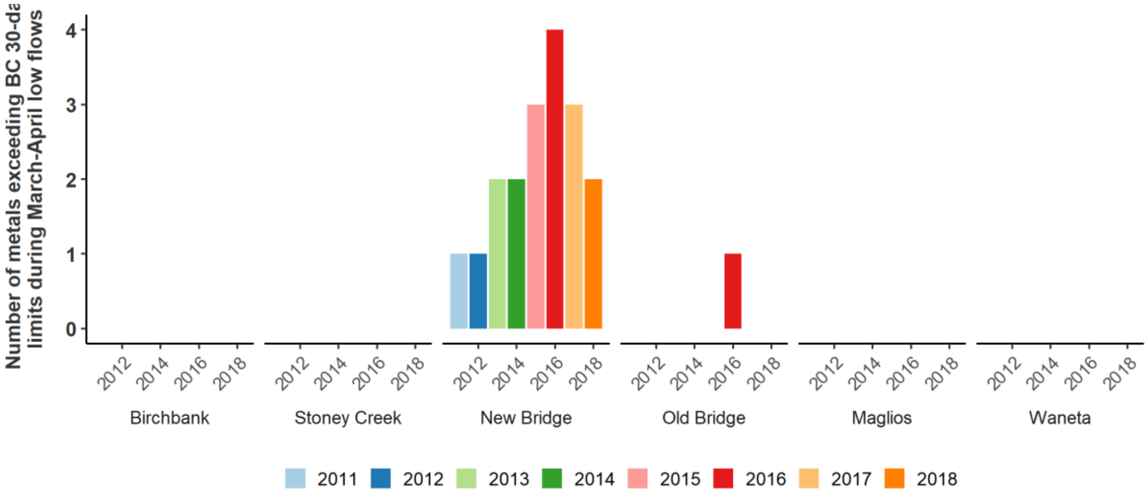


Figure 4-22: Total number of metals exceeding the BC long-term WQG for the March-April low flow periods from 2011 to 2018. Exceedances in the IDZ (Stoney Creek to Old Bridge) do not constitute non-attainment of Water Quality Objectives.

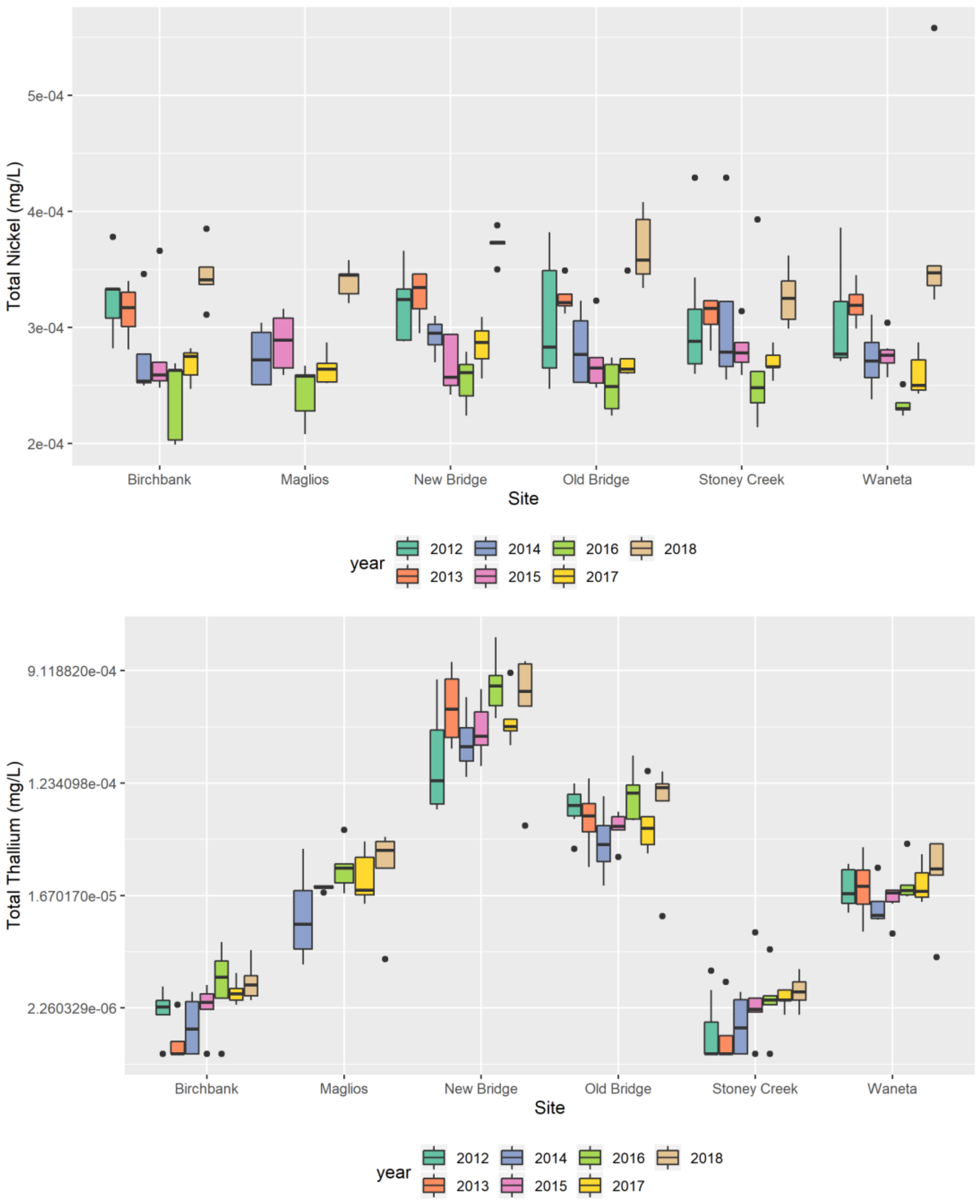


Figure 4-23: Spring right bank shallow samples from 2012-2018 for T-Ni and T-Tl.

The relationship between effluent loadings and metals concentrations at New Bridge between 2012-2018 was evaluated through multiple linear regression (Table A43). Generally, New Bridge concentrations did not show an association with effluent loadings, with the exception of As and Zn. Arsenic concentrations at New Bridge were positively associated with effluent loadings whereas Zn concentrations at New Bridge were negatively associated with effluent loadings (Figure 4-24). Fe and Hg also indicated a positive association, but this was driven by single data points and does not infer a significant relationship.

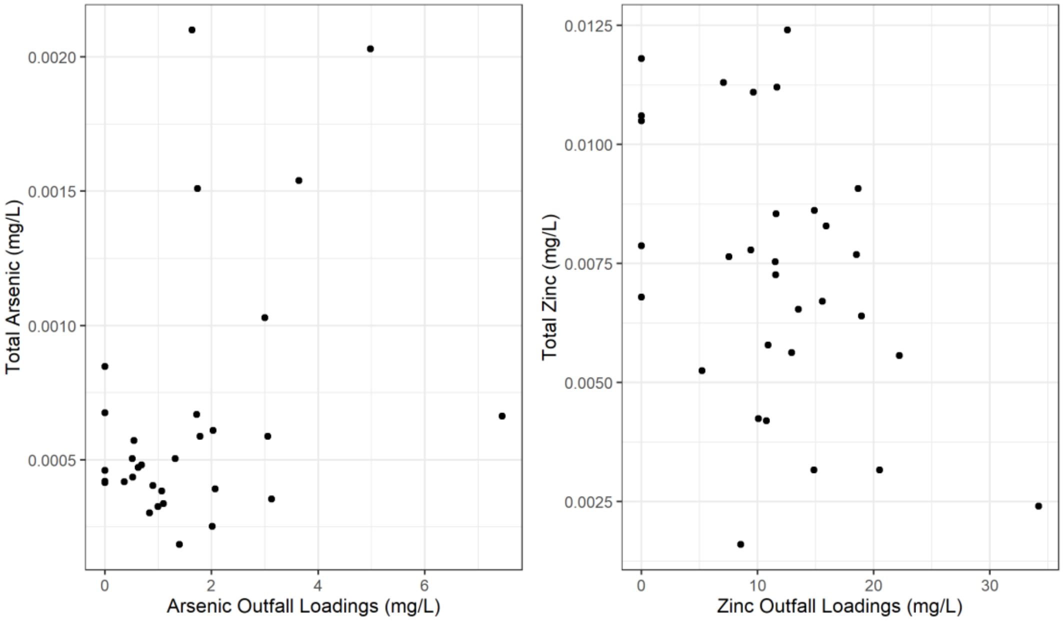


Figure 4-24: New Bridge R-Sh concentrations of Total As and Zn from 2012-2018 compared to outfall loadings from Stoney Creek, CIV, CIII and CII.

Flow-weighted concentrations of spring samples were used for trend analysis. Spring right bank shallow samples were the focus of the trend analysis because spring had continuous sampling from 2011-2018. The 2011 samples were excluded from analysis because a higher analytical detection limit was used in 2011. To account for the effect of flow, flow weighted-concentrations were calculated for the five spring sampling events for the right shallow samples. Maglios was not included in this analysis because Maglios was added to the AEMP in 2014.

The only two significant trends out of 95 analyses were for total selenium and dissolved cadmium. Results for all parameters are reported in Table A44. The flow-weighted concentrations of total selenium increased from 2012-2018 at Waneta (Table 4-8). Similar to Waneta, the reference site Birchbank had high flow-weighted total selenium concentrations in 2016-2018 (Figure 4-25). Other sites also had the highest flow-weighted selenium concentrations in 2016.

The flow-weighted dissolved cadmium concentrations increased from 2012-2018 at Stoney Creek (Figure 4-26). In 2016-2018, the flow-weighted cadmium concentrations were much higher compared to previous years at Stoney Creek (Figure 4-26). At the Birchbank reference site, flow-weighted cadmium concentrations were also high in 2016-2017. These two statistically significant trends are likely not related to the effluent because similar trends were observed upstream at the Birchbank Reference site.

Table 4-8: Mann-Kendall Parameters for spring long-term average from R-sh samples 2012-2018.

Site	Metric	Sample	tau	pval	n	Season
Waneta	T-Se	R-sh	0.714	0.0355	7	Spring
Stoney Creek	D-Cd	R-sh	0.714	0.0355	7	Spring

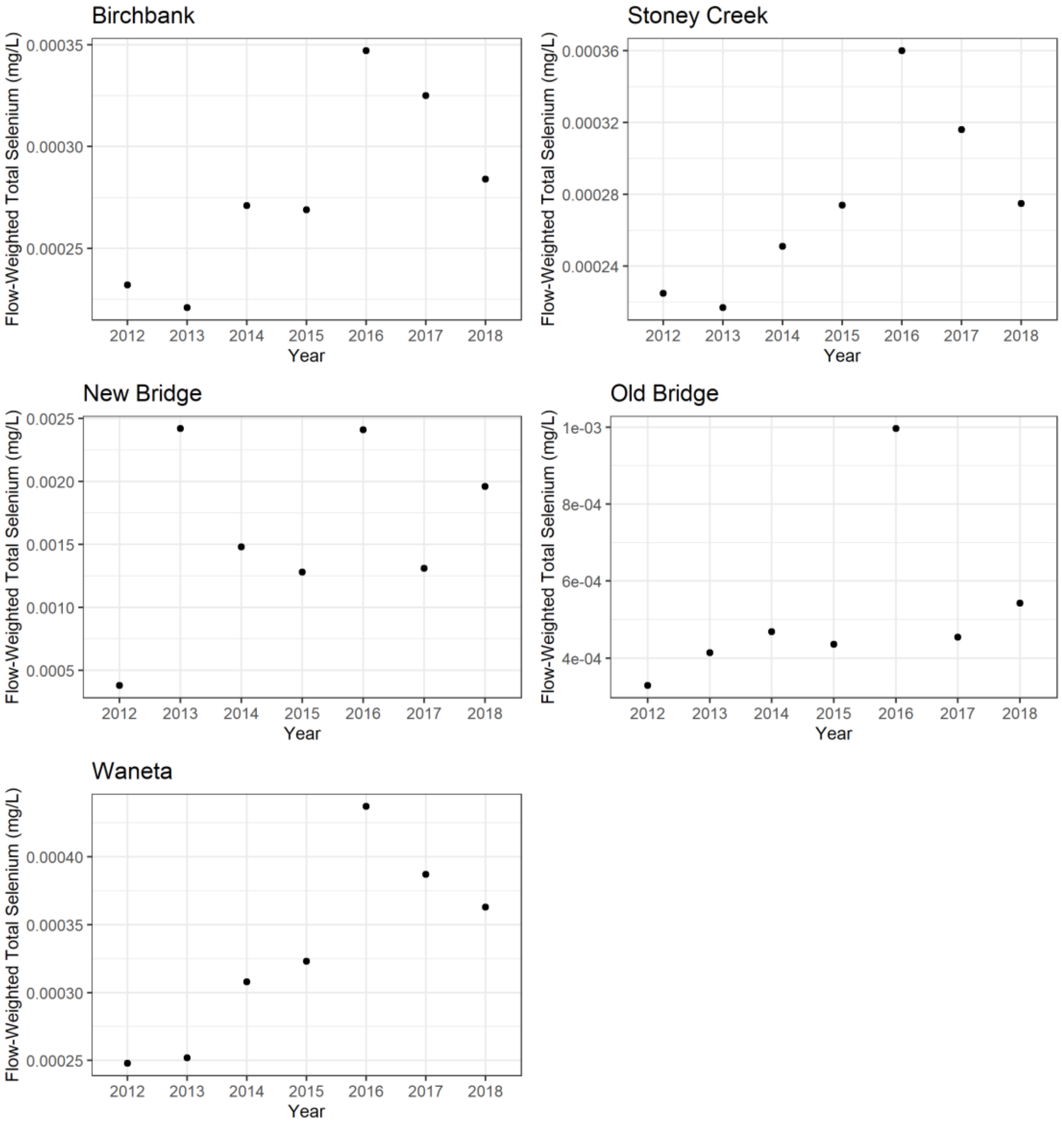


Figure 4-25: Spring flow-weighted concentrations of T-Se in R-sh samples from 2012-2018.

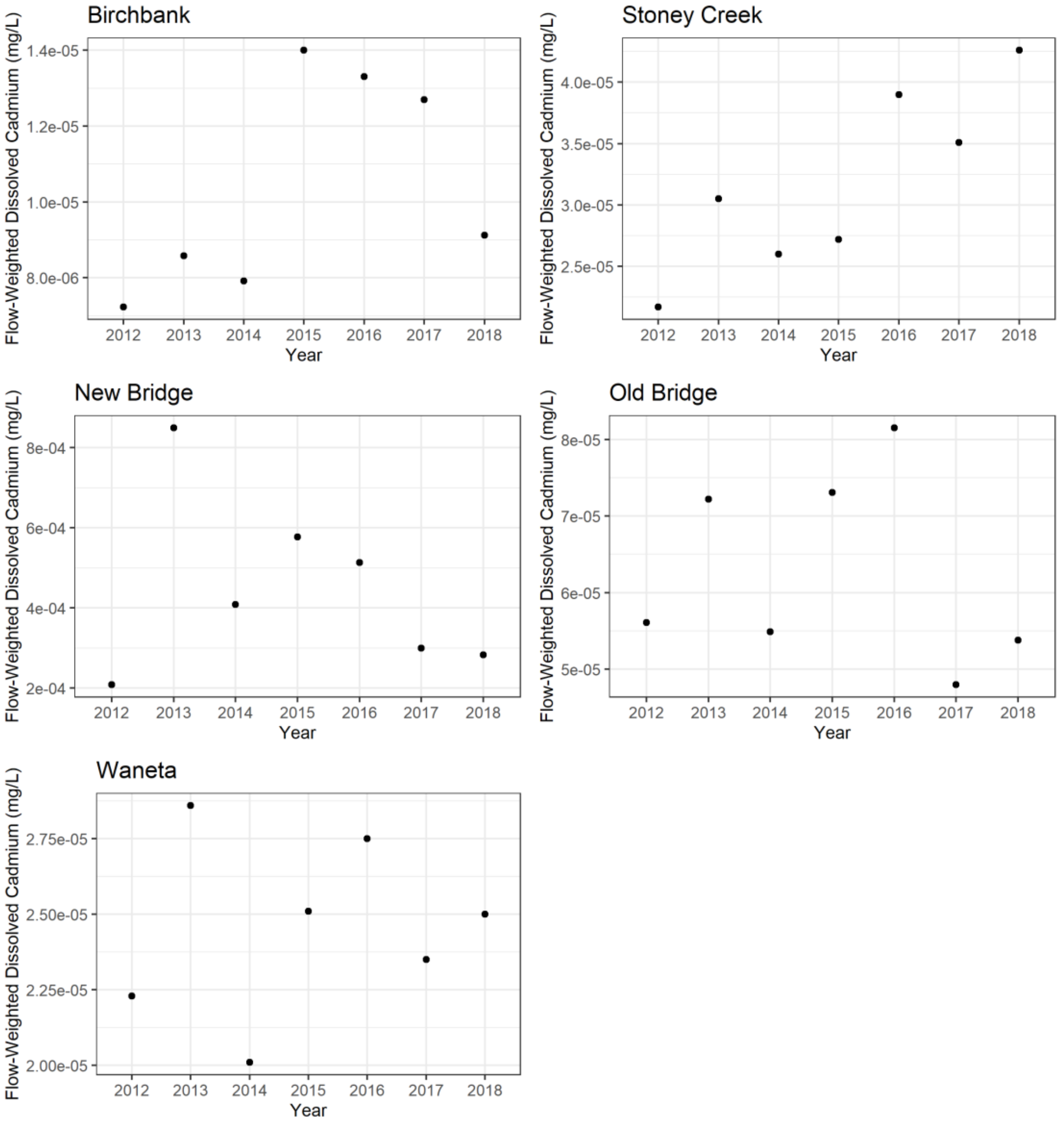


Figure 4-26: Spring flow-weighted concentrations of D-Cd in R-sh samples from 2012-2018.

4.1.17 Quality Assurance and Quality Control

In ultra-low metals detection, a small discrepancy between duplicate samples causes a relatively large percentage difference that can exceed the QC assessment criterion of 50%. The samples with >50% RPD (reportable detection limit) were less than 5 times the method limit of detection and therefore below the practical calculated limit. (Appendix D).

The resulting AEMP analytical values were suitable for addressing water quality objectives of this study. The residual analytical discrepancies did not interfere with data interpretation.

4.1.18 Summation

Provincial Water Quality Objectives were attained at the downstream end of the IDZ during low flows. The only exception was mercury and cadmium in 2012, which exceeded the objectives or guidelines at some of the reference sites upstream of the smelter as well as below the IDZ. Nutrient concentrations in the LCR below the IDZ were not significantly altered by the effluent discharges.

Water quality in the study area varied spatially and temporally but was not the sole result of the smelter's point source effluent discharges. Spatial variation was affected by non-point groundwater discharge and other non-smelter discharges. Temporal variation was affected by flows. The AEMP transect water quality sampling showed spatial variation in water quality within the IDZ but not at Waneta where full mixing is evident. The effluent plume hugs the right bank (~1/3 channel width or approximately 60 m) through to the downstream end of the IDZ.

The AEMP water quality monitoring study, conducted from 2011-2018, meets all requirements for assessing potential smelter-related impacts. It focusses on lower flow periods where mixing and dilution are reduced, and water quality impacts are expected to be greatest. Existing parameters and their reportable detection limits are appropriate for this study. In future sampling DOC analyses will be needed for calculation of the biotic ligand model for copper, since ENV introduced a new biotic ligand copper guideline in fall 2019 that requires the addition of DOC analyses.

4.2 Depositional Area Sediment Quality

Sediment quality is one aspect of the depositional habitat component of the monitoring program (Sections 4.3 and 4.4 review the periphyton and benthic invertebrate communities associated with the depositional habitats).

Hydrodynamics of the Columbia River in the study area create conditions where long-term depositional areas are expected to be rare (Golder 2003). The spatial extent of depositional habitat in the LCR is small, accounting for only 33 ha or 2% of the total area of the LCR between HLK Dam and the Canada - US border. In the study area, the area of depositional habitat was estimated to be 0.1% of the total sediment habitat (Golder 2007a). The importance of these depositional areas is therefore restricted by their small size (Golder 2007a). In addition, some of these depositional areas can become nearly to completely exposed/dewatered during low flows, reducing their contribution to the LCR as fish habitat and fish foraging areas. As demonstrated in the fish food analysis completed by Olson-Russello et al. (2019), fish species found in the LCR generally forage in erosional habitats where chironomids are present with minimal amounts of their diet deriving from depositional habitats.

Sediment chemistry of depositional areas in the LCR are distinct from erosional cobble substrates. Depositional sediments tend to develop lower dissolved oxygen, lower redox, high organic components and therefore, unique microflora communities dominated by decomposers.

Influences on sediment chemistry in depositional areas include historical and contemporary sources from smelter and non-smelter sources along with the dynamics of the river system. Depositional areas may still reflect the influences of historical practices as well as current effluent discharges and other inputs.

Each depositional site has its own character in contrast to the comparatively uniform erosional habitats, and the character of individual sites can change over time. This must be considered when interpreting sediment and benthic community results collected in this study.

4.2.1 Sediment Condition and Composition

Depositional sediments are dynamic. Sediment composition measured at the same LCR sites is variable between years, almost certainly as a function of flow regime. The percentage of fines in depositional sites in the silt/clay fraction were generally low, ranging from 0.7 to 36% (Hatfield 2008), from 3 – 23 % (Golder 2003), and between <1 – 9% in 2012 Hawes et al 2014). In all studies, the dominant material in the LCR depositional areas was coarse sand (Hawes et al. 2019). As this demonstrates, the sediment sample sites and depths within a depositional area are unlikely to be precisely matched between the sampling years.

In sediment sampling, a strong correlation between decreasing grain size and increasing metal concentrations is expected, making comparison of samples dominated by a sand fraction with one dominated by a silt fraction inappropriate (Wisconsin DoNR 2003). Sediment samples collected from reference sites since 2012 contained >94% sand, and exposure sites contained >92% sand, therefore reference and exposure samples can be compared.

Microscope evaluation of depositional sediments in 2012 through 2018 confirmed that the contribution made to the biofilm by algae was small compared to erosional periphyton biofilms, while the contribution made by bacteria and organic debris was greater. Together, these depositional sediment components exert an influence on metal concentrations and bioavailability at these small LCR depositional pockets.

It was very difficult to determine slag presence in the field and even with a microscope because differentiating between slag and other dark particulates was challenging; therefore, results should be interpreted with caution. Similarly, assumptions made in earlier reports that were based only on visual inspection in the field should be interpreted with caution. Thus, field visual slag identification and microscopic identification of residual slag remaining in the LCR AOI is tentative at best. With these limitations in mind, field and microscope estimates of the percent contribution of slag in the depositional sediments decreased as the years passed since the last slag discharge in 1995. Field estimates from depositional areas were higher in 2003 than microscope estimates from 2012 and estimates were lower still in 2015 and restricted to 1 or 2 particles per sample viewed in 2018. In recent years, dark particulates that appeared to be a slag-type material were only noted in DEP-Exp-2, and to a lesser extent, DEP-Exp-3 samples.

4.2.2 LCR Sediment Metal Content

In the LCR, sediments are confined to small depositional areas and to a much lesser extent, interstices between cobbles in erosional areas. Whole, composite sediment samples (excluding >2 mm) were subjected to sediment digestion using the strong acid leachable method (SALM), which is intended to dissolve metals that may be environmentally available (BC ENV 2017). This method may include metals that are not bioavailable, thus the results may over-represent risk. They are reported as total metals, even though digestion of silicate minerals will be incomplete and may result in partial extraction. The 2012, 2015, and 2018 results reported here were treated this way. In 2018, large sediment samples from the small depositional areas were split and each subsample was analyzed using one of the two sediment size fractions:

1) <2 mm to align with historical sediment sampling and to gain an understanding of bioavailability as this fraction includes fine organic material (Devesa-Rey et al. 2011; Förstner and Wittmann 1981; Marenggo et al. 2006)
2) <63 µm for comparison and to capture very small particles

This additional step was designed to establish a relationship between the two grain size fractions.

Sediment working guidelines are generally stated in two ways: safe levels of substances that will protect aquatic life from adverse effects of toxic substance (ISQG), or levels which, if exceeded, can cause severe effects on aquatic life (PEL). These guidelines are not based on cause-effect studies, but on levels of toxic substances found in the sediment where biological effects have been measured. Therefore, caution should be exercised in the application of these working guidelines.

Canadian sediment quality objectives and guidelines are deliberately set to be protective. Therefore, if concentrations of metals of concern are less than the established objectives, potential risks to the receptor groups can be ruled out with confidence. Further, sediment samples with metal exceedances do not necessarily indicate effects to the resident plant and animal communities. Depositional sediment samples will include adsorbed forms of metals with limited bioavailability. In addition, sediment metal concentrations, pore water concentrations, and bioavailable metal concentrations may be linked, but they are not necessarily similar in scale or slope.

An important consideration in LCR sediment studies is how metal concentrations have the potential to adversely affect the LCR aquatic food web.

For this study, sediment metals of interest were defined as those that either:

- identified as metals of concern in earlier studies (Golder 2003, Hatfield 2008, Golder 2010)
- sediment concentrations at near-field sites that were significantly higher than at reference sites
- metals that exceeded sediment guidelines at depositional sites downstream of the smelter from 1992 - 2015

Resultant metals of interest are identified in Table 4-9.

Table 4-9: Matrix for Determining Sediment Metals of Interest.

Metal	Metals of interest from previous reports	Near-field sites >> reference sites 2012 samples	Near-field sites >> reference sites 2015 samples	Near-field sites >> reference sites 2018 samples	Guideline sediment exceedances in past 20 years
Aluminum		✓			
Antimony		✓	✓	✓	
Arsenic	✓	✓	✓	✓	✓
Cadmium	✓	✓	✓	✓	✓
Chromium	✓	✓	✓	✓	✓
Copper	✓	✓	✓	✓	✓
Iron		✓	✓	✓	✓
Lead	✓	✓	✓	✓	✓
Manganese		✓	✓	✓	✓
Mercury	✓	✓	✓	✓	✓
Nickel	✓	✓	✓	✓	✓
Selenium		✓		✓	
Silver	✓	✓	✓	✓	✓
Thallium	✓	✓	✓	✓	
Tin		✓	✓	✓	
Zinc	✓	✓	✓	✓	✓

(Golder 2003, Hatfield 2008, Golder 2010)

>> signifies a difference of >50%

In this report, we considered all potential metals of interest, but focused on those most likely to have potential adverse effects and that could have originated in releases from the smelter, as defined in Golder (2007). Several of the metals listed in Table 4-9 have other important drivers of their distributions. For example, iron and manganese are very common and are mobile in low redox sediments. Aluminum is naturally prevalent throughout the LCR, as is mercury. Some metals such as silver exceeded guidelines much more frequently in the past than they did in samples from the last decade.

Table 4-10 provides a comparison of reference sample sites and exposure sites for both the <63 µm and the <2 mm sediment fractions. Concentrations of the metals of interest in depositional sediments were significantly higher at exposure sites than at reference sites in 2012, 2015 and 2018 (exposure site concentrations greater than two times the standard deviation of reference site concentration; Table 4-10).

Elevated metals concentrations in exposure site sediments may also be influenced by inputs from tributary creeks such as Blueberry, Murphy, Hanna, and Topping Creek, where high elevation creek sediments have concentrations comparable to depositional sites downstream of the smelter for lead, copper, arsenic and cadmium (Reyes, 2004). Thus, the elevated metal concentrations in sediments downstream of the smelter cannot be attributed to past or present smelter activity alone.

Table 4-10: Average and standard deviation (n=3) for depositional sediment samples (2 mm fraction mg/kg dry) from upstream reference sites and downstream exposure sites collected in 2012, 2015, and 2018.

Sediment Metal	DEP-EXP (63 µm)	DEP-EXP (2 mm)	DEP-REF (63 µm)	DEP-REF (2 mm)
Antimony	34.89±26.24	25.01±17.24	0.35±0.2078	0.08333±0.05774
Arsenic	17.86±11.15	7.953±2.631	2.487±0.281	1.24±0.1572
Cadmium	4.379±3.267	1.303±0.6267	0.5797±0.00611	0.207±0.04151
Chromium	38.76±10.43	28.14±5.775	23.83±2.701	12.97±1.834
Copper	294.1±222	250.7±134.7	13.4±0.9165	5.557±0.2888
Iron	34010±17310	28310±11570	14630±1904	9623±652.4
Lead	360.7±305.1	114.7±67.84	12.93±2.417	6.33±0.8272
Manganese	408.1±160.5	393.4±162.7	161.3±9.866	112.7±3.215
Mercury	2.484±2.736	0.1723±0.1799	0.08667±0.08694	0.02±0
Nickel	22.06±5.453	11.91±1.813	15.6±0.9644	9.117±0.4888
Selenium	2.357±3.106	0.5571±0.5772	0.3367±0.07234	0.1±0
Silver	2.767±1.886	0.8586±0.7004	0.1567±0.1222	0.05±0
Thallium	0.4857±0.4256	0.1971±0.1003	0.06667±0.02887	0.05±0
Tin	36.27±39.37	30.96±22.35	0.84±0.2464	0.35±0.04583
Zinc	1660±1398	1601±1119	88.97±9.506	60.63±4.352

Figure 4-28 to Figure 4-34 illustrate concentrations of other metals of interest measured in sediments collected from three reference sites (Kootenay Eddy, Genelle, and Birchbank), and from seven downstream exposure sites (Korpac, Maglios, Casino, Airport Bar, Trimac, Fort Shepherd Eddy, and Waneta). Where they exist, published guidelines are indicated on each figure to illustrate where exceedances may have occurred.

A principal component analysis (PCA) was used to simplify data before it was incorporated into the mixed effects models because multiple variables (i.e., sediment metals) were correlated. The components accounting for the majority of data variability are referred to as the principal components. The purpose of the depositional sediment PCA is to understand which metals underpinned the most variation observed in the multivariate metal concentration data. The principal components are new variables that are constructed as linear combinations or mixtures of the initial variables (i.e., the correlated sediment metals). The first principal component (PC1) accounts for the largest possible variance and represents concentrations of As, Cr, Zn and Cu. The second principal component (PC2) represents concentrations of Cd, Pb, Hg, and Tl), is uncorrelated with the first principal component, and accounts for the next highest variance. Diagnostic plots that describe how much of the variance is described by PC1 and PC2 were output to identify how meaningful the PCA is (Appendix P).

The first two components of the PCA explained 87% of the variation in sediment metal concentrations in the <2 mm fraction. The first axis (PC1) explained the most variation at 55%, and the second axis (PC2) proportionally explained 45%. Positively correlated sediment metals in PC1 included As, Cr, Zn and Cu, while PC2 contained Cd, Pb, Hg, and Tl. Reference sites had lower PC1 loadings compared to exposure sites, indicating lower concentrations of As, Cr, Zn and Cu (Figure 4-27). PC2 (Cd, Pb, Hg, and Tl) did not provide clear separation between reference and exposure sites. The Maglios site (DEP-EXP-2) was sampled from a different location in 2018 and this site had higher concentrations of Cd, Pb and Tl in 2018 compared to the original site sampled in 2012 and 2015.

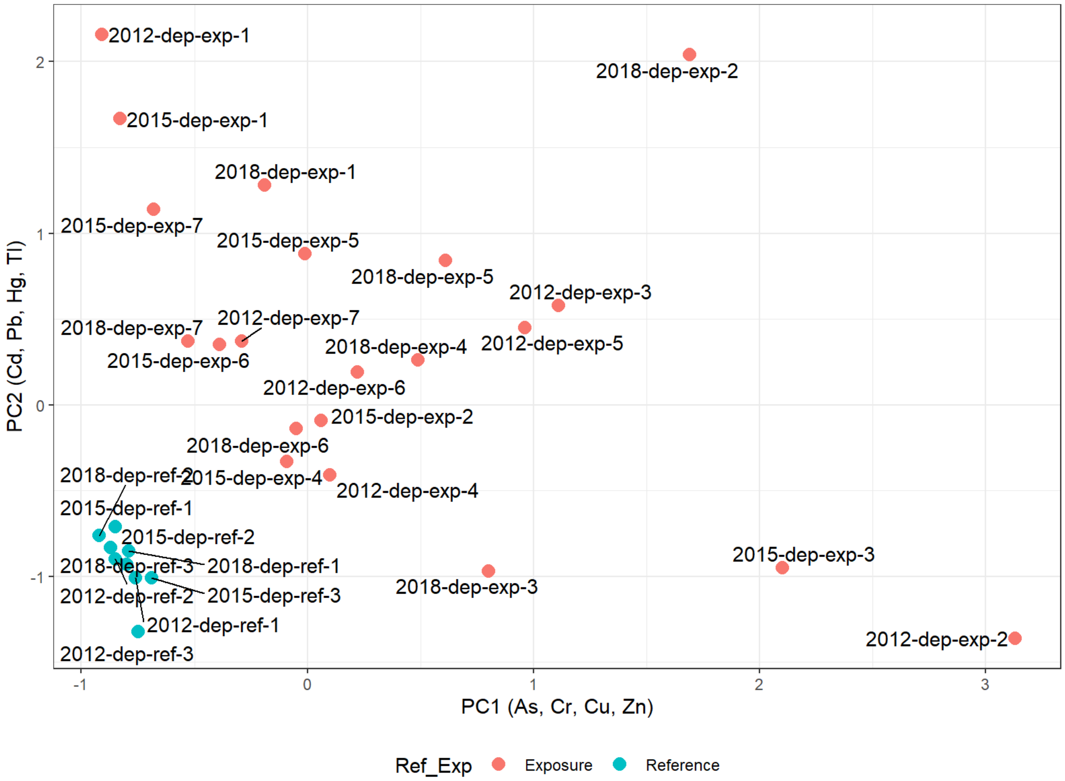


Figure 4-27: PCA sediment metals biplot of PCs for 2mm fraction. Only the first two axis are shown which explain 87% of the variation.

Many sediment metals were strongly correlated, particularly in the <63 µm fraction samples. Iron was highly correlated with Tl, Zn, Se, Hg, Cd and Sn (r>0.97). Zinc was also highly correlated with Sn, Se, Tl and Hg (r >0.97).

4.2.2.1 Sediment Metal Distributions and Trends

Sediment metal distributions are presented in the following Figure series as a function of distance from the smelter. The <63 um fraction was analyzed only in 2018, and biases metal concentrations high relative to the <2 mm fraction due to higher organic content. To assess trends between sampling years, only the <2 mm fraction results should be used.

A summary of all sediment data collected since 2003 is presented in Table 4-12. The number of <2 mm sediment samples that had metal concentrations below the lab reportable detection limits affects subsequent data analyses because with frequent non-detects, the data does not conform to a normal distribution. The 2012, 2015 and 2018 sediment concentrations of As, Cd, Cr, Cu, Pb, and Zn were all above the limit of detection. Of the mercury sediment samples, 30%, 20% and 30% were below the limit of detection in 2 mm fraction samples in 2012, 2015 and 2018, respectively. Selenium sediment samples had 50%, 90% and 30% below detection limits in 2012, 2015 and

2018, respectively. In Tl samples, 40 to 50% of samples were below the limit of detection in all three years.

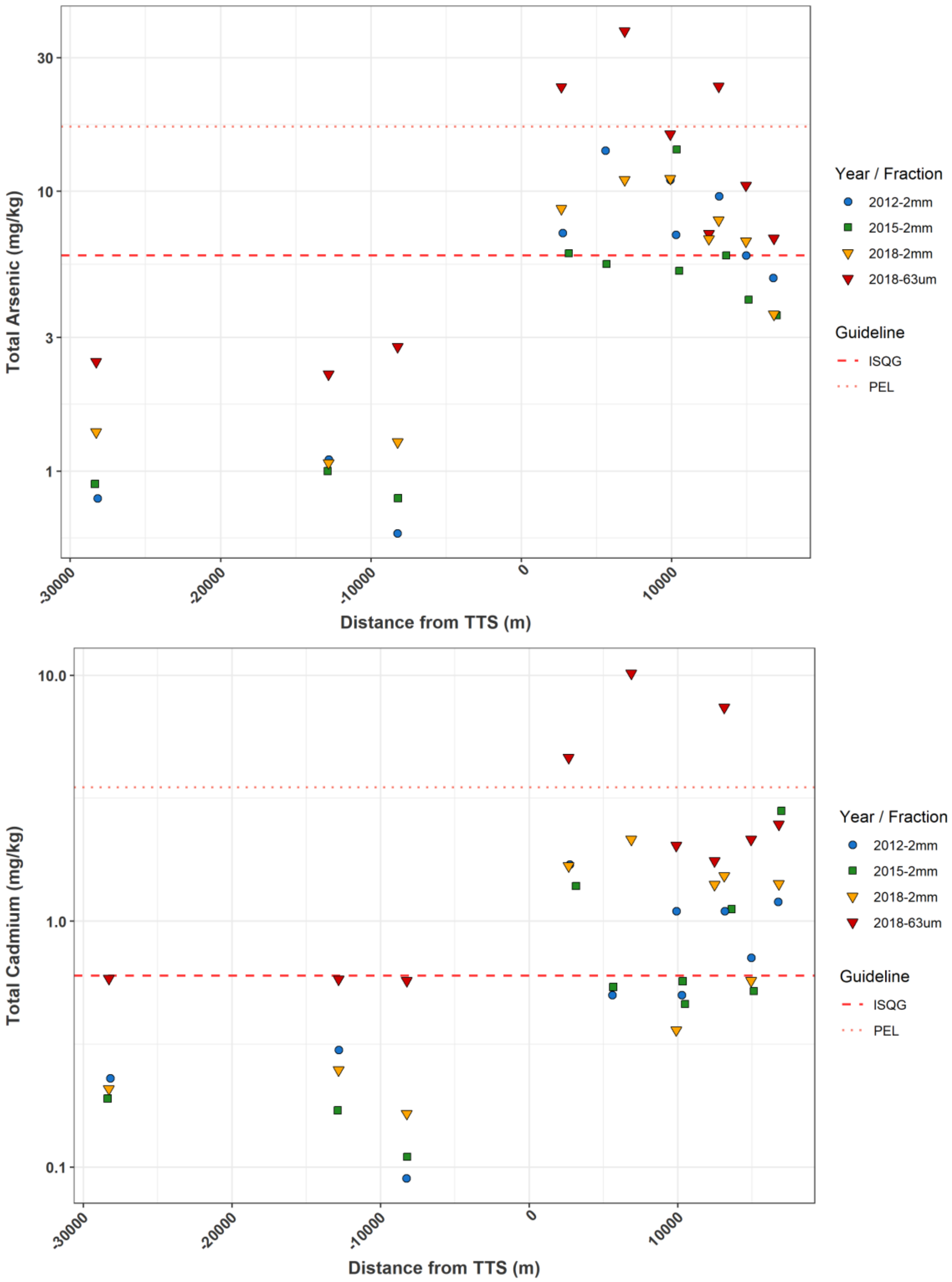
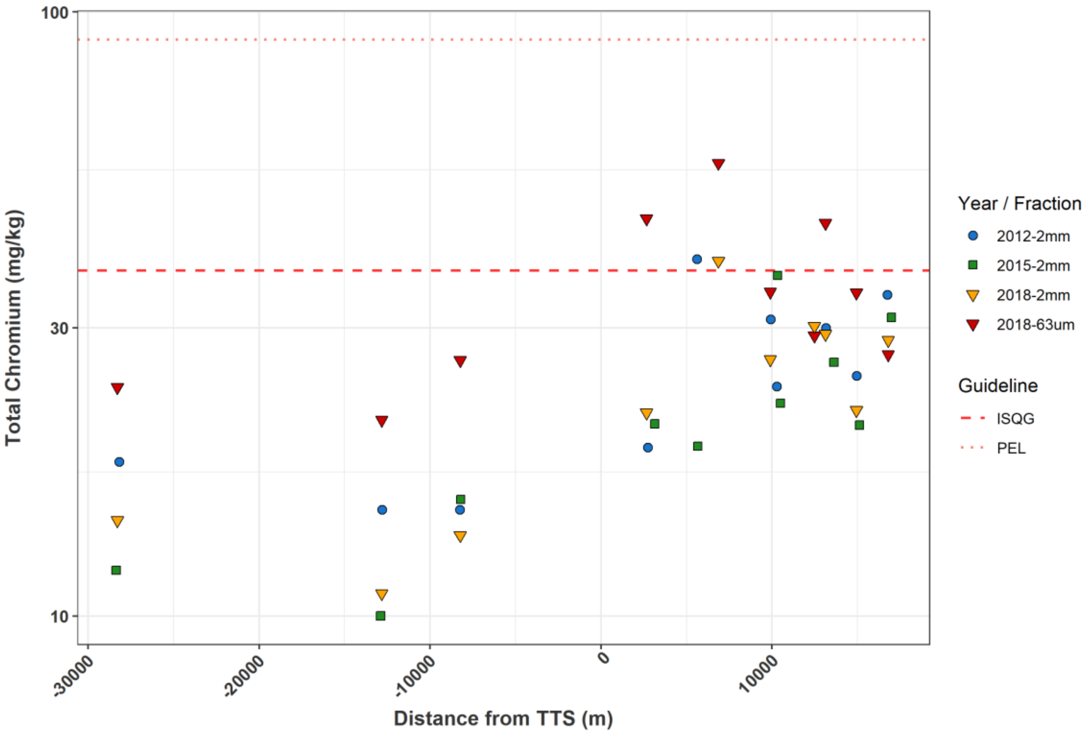


Figure 4-28: Distribution of arsenic and cadmium, concentrations in depositional sediments with distance from the TTS -Teck Trail Smelter.



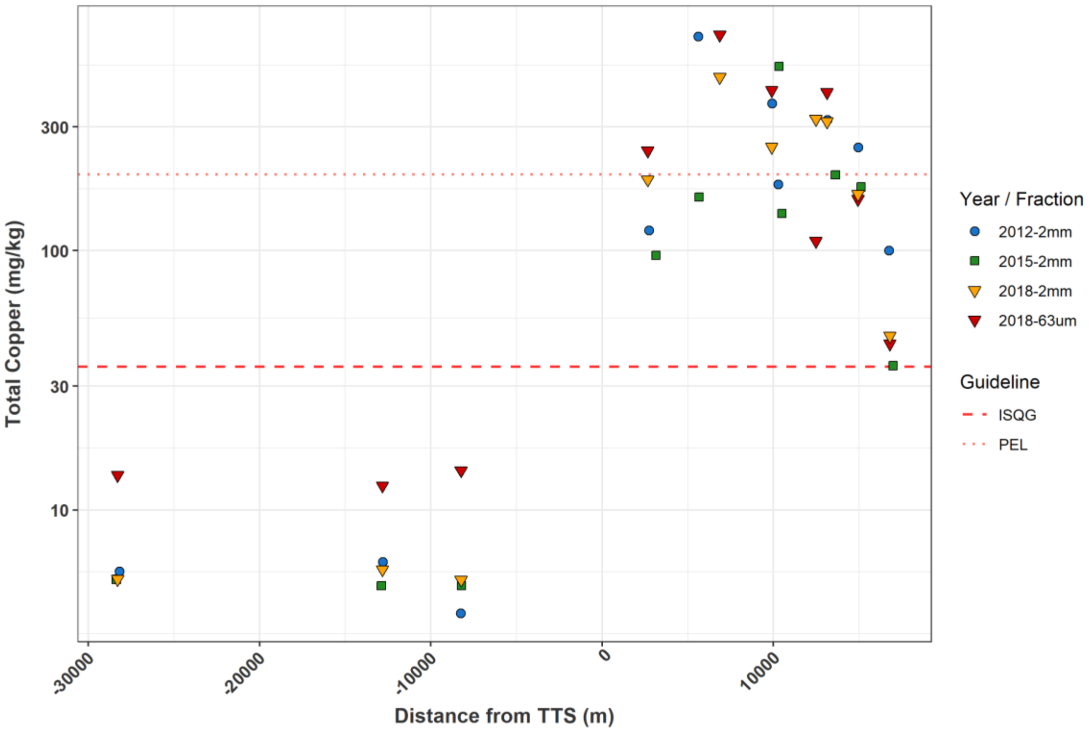


Figure 4-29: Distribution of chromium and copper concentrations in depositional sediments with distance from the smelter.

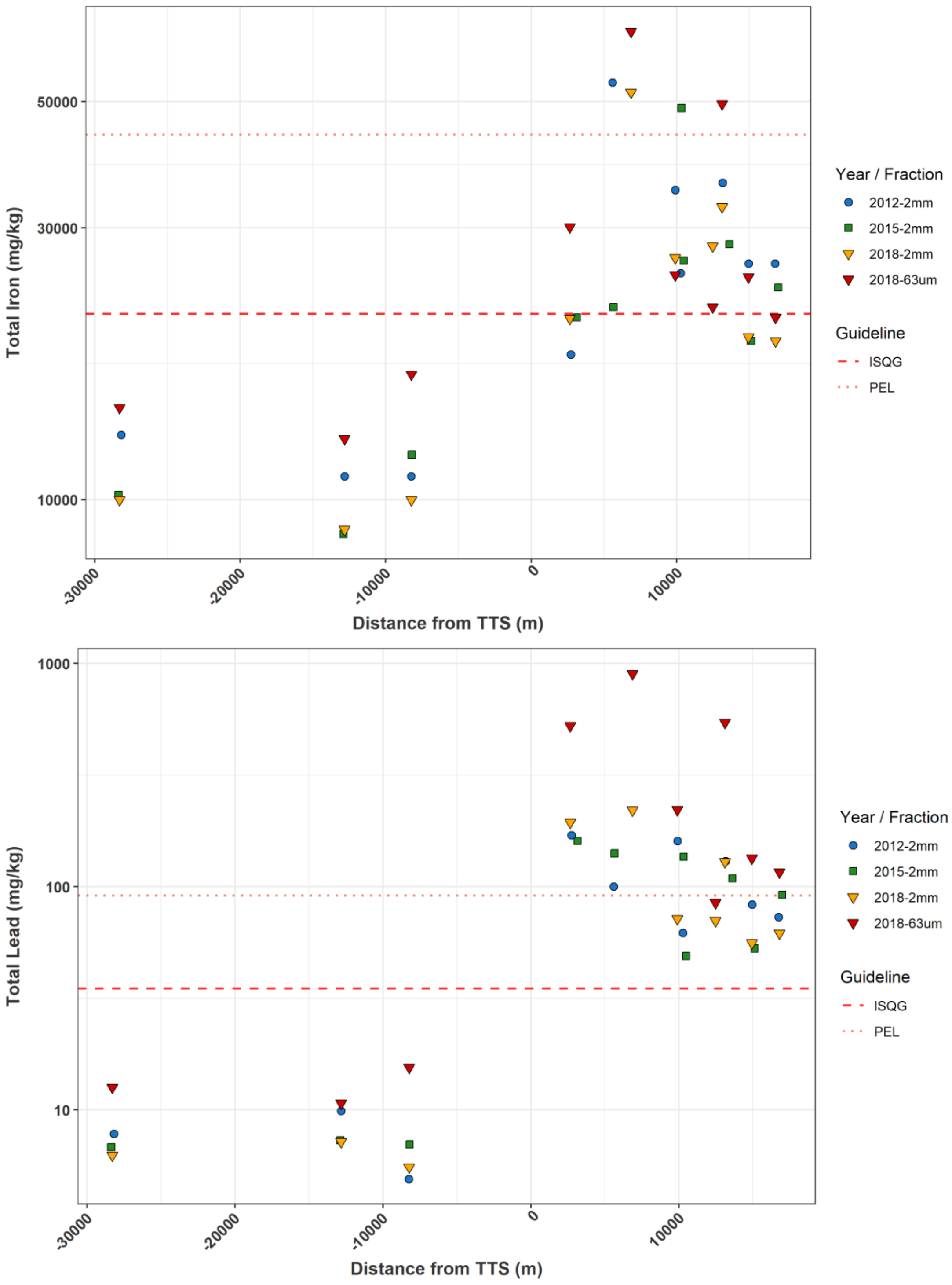
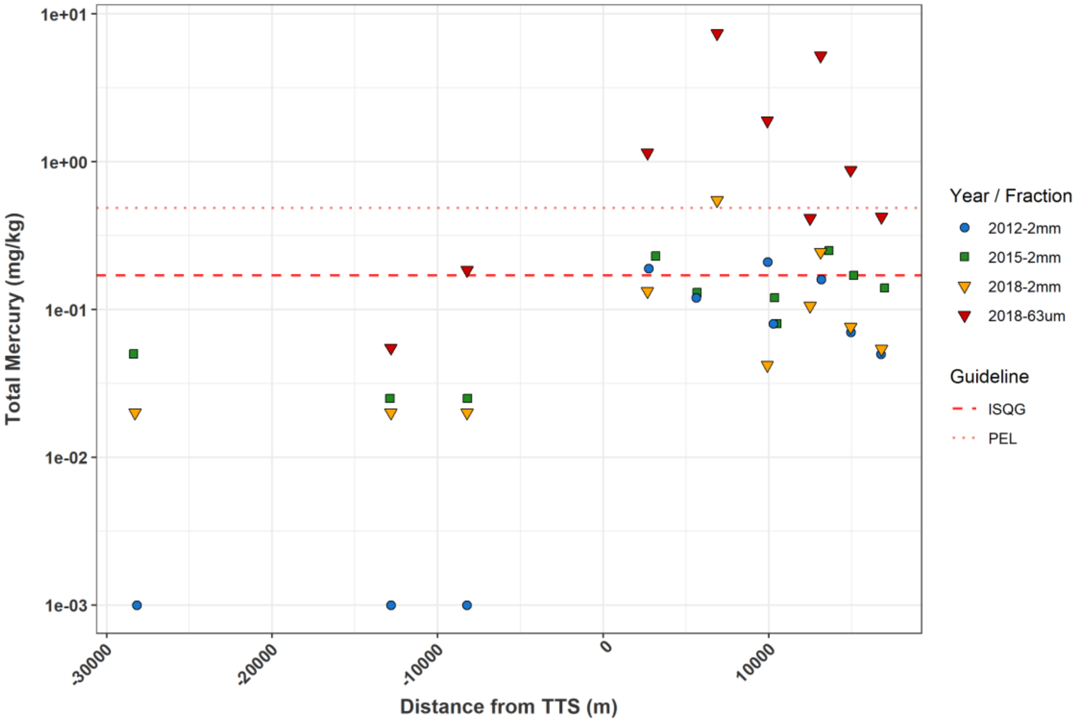


Figure 4-30: Distribution of iron and lead concentrations in depositional sediments with distance from the smelter.



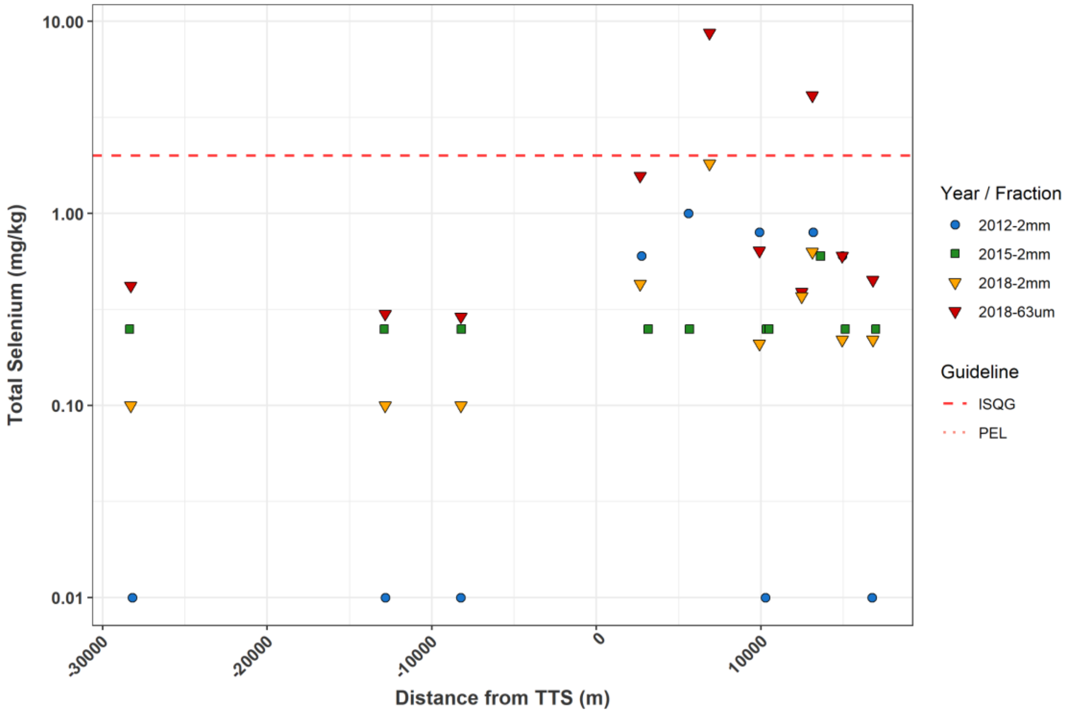


Figure 4-31: Distribution of mercury and selenium concentrations in depositional sediments with distance from the smelter.

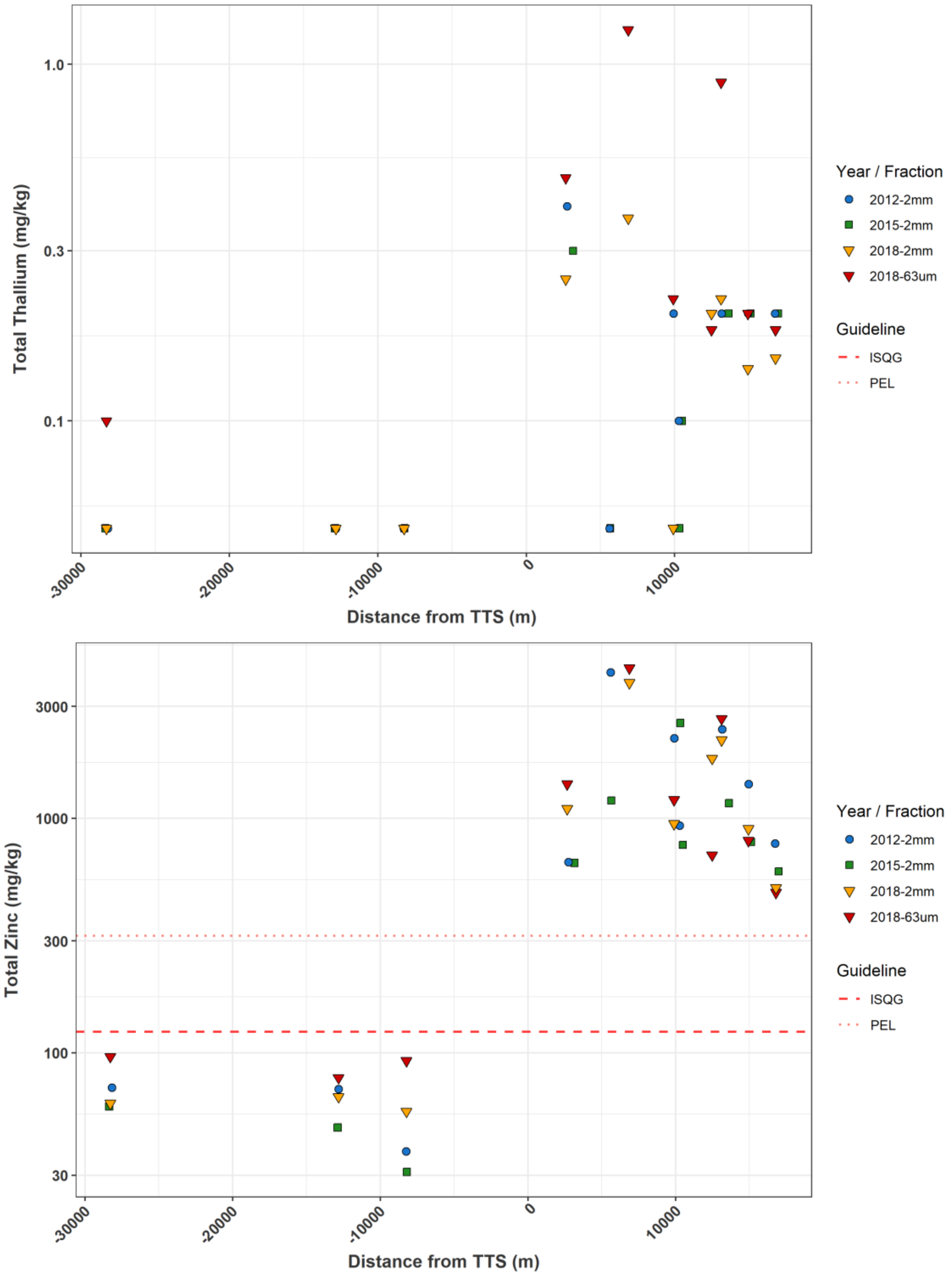
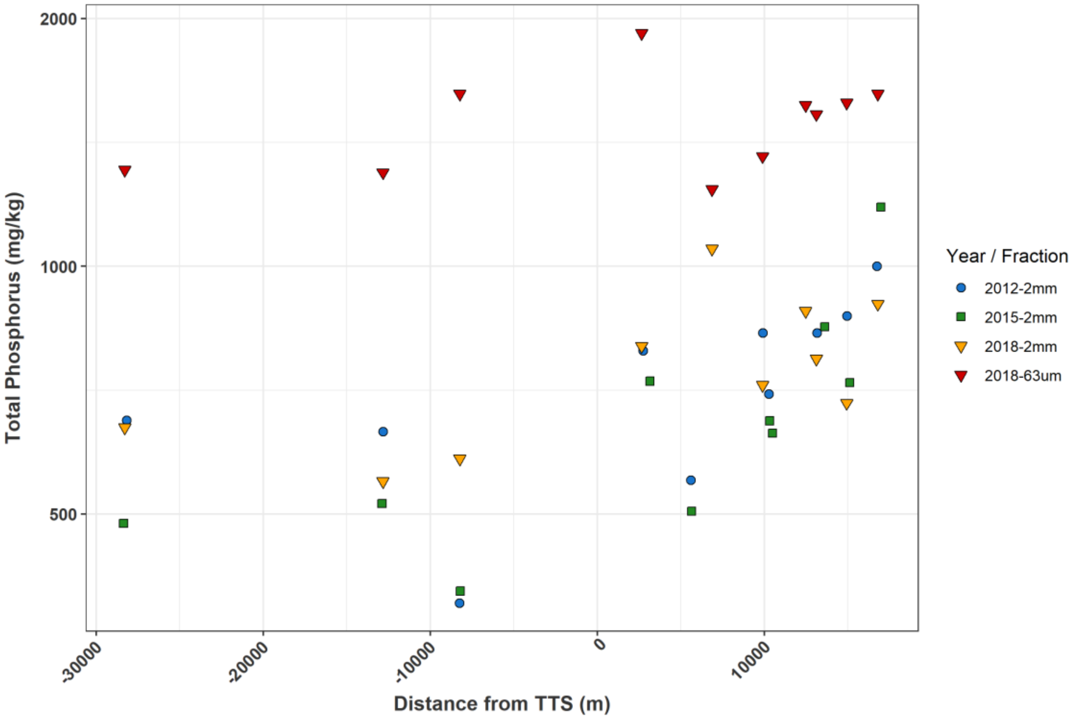


Figure 4-32: Distribution of thallium and zinc concentrations in depositional sediments with distance from the smelter.



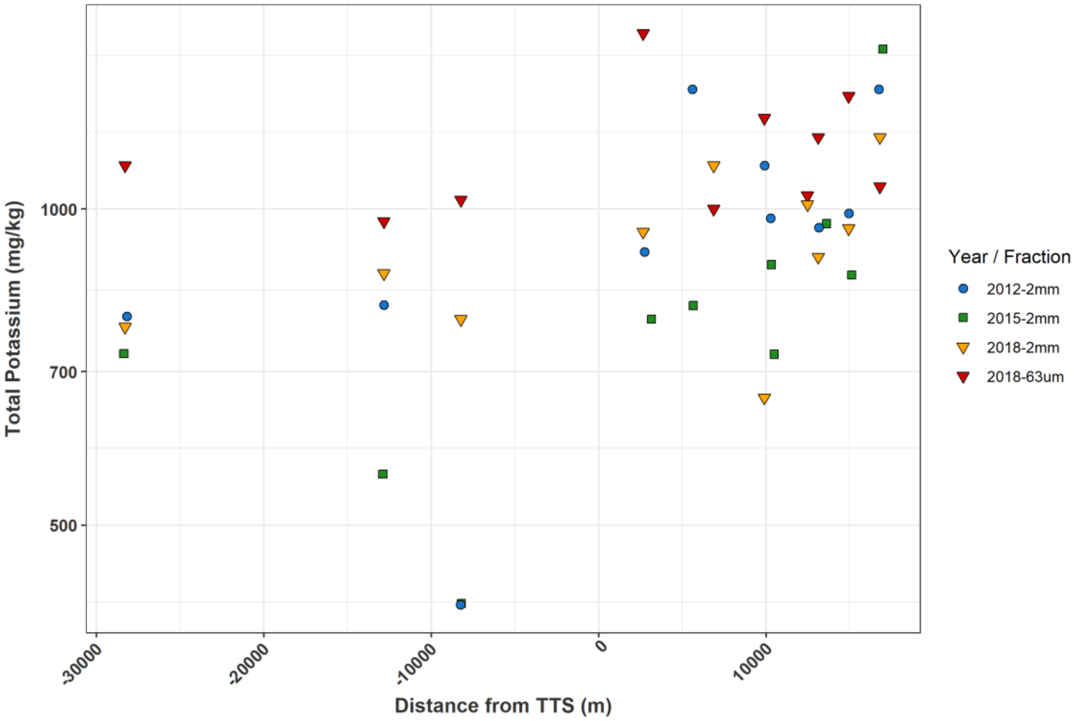


Figure 4-33: Distribution of phosphorus and potassium concentrations in depositional sediments with distance from the smelter. No applicable guidelines are defined for P and K.

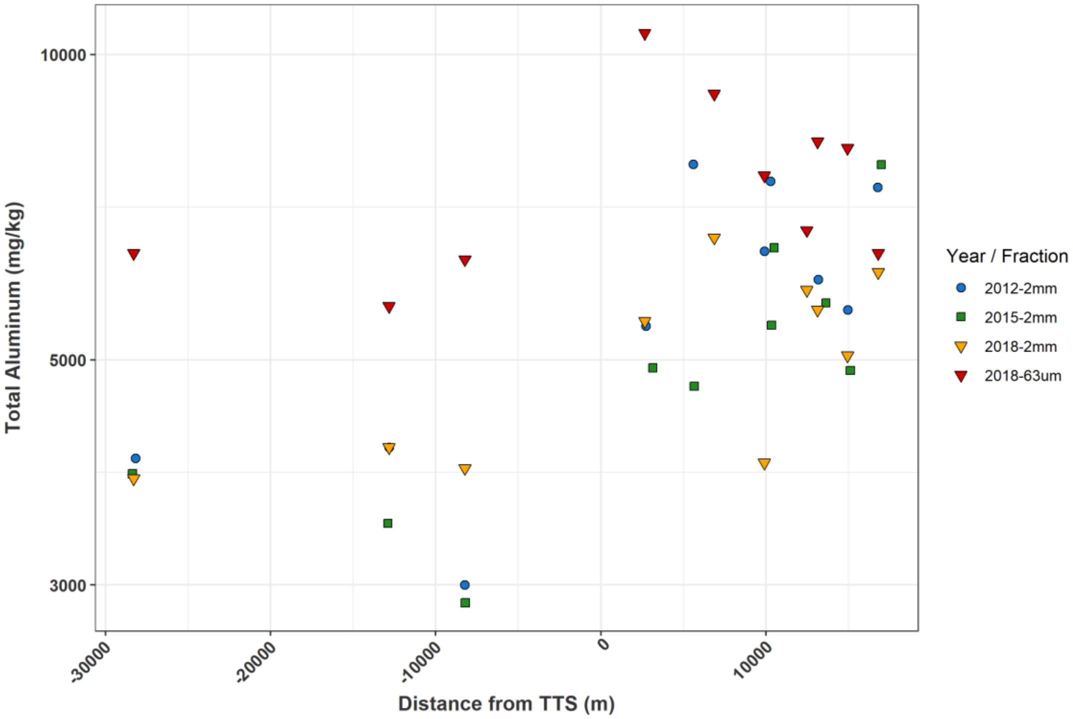


Figure 4-34: Distribution of aluminum concentrations in depositional sediments with distance from the smelter. No applicable guidelines are defined for Al.

Distance from the smelter was a factor in sediment metal distribution but had a non-linear relationship to sediment metal distribution for: aluminum, arsenic, cadmium, chromium, copper, lead, and zinc (Figure 4-28 through Figure 4-34). No sediment metals of interest consistently decreased with distance from smelter in 2018. The non-linear pattern of sediment exceedances as distance from the smelter increases suggests there are site-specific effects which may include influences of river flow dynamics along with other sources of metals such as naturally occurring metal concentrations, historical mining and milling, municipal effluent and/or stormwater.

Due to the dynamic nature of the LCR, the historical Maglios, Airport Bar, and Birchbank sites had been scoured by high flows and were no longer suitable depositional sites in 2018. As a result, new sites were located in the vicinity of the original sites and sampled in 2018. Due to the movement of sample sites at these locations, data from 2018 is not directly comparable to historical data from these sites.

Temporal changes in sediment metal concentrations in these small depositional pockets will not only reflect effluent quality improvements (including the cessation of slag discharge along with other environmental improvements), but they will also reflect the dynamics of the river flow regime where high flows scour, and low flows allow deposition of organics. Due to the river flow dynamics and transient nature of some of the small sample sites, sediment metal trends are difficult to discern, and more years of sampling are required to evaluate trends further (Table 4-11).

More historical sediment data were available for Waneta Eddy, the largest (and therefore more stable) depositional area downstream of the smelter within the LCR, than for the other depositional sites. At the Waneta location, metals concentrations in sediment show declining trends after 2003, and as of 2018, arsenic and lead in the <2 mm fraction no longer exceed the BC or CCME guidelines (Figure 4-36-Figure 4-37).

Table 4-11: Sediment Metal Exceedances (<2 mm fraction) of CCME ISQG in Depositional Exposure Sites 2003, 2012, 2015 and 2018.[1]

Sites	2003	2012	2015	2018	2012	2015	2018
DEP-EXP-1 Korpac	7	7	6	5	As Cd Cu Pb Hg Ag Zn	As Cd Cu Pb Hg Zn	As Cd Cu Pb Zn
DEP-EXP-2* Maglios	8	7	5	9	As Cr Cu Fe Pb Ag Zn	Cu Fe Pb Ag Zn	As Cd Cr Cu Fe Pb Hg Ag Zn
DEP-EXP-3 Casino	8	8	6	6	As Cd Cu Fe Pb Hg Ag Zn	As Cu Fe Pb Ag Zn	As Cu Fe Pb Ag Zn
DEP-EXP-4* Airport Bar	8	6	4	7	As Cu Fe Pb Ag Zn	Cu Fe Pb Zn	As Cd Cu Fe Pb Ag Zn
DEP-EXP-5 Trimac	9	7	7	7	As Cd Cu Fe Pb Ag Zn	Cd Cu Fe Pb Hg Ag Zn	As Cd Cu Fe Pb Hg Zn
DEP-EXP-6 Ft Shepard	7	6	4	5	Cd Cu Fe Pb Ag Zn	Cu Pb Ag Zn	As Cu Pb Ag Zn
DEP-EXP-7 Waneta	8	6	5	4	Cd Cu Fe Pb Ag Zn	Cd Cu Fe Pb Zn	Cd Cu Pb Zn
TOTAL	55	47	37	43			

1. 5 sediment cores were collected at each site and combined to form a single sample in each year.

* New Maglios and Airport Bar sites sampled in 2018 because the historical depositional sites no longer exist.

Sediment metal concentrations in the <2 mm fraction remained relatively steady in the 2012 to 2018 data, both in terms of concentration and number of guideline exceedances (Table 4-12). Some decline in concentrations is evident when the 2012-2018 data is compared to 2003 data. Inter-annual variability in sediment metals concentrations is expected due to the dynamic and mobile nature of LCR sediments. Sediment metals concentrations in 2018 were higher than in 2015 at several sites (Table 4-12). This is interpreted to be a reflection of inter-annual variability due to the transient nature of the smaller depositional sites (e.g., Maglios and Airport Bar sample sites were new depositional areas in 2018).

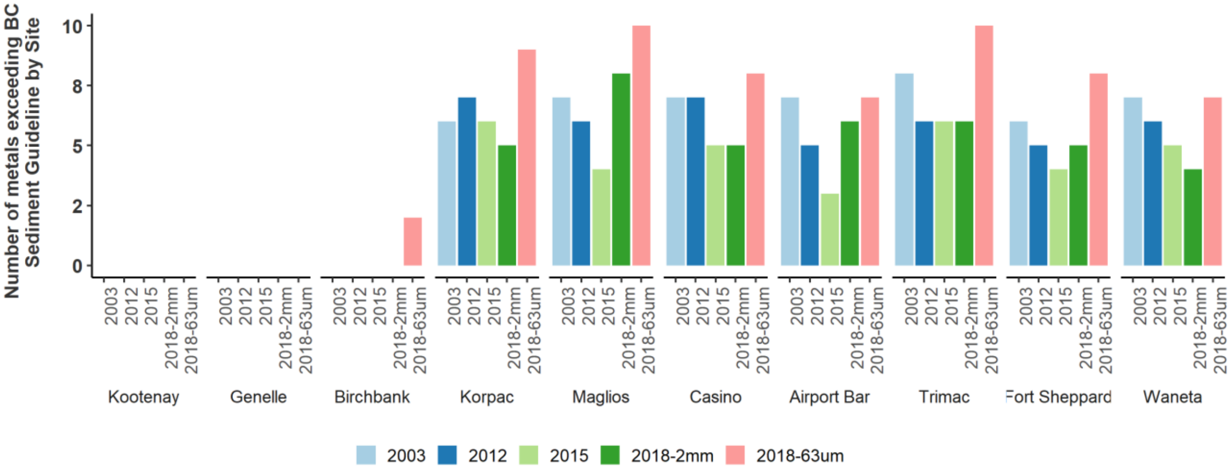


Figure 4-35: Number of sediment metal BC guideline exceedances at depositional sites (<2mm fraction) in the LCR area of interest: 2003, 2012, 2015 and 2018.

The ecological importance of sediment guideline exceedances in the LCR is small relative to the context of the entire AOI, where the area of depositional habitat in the AOI is only about 0.1% (Golder 2007). Shifting conditions at these small depositional areas, with continual sediment influx from upstream sources and scouring to downstream mainstem sites caused variable results.

Table 4-12: Sediment Data Summary (2003-2018) Denoting Exceedances of BC/CCME ISQG and PEL Sediment Quality Guidelines.

	Sediment Quality Guideline						Size Fraction Analyzed	Location									
	CCME		BC		LCR Obj.			Reference Sites			Exposure Sites						
COPC	ISQG	PEL	ISQG	PEL		Year		Kootenay	Genelle	Birchbank*	Korpac	Maglios*	Casino	Airport Bar*	Trimac	Ft Shep.	Waneta
Arsenic	5.9	17	5.9	17	5.7	2003	2 mm	-	-	-	**10.0**	**20.0**	**17.0**	**8.3**	**7.2**	**20.0**	**6.0**
						2012	2 mm	0.8	1.1	0.6	**7.1**	**14.0**	**11.0**	**7.0**	**9.6**	**5.9**	4.9
						2015	2 mm	0.9	1	0.8	**6**	5.5	**14.1**	5.2	**5.9**	4.1	3.6
						2018	2 mm	1.38	1.07	1.27*	**8.66**	**11.0***	**11.1**	**6.76***	**7.88**	**6.64**	3.63
							63 um	2.46	2.22	2.78*	**23.6**	**37.4***	**16.0**	**7.05***	**23.7**	**10.5**	**6.79**
Cadmium	0.6	3.5	0.6	3.5	0.6	2003	2 mm	0.6			**1.8**	**2.2**	**1.2**	**0.83**	**3.2**	**1.07**	**0.71**
						2012	2 mm	0.23	0.3	0.09	**1.7**	0.5	**1.1**	0.6	**1.1**	**0.71**	**1.2**
						2015	2 mm	0.19	0.17	0.11	**1.39**	0.54	0.57	0.46	**1.12**	0.52	**2.81**
						2018	2 mm	0.208	0.248	0.165*	**1.68**	**2.15***	0.361	**1.41***	**1.53**	0.573	**1.42**
							63 um	0.584	0.580	0.572*	**4.63**	**10.19***	**2.029**	**1.76***	**7.4**	**2.15**	**2.48**
Chromium	37	90	37	90	36	2003	2 mm	-	-	-	-	**56.0**	-	-	-	-	**80.0**
						2012	2 mm	18	15	15	19.0	**39.0**	31.0	24.0	30.0	25.0	34.0
						2015	2 mm	11.9	10	15.6	20.8	19.1	**36.6**	22.5	26.3	20.7	31.2
						2018	2 mm	14.4	10.9	13.6*	21.7	**38.7***	26.6	30.2*	29.3	21.9	28.6
							63 um	23.9	21.1	26.5*	**45.5**	**56.2***	34.4	29.1*	**44.7**	34.29	27.1
Copper	36	197	36	197	35	2003	2 mm	-	-	-	**415**	**1156**	**466**	**338**	**174**	**506**	**1685**
						2012	2 mm	5.8	6.3	4	**120**	**670**	**370**	**180**	**320**	**250**	**100**
						2015	2 mm	5.4	5.1	5.1	**95.9**	**161**	**514**	**139**	**196**	**176**	**36**
						2018	2 mm	5.4	5.89	5.38*	**188**	**467***	**251**	**322***	**315**	**165**	**46.9**
							63 um	13.6	12.4	14.2*	**243**	**681***	**416**	**109***	**408**	**158**	**43.8**
Lead	35	91	35	91	33	2003	2 mm	-	-	-	**173**	**335**	**142**	**122**	**150**	**193**	**126**
						2012	2 mm	7.8	9.9	4.9	**170**	**100**	**160**	**62.0**	**130**	**83.0**	**73.0**
						2015	2 mm	6.8	7.3	7	**160**	**141**	**136**	**48.9**	**109**	**52.8**	**91.9**
						2018	2 mm	6.26	7.19	5.54*	**194**	**220***	**71.8**	**70.4***	**129**	**56.0**	**61.9**
							63 um	12.6	10.7	15.5*	**526**	**900***	**221**	**84.6***	**543**	**134**	**116**
Mercury	0.2	0.5	0.2	0.5	0.2	2003	2 mm	-	-	-	-	-	**0.30**	**0.19**	**0.34**	**0.17**	-
						2012	2 mm	<0.05	<0.05	<0.05	**0.19**	0.12	**0.21**	0.08	0.16	0.07	0.05
						2015	2 mm	0.05	<0.05	<0.05	**0.23**	0.13	0.12	0.08	**0.25**	**0.17**	0.14
						2018	2 mm	<0.040	<0.040	<0.040*	0.133	**0.55***	0.042	0.106*	**0.245**	0.076	0.054
							63 um	<0.040	0.055	0.185*	**1.149**	**7.41***	**1.9**	**0.414***	**5.21**	**0.879**	**0.422**
Nickel	n/a	n/a	16	75	n/a	2003	2 mm	-	-	-	-	-	-	-	**18.0**	-	-
						2012	2 mm	9.1	9.7	6.1	10.0	10.0	14.0	12.0	10.0	11.0	**18.0**
						2015	2 mm	7.9	7.3	6.4	10.5	8.4	10.2	10.1	11.6	9.8	**18.3**
						2018	2 mm	9.01	9.65	8.69*	12.5	12.9*	10.2	11.3*	10.9	10.3	15.3
							63 um	16	14.5	**16.3***	**27.6**	**29.3***	**18.89**	15.0*	**25.9**	**19.1**	**18.6**
Silver	n/a	n/a	n/a	n/a	0.5	2003	2 mm	-	-	-	**108**	**5.2**	**10.0**	**1.8**	**1.5**	**3.4**	**1.2**
						2012	2 mm	<0.2	<0.2	<0.2	**0.6**	**5.7**	**2.6**	**0.8**	**2.1**	**1.4**	**0.9**
						2015	2 mm	<0.2	<0.2	<0.2	0.5	**0.6**	**3.6**	0.4	**0.9**	**1.1**	0.5
						2018	2 mm	<0.10	<0.10	<0.10*	0.39	**0.82***	**2.26**	**1.17***	0.5	**0.73**	0.14
							63 um	<0.10	0.13	0.289*	**1.56**	**3.24***	**6.14**	**1.44***	**3.89**	**2.62**	0.48
Zinc	123	315	123	315	120	2003	2 mm	-	-	-	**2455**	**7746**	**2276**	**1638**	**1067**	**3307**	**17925**
						2012	2 mm	71	70	38	**650**	**4200**	**2200**	**930**	**2400**	**1400**	**780**
						2015	2 mm	59	48	31	**645**	**1190**	**2550**	**770**	**1160**	**793**	**594**
						2018	2 mm	60.8	64.9	56.2*	**1100**	**3790***	**949**	**1800***	**2160**	**902**	**506**
							63 um	96.2	78.2	92.5*	**1400**	**4380***	**1200**	**697***	**2660**	**803**	**482**

* location of sample site changed in 2018 due to lack of depositional sediment in previous location.

# bold	> LCR objective / ISQG
# bold	> PEL and LCR objective /ISQG

63 um fraction tested in 2018 only. This smaller sediment fraction is expected to have a greater proportion of organic matter which more readily adsorbs metals. Results cannot be directly compared to data from 2mm fraction.

Note: the highest value among duplicate pairs is presented in this table

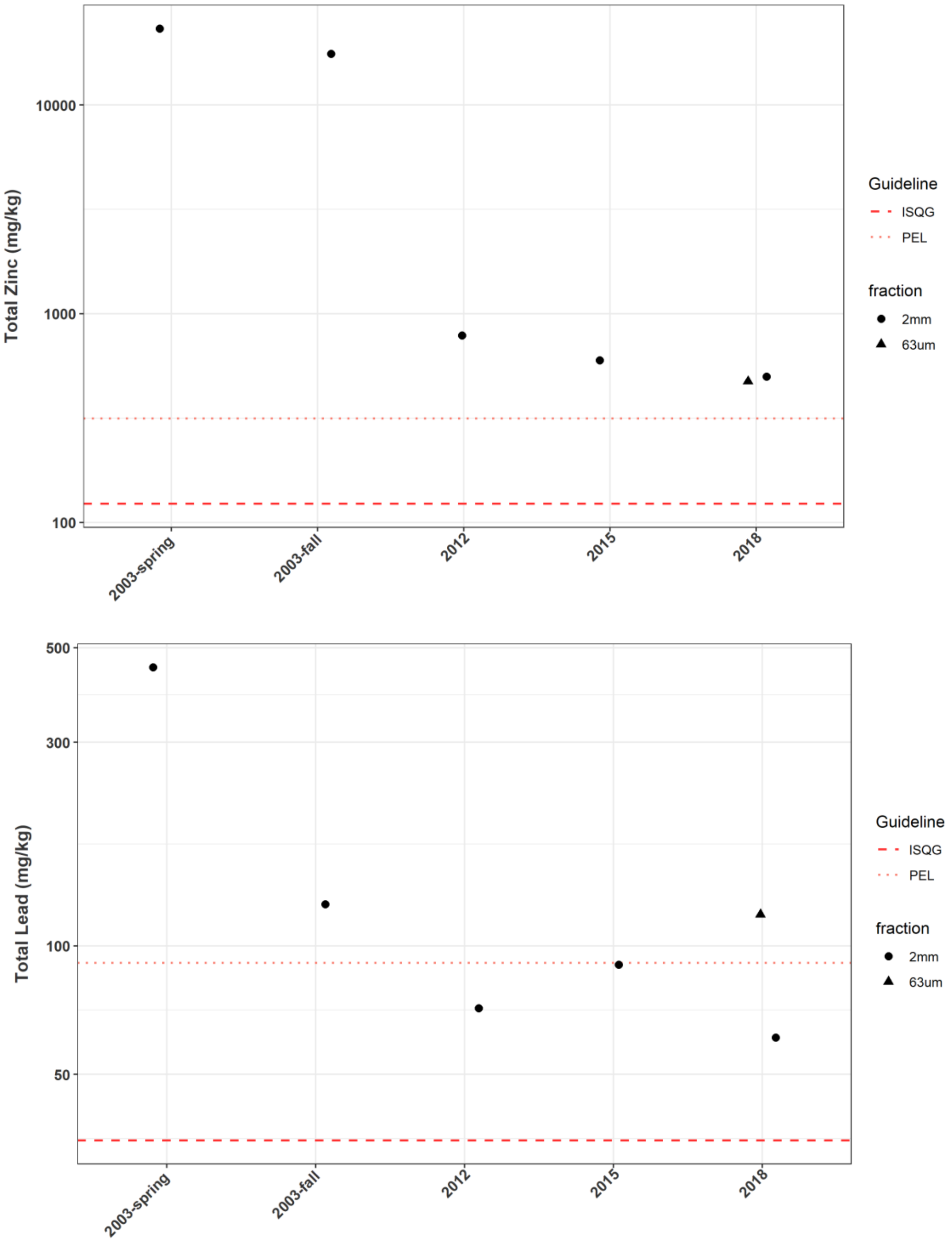


Figure 4-36: Maximum observed concentrations for Lead and Zinc at the Waneta Eddy for depositional sediment metals of interest from 2003 to 2018, compared to BC guidelines.

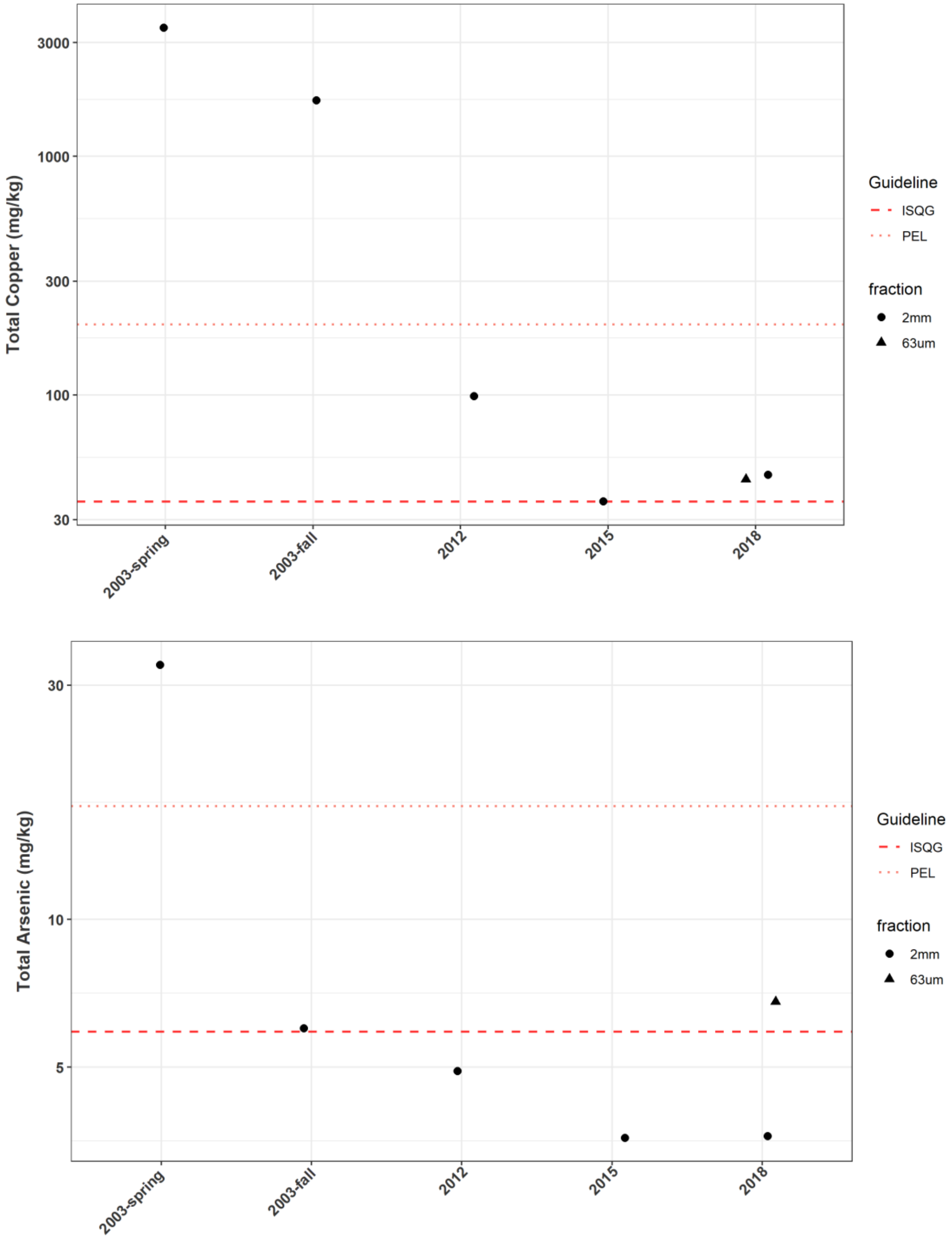


Figure 4-37: Maximum observed concentrations of Copper and Arsenic at the Waneta Eddy for depositional sediment metals of interest from 2003 to 2018, compared to BC guidelines.

4.2.2.1 Comparison of Sediment Size Fraction Results

Metal concentrations in the smaller <63 µm size fraction were greater than the <2 mm fraction samples for the following metals of interest: Ni, Cr, Ag, Cd, As, Fe, Pb, Tl (in order of greatest difference to least) (Table A45). This occurred at both exposure and reference sites. Arsenic, Cd, Hg, Pb and Se concentrations were higher in the <63 µm fraction compared to the <2 mm fraction at Maglios and Trimac. Phosphorus demonstrated the biggest difference between the two sediment fractions, indicating that organic materials were captured more with the smaller fraction (Table A45). All these metals are known to adsorb onto organics in the pH range found in the LCR, and many are also scavenged by carbonates and oxides (Forstner & Wittmann 1981; Sholkovitz and Copland 1981; Lin and Xhen 1998; Coquery and Wolborn 1995; Yang et al. 2010; Erhayem and Sohn 2014). The higher proportion of detectable metals in the <63 µm fraction samples are indicative of the greater inclusion of organics compared to the <2 mm results. Both sediment fractions followed similar distribution patterns at the sample sites with respect to metals concentrations.

4.2.2.2 Sediment Nutrients

Most sediment nutrients including phosphorus, ammonia and potassium were elevated downstream of Trail, and likely contributed to the increased periphyton growth. This is a common occurrence in rivers receiving urban stormwater. The Regional District of Kootenay Boundary (RDKB) wastewater treatment outfall is located upstream of the Maglios depositional area (Schedule A, Mapsheet 7). The impacts to groundwater from historical fertilizer manufacturing is another potential nutrient source. No nuisance algae growths were detected at depositional sites in 2012, 2015 or 2018; thus, the elevated nutrients were not problematic.

4.2.2.3 Summation

Depositional sediment quality in the 2018 samples showed lower concentrations of metals of interest than samples collected in the preceding years at most depositional sites. The highly variable nature of the small depositional areas that account for only about 0.1% of the AOI in the LCR was evident in these results. Sediment metals that exceeded guideline PEL concentrations in 2018 were limited to Cu, Hg, Pb, and Zn in the <2mm fraction. Similar results were obtained in the <63 micron samples, but with higher concentrations of metals. The <63 um sediment fraction is expected to have a greater proportion of organic matter which more readily adsorbs metals.

The length of time that deposited materials remain in depositional areas is also important. Larger depositional sites such as Waneta Eddy and Genelle Eddy can be expected to have longer storage than small depositional sites, thus Waneta Eddy may take longer to return to a natural state than adjacent erosional sites. The dynamic and transient nature of the smaller depositional sites is illustrated by the Maglios and Airport Bar sites having been scoured and new sites being established in 2018. Fines that accumulated during low flows are frequently scoured and re-sorted during high flows (Parametrix et al. 2010). Estimates of percent slag in this study were lower in recent years than in earlier studies (Golder 2003 & 2007).

4.3 Depositional Area Periphyton

Primary objectives of the depositional periphyton sampling program are to assess effects of the effluent discharge on discrete depositional periphyton communities in terms of community structure, composition, and standing crop biomass, and to detect any trends over time.

Depositional periphyton communities are usually distinct from their erosional counterparts (Table 4-13). Depositional communities are smaller and are driven by unique site characteristics unlike the comparatively uniform mainstem erosional habitats. Additionally, depositional sediments retain historical discharges and are therefore slower to demonstrate improved conditions than erosional habitats. Most sediment nutrients including phosphorus, ammonia and potassium were progressively elevated downstream of Trail, and may contribute to increased periphyton growth. This is frequently observed in rivers receiving urban stormwater and wastewater.

Algae including diatoms have varying sensitivity to dissolved metals and varying requirements for trace metals as nutrients including the metals Mn, Fe, Co, Ni, Cu, Zn, and Cd (Medley and Clemens 1998). Depositional sediment metals that exceeded guideline PEL concentrations in 2018 were primarily Zn, Pb and Cu. These three metals were identified by Golder (2007a; 2010) in tests of bioavailability that ranked depositional sites with potential toxicity as Maglios > Fort Shepherd > Waneta. These sites showed lower abundance but did not show lower periphyton biovolume than adjacent exposure sites in 2018 data (Figure 4-38; Table 4-13).

Growth of periphyton and macrophytes in LCR depositional sites downstream of Trail has decreased dramatically over the 2005 - 2018 period (Golder 2007), likely in response to variable flow regimes and declining nutrient concentrations. Nutrient concentrations in LCR water measured in 2012 through 2018 would classify the LCR as oligotrophic (Olson-Russello et al. 2019).

4.3.1 Comparison of Depositional and Erosional Periphyton

The profound differences between LCR erosional and depositional physical conditions drives periphyton productivity. Depositional periphyton communities frequently generate about half of the erosional periphyton abundance per unit area because unstable sandy substrate does not allow slow-growing species to develop before substrate disruption (Barbour, 1999, Wetzel, 2001). Further, they are subject to scour during high flows as happened in 2012 extreme flows throughout the LCR. However, if depositional areas are not scoured and offer macrophytes or other stable growth media, then depositional abundance can exceed that of erosional substrates as was observed in some depositional sites in 2015 and 2018 (Table 4-13). Differences in biovolume, species richness, and diversity metrics are expected between the two habitat types because smaller species are more common in high-flow erosional environments and larger species are more common in depositional environments. In depositional habitat, the small, closely attached species so prevalent in high flow situations are absent (Figure 4-38). Instead, larger and motile diatom guilds are prevalent, as well as large diatoms from upstream reservoirs that settle in the calm backwaters and eddies. These factors culminate in greater species richness and diversity in depositional sites versus erosional sites in 2015 and 2018 samples (Table 4-13). Additionally, the contribution made to biofilm by algae was small in depositional periphyton, while the contribution made by bacteria and organic debris was much greater than it was in erosional periphyton biofilms (Hawes et al. 2014). These natural factors explained the observed variability while exposure to TTS effluent did not.

The depositional and erosional metrics summarized in Table 4-13, and illustrated in the succeeding figures, are expressed as a single value for each reference and exposure area. Metrics are based on replicate averages of a single sample at depositional sites and five sub-samples at erosional sites. Five replicate sub-samples taken from erosional areas were combined to avoid pseudo replication in statistical tests. Due to this methodology, analysis of periphyton community data solely collected in 2018 could not be completed.

Table 4-13: Summary statistics describing periphyton community productivity and diversity in depositional and erosional sites above and below smelter outflow (reference and exposure sites respectively) in samples collected October 2018.

		Depositional Sites		Erosional Sites	
	Statistic	Reference	Exposure	Reference	Exposure
Metric	Sample Size	3	7	10	25
Abundance (cells/cm^2 × 10^5)	Mean (± SD)	10.75 ± 2.23	12.9 ± 6.6	1.68 ± 1.13	1.06 ± 0.43
	Median	9.79	10.95	1.41	0.98
	Minimum	9.17	5.22	0.37	0.63
	Maximum	13.3	22.3	5.71	2.00
Species Richness (# species)	Mean (± SD)	36.7 ± 4.7	40.0 ± 5.2	30 ± 4.8	31.3 ± 6.3
	Median	36	37	30	30
	Minimum	30	37	21	22
	Maximum	42	46	37	45
Total biovolume (cm^3/m^2)	Mean (± SD)	6.74 ± 0.65	5.96 ± 3.01	0.58 ± 0.27	2.03 ± 1.3
	Median	6.63	6.15	0.63	1.93
	Minimum	6.16	1.68	0.23	0.22
	Maximum	7.44	9.27	0.98	5.66
Chlorophyll-a (µg/cm^2)	Mean (± SD)	n/a	n/a	0.73 ± 0.13	1.28 ± 1.07
	Median	n/a	n/a	0.74	0.96
	Minimum	n/a	n/a	0.50	0.31
	Maximum	n/a	n/a	0.90	4.67
Shannon EQ Index	Mean (± SD)	0.76 ± 0.02	0.78 ± 0.05	0.73 ± 0.04	0.67 ± 0.05
	Median	0.77	0.78	0.75	0.68
	Minimum	0.74	0.72	0.63	0.40
	Maximum	0.77	0.84	0.78	0.80

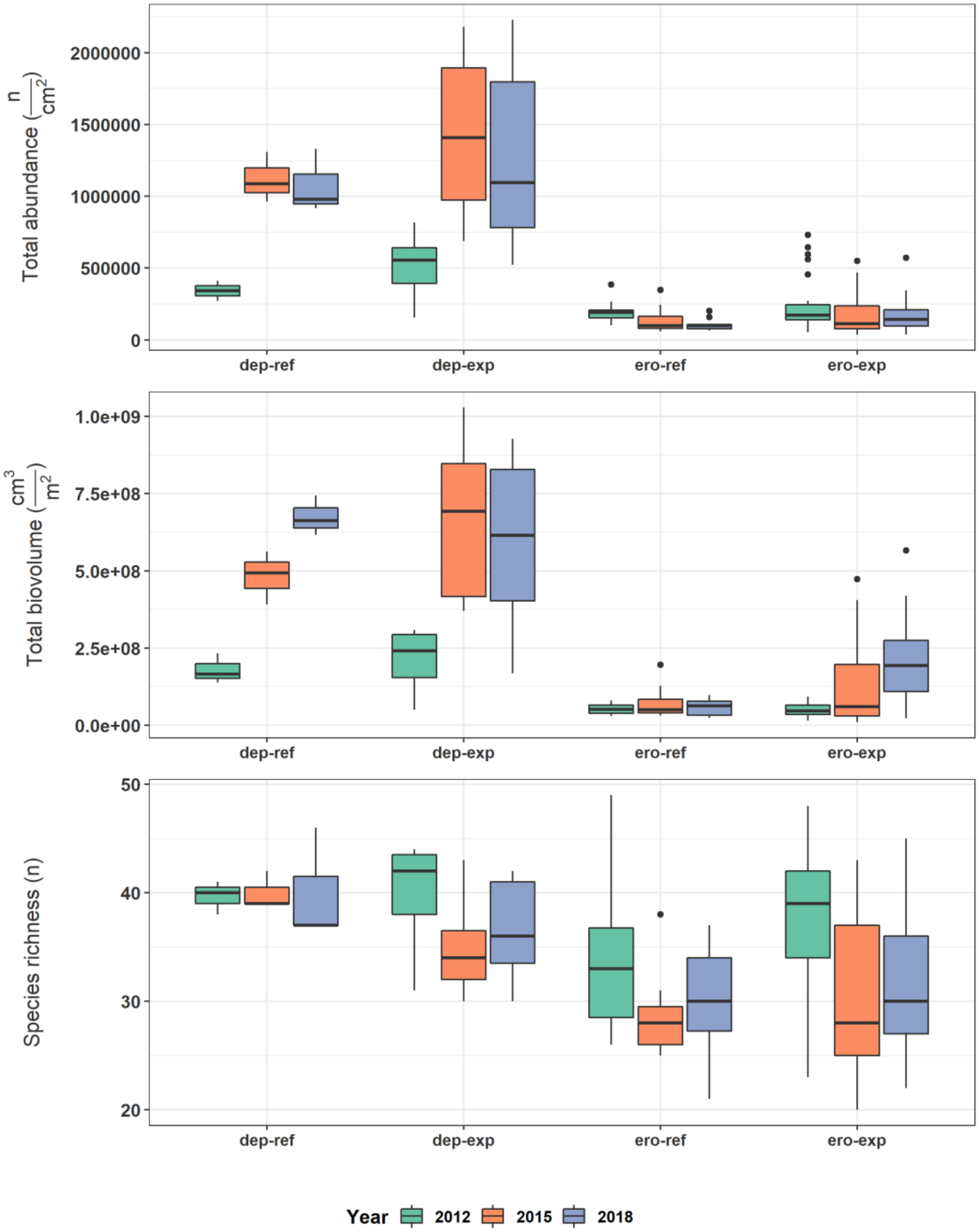


Figure 4-38: Boxplots of abundance, biovolume, and species richness in the different types of periphyton communities evaluated in 2012, 2015, and 2018. Dep = depositional, Ero = erosional, Exp = exposure (downstream of smelter outflows), Ref = reference (upstream of smelter outflows).

4.3.2 Dominant Taxa

Erosional Sites

Green algae, specifically filamentous *Stigeoclonium sp.*, composed a majority of the biovolume percentage at both reference and exposure erosional sites in 2018. As shown in Table 4-14, seven of the ten dominant taxa present in erosional sites remained consistent, demonstrating no significant change in species composition between reference and exposure sites. Minimal change in biovolume percentages at erosional exposure sites implies evidence of periphyton species change due to effluent discharge.

Depositional Sites

Consistent with 2012 and 2015 results, there was no evidence of periphyton species shifts reflecting smelter effects at depositional sites in 2018. This was demonstrated by nine of the ten dominant taxa remaining consistent between reference and exposure sites, including the top three dominant taxa, Depositional reference and exposure site periphyton were dominated by a similar community of diatoms and filamentous green algae in all years of study.

Reservoir taxa such as *Cyclotella spp., Synedra ulna and Fragilaria crotonensis* accounted for a significant portion of the 2018 depositional periphyton (Table 4-14) as it has in earlier years, particularly in reference sites that are physically closer to reservoirs. *Didymosphenia geminata* (also called Didymo or rock snot) dominated both reference and exposure depositional sites in 2018.

The 20% difference of *D. geminata* biovolume in reference and exposure depositional sites in the LCR is likely an artifact of its clumped distribution. If an environmental influence is driving this difference, light, flows, and water temperature are common drivers (Canter-Lund & Lund, 1995; Kilroy et al., 2008, Whitton et al., 2008; Whitton et al., 2009). Although it is native to BC, Didymo can behave invasively. In the LCR, visible periphyton mats in stretches of the LCR are considered a natural occurrence rather than a symptom of stress (Columbia River Integrated Environmental Program 2005; Lindstrøm & Skulberg 2007; Whitton et al. 2009).

Table 4-14: Dominant periphyton species as defined by percent biovolume for erosional and depositional sites with upstream reference sites shown separately from downstream exposure sites, 2018.

Erosional

Dominant Reference Taxa	Biovolume (%)		Dominant Exposure Taxa
Stigeoclonium sp.	44.8	49.1	*Stigeoclonium sp.*
Gomphonema olivaceum	16.7	22.7	*Phormidium autumnale*
Navicula spp.	8.6	8.5	*Didymosphenia geminata*
Synedra nana	6.4	4.6	*Chladophora sp.*
Achnanthidium minutissima	3.4	3.8	*Navicula spp.*
Synedra ulna	3.1	3.0	*Gomphonema olivaceum*
Tabellaria fenestrata	2.1	1.8	*Synedra ulna*
Cyclotella ocellata	2.0	1.2	*Achnanthidium minutissima*
Cyclotella bodanica	1.8	0.7	*Cyclotella ocellata*
Synedra acus	1.7	0.65	*Fragilaria crotonensis*

Depositional

Dominant Reference Taxa	Biovolume (%)		Dominant Exposure Taxa
Didymosphenia geminata	40.4	20.8	*Didymosphenia geminata*
Navicula spp.	13.8	16.4	*Navicula spp.*
Synedra ulna	9.4	9.95	*Synedra ulna*
Eucocconeis flexella	9.0	6.7	*Cyclotella bodanica*
Cyclotella ocellata	5.7	6.22	*Staurosira construens*
Cyclotella bodanica	4.5	6.2	*Eucocconeis flexella*
Staurosira construens	3.7	4.6	*Synedra ulna (sm variety)*
Fragilaria crotonensis	3.3	3.7	*Nitzschia sp.*
Pinnularia sp.	3.1	3.25	*Cyclotella ocellata*
Synedra ulna (sm variety)	2.3	3.1	*Fragilaria crotonensis*

NOTE: (?) indicates that the identification was tentative

4.3.3 Species Richness and Diversity

Effective number of species did not differ significantly (P = 0.096) between the 7 exposure and 3 reference sites in depositional habitats during 2012, 2015 or 2018 (Table A5 and Figure 4-39).

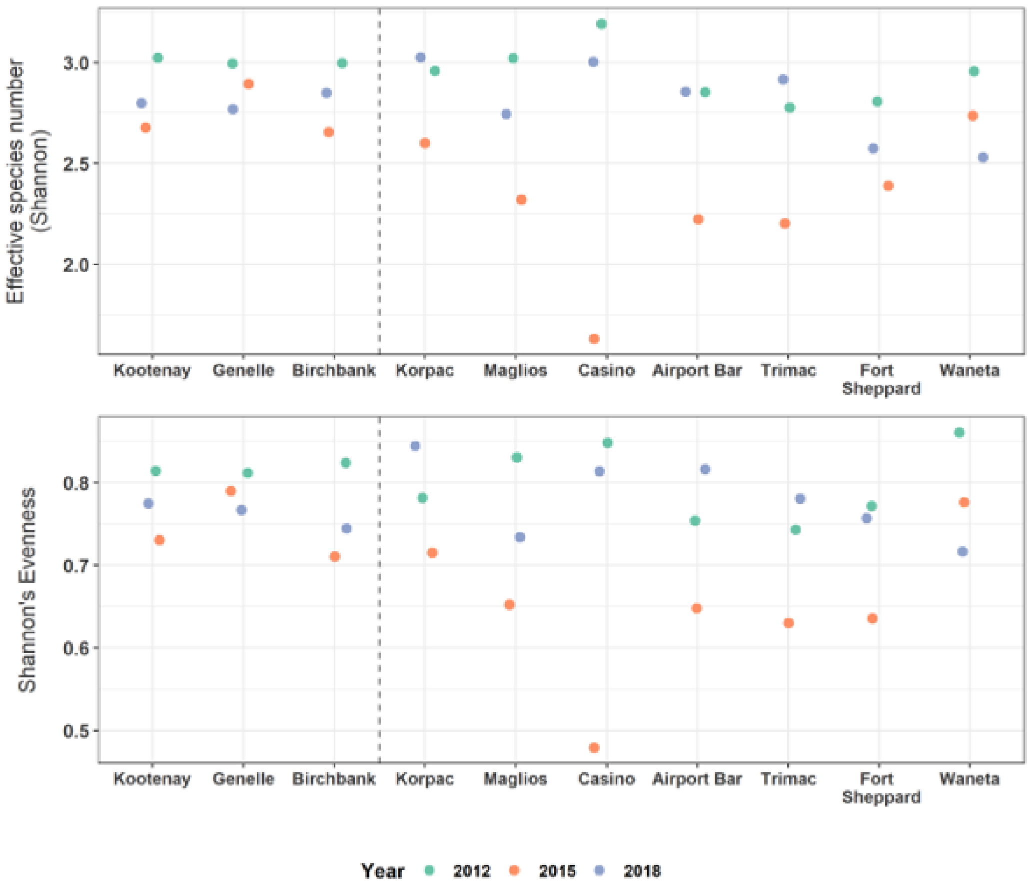


Figure 4-39: Plots of 2012, 2015 and 2018 periphyton community productivity and diversity in depositional sites.

4.3.4 Productivity Metrics

Productivity metrics at depositional sites exceeded those of erosional sites in all studied years including 2018 (Table 4-15). Reference and exposure depositional sites had similar growth metrics. For example, the depositional reference site biovolume averaged 6.74 ± 0.65 cm^3/cm^2 and the exposure sites averaged 5.96 ± 3.01 cm^3/cm^2 in 2018 (Table 4-15).

Table 4-15: Average Periphyton growth metrics by depositional sample site for 2018 samples.

	Exposure							Reference		
	Korpac Dep Exp 1	Maglios Dep Exp 2	Casino Dep Exp 3	Airport Bar Dep Exp 4	Trimac Dep Exp 5	Ft Shepherd Dep Exp 6	Waneta Dep Exp 7	Kootenay Dep Ref 1	Birchbank DEP Ref 2	Genelle Dep Ref 3
Abundance (cells /cm^3 × 10^5)	16.17	9.12	19.78	10.95	22.29	5.22	6.51	13.3	9.17	9.77
Species Richness (# taxa)	36	42	40	33	42	30	34	37	37	46
Bio Volume (cm^3/m^2)	6.15E+08	5.71E+08	9.27E+08	7.60E+08	8.97E+08	1.68E+08	2.35E+08	7.44E+08	6.63E+08	6.16E+08
Shannon EQ Index	0.844	0.734	0.814	0.816	0.781	0.757	0.717	0.775	0.767	0.744

The cumulative effect of flows, weather, and timing of sampling versus flow changes are reflected in the significant difference between sampled years across all periphyton growth metrics (ANOVA p=<0.001 for abundance, biovolume and effective number of species). In contrast, the difference between reference and exposure site was not significant for periphyton growth metrics, suggesting that exposure to effluents is less important than other factors that control growth (Appendix H) (Figure 4-40).

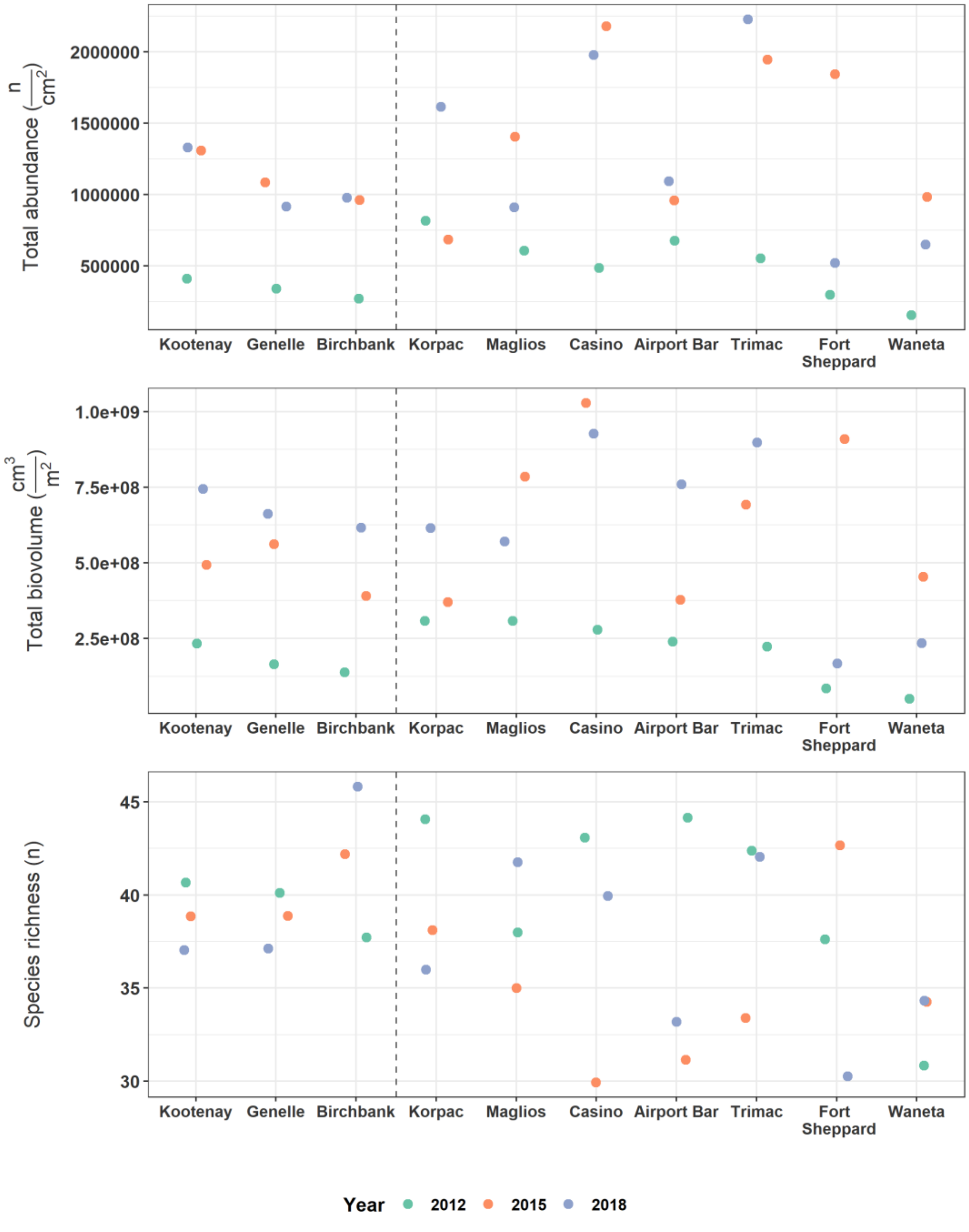


Figure 4-40: Plots of 2012, 2015 and 2018 periphyton community productivity and diversity in depositional sites.

Large depositional sites such as downstream Waneta and upstream Genelle eddies had lower periphyton abundance and biovolume in 2012, 2015 and 2018 than smaller depositional sites (Table 4-16). Large depositional sites likely have other influences restricting periphyton productivity unrelated to the smelter, such as increased water depth and increased density of invertebrate consumers.

Depositional sediment metal concentrations have been declining since 2003 (Hawes et al. 2014, Hawes et al. 2019). Depositional periphyton abundance and biovolume showed no consistent gradient from upstream reference to downstream exposure sites in any year of study including 2018 (Figure 4-40; Table 4-16). Sediment copper concentrations did not have significant correlations with growth and community composition metrics, measured at exposure sites in 2012, 2015 and 2018 (p>0.05, Table 4-16). Taken together, these results indicate that the algicidal effects of copper were not resulting in reduced periphyton growth but may contribute to differences recorded in relative concentrations of dominant taxa.

Table 4-16: Pearson's r correlation coefficients comparing copper (mg/kg) and available measures of periphyton biodiversity.

Treatment	Measure	Pearson's r	p Value
Exposure	Effective Species	0.319	0.486
Exposure	Shannon's H	0.375	0.407
Exposure	Shannon's Equitability	0.094	0.842
Exposure	Species Richness	0.628	0.131
Exposure	Total Abundance	0.262	0.570
Exposure	Total Biovolume	0.555	0.196

In each study year, the range of productivity metrics varied within the 3 reference sites and within the 7 exposure sites (Figure 4-40). Productivity metrics of depositional exposure sites downstream of the smelter historically exceeded the average of the reference sites, but the difference was not significant in 2018 (Appendix H). Nutrients are introduced by many sources including groundwater from the smelter site, City of Trail stormwater, and primary-treated effluent from the Regional Wastewater Treatment Facility that discharges to the Columbia River just above the Maglios site. These may have contributed to the progressive increase in sediment nutrient concentrations the further down the river the depositional site occurred. Increases in periphyton production as water progresses downstream are normal in large river systems and are frequently nutrient-driven (Wetzel, 2001).

4.3.5 Community Composition

Diatoms accounted for 95 – 99% of the total periphyton biovolume in 2012, 2015 and 2018 in depositional surface sediments (Table 4-17). All 10 dominant taxa were diatoms at reference and exposure sites (Table 4-17). The many taxa that occurred in both reference and exposure sites helps explain why the NMDS analysis did not detect major periphyton community differences attributable to effluent exposure (F=1.08, r^2=0.04, p=0.032;(Figure 4-41). Year-to-year differences were detected (F=8.26, r^2=0.23, $p<0.001$) due to shifts in prevalence of dominant diatoms. The first NMDS axis was positively correlated with the three diatoms of *Diatoma* spp., *Navicula* spp. and *Achnanthidium* spp. These three diatom taxa were more abundant in 2018 compared to 2012 and 2015. *Ochromonas* spp. was negatively associated with the MDS1 (r^2= 0.54, $p<0.001$). In 2012, the golden algae of *Ochromonas* spp. was present at all sites, whereas in 2018, *Ochromonas* spp. was absent.

Table 4-17: Percent contribution of major algae groups to periphyton biovolume by site - Depositional Sites, 2018.

	Reference Sites			Exposure Sites						
Algae Type	Kootenay	Genelle	Birchbank	Korpak	Maglios	Casino	Airport Bar	Trimac	Ft Shepherd	Waneta
Diatoms	100	99.4	99.2	99.5	99.3	99.1	98.9	97.6	99.9	99.9
Green Algae	0	0	0.1	0.2	0.6	0.8	0.5	2.1	0	0
Flagellates	0	0	0.5	0	0	0	0.6	0.1	0	0
Cyanobacteria	0	0.6	0.1	0.3	0.1	0	0	0.2	0.1	0.1
Dinoflagellates	0	0	0.1	0	0	0	0	0	0	0

There was no spatial trend in the depositional community structure with distance downstream of the smelter in 2012, 2015 or 2018 periphyton data (Table 4-17). This data was collected during fall low flows, when the potential to generate a downstream spatial trend could be expected to be the greatest. In 2012, Waneta had unusually high densities of flagellated algae, known as a group for their metal tolerance. In 2015, flagellates were still common, and in 2018 samples, they were not detected. The 2018 Waneta periphyton community structure was less distinct and more aligned with the large reference depositional areas (Table 4-17).

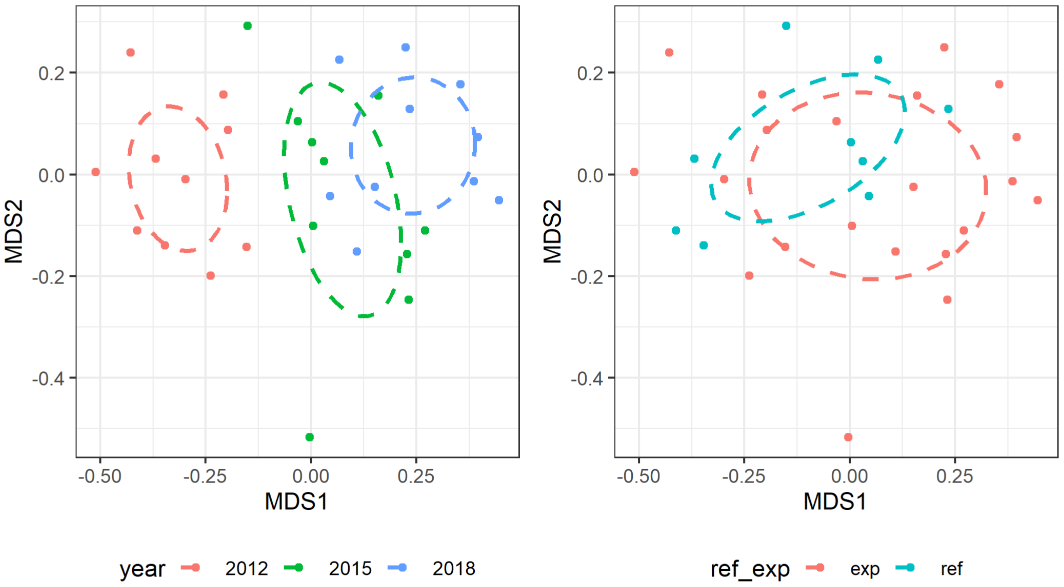


Figure 4-41: NMDS of depositional periphyton abundance at the genus level grouped by year (left panel), and grouped by exposure (EXP) sites in red and reference (REF) sites in blue (right panel). The stress value was 0.19.

The effect of treatment (reference vs. exposure area) was tested on three periphyton metrics which quantify community composition and productivity. The interaction term of year and treatment was not significant for all three periphyton models, so it was dropped from the final model. Periphyton biovolume, abundance and effective number of species at reference depositional sites had no significant differences when compared to exposure sites. However, the ANOVA indicated there were significant annual differences in periphyton productivity and diversity. The 2012 total abundance and total biovolume of periphyton at the depositional sites was significantly lower than abundance and biovolume in 2015 and 2018 ($p<0.001$). The effective number of species was significantly lower in 2015 compared to 2012 and 2018 (Figure 4-41; Appendix H).

4.3.6 Summation

Depositional periphyton analysis found significant differences in community metrics between sample sites. The causation of these differences in community metrics is not clear because, in addition to smelter effluent, they can be affected by multiple variables and annual variability in the LCR AOI including habitat, flow regimes, and nutrient inputs such as groundwater inflow from the smelter site, stormwater, and the City of Trail sewage treatment outfall. The influence of the smelter outfall on depositional periphyton metrics was minor and far smaller than the effect of year-to-year influences in the LCR such as flow regime.

4.4 Erosional Habitat Periphyton

The erosional periphyton sampling program was designed to assess effects of the effluent discharge on erosional periphyton communities in terms of community structure, composition, and standing crop biomass, and to detect any trends over time in these metrics.

Erosional substrates consisting of pebble/cobble/boulder account for approximately 1,517 ha or 98% of the total area of the LCR between HLK Dam and the Canada - US border. In the AOI (Birchbank to Waneta), erosional areas account for 99.9% of substrates (Golder 2007). This highlights the erosional nature of the Columbia River in this area and the importance of erosional habitats to the LCR. Years when periphyton studies were conducted in the LCR AOI are 1995, 1999, 2003, 2010, 2012, 2015, and 2018.

Periphytic algae are the main primary producers in freshwater environments. Periphyton biofilms in erosional LCR habitats are complex, layered assemblages of autotrophic algae/photosynthetic bacteria and heterotrophic bacteria/fungi/yeasts/protozoa, all embedded in a protective polymeric matrix (Wetzel 1993, Decho 1990, Drenner *et al.* 1993, Sobczack 1996). This biofilm supplies a large portion of the energy to higher trophic levels in the LCR as it does in all rivers (Azim 2009). Diatoms commonly constitute the dominant group of algae in river biofilms (Stevenson and Bahls 1999), as they did in every study of the LCR including this one.

Biomonitoring is a useful tool for assessing aquatic ecosystem health, and it complements physical and chemical analyses (Morin et al. 2008). Periphytic algae are very sensitive to systemic modifications in water quality and hydrologic regime (Fernandes and Esteves 2003). After a high-flow period that scours the biofilm such as freshet, bacteria and small closely attached diatoms are among the rapid, early colonizers, while slower growing filamentous green algae are among the later arrivals. Diatoms arriving from upstream reservoirs that become entrapped on the biofilm are important to the LCR periphyton (Larratt et al. 2013).

Summary data from 2018 agrees with earlier AEMP studies. When 2018 data are compared to other large rivers including the LCR above the AOI, most metrics place the AOI in the oligotrophic to typical large river category, with small differences between years and between the AOI and upstream LCR Reach 2 (Table 4-18). An influence from the smelter on LCR erosional periphyton is not detectable.

Table 4-18: Summary of typical range of LCR periphyton metrics from 2015, with comparison to oligotrophic, typical, and productive large rivers and upstream Reach 2 LCR.

Metric	Oligo-trophic or stressed	Typical large rivers	Eutrophic or productive	LCR-upstream Reach 2*	Exposure Erosional AOI of LCR 2012	Exposure Erosional AOI of LCR 2015	Exposure Erosional AOI of LCR 2018
Number of taxa (live & dead)	<20 – 40	25 - 60	Variable	8 – 60	23 – 48	22 – 44	21 – 49
Chlorophyll-a µg/cm^2	<2	2 – 5 (7)	>7 – 10 (30+)	0.04 – 15.3	0.37 – 3.50	0.23 – 0.99	0.15 – 4.67
Algae density cells/cm^2	<0.2 x10^6	1 - 4 x10^6	>10 x10^6	0.03 – 3.9 x10^6	0.05 – 0.73x10^6	0.05 – 0.29x10^6	0.04 – 0.73 x10^6
Algae biovolume cm^3/m^2	<0.5	0.5 – 5	20 - 80	0.1 – 25	0.15 – 0.93	0.18 – 1.46	0.22 – 5.66
Diatom density frustules/cm^2	<0.15 x10^6	1 - 2 x10^6	>20 x10^6	0.4 – 2.3 x10^6	0.07 – 0.28 x10^6	0.04 – 0.55 x10^6	0.26-0.47 x10^6
Biomass – AFDW mg/cm^2	<0.5	0.5 - 2	>3	0.35 – 7.1	Not sampled	Not sampled	Not sampled
Biomass – dry wt mg/cm^2	<1	1 – 5	>10	3.1	Not sampled	Not sampled	Not sampled
Bacteria sed. HTPC CFU/cm^2	<4 -10 x10^6	0.4 – 50 ×10^6	>50×10^6 – >10^{10}	1.5 - >5 x 10^6	0.36 – >2 x 10^6	Not re-sampled	Not re-sampled
Fungal count CFU/cm^2	<50	50 – 200	>200	8 - 1830	<200 – 1000	Not re-sampled	Not re-sampled

Comparison data obtained from Flinders and Hart 2009; Biggs 1996; Peterson and Porter 2000; Freese et al. 2006; Durr and Thomason 2009; Romani 2009; Biggs and Close 2006. Dodds et al, 1998
*Artificial substrate samples, tends to inflate growth metrics compared to natural substrates

4.4.1 Dominant Taxa

Diatoms were the dominant algae class in all studies of the AOI, as is typical of large rivers (Table 4-19). In most of this work, the small diatom *Achnanthidium minutissima* was dominant numerically at erosional sites. However, when the dominant taxa are ranked by their biovolume contributions to standing crop, a variety of dominant diatoms emerge (Table 4-19). Both reference and exposure erosional sites shared 6 of 10 dominant taxa and the same top dominant – a filamentous green algae in 2018. Timing of sampling with respect to flow events likely accounts for much of the observed dominant species variation between years of study as it does throughout the LCR (Olson-Russello et al. 2014).

Table 4-19: Percent contribution of the major algae groups to periphyton biovolume by erosional sample site, 2018.

	Reference Sites		Exposure Sites				
2018 Algae Type	Ero Ref 1 Birchbank	Ero Ref 2 u/s Stoney	Ero Exp 1 CIV-Stoney	Ero Exp 2 CIII	Ero Exp 3 CIII-Korpac	Ero Exp 4 Kor-Mag	Ero Exp 5 Mag-Wan
Diatoms	37.3	84.8	23.8	27.3	35.7	16.4	37.3
Green algae	60.6	13.9	7.3	71.5	62.7	83.5	60.6
Flagellates	0.2	0.4	0.2	0.1	0.3	0.1	0.2
Cyanobacteria	1.3	0.9	68.7	0.4	0.2	0	1.3
Dinoflagellates	0	0	0	0.7	0.8	0	0
Red algae	0	0	0	0	0.3	0	0

In 2018, periphyton samples from erosional reference sites had 9 diatom dominants and 1 dominant filamentous green taxa, while those from erosional exposure sites had 7 diatom dominants, 2 dominant filamentous green taxa, and one dominant filamentous cyanobacteria (Table 4-20). Unique dominants occurring only at the exposure sites in 2018 were all filamentous taxa that display strong water velocity preferences.

Diatom frustule abnormalities were extremely rare (<1 in 500) in the 2012 through 2018 results and were evenly distributed between reference and exposure sites. Sites with heavy loads of metal pollution are known to have abnormality levels of more than 3.5 to >10% (Guasch et al 2012), while no sample exceeded 0.2% in the LCR AOI.

Table 4-20: Distribution of filamentous periphyton (biovolume cm^3/m^2) in LCR 2018

	Reference Areas		Exposure Ares				
Filamentous dominants	ero-ref-1	ero-ref-2	ero-exp-1	ero-exp-2	ero-exp-3	ero-exp-4	ero-exp-5
Cyanobacteria							
Calothrix sp.	5.92x10^6	0	0	0	0	0	0
Oscillatoria spp.	0	0	0	0	1.02x10^7	0	0
Phormidium autumnale	9.59x10^6	0	9.35x10^7	6.58x10^9	0	0	0
Green Algae							
Cladophora sp.	0	0	0	0	0	1.6x10^8	1.19x10^9
Spirogyra sp.	0	0	0	0	0	0	3.34x10^8
Stigeoclonium sp.	1.22x10^9	1.95x10^8	4.76x10^9	5.74x10^8	4.44x10^9	1.54x10^9	1.52x10^9

4.4.2 Species Richness and Diversity

Periphyton community metrics of species richness and effective species number showed little difference between erosional reference and exposure habitats in 2018 data. Like 2012 and 2015, reference and exposure areas had similar mean species richness with 30 ± 6 taxa in reference areas and 31-37 ± 6 taxa in 2018 exposure area samples (Table 4-21). Similarly, diversity metrics of effective number of species and Shannon Evenness were similar between exposure and reference sites in 2018 data (Figure 4-42). However, statistically significant differences occurred at ERO–EXP-2 located in the side channel that receives the CIII outfall. It had a significantly lower effective number of species and Shannon evenness than ERO-REF-1, ERO-REF-2, ERO-EXP-3 and ERO-EXP-4 (Appendix I). Shannon Evenness at ERO-EXP-2 was also significantly lower than Shannon Evenness at ERO-EXP-5 ($p=0.002$). In 2018 and in previous sampling years at ERO-EXP-2, unusually large cyanobacteria numbers take advantage of the warmer water temperatures in the side channel. Filamentous green algae were also prevalent in the side channel for the first time in 2018. The side channel with CIII effluent creates a unique erosional habitat area with high water velocities and warmer water temperatures.

Twenty to 49 taxa per site were measured in 2018, while earlier studies measured between 63 and 84 taxa per site in the LCR AOI (Golder 2003, 2007). Improved effluent management throughout the LCR may have lowered phosphorus levels sufficiently to gradually lower species richness over time toward a natural, background range. Identifying lower diversity throughout the LCR is important because reduced periphyton species richness is universally found at sites with metal effluent impacts (Guasch et al. 2012; Morin et al. 2008), and the lower diversity could be incorrectly attributed to metal effluent impacts.

Most erosional sites had more diatoms and fewer filamentous algae in 2015 and 2018 compared to 2012, with the biggest differences in diversity at near-field sites (Table 4-21). Similar periphyton community compositions in 2015 and 2018 were likely a result of lower and earlier freshets in those years compared to 2012. The freshet of 2012 was high with a peak mean daily flow of 6,043 m^3/s on July 21, 2012, whereas 2015 and 2018 freshets were lower with a peak mean daily flow of 3,469 m^3/s on June 7, 2015 and 4474 m^3/s on May 26, 2018.

The density of filamentous green algae was higher at erosional sites than at depositional sites in all sampled years, reflecting habitat preference (Table 4-21). This is supported by previous ecological studies that show water velocity, substrate type, and nutrient concentrations affect algae growth (Larratt et al. 2013).

4.4.3 Productivity Metrics

Most samples from the LCR AOI were in the oligotrophic category for periphyton growth in 2003 chl-a results (Golder, 2007b). Only four chlorophyll-a samples reached the mesotrophic 2 – 5 µg/cm² chl-a range in the near field during 2012, none in 2015, and three from the near field in 2018 (Table 4-21). The fall 2018 erosional periphyton chlorophyll-a data averaged 0.7 – 0.8 ± 0.3 µg/cm² at the two reference sites and was unchanged 0.5 – 1.48 µg/cm² at the five exposure sites (Table 4-21). These results are consistent with 2012 and 2015.

Table 4-21: Periphyton growth metrics by erosional sample site, 2018.

		Near Field			Far Field		Reference	
Erosional Periphyton	Statistic	CIV/ Stoney Exp-1	CIII Exp-2	CII - Kor Exp-3	Kor - Mag Exp-4	Mag - Wan Exp-5	LB opp. CIV Ref-1	Birchbank Ref-2
Abundance (cells /cm³ × 10⁵)	Mean (± SD)	1.80 ± 1.1	3.58 ± 2.19	2.16 ± 1.2	0.86 ± 0.45	1.42± 0.80	1.27 ± 0.55	1.36 ± 0.90
	Median	1.59	3.21	1.67	0.72	1.23	1.04	0.96
	Minimum	0.78	0.81	0.95	0.36	0.54	0.61	0.58
	Maximum	5.50	7.30	4.69	1.73	3.54	2.45	3.47
Species Richness (# taxa)	Mean (± SD)	37.3 ± 6.1	31.4 ± 4.72	37.0 ± 6.14	29.9 ± 8.8	30.7 ± 6.01	31.2 ± 6.58	29.5± 4.5
	Median	39	30	37	25	29	30	28
	Minimum	24	23	28	20	22	21	25
	Maximum	45	39	48	46	42	49	37
Bio Volume (cm³/m²)	Mean (± SD)	1.43 ± 1.03	1.60 ± 1.91	1.39 ± 1.1	0.51 ± 0.05	1.20 ± 0.92	0.63 ± 0.28	0.62 ± 0.51
	Median	0.97	0.40	0.93	0.40	0.87	0.54	0.41
	Minimum	0.45	0.18	0.22	0.098	0.16	0.31	0.23
	Maximum	4.05	5.66	3.66	2.18	3.04	1.28	1.95
Shannon EQ Index	Mean (± SD)	0.73 ± 0.05	0.54 ± 0.14	0.68 ± 0.08	0.75 ± 0.06	0.69 ± 0.10	0.72 ± 0.05	0.67 ± 0.11
	Median	0.74	0.57	0.66	0.76	0.71	0.72	0.72
	Minimum	0.59	0.33	0.56	0.60	0.46	0.61	0.40
	Maximum	0.82	0.73	0.82	0.82	0.83	0.79	0.78
Chlorophyll-a (µg/cm²)	Mean (± SD)	1.24 ± 0.49	1.40 ± 1.26	1.48 ± 0.85	0.54 ± 0.40	0.82 ± 0.43	0.84 ± 0.33	0.72 ± 0.15
	Median	1.19	1.01	1.43	0.37	0.76	0.84	0.70
	Minimum	0.48	0.33	0.34	0.15	0.34	0.25	0.50
	Maximum	2.33	4.66	3.47	1.40	1.78	1.64	0.96

Kor = Korpac, Mag = Maglios, Wan = Waneta

Mirroring chl-a results, periphyton abundance continued its decline since 2003 to average 1.3-1.4 ± 0.9 ×10⁵ cells/cm² at reference sites and 0.86 – 3.58 ×10⁵ cells/cm² at exposure sites in 2018 data. This decline in periphyton abundance has been most dramatic at exposure sites and is approaching the range of standing crop estimates typical for LCR (Table 4-21). Like other 2018 periphyton metrics, biovolumes from erosional sites did not show any significant difference between reference and exposure sites (Figure 4-43). All periphyton production metrics showed higher variability in 2015 than in 2012 and 2018 throughout the data set.

While there was variation among exposure sites, no spatial gradients in abundance data emerged within near- and far-field sites or between exposure and reference sites attributable to smelter operations (Table 4-21). Similarly, in all years of study 2003 - 2018, no strong spatial gradients in chl-a occurred with distance upstream or downstream of the smelter (Figure 4-44).

All 2018 productivity metrics were significantly different between erosional sites: total abundance (F=9.18, p<0.001), total biovolume (F=4.78, p=0.002), and chl-a (F=8.02, p<0.001). For example, ERO-EXP-2 had significantly higher chl-a and abundance than ERO-REF 1-2 and ER0-EXP 4-5. Within each site, differences between 2012, 2015 and 2018 erosional periphyton metrics occurred at ERO-EXP-1, ERO-EXP-2 in the near-field and ERO-EXP-4 in the far field (Figure 4-43), and of these, only ERO-EXP-2 was significant in 2018 data.

Samples collected at ERO-EXP-1 adjacent to Stoney Creek showed high green filamentous algae production in the 1990's before upgrades at the fertilizer plant reduced effluent concentrations. Filamentous populations have since declined to levels closer to those of the reference sites (Table 4-21). Increased filamentous growth at the furthest downstream ERO-EXP-4 and ERO-EXP-5 sites is likely related to localized nutrient inputs, such as municipal sewage effluent.

Instead of adverse impacts at the ERO-EXP-2 site as noted by Golder (2003), the highest periphyton density and diversity occurred at the near-field sites in 2012, 2015 and 2018 (Hawes et al. 2014, Hawes et al. 2019). Groundwater discharges from the smelter elevated temperature and nutrients including ammonia and sulphate (Golder, 2012c). Periphyton productivity in this near field area is also influenced by greater water velocities and is situated immediately downstream of the CIII outfall. The sum of these nutrient, temperature and velocity conditions can be stimulatory for many algae taxa including cyanobacteria. Cyanobacteria are also known for their metal tolerance (Fiore and Trevors, 1994). ERO-EXP-2 samples had more filamentous cyanobacteria than other exposure sites in 2012 and 2018 but were typical of upstream LCR in 2015. These near-field taxonomic results confirm productivity metrics from recent years, suggesting that the influence of the smelter on the AOI is diminishing.

In previous studies, the Old Bridge area (ERO-EXP-3) was distinctive with more Chrysophytes (golden algae) and higher green algae densities (Golder 2003), which often indicates organic or nutrient enrichment (Felisberto, et al. 2011; Wetzel 2001). In 2012, 2015 and 2018 results, these algae were no longer prevalent.

Far field area ERO-EXP-4 showed low productivity in 2012, 2015 and 2018 (Figure 4-43). In addition to the dilute smelter effluent plume, there are other important influences acting on this area including lower velocities over more embedded substrates with more fines, and Ryan Creek inflows. Since productivity metrics are consistently higher above and below this area, smelter impact is not the primary cause of the low productivity observed in this area.

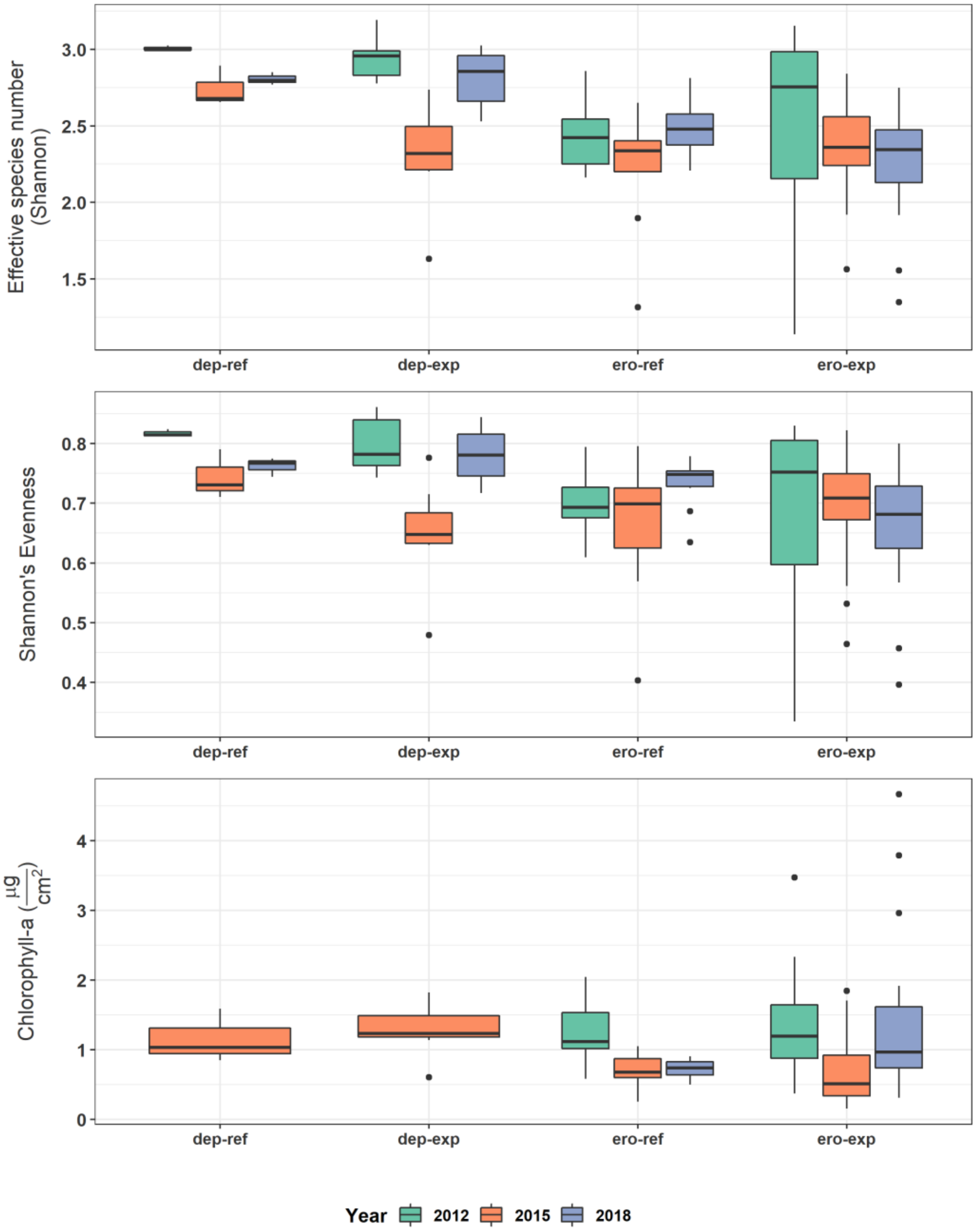


Figure 4-42: Boxplots of effective species number, Shannon's evenness, and chlorophyll-a productivity for 2012, 2015 and 2018 periphyton community productivity and diversity in depositional and erosional sites above and below smelter outflow (reference versus exposure respectively). Dep = depositional, Ero = erosional, Exp = exposure, Ref = reference.

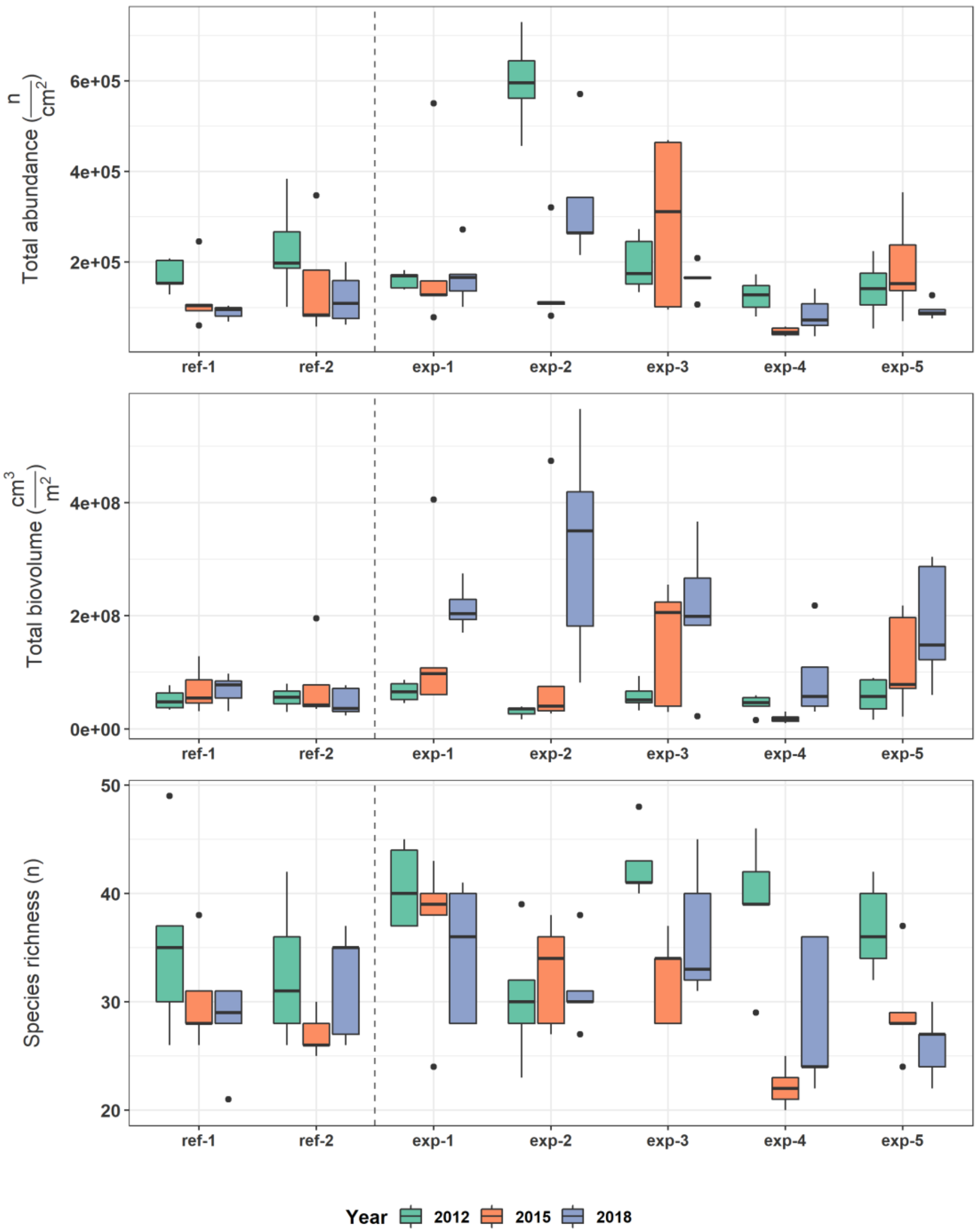


Figure 4-43: Boxplots of abundance, biovolume and species richness of 2012, 2015 and 2018 periphyton community productivity in erosional sites. Exp = exposure, Ref = reference.

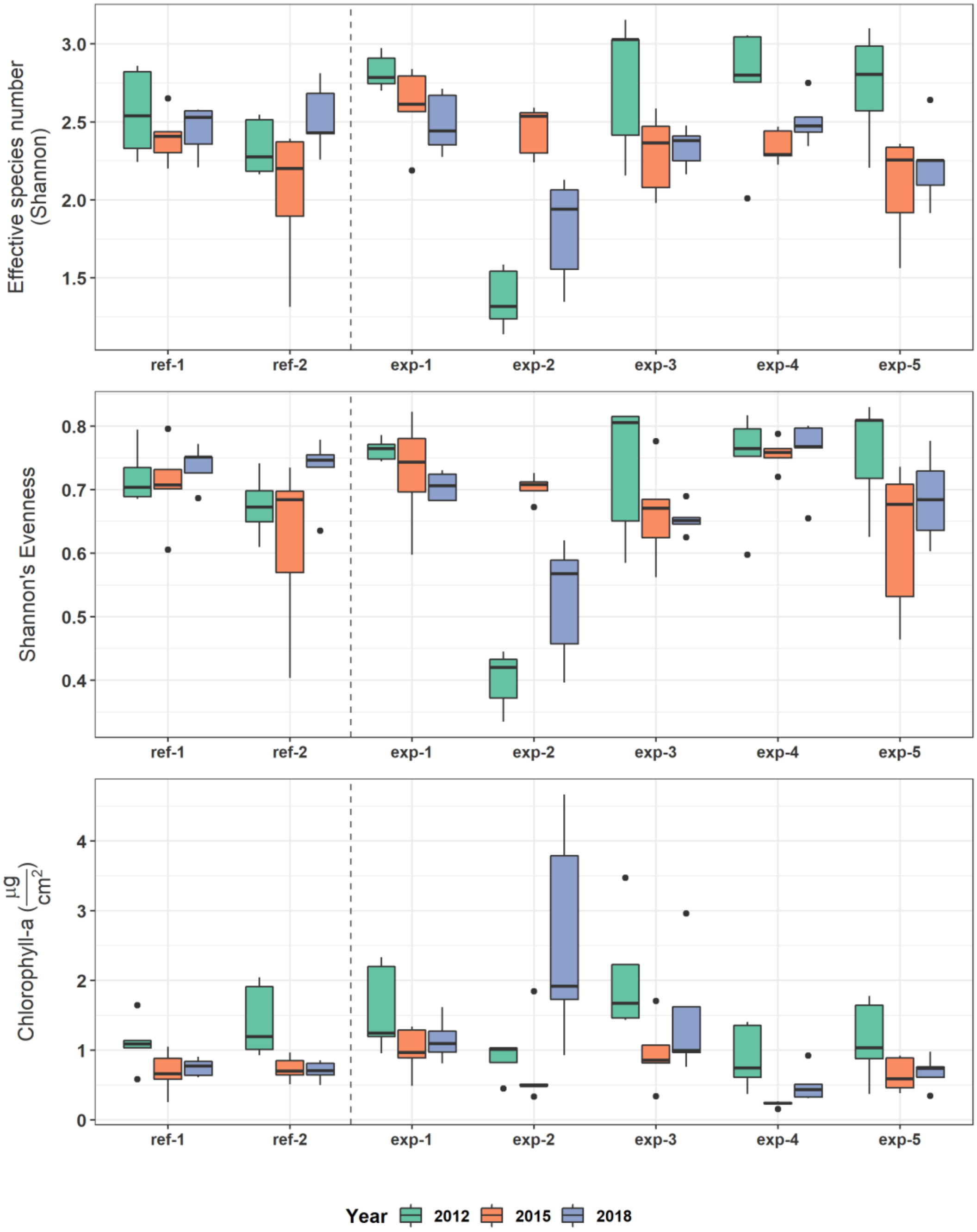


Figure 4-44: Boxplots of effective number of species, Shannon's Evenness and chl-a of 2012, 2015 and 2018 periphyton community productivity in erosional sites. Exp = exposure, Ref = reference.

4.4.4 Community Analysis

4.4.4.1 Community Composition

The difference between reference and exposure periphyton communities was statistically significant but explained only 3% of the periphyton community variation (F=2.57, p = 0.008; Figure 4-45). These analyses were completed at the genus level and excluded rare (occurred in <5% of samples) taxa that can bias the analyses (Guasch et al. 2012). NMDS analysis of the 2012, 2015 and 2018 indicated that the most important factor determining periphyton community was the year sampled (F=7.78, R^2=0.07, p<0.001) (Figure 4-45). Significant differences between years have been identified throughout the Lower and Middle Columbia River, and are caused by annual variations in weather, flow patterns, water temperature, etc.

Taxa primarily responsible for causing differences between years in erosional periphyton communities include the cyanobacteria *Synechocystis and Aphanothece spp*., which were higher in 2012, and the green alga *Botryococcus spp.*, which had higher abundances in 2015 compared to 2012 and 2018.

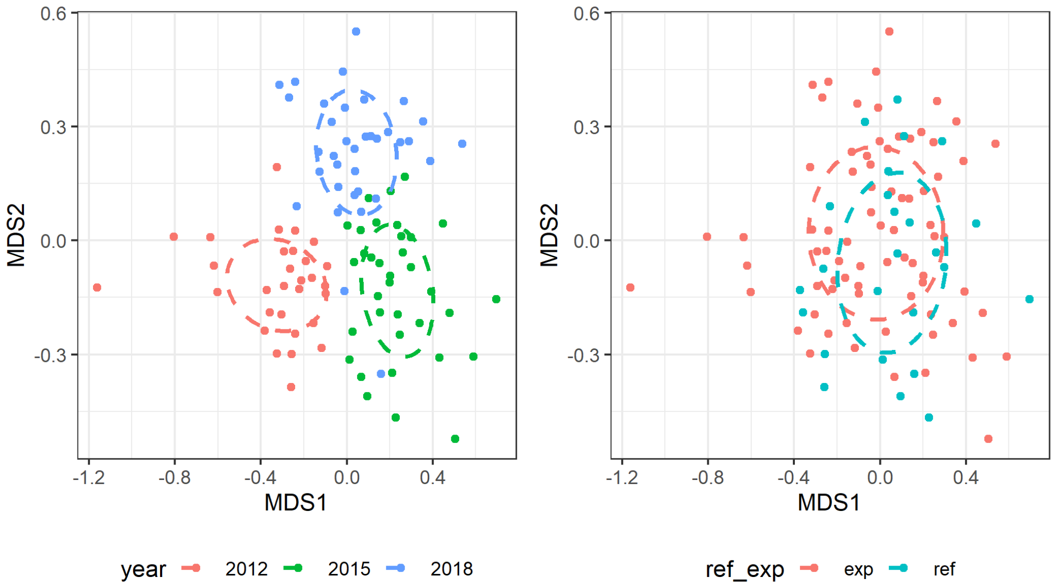


Figure 4-45: NMDS of erosional periphyton abundance at the genus level grouped by year (left panel) and grouped by exposure (EXP) sites in red and reference (REF) sites in blue (right panel). The stress value was 0.25.

Periphyton communities in depositional sites were distinct from erosional sites due to the higher prevalence of *Staurosira sp., Eucocconeis sp. Cymbella spp.*, and to a lesser extent, *Nitzschia spp.*, and *Fragilaria spp.* at depositional sites. These diatoms are either motile, require warm water with elevated organic content, and/or are tolerant of dissolved metals (Figure 4-46) (Schmidt et al. 2004). The diversity of metal-tolerant taxa is indicative of moderate concentrations of metals. The depositional sediment metals are not present in concentrations that are known to adversely affect periphyton communities (Hawes et al. 2014; Medley and Clements 1998).

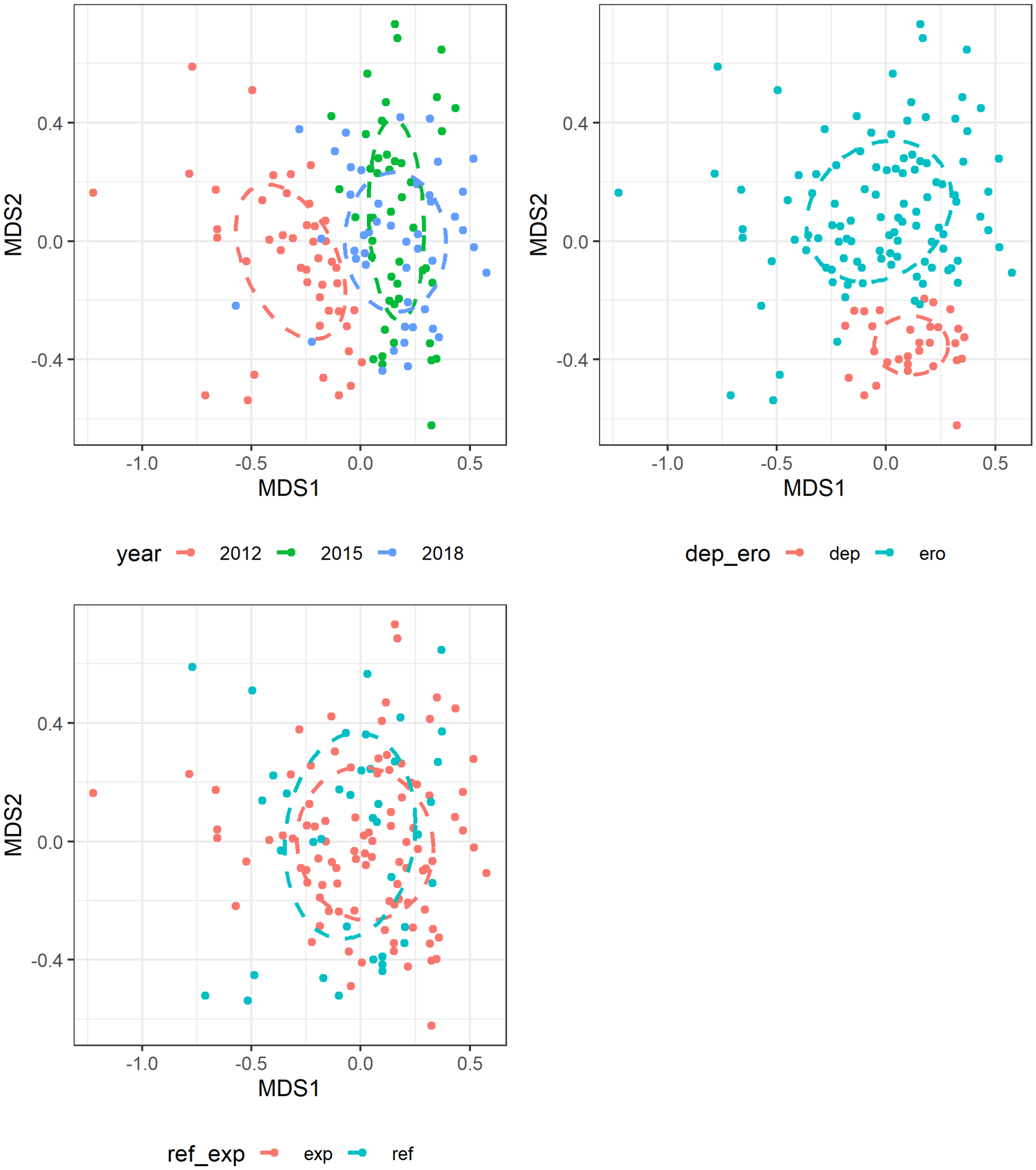


Figure 4-46: NMDS of periphyton abundance erosional and depositional areas at the genus level grouped by year, grouped by depositional (dep) and erosional (ero) sites, and grouped by exposure (EXP) sites in red and reference (REF) sites in blue. The stress value was 0.25.

The NMDS with both erosional and depositional sites showed overall periphyton community structure in 2015 and 2108 had more diatoms and fewer cyanobacteria than in 2012. The models showed abundance, chl-a, and effective number of species were higher in 2012; while 2018 had higher biovolume at exposure sites. Higher biovolumes in 2018 resulted from the prevalence of green alga *Stigeoclonium* at erosional exposure areas 1, 3-5 and the cyanobacteria *Phormidium* at ERO-EXP-2.

Attempts to find periphyton species whose distributions were correlated to metals of interest in the AOI and could serve as indicator taxa were largely unsuccessful and contradictory (G3 1999, Golder 2003, Golder 2007). Other more important driving forces on periphyton included overall river flows, localized water velocities, irradiance, nutrient concentrations, and benthic invertebrate grazing pressure. Instead of looking within the diatoms for indicators of metal exposure, it is better to analyze the overall community structure and the distribution of the main algae classes in LCR samples (Morin et al. 2008). Using this approach, no indication of a spatial trend in the periphyton community structure with distance downstream of the smelter in either the 2003 (Golder) or the 2012, 2015 and 2018 data was detected using NMDS.

4.4.4.2 Model Averaging

Like previous years, model averaging on the 2012, 2015 and 2018 periphyton data demonstrated that physical habitat factors, including substrate size (D50) was important in predicting biovolume, and effective number of species (Figure 4-47). The positive relationship between substrate size and chl-a and effective number of species occurs because large substrates have large, stable surfaces available for periphyton growth.

Erosional periphyton productivity and diversity metrics showed large annual differences in 2012, 2015, and 2018. Periphyton abundance was higher in 2012 compared to 2015 and 2018 at ERO-REF-1, ERO-EXP-2, and ERO-EXP-4 (Figure 4-43 and Figure 4-47). Overall chlorophyll-a and effective species number were higher in 2012 compared to 2015 (Figure 4-47). Overall periphyton biovolume was also higher in 2018 compared to 2012. However, biovolumes were only higher at exposure sites in 2018; at reference sites biovolumes were similar across all years (Figure 4-48). The consistency of reference site periphyton biovolumes compared to exposure sites suggests that growing conditions are more variable (e.g., local nutrient donations, local water velocities) at the downstream exposure sites.

Velocity was negatively associated with the diversity metrics of effective species number and Shannon evenness. This negative association was magnified by the high velocity and low diversity at ERO-EXP-2. High velocities cause a reduction in periphyton diversity because it shears off high profile taxa (Passy 2007). In addition, the low diversity at ERO-EXP-2 was also a result of warmer water temperatures in the side channel that encouraged the observed prevalence of cyanobacteria.

The effect of treatment (reference/exposure) was included in periphyton community and productivity models to test if the effluent discharge influenced periphyton community composition and productivity. Reference/exposure did not explain a significant portion of the variation in periphyton growth metrics nor in community structure metrics (Figure 4-47 and Figure 4-48). This lack of significant impact at exposure sites was also observed in 2012 and 2015 data (Hawes et al. 2019).

Earlier research in the LCR AOI reported adverse effects of metals on periphyton growth within the near-field prior to 2003 (G3 2001, Suter and Tsao, 1996, Golder 2010). Suter and Tsao (1996) identified chronic effects values were possibly exceeded for Cd Cu Zn, while later reports suggested Pb, Tl and Cu negatively correlated with periphyton growth in the IDZ (Golder 2010). While this may have been the case in the past, 2012 to 2018 periphyton community metrics did not differ significantly between reference and exposure sites, based on results from mixed effects models and model averaging (Figure 4-48), and results from NMDS (Figure 4-46).

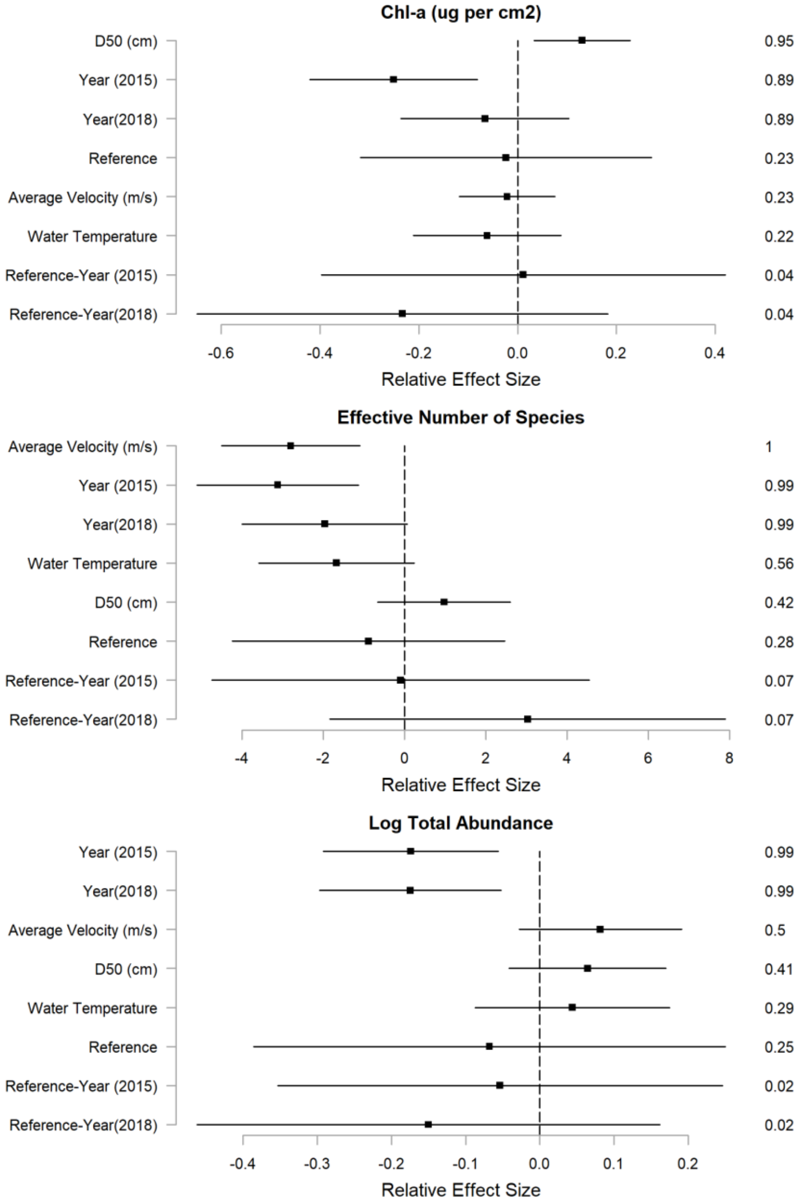


Figure 4-47: The coefficients and their 95% CLs of standardized explanatory variables of periphyton erosional samples. Periphyton responses included chl-a, effective number of species and abundance. Explanatory variables included D50 (substrate), velocity, water temperature, year sampled and treatment (reference or exposure). Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.

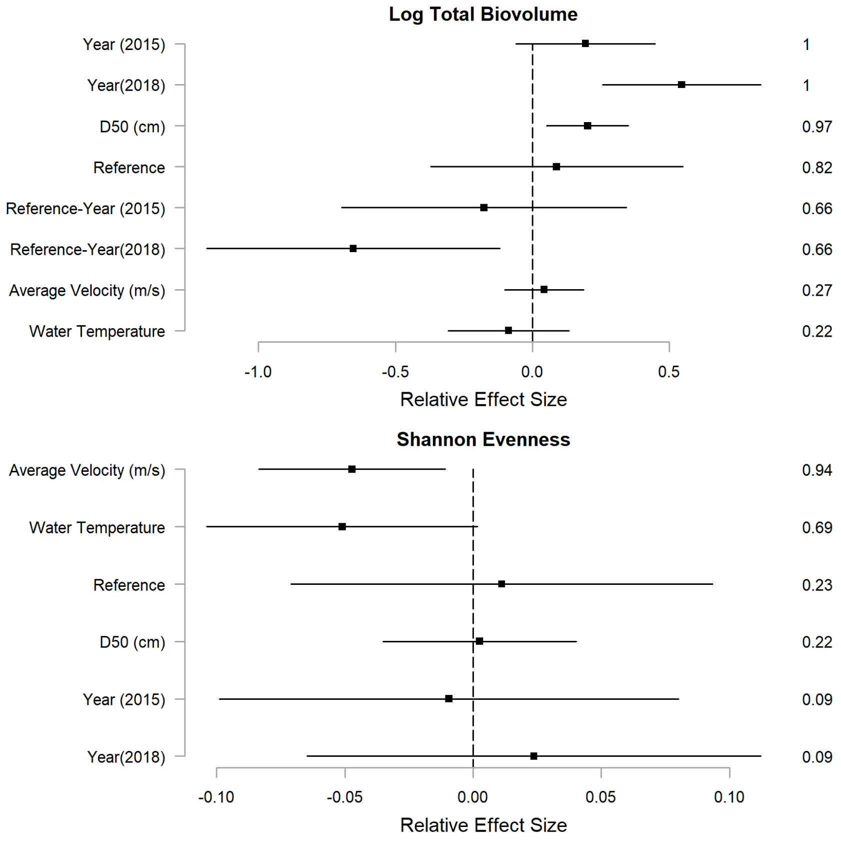


Figure 4-48: The coefficients and their 95% CLs of standardized explanatory variables of periphyton erosional samples. Periphyton responses included biovolume and Shannon Evenness. Explanatory variables included D50 (substrate), velocity, water temperature, year sampled and treatment (reference or exposure). Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero influence the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.

4.4.5 Summation

Near-field taxonomic results from 2018 confirm the erosional productivity metrics, suggesting that the influence of the smelter on periphyton in the AOI is diminishing. Periphyton community metrics from 2012 through 2018 do not differ significantly between reference and exposure sites, indicating that periphyton growth was not significantly impacted by exposure to smelter effluents. Over the course of 2003-2018 periphyton studies, productivity metrics within the IDZ and near-field have been trending lower toward more typical LCR levels.

Erosional periphyton analysis in 2018 found significant differences in community metrics between sample sites, particularly at ERO-EXP-2 in the CIII side-channel. The causation of these differences in community metrics is likely due primarily to elevated water velocity and temperature at ERO-EXP-2, and may be secondarily due to nutrient and/or metals inputs from CIII outflow.

4.5 Depositional Area Benthic Invertebrates

Benthic invertebrate community metrics in depositional areas from 2018 continue to illustrate natural annual variability across all sites. At the same time, 2018 metrics showed similar reference and exposures site results as 2012 and 2015 data (Hawes et al. 2019). The metrics illustrated in the succeeding figures are expressed as a single value for each reference and exposure depositional area. This is because the five replicate samples taken from each small depositional area were combined to avoid pseudoreplication. Due to this methodology, analysis of depositional benthic invertebrate community data solely collected in 2018 could not be completed.

4.5.1 Dominant Taxa

In 2018, detritus worms (Naididae) were the predominant taxa in five of the ten depositional habitats including the three reference areas as well as Airport (DEP-EXP-4) and Trimac (DEP-EXP-5) exposure areas. Pill clams (Pisidiidae) were the predominant taxa in three of the depositional areas including Korpac (DEP-EXP-1), Maglios (DEP-EXP-2), and Fort Sheppard (DEP-EXP-6). Chironomids were the predominant taxa at Casino (DEP-EXP-3), while isopods (Asellidae) continue to dominate the depositional area at Waneta (Dep-EXP-7) (Figure 4-49). Table 4-22 lists dominant taxa and functional feeding groups that are illustrated in Figure 4-49.

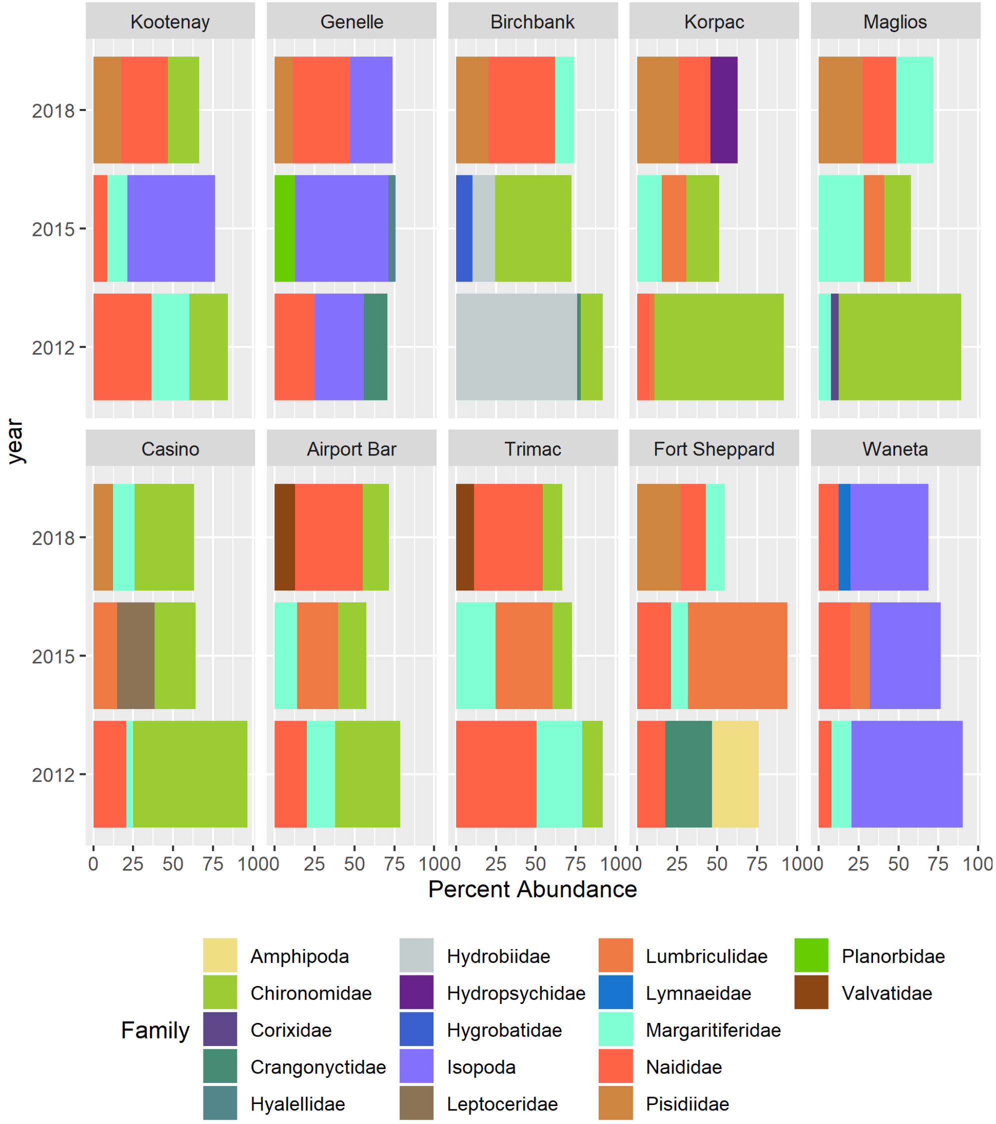


Figure 4-49: Benthic percent abundance by Family level at depositional sites. Upstream reference sites are Kootenay, Genelle and Birchbank and the remainder are exposure sites.

Table 4-22: Dominant taxa represented in depositional habitats for 2018 samples.

Class	Order	Family	Predominant Taxa*	Common Name	Functional Feeding Group
Arachnida	Trombidiformes	Hygrobatidae	*Hygrobates*	water mite	Predator
		Lebertiidae	*Lebertia*	water mite	Predator
Bivalvia	Veneroida	Pisidiidae	*Pisidiidae*	pill clam	Collector - Filterer
			Pisidium	pill clam	Collector - Filterer
	Unionida	Margaritiferidae		pearl mussel	Collector - Filterer
Gastropoda	Basommatophora	Lymnaeidae	*Lymnaeidae*	pond snail	Scraper
		Physidae	*Physa*	bladder snail	Scraper
		Planorbidae	*Planorbidae*	ramshorn snail	Scraper
	Heterostropha	Valvatidae	*Valvata*	valve snail	Scraper
			Valvata tricarinata	valve snail	Scraper
	Hypsogastropoda	Hydrobiidae	*Hydrobiidae*	mud snail	Scraper
Insecta	Diptera	Chironomidae	*Cryptochironomus*	chironomid	Predator
			Microtendipes pedellus group	chironomid	Collector-Gatherer
			Polypedilum sp.	chironomid	Collector-Gatherer
			Procladius	chironomid	Predator
			Rheotanytarsus	chironomid	Collector-Filterer
			Robackia demeijerei	chironomid	Collector-Gatherer
			Tanytarsus	chironomid	Collector-Filterer
	Ephemeroptera	Ephemerellidae	*Ephemerellidae*	spiny crawler mayfly	Collector-Gatherer
	Trichoptera	Leptoceridae	*Mystacides*	black dancer caddisfly	Omnivore
		Leptoceridae	*Oecetis*	brown caddisfly	Predator
		Hydropsychidae		net-spinning caddisfly	Collector-Filterer
	Hemiptera	Corixidae		water boatman	Predator
Malacostraca	Amphipoda	Crangonyctidae	*Crangonyx*	amphipod	Collector-Gatherer
		Hyalellidae	*Hyalella*	amphipod	Collector-Gatherer
	Isopoda	Asellidae	*Caecidotea*	isopod	Collector-Gatherer
Maxillopoda	Pygophora	Lithoglyptidae			Unclassified
Oligochaeta	Lumbriculida	Lumbriculidae	*Lumbriculidae*	aquatic worm	Collector-Gatherer
	Tubificida	Enchytraeidae	*Enchytraeus*	white worm	Collector-Gatherer
		Naididae	*Naididae*	detritus worm	Collector-Gatherer

*Based on metric data provided by Cordillera Consulting (2019)

4.5.2 Community Metrics

Total abundance was highest (33,138 organisms/m^2) at the Genelle reference area (DEP-REF-2) in 2018 (Figure 4-50). The Genelle site is a large depositional habitat with dense macrophyte cover consisting of pondweeds (*Potamogeton sp.*) and Canada waterweed (*Elodea canadensis*). The Trimac exposure area (DEP-EXP-5) had the second highest total abundance (18,249 organisms/m^2) followed by Kootenay Eddy reference area (DEP-REF-1) at 16,116 organisms/m^2.

Table 4-23: Summary of benthic community metrics for depositional habitats for 2012, 2015, and 2018 AEMP data collection.

		2012			2015			2018		
Row Labels		Mean	St. Dev	Max	Mean	St. Dev	Max	Mean	St. Dev	Max
Effective Species	Ref	5.35	2.00	7.50	8.00	4.06	12.69	10.37	2.00	12.48
	Exp	6.91	3.32	11.73	9.69	4.18	15.56	12.44	3.59	19.34
EPT Richness	Ref	3.25	2.63	6.00	3.33	0.58	4.00	6.33	3.06	9.00
	Exp	3.43	2.07	7.00	4.00	2.52	9.00	6.14	2.85	10.00
% Chironomidae	Ref	11.42%	9.92%	23.84%	17.82%	25.88%	47.63%	12.40%	6.36%	19.53%
	Exp	41.28%	35.50%	81.03%	13.94%	9.08%	25.70%	15.22%	10.49%	37.33%
% EPT	Ref	1.31%	0.66%	2.00%	2.08%	1.50%	3.70%	4.00%	5.38%	10.20%
	Exp	1.34%	1.36%	3.93%	8.49%	8.80%	23.73%	4.94%	7.75%	21.85%
Shannon	Ref	1.62	0.42	2.01	2.00	0.47	2.54	2.33	0.19	2.52
	Exp	1.84	0.47	2.46	2.16	0.54	2.75	2.49	0.26	2.96
Shannon Eq	Ref	0.52	0.09	0.63	0.58	0.13	0.73	0.61	0.05	0.65
	Exp	0.57	0.15	0.79	0.66	0.14	0.84	0.66	0.06	0.77
Species Richness	Ref	24.25	12.61	38.00	31.33	1.15	32.00	47.00	5.29	51.00
	Exp	26.29	3.99	33.00	28.00	9.04	39.00	45.00	6.63	57.00
Total Abundance	Ref	14780	11923	27698	20116	16761	37404	19742	12001	33138
	Exp	8302	5766	17644	8888	9252	28622	9652	4750	18249
Total Biomass	Ref	NA	NA	NA	1466.67	1548.07	3164.44	2610.37	1958.47	4871.11
	Exp	NA	NA	NA	836.83	1034.41	3022.22	4316.19	3979.43	12266.67

Note, biomass data were not measured in 2012.

Total biomass was highest at the new Airport depositional area (DEP-EXP-4) with 12,267 mg/m^2 (Figure 4-50). An abundance of valve snails (Valvatidae), chironomids, detritus worms (Naididae) and ramshorn snails (Planorbidae) contributed to the high biomass in this area. Trimac (DEP-EXP-5) had the second highest biomass with 5,564 mg/m^2 and Waneta had the third largest biomass of 5,467 mg/m^2.

Species richness was greatest at the Korpac exposure area (DEP-EXP-1) just downstream of the Ryan Creek and McAlister Creek confluences with 57 taxa documented (Figure 4-50). The Genelle reference area (DEP-REF-2) and Kootenay Eddy reference area (DEP-REF-1) had 51 and 49 taxa respectively.

Effective species number (diversity) was greatest in the Casino Eddy exposure area (DEP-EXP-3) followed by Fort Sheppard (DEP-EXP-6) and Korpac (DEP-EXP-1) (Figure 4-51).

Shannon's evenness was also greatest in the Casino Eddy exposure area (DEP-EXP-3) followed by Fort Sheppard (DEP-EXP-6). The Kootenay Eddy reference area (DEP-REF-1) had the third highest community evenness value (Figure 4-51).

EPT Richness was highest at the Fort Sheppard exposure area (DEP-EXP-6) with 10 taxa (Figure 4-51). Kootenay Eddy (DEP-REF-1) and Korpac (DEP-EXP-1) followed with 9 and 8 EPT taxa respectively. Korpac had the highest relative abundance of EPT (21.85%) followed by Kootenay Eddy (10.2%) and Fort Sheppard (6.76%).

Chironomid relative abundance was highest in the Casino Eddy exposure area (DEP-EXP-3) accounting for 37.3 % of the sample. Kootenay Eddy and Airport depositional area (DEP-EXP-4) had 19.5% and 16.5% Chironomidae abundance respectively (Figure 4-52).

Oligochaeta relative abundance was greatest at the Birchbank reference area (DEP-REF-3) accounting for over 4.47% of the community sample followed by Trimac (DEP-EXP-5) and Airport with 43.2% and 42.2% Oligochaeta respectively (Figure 4-52).

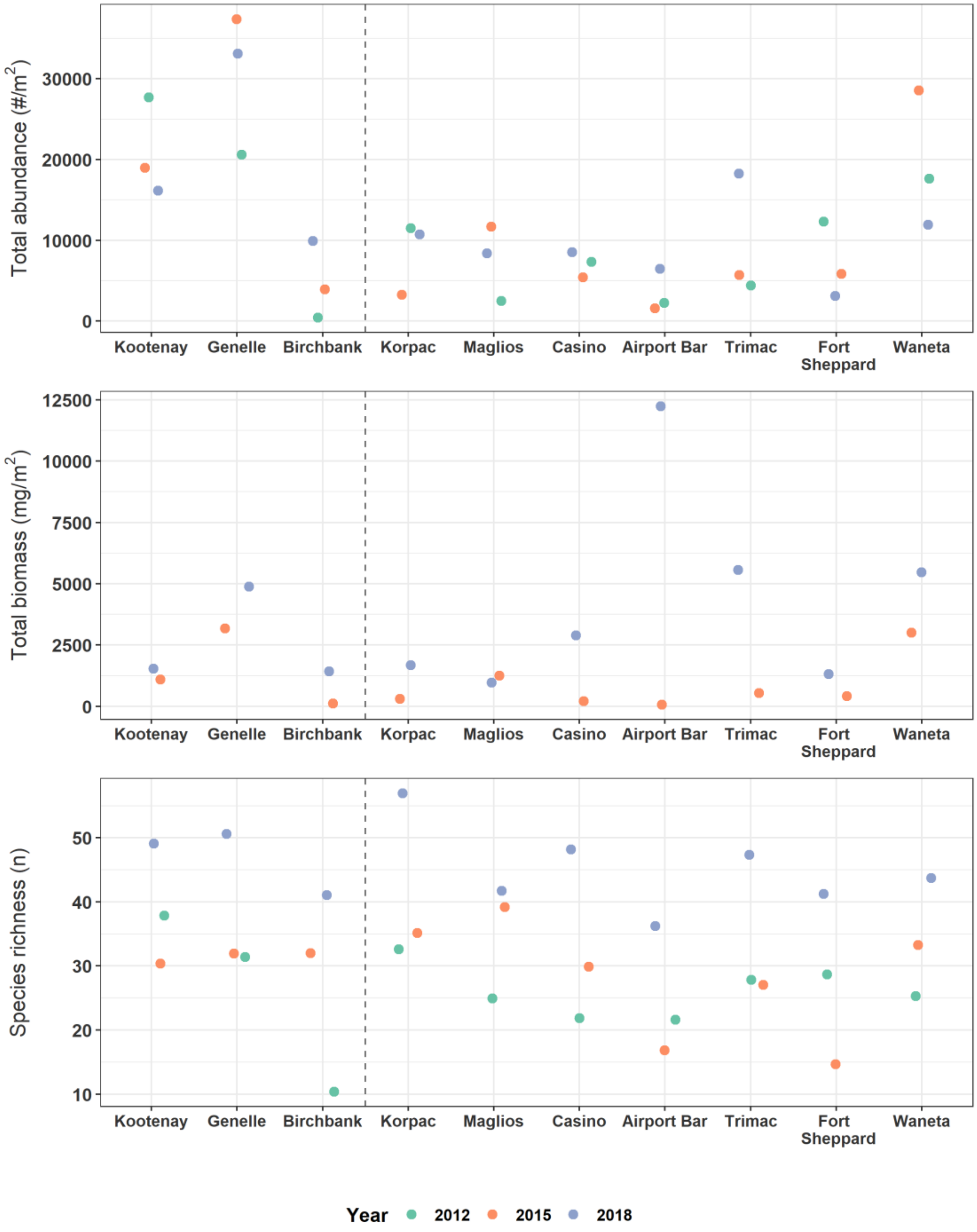


Figure 4-50: Plots of abundance, biomass, and species richness for 2012, 2015, and 2018 benthic invertebrate community productivity and diversity metrics at depositional sites upstream (reference) and downstream (exposure) of smelter outflow. The vertical dashed line separates reference (left) and exposure (right) sites.

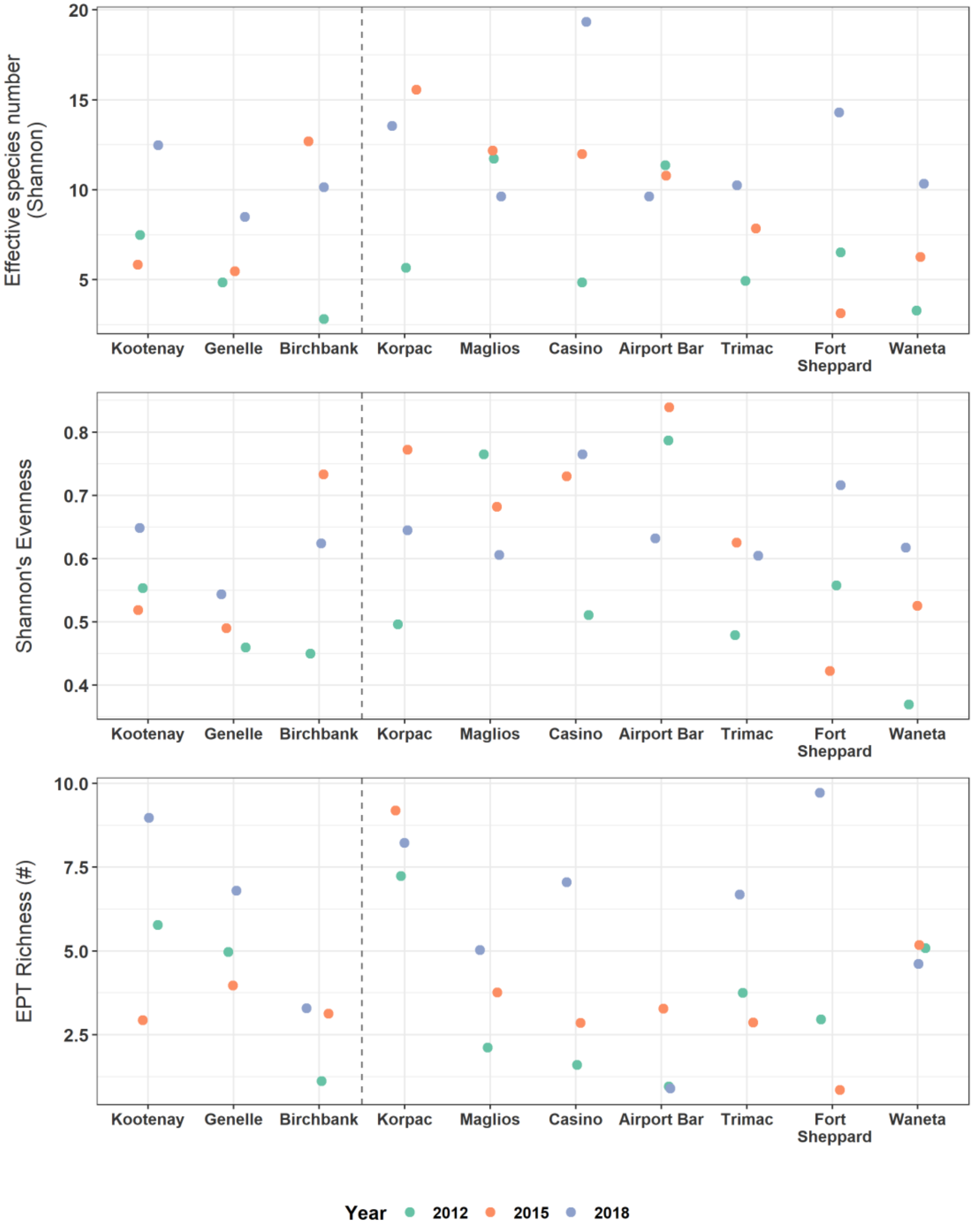


Figure 4-51: Plots of effective species number, Shannon's evenness, and EPT Richness for 2012, 2015, and 2018 benthic invertebrate community productivity and diversity metrics at depositional sites upstream (reference) and downstream (exposure) of smelter outflow. The vertical dashed line separates reference (left) and exposure (right) sites.

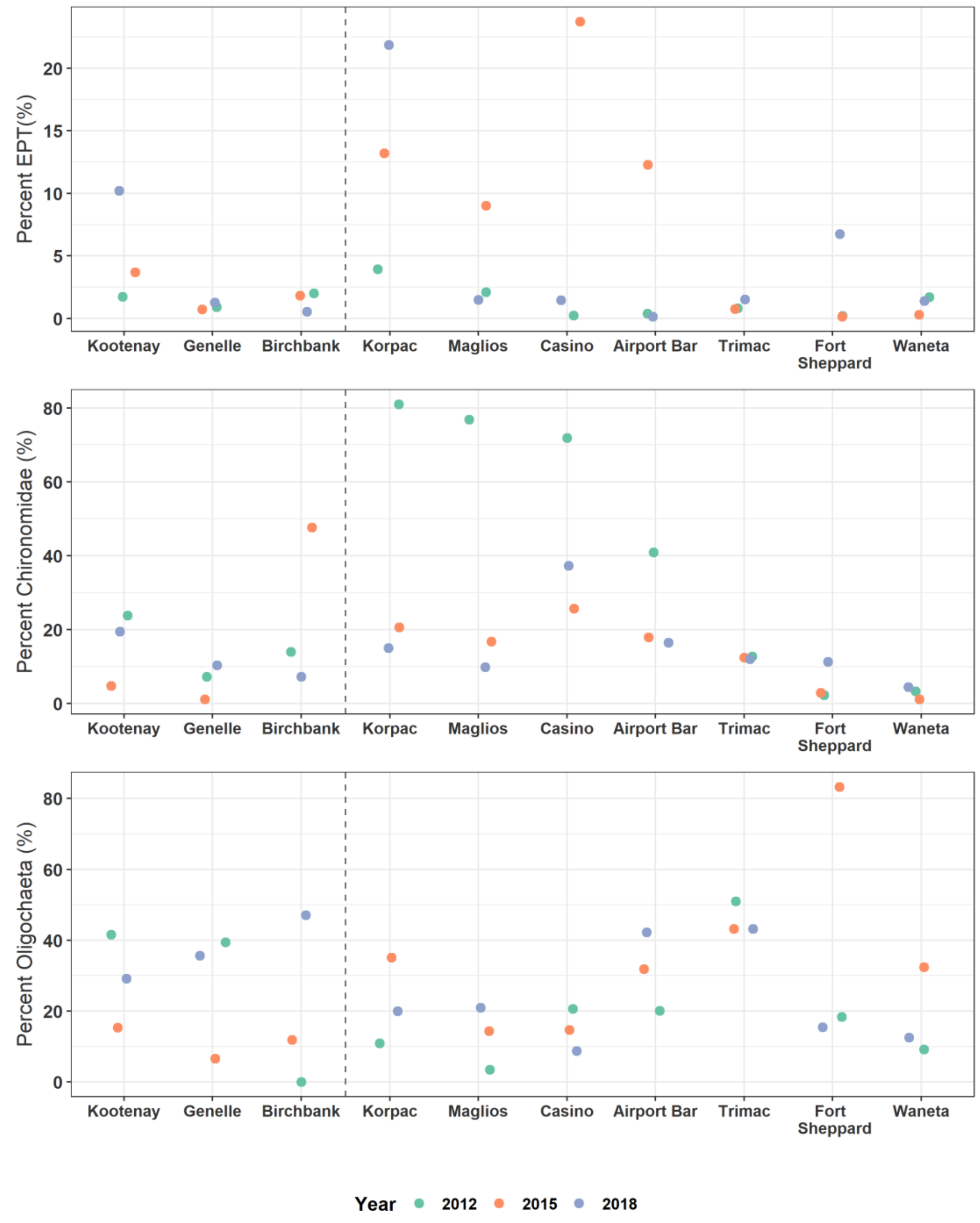


Figure 4-52: Plots of percent EPT, percent Chironomidae, and % Oligochaeta for 2012, 2015, and 2018 benthic invertebrate community productivity and diversity metrics at depositional sites upstream (reference) and downstream (exposure) of smelter outflow. The vertical dashed line separates reference (left) and exposure (right) sites.

4.5.3 Community Composition

NMDS was utilized to analyze how invertebrate species compositions shift between years and within areas. Community analyses of depositional habitats were completed at the genus level. Rare taxa were excluded from the analysis and defined as taxa that occurred in <5% of samples. The NMDS for depositional areas provided an adequate representation of the community (stress index=0.21).

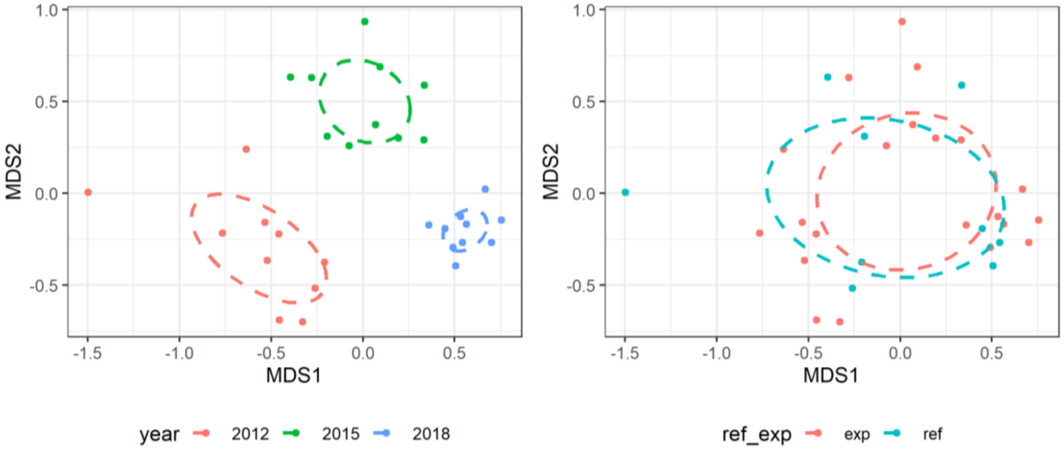


Figure 4-53: NMDS of depositional habitat benthic invertebrate communities at the species grouped year (left) and by exposure and reference sites (right). The stress value was 0.21.

Annual variation (year) between the 2012, 2015 and 2018 invertebrate samples explained 18% of the invertebrate community variation (p<0.001; Figure 4-53). DEP-REF-3 (Birchbank Reference site) showed a distinct community in 2012 that was driven primarily by the abundant pebble snails (*Fluminiciola sp.*). Invertebrate community variation did not have a significant difference between reference and exposure areas (p=0.178).

The effect of treatment (reference vs. exposure area) was tested on four benthic invertebrate metrics that quantify community composition and productivity. To test for the effect of year (2012, 2015, and 2018) and if the effect of treatment differs with year an interaction term was initially tested. The interaction term of year and treatment was not significant for all four benthic invertebrate models, so it was dropped from the final model.

Invertebrate productivity metrics at depositional sites were similar in reference and exposure areas. The two-way ANOVA showed no significant difference in total abundance when grouped by year (p=0.558) or treatment (p=0.178). For % chironomid composition, no significant difference emerged when grouped by year (i.e., 2012, 2015, and 2018; p=0.662) or by exposure or reference sites (p=0.207). For %EPT there was no significant difference between year (p=0.30) or treatment (p=0.975). Community diversity expressed by Effective Species differed significantly between year (p=0.003). Effective number of species was higher in 2018 compared to 2012 (p=0.002). However, there was no significant difference between reference and exposure areas (p=0.184).

4.5.4 Summation

Benthic invertebrate community metrics in depositional areas from 2018 continue to illustrate natural annual variability across all sites. Invertebrate community diversity was lowest in 2012 compared to 2015 and 2018. Reference and exposure areas did not have significantly different invertebrate production metrics. There was also limited annual variation of invertebrate production metrics in in depositional areas.

4.6 Erosional Habitat Benthic Invertebrates

The LCR benthic invertebrate communities are productive, diverse, and variable (Larratt et al. 2013). Benthic macroinvertebrates were collected from several historical sites in the Columbia River between 1980 and 1992, with densities varying from 1,518 to 32,712 organisms/m^2, and with the number of taxa ranging from 18 to 47 (Hatfield 1994). Benthic invertebrate communities were considered to be healthy and diverse in the Castlegar area, upstream of the AEMP AOI (Hatfield 1997).

Similar to depositional habitats, benthic invertebrate community metrics in erosional habitats in 2018 continue to illustrate natural annual variability across all sites. The structure of benthic macroinvertebrate communities showed little to no difference between reference and exposure areas for erosional habitats. Community structure for both habitat types differed significantly between years (2012, 2015, 2018), but the most important variables influencing communities in LCR erosional habitats are water velocity and to a lesser extent, substrate size.

Within the AOI, at both the upstream reference and downstream exposure sites, benthic invertebrate abundance and diversity can vary by an order of magnitude among sites of the same type. However, species assemblages and distributions observed within this study were comparable to those sampled in other productivity studies carried out in the LCR upstream of the AEMP study area (Larratt et al. 2013).

4.6.1 Dominant Taxa

Dominant taxa in erosional habitats (Table 4-24) were consistent across reference and exposure areas with EPT taxa dominating all area communities (Figure 4-54 – Figure 4-60). Net-spinning caddisflies (Hydropsychidae) dominated all sampled reference and exposure areas in 2018. In 2015, ERO-EXP-5 was dominated by the spiny crawler mayfly (Ephemerellidae), which was the third most dominant taxa in all other areas. The reduced abundance of this mayfly in 2018 is likely due to a late-season hatch that would have lowered mayfly nymph abundance during the data collection period.

Within Reference Area 1 and 2, individual sites with low water velocities (ERO-REF-1-2, ERO-REF-1-5, ERO-REF-2-4, ERO-REF-2-5) were dominated by pond snails (Lymnaeidae) and other gastropods. Numerous studies have demonstrated that current velocity is the most important variable explaining community composition and that correlations exist between community diversity and current velocities (Nelson and Lieberman 2002; Degani et al. 1993; Tien Nguyen et al. 2018). Flow can strongly affect habitat characteristics, dispersal, resource acquisition, competition, and predation (Hart and Finelli 1990).

Table 4-24: Dominant benthic taxa in erosional area samples collected in 2012, 2015, and 2018.

Class	Order	Family	Predominant Taxa*	Common Name	Functional Feeding Group
Arachnida	Trombidiformes	Hygrobatidae	*Hygrobates*	Water mite	Predator
	Trombidiformes	Sperchontidae		Prostig mite	Predator
Bivalvia	Veneroida	Pisidiidae	*Pisidium*	Pill clam	Collector – Filterer
	Unionida	Margaritiferidae		Pearl mussel	Collector – Filterer
Gastropoda	Basommatophora	Lymnaeidae	*Lymnaeidae*	Pond snail	Scraper
		Physidae	*Physa*	Bladder snail	Scraper
		Planorbidae	*Planorbidae*	Ramshorn snail	Scraper
	Hypsogastropoda	Hydrobiidae	*Hydrobiidae*	Mud snail	Scraper
Insecta	Diptera	Empididae	*Hemerodromia sp.*	Dance fly	Predator
	Diptera	Chironomidae			Collector-Gatherer
	Ephemeroptera	Ephemerellidae	*Drunella grandis group*	Western green Drake	Collector-Gatherer
			Ephemerella	Pale morning Dun	Collector-Gatherer
		Baetidae		Small minnow Mayflies	Collector-Gatherer
	Hemiptera	Corixidae	*Sigara*	Water boatman	Predator
	Trichoptera	Brachycentridae	*Brachycentrus occidentalis*	Humpless Casemaker	Collector-Filterer
		Hydropsychidae	*Cheumatopsyche*	Net-spinning Caddisfly	Collector-Filterer
			Hydropsyche		Collector-Filterer
		Leptoceridae		Long-horned Caddisfly	Collector-Gatherer/Predator
		Glossosomatidae	*Protoptila*	Saddle-case Maker	Scraper
Malacostraca	Amphipoda	Crangonyctidae	*Crangonyx*		Collector-Gatherer
Oligochaeta	Lumbriculida	Lumbriculidae	*Lumbriculidae*	Aquatic worm	Collector-Gatherer
	Tubificida	Enchytraeidae	*Enchytraeus*	White worm	Collector-Gatherer
		Naididae	*Naididae*	Detritus worm	Collector-Gatherer

Predator; Shredder-Herbivore; Collector-Gatherer; Scraper; Macrophyte-Herbivore; Collector-Filterer; Omnivore; Parasite; Piercer-Herbivore; Gatherer

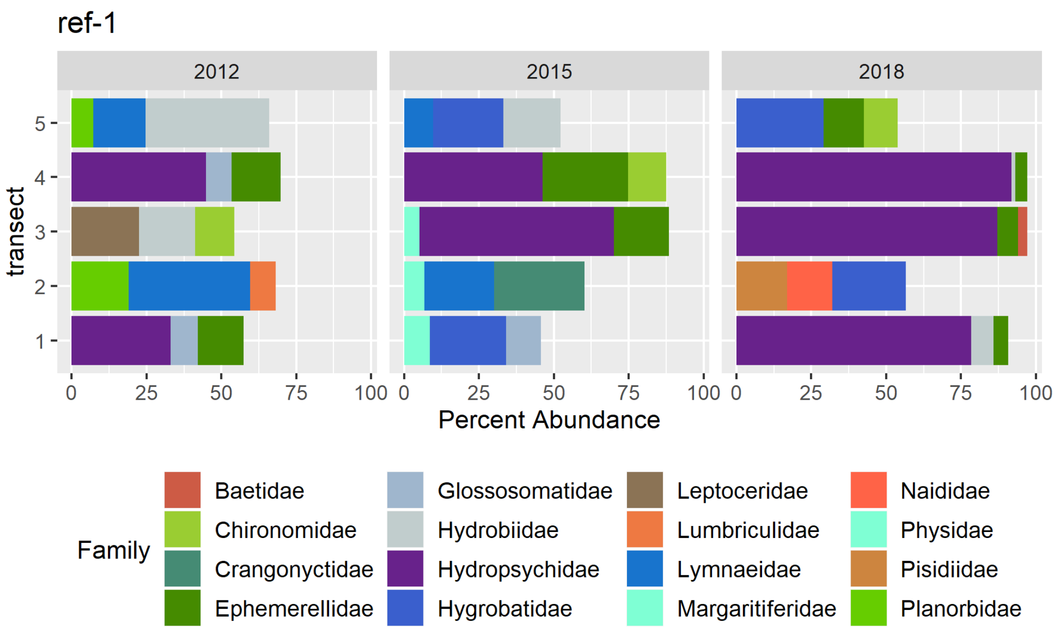


Figure 4-54: Benthic invertebrate percent abundance by family level at ref-1.

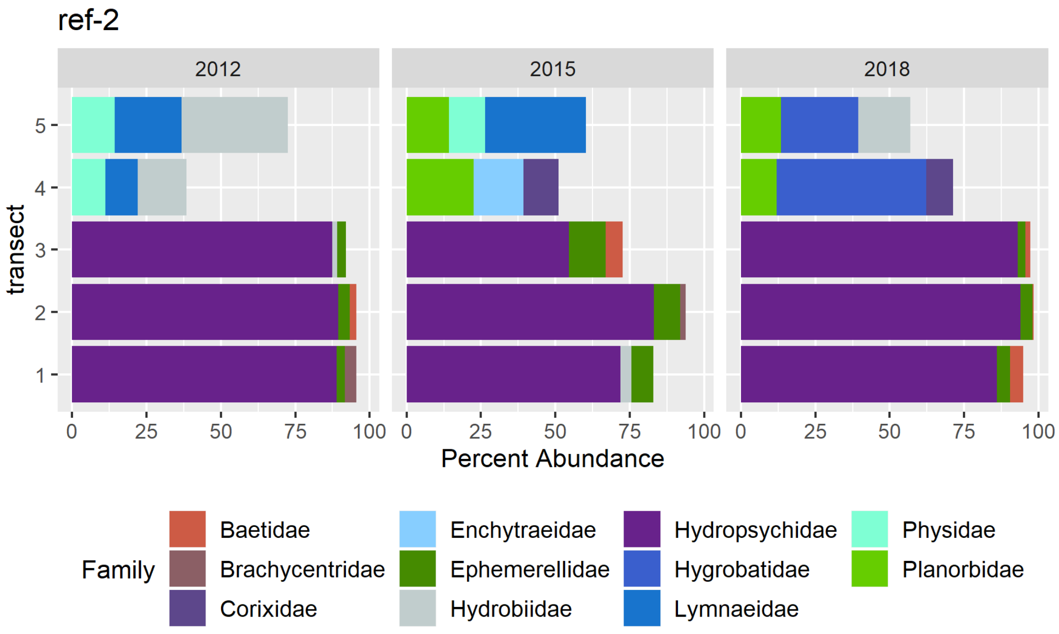


Figure 4-55: Benthic invertebrate percent abundance by family level at ref-2.

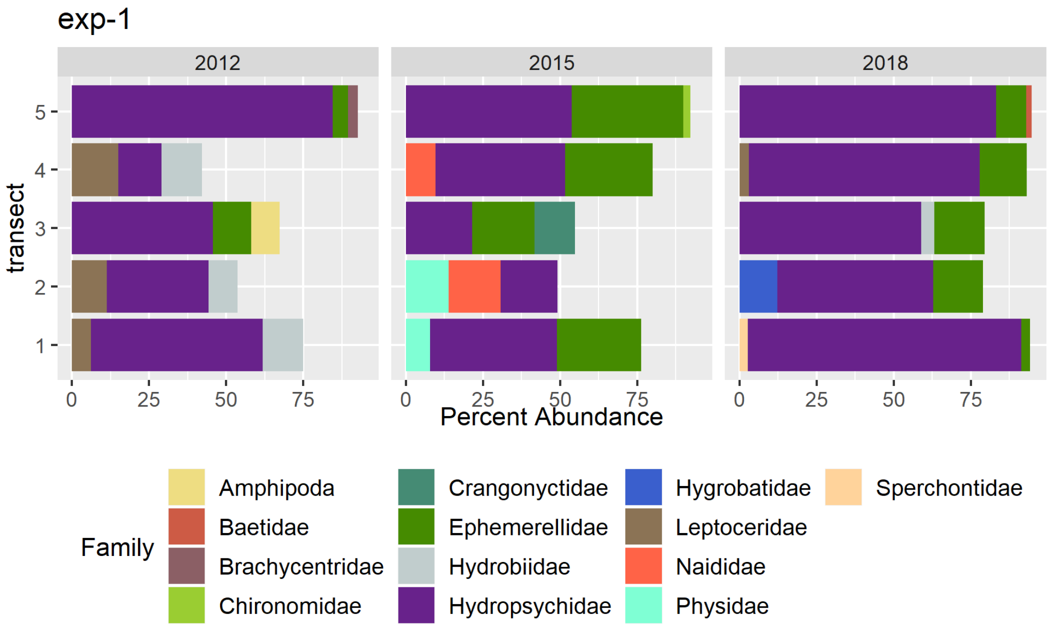


Figure 4-56: Benthic invertebrate percent abundance by family level at exp-1.

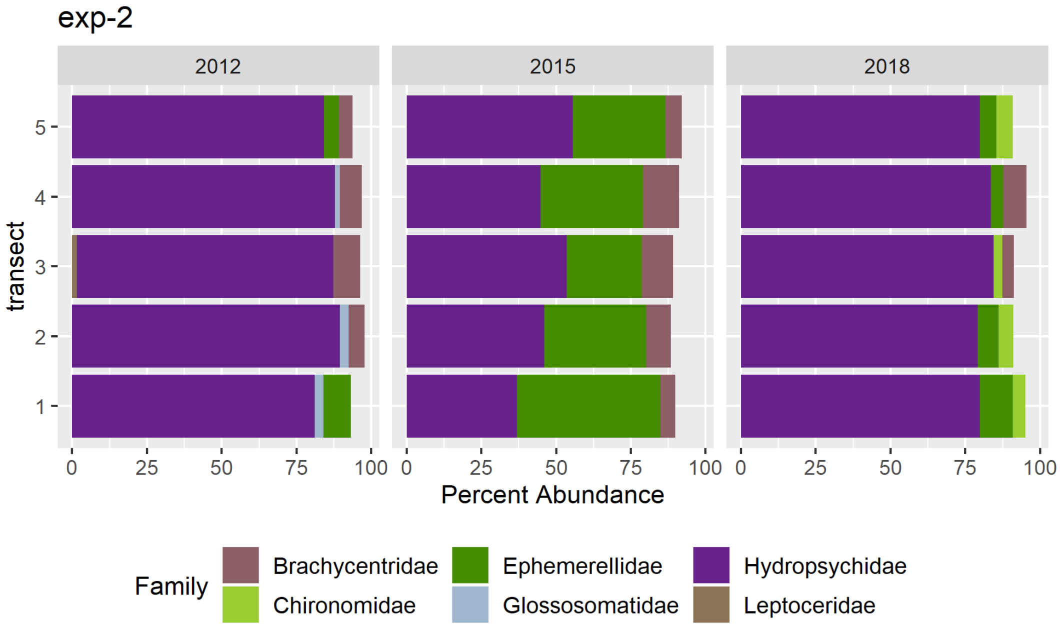


Figure 4-57: Benthic invertebrate percent abundance by family level at exp-2.

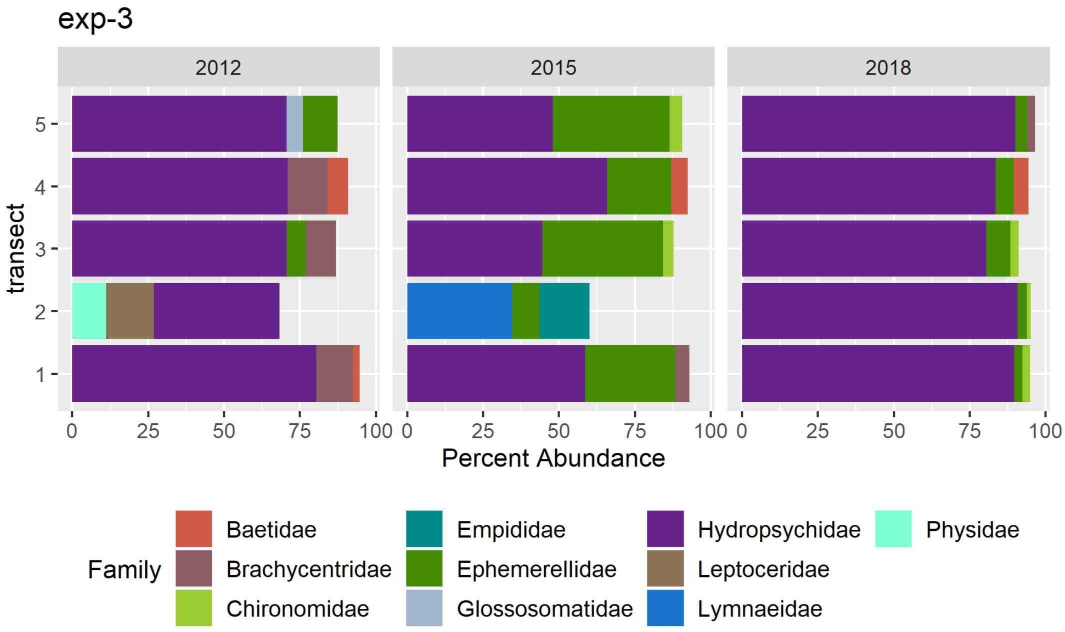


Figure 4-58: Benthic invertebrate percent abundance by family level at exp-3.

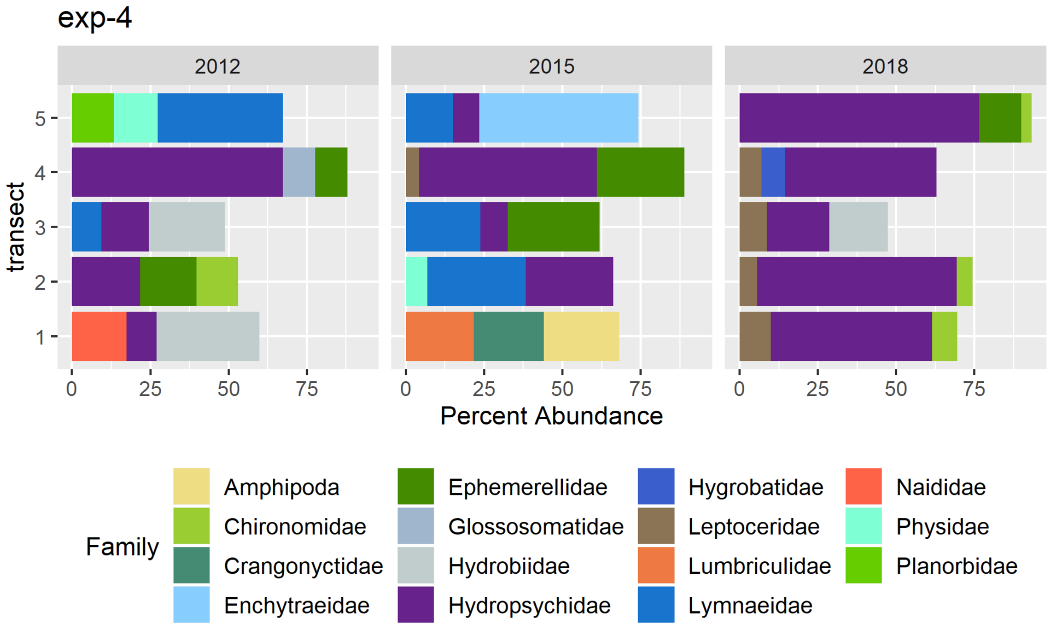


Figure 4-59: Benthic invertebrate percent abundance by family level at exp-4.

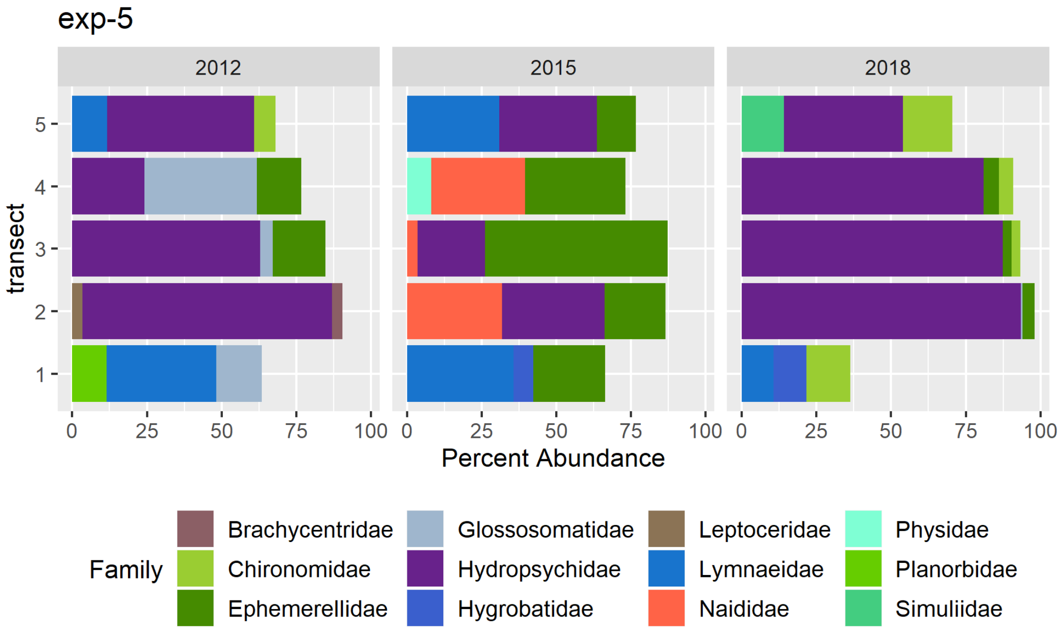


Figure 4-60: Benthic invertebrate percent abundance by family level at exp-5.

4.6.2 Community Metrics

A summary of benthic invertebrate community metrics for erosional habitats sampled in 2012, 2015, and 2018 is provided in Table 4-25.

In 2018, there was no significant difference in total abundance between the reference areas and any exposure areas. ERO-EXP-4 had significantly lower total abundance than both ERO-EXP-2 (p=0.008) and ERO-EXP-3 (p=0.02) (Figure 4-61). Total abundance was highest in ERO-EXP-2 with 8,829 organisms/m^2. This is the side channel into which the CIII outfall discharges and higher water velocities and temperatures are common. The Birchbank reference area (ERO-REF-2) had the second highest abundance with 7,864 organisms/m^2 followed by ERO-EXP-3 with 5,771 organisms/m^2. ERO-EXP-3 includes the lower portion of the IDZ beginning below the CII outfall and extends downstream to just below the Ryan Creek and McAlister Creek fans.

Table 4-25: Summary of benthic invertebrate community metrics for erosional habitats for 2012, 2015, and 2018 AEMP data collection.

Metric		2012			2015			2018		
		Mean	St.dev	Max	Mean	St.dev	Max	Mean	St.dev	Max
Effective Species	Ref	9.52	5.85	18.61	9.8	3.77	16.59	7.07	4.39	16.06
	Exp	8.62	5	19.22	8.34	2.78	15.64	7.32	5.68	24.47
EPT Richness	Ref	9.3	2.79	15	9.4	3.24	15	9.2	2.15	13
	Exp	11.96	2.72	20	10.88	2.47	17	12.24	1.79	16
Hilsenhoff Biotic Index	Ref	4.67	1.15	6.62	4.74	1.07	6.8	5.29	1.48	7.44
	Exp	3.98	0.86	6.27	3.84	1.25	7.29	4.21	0.66	6.28
% Chironomidae	Ref	3.7%	4.4%	13.2%	3.9%	3.4%	12.6%	2.5%	3.4%	11.2%
	Exp	3.3%	3.1%	13.4%	2.3%	2.0%	8.2%	4.4%	4.0%	16.5%
% EPT	Ref	52.8%	39.4%	98.1%	48.4%	40.8%	96.4%	61.9%	44.5%	99.1%
	Exp	76.5%	27.4%	99.5%	67.2%	30.1%	97.6%	83.3%	21.5%	99.2%
Shannon	Ref	2.06	0.69	2.92	2.2	0.44	2.81	1.8	0.58	2.78
	Exp	1.99	0.59	2.96	2.07	0.31	2.75	1.77	0.64	3.2
Shannon Eq	Ref	0.65	0.16	0.83	0.67	0.1	0.8	0.56	0.12	0.75
	Exp	0.63	0.14	0.89	0.66	0.08	0.83	0.54	0.15	0.84
Species Richness	Ref	24	9	39	27	5	33	25	10	41
	Exp	23	8	42	24	5	39	26	8	46
Total Abundance	Ref	1674	2083	6264	504	412	1485	2786	2611	7864
	Exp	2146	2341	9264	490	414	1500	2926	2236	8829
Total Biomass	Ref	NA	NA	NA	111.8	115.0	372.5	1928.4	1616.4	4978.2
	Exp	NA	NA	NA	99.4	78.4	262.1	2569.2	2866.3	13453.6

Note: biomass data were not measured in 2012

There was no significant difference in total invertebrate biomass between any pairings of reference and exposure areas (p=0.081). ERO-EXP-1 had the highest total biomass with 13,453 mg/m^2 followed by ERO-EXP-2 and ERO-REF-2 with 5,185.36 mg/m^2 and 4,978 mg/m^2 respectively (Figure 4-61). While general community structure was the same among these areas, dominated by net-spinning caddisflies (Hydropsychidae), biomass of the Hydropsychids collected from ERO-EXP-1 was higher, which contained larger hydropsychids of the Genus *Hydropsyche* and *Cheumatopsyche*.

There was no significant difference in species richness between any pairs of erosional habitats in either reference or exposure areas. (p=0.116). ERO-EXP-5 had the highest measured species richness with 46 taxa followed by ERO-REF-1 and ERO-EXP-4 with 41 and 38 taxa respectively (Figure 4-61).

The diversity metric effective species number was significantly lower (p=0.031) in ERO-EXP-3 than in ERO-EXP-4, and lower (p=0.06) in ERO-EXP-2 than in ERO-EXP-4, though not significant. There was no significant difference in effective species numbers between any pairings of reference and exposure areas. Similarly, community evenness (Shannon's Evenness) was significantly lower in both ERO-EXP-2 (p=0.049) and ERO-EXP-3 (p=0.034) than in ERO-EXP-4. However, no significant difference in evenness occurred between any pairings of reference and exposure areas. ERO-EXP-5 had the highest effective species number equaling 24, followed by ERO-EXP-4 and ERO-REF-1 with 18 and 16 respectively (Figure 4-60). The same rank order was observed for Shannon's Evenness with ERO-EXP-5 equaling 0.84, ERO-EXP-4 equaling 0.80, and ERO-REF-1 with 0.75 (Figure 4-62).

EPT richness was significantly greater in ERO-EXP-1 (p=0.014); ERO-EXP-2 (p=0.004); ERO-EXP-3 (p=0.024); and ERO-EXP-4 (p=0.05) than in Birchbank (ERO-REF-2). No significant difference in EPT richness occurred between any other pairings of reference and exposure areas. Both ERO-EXP-1 and ERO-EXP-2 has an EPT Richness of 16 taxa followed by ERO-EXP-3 with 15 EPT taxa (Figure 4-62). While EPT richness was greater in four of the five exposure areas than in the reference area 1, percent EPT did not differ significantly (p=0.267) between any pairings of reference and exposure areas (Figure 4-63).

Hilsenhoff Biotic Index values were lower in exposure areas within the IDZ (ERO-EXP-1, ERO-EXP-2, and upper ERO-EXP-3) than the two upstream reference areas and exposure areas further downstream. However, the difference was not significant (lowest p=0.088). Lower HBI scores coincided with higher percentages of metal-sensitive taxa. ERO-EXP-2 had the lowest HBI score of 3.91 followed by ERO-EXP-3 and ERO-EXP-1 with 3.97 and 4.45 respectively (Figure 4-63). This corroborates results of both the 2012 and 2015 AREMP data collection and interpretation - that the smelter is not having an adverse effect on benthic community composition. Some of reference sites had lower velocities, that can favour a higher abundance of gastropods and oligochaetes as was observed in ERO-REF-1-2, ERO-REF-1-5, and ERO-REF-2-4 and ERO-REF-2-5. These taxa are more metal-tolerant and thus have higher HBI values, resulting in the observed elevated HBI scores over the higher velocity exposure areas.

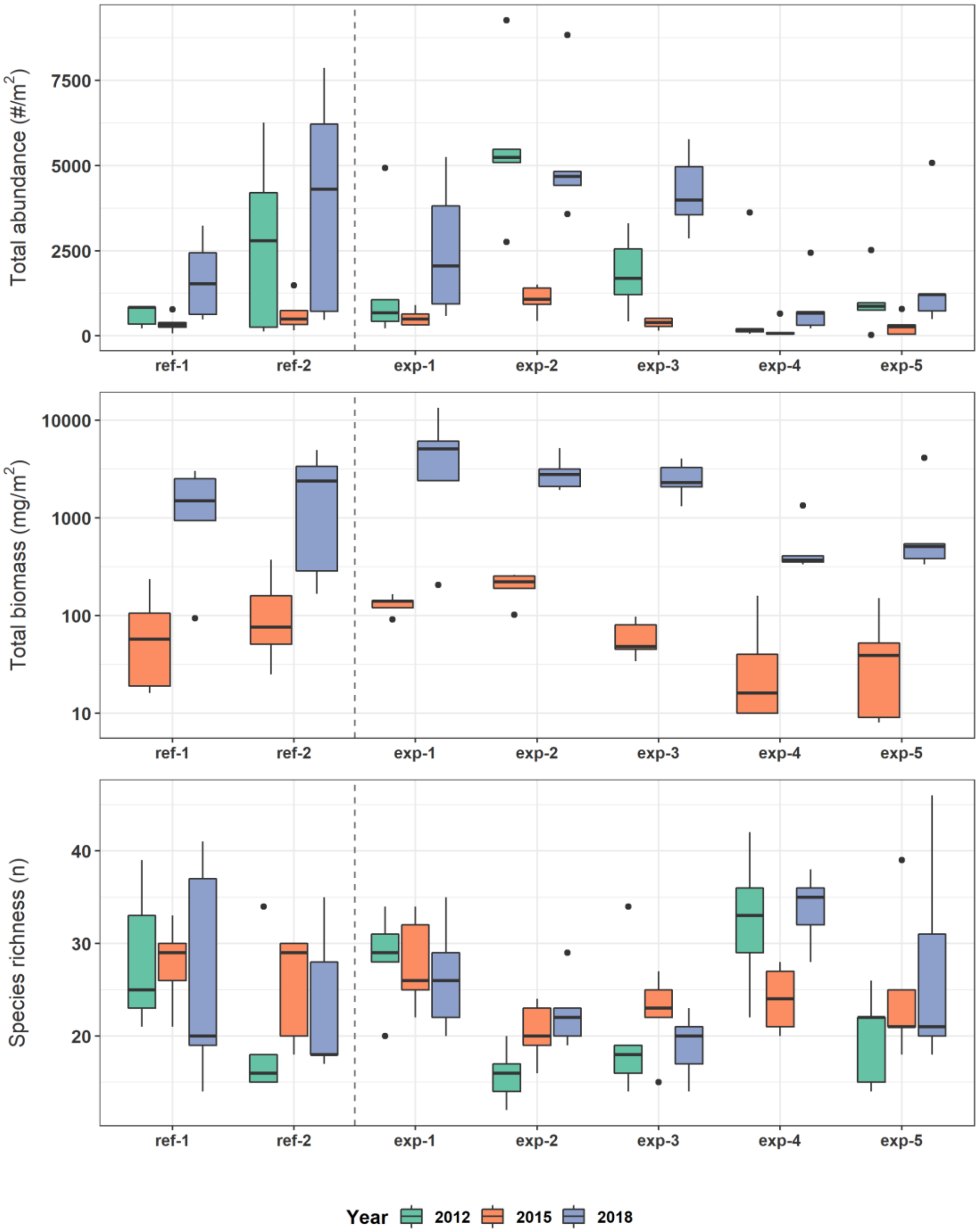


Figure 4-61: Boxplots of abundance, biomass, and species richness for 2012, 2015, and 2018 benthic invertebrate community productivity and diversity at erosional sites above and below smelter outflow.

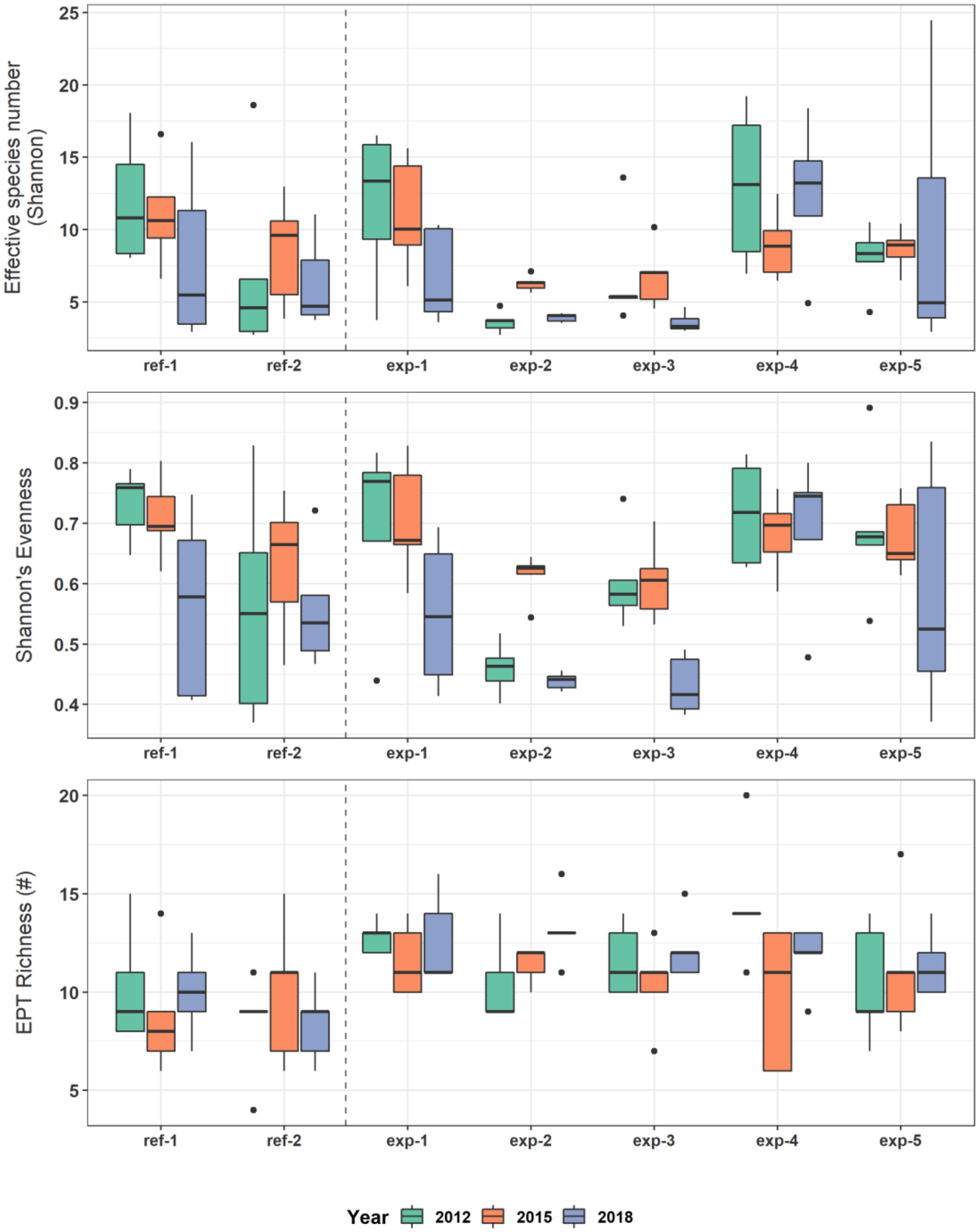


Figure 4-62: Boxplots of effective species number, Shannon's evenness, and EPT Richness for 2012, 2015, and 2018 benthic invertebrate community productivity and diversity at erosional sites above and below smelter outflow.

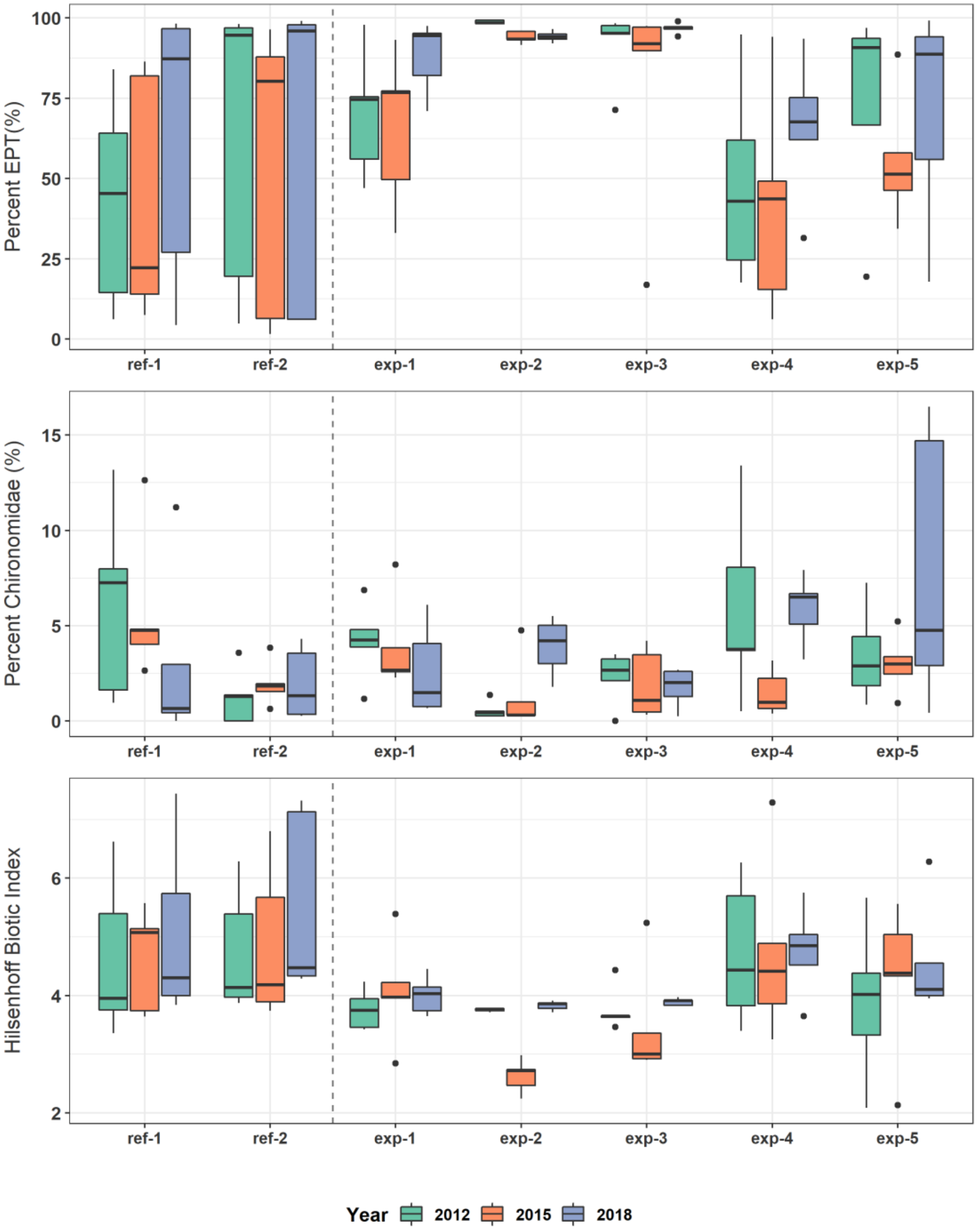


Figure 4-63: Boxplots of percent EPT, percent Chironomidae, and Hilsenhoff Biotic Index for 2012, 2015, and 2018 benthic invertebrate community productivity and diversity at erosional sites above and below smelter outflow.

4.6.3 Community Composition

NMDS was utilized to analyze how species compositions shift between years, between treatments (Reference or Exposure), and within areas. Community analyses was completed at the genus level. Rare taxa were excluded from the analysis and defined as taxa that occurred in <5% of samples. The NMDS for erosional sites provided a good representation of the community (stress index=0.19).

NMDS illustrates a significant difference (F=5.20, R^2=0.05, p = 0.002) in benthic community composition between years.

In contrast, no difference (F=2.40, R^2=0.02, p=0.03) in overall species composition was detected between reference and exposure sites (Figure 4-64). When grouped by treatment, ERO-EXP-2 and ERO-EXP-3 occurred to the right of 0.0 on the first axis (MDS1). Sites within these areas generally had higher velocities. Furthermore, the area grouping explains more of community distribution than year. In terms of species loadings, caddisflies (Hydrospychidae and Brachycentridae) and mayflies of the family Baetidae load strongly on the first axis. Hydrobiidae (mud snails) load strongly on the second axis, which occurred prominently in EXP-1 and REF-1 and REF-2 sites, some of which had markedly lower velocities.

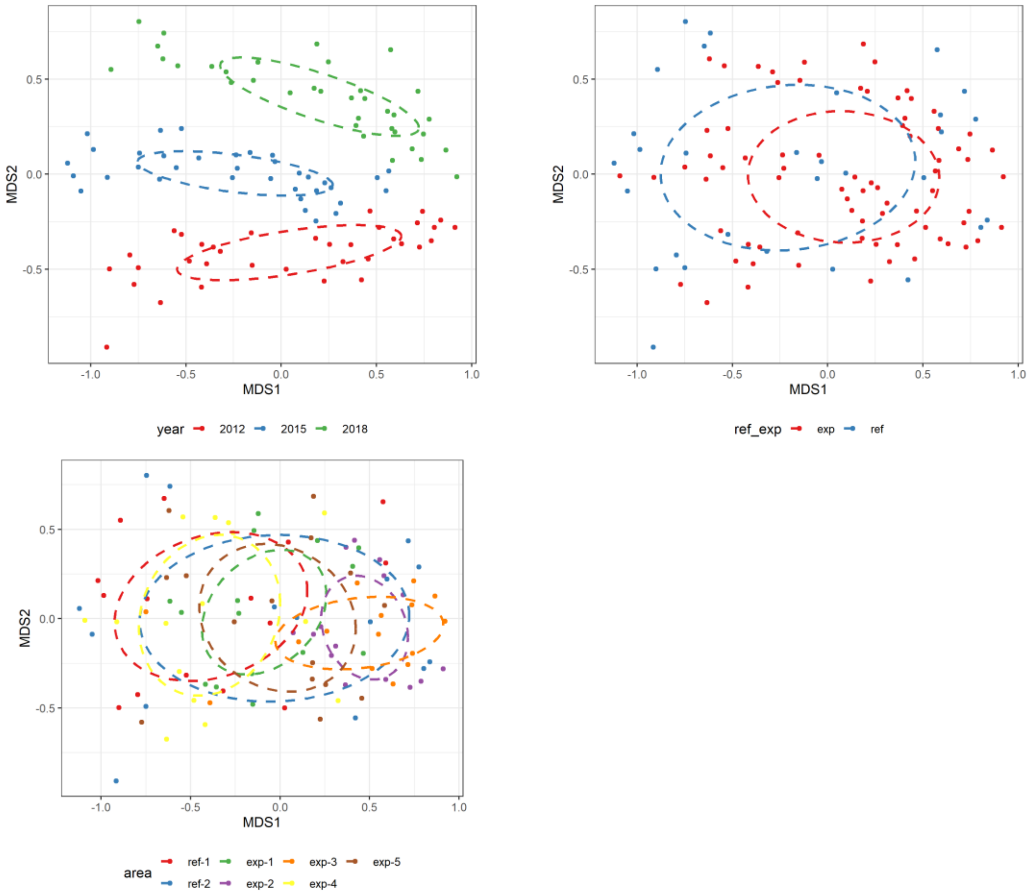


Figure 4-64: NMDS of erosional habitat benthic invertebrate communities at the genus level grouped by year (left) and by exposure and reference sites (right), and then by treatment (bottom). The stress value was 0.19.

4.6.4 Functional Feeding Groups

Distribution and relative abundance of the various functional feeding groups in both reference and exposure areas were typical for a river of the order and hydrologic character of the LCR. The River Continuum Concept (RCC) predicts that community functional composition changes with habitat size and structure. Shredders (detritivores) should be relatively abundant in upper headwater reaches and then decrease downstream as the relative importance of coarse detritus declines. With a more open canopy and increased primary production, scrapers that graze algae and fine particles become more dominant (Bottorff & Knight, 1988; Uwadiae, 2010).

Figure 4-65 and Figure 4-66 display the relative distribution of various functional feeding groups collected and identified in each of the reference and exposure erosional habitats. Analysis of variance of all reference and exposure erosional areas found no significant difference in the relative distribution of functional feeding groups by exposure: Collector gatherers (p=0.514); Collector Filterers (p=0.274); Predators (p=0.182); or Scrapers (p=0.234). Only ERO-EXP-4 had statistically significantly more omnivores in 2018 than both reference areas (ERO-EXP-1 p=0.02) and ERO-EXP-2 p=0.018). This difference was driven by the abundance of the long-horned caddisfly (*Ceraclea sp.*) in ERO-EXP-4.

Observed shifts in dominant functional feeding groups and altered insect community composition in some sites within erosional areas is tied to differences in instream habitat structure (Slavik et al 2004). This is particularly evident in the sites that had lower velocities.

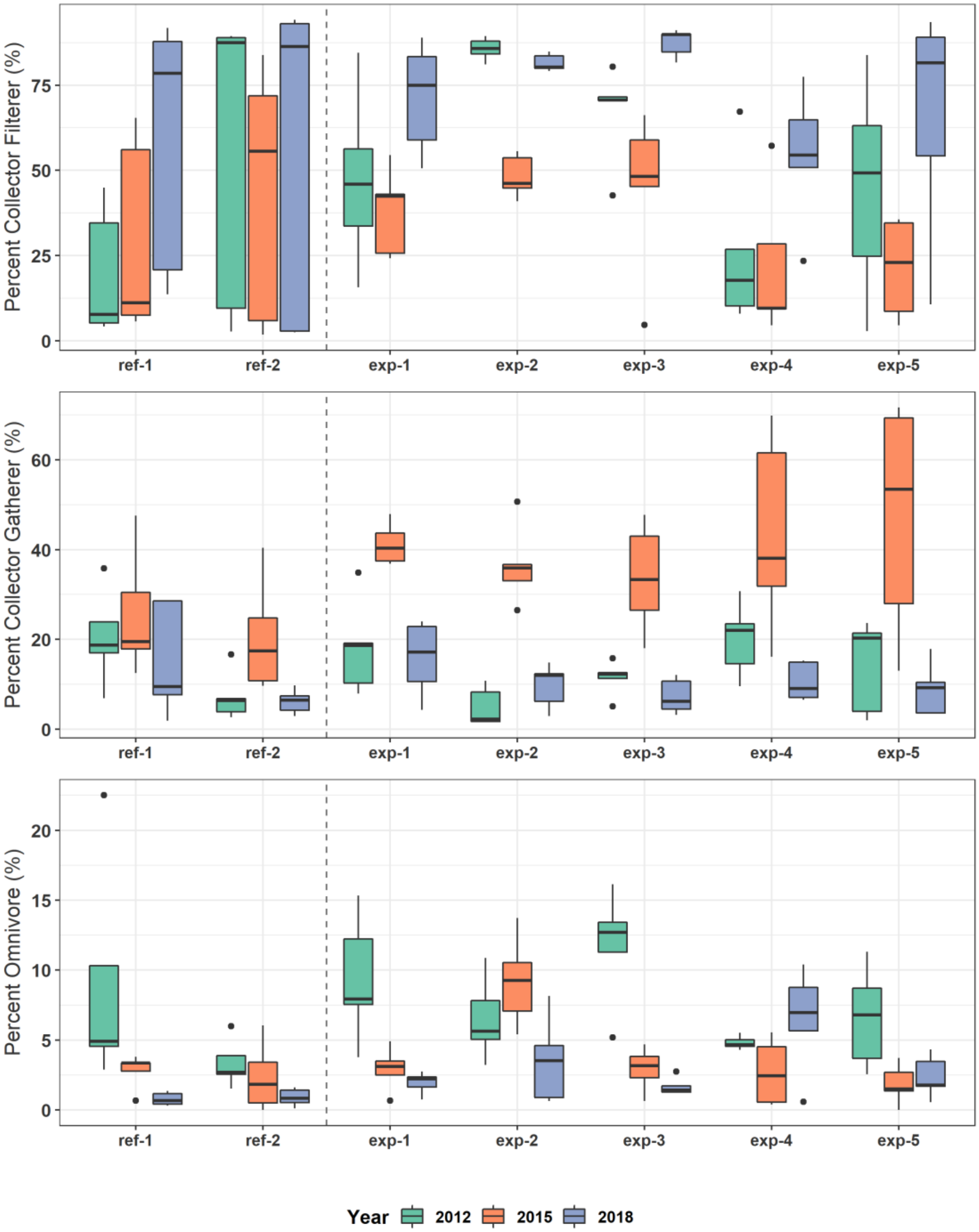


Figure 4-65: Boxplots of percent Collector Filterer, percent Collector Gatherer and percent Omnivore for 2012, 2015, and 2018 benthic invertebrate samples at erosional sites above and below smelter outflow.

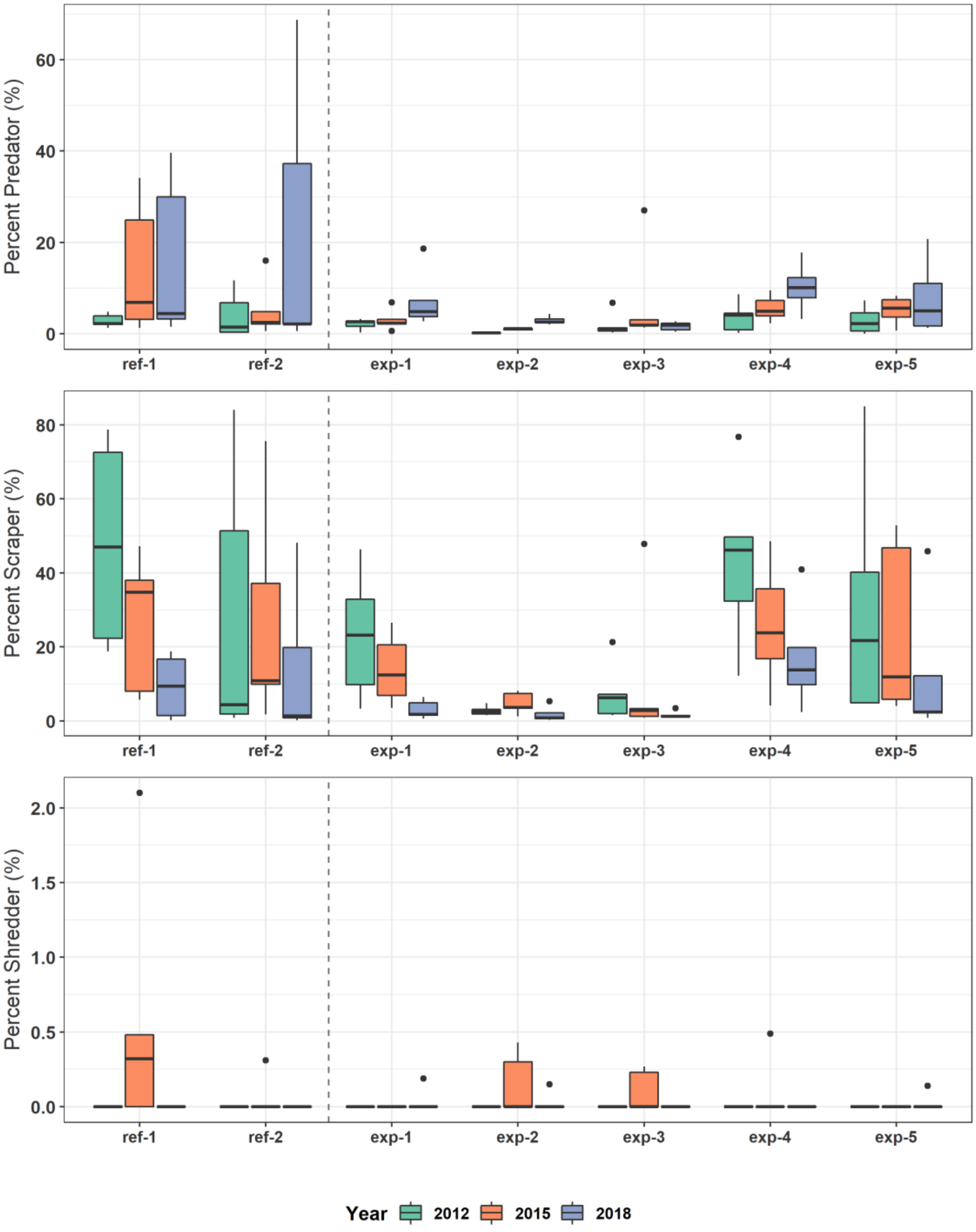


Figure 4-66: Boxplots of percent Predator, percent Scraper and percent Shredder for 2012, 2015, and 2018 benthic invertebrate samples at erosional sites above and below smelter outflow.

4.6.5 Community Response

Erosional sites with higher velocities had greater benthic macroinvertebrate abundance and were dominated by EPT taxa in 2018. This remains consistent with 2012 and 2015 AREMP study results (Hawes et al. 2014 and Hawes et al. 2019), and previous studies by Larratt et al. (2013).

There are many potential explanatory variables that influence benthic community structure and productivity. Flows and related factors of velocity, substrate size, shear stress, light penetration and particulate suspension exert control over periphyton and benthic macroinvertebrate growth and species assemblages. While the AEMP focuses on studying the effects of effluent discharge on aquatic environments, Larratt et al. (2013) found that key controlling factors of LCR production shift with season. During summer high flow periods, water temperature and substrate type are the primary controlling factors. During fall lower flow periods, substrate size and wetted depth were dominant factors in the LCR.

Water velocity is the most important variable influencing benthic macroinvertebrate community diversity (effective number of species) in erosional habitats (Figure 4-67). Velocity had a large negative correlation coefficient on effective number of species indicating that sites with higher velocities had lower diversity. The high velocity sites (e.g., ERO-EXP-2) have been strongly dominated by Hydropsychidae in 2012 and 2018, but in 2015, Hydropsychidae was codominant with Ephemerellidae along with low numbers of other taxa. The low abundance of Ephemerellidae in 2012 and 2018 is likely due to annual variation. For instance, a large emergence (hatch) may have occurred in the days that preceded sampling.

The EPT metric was lower in reference sites than exposure sites, causing a strong negative correlation coefficient (Figure 4-67). However, a greater proportion of reference sites (ERO-REF-1-2; ERO-REF-1-5; ERO-REF-2-4; ERO-REF-2-5) had lower water velocities and increased abundance of gastropod snails, pill clams, and detritus worms. In 2018 sampling, higher velocity microhabitats within the larger low velocity areas were targeted to help reduce the effect of physical habitat variability. In some situations, Hydropsychidae were more dominant in these areas and sites than in previous years (e.g., ERO-REF-1).

Velocity had a strong negative correlation coefficient for the HBI (Figure 4-67). This aligns with observations of higher EPT taxa in sites with higher velocities. This is illustrated in Figure 4-63 for ERO-EXP-2 and ERO-EXP-3.

The effect of treatment, expressed in the model as reference compared to exposure, had a moderately strong positive correlation coefficient with the HBI. A low HBI score indicated a high relative abundance of metals-sensitive species whereas a high score indicated a low relative abundance of metal-sensitive species. Reference sites had a lower relative abundance of metal sensitive species than exposure sites. Most EPT taxa were classified as metal sensitive species. EPT richness and % EPT was also lower at reference sites compared to exposure sites. The higher % abundance of EPT taxa and lower HBI scores at exposure sites are indicative of healthy invertebrate communities. Combined 2018 model results indicated that smelter effluent discharges did not have a negative effect on downstream erosional habitat benthic invertebrate communities.

Total abundance and % EPT both had strong positive correlation coefficients with velocity and substrate size (Figure 4-67 and Figure 4-68). In other words, sites with higher velocities and larger substrates have higher total abundance. Conversely sites with lower velocities had higher %chironomid taxa (Figure 4-68).

The covariate Reference spanned zero for community diversity (effective number of species and Shannon Evenness) (Figure 4-68). The effect of Reference or Exposure was therefore of low importance in describing variation in benthic invertebrate community diversity in erosional habitats.

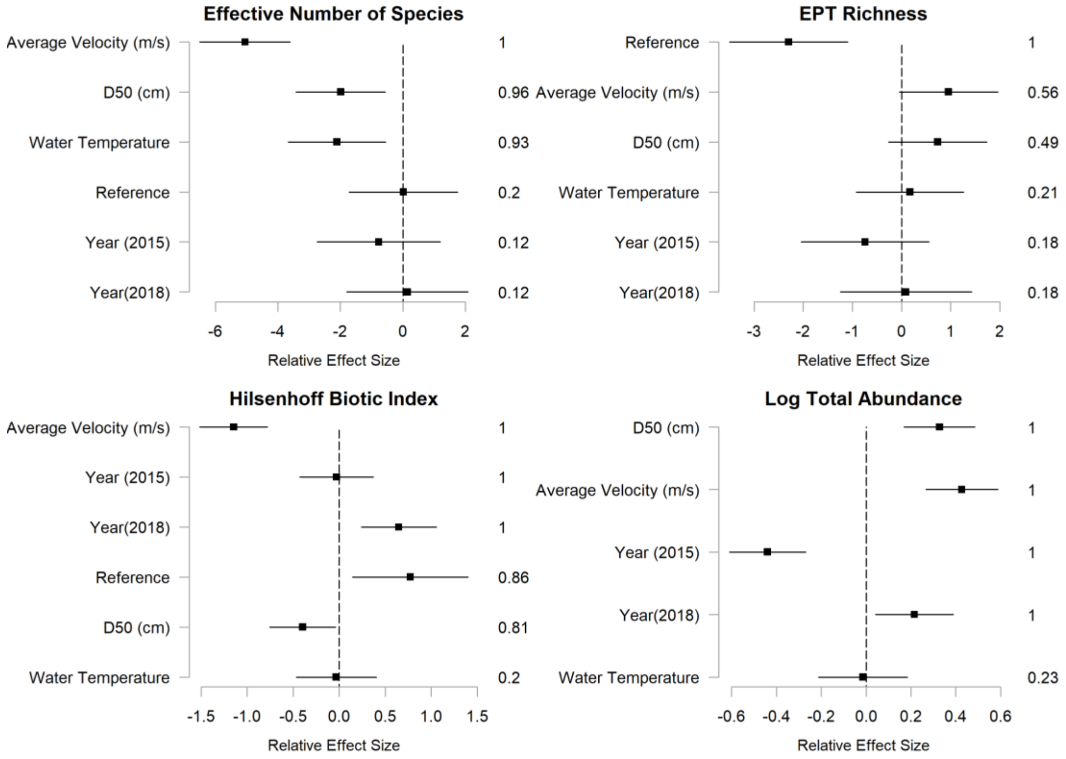


Figure 4-67: The coefficients and their 95% CLs of standardized explanatory variables of benthic invertebrate erosional samples. Invertebrate responses included abundance, effective number of species, Hilsenhoff Biotic Index and EPT Richness. Explanatory variables included D50 (substrate), velocity, water temperature, year sampled and treatment (reference or exposure). Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.

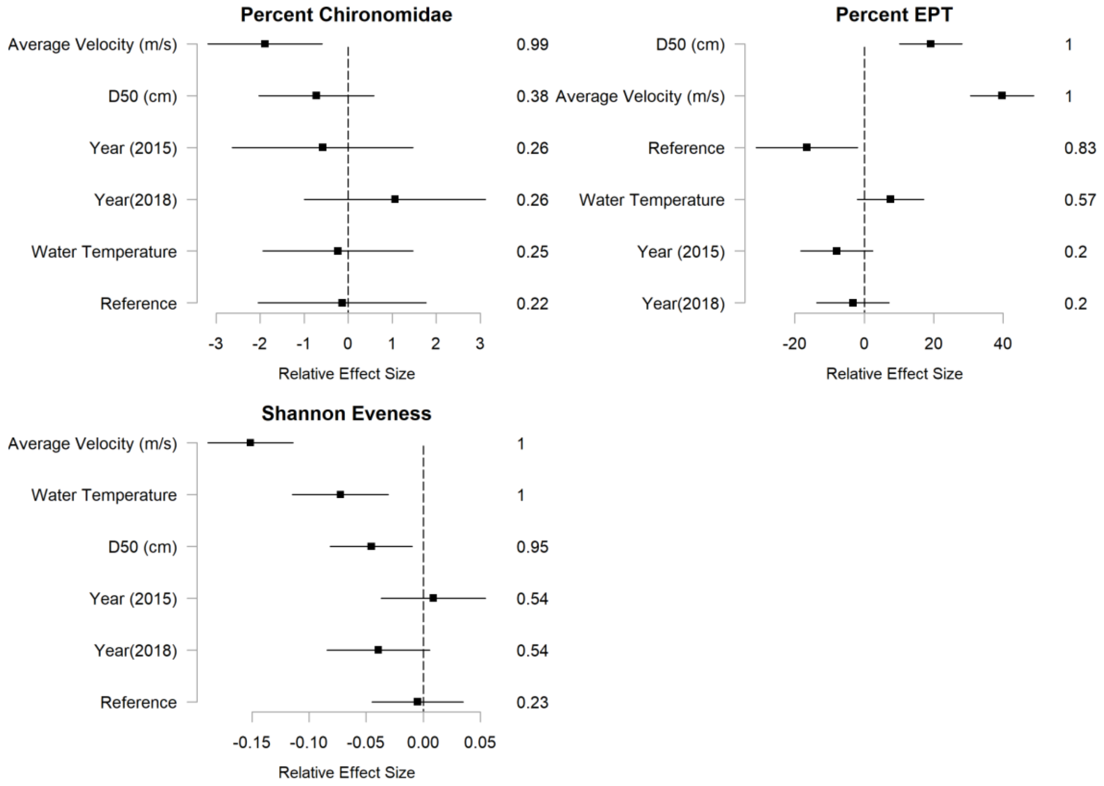


Figure 4-68: The coefficients and their 95% CLs of standardized explanatory variables of benthic invertebrate erosional samples. Invertebrate responses included percent EPT, percent Chironomidae and Shannon Evenness. Explanatory variables included D50 (substrate), velocity, water temperature, year sampled and treatment (reference or exposure). Coefficients were standardized to allow comparisons of the direction and size of effects, noting that variables with CLs that do not cross zero have an effect on the response variable. Key explanatory variables are those that have a relative variable importance (RVI) of greater than 0.6-0.7 and the RVI is shown on the right-hand side of each figure.

Current velocity is the most important variable affecting macroinvertebrate community structure in the Lower Columbia River as illustrated in the above models. Differences in community structure and shifts in dominant taxa were observed at some sites. However, there was no overall significant difference in communities and numerous metrics (e.g., total abundance, species richness etc.) between reference and exposure areas sampled. Figure 4-69 illustrates key physical predictors of benthic communities of this study.

Sites with low current velocities had apparent differences in community structure. There was a higher percentage of reference sites that had lower current velocities than exposure sites. In particular, sites within Reference Area 1 and Reference Area 2 and Exposure Area 4 had the lowest measured current velocities. These sites were more different in their benthic community structure. This is illustrated further in the current velocity and community metric plots below (Figure 4-70 - Figure 4-75).

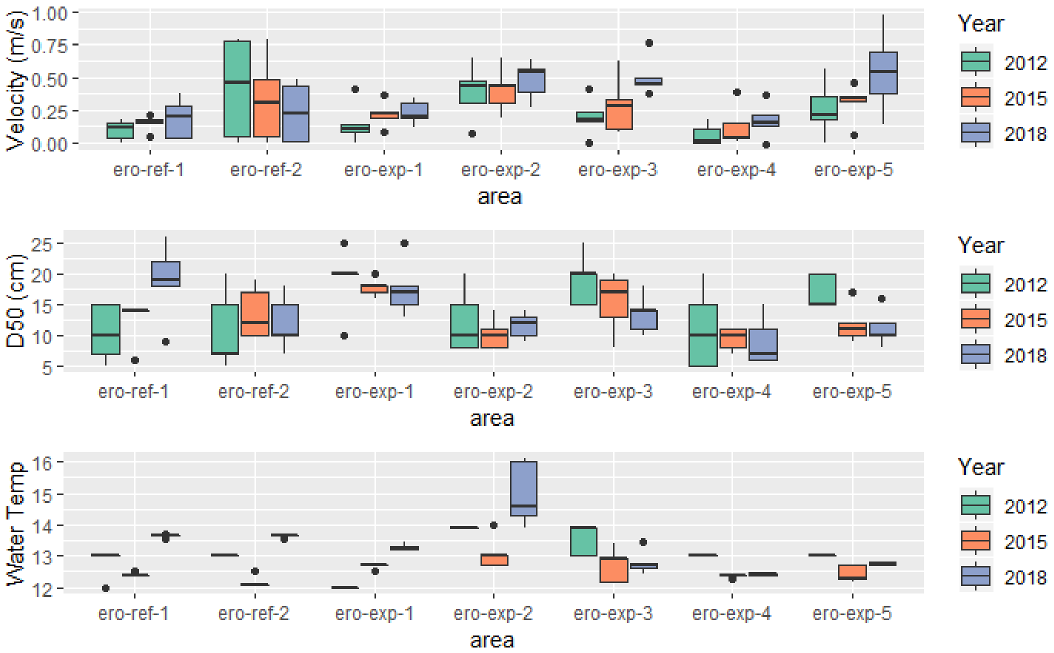


Figure 4-69: Boxplots of key physical predictors in erosional areas.

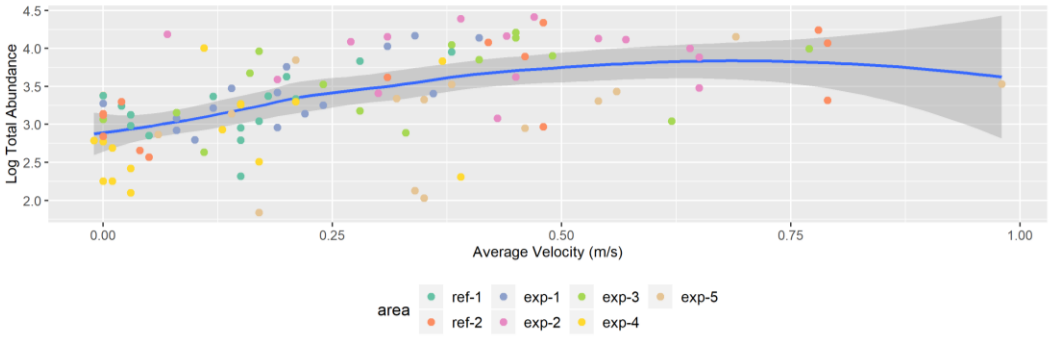


Figure 4-70: Current velocity and Log Total Abundance grouped by site.

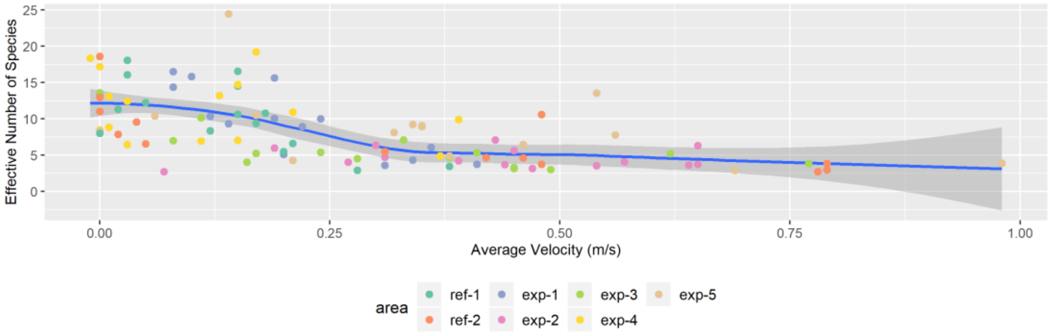


Figure 4-71: Current velocity and effective number of species grouped by site for riverine samplers.

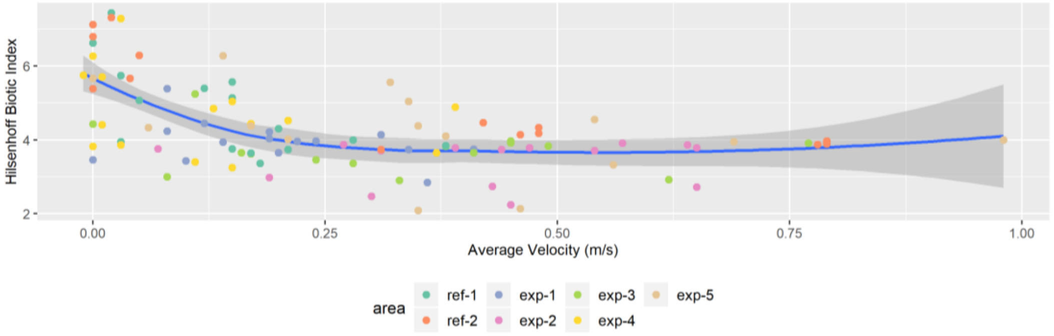


Figure 4-72: Current velocity and Hilsenhoff Biotic Index grouped by site for riverine samplers.

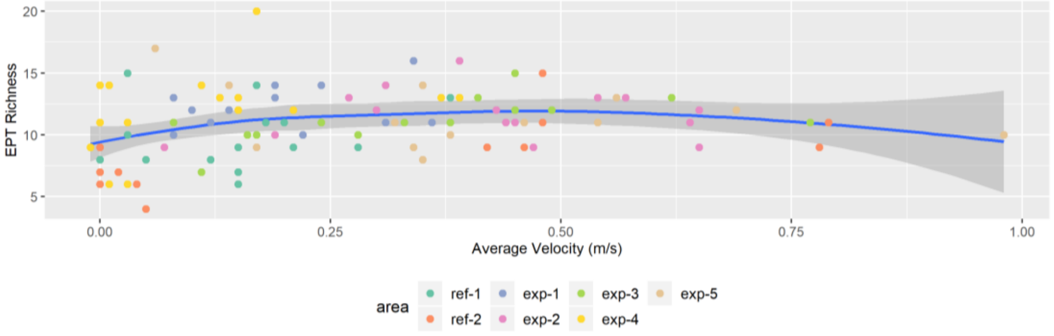


Figure 4-73: Current velocity and EPT Richness grouped by site for riverine samplers.

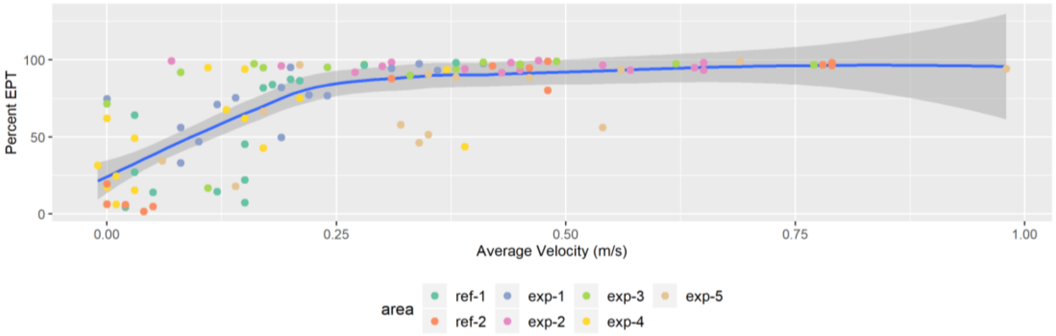


Figure 4-74: Current velocity and Percent EPT grouped by site for riverine samplers.

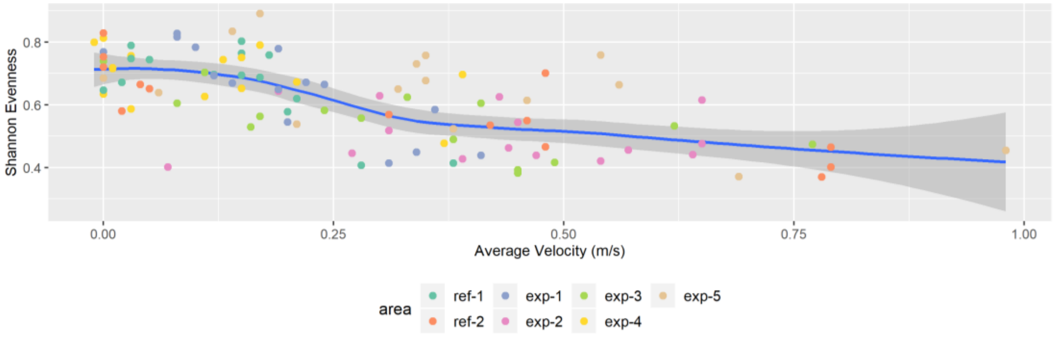


Figure 4-75: Current velocity and Shannon Evenness grouped by site for riverine samplers.

4.6.6 Species At Risk

The shortface lanx (*Fisherola nuttallii*) is a small limpet-shaped freshwater snail that requires flowing well oxygenated waters. In British Columbia, the shortface lanx has a list rank of Red, indicating that it is a candidate for either extirpated, endangered, or threatened status in BC. It is restricted to the Columbia River drainage in Canada and has only been documented in an area extending about 14 km upstream and 6 km downstream of the City of Trail. Increased periphyton abundance on rock surfaces increases detection success for this species. However, the sampling approach employed in the AEMP would collect this species regardless of the degree of periphyton present since the rocks are washed and the contents collected in a downstream receiving net.

The shortface lanx was collected from erosional reference habitats in ERO-REF-2 situated along the river left bank across from Stoney Creek during the 2012 AEMP data collection. However, it was not documented in any of the samples from 2015 or 2018 AEMP data collection cycles.

4.6.7 Summation

The structure of benthic macroinvertebrate communities showed little to no difference between reference and exposure areas for erosional habitats. We conclude that smelter effluent discharges did not have a detectable negative effect on downstream erosional habitat benthic communities. Community structure for both habitat types differed significantly between years (2012, 2015, 2018), but the most important variables influencing communities in LCR erosional habitats are water velocity and to a lesser extent, substrate size.

5.0 SUMMARY AND CONCLUSIONS

Use of statistical models in the 2018 AEMP and in other river studies found that flows and related factors including velocity, substrate size, shear stress, light penetration, and particulate suspension exert control over periphyton and benthic macroinvertebrate growth and their species assemblages. While this AEMP focuses on studying the effects of effluent discharge on aquatic environments, it must be remembered that seasonal and annual shifts in channel characteristics control LCR productivity and these controls shift with season and year (Larratt et al. 2013).

5.1 Water quality

The purpose of the AEMP water quality component is to carry out a long-term monitoring program to evaluate effects of Teck's permitted effluent discharges on the LCR.

The summary of water quality related to each key questions is outlined in the following sections.

5.1.1 Are Provincial Water Quality Objectives attained at the downstream end of the Initial Dilution Zone during low flows (less than 40 kcfs) as per long-term trend monitoring?

Yes, Provincial Water Quality Objectives were attained at the downstream end of the IDZ, or Old Bridge Site, even during low flows during all 2018 sampling events. No metal exceedances attributable to the smelter were detected in 2018 samples below the IDZ.

In both the IDZ and the entire AOI, none of the general water quality parameters or nutrients exceeded the LCR Water Quality Objectives in the 2015-2018 samples. All nutrients remained within their respective water quality objectives and guidelines throughout the LCR. Nutrient concentrations in the LCR below the IDZ were not significantly altered by effluent discharges. The largest nutrient inputs were above the Birchbank reference site.

5.1.2 Does water quality in the study area vary spatially in the Columbia River including point source discharge sites and reference sites, and temporally as a result of Teck's point source effluent discharges?

Transect water quality sampling showed spatial variation in water quality within the IDZ. The effluent plume hugged the right bank (~1/3 channel width or approximately 60 m) through to the downstream end of the IDZ. Water quality varied in the river cross-section in both horizontal and vertical stations within the IDZ. The highest metal values within the IDZ are found in right-bank samples adjacent to the smelter. Some metals were also elevated in left-bank samples collected within the IDZ.

Water sampling at Maglios (at the Bear Creek confluence, near Rock Island), indicated effective (near to full) mixing of effluent is attained about 4.2 km downstream of the IDZ. Between this station and the smelter outfalls, all metals of interest were within the LCR and BC guidelines by the downstream end of the IDZ. Complete mixing of the plume occurred between Maglios and Waneta.

Mann-Kendall analysis of spring flow-weighted concentrations of the R-sh samples from 2012-2018 showed statistically significant trends for only two parameters: T-Se at Waneta; and D-Cd at Stoney Creek. These two statistically significant trends are likely not related to the effluent because similar trends were observed upstream at the Birchbank Reference site.

5.1.3 Are water quality parameters that are analyzed at the AEMP stations appropriate?

The AEMP water quality monitoring study met all requirements. Existing parameters, along with their reportable detection limits, were appropriate. However, to facilitate use of the BLM model for copper, future sampling events will include collection of dissolved organic carbon in addition to the currently collected total organic carbon.

5.2 Depositional habitat

The depositional habitat component of the AEMP is designed to assess potential effects of Teck Trail Operations' permitted effluent discharges on depositional habitat by comparing periphyton and benthic invertebrate community structure and composition between areas upstream (reference) and downstream (exposure) of the smelter.

Hydrodynamics of the Columbia River in the study area create conditions where long-term depositional zones are rare (Golder, 2003). Depositional habitat was estimated at 0.1% of the total sediment habitat within the AOI (Golder 2007c). Therefore, the relative importance of these diverse depositional areas is restricted by their small contribution to the overall LCR habitat.

Depositional sites are dynamic, and each site has its own character in contrast to the comparatively uniform erosional habitats. The character of individual sites can change over time, and this must be considered when interpreting sediment and benthic community results collected in this study.

Key questions for this component include the following four sections:

5.2.1 What is the sediment quality in the depositional areas upstream and downstream of the smelter?

Sediment chemistry of the small LCR depositional areas was distinct from erosional cobble substrates. Sand dominated in all depositional sites within the AOI. Depositional sediments developed lower dissolved oxygen, lower redox, and elevated organic components compared to erosional habitats. these sediment conditions induced unique microflora communities dominated by decomposers.

The 2012, 2015, and 2018 AEMP data show that metal concentrations in depositional sediments downstream of the smelter (exposure sites) were higher than reference sites. This is consistent with the results of earlier studies (Golder 2007, Hatfield 2008). Distance from the smelter was a factor in sediment metal distribution but had a non-linear relationship. None of the sediment metals of interest consistently decreased with distance from smelter in 2018. The non-linear pattern of sediment exceedances as distance from the smelter increases suggests there are site-specific effects which may include influences of river flow dynamics along with other sources of metals such as naturally occurring metal concentrations, historical mining and milling, municipal effluent and/or stormwater. Estimates of percent slag in this study were lower in recent years than in earlier studies (Golder 2003; 2007).

Sediment metal concentrations remained relatively steady in the 2012 to 2018 data, both in terms of concentration and number of guideline exceedances (Table 4-12). In 2018, metals concentrations were higher than 2015 at several sites but were similar to 2012 levels. Some decline in concentrations is evident when the 2012-2018 data is compared to 2003. In 2018, sediment metals concentrations in a smaller grain size fraction (<63um) were also analyzed. The <63 µm samples had higher concentrations of metals than the <2mm fraction, interpreted to result from metals adsorption on organics which are proportionately higher in the <63um fraction. Metals in both sediment fractions followed similar distribution patterns at the sample sites.

In addition to physical and chemical characteristics of the sediment, a critical part of the depositional habitat component is assessment of benthic community structure to evaluate whether elevated metals in sediment result in impairment of the benthic communities and their role as nutrition for higher trophic level consumers. Abundance, species diversity, and species composition are measured and differences between exposure and references sites are assessed graphically and statistically. Physical elements of the habitat formed an important component of this assessment. While variations in habitat between deposition sites are evident, the differences did not indicate detectable impacts from sediment metal concentrations or from current effluent discharges on depositional periphyton or benthic invertebrate community structure.

5.2.2 Are periphyton on depositional sediments downstream of the smelter different from the upstream communities in terms of abundance, species diversity and biovolume?

Depositional periphyton communities throughout the LCR had lower overall productivity than adjacent erosional habitats following high scour years such as 2012; but their productivity was greater than erosional areas following stable flows as in 2015 and 2018. Depositional community structure included more diatoms settling out from reservoir releases and more motile genera than erosional community structures. Depositional periphyton accumulated more organic debris and had more decomposer components in the biofilm than adjacent erosional cobble substrates. No indication of a spatial trend in the depositional community structure was evident with distance downstream of the smelter in 2012, 2015 or in 2018 periphyton data.

There was no detectable impact of sediment metal concentrations on depositional periphyton community structure or standing crop. Similarly, no detectable impact of current effluent discharges was evident in depositional periphyton community structure or standing crop. In fact, all periphyton growth metrics were higher at the depositional sites downstream of the smelter than they were in the upstream reference sites in 2018.

Depositional periphyton results indicated a range of impacts on the LCR AOI, predominated by areas when nutrient outfalls occur such as the groundwater inflow from the smelter, and the City of Trail municipal outfall. Influence of the smelter outfall on periphyton metrics was smaller than the effect of year-to-year influences such as flow regime and weather.

5.2.3 Are the benthic invertebrate communities in depositional sediments downstream of the smelter different from the upstream communities in terms of abundance, species diversity and species composition?

Community structure differed significantly between sites and years (2012, 2015, and 2018), which continues to highlight the natural seasonal and annual variability that can occur in benthic communities.

In 2018, no significant difference in the total abundance, or %chironomid composition was evident when reference and exposure sites were grouped by year. Community diversity expressed by Effective Species differed significantly between year, however, no significant difference between reference and exposure areas was detected.

In 2018, total abundance was highest at the Genelle reference area, while biomass was highest in the Airport exposure area, and species richness was greatest at the Korpac exposure area. Effective species number (diversity) and Chironomid relative abundance were greatest in the Casino Eddy.

5.2.4 If differences in benthic communities exist, do these differences suggest adverse effects (i.e., impairment of benthic communities such that they provide poor habitat to upper trophic consumers) and is this linked to current permitted effluent discharges?

Differences in LCR benthic communities were detected, as described above, but these differences did not suggest adverse effects or impairment of benthic communities such that they provided poor habitat to upper trophic consumers. No impairment linked to current permitted effluent discharges was detected.

5.3 Erosional Habitat

The main objective of the AEMP erosional habitat sampling was to assess potential effects of the effluent discharge on erosional periphyton communities in terms of community structure, composition, and standing crop biomass, and to detect any trends over time. The three key erosional habitat questions are addressed in the following sections.

5.3.1 What is the difference in erosional periphyton communities in erosional habitat downstream of the smelter compared to the upstream communities in terms of community structure, composition, and standing crop biomass?

In riverine cobble substrates, localized variability in species distribution is very high. As in all large rivers, LCR periphyton continued to show wide natural variance in abundance within and between sites, including reference and exposure sites. There was little indication of a spatial trend in the presence of algae classes with distance upstream or downstream of the smelter in the 1995, 2003, 2012, 2015 or 2018 data. All metrics and statistical analyses conducted on 2018 data indicate there was no adverse impact on erosional periphyton community structure attributable to the smelter.

Diatoms are the most prevalent type of algae in erosional river biofilms and account for an increasing percentage of periphyton production within the IDZ. This population conforms to typical LCR results (Olson-Russello et al. 2019). Dominant species lists did not indicate measurable change between erosional reference and exposure sites. However, within the IDZ where warmer effluent and comparatively nutrient-rich groundwater can infiltrate, a shift to increased concentrations of cyanobacteria and filamentous green algae was observed. The side-channel receiving CIII effluent developed a distinctive cyanobacteria periphyton in all years including 2018.

Major driving forces on LCR periphyton communities include flows and localized water velocity, irradiance, nutrient concentrations, algae settling from upstream reservoirs and grazing pressure. Periphyton community metrics did not differ significantly between reference and exposure sites in

2012, 2015 or 2018. Other stressors such as flow regime drive the LCR periphyton community as they do in most large river systems.

Near-field taxonomic results from 2018 confirmed erosional productivity metrics, suggesting that the influence of the smelter on the AOI is diminishing. Periphyton community metrics from 2012 through 2018 do not differ significantly between reference and exposure sites, indicating that periphyton growth was not significantly impacted by exposure to recent smelter effluents. Over the course of 2003-2018 periphyton studies, productivity metrics within the IDZ and near-field have been trending lower toward more typical LCR levels found in upstream reference areas. It must be remembered that periphyton systems are influenced by a wide number of factors and apparent changes may reflect timing of sampling relative to the time elapsed since the last major flow event or simply large annual variations that are observed on the LCR (Larratt et al. 2013). The enhanced near-field productivity does not approach nuisance proportions but may benefit benthic invertebrates - it is not harmful from a habitat perspective, only different and the causation is not clear (e.g., physical habitat vs. effluent).

5.3.2 What is the difference in the erosional benthic invertebrate communities in erosional habitat downstream of the smelter compared to the upstream communities in terms of community structure and composition?

In 2018, there was no significant difference in benthic invertebrate total abundance between reference areas and any exposure areas. Total abundance was highest in ERO-EXP-2, the side channel receiving CIII discharges. Similarly, 2018 data showed no significant difference in total invertebrate biomass, species richness, or effective species numbers between any other pairings of reference and exposure areas. Hilsenhoff Biotic Index values were again lower in the exposure areas of the IDZ than upstream reference areas and exposure areas further downstream. This corroborates results of both the 2012 and 2015 data collection and interpretation.

2018 data corroborates previous AEMP cycle results, that the smelter did not exert an adverse influence on benthic community composition. Although some differences within sites were observed, they were driven by physical variables, including current velocity and associated substrate size. Sites with higher velocities had greater benthic macroinvertebrate abundance and were dominated by EPT taxa and thus had lower HBI scores.

Physical habitat attributes, velocity and substrate size were the most important variables influencing communities in erosional habitats. Velocity was an important variable for explaining benthic macroinvertebrate abundance, %EPT, and HBI scores. Sites with higher water velocity had higher abundance and %EPT while having lower HBI scores. Exposure Area 2, within the side channel downstream of the CIII outfall, had the highest mean velocity of all areas followed by Exposure Area 5 and Exposure Area 3. Substrate size

(D90) and water temperature were also important variables influencing abundance, species richness, species diversity, and % EPT.

5.3.3 On the basis of qualitative review, is there a trend in periphyton and benthic metrics over time?

Adding 2018 data corroborates previous AEMP cycle results and further strengthens the review that the smelter did not cause an adverse effect on periphyton and benthic community composition. Periphyton and benthic metric trends over time were driven by other stressors such as flow regime, and not smelter influence.

6.0 CLOSURE

This report has been prepared exclusively for Teck Metals Limited.

If you have any questions pertaining to this report, you may contact the undersigned.

Respectfully Submitted,

ECOSCAPE ENVIRONMENTAL CONSULTANTS LTD. AND
LARRATT AQUATIC CONSULTING LTD.

Heather Larratt, R.P.Bio.
Senior Aquatic Biologist - Larratt Aquatic
Line: (250) 769-5444

Rachel Plewes, M.Sc.
Limnologist/Senior Data Analyst Direct
Direct Line: (250) 491-7337 ext. 208

Kyle Hawes, R.P.Bio.
Senior Aquatic Biologist
Direct Line: (250) 491-7337 ext. 203

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SCHEDULE - A

MAP SHEETS

Lower Columbia River Aquatic Environment Monitoring Program

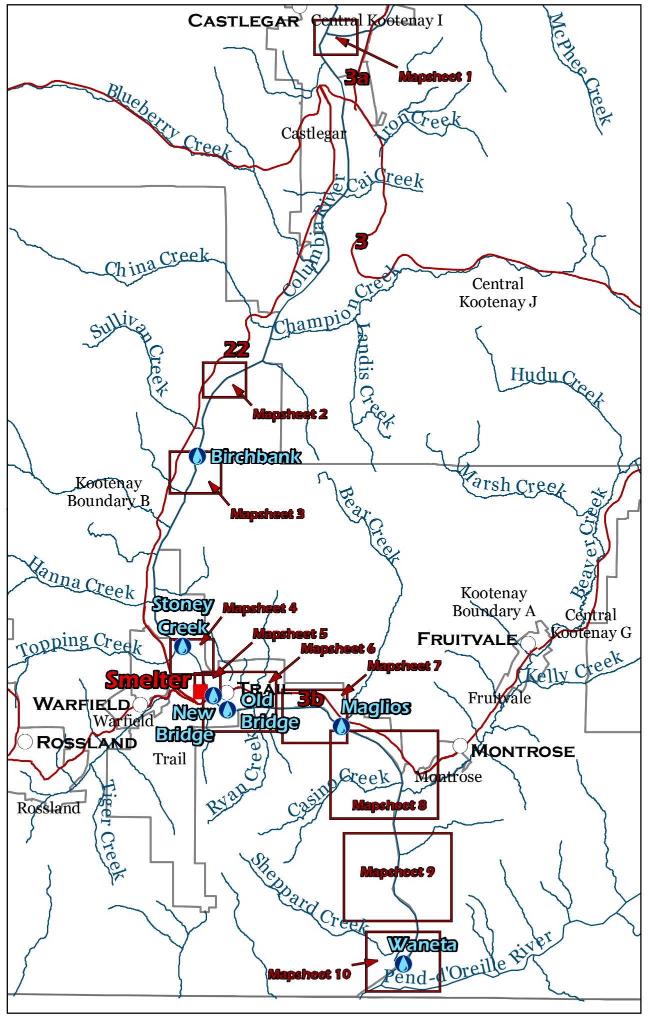
Mapsheet 1

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
Imagery:	ESRI Base
Map Date:	September 10, 2019

LEGEND

●	Water Quality Sites (AREMP Program)
●	Depositional Area Sample Sites
●	Erosional Area Sample Sites
■	Smelter
💧	Monitoring Stations
—	Streams and Rivers
🟩	Exposure Area
🟥	Reference Zone

Regional Location of the Sampling Site



DISCLAIMER
The data displayed is for conceptual purposes only and should not be interpreted as a legal survey or for legal purposes. If discrepancies are found between the data portrayed in this report and that of a legal survey, the legal survey will supersede any data presented herein.

ECOSCAPE
Environmental Consultants Ltd.

Lower Columbia River Aquatic Environment Monitoring Program

Mapsheet 2

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
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LEGEND

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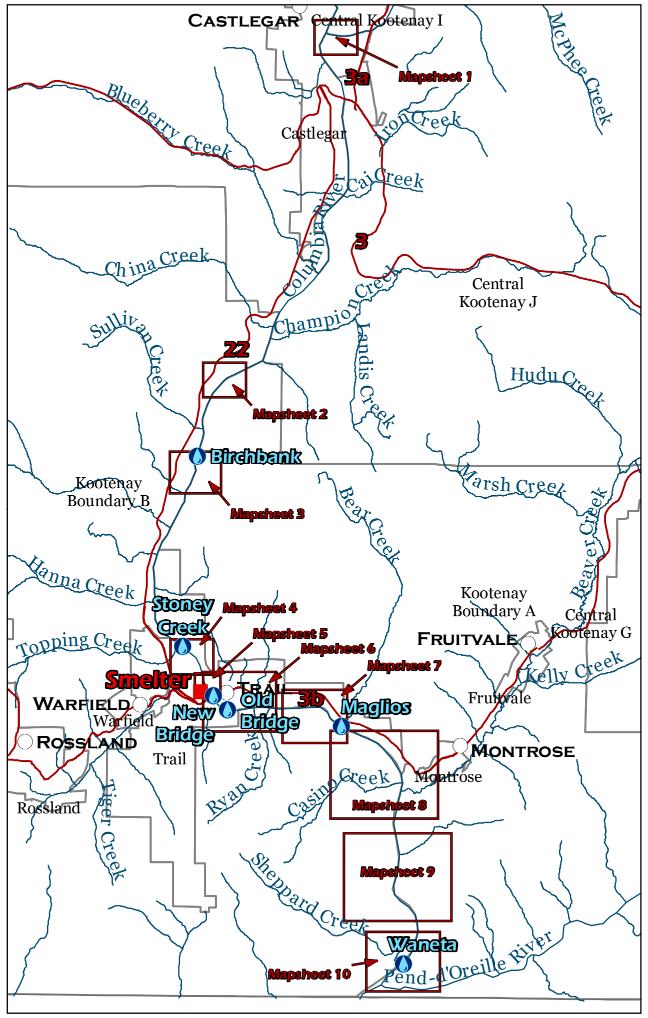
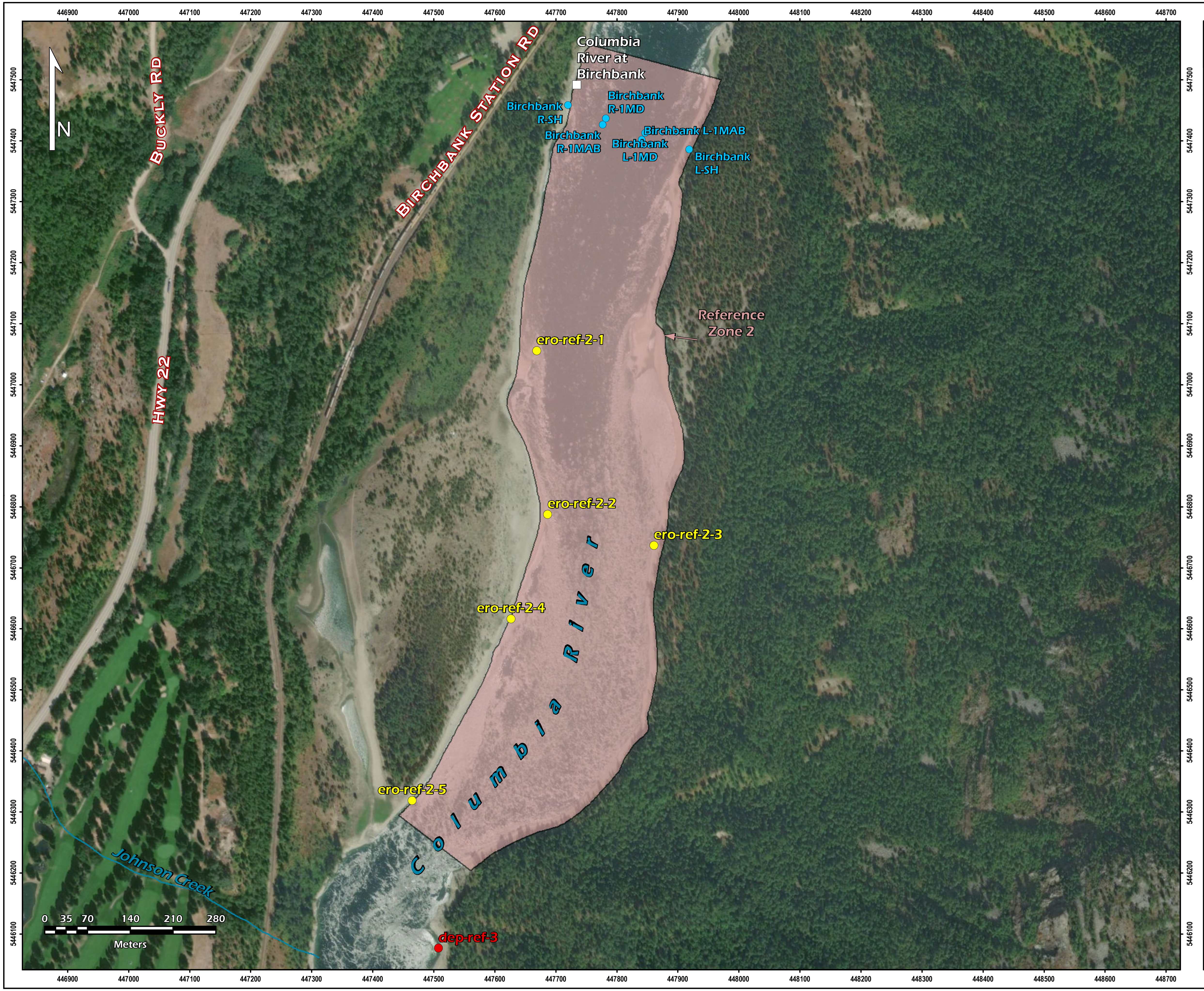
■	Smelter
💧	Monitoring Stations
—	Streams and Rivers
🟩	Exposure Area
▨	Reference Zone

Regional Location of the Sampling Site



ECOSCAPE
Environmental Consultants Ltd.



Lower Columbia River Aquatic Environment Monitoring Program

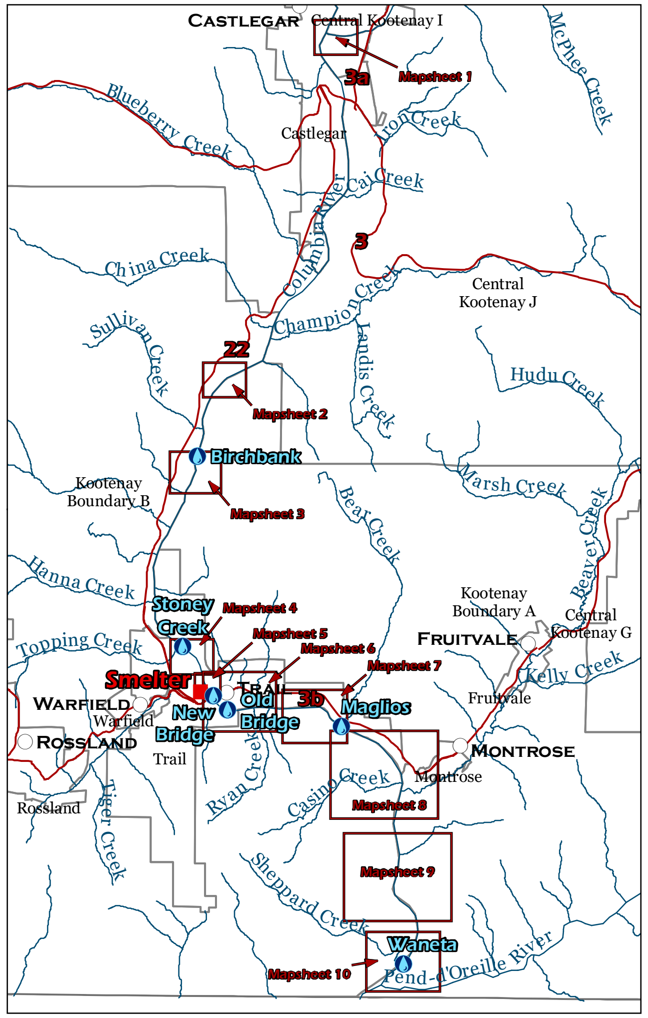
Mapsheet 3

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
Imagery:	ESRI Base
Map Date:	September 10, 2019

LEGEND

●	Water Quality Sites (AREMP Program)
●	Depositional Area Sample Sites
●	Erosional Area Sample Sites
■	Smelter
💧	Monitoring Stations
—	Streams and Rivers
🟩	Exposure Area
▨	Reference Zone

Regional Location of the Sampling Site



ECOSCAPE
Environmental Consultants Ltd.

Lower Columbia River Aquatic Environment Monitoring Program

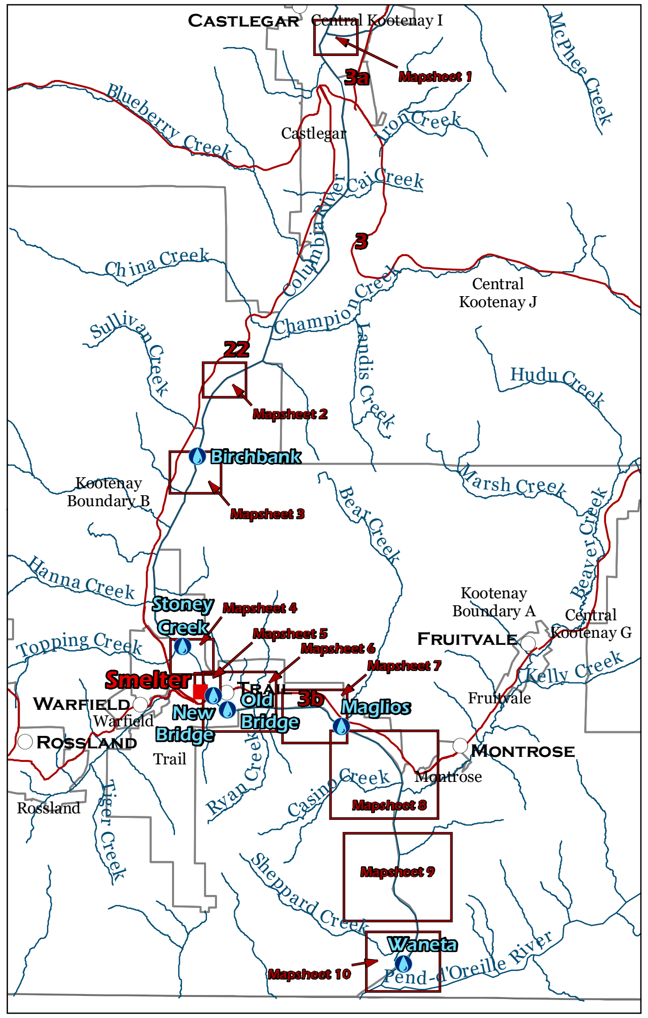
Mapsheet 4

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
Imagery:	ESRI Base
Map Date:	September 10, 2019

LEGEND

●	Water Quality Sites (AREMP Program)
●	Depositional Area Sample Sites
●	Erosional Area Sample Sites
■	Smelter
💧	Monitoring Stations
—	Streams and Rivers
🟩	Exposure Area
▨	Reference Zone

Regional Location of the Sampling Site



Lower Columbia River Aquatic Environment Monitoring Program

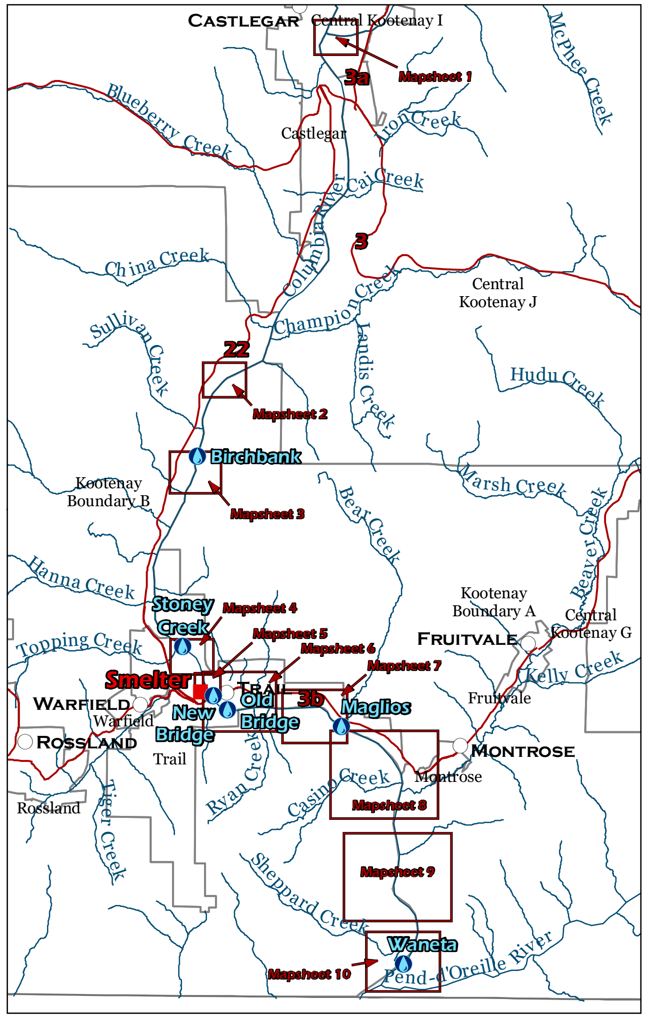
Mapsheet 5

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
Imagery:	ESRI Base
Map Date:	September 10, 2019

LEGEND

●	Water Quality Sites (AREMP Program)
●	Depositional Area Sample Sites
●	Erosional Area Sample Sites
■	Smelter
💧	Monitoring Stations
—	Streams and Rivers
🟩	Exposure Area
▨	Reference Zone

Regional Location of the Sampling Site



<u>DISCLAIMER</u>
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ECOSCAPE
Environmental Consultants Ltd.

Lower Columbia River Aquatic Environment Monitoring Program

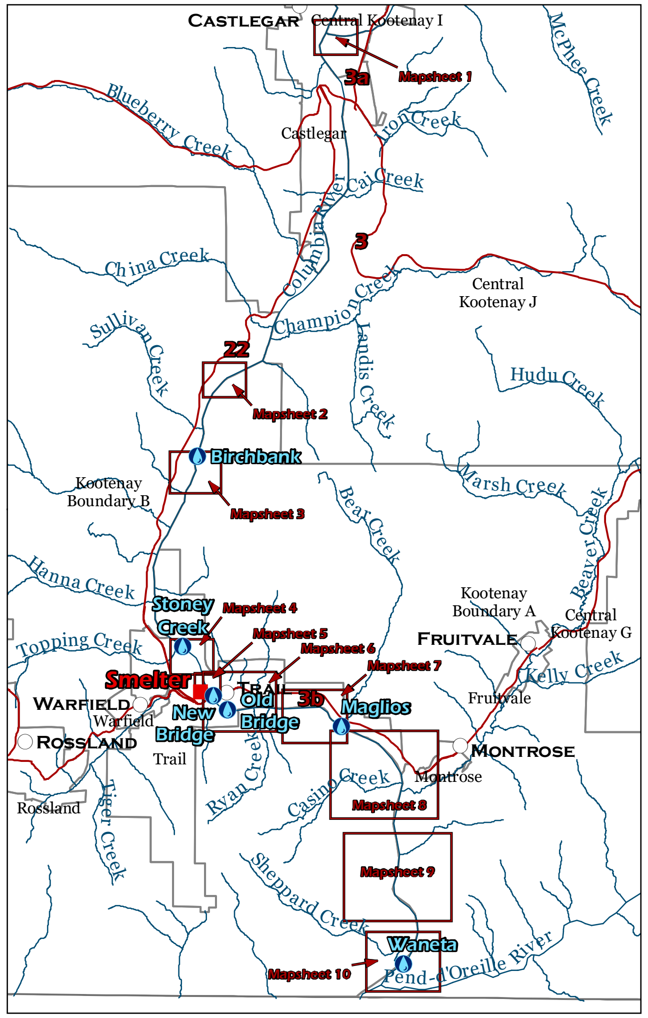
Mapsheet 6

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
Imagery:	ESRI Base
Map Date:	September 10, 2019

LEGEND

●	Water Quality Sites (AREMP Program)
●	Depositional Area Sample Sites
●	Erosional Area Sample Sites
■	Smelter
💧	Monitoring Stations
—	Streams and Rivers
🟩	Exposure Area
▨	Reference Zone

Regional Location of the Sampling Site



DISCLAIMER

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ECOSCAPE
Environmental Consultants Ltd.

Lower Columbia River Aquatic Environment Monitoring Program

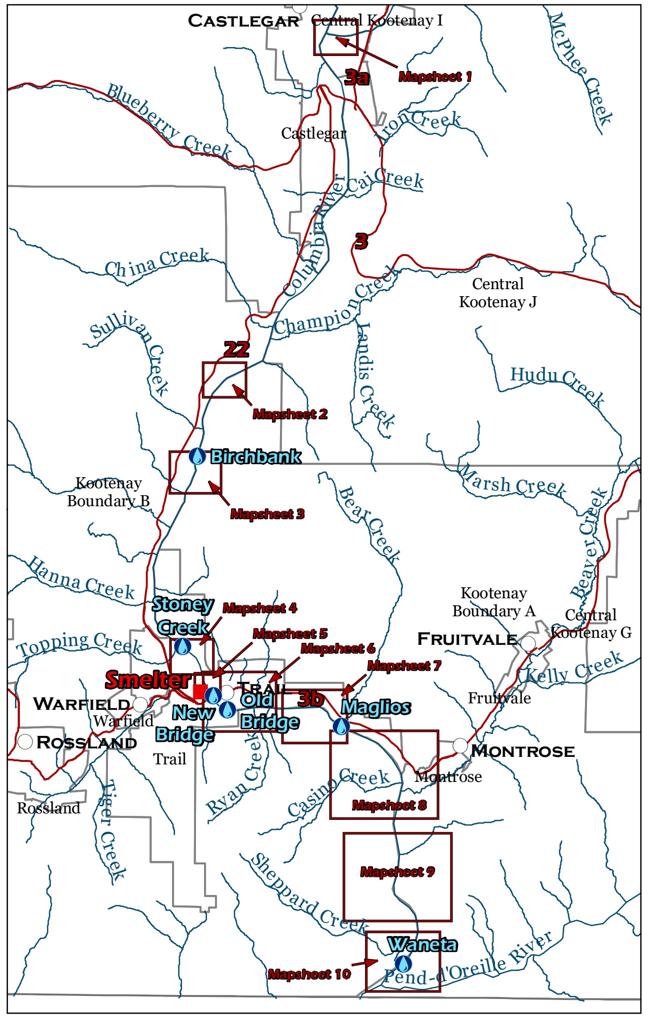
Mapsheet 7

Project: Aquatic Environment Monitoring
Location: Trail, BC
Project No.: 18-2411
Prepared for: Teck Metals Ltd. - Trail Operations
Prepared by: Ecoscape Environmental Consultants Ltd.
Coordinate System: NAD83-UTM Zone 11
Imagery: ESRI Base
Map Date: September 10, 2019

LEGEND

- ● Water Quality Sites (AREMP Program)
- ● Depositional Area Sample Sites
- ● Erosional Area Sample Sites
- ■ Smelter
- ● Monitoring Stations
- — Streams and Rivers
- 🟩 Exposure Area
- 🟥 Reference Zone

Regional Location of the Sampling Site



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ECOSCAPE
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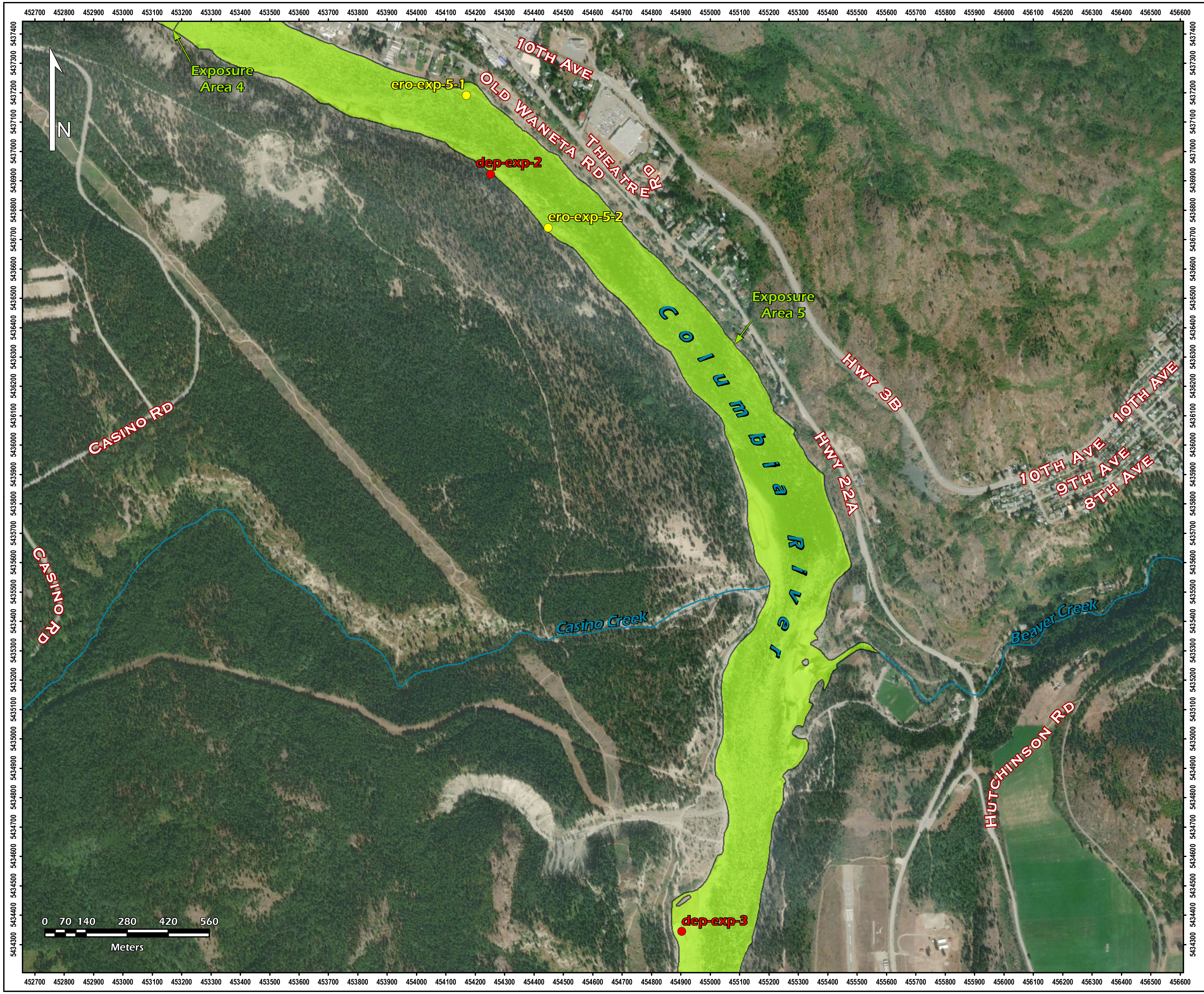


Lower Columbia River Aquatic Environment Monitoring Program

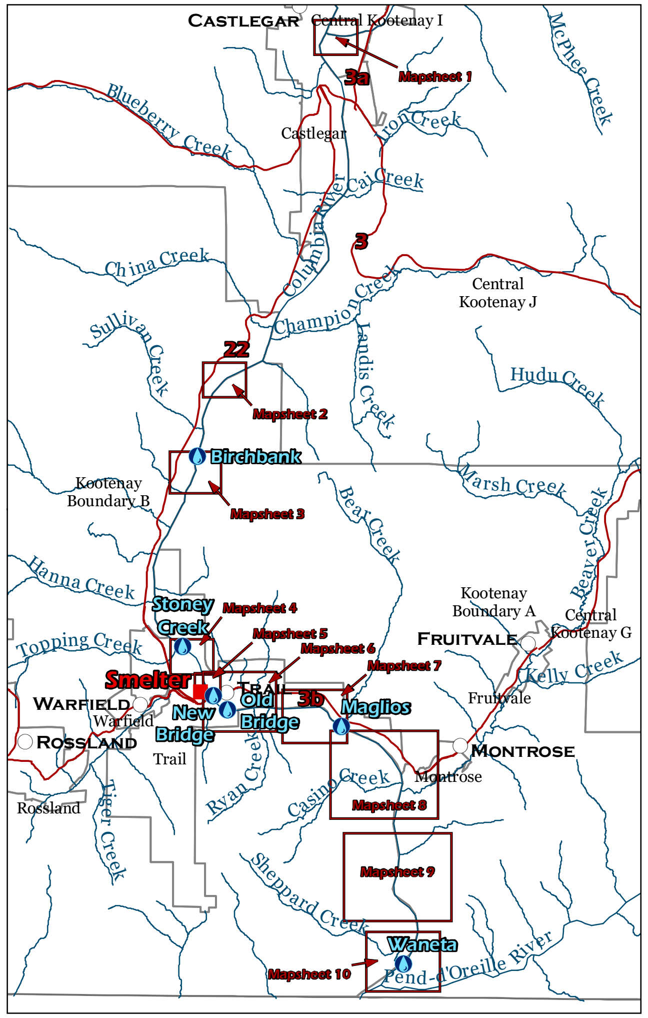
Mapsheet 8

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
Imagery:	ESRI Base
Map Date:	September 10, 2019

LEGEND

- ● Water Quality Sites (AREMP Program)
- ● Depositional Area Sample Sites
- ● Erosional Area Sample Sites
- ■ Smelter
- 💧 Monitoring Stations
- — Streams and Rivers
- 🟩 Exposure Area
- ▨ Reference Zone

Regional Location of the Sampling Site



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Lower Columbia River Aquatic Environment Monitoring Program

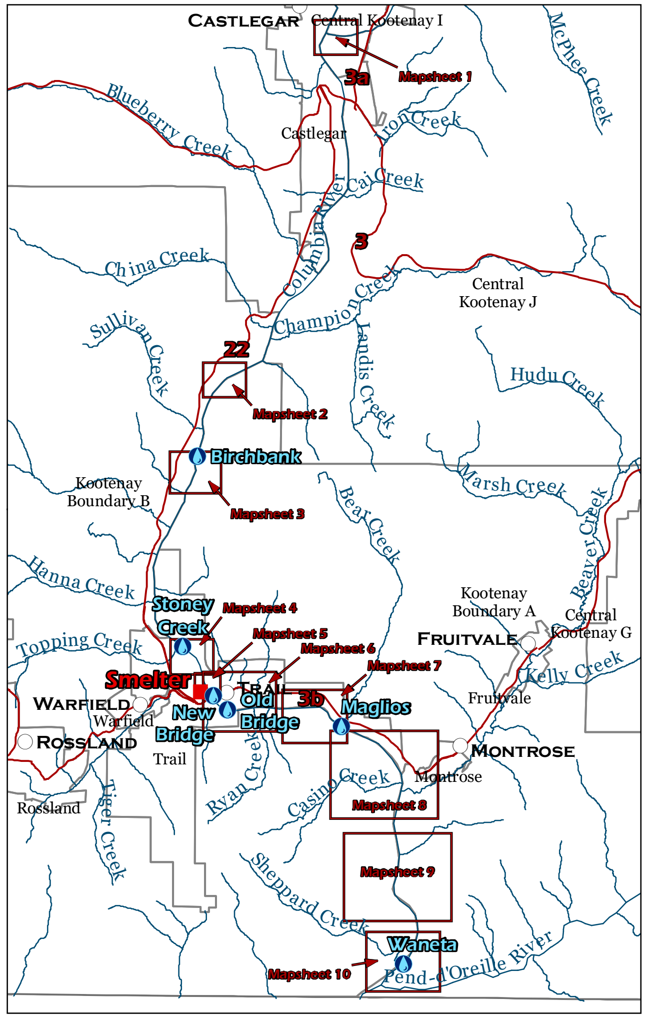
Mapsheet 9

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
Imagery:	ESRI Base
Map Date:	September 10, 2019

LEGEND

●	Water Quality Sites (AREMP Program)
●	Depositional Area Sample Sites
●	Erosional Area Sample Sites
■	Smelter
💧	Monitoring Stations
—	Streams and Rivers
🟩	Exposure Area
🟥	Reference Zone

Regional Location of the Sampling Site



ECOSCAPE
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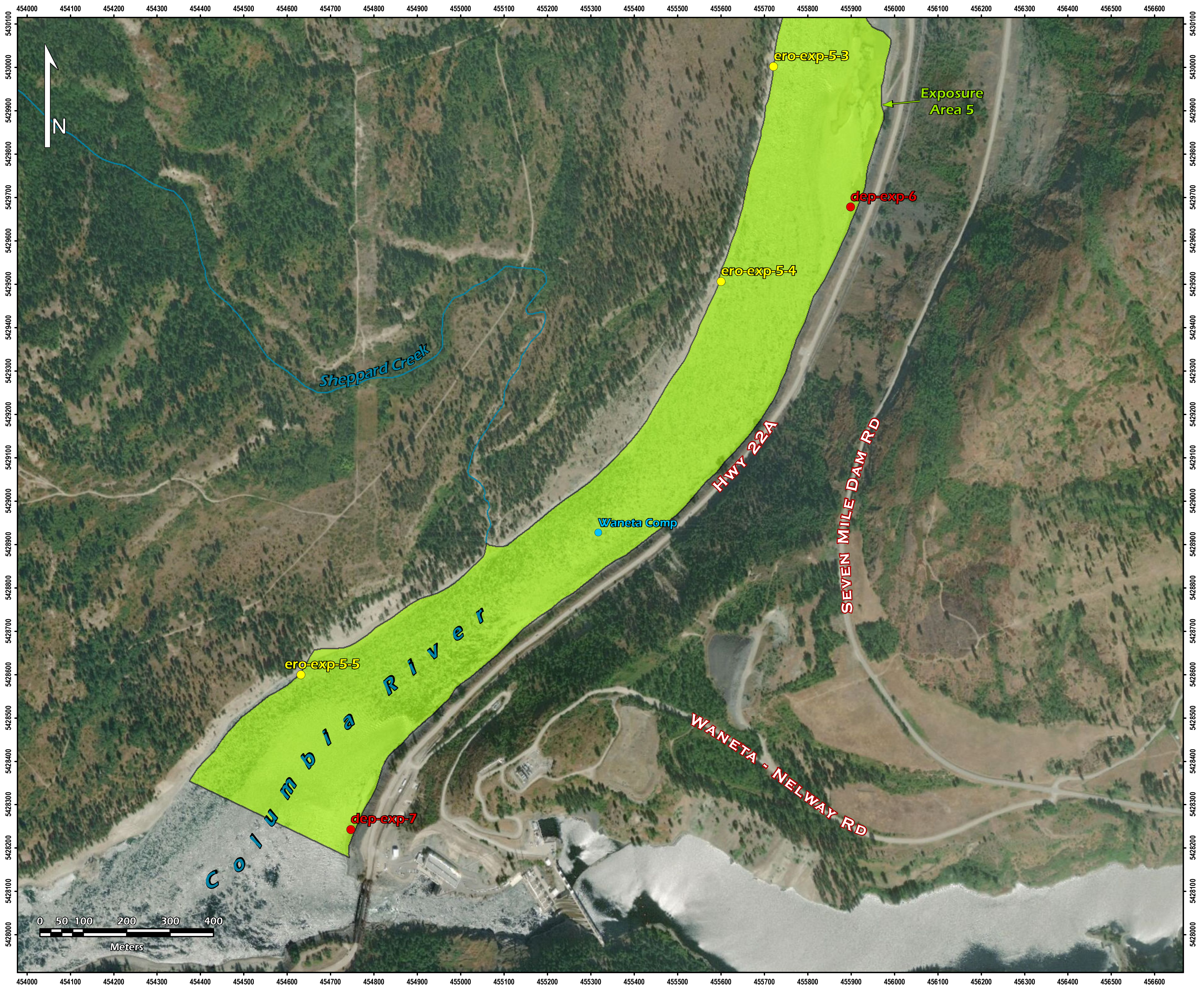


Lower Columbia River Aquatic Environment Monitoring Program

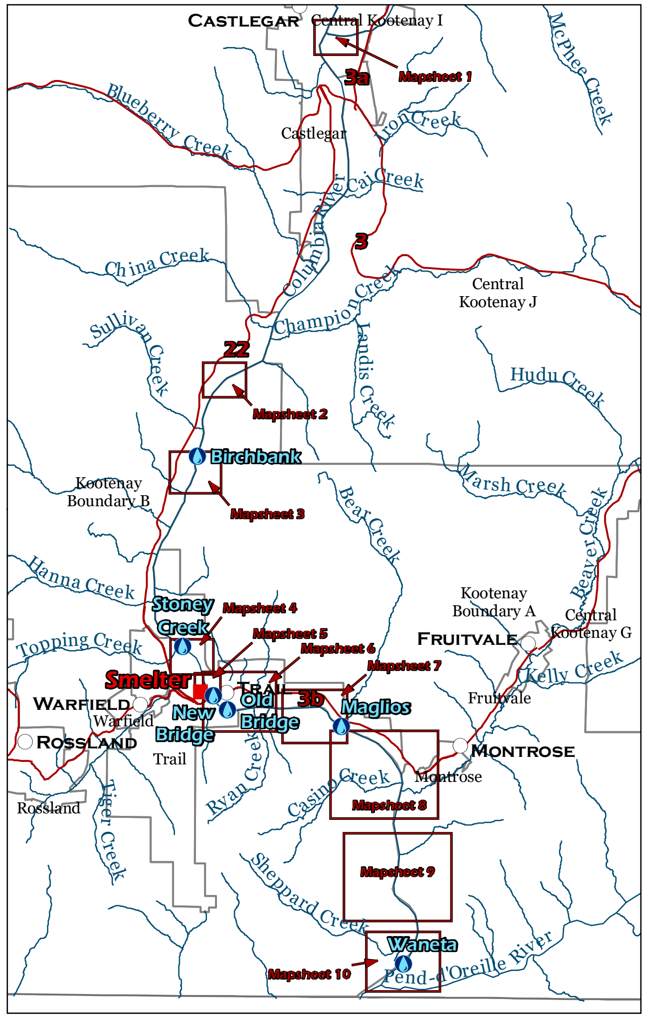
Mapsheet 10

Project:	Aquatic Environment Monitoring
Location:	Trail, BC
Project No.:	18-2411
Prepared for:	Teck Metals Ltd. - Trail Operations
Prepared by:	Ecoscape Environmental Consultants Ltd.
Coordinate System:	NAD83-UTM Zone 11
Imagery:	ESRI Base
Map Date:	September 10, 2019

LEGEND

●	Water Quality Sites (AREMP Program)
●	Depositional Area Sample Sites
●	Erosional Area Sample Sites
■	Smelter
💧	Monitoring Stations
—	Streams and Rivers
🟩	Exposure Area
▨	Reference Zone

Regional Location of the Sampling Site



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APPENDIX A AQUATIC COMMUNITY SAMPLING OUTLINE

Appendix A. AEMP erosional habitat sampling areas and sites.

Area	Description	Area-Site	Bank	Periphyton Community	Benthic Community	Periphyton Tissue	Benthic Tissue	Sculpin Tissue
KOOT-REF-1	Erosional habitat on left bank of Kootenay River	KOOT-REF-1	L					KOOT-REF-1
ERO-REF-1	Left bank opposite Stoney Creek	ERO-REF-1-1	L	ERO-REF-1-1A	ERO-REF-1-1	ERO-REF-1-1-PeriT	ERO-REF-1-1-BenTS	
				ERO-REF-1-1B				
				ERO-REF-1-1C				
		ERO-REF-1-2	L	ERO-REF-1-2A	ERO-REF-1-2	ERO-REF-1-2-PeriT	ERO-REF-1-2-BenTS	
				ERO-REF-1-2B				
				ERO-REF-1-2C				
		ERO-REF-1-3	L	ERO-REF-1-3A	ERO-REF-1-3	ERO-REF-1-3-PeriT	ERO-REF-1-3-BenTC	
				ERO-REF-1-3B				
				ERO-REF-1-3C				
		ERO-REF-1-4	L	ERO-REF-1-4A	ERO-REF-1-4	ERO-REF-1-4-PeriT	ERO-REF-1-4-BenTC	
				ERO-REF-1-4B				
				ERO-REF-1-4C				
		ERO-REF-1-5	L	ERO-REF-1-5A	ERO-REF-1-5	ERO-REF-1-5-PeriT	ERO-REF-1-5-BenTS	
				ERO-REF-1-5B				
				ERO-REF-1-5C				
ERO-REF-2	Birchbank	ERO-REF-2-1	B	ERO-REF-2-1A	ERO-REF-2-1	ERO-REF-2-1-PeriT	ERO-REF-2-1-BenTC	ERO-REF-2
				ERO-REF-2-1B				
				ERO-REF-2-1C				
		ERO-REF-2-2	B	ERO-REF-2-2A	ERO-REF-2-2	ERO-REF-2-2-PeriT	ERO-REF-2-2-BenTC	
				ERO-REF-2-2B				
				ERO-REF-2-2C				
		ERO-REF-2-3	B	ERO-REF-2-3A	ERO-REF-2-3	ERO-REF-2-3-PeriT	ERO-REF-2-3-BenTC	
				ERO-REF-2-3B				
				ERO-REF-2-3C				
		ERO-REF-2-4	B	ERO-REF-2-4A	ERO-REF-2-4	ERO-REF-2-4-PeriT	ERO-REF-2-4-BenTS	
				ERO-REF-2-4B				
				ERO-REF-2-4C				
		ERO-REF-2-5	B	ERO-REF-2-5A	ERO-REF-2-5	ERO-REF-2-5-PeriT	ERO-REF-2-5-BenTS	
				ERO-REF-2-5B				
				ERO-REF-2-5C				
ERO-REF-3	Gennelle		B					ERO-REF-3
ERO-EXP-1	Right bank from Stoney Creek to side channel	ERO-EXP-1-1	R	ERO-EXP-1-1A	ERO-EXP-1-1			ERO-EXP-1
				ERO-EXP-1-1B				
				ERO-EXP-1-1C				
		ERO-EXP-1-2	R	ERO-EXP-1-2A	ERO-EXP-1-2			
				ERO-EXP-1-2B				
				ERO-EXP-1-2C				
		ERO-EXP-1-3	R	ERO-EXP-1-3A	ERO-EXP-1-3			
				ERO-EXP-1-3B				
				ERO-EXP-1-3C				
		ERO-EXP-1-4	R	ERO-EXP-1-4A	ERO-EXP-1-4			
				ERO-EXP-1-4B				
				ERO-EXP-1-4C				
		ERO-EXP-1-5	R	ERO-EXP-1-5A	ERO-EXP-1-5			
				ERO-EXP-1-5B				
				ERO-EXP-1-5C				
ERO-EXP-2	Side channel from CIII outfall down to CII Outfall	ERO-EXP-2-1	R	ERO-EXP-2-1A	ERO-EXP-2-1	ERO-EXP-2-1-PeriT	ERO-EXP-2-1-BenTC	ERO-EXP-2
				ERO-EXP-2-1B				
				ERO-EXP-2-1C				
		ERO-EXP-2-2	R	ERO-EXP-2-2A	ERO-EXP-2-2	ERO-EXP-2-2-PeriT	ERO-EXP-2-2-BenTC	
				ERO-EXP-2-2B				
				ERO-EXP-2-2C				
		ERO-EXP-2-3	R	ERO-EXP-2-3A	ERO-EXP-2-3	ERO-EXP-2-3-PeriT	ERO-EXP-2-3-BenTC	
				ERO-EXP-2-3B				
				ERO-EXP-2-3C				
		ERO-EXP-2-4	R	ERO-EXP-2-4A	ERO-EXP-2-4	ERO-EXP-2-4-PeriT	ERO-EXP-2-4-BenTC	
				ERO-EXP-2-4B				
				ERO-EXP-2-4C				
		ERO-EXP-2-5	R	ERO-EXP-2-5A	ERO-EXP-2-5	ERO-EXP-2-5-PeriT	ERO-EXP-2-5-BenTC	
				ERO-EXP-2-5B				

Area	Description	Area-Site	Bank	Periphyton Community	Benthic Community	Periphyton Tissue	Benthic Tissue	Sculpin Tissue
				ERO-EXP-2-5C				
ERO-EXP-3	CII Outfall downstream to Korpac	ERO-EXP-3-1	R	ERO-EXP-3-1A ERO-EXP-3-1B ERO-EXP-3-1C	ERO-EXP-3-1	ERO-EXP-3-1-PeriT	ERO-EXP-3-1-BenTC	ERO-EXP-3-1-R
		ERO-EXP-3-1-L	L					ERO-EXP-3-1-L
		ERO-EXP-3-2	R	ERO-EXP-3-2A ERO-EXP-3-2B ERO-EXP-3-2C	ERO-EXP-3-2	ERO-EXP-3-2-PeriT	ERO-EXP-3-2-BenTS	
		ERO-EXP-3-2-L	L					ERO-EXP-3-2-L
		ERO-EXP-3-3	L	ERO-EXP-3-3A ERO-EXP-3-3B ERO-EXP-3-3C	ERO-EXP-3-3	ERO-EXP-3-3-PeriT	ERO-EXP-3-3-BenTC	ERO-EXP-3-3-L
		ERO-EXP-3-4	R	ERO-EXP-3-4A ERO-EXP-3-4B ERO-EXP-3-4C	ERO-EXP-3-4	ERO-EXP-3-4-PeriT	ERO-EXP-3-4-BenTC	ERO-EXP-3-4-R
		ERO-EXP-3-5	L	ERO-EXP-3-5A ERO-EXP-3-5B ERO-EXP-3-5C	ERO-EXP-3-5	ERO-EXP-3-5-PeriT	ERO-EXP-3-5-BenTC	ERO-EXP-3-4-L
		ERO-EXP-3-6	R			ERO-EXP-3-6-PeriT	ERO-EXP-3-6-BenTC	ERO-EXP-3-3-R
ERO-CRADT	Right bank From New Bridge to D/S End of right bank retaining wall	ERO-CRADT-3-1	R	ERO-CRADT-3-1A ERO-CRADT-3-1B ERO-CRADT-3-1C	ERO-CRADT-3-1	ERO-CRADT-3-1-PeriT	ERO-CRADT-3-1-BenTC	ERO-EXP-3-2R
		ERO-CRADT-3-2	R	ERO-CRADT-3-2A ERO-CRADT-3-2B ERO-CRADT-3-2C	ERO-CRADT-3-2	ERO-CRADT-3-2-PeriT	ERO-CRADT-3-2-BenTS	
		ERO-CRADT-3-3	R	ERO-CRADT-3-3A ERO-CRADT-3-3B ERO-CRADT-3-3C	ERO-CRADT-3-3	ERO-CRADT-3-3-PeriT	ERO-CRADT-3-3-BenTC	
		ERO-CRADT-3-4	R	ERO-CRADT-3-4A ERO-CRADT-3-4B ERO-CRADT-3-4C	ERO-CRADT-3-4	ERO-CRADT-3-4-PeriT	ERO-CRADT-3-4-BenTC	
		ERO-CRADT-3-5	R	ERO-CRADT-3-5A ERO-CRADT-3-5B ERO-CRADT-3-5C	ERO-CRADT-3-5	ERO-CRADT-3-5-PeriT	ERO-CRADT-3-5-BenTS	
ERO-EXP-4	Korpac downstream to below Maglios	ERO-EXP-4-1	L	ERO-EXP-4-1A ERO-EXP-4-1B ERO-EXP-4-1C	ERO-EXP-4-1	ERO-EXP-4-1-PeriT	ERO-EXP-4-1-BenTS	
		ERO-EXP-4-2	L	ERO-EXP-4-2A ERO-EXP-4-2B ERO-EXP-4-2C	ERO-EXP-4-2	ERO-EXP-4-2-PeriT	ERO-EXP-4-2-BenTS	
		ERO-EXP-4-3	L	ERO-EXP-4-3A ERO-EXP-4-3B ERO-EXP-4-3C	ERO-EXP-4-3	ERO-EXP-4-3-PeriT	ERO-EXP-4-3-BenTS	
		ERO-EXP-4-4	L	ERO-EXP-4-4A ERO-EXP-4-4B ERO-EXP-4-4C	ERO-EXP-4-4	ERO-EXP-4-4-PeriT	ERO-EXP-4-4-BenTC	
		ERO-EXP-4-5	R	ERO-EXP-4-5A ERO-EXP-4-5B ERO-EXP-4-5C	ERO-EXP-4-5	ERO-EXP-4-5-PeriT	ERO-EXP-4-5-BenTS	
		ERO-EXP-4-7	R			ERO-EXP-4-7-PeriT	ERO-EXP-4-7-BenTC	
		ERO-EXP-4-8	R			ERO-EXP-4-8-PeriT	ERO-EXP-4-8-BenTC	

Area	Description	Area-Site	Bank	Periphyton Community	Benthic Community	Periphyton Tissue	Benthic Tissue	Sculpin Tissue
		ERO-EXP-4-9	R			ERO-EXP-4-9-PeriT	ERO-EXP-4-9-BenTC	ERO-EXP-4-5-R
			L					ERO-EXP-4-5-L
ERO-EXP-5	Maglios downstream to Waneta	ERO-EXP-5-1	L	ERO-EXP-5-1A	ERO-EXP-5-1	ERO-EXP-5-1-PeriT	ERO-EXP-5-1-BenTS	
				ERO-EXP-5-1B				
				ERO-EXP-5-1C				
		ERO-EXP-5-2	R	ERO-EXP-5-2A	ERO-EXP-5-2	ERO-EXP-5-2-PeriT	ERO-EXP-5-2-BenTC	
				ERO-EXP-5-2B				
				ERO-EXP-5-2C				
		ERO-EXP-5-3	R	ERO-EXP-5-3A	ERO-EXP-5-3	ERO-EXP-5-3-PeriT	ERO-EXP-5-3-BenTComp	
				ERO-EXP-5-3B				
				ERO-EXP-5-3C				
		ERO-EXP-5-4	R	ERO-EXP-5-4A	ERO-EXP-5-4	ERO-EXP-5-4-PeriT	ERO-EXP-5-4-BenTS	
				ERO-EXP-5-4B				
				ERO-EXP-5-4C				
		ERO-EXP-5-5	R	ERO-EXP-5-5A	ERO-EXP-5-5	ERO-EXP-5-5-PeriT	ERO-EXP-5-5-BenTS	
				ERO-EXP-5-5B				
				ERO-EXP-5-5C				
		ERO-EXP-5-6	R			ERO-EXP-5-6-PeriT	ERO-EXP-5-6-BenTC	ERO-EXP-5

Appendix A. AEMP depositional habitat sampling areas and sites.

Area	Description	Area-Site	Bank	Periphyton Community	Benthic Community
DEP-REF-1	Kootenay Eddy	DEP-REF-1	R	DEP-REF- KE-1	DEP-REF-1-1
				DEP-REF- KE-2	DEP-REF-1-2
				DEP-REF- KE-3	DEP-REF-1-3
					DEP-REF-1-4
					DEP-REF-1-5
DEP-REF-2	Genelle	DEP-REF-2	R	DEP-REF- GE-1	DEP-REF-2-1
				DEP-REF- GE-2	DEP-REF-2-2
				DEP-REF- GE-3	DEP-REF-2-3
					DEP-REF-2-4
					DEP-REF-2-5
DEP-REF-3	Birchbank	DEP-REF-3	L	DEP-REF- BB-1	DEP-REF-3-1
				DEP-REF- BB-2	DEP-REF-3-2
				DEP-REF- BB-3	DEP-REF-3-3
					DEP-REF-3-4
					DEP-REF-3-5
DEP-EXP-1	Korpac	DEP-EXP-1	R	DEP-EXP- KO-1	DEP-EXP-1-1
				DEP-EXP- KO-2	DEP-EXP-1-2
				DEP-EXP- KO-3	DEP-EXP-1-3
					DEP-EXP-1-4
					DEP-EXP-1-5
DEP-EXP-2	Maglios	DEP-EXP-2	L	DEP-EXP- MG-1	DEP-EXP-2-1
				DEP-EXP- MG-2	DEP-EXP-2-2
				DEP-EXP- MG-3	DEP-EXP-2-3
					DEP-EXP-2-4
					DEP-EXP-2-5
DEP-EXP-3	Casino Eddy	DEP-EXP-3	R	DEP-EXP- C-1	DEP-EXP-3-1
				DEP-EXP- C-2	DEP-EXP-3-2
				DEP-EXP- C-3	DEP-EXP-3-3
					DEP-EXP-3-4
					DEP-EXP-3-5
DEP-EXP-4	Airport Bar	DEP-EXP-4	L	DEP-EXP-AB-1	DEP-EXP-4-1
				DEP-EXP-AB-2	DEP-EXP-4-2
				DEP-EXP-AB-3	DEP-EXP-4-3
					DEP-EXP-4-4
					DEP-EXP-4-5
DEP-EXP-5	Trimac	DEP-EXP-5	R	DEP-EXP- TR-1	DEP-EXP-5-1
				DEP-EXP- TR-2	DEP-EXP-5-2
				DEP-EXP- TR-3	DEP-EXP-5-3
					DEP-EXP-5-4
					DEP-EXP-5-5
DEP-EXP-6	Fort Shepherd	DEP-EXP-6	L	DEP-EXP- FS-1	DEP-EXP-6-1
				DEP-EXP- FS-2	DEP-EXP-6-2
				DEP-EXP- FS-3	DEP-EXP-6-3
					DEP-EXP-6-4
					DEP-EXP-6-5
DEP-EXP-7	Waneta	DEP-EXP-7	L	DEP-EXP- WA-1	DEP-EXP-7-1
				DEP-EXP- WA-2	DEP-EXP-7-2
				DEP-EXP- WA-3	DEP-EXP-7-3
					DEP-EXP-7-4
					DEP-EXP-7-5

APPENDIX B AEMP SAMPLE SITES PHYSICAL DATA

Erosional Area Physical Habitat Parameters.

label	Date	Time	Field_Crew	Weather	WaterTemp	River_Bank	Sub_Comp_Bedrock	Sub_Comp_Boulder	Sub_Comp_Large_Cobble	Sub_Comp_Small_Cobble	Sub_Comp_Large_Pebble	Sub_Comp_Small_Pebble	Sub_Comp_Gravel	Sub_Comp_Coarse_Sand	Sub_Comp_Fine_Sand	Sub_Comp_Organic
ero-exp-1-1	2018-10-01	905	KH;RP;CB;MAO	Overcast	13.00	Right	0.00	10.00	80.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00
ero-exp-1-2	2018-10-01	1000	KH;RP;CB;MAO	Partly Cloudy/Sunny	13.00	Right	0.00	60.00	30.00	0.00	5.00	0.00	0.00	0.00	5.00	0.00
ero-exp-1-3	2018-10-01	1045	KH;RP;CB;MAO	Partly Cloudy/Sunny	13.00	Right	0.00	70.00	25.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00
ero-exp-1-4	2018-10-01	1140	KH;RP;CB;MAO	Sunny	13.00	Right	0.00	30.00	63.00	0.00	8.00	0.00	2.00	0.00	0.00	0.00
ero-exp-1-5	2018-10-01		KH;RP;CB;MAO	Partly Cloudy/Sunny	13.00	Right	0.00	70.00	25.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00
ero-exp-2-1	2018-10-01	1400	KH;RP;CB;MAO	Overcast	14.00	Right	0.00	30.00	60.00	0.00	5.00	0.00	5.00	0.00	0.00	0.00
ero-exp-2-2	2018-10-01	1450	KH;RP;CB;MAO	Partly Cloudy	16.00	Right	0.00	5.00	60.00	0.00	25.00	0.00	10.00	0.00	0.00	0.00
ero-exp-2-3	2018-10-01	1525	KH;RP;CB;MAO	Overcast,Warm	16.00	Right	0.00	0.00	15.00	0.00	80.00	0.00	5.00	0.00	0.00	0.00
ero-exp-2-4	2018-10-01	1730	KH;RP;CB;MAO	Overcast	14.00	Left	0.00	10.00	75.00	0.00	10.00	0.00	5.00	0.00	0.00	0.00
ero-exp-2-5	2018-10-01	1640	KH;RP;CB;MAO	Overcast	15.00	Right	0.00	15.00	60.00	0.00	10.00	0.00	5.00	0.00	0.00	0.00
ero-exp-3-1	2018-10-02	915	KH;RP;CB;MAO	Overcast	13.00	Right	0.00	5.00	50.00	0.00	35.00	0.00	10.00	0.00	0.00	0.00

label	Date	Time	Field_Crew	Weather	WaterTemp	River_Bank	Sub_Comp_Bedrock	Sub_Comp_Boulder	Sub_Comp_Large_Cobble	Sub_Comp_Small_Cobble	Sub_Comp_Large_Pebble	Sub_Comp_Small_Pebble	Sub_Comp_Gravel	Sub_Comp_Coarse_Sand	Sub_Comp_Fine_Sand	Sub_Comp_Organic
ero-exp-3-2	2018-10-02	1000	KH;RP;CB;MAO	Overcast	13.00	Right	0.00	40.00	50.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00
ero-exp-3-3	2018-10-02	1055	KH;RP;CB;MAO	Overcast	13.00	Left	0.00	60.00	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ero-exp-3-4	2018-10-02	1159	KH;RP;CB;MAO	Overcast	13.00	Right	0.00	20.00	75.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00
ero-exp-3-5	2018-10-02	1254	KH;RP;CB;MAO	Overcast	12.00	Left	0.00	35.00	60.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00
ero-exp-4-1	2018-10-02	1400	KH;RP;CB;MAO	Overcast	12.00	Left	0.00	25.00	70.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00
ero-exp-4-2	2018-10-02	1440	KH;RP;CB;MAO	Partly Cloudy	12.00	Left	0.00	10.00	40.00	0.00	30.00	0.00	15.00	5.00	0.00	0.00
ero-exp-4-3	2018-10-02	1515	KH;RP;CB;MAO	Partly Cloudy	12.00	Left	0.00	10.00	50.00	0.00	20.00	0.00	10.00	10.00	0.00	0.00
ero-exp-4-4	2018-10-02	1606	KH;RP;CB;MAO	Partly Cloudy	12.00	Left	0.00	30.00	30.00	0.00	30.00	5.00	5.00	0.00	0.00	0.00
ero-exp-4-5	2018-10-02	1642	KH;RP;CB;MAO	Overcast	12.00	Right	0.00	40.00	30.00	0.00	30.00	0.00	0.00	0.00	0.00	0.00
ero-exp-5-1	2018-10-03	1000	KH;RP;CB;MAO	Sunny	13.00	Left	0.00	20.00	70.00	0.00	0.00	0.00	0.00	10.00	0.00	0.00
ero-exp-5-2	2018-10-03	1042	KH;RP;CB;MAO	Sunny	13.00	Right	0.00	30.00	30.00	0.00	30.00	0.00	10.00	0.00	0.00	0.00
ero-exp-5-3	2018-10-03	1152	KH;RP;CB;MAO	Partly Cloudy	13.00	Right	0.00	40.00	30.00	0.00	30.00	0.00	0.00	0.00	0.00	0.00

label	Date	Time	Field_Crew	Weather	WaterTemp	River_Bank	Sub_Comp_Bedrock	Sub_Comp_Boulder	Sub_Comp_Large_Cobble	Sub_Comp_Small_Cobble	Sub_Comp_Large_Pebble	Sub_Comp_Small_Pebble	Sub_Comp_Gravel	Sub_Comp_Coarse_Sand	Sub_Comp_Fine_Sand	Sub_Comp_Organic
ero-exp-5-4	2018-10-03	1255	KH;RP;CB;MAO	Partly Cloudy/Sun	13.00	Right	0.00	10.00	80.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00
ero-exp-5-5	2018-10-03	1346	KH;RP;CB;MAO	Overcast	13.00	Right	0.00	5.00	60.00	0.00	30.00	0.00	5.00	0.00	0.00	0.00
ero-ref-1-1	2018-09-30	1445	KH;RP;CB;MAO	Overcast	14.00	Left	0.00	40.00	50.00	0.00	3.00	0.00	0.00	0.00	7.00	0.00
ero-ref-1-2	2018-09-30	1600	KH;RP;CB;MAO	Overcast,Cold	14.00	Right	0.00	10.00	40.00	0.00	0.00	0.00	0.00	0.00	0.00	40.00
ero-ref-1-3	2018-09-30	1630	KH;RP;CB;MAO	Overcast/Breezy	14.00	Left	0.00	60.00	20.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00
ero-ref-1-4	2018-09-30	1726	KH;RP;CB;MAO	Overcast/Breezy	14.00	Left	0.00	30.00	65.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00
ero-ref-1-5	2018-09-30	1830	KH;RP;CB;MAO	Overcast/Breezy	14.00	Left	0.00	60.00	25.00	0.00	5.00	0.00	0.00	0.00	10.00	0.00
ero-ref-2-1	2018-09-30	1040	KH;RP;CB;MAO	Overcast	14.00	Right	0.00	10.00	80.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00
ero-ref-2-2	2018-09-30	1115	KH;RP;CB;MAO	Overcast,Cool	14.00	Right	0.00	10.00	80.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00
ero-ref-2-3	2018-09-30	1200	KH;RP;CB;MAO	Overcast	14.00	Left	0.00	5.00	0.00	30.00	60.00	5.00	0.00	0.00	0.00	0.00
ero-ref-2-4	2018-09-30	1300	KH;RP;CB;MAO	Overcast	14.00	Right	0.00	0.00	60.00	0.00	30.00	0.00	0.00	10.00	0.00	0.00
ero-ref-2-5	2018-09-30	1400	KH;RP;CB;MAO	Overcast	14.00	Right	0.00	0.00	50.00	0.00	20.00	0.00	10.00	0.00	20.00	0.00

Depositional Area Physical Habitat Parameters.

label	Date	Time	Field_Crew	Weather	WaterTemp	River_Bank	Sub_Comp_Bedrock	Sub_Comp_Boulder	Sub_Comp_Large_Cobble	Sub_Comp_Small_Cobble	Sub_Comp_Large_Pebble	Sub_Comp_Small_Pebble	Sub_Comp_Gravel	Sub_Comp_Coarse_Sand	Sub_Comp_Fine_Sand	Sub_Comp_Organic
dep-exp-1	2018-10-04	1530	KH;RP;CB;MAO	Overcast	13.00	Right	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.00	15.00	5.00
dep-exp-2	2018-10-04	1245	CB;MAO	Partly Cloudy	13.00	Right	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
dep-exp-3	2018-10-04	1045	KH;RP;CB;MAO	Overcast	10.00	Right	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.00	10.00
dep-exp-4	2018-10-04	1000	KH;RP;CB;MAO	Partly Cloudy	13.00	Left	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
dep-exp-5	2018-10-03	na	KH;RP;CB;MAO	Overcast	N/A	Right	25.00	0.00	25.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00
dep-exp-6	2018-10-03	1405	KH;RP;CB;MAO	Overcast	13.00	Left	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	80.00
dep-exp-7	2018-10-03	1452	KH;RP;CB;MAO	Overcast	13.00	Left	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.00	20.00
dep-ref-1	2018-09-29	1230	KH;RP;CB;MAO	Overcast,Windy	15.00	Right	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
dep-ref-2	2018-09-29	1545	KH;RP;CB;MAO	Overcast	14.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	75.00	25.00
dep-ref-3	2018-09-29	1710	KH;RP;CB;MAO	Overcast	14.00	Left	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00

APPENDIX C 2018 WATER QUALITY DATA

Water Quality 2018 R-Sh Samples.

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
17-Jul-18	Alkalinity..Total..as.CaCO3.	51.1	51.2	51	51.3	51.2	50.9
17-Jul-18	Aluminum	0.0194	0.0184	0.0203	0.0184	0.0179	0.0191
17-Jul-18	Aluminum..Al..Dissolved	0.0131	0.0126	0.0134	0.0118	0.0119	0.0128
17-Jul-18	Ammonia	0.0065	0.007	0.0101	0.0081	0.0089	0.0071
17-Jul-18	Antimony..Sb..Dissolved	0.000028	0.000056	0.000419	0.000111	0.00004	0.00006
17-Jul-18	Antimony..Sb..Total	0.000041	0.000074	0.000476	0.000128	0.000055	0.000077
17-Jul-18	Arsenic	0.000171	0.000172	0.000302	0.000186	0.000229	0.000176
17-Jul-18	Arsenic..As..Dissolved	0.000145	0.000164	0.000249	0.000182	0.000222	0.000167
17-Jul-18	Barium..Ba..Dissolved	0.0174	0.0166	0.0173	0.017	0.0164	0.0175
17-Jul-18	Barium..Ba..Total	0.0167	0.0168	0.0171	0.0167	0.0169	0.0165
17-Jul-18	Beryllium..Be..Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
17-Jul-18	Beryllium..Be..Total	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
17-Jul-18	Bismuth..Bi..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
17-Jul-18	Bismuth..Bi..Total	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
17-Jul-18	Boron..B..Dissolved	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
17-Jul-18	Boron..B..Total	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
17-Jul-18	Bromide..Br.	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
17-Jul-18	Cadmium	0.0000085	0.0000106	0.000117	0.0000232	0.0000078	0.0000109
17-Jul-18	Cadmium..Cd..Total	0.0000124	0.0000168	0.000128	0.0000251	0.0000147	0.0000157
17-Jul-18	Calcium..Ca..Dissolved	15.5	15.1	16.7	15.7	15.7	15.6
17-Jul-18	Calcium..Ca..Total	15.8	16	16.4	16.2	16.1	15.9

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
17-Jul-18	Chloride..Cl.	<0.50	<0.50	0.66	0.82	<0.50	<0.50
17-Jul-18	Chromium	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
17-Jul-18	Chromium..Cr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
17-Jul-18	Cobalt..Co..Dissolved	0.0000156	0.0000075	0.0000128	0.0000093	0.0000068	0.0000122
17-Jul-18	Cobalt..Co..Total	0.0000156	0.0000154	0.0000225	0.0000152	0.0000131	0.0000182
17-Jul-18	Conductivity	118	119	125	120	118	118
17-Jul-18	Copper	0.00034	0.00037	0.00049	0.00035	0.00032	0.0004
17-Jul-18	Copper..Cu..Dissolved	0.00031	0.00025	0.00037	0.00023	0.00025	0.00026
17-Jul-18	Fluoride..F.	0.062	0.063	0.089	0.067	0.064	0.065
17-Jul-18	Iron	0.0116	0.0104	0.011	0.0098	0.0114	0.0125
17-Jul-18	Iron..Fe..Dissolved	0.0105	0.0035	0.0043	0.0029	0.0034	0.0044
17-Jul-18	Lead	0.000045	0.000095	0.000396	0.000114	0.00005	0.000069
17-Jul-18	Lead..Pb..Dissolved	0.0000111	0.00002	0.000173	0.0000457	0.0000105	0.0000209
17-Jul-18	Lithium..Li..Dissolved	0.00095	0.00092	0.00097	0.00095	0.00094	0.00094
17-Jul-18	Lithium..Li..Total	0.00096	0.00096	0.00099	0.00096	0.00096	0.00095
17-Jul-18	Magnesium..Mg..Dissolved	3.35	3.26	3.41	3.35	3.28	3.35
17-Jul-18	Magnesium..Mg..Total	3.51	3.48	3.55	3.41	3.44	3.47
17-Jul-18	Manganese..Mn..Dissolved	0.000457	0.000326	0.00127	0.000523	0.000279	0.000325
17-Jul-18	Manganese..Mn..Total	0.00172	0.00177	0.00279	0.00183	0.00164	0.00171
17-Jul-18	Mercury	<0.00050	<0.00050	0.00078	<0.00050	<0.00050	<0.00050
17-Jul-18	Mercury..Hg..Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
17-Jul-18	Molybdenum..Mo..Dissolved	0.000499	0.000474	0.000527	0.000512	0.000513	0.000478
17-Jul-18	Molybdenum..Mo..Total	0.000487	0.000475	0.000543	0.000496	0.000482	0.000494
17-Jul-18	Nickel	0.000348	0.000392	0.000362	0.000353	0.000349	0.0004

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
17-Jul-18	Nickel..Ni..Dissolved	0.000588	0.000357	0.000343	0.00032	0.000329	0.000377
17-Jul-18	Nitrate	0.0448	0.0546	0.102	0.0638	0.0519	0.0537
17-Jul-18	Nitrite	<0.0010	0.0012	0.0018	0.0012	0.0011	0.0013
17-Jul-18	Organic.Carbon	1.68	1.65	1.48	1.68	1.63	1.66
17-Jul-18	Phosphorus	0.0039	0.0051	0.0049	0.0041	0.0038	0.0045
17-Jul-18	Phosphorus..P..Dissolved	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
17-Jul-18	Phosphorus..P..Total..Dissolved	0.0021	<0.0020	<0.0020	0.0021	0.002	0.0021
17-Jul-18	Phosphorus..P..Total.1	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
17-Jul-18	Potassium	0.568	0.576	0.593	0.562	0.559	0.579
17-Jul-18	Potassium..K..Dissolved	0.571	0.575	0.602	0.57	0.555	0.583
17-Jul-18	Selenium	0.000152	0.000179	0.000759	0.000301	0.000174	0.000213
17-Jul-18	Selenium..Se..Dissolved	0.000161	0.000151	0.000637	0.000261	0.000142	0.000181
17-Jul-18	Silicon..Si..Dissolved	1.55	1.56	1.53	1.53	1.57	1.56
17-Jul-18	Silicon..Si..Total	1.76	1.67	1.68	1.7	1.7	1.7
17-Jul-18	Silver	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
17-Jul-18	Silver..Ag..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
17-Jul-18	Sodium..Na..Dissolved	1.1	1.11	1.95	1.29	1.08	1.13
17-Jul-18	Sodium..Na..Total	1.08	1.11	1.85	1.22	1.06	1.12
17-Jul-18	Strontium..Sr..Dissolved	0.11	0.112	0.106	0.111	0.107	0.11
17-Jul-18	Strontium..Sr..Total	0.108	0.111	0.111	0.11	0.11	0.111
17-Jul-18	Sulfate	9.42	9.68	11.7	10	9.59	9.74
17-Jul-18	Thallium	0.0000045	0.0000113	0.000196	0.0000449	0.0000032	0.0000178

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
17-Jul-18	Thallium..Tl..Dissolved	0.0000024	0.0000102	0.000207	0.000044	0.0000025	0.0000162
17-Jul-18	Tin..Sn..Dissolved	0.000101	<0.000010	0.000018	<0.000010	0.000041	0.000028
17-Jul-18	Tin..Sn..Total	0.000039	<0.000020	<0.000020	<0.000020	0.000043	0.000022
17-Jul-18	Titanium..Ti..Dissolved	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
17-Jul-18	Titanium..Ti..Total	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
17-Jul-18	Total.Dissolved.Solids	72	69	76	72	70	76
17-Jul-18	Total.Kjeldahl.Nitrogen	0.123	0.105	0.083	0.105	0.104	0.112
17-Jul-18	Total.Suspended.Solids	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
17-Jul-18	Turbidity	0.84	0.73	1.12	0.71	0.86	0.78
17-Jul-18	Uranium..U..Dissolved	0.000433	0.00043	0.000438	0.000428	0.00042	0.00043
17-Jul-18	Uranium..U..Total	0.000397	0.000417	0.000415	0.000419	0.00041	0.000417
17-Jul-18	Vanadium..V..Dissolved	0.000137	0.000135	0.000145	0.000135	0.00013	0.00014
17-Jul-18	Vanadium..V..Total	0.000147	0.00015	0.000161	0.000156	0.000151	0.000159
17-Jul-18	Zinc	0.00359	0.00128	0.00316	0.00137	0.00127	0.00142
17-Jul-18	Zinc..Zn..Dissolved	0.0023	0.0017	0.0159	0.0028	0.001	0.001
17-Jul-18	Zirconium..Zr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
17-Jul-18	Zirconium..Zr..Total	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
18-Apr-18	Alkalinity..Total..as.CaCO3.						
18-Apr-18	Aluminum	0.0206	0.0243	0.0255	0.0271	0.0279	0.0258
18-Apr-18	Aluminum..Al..Dissolved	0.00883	0.0095	0.00866	0.00924	0.0102	0.0106
18-Apr-18	Ammonia	<0.0050	0.0087	0.0197	0.0098	0.01	0.0096
18-Apr-18	Antimony..Sb..Dissolved	0.000055	0.000125	0.000872	0.000203	0.000105	0.000127
18-Apr-18	Antimony..Sb..Total	0.000062	0.000121	0.000885	0.000224	0.00011	0.000128
18-Apr-18	Arsenic	0.000267	0.000305	0.000505	0.000382	0.000637	0.000313

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
18-Apr-18	Arsenic..As..Dissolved	0.00027	0.000279	0.000416	0.000322	0.000572	0.000286
18-Apr-18	Barium..Ba..Dissolved	0.0227	0.023	0.0225	0.0225	0.0227	0.0231
18-Apr-18	Barium..Ba..Total	0.0225	0.0224	0.0227	0.0229	0.0237	0.022
18-Apr-18	Beryllium..Be..Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
18-Apr-18	Beryllium..Be..Total	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
18-Apr-18	Bismuth..Bi..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
18-Apr-18	Bismuth..Bi..Total	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
18-Apr-18	Boron..B..Dissolved	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
18-Apr-18	Boron..B..Total	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
18-Apr-18	Bromide..Br.	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
18-Apr-18	Cadmium	0.0000077	0.0000265	0.000313	0.0000657	0.0000481	0.0000254
18-Apr-18	Cadmium..Cd..Total	0.0000137	0.0000319	0.000334	0.0000777	0.000056	0.0000324
18-Apr-18	Calcium..Ca..Dissolved	20.3	19.9	22	20.1	20	20.7
18-Apr-18	Calcium..Ca..Total	19.8	19.9	22	20.2	19.4	19.8
18-Apr-18	Chloride..Cl.	1.04	1.12	1.91	1.26	1.2	1.15
18-Apr-18	Chromium	<0.00010	<0.00010	0.0001	0.0001	0.00011	<0.00010
18-Apr-18	Chromium..Cr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
18-Apr-18	Cobalt..Co..Dissolved	0.0000093	0.0000112	0.000024	0.0000129	0.000011	0.0000124
18-Apr-18	Cobalt..Co..Total	0.000019	0.0000231	0.0000367	0.0000282	0.0000236	0.000022
18-Apr-18	Conductivity						
18-Apr-18	Copper	0.00036	0.00045	0.00106	0.00062	0.00042	0.00054
18-Apr-18	Copper..Cu..Dissolved	0.00036	0.00044	0.00091	0.00051	0.00038	0.00048
18-Apr-18	Fluoride..F.	0.074	0.077	0.153	0.085	0.075	0.079

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
18-Apr-18	Iron	0.0244	0.028	0.0285	0.0311	0.029	0.0313
18-Apr-18	Iron..Fe..Dissolved	0.0064	0.0127	0.0056	0.0062	0.0071	0.0081
18-Apr-18	Lead	0.000071	0.000115	0.000678	0.000186	0.000115	0.000162
18-Apr-18	Lead..Pb..Dissolved	0.0000173	0.0000338	0.000356	0.0000561	0.0000369	0.0000453
18-Apr-18	Lithium..Li..Dissolved	0.00129	0.00125	0.00137	0.00126	0.00125	0.00126
18-Apr-18	Lithium..Li..Total	0.00127	0.00128	0.00138	0.00129	0.00127	0.00125
18-Apr-18	Magnesium..Mg..Dissolved	4.75	4.72	4.63	4.51	4.64	4.75
18-Apr-18	Magnesium..Mg..Total	4.61	4.64	4.76	4.85	4.83	4.61
18-Apr-18	Manganese..Mn..Dissolved	0.00128	0.00169	0.00422	0.0019	0.00154	0.00171
18-Apr-18	Manganese..Mn..Total	0.00242	0.00291	0.0058	0.00354	0.00276	0.00314
18-Apr-18	Mercury	<0.00050	<0.00050	0.00129	0.00139	0.00056	0.00057
18-Apr-18	Mercury..Hg..Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
18-Apr-18	Molybdenum..Mo..Dissolved	0.000569	0.000582	0.000745	0.000602	0.000586	0.00061
18-Apr-18	Molybdenum..Mo..Total	0.000555	0.000552	0.00072	0.000573	0.000555	0.000569
18-Apr-18	Nickel	0.000311	0.000321	0.000372	0.000408	0.000362	0.000324
18-Apr-18	Nickel..Ni..Dissolved	0.000289	0.000296	0.000305	0.000282	0.000294	0.000329
18-Apr-18	Nitrate	0.131	0.141	0.245	0.152	0.131	0.146
18-Apr-18	Nitrite	<0.0010	<0.0010	<0.0010	0.0029	<0.0010	<0.0010
18-Apr-18	Organic.Carbon	1.78	1.71	1.65	1.87	1.94	2.27
18-Apr-18	Phosphorus	0.0038	0.0049	0.0049	0.005	0.005	0.0053
18-Apr-18	Phosphorus..P..Dissolved	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
18-Apr-18	Phosphorus..P..Total..Dissolved	0.0032	0.0024	0.0028	0.0029	0.0032	0.0031
18-Apr-18	Phosphorus..P..Total.1	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
18-Apr-18	Potassium	0.672	0.683	0.773	0.76	0.733	0.717
18-Apr-18	Potassium..K..Dissolved	0.673	0.694	0.769	0.708	0.708	0.737
18-Apr-18	Selenium	0.00031	0.000381	0.00235	0.000634	0.000241	0.000367
18-Apr-18	Selenium..Se..Dissolved	0.000343	0.000347	0.00231	0.000531	0.000297	0.000333
18-Apr-18	Silicon..Si..Dissolved	2.43	2.47	2.47	2.5	2.62	2.51
18-Apr-18	Silicon..Si..Total	2.33	2.4	2.47	2.59	2.64	2.51
18-Apr-18	Silver	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
18-Apr-18	Silver..Ag..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
18-Apr-18	Sodium..Na..Dissolved	1.92	2.03	4.06	2.23	1.97	2.07
18-Apr-18	Sodium..Na..Total	1.85	1.97	4.08	2.29	2	1.96
18-Apr-18	Strontium..Sr..Dissolved	0.115	0.119	0.117	0.118	0.117	0.117
18-Apr-18	Strontium..Sr..Total	0.117	0.115	0.121	0.119	0.117	0.116
18-Apr-18	Sulfate	12	12.5	19.4	13.5	12	12.3
18-Apr-18	Thallium	0.000004	0.0000474	0.00103	0.000152	0.000003	0.0000423
18-Apr-18	Thallium..Tl..Dissolved	0.0000036	0.0000514	0.0011	0.000154	0.0000035	0.0000452
18-Apr-18	Tin..Sn..Dissolved	0.00001	<0.000010	0.00001	<0.000010	<0.000010	0.000016
18-Apr-18	Tin..Sn..Total	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
18-Apr-18	Titanium..Ti..Dissolved	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
18-Apr-18	Titanium..Ti..Total	0.0009	0.00103	0.00093	0.00122	0.00107	<0.0015
18-Apr-18	Total.Dissolved.Solids						
18-Apr-18	Total.Kjeldahl.Nitrogen	0.071	0.102	0.113	0.105	0.086	0.088
18-Apr-18	Total.Suspended.Solids						
18-Apr-18	Turbidity	0.63	0.79	1.39	0.81	0.65	1.24

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
18-Apr-18	Uranium..U..Dissolved	0.000565	0.000574	0.000588	0.000566	0.000565	0.000571
18-Apr-18	Uranium..U..Total	0.000565	0.000561	0.00057	0.000566	0.000548	0.000542
18-Apr-18	Vanadium..V..Dissolved	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015
18-Apr-18	Vanadium..V..Total	0.000225	0.00022	0.00023	0.000287	0.000257	0.000216
18-Apr-18	Zinc	0.00128	0.00187	0.00778	0.00597	0.00362	0.00376
18-Apr-18	Zinc..Zn..Dissolved	0.0011	0.0018	0.0062	0.0029	0.0032	0.0034
18-Apr-18	Zirconium..Zr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
18-Apr-18	Zirconium..Zr..Total	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
19-Apr-18	Alkalinity..Total..as.CaCO3.						
19-Apr-18	Aluminum	0.0198	0.0205	0.0227	0.0214	0.0224	0.0254
19-Apr-18	Aluminum..Al..Dissolved	0.00775	0.0083	0.00836	0.00812	0.00951	0.00814
19-Apr-18	Ammonia	<0.0050	0.008	0.021	0.0129	0.0105	0.008
19-Apr-18	Antimony..Sb..Dissolved	0.000057	0.00012	0.000645	0.000167	0.000099	0.000129
19-Apr-18	Antimony..Sb..Total	0.000059	0.000114	0.000701	0.000169	0.000115	0.000141
19-Apr-18	Arsenic	0.000268	0.000277	0.000572	0.000338	0.000605	0.000292
19-Apr-18	Arsenic..As..Dissolved	0.000249	0.000279	0.000441	0.000323	0.00059	0.000275
19-Apr-18	Barium..Ba..Dissolved	0.023	0.0235	0.0235	0.023	0.0225	0.0227
19-Apr-18	Barium..Ba..Total	0.0218	0.0219	0.0238	0.0223	0.022	0.0232
19-Apr-18	Beryllium..Be..Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
19-Apr-18	Beryllium..Be..Total	<0.000010	<0.000010	<0.000010	<0.000010	0.000015	<0.000010
19-Apr-18	Bismuth..Bi..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
19-Apr-18	Bismuth..Bi..Total	<0.0000050	<0.0000050	0.0000077	<0.0000050	<0.0000050	<0.0000050
19-Apr-18	Boron..B..Dissolved	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
19-Apr-18	Boron..B..Total	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
19-Apr-18	Bromide..Br.	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
19-Apr-18	Cadmium	0.0000146	0.0000247	0.000261	0.0000584	0.000047	0.0000266
19-Apr-18	Cadmium..Cd..Total	0.0000144	0.0000289	0.000301	0.0000686	0.0000426	0.0000302
19-Apr-18	Calcium..Ca..Dissolved	20.8	20.7	21.5	20.5	20	20
19-Apr-18	Calcium..Ca..Total	19.6	19.4	21.2	19.9	19	19.9
19-Apr-18	Chloride..Cl.	1.03	1.1	1.63	1.19	1.14	1.15
19-Apr-18	Chromium	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	0.0001
19-Apr-18	Chromium..Cr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
19-Apr-18	Cobalt..Co..Dissolved	0.0000109	0.0000116	0.0000229	0.0000147	0.0000089	0.0000089
19-Apr-18	Cobalt..Co..Total	0.0000149	0.0000191	0.0000386	0.0000242	0.0000189	0.0000232
19-Apr-18	Conductivity						
19-Apr-18	Copper	0.00033	0.00045	0.00077	0.00054	0.00038	0.0005
19-Apr-18	Copper..Cu..Dissolved	0.00036	0.0004	0.00062	0.00048	0.00036	0.00044
19-Apr-18	Fluoride..F.	0.073	0.075	0.132	0.08	0.074	0.074
19-Apr-18	Iron	0.0216	0.024	0.0257	0.0246	0.026	0.0294
19-Apr-18	Iron..Fe..Dissolved	0.0063	0.0063	0.0054	0.0062	0.0066	0.0067
19-Apr-18	Lead	0.000087	0.000134	0.00172	0.000281	0.000124	0.000139
19-Apr-18	Lead..Pb..Dissolved	0.0000237	0.0000372	0.000481	0.0000725	0.0000383	0.0000364
19-Apr-18	Lithium..Li..Dissolved	0.00129	0.00129	0.00135	0.00128	0.00125	0.00122
19-Apr-18	Lithium..Li..Total	0.00126	0.0013	0.00137	0.00129	0.00126	0.00128
19-Apr-18	Magnesium..Mg..Dissolved	5.05	4.88	4.92	4.73	4.74	4.6
19-Apr-18	Magnesium..Mg..Total	4.65	4.63	5.03	4.64	4.49	4.87
19-Apr-18	Manganese..Mn..Dissolved	0.00136	0.00172	0.00523	0.00209	0.00138	0.00179

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
19-Apr-18	Manganese..Mn..Total	0.00221	0.00265	0.00674	0.00327	0.00241	0.00318
19-Apr-18	Mercury	<0.00050	0.00055	0.00353	0.0008	0.00056	0.00051
19-Apr-18	Mercury..Hg..Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
19-Apr-18	Molybdenum..Mo..Dissolved	0.000548	0.000601	0.000691	0.000574	0.000569	0.000575
19-Apr-18	Molybdenum..Mo..Total	0.000549	0.000515	0.000628	0.000571	0.00056	0.00055
19-Apr-18	Nickel	0.000341	0.000345	0.000388	0.000334	0.000307	0.000558
19-Apr-18	Nickel..Ni..Dissolved	0.000341	0.000289	0.000331	0.000317	0.000308	0.000286
19-Apr-18	Nitrate	0.138	0.143	0.279	0.16	0.137	0.143
19-Apr-18	Nitrite	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
19-Apr-18	Organic.Carbon	1.68	1.57	1.82	1.7	1.76	1.72
19-Apr-18	Phosphorus	0.0043	0.0045	0.0045	0.0046	0.0043	0.0185
19-Apr-18	Phosphorus..P..Dissolved	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
19-Apr-18	Phosphorus..P..Total..Dissolved	0.0035	0.0026	0.003	0.0026	0.0035	0.0032
19-Apr-18	Phosphorus..P..Total.1	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
19-Apr-18	Potassium	0.671	0.674	0.771	0.712	0.699	0.737
19-Apr-18	Potassium..K..Dissolved	0.694	0.701	0.746	0.715	0.69	0.695
19-Apr-18	Selenium	0.000291	0.000311	0.00206	0.00051	0.000296	0.000415
19-Apr-18	Selenium..Se..Dissolved	0.000267	0.000374	0.00196	0.000403	0.000235	0.000377
19-Apr-18	Silicon..Si..Dissolved	2.29	2.48	2.51	2.54	2.47	2.52
19-Apr-18	Silicon..Si..Total	2.32	2.36	2.53	2.46	2.41	2.52
19-Apr-18	Silver	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
19-Apr-18	Silver..Ag..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
19-Apr-18	Sodium..Na..Dissolved	1.87	2.04	3.71	2.21	1.91	2.04
19-Apr-18	Sodium..Na..Total	1.83	1.93	3.75	2.16	1.91	2.12
19-Apr-18	Strontium..Sr..Dissolved	0.119	0.116	0.115	0.116	0.115	0.116
19-Apr-18	Strontium..Sr..Total	0.116	0.116	0.12	0.116	0.114	0.117
19-Apr-18	Sulfate	12	12.4	17.5	12.7	12.1	12.4
19-Apr-18	Thallium	0.0000063	0.0000437	0.00108	0.000122	0.0000045	0.0000418
19-Apr-18	Thallium..Tl..Dissolved	0.0000045	0.0000489	0.00112	0.000127	0.0000025	0.0000406
19-Apr-18	Tin..Sn..Dissolved	0.000015	<0.000010	<0.000010	0.000018	<0.000010	<0.000010
19-Apr-18	Tin..Sn..Total	0.000078	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
19-Apr-18	Titanium..Ti..Dissolved	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
19-Apr-18	Titanium..Ti..Total	0.00081	<0.0010	0.00089	0.00079	0.00093	0.00105
19-Apr-18	Total.Dissolved.Solids						
19-Apr-18	Total.Kjeldahl.Nitrogen	0.052	0.08	0.111	0.095	0.073	0.068
19-Apr-18	Total.Suspended.Solids						
19-Apr-18	Turbidity	0.53	0.64	0.57	0.57	0.62	0.63
19-Apr-18	Uranium..U..Dissolved	0.000589	0.000594	0.000583	0.000575	0.000572	0.000575
19-Apr-18	Uranium..U..Total	0.000559	0.000565	0.000563	0.000557	0.000538	0.000571
19-Apr-18	Vanadium..V..Dissolved	0.000214	<0.00015	<0.00015	<0.00015	0.000211	<0.00030
19-Apr-18	Vanadium..V..Total	0.000175	0.000211	0.000205	0.0002	0.000192	0.000228
19-Apr-18	Zinc	0.0014	0.00202	0.00754	0.00338	0.00311	0.00258
19-Apr-18	Zinc..Zn..Dissolved	<0.0010	0.0017	0.0055	0.0031	0.0025	0.0019
19-Apr-18	Zirconium..Zr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
19-Apr-18	Zirconium..Zr..Total	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
21-Mar-18	Alkalinity..Total..as.CaCO3.						

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
21-Mar-18	Aluminum	0.01					
21-Mar-18	Aluminum..Al..Dissolved	0.00475					
21-Mar-18	Ammonia	<0.0050					
21-Mar-18	Antimony..Sb..Dissolved	0.000036					
21-Mar-18	Antimony..Sb..Total	0.000035					
21-Mar-18	Arsenic	0.000204					
21-Mar-18	Arsenic..As..Dissolved	0.000228					
21-Mar-18	Barium..Ba..Dissolved	0.0209					
21-Mar-18	Barium..Ba..Total	0.0202					
21-Mar-18	Beryllium..Be..Dissolved	<0.000010					
21-Mar-18	Beryllium..Be..Total	<0.000010					
21-Mar-18	Bismuth..Bi..Dissolved	<0.0000050					
21-Mar-18	Bismuth..Bi..Total	<0.0000050					
21-Mar-18	Boron..B..Dissolved	<0.010					
21-Mar-18	Boron..B..Total	<0.0050					
21-Mar-18	Bromide..Br.	<0.050					
21-Mar-18	Cadmium	0.000006					
21-Mar-18	Cadmium..Cd..Total	0.0000071					
21-Mar-18	Calcium..Ca..Dissolved	20.6					
21-Mar-18	Calcium..Ca..Total	22.2					
21-Mar-18	Chloride..Cl.	0.79					
21-Mar-18	Chromium	<0.00010					
21-Mar-18	Chromium..Cr..Dissolved	<0.00010					

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
21-Mar-18	Cobalt..Co..Dissolved	<0.0000050					
21-Mar-18	Cobalt..Co..Total	0.0000131					
21-Mar-18	Conductivity						
21-Mar-18	Copper	0.00027					
21-Mar-18	Copper..Cu..Dissolved	0.00027					
21-Mar-18	Fluoride..F.	0.061					
21-Mar-18	Iron	0.008					
21-Mar-18	Iron..Fe..Dissolved	0.003					
21-Mar-18	Lead	0.000043					
21-Mar-18	Lead..Pb..Dissolved	0.0000061					
21-Mar-18	Lithium..Li..Dissolved	0.00109					
21-Mar-18	Lithium..Li..Total	0.00123					
21-Mar-18	Magnesium..Mg..Dissolved	4.82					
21-Mar-18	Magnesium..Mg..Total	5.11					
21-Mar-18	Manganese..Mn..Dissolved	0.000739					
21-Mar-18	Manganese..Mn..Total	0.00138					
21-Mar-18	Mercury	<0.00050					
21-Mar-18	Mercury..Hg..Dissolved	<0.00050					
21-Mar-18	Molybdenum..Mo..Dissolved	0.000514					
21-Mar-18	Molybdenum..Mo..Total	0.000544					
21-Mar-18	Nickel	0.000385					
21-Mar-18	Nickel..Ni..Dissolved	0.000357					
21-Mar-18	Nitrate	0.148					

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
21-Mar-18	Nitrite	<0.0010					
21-Mar-18	Organic.Carbon	1.18					
21-Mar-18	Phosphorus	0.0041					
21-Mar-18	Phosphorus..P..Dissolved	<0.050					
21-Mar-18	Phosphorus..P..Total..Dissolved	<0.0020					
21-Mar-18	Phosphorus..P..Total.1	<0.050					
21-Mar-18	Potassium	0.633					
21-Mar-18	Potassium..K..Dissolved	0.657					
21-Mar-18	Selenium	0.000221					
21-Mar-18	Selenium..Se..Dissolved	0.000251					
21-Mar-18	Silicon..Si..Dissolved	2.02					
21-Mar-18	Silicon..Si..Total	2.04					
21-Mar-18	Silver	<0.0000050					
21-Mar-18	Silver..Ag..Dissolved	<0.0000050					
21-Mar-18	Sodium..Na..Dissolved	1.69					
21-Mar-18	Sodium..Na..Total	1.59					
21-Mar-18	Strontium..Sr..Dissolved	0.127					
21-Mar-18	Strontium..Sr..Total	0.131					
21-Mar-18	Sulfate	12.7					
21-Mar-18	Thallium	0.0000028					
21-Mar-18	Thallium..Tl..Dissolved	<0.0000020					
21-Mar-18	Tin..Sn..Dissolved	0.000015					

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
21-Mar-18	Tin..Sn..Total	0.000041					
21-Mar-18	Titanium..Ti..Dissolved	<0.00030					
21-Mar-18	Titanium..Ti..Total	<0.00050					
21-Mar-18	Total.Dissolved.Solids						
21-Mar-18	Total.Kjeldahl.Nitrogen	<0.050					
21-Mar-18	Total.Suspended.Solids						
21-Mar-18	Turbidity	0.27					
21-Mar-18	Uranium..U..Dissolved	0.000515					
21-Mar-18	Uranium..U..Total	0.000508					
21-Mar-18	Vanadium..V..Dissolved	0.000091					
21-Mar-18	Vanadium..V..Total	0.000087					
21-Mar-18	Zinc	0.00127					
21-Mar-18	Zinc..Zn..Dissolved	0.0011					
21-Mar-18	Zirconium..Zr..Dissolved	<0.00010					
21-Mar-18	Zirconium..Zr..Total	<0.00010					
22-Mar-18	Alkalinity..Total..as.CaCO3.						
22-Mar-18	Aluminum		0.0129	0.0114	0.015	0.0117	0.0118
22-Mar-18	Aluminum..Al..Dissolved		0.00441	0.00499	0.00452	0.00483	0.00448
22-Mar-18	Ammonia		0.0052	0.0108	0.0071	0.0054	0.0052
22-Mar-18	Antimony..Sb..Dissolved		0.000062	0.000499	0.000104	0.000073	0.000061
22-Mar-18	Antimony..Sb..Total		0.000064	0.000508	0.000115	0.000096	0.000079
22-Mar-18	Arsenic		0.000242	0.000346	0.000247	0.000585	0.000233
22-Mar-18	Arsenic..As..Dissolved		0.000218	0.000329	0.000267	0.000526	0.000227

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
22-Mar-18	Barium..Ba..Dissolved		0.0219	0.0217	0.0213	0.0212	0.0218
22-Mar-18	Barium..Ba..Total		0.0207	0.0209	0.0199	0.0213	0.0194
22-Mar-18	Beryllium..Be..Dissolved		<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
22-Mar-18	Beryllium..Be..Total		<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
22-Mar-18	Bismuth..Bi..Dissolved		<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
22-Mar-18	Bismuth..Bi..Total		<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
22-Mar-18	Boron..B..Dissolved		<0.010	<0.010	<0.010	<0.010	<0.010
22-Mar-18	Boron..B..Total		<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
22-Mar-18	Bromide..Br.		<0.050	<0.050	<0.050	<0.050	<0.050
22-Mar-18	Cadmium		0.0000181	0.000345	0.0000456	0.0000496	0.0000257
22-Mar-18	Cadmium..Cd..Total		0.0000205	0.000339	0.0000479	0.0000516	0.0000234
22-Mar-18	Calcium..Ca..Dissolved		20.1	21.6	20.6	20.8	19.6
22-Mar-18	Calcium..Ca..Total		22.3	23.6	21.8	22.1	21.8
22-Mar-18	Chloride..Cl.		0.92	1.3	1.01	0.9	0.93
22-Mar-18	Chromium		<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
22-Mar-18	Chromium..Cr..Dissolved		<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
22-Mar-18	Cobalt..Co..Dissolved		<0.0000050	0.0000102	0.000007	0.0000051	<0.0000050
22-Mar-18	Cobalt..Co..Total		0.0000124	0.0000198	0.0000186	0.0000165	0.0000142
22-Mar-18	Conductivity						
22-Mar-18	Copper		0.00033	0.00078	0.00037	0.00028	0.00036
22-Mar-18	Copper..Cu..Dissolved		0.00024	0.00073	0.00029	0.00024	0.00027
22-Mar-18	Fluoride..F.		0.068	0.117	0.073	0.063	0.068

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
22-Mar-18	Iron		0.012	0.0107	0.0147	0.0118	0.012
22-Mar-18	Iron..Fe..Dissolved		0.0017	0.0021	0.0022	0.0023	0.0021
22-Mar-18	Lead		0.000087	0.000689	0.000228	0.000287	0.000338
22-Mar-18	Lead..Pb..Dissolved		0.0000157	0.000359	0.0000508	0.0000239	0.0000682
22-Mar-18	Lithium..Li..Dissolved		0.0012	0.0013	0.00119	0.00119	0.00103
22-Mar-18	Lithium..Li..Total		0.00117	0.00148	0.00123	0.00126	0.00125
22-Mar-18	Magnesium..Mg..Dissolved		4.83	4.95	4.74	4.89	4.75
22-Mar-18	Magnesium..Mg..Total		5.02	5.02	4.94	4.95	4.58
22-Mar-18	Manganese..Mn..Dissolved		0.000767	0.00228	0.000907	0.000834	0.000812
22-Mar-18	Manganese..Mn..Total		0.00162	0.0033	0.00199	0.00192	0.0016
22-Mar-18	Mercury		<0.00050	0.00106	<0.00050	<0.00050	<0.00050
22-Mar-18	Mercury..Hg..Dissolved		<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
22-Mar-18	Molybdenum..Mo..Dissolved		0.000521	0.00059	0.000519	0.000543	0.000507
22-Mar-18	Molybdenum..Mo..Total		0.000526	0.000576	0.00054	0.000562	0.000541
22-Mar-18	Nickel		0.000358	0.000374	0.000358	0.00034	0.000353
22-Mar-18	Nickel..Ni..Dissolved		0.000293	0.000329	0.000311	0.000281	0.000309
22-Mar-18	Nitrate		0.157	0.255	0.166	0.154	0.156
22-Mar-18	Nitrite		<0.0010	0.0014	<0.0010	<0.0010	<0.0010
22-Mar-18	Organic.Carbon		1.17	1.21	1.05	1.21	1.21
22-Mar-18	Phosphorus		0.0039	0.0047	0.0043	0.004	0.0039
22-Mar-18	Phosphorus..P..Dissolved		<0.050	<0.050	<0.050	<0.050	<0.050
22-Mar-18	Phosphorus..P..Total..Dissolved		<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
22-Mar-18	Phosphorus..P..Total.1		<0.050	<0.050	<0.050	<0.050	<0.050

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
22-Mar-18	Potassium		0.647	0.688	0.636	0.641	0.609
22-Mar-18	Potassium..K..Dissolved		0.645	0.714	0.67	0.66	0.657
22-Mar-18	Selenium		0.000287	0.00172	0.000434	0.000237	0.000303
22-Mar-18	Selenium..Se..Dissolved		0.000311	0.00162	0.00038	0.000236	0.000287
22-Mar-18	Silicon..Si..Dissolved		2.01	2.07	2.03	2.09	2.05
22-Mar-18	Silicon..Si..Total		1.99	2.01	2.04	2.05	2.01
22-Mar-18	Silver		<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
22-Mar-18	Silver..Ag..Dissolved		<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
22-Mar-18	Sodium..Na..Dissolved		1.71	3.13	1.87	1.7	1.65
22-Mar-18	Sodium..Na..Total		1.7	3.04	1.78	1.65	1.58
22-Mar-18	Strontium..Sr..Dissolved		0.12	0.129	0.122	0.12	0.118
22-Mar-18	Strontium..Sr..Total		0.127	0.131	0.125	0.127	0.127
22-Mar-18	Sulfate		13	18.1	13.5	12.9	13
22-Mar-18	Thallium		0.0000054	0.0000578	0.0000116	0.0000036	0.0000056
22-Mar-18	Thallium..Tl..Dissolved		0.0000047	0.0000591	0.0000109	<0.0000020	0.0000043
22-Mar-18	Tin..Sn..Dissolved		<0.000010	<0.000010	<0.000010	0.000017	0.000026
22-Mar-18	Tin..Sn..Total		<0.000020	<0.000020	<0.000020	0.000038	0.000042
22-Mar-18	Titanium..Ti..Dissolved		<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
22-Mar-18	Titanium..Ti..Total		<0.00050	<0.00050	0.00068	<0.00050	<0.00050
22-Mar-18	Total.Dissolved.Solids						
22-Mar-18	Total.Kjeldahl.Nitrogen		<0.050	0.063	0.067	0.059	0.064
22-Mar-18	Total.Suspended.Solids						

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
22-Mar-18	Turbidity		0.33	0.3	0.43	0.34	0.4
22-Mar-18	Uranium..U..Dissolved		0.00051	0.000545	0.000504	0.000516	0.000511
22-Mar-18	Uranium..U..Total		0.000528	0.000515	0.000512	0.000527	0.000501
22-Mar-18	Vanadium..V..Dissolved		0.000085	0.000091	0.000107	0.000099	0.00009
22-Mar-18	Vanadium..V..Total		0.000103	0.00012	0.000105	0.000102	0.000092
22-Mar-18	Zinc		0.00133	0.00601	0.0021	0.00359	0.00313
22-Mar-18	Zinc..Zn..Dissolved		0.0011	0.0055	0.0018	0.003	0.0031
22-Mar-18	Zirconium..Zr..Dissolved		<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
22-Mar-18	Zirconium..Zr..Total		<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
4-Apr-18	Alkalinity..Total..as.CaCO3.						
4-Apr-18	Aluminum	0.00814	0.00843	0.00991	0.00879	0.00855	0.00804
4-Apr-18	Aluminum..Al..Dissolved	0.00442	0.00444	0.00547	0.00483	0.005	0.00461
4-Apr-18	Ammonia	<0.0050	0.0081	0.0289	0.0131	0.0086	0.0079
4-Apr-18	Antimony..Sb..Dissolved	<0.000020	0.000094	0.000992	0.000218	0.000044	0.000084
4-Apr-18	Antimony..Sb..Total	<0.000020	0.00011	0.00106	0.000235	0.000051	0.000092
4-Apr-18	Arsenic	0.000276	0.000302	0.000435	0.000328	0.000495	0.000293
4-Apr-18	Arsenic..As..Dissolved	0.000262	0.000252	0.000412	0.000291	0.000473	0.000261
4-Apr-18	Barium..Ba..Dissolved	0.0227	0.0216	0.0226	0.0225	0.0225	0.0223
4-Apr-18	Barium..Ba..Total	0.0232	0.0237	0.0244	0.0244	0.0233	0.0237
4-Apr-18	Beryllium..Be..Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
4-Apr-18	Beryllium..Be..Total	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
4-Apr-18	Bismuth..Bi..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
4-Apr-18	Bismuth..Bi..Total	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
4-Apr-18	Boron..B..Dissolved	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
4-Apr-18	Boron..B..Total	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
4-Apr-18	Bromide..Br.	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
4-Apr-18	Cadmium	0.0000081	0.0000196	0.000221	0.0000527	0.0000308	0.0000236
4-Apr-18	Cadmium..Cd..Total	0.0000123	0.0000246	0.000247	0.0000627	0.0000317	0.000023
4-Apr-18	Calcium..Ca..Dissolved	21	21.4	23.1	21.2	20.7	22.6
4-Apr-18	Calcium..Ca..Total	19.1	18.9	20	19.2	19.5	19.4
4-Apr-18	Chloride..Cl.	1.03	1.07	1.41	1.16	1.08	1.08
4-Apr-18	Chromium	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
4-Apr-18	Chromium..Cr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
4-Apr-18	Cobalt..Co..Dissolved	<0.0000050	0.0000065	0.0000168	0.000009	<0.0000050	<0.0000050
4-Apr-18	Cobalt..Co..Total	0.0000078	0.0000083	0.0000196	0.0000108	0.0000071	0.0000082
4-Apr-18	Conductivity						
4-Apr-18	Copper	0.00032	0.00036	0.00069	0.00054	0.0003	0.00035
4-Apr-18	Copper..Cu..Dissolved	0.00029	0.00032	0.00062	0.00037	0.00031	0.00033
4-Apr-18	Fluoride..F.	0.066	0.07	0.117	0.072	0.068	0.068
4-Apr-18	Iron	0.0103	0.0091	0.0095	0.0098	0.0092	0.009
4-Apr-18	Iron..Fe..Dissolved	0.0031	0.0027	0.0033	0.0031	0.0031	0.0033
4-Apr-18	Lead	0.000041	0.000056	0.000262	0.000075	0.000055	0.00006
4-Apr-18	Lead..Pb..Dissolved	0.0000105	0.000018	0.000186	0.0000324	0.0000206	0.0000406
4-Apr-18	Lithium..Li..Dissolved	0.0014	0.00144	0.00158	0.00159	0.0014	0.00176
4-Apr-18	Lithium..Li..Total	0.00112	0.00099	0.00115	0.00133	0.00111	0.00099
4-Apr-18	Magnesium..Mg..Dissolved	5.08	5.3	4.92	5.28	5.03	5.34

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
4-Apr-18	Magnesium..Mg..Total	5.13	5.42	5.56	5.25	4.98	5.11
4-Apr-18	Manganese..Mn..Dissolved	0.00101	0.00131	0.00486	0.0019	0.00103	0.0013
4-Apr-18	Manganese..Mn..Total	0.00169	0.00212	0.00576	0.00263	0.00173	0.002
4-Apr-18	Mercury	<0.00050	<0.00050	0.00144	0.00054	<0.00050	<0.00050
4-Apr-18	Mercury..Hg..Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
4-Apr-18	Molybdenum..Mo..Dissolved	0.000568	0.000573	0.000622	0.000595	0.000575	0.00056
4-Apr-18	Molybdenum..Mo..Total	0.000577	0.000581	0.000636	0.000575	0.000554	0.000541
4-Apr-18	Nickel	0.000352	0.000329	0.00035	0.000346	0.000299	0.000336
4-Apr-18	Nickel..Ni..Dissolved	0.000299	0.000303	0.000331	0.000285	0.000306	0.000301
4-Apr-18	Nitrate	0.143	0.153	0.265	0.168	0.147	0.152
4-Apr-18	Nitrite	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
4-Apr-18	Organic.Carbon	1.38	1.34	1.3	1.34	1.34	1.2
4-Apr-18	Phosphorus	0.0046	0.0041	0.0059	0.0045	0.0043	0.0051
4-Apr-18	Phosphorus..P..Dissolved	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
4-Apr-18	Phosphorus..P..Total..Dissolved	<0.0020	<0.0020	0.0022	<0.0020	<0.0020	<0.0020
4-Apr-18	Phosphorus..P..Total.1	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
4-Apr-18	Potassium	0.673	0.675	0.706	0.69	0.683	0.68
4-Apr-18	Potassium..K..Dissolved	0.657	0.647	0.658	0.674	0.64	0.653
4-Apr-18	Selenium	0.0003	0.000391	0.00185	0.000567	0.000312	0.000384
4-Apr-18	Selenium..Se..Dissolved	0.00027	0.000355	0.00177	0.00051	0.000241	0.000339
4-Apr-18	Silicon..Si..Dissolved	2.08	2.12	2.16	2.15	2.17	2.11
4-Apr-18	Silicon..Si..Total	2.25	2.28	2.27	2.29	2.27	2.27
4-Apr-18	Silver	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
4-Apr-18	Silver..Ag..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
4-Apr-18	Sodium..Na..Dissolved	2.09	2.09	3.11	2.32	1.98	2.25
4-Apr-18	Sodium..Na..Total	2.1	2.22	3.49	2.47	2.15	2.19
4-Apr-18	Strontium..Sr..Dissolved	0.117	0.111	0.122	0.114	0.118	0.122
4-Apr-18	Strontium..Sr..Total	0.114	0.114	0.119	0.112	0.11	0.113
4-Apr-18	Sulfate	12.3	12.8	18.1	13.5	12.5	12.7
4-Apr-18	Thallium	0.0000026	0.0000372	0.000632	0.000114	0.000002	0.0000268
4-Apr-18	Thallium..Tl..Dissolved	0.0000024	0.000036	0.000646	0.000118	0.0000023	0.0000289
4-Apr-18	Tin..Sn..Dissolved	0.000032	<0.000010	<0.000010	<0.000010	0.000041	<0.000010
4-Apr-18	Tin..Sn..Total	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
4-Apr-18	Titanium..Ti..Dissolved	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
4-Apr-18	Titanium..Ti..Total	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
4-Apr-18	Total.Dissolved.Solids						
4-Apr-18	Total.Kjeldahl.Nitrogen	0.069	0.059	0.088	0.065	0.062	0.074
4-Apr-18	Total.Suspended.Solids						
4-Apr-18	Turbidity	0.31	0.29	0.32	0.3	0.29	0.3
4-Apr-18	Uranium..U..Dissolved	0.000615	0.00062	0.00065	0.000616	0.000604	0.000627
4-Apr-18	Uranium..U..Total	0.000609	0.000595	0.000618	0.000585	0.000584	0.000581
4-Apr-18	Vanadium..V..Dissolved	0.000121	0.000115	0.000117	0.00013	0.000111	0.000121
4-Apr-18	Vanadium..V..Total	0.000124	0.000136	0.000116	0.000124	0.000136	0.000122
4-Apr-18	Zinc	0.00123	0.00149	0.00525	0.00272	0.00226	0.00153
4-Apr-18	Zinc..Zn..Dissolved	0.0013	0.0014	0.0047	0.0025	0.0023	0.0013
4-Apr-18	Zirconium..Zr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
4-Apr-18	Zirconium..Zr..Total	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
5-Apr-18	Alkalinity..Total..as.CaCO3.						
5-Apr-18	Aluminum	0.00785	0.00819	0.00829	0.00875	0.00817	0.00866
5-Apr-18	Aluminum..Al..Dissolved	0.00387	0.00399	0.00536	0.00479	0.00437	0.00399
5-Apr-18	Ammonia	<0.0050	0.0073	0.0194	0.0112	0.009	0.0084
5-Apr-18	Antimony..Sb..Dissolved	<0.000020	0.000082	0.0007	0.000153	0.000056	0.000073
5-Apr-18	Antimony..Sb..Total	0.000022	0.00009	0.000748	0.000173	0.00006	0.00008
5-Apr-18	Arsenic	0.000246	0.000277	0.000419	0.000324	0.000554	0.000294
5-Apr-18	Arsenic..As..Dissolved	0.000261	0.000277	0.000364	0.000312	0.000474	0.000253
5-Apr-18	Barium..Ba..Dissolved	0.0234	0.0229	0.0231	0.0227	0.0226	0.0224
5-Apr-18	Barium..Ba..Total	0.0238	0.0248	0.0238	0.0237	0.0243	0.0249
5-Apr-18	Beryllium..Be..Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
5-Apr-18	Beryllium..Be..Total	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
5-Apr-18	Bismuth..Bi..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
5-Apr-18	Bismuth..Bi..Total	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
5-Apr-18	Boron..B..Dissolved	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
5-Apr-18	Boron..B..Total	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
5-Apr-18	Bromide..Br.	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
5-Apr-18	Cadmium	0.0000108	0.0000222	0.000245	0.0000508	0.0000339	0.0000236
5-Apr-18	Cadmium..Cd..Total	0.000012	0.000029	0.000275	0.000059	0.0000411	0.0000288
5-Apr-18	Calcium..Ca..Dissolved	21.9	22.1	23.8	21.8	21.7	20.9
5-Apr-18	Calcium..Ca..Total	19.4	20.1	21.9	20.9	20.9	19.6
5-Apr-18	Chloride..Cl.	1.02	1.06	1.38	1.16	1.08	1.1

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
5-Apr-18	Chromium	<0.00010	<0.00010	<0.00010	0.00015	<0.00010	<0.00010
5-Apr-18	Chromium..Cr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
5-Apr-18	Cobalt..Co..Dissolved	<0.0000050	<0.0000050	0.0000137	0.0000075	0.0000054	0.0000052
5-Apr-18	Cobalt..Co..Total	0.000008	0.0000107	0.0000217	0.0000149	0.0000075	0.0000103
5-Apr-18	Conductivity						
5-Apr-18	Copper	0.0003	0.00036	0.00075	0.00039	0.0003	0.00036
5-Apr-18	Copper..Cu..Dissolved	0.00028	0.00035	0.00067	0.00037	0.00029	0.00032
5-Apr-18	Fluoride..F.	0.068	0.069	0.116	0.076	0.068	0.069
5-Apr-18	Iron	0.0092	0.0103	0.0094	0.0118	0.0092	0.0101
5-Apr-18	Iron..Fe..Dissolved	0.0037	0.0029	0.003	0.0035	0.0032	0.0029
5-Apr-18	Lead	0.000037	0.000063	0.0003	0.000109	0.000054	0.000068
5-Apr-18	Lead..Pb..Dissolved	0.0000095	0.0000217	0.000185	0.0000363	0.0000194	0.0000204
5-Apr-18	Lithium..Li..Dissolved	0.0016	0.00184	0.00188	0.00158	0.00177	0.00157
5-Apr-18	Lithium..Li..Total	0.0011	0.00114	0.00152	0.00126	0.00144	0.00112
5-Apr-18	Magnesium..Mg..Dissolved	5.04	5.58	5.31	5.31	5.04	5.08
5-Apr-18	Magnesium..Mg..Total	5.4	5.26	5.24	5.44	5.17	5.22
5-Apr-18	Manganese..Mn..Dissolved	0.000901	0.00126	0.00355	0.00168	0.00102	0.00119
5-Apr-18	Manganese..Mn..Total	0.00161	0.00204	0.00438	0.00239	0.00178	0.00205
5-Apr-18	Mercury	<0.00050	<0.00050	0.00103	<0.00050	<0.00050	<0.00050
5-Apr-18	Mercury..Hg..Dissolved	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
5-Apr-18	Molybdenum..Mo..Dissolved	0.000563	0.000565	0.000586	0.000544	0.000612	0.000545
5-Apr-18	Molybdenum..Mo..Total	0.000574	0.000592	0.000621	0.000608	0.000617	0.000587
5-Apr-18	Nickel	0.000337	0.000346	0.000373	0.000393	0.000325	0.000347

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
5-Apr-18	Nickel..Ni..Dissolved	0.00031	0.000312	0.000336	0.000321	0.000271	0.000302
5-Apr-18	Nitrate	0.15	0.157	0.259	0.173	0.149	0.159
5-Apr-18	Nitrite	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
5-Apr-18	Organic.Carbon	1.37	1.26	1.21	1.27	1.48	1.26
5-Apr-18	Phosphorus	0.004	0.0039	0.0049	0.0041	0.0045	0.0039
5-Apr-18	Phosphorus..P..Dissolved	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
5-Apr-18	Phosphorus..P..Total..Dissolved	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
5-Apr-18	Phosphorus..P..Total.1	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
5-Apr-18	Potassium	0.666	0.684	0.683	0.694	0.687	0.678
5-Apr-18	Potassium..K..Dissolved	0.631	0.634	0.651	0.665	0.636	0.643
5-Apr-18	Selenium	0.000328	0.000436	0.00193	0.000622	0.000308	0.000375
5-Apr-18	Selenium..Se..Dissolved	0.000287	0.000376	0.00177	0.000596	0.000262	0.00035
5-Apr-18	Silicon..Si..Dissolved	2.1	2.15	2.15	2.18	2.2	2.16
5-Apr-18	Silicon..Si..Total	2.25	2.28	2.29	2.39	2.35	2.31
5-Apr-18	Silver	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
5-Apr-18	Silver..Ag..Dissolved	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
5-Apr-18	Sodium..Na..Dissolved	1.95	2.11	3.2	2.45	1.98	2.14
5-Apr-18	Sodium..Na..Total	2.18	2.24	3.53	2.44	2.22	2.12
5-Apr-18	Strontium..Sr..Dissolved	0.116	0.116	0.122	0.114	0.121	0.116
5-Apr-18	Strontium..Sr..Total	0.113	0.117	0.113	0.115	0.118	0.116
5-Apr-18	Sulfate	12.3	12.7	17	13.4	12.5	12.7
5-Apr-18	Thallium	0.0000034	0.0000272	0.000486	0.00009	0.0000026	0.000024

Date.Sampled	metric	Birchbank_r-sh	Maglios_r-sh	New Bridge_r-sh	Old Bridge_r-sh	Stoney Creek_r-sh	Waneta_comp
5-Apr-18	Thallium..Tl..Dissolved	0.0000049	0.0000314	0.000516	0.000101	0.0000032	0.0000236
5-Apr-18	Tin..Sn..Dissolved	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
5-Apr-18	Tin..Sn..Total	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
5-Apr-18	Titanium..Ti..Dissolved	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
5-Apr-18	Titanium..Ti..Total	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
5-Apr-18	Total.Dissolved.Solids						
5-Apr-18	Total.Kjeldahl.Nitrogen	<0.050	0.065	0.088	0.083	0.07	0.055
5-Apr-18	Total.Suspended.Solids						
5-Apr-18	Turbidity	0.31	0.32	0.32	0.32	0.31	0.31
5-Apr-18	Uranium..U..Dissolved	0.000607	0.000612	0.000611	0.000633	0.000593	0.000618
5-Apr-18	Uranium..U..Total	0.00057	0.000581	0.000575	0.000564	0.000586	0.000596
5-Apr-18	Vanadium..V..Dissolved	0.000121	0.000121	0.000129	0.000129	0.00011	0.000127
5-Apr-18	Vanadium..V..Total	0.000121	0.000136	0.000137	0.000147	0.000143	0.000136
5-Apr-18	Zinc	0.001	0.00172	0.00579	0.00267	0.00247	0.00173
5-Apr-18	Zinc..Zn..Dissolved	0.0011	0.0014	0.0053	0.0025	0.0023	0.0016
5-Apr-18	Zirconium..Zr..Dissolved	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
5-Apr-18	Zirconium..Zr..Total	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

Water Quality 2018 Fall Transect Samples.

metric	Date.Sampled	Birchbank_l-1mab	Birchbank_l-1md	Birchbank_l-sh	Birchbank_r-1mab	Birchbank_r-1md	Birchbank_r-sh
Alkalinity..Total..as.CaCO3.	5-Oct-18						

metric	Date.Sampled	Birchbank_l-1mab	Birchbank_l-1md	Birchbank_l-sh	Birchbank_r-1mab	Birchbank_r-1md	Birchbank_r-sh
Aluminum	5-Oct-18	0.0142	0.0143	0.0143	0.0143	0.0155	0.0148
Aluminum..Al..Dissolved	5-Oct-18	0.00751	0.0065	0.00709	0.00654	0.00653	0.00678
Ammonia	5-Oct-18	<0.0050	0.0054	0.006	<0.0050	<0.0050	<0.0050
Antimony..Sb..Dissolved	5-Oct-18	0.000034	0.000034	0.000033	0.000035	0.000034	0.000031
Antimony..Sb..Total	5-Oct-18	0.000039	0.000033	0.000032	0.000037	0.000048	0.000096
Arsenic	5-Oct-18	0.000172	0.000181	0.000191	0.000168	0.000155	0.000164
Arsenic..As..Dissolved	5-Oct-18	0.00018	0.000178	0.000178	0.000168	0.000157	0.00017
Barium..Ba..Dissolved	5-Oct-18	0.0167	0.0167	0.0171	0.0169	0.0167	0.0171
Barium..Ba..Total	5-Oct-18	0.0173	0.017	0.0175	0.0171	0.0172	0.0176
Beryllium..Be..Dissolved	5-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Beryllium..Be..Total	5-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Bismuth..Bi..Dissolved	5-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Bismuth..Bi..Total	5-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Boron..B..Dissolved	5-Oct-18	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Boron..B..Total	5-Oct-18	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Bromide..Br.	5-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Cadmium	5-Oct-18	0.0000061	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Cadmium..Cd..Total	5-Oct-18	0.0000107	0.0000094	0.0000094	0.0000084	0.0000089	0.0000071
Calcium..Ca..Dissolved	5-Oct-18	15.5	15	15.8	15.6	15.5	15.6
Calcium..Ca..Total	5-Oct-18	16.8	17	16.9	16.4	17	16.4
Chloride..Cl.	5-Oct-18	0.66	0.68	0.65	0.67	0.65	0.66
Chromium	5-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

metric	Date.Sampled	Birchbank_l-1mab	Birchbank_l-1md	Birchbank_l-sh	Birchbank_r-1mab	Birchbank_r-1md	Birchbank_r-sh
Chromium..Cr..Dissolved	5-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cobalt..Co..Dissolved	5-Oct-18	0.0000078	0.0000074	0.0000076	0.0000061	0.0000061	0.000007
Cobalt..Co..Total	5-Oct-18	0.0000146	0.0000145	0.0000143	0.0000126	0.0000162	0.0000151
Conductivity	5-Oct-18						
Copper	5-Oct-18	0.00032	0.00032	0.00032	0.00032	0.00032	0.00033
Copper..Cu..Dissolved	5-Oct-18	0.00031	0.00029	0.00031	0.00031	0.0003	0.0003
Fluoride..F.	5-Oct-18	0.058	0.059	0.059	0.058	0.057	0.057
Iron	5-Oct-18	0.0152	0.0155	0.0155	0.0158	0.0162	0.0153
Iron..Fe..Dissolved	5-Oct-18	0.0034	0.0026	0.0027	0.0031	0.0028	0.0031
Lead	5-Oct-18	0.000044	0.000045	0.000049	0.000048	0.000048	0.000049
Lead..Pb..Dissolved	5-Oct-18	0.0000134	0.0000101	0.00001	0.0000129	0.0000117	0.0000174
Lithium..Li..Dissolved	5-Oct-18	0.00099	0.00097	0.00099	0.00098	0.00096	0.00101
Lithium..Li..Total	5-Oct-18	0.00104	0.00102	0.00104	0.00103	0.00103	0.00101
Magnesium..Mg..Dissolved	5-Oct-18	3.86	3.71	3.75	3.73	3.65	3.7
Magnesium..Mg..Total	5-Oct-18	4	3.98	3.92	4.03	3.87	3.95
Manganese..Mn..Dissolved	5-Oct-18	0.00352	0.00349	0.00336	0.00348	0.00342	0.00349
Manganese..Mn..Total	5-Oct-18	0.00497	0.00504	0.00497	0.00498	0.00503	0.00515
Mercury	5-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Mercury..Hg..Dissolved	5-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Molybdenum..Mo..Dissolved	5-Oct-18	0.000504	0.000496	0.000494	0.000501	0.000498	0.00049
Molybdenum..Mo..Total	5-Oct-18	0.000552	0.000538	0.000576	0.000537	0.000565	0.000543
Nickel	5-Oct-18	0.000373	0.000384	0.00036	0.000386	0.000368	0.000367
Nickel..Ni..Dissolved	5-Oct-18	0.000334	0.000331	0.000338	0.000333	0.000339	0.000338
Nitrate	5-Oct-18	0.0649	0.0652	0.0639	0.0665	0.0652	0.0651

metric	Date.Sampled	Birchbank_l-1mab	Birchbank_l-1md	Birchbank_l-sh	Birchbank_r-1mab	Birchbank_r-1md	Birchbank_r-sh
Nitrite	5-Oct-18	0.0012	0.0014	0.0011	0.0011	<0.0010	<0.0010
Organic.Carbon	5-Oct-18	1.12	1.09	1.10	1.07	1.42	1.15
Phosphorus	5-Oct-18	0.0065	0.0064	0.0055	0.0056	0.0062	0.006
Phosphorus..P..Dissolved	5-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Phosphorus..P..Total..Dissolved	5-Oct-18	0.0032	0.0039	0.0035	0.0029	0.0035	0.0035
Phosphorus..P..Total.1	5-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Potassium	5-Oct-18	0.583	0.585	0.589	0.583	0.583	0.596
Potassium..K..Dissolved	5-Oct-18	0.599	0.59	0.594	0.587	0.579	0.585
Selenium	5-Oct-18	0.000174	0.000189	0.000169	0.000171	0.000177	0.000196
Selenium..Se..Dissolved	5-Oct-18	0.000144	0.000173	0.000161	0.000173	0.00017	0.000187
Silicon..Si..Dissolved	5-Oct-18	1.44	1.42	1.4	1.42	1.42	1.39
Silicon..Si..Total	5-Oct-18	1.47	1.47	1.49	1.51	1.43	1.45
Silver	5-Oct-18	0.000214	<0.0000050	<0.0000050	0.000368	<0.0000050	0.000989
Silver..Ag..Dissolved	5-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Sodium..Na..Dissolved	5-Oct-18	1.49	1.43	1.49	1.43	1.43	1.48
Sodium..Na..Total	5-Oct-18	1.38	1.39	1.41	1.36	1.38	1.42
Strontium..Sr..Dissolved	5-Oct-18	0.0938	0.0931	0.097	0.0963	0.0945	0.098
Strontium..Sr..Total	5-Oct-18	0.0972	0.0947	0.0978	0.0966	0.0964	0.0963
Sulfate	5-Oct-18	10.1	10.1	10	10	9.98	10.1
Thallium	5-Oct-18	0.0000029	0.0000032	0.0000038	0.0000032	0.0000039	0.0000058
Thallium..Tl..Dissolved	5-Oct-18	0.0000024	0.0000026	0.0000025	0.0000027	0.0000024	0.0000024
Tin..Sn..Dissolved	5-Oct-18	0.000012	<0.000010	<0.000010	0.000012	0.000011	0.000013

metric	Date.Sampled	Birchbank_l-1mab	Birchbank_l-1md	Birchbank_l-sh	Birchbank_r-1mab	Birchbank_r-1md	Birchbank_r-sh
Tin..Sn..Total	5-Oct-18	0.000054	<0.000020	<0.000020	<0.000020	<0.000020	0.000032
Titanium..Ti..Dissolved	5-Oct-18	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
Titanium..Ti..Total	5-Oct-18	<0.00050	0.0005	<0.00050	<0.00050	0.00051	<0.00050
Total.Dissolved.Solids	5-Oct-18						
Total.Kjeldahl.Nitrogen	5-Oct-18	0.07	0.062	0.064	0.083	0.079	0.073
Total.Suspended.Solids	5-Oct-18						
Turbidity	5-Oct-18	0.45	0.5	0.45	0.46	0.51	0.6
Uranium..U..Dissolved	5-Oct-18	0.00044	0.000443	0.000437	0.000437	0.000445	0.000448
Uranium..U..Total	5-Oct-18	0.000403	0.000403	0.000406	0.000416	0.000412	0.000418
Vanadium..V..Dissolved	5-Oct-18	0.000127	0.000116	0.000123	0.00012	0.000127	0.000117
Vanadium..V..Total	5-Oct-18	0.000168	0.000155	0.000169	0.000148	0.000155	0.000141
Zinc	5-Oct-18	0.00085	0.00061	<0.00050	0.00066	0.00071	0.00063
Zinc..Zn..Dissolved	5-Oct-18	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Zirconium..Zr..Dissolved	5-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Zirconium..Zr..Total	5-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

metric	Date.Sampled	Maglios_l-1mab	Maglios_l-1md	Maglios_l-sh	Maglios_r-1mab	Maglios_r-1md	Maglios_r-sh
Alkalinity..Total..as.CaCO3.	4-Oct-18						
Aluminum	4-Oct-18	0.0217	0.0221	0.0224	0.0235	0.0234	0.0236
Aluminum..Al..Dissolved	4-Oct-18	0.00704	0.00653	0.00686	0.00675	0.00662	0.00646
Ammonia	4-Oct-18	0.0076	0.0096	0.0106	0.0106	0.0086	0.0087
Antimony..Sb..Dissolved	4-Oct-18	0.000088	0.000073	0.000084	0.000092	0.000107	0.000099
Antimony..Sb..Total	4-Oct-18	0.000081	0.000069	0.000078	0.000086	0.000085	0.000089
Arsenic	4-Oct-18	0.000187	0.000195	0.000199	0.000221	0.000213	0.000217
Arsenic..As..Dissolved	4-Oct-18	0.000202	0.000191	0.000184	0.000192	0.0002	0.000192
Barium..Ba..Dissolved	4-Oct-18	0.0162	0.0169	0.0165	0.0168	0.0168	0.017
Barium..Ba..Total	4-Oct-18	0.0175	0.0168	0.0171	0.0174	0.0173	0.0171
Beryllium..Be..Dissolved	4-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Beryllium..Be..Total	4-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Bismuth..Bi..Dissolved	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Bismuth..Bi..Total	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Boron..B..Dissolved	4-Oct-18	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Boron..B..Total	4-Oct-18	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Bromide..Br.	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Cadmium	4-Oct-18	0.0000052	0.0000098	0.0000108	0.0000167	0.0000133	0.0000165
Cadmium..Cd..Total	4-Oct-18	0.0000186	0.0000176	0.0000149	0.00002	0.0000214	0.0000219
Calcium..Ca..Dissolved	4-Oct-18	15.8	15.7	15.6	15.8	15.9	15.4
Calcium..Ca..Total	4-Oct-18	16.7	16.7	16.3	16.4	16.5	16.1
Chloride..Cl.	4-Oct-18	0.64	0.62	0.63	0.63	0.63	0.63
Chromium	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

metric	Date.Sampled	Maglios_l-1mab	Maglios_l-1md	Maglios_l-sh	Maglios_r-1mab	Maglios_r-1md	Maglios_r-sh
Chromium..Cr..Dissolved	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cobalt..Co..Dissolved	4-Oct-18	0.0000084	0.0000077	0.0000073	0.0000067	0.000008	0.0000069
Cobalt..Co..Total	4-Oct-18	0.00002	0.0000205	0.0000206	0.0000224	0.0000188	0.0000209
Conductivity	4-Oct-18						
Copper	4-Oct-18	0.00038	0.00036	0.00038	0.00037	0.00039	0.00037
Copper..Cu..Dissolved	4-Oct-18	0.00029	0.00034	0.00033	0.00032	0.00032	0.00031
Fluoride..F.	4-Oct-18	0.062	0.06	0.061	0.061	0.062	0.062
Iron	4-Oct-18	0.0306	0.0287	0.0293	0.0299	0.0294	0.0286
Iron..Fe..Dissolved	4-Oct-18	0.0037	0.0034	0.0031	0.003	0.003	0.0033
Lead	4-Oct-18	0.000094	0.000079	0.0001	0.000094	0.000103	0.000097
Lead..Pb..Dissolved	4-Oct-18	0.0000234	0.0000236	0.0000188	0.000023	0.0000258	0.000026
Lithium..Li..Dissolved	4-Oct-18	0.00099	0.00098	0.00097	0.00097	0.00098	0.00098
Lithium..Li..Total	4-Oct-18	0.00102	0.00102	0.001	0.00102	0.00102	0.00101
Magnesium..Mg..Dissolved	4-Oct-18	3.62	3.57	3.67	3.55	3.62	3.64
Magnesium..Mg..Total	4-Oct-18	3.92	3.97	4.02	4.04	4.04	4.03
Manganese..Mn..Dissolved	4-Oct-18	0.000748	0.00074	0.000774	0.000702	0.000731	0.000756
Manganese..Mn..Total	4-Oct-18	0.00221	0.00226	0.00219	0.00226	0.00222	0.00224
Mercury	4-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Mercury..Hg..Dissolved	4-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Molybdenum..Mo..Dissolved	4-Oct-18	0.000558	0.000528	0.000524	0.000562	0.000558	0.000546
Molybdenum..Mo..Total	4-Oct-18	0.000583	0.000518	0.000542	0.000574	0.00056	0.000579
Nickel	4-Oct-18	0.000387	0.000423	0.000407	0.000411	0.000415	0.000407
Nickel..Ni..Dissolved	4-Oct-18	0.000359	0.000349	0.000334	0.000339	0.000348	0.00036
Nitrate	4-Oct-18	0.0707	0.0704	0.0701	0.0709	0.0697	0.0709

metric	Date.Sampled	Maglios_l-1mab	Maglios_l-1md	Maglios_l-sh	Maglios_r-1mab	Maglios_r-1md	Maglios_r-sh
Nitrite	4-Oct-18	<0.0010	<0.0010	<0.0010	0.0012	<0.0010	0.0011
Organic.Carbon	4-Oct-18	1.11	1.08	1.10	1.18	1.12	1.13
Phosphorus	4-Oct-18	0.0063	0.006	0.0062	0.0057	0.0051	0.0064
Phosphorus..P..Dissolved	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Phosphorus..P..Total..Dissolved	4-Oct-18	0.0034	0.0038	0.0037	0.0028	0.0037	0.0035
Phosphorus..P..Total.1	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Potassium	4-Oct-18	0.592	0.601	0.602	0.599	0.597	0.596
Potassium..K..Dissolved	4-Oct-18	0.595	0.587	0.593	0.598	0.596	0.603
Selenium	4-Oct-18	0.000246	0.000239	0.000214	0.00029	0.0003	0.00027
Selenium..Se..Dissolved	4-Oct-18	0.00028	0.000218	0.000222	0.000316	0.000237	0.00028
Silicon..Si..Dissolved	4-Oct-18	1.39	1.42	1.4	1.42	1.24	1.42
Silicon..Si..Total	4-Oct-18	1.53	1.49	1.5	1.51	1.51	1.5
Silver	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Silver..Ag..Dissolved	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Sodium..Na..Dissolved	4-Oct-18	1.41	1.37	1.4	1.44	1.4	1.45
Sodium..Na..Total	4-Oct-18	1.45	1.43	1.44	1.44	1.43	1.46
Strontium..Sr..Dissolved	4-Oct-18	0.0958	0.0972	0.0998	0.0974	0.0986	0.0971
Strontium..Sr..Total	4-Oct-18	0.0958	0.0975	0.0959	0.0978	0.0972	0.0974
Sulfate	4-Oct-18	10.4	10.2	10.2	10.5	10.4	10.4
Thallium	4-Oct-18	0.0000491	0.0000318	0.0000332	0.0000557	0.0000563	0.0000555
Thallium..Tl..Dissolved	4-Oct-18	0.0000507	0.0000306	0.0000292	0.0000547	0.0000598	0.0000573
Tin..Sn..Dissolved	4-Oct-18	0.000015	<0.000010	0.000014	0.000011	0.000014	<0.000010

metric	Date.Sampled	Maglios_l-1mab	Maglios_l-1md	Maglios_l-sh	Maglios_r-1mab	Maglios_r-1md	Maglios_r-sh
Tin..Sn..Total	4-Oct-18	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
Titanium..Ti..Dissolved	4-Oct-18	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
Titanium..Ti..Total	4-Oct-18	0.00103	0.00087	0.00095	0.00098	0.0009	0.00085
Total.Dissolved.Solids	4-Oct-18						
Total.Kjeldahl.Nitrogen	4-Oct-18	0.075	0.071	0.094	0.074	0.074	0.077
Total.Suspended.Solids	4-Oct-18						
Turbidity	4-Oct-18	0.59	0.61	0.6	0.57	0.81	0.65
Uranium..U..Dissolved	4-Oct-18	0.000433	0.000449	0.000428	0.00044	0.000453	0.000439
Uranium..U..Total	4-Oct-18	0.000409	0.00042	0.000412	0.000408	0.000401	0.000403
Vanadium..V..Dissolved	4-Oct-18	0.000126	0.000114	0.000133	0.000126	0.000126	0.000121
Vanadium..V..Total	4-Oct-18	0.00018	0.000201	0.000176	0.000192	0.000202	0.000186
Zinc	4-Oct-18	0.00106	0.00105	0.00102	0.00119	0.00134	0.00139
Zinc..Zn..Dissolved	4-Oct-18	0.0014	<0.0010	<0.0010	<0.0010	0.001	0.0013
Zirconium..Zr..Dissolved	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Zirconium..Zr..Total	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

metric	Date.Sampled	New Bridge_l-1mab	New Bridge_l-1md	New Bridge_l-sh	New Bridge_r-1mab	New Bridge_r-1md	New Bridge_r-sh
Alkalinity..Total..as.CaCO3.	4-Oct-18						
Aluminum	4-Oct-18	0.0229	0.0213	0.0221	0.0239	0.0209	0.0236
Aluminum..Al..Dissolved	4-Oct-18	0.00691	0.00738	0.00685	0.00697	0.00687	0.00703
Ammonia	4-Oct-18	0.0063	0.0061	0.0447	0.0061	0.0058	0.0198
Antimony..Sb..Dissolved	4-Oct-18	0.000037	0.000043	0.000039	0.000036	0.000037	0.000774
Antimony..Sb..Total	4-Oct-18	0.000032	0.00003	0.000034	0.000034	0.000033	0.00075
Arsenic	4-Oct-18	0.000194	0.000164	0.000183	0.000184	0.000169	0.000562
Arsenic..As..Dissolved	4-Oct-18	0.000156	0.00017	0.000173	0.000157	0.000152	0.00052
Barium..Ba..Dissolved	4-Oct-18	0.0167	0.0167	0.0172	0.0165	0.0164	0.017
Barium..Ba..Total	4-Oct-18	0.0174	0.0174	0.0174	0.0172	0.0171	0.0178
Beryllium..Be..Dissolved	4-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Beryllium..Be..Total	4-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Bismuth..Bi..Dissolved	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Bismuth..Bi..Total	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Boron..B..Dissolved	4-Oct-18	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Boron..B..Total	4-Oct-18	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Bromide..Br.	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Cadmium	4-Oct-18	<0.0000050	0.0000067	0.0000078	<0.0000050	0.0000088	0.000272
Cadmium..Cd..Total	4-Oct-18	0.00001	0.0000101	0.0000133	0.0000099	0.0000127	0.000297
Calcium..Ca..Dissolved	4-Oct-18	15.4	16.2	16	15.6	15.5	16.9
Calcium..Ca..Total	4-Oct-18	16.5	16.7	16.8	16	16.4	18
Chloride..Cl.	4-Oct-18	0.63	0.63	0.74	0.63	0.62	0.94

metric	Date.Sampled	New Bridge_l-1mab	New Bridge_l-1md	New Bridge_l-sh	New Bridge_r-1mab	New Bridge_r-1md	New Bridge_r-sh
Chromium	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Chromium..Cr..Dissolved	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cobalt..Co..Dissolved	4-Oct-18	0.0000087	0.000008	0.0000095	0.0000077	0.0000081	0.0000174
Cobalt..Co..Total	4-Oct-18	0.0000193	0.0000189	0.0000192	0.0000195	0.0000194	0.0000305
Conductivity	4-Oct-18						
Copper	4-Oct-18	0.00033	0.00033	0.00033	0.00034	0.00034	0.00059
Copper..Cu..Dissolved	4-Oct-18	0.00028	0.00029	0.00026	0.00028	0.00029	0.00048
Fluoride..F.	4-Oct-18	0.058	0.058	0.059	0.058	0.058	0.123
Iron	4-Oct-18	0.0285	0.0274	0.0269	0.0287	0.0283	0.0292
Iron..Fe..Dissolved	4-Oct-18	0.0031	0.0037	0.0032	0.0029	0.0029	0.0034
Lead	4-Oct-18	0.000058	0.000058	0.000057	0.000057	0.000059	0.000943
Lead..Pb..Dissolved	4-Oct-18	0.0000097	0.0000129	0.0000146	0.000011	0.0000128	0.000377
Lithium..Li..Dissolved	4-Oct-18	0.00096	0.001	0.00102	0.00097	0.00099	0.00108
Lithium..Li..Total	4-Oct-18	0.00102	0.00102	0.00104	0.00101	0.00102	0.0011
Magnesium..Mg..Dissolved	4-Oct-18	3.6	3.6	3.7	3.64	3.65	3.8
Magnesium..Mg..Total	4-Oct-18	4	3.94	3.96	3.9	3.91	3.99
Manganese..Mn..Dissolved	4-Oct-18	0.000704	0.000714	0.00195	0.000646	0.000658	0.00224
Manganese..Mn..Total	4-Oct-18	0.00213	0.00211	0.0034	0.0021	0.00206	0.00395
Mercury	4-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	0.00265
Mercury..Hg..Dissolved	4-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	0.00078
Molybdenum..Mo..Dissolved	4-Oct-18	0.000515	0.000528	0.000518	0.000516	0.000512	0.00123
Molybdenum..Mo..Total	4-Oct-18	0.000543	0.000546	0.00052	0.000501	0.000498	0.00125
Nickel	4-Oct-18	0.000383	0.000401	0.000398	0.000401	0.000394	0.000449
Nickel..Ni..Dissolved	4-Oct-18	0.00033	0.000338	0.000359	0.000345	0.000353	0.000359

metric	Date.Sampled	New Bridge_l-1mab	New Bridge_l-1md	New Bridge_l-sh	New Bridge_r-1mab	New Bridge_r-1md	New Bridge_r-sh
Nitrate	4-Oct-18	0.0676	0.0678	0.0863	0.0665	0.0662	0.176
Nitrite	4-Oct-18	<0.0010	0.001	0.0013	<0.0010	<0.0010	<0.0010
Organic.Carbon	4-Oct-18	1.14	1.06	1.12	1.22	1.36	1.18
Phosphorus	4-Oct-18	0.0075	0.0077	0.0067	0.0061	0.0065	0.007
Phosphorus..P..Dissolved	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Phosphorus..P..Total..Dissolved	4-Oct-18	0.0027	0.0027	0.0031	0.0023	0.003	0.0039
Phosphorus..P..Total.1	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Potassium	4-Oct-18	0.58	0.594	0.611	0.59	0.593	0.683
Potassium..K..Dissolved	4-Oct-18	0.587	0.596	0.587	0.589	0.586	0.696
Selenium	4-Oct-18	0.000189	0.000173	0.000176	0.000146	0.000174	0.00184
Selenium..Se..Dissolved	4-Oct-18	0.00019	0.000183	0.000175	0.000159	0.000179	0.00184
Silicon..Si..Dissolved	4-Oct-18	1.42	1.41	1.4	1.42	1.41	1.42
Silicon..Si..Total	4-Oct-18	1.48	1.55	1.45	1.46	1.45	1.47
Silver	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Silver..Ag..Dissolved	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Sodium..Na..Dissolved	4-Oct-18	1.38	1.41	1.46	1.41	1.38	3.9
Sodium..Na..Total	4-Oct-18	1.42	1.4	1.51	1.45	1.46	3.98
Strontium..Sr..Dissolved	4-Oct-18	0.0969	0.0998	0.1	0.0992	0.0979	0.102
Strontium..Sr..Total	4-Oct-18	0.0992	0.0996	0.0977	0.0972	0.0978	0.101
Sulfate	4-Oct-18	10.1	10.1	11.1	10.1	10	18.6
Thallium	4-Oct-18	0.0000036	0.0000029	0.0000036	0.0000037	0.0000066	0.00114
Thallium..Tl..Dissolved	4-Oct-18	0.0000026	0.0000026	0.0000025	0.0000027	0.0000087	0.0012

metric	Date.Sampled	New Bridge_l-1mab	New Bridge_l-1md	New Bridge_l-sh	New Bridge_r-1mab	New Bridge_r-1md	New Bridge_r-sh
Tin..Sn..Dissolved	4-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	0.00001
Tin..Sn..Total	4-Oct-18	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
Titanium..Ti..Dissolved	4-Oct-18	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
Titanium..Ti..Total	4-Oct-18	0.00091	0.00087	0.00082	0.00091	0.00086	0.00082
Total.Dissolved.Solids	4-Oct-18						
Total.Kjeldahl.Nitrogen	4-Oct-18	0.078	0.088	0.132	0.09	0.076	0.127
Total.Suspended.Solids	4-Oct-18						
Turbidity	4-Oct-18	0.62	0.66	0.6	0.62	0.51	0.54
Uranium..U..Dissolved	4-Oct-18	0.000444	0.000429	0.000441	0.000451	0.000435	0.000472
Uranium..U..Total	4-Oct-18	0.000426	0.000423	0.000432	0.000405	0.000411	0.000413
Vanadium..V..Dissolved	4-Oct-18	0.000113	0.000118	0.000107	0.000119	0.000119	0.000117
Vanadium..V..Total	4-Oct-18	0.000182	0.000189	0.000183	0.000182	0.00017	0.000184
Zinc	4-Oct-18	0.00067	0.00077	0.00084	0.00062	0.00083	0.00659
Zinc..Zn..Dissolved	4-Oct-18	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.006
Zirconium..Zr..Dissolved	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Zirconium..Zr..Total	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

metric	Date.Sampled	Old Bridge_l-1mab	Old Bridge_l-1md	Old Bridge_l-sh	Old Bridge_r-1mab	Old Bridge_r-1md	Old Bridge_r-sh
Alkalinity..Total..as.CaCO3.	4-Oct-18						
Aluminum	4-Oct-18	0.0237	0.0221	0.0261	0.0246	0.0224	0.0213
Aluminum..Al..Dissolved	4-Oct-18	0.00672	0.00694	0.00727	0.00727	0.0069	0.00639
Ammonia	4-Oct-18	0.0059	0.0134	0.0247	0.0096	0.0084	0.0095
Antimony..Sb..Dissolved	4-Oct-18	0.000044	0.000035	0.000043	0.000127	0.000104	0.00016
Antimony..Sb..Total	4-Oct-18	0.000046	0.000033	0.00004	0.000115	0.00009	0.000156
Arsenic	4-Oct-18	0.000193	0.000174	0.000194	0.000262	0.000219	0.000263
Arsenic..As..Dissolved	4-Oct-18	0.000175	0.000175	0.000162	0.000212	0.000213	0.000262
Barium..Ba..Dissolved	4-Oct-18	0.0166	0.0163	0.0174	0.0166	0.0162	0.0165
Barium..Ba..Total	4-Oct-18	0.017	0.0172	0.0176	0.0169	0.0172	0.017
Beryllium..Be..Dissolved	4-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Beryllium..Be..Total	4-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Bismuth..Bi..Dissolved	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Bismuth..Bi..Total	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Boron..B..Dissolved	4-Oct-18	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Boron..B..Total	4-Oct-18	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Bromide..Br.	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Cadmium	4-Oct-18	<0.0000050	0.000007	0.0000103	0.0000209	0.000019	0.000033
Cadmium..Cd..Total	4-Oct-18	0.0000104	0.0000095	0.0000194	0.0000316	0.0000239	0.0000393
Calcium..Ca..Dissolved	4-Oct-18	15.5	15.9	15.7	15.9	15.4	15.7
Calcium..Ca..Total	4-Oct-18	16.1	16.2	17.1	16.4	16.6	16.1
Chloride..Cl.	4-Oct-18	0.62	0.62	0.79	0.67	0.65	0.67

metric	Date.Sampled	Old Bridge_l-1mab	Old Bridge_l-1md	Old Bridge_l-sh	Old Bridge_r-1mab	Old Bridge_r-1md	Old Bridge_r-sh
Chromium	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Chromium..Cr..Dissolved	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cobalt..Co..Dissolved	4-Oct-18	0.0000089	0.000008	0.0000099	0.0000077	0.0000082	0.0000092
Cobalt..Co..Total	4-Oct-18	0.000021	0.0000193	0.0000217	0.0000219	0.000018	0.0000229
Conductivity	4-Oct-18						
Copper	4-Oct-18	0.00034	0.00034	0.00035	0.00038	0.00038	0.0004
Copper..Cu..Dissolved	4-Oct-18	0.00031	0.00029	0.00032	0.00031	0.00032	0.00036
Fluoride..F.	4-Oct-18	0.059	0.059	0.058	0.066	0.063	0.067
Iron	4-Oct-18	0.0316	0.0303	0.0347	0.0297	0.0305	0.0286
Iron..Fe..Dissolved	4-Oct-18	0.003	0.0032	0.0038	0.0031	0.003	0.0029
Lead	4-Oct-18	0.000058	0.000057	0.000148	0.000116	0.000106	0.000193
Lead..Pb..Dissolved	4-Oct-18	0.0000119	0.000016	0.0000188	0.0000365	0.0000288	0.0000513
Lithium..Li..Dissolved	4-Oct-18	0.00096	0.00101	0.00098	0.00102	0.001	0.00098
Lithium..Li..Total	4-Oct-18	0.00102	0.00103	0.00105	0.00102	0.001	0.00103
Magnesium..Mg..Dissolved	4-Oct-18	3.61	3.77	3.71	3.62	3.66	3.59
Magnesium..Mg..Total	4-Oct-18	3.99	3.87	3.99	4.06	3.88	4
Manganese..Mn..Dissolved	4-Oct-18	0.000676	0.000725	0.00129	0.000822	0.00075	0.000892
Manganese..Mn..Total	4-Oct-18	0.00213	0.00218	0.00285	0.00232	0.00229	0.0024
Mercury	4-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	0.00056
Mercury..Hg..Dissolved	4-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Molybdenum..Mo..Dissolved	4-Oct-18	0.00051	0.000521	0.00051	0.000595	0.000574	0.000603
Molybdenum..Mo..Total	4-Oct-18	0.000548	0.000536	0.000526	0.000584	0.000589	0.000641
Nickel	4-Oct-18	0.000408	0.000394	0.000425	0.000398	0.000393	0.000386
Nickel..Ni..Dissolved	4-Oct-18	0.000347	0.000351	0.000359	0.000333	0.000348	0.000348

metric	Date.Sampled	Old Bridge_l-1mab	Old Bridge_l-1md	Old Bridge_l-sh	Old Bridge_r-1mab	Old Bridge_r-1md	Old Bridge_r-sh
Nitrate	4-Oct-18	0.0669	0.0672	0.0929	0.0771	0.0722	0.0791
Nitrite	4-Oct-18	<0.0010	<0.0010	<0.0010	0.0014	0.001	<0.0010
Organic.Carbon	4-Oct-18	1.10	1.22	1.32	1.08	1.20	1.12
Phosphorus	4-Oct-18	0.0058	0.0091	0.0073	0.0059	0.0061	0.0062
Phosphorus..P..Dissolved	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Phosphorus..P..Total..Dissolved	4-Oct-18	0.0035	0.003	0.0032	0.0041	0.0035	0.0035
Phosphorus..P..Total.1	4-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Potassium	4-Oct-18	0.596	0.591	0.603	0.607	0.603	0.608
Potassium..K..Dissolved	4-Oct-18	0.583	0.592	0.601	0.592	0.598	0.595
Selenium	4-Oct-18	0.000172	0.000152	0.000174	0.000361	0.000374	0.000479
Selenium..Se..Dissolved	4-Oct-18	0.000202	0.00014	0.000168	0.000365	0.000328	0.000434
Silicon..Si..Dissolved	4-Oct-18	1.43	1.44	1.45	1.42	1.41	1.42
Silicon..Si..Total	4-Oct-18	1.45	1.45	1.47	1.5	1.47	1.49
Silver	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Silver..Ag..Dissolved	4-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Sodium..Na..Dissolved	4-Oct-18	1.39	1.38	1.53	1.61	1.53	1.73
Sodium..Na..Total	4-Oct-18	1.44	1.42	1.52	1.67	1.61	1.77
Strontium..Sr..Dissolved	4-Oct-18	0.0976	0.0993	0.0999	0.0981	0.0966	0.0949
Strontium..Sr..Total	4-Oct-18	0.0993	0.0984	0.0986	0.096	0.0963	0.0976
Sulfate	4-Oct-18	10.1	10.1	10.9	10.9	10.6	11.2
Thallium	4-Oct-18	0.0000066	0.0000033	0.0000045	0.000111	0.0000813	0.00016
Thallium..Tl..Dissolved	4-Oct-18	0.000005	0.000003	0.0000039	0.000112	0.0000842	0.000161

metric	Date.Sampled	Old Bridge_l-1mab	Old Bridge_l-1md	Old Bridge_l-sh	Old Bridge_r-1mab	Old Bridge_r-1md	Old Bridge_r-sh
Tin..Sn..Dissolved	4-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	0.000033
Tin..Sn..Total	4-Oct-18	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	0.000034
Titanium..Ti..Dissolved	4-Oct-18	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030	<0.00030
Titanium..Ti..Total	4-Oct-18	0.00095	0.00104	0.00111	<0.0010	0.00099	0.00095
Total.Dissolved.Solids	4-Oct-18						
Total.Kjeldahl.Nitrogen	4-Oct-18	0.077	0.088	0.101	0.083	0.084	0.098
Total.Suspended.Solids	4-Oct-18						
Turbidity	4-Oct-18	0.65	0.63	0.55	0.68	0.57	0.64
Uranium..U..Dissolved	4-Oct-18	0.000437	0.00044	0.000472	0.00044	0.000442	0.000435
Uranium..U..Total	4-Oct-18	0.000412	0.000416	0.000445	0.000414	0.000406	0.000417
Vanadium..V..Dissolved	4-Oct-18	0.00011	0.000111	0.000115	0.000116	0.000117	0.000115
Vanadium..V..Total	4-Oct-18	0.000179	0.000189	0.000193	0.000181	0.000202	0.000191
Zinc	4-Oct-18	0.0007	0.00068	0.00084	0.00141	0.00101	0.00168
Zinc..Zn..Dissolved	4-Oct-18	<0.0010	<0.0010	<0.0010	0.0012	<0.0010	0.0014
Zirconium..Zr..Dissolved	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Zirconium..Zr..Total	4-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

metric	Date.Sampled	Stoney Creek_l-1mab	Stoney Creek_l-1md	Stoney Creek_l-sh	Stoney Creek_r-1mab	Stoney Creek_r-1md	Stoney Creek_r-sh
Alkalinity..Total..as.CaCO3.	5-Oct-18						
Aluminum	5-Oct-18	0.0145	0.0145	0.0163	0.0147	0.0157	0.014
Aluminum..Al..Dissolved	5-Oct-18	0.00638	0.00662	0.00675	0.00618	0.00785	0.00682
Ammonia	5-Oct-18	<0.0050	<0.0050	0.0079	<0.0050	0.005	0.0133
Antimony..Sb..Dissolved	5-Oct-18	0.000033	0.000034	0.000032	0.000035	0.000043	0.000034
Antimony..Sb..Total	5-Oct-18	0.000027	0.000033	0.000032	0.000031	0.00003	0.000034
Arsenic	5-Oct-18	0.000168	0.000175	0.000182	0.000175	0.000166	0.00018
Arsenic..As..Dissolved	5-Oct-18	0.000169	0.000175	0.000167	0.000181	0.000174	0.000178
Barium..Ba..Dissolved	5-Oct-18	0.017	0.0167	0.0166	0.0166	0.0169	0.017
Barium..Ba..Total	5-Oct-18	0.0176	0.0171	0.0175	0.0172	0.0172	0.017
Beryllium..Be..Dissolved	5-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Beryllium..Be..Total	5-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Bismuth..Bi..Dissolved	5-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Bismuth..Bi..Total	5-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Boron..B..Dissolved	5-Oct-18	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Boron..B..Total	5-Oct-18	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Bromide..Br.	5-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Cadmium	5-Oct-18	<0.0000050	<0.0000050	0.0000052	0.0000051	0.0000052	0.0000062
Cadmium..Cd..Total	5-Oct-18	0.0000084	0.0000093	0.0000074	0.0000089	0.0000077	0.0000085
Calcium..Ca..Dissolved	5-Oct-18	15.9	15.7	15.9	15.4	15.8	15.5
Calcium..Ca..Total	5-Oct-18	17.2	16.6	17	16.7	16.9	16.8
Chloride..Cl.	5-Oct-18	0.65	0.65	0.66	0.66	0.65	0.68

metric	Date.Sampled	Stoney Creek_l-1mab	Stoney Creek_l-1md	Stoney Creek_l-sh	Stoney Creek_r-1mab	Stoney Creek_r-1md	Stoney Creek_r-sh
Chromium	5-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Chromium..Cr..Dissolved	5-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cobalt..Co..Dissolved	5-Oct-18	0.0000069	0.0000065	0.0000078	0.0000067	0.0000074	0.0000068
Cobalt..Co..Total	5-Oct-18	0.0000155	0.0000139	0.0000169	0.0000131	0.0000171	0.000015
Conductivity	5-Oct-18						
Copper	5-Oct-18	0.00033	0.00032	0.00034	0.00033	0.00033	0.00032
Copper..Cu..Dissolved	5-Oct-18	0.00028	0.00029	0.00031	0.00029	0.0003	0.00028
Fluoride..F.	5-Oct-18	0.058	0.058	0.058	0.058	0.058	0.058
Iron	5-Oct-18	0.0164	0.0156	0.0187	0.0172	0.0192	0.0162
Iron..Fe..Dissolved	5-Oct-18	0.0027	0.0027	0.0028	0.0026	0.0059	0.0026
Lead	5-Oct-18	0.000045	0.000047	0.000055	0.000047	0.000047	0.000053
Lead..Pb..Dissolved	5-Oct-18	0.0000094	0.0000102	0.0000097	0.0000099	0.0000142	0.0000128
Lithium..Li..Dissolved	5-Oct-18	0.00099	0.00099	0.001	0.00098	0.00101	0.00097
Lithium..Li..Total	5-Oct-18	0.00103	0.00101	0.00102	0.00105	0.00103	0.00101
Magnesium..Mg..Dissolved	5-Oct-18	3.57	3.59	3.63	3.61	3.59	3.69
Magnesium..Mg..Total	5-Oct-18	3.98	3.96	4.1	4.06	3.99	4.05
Manganese..Mn..Dissolved	5-Oct-18	0.00324	0.00327	0.00322	0.00331	0.00339	0.00333
Manganese..Mn..Total	5-Oct-18	0.00498	0.00493	0.00517	0.00498	0.00504	0.00501
Mercury	5-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Mercury..Hg..Dissolved	5-Oct-18	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Molybdenum..Mo..Dissolved	5-Oct-18	0.000525	0.000497	0.000526	0.000499	0.000514	0.000501
Molybdenum..Mo..Total	5-Oct-18	0.000548	0.000512	0.000554	0.000523	0.000517	0.000542
Nickel	5-Oct-18	0.000384	0.000366	0.000373	0.000393	0.000389	0.00038
Nickel..Ni..Dissolved	5-Oct-18	0.000344	0.000334	0.000337	0.000351	0.000353	0.000358

metric	Date.Sampled	Stoney Creek_l-1mab	Stoney Creek_l-1md	Stoney Creek_l-sh	Stoney Creek_r-1mab	Stoney Creek_r-1md	Stoney Creek_r-sh
Nitrate	5-Oct-18	0.0643	0.0647	0.0663	0.0652	0.0639	0.0656
Nitrite	5-Oct-18	0.001	0.0012	0.0011	0.0011	0.0011	0.0012
Organic.Carbon	5-Oct-18	1.17	1.47	1.12	1.13	1.15	1.09
Phosphorus	5-Oct-18	0.0082	0.0061	0.0065	0.0063	0.0057	0.0063
Phosphorus..P..Dissolved	5-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Phosphorus..P..Total..Dissolved	5-Oct-18	0.0036	0.0035	0.0036	0.0032	0.0034	0.0032
Phosphorus..P..Total.1	5-Oct-18	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Potassium	5-Oct-18	0.584	0.591	0.591	0.588	0.589	0.588
Potassium..K..Dissolved	5-Oct-18	0.589	0.577	0.589	0.585	0.592	0.587
Selenium	5-Oct-18	0.000195	0.000212	0.000161	0.000143	0.000178	0.000186
Selenium..Se..Dissolved	5-Oct-18	0.000193	0.000167	0.000171	0.000163	0.00017	0.000164
Silicon..Si..Dissolved	5-Oct-18	1.39	1.39	1.36	1.38	1.37	1.38
Silicon..Si..Total	5-Oct-18	1.52	1.5	1.52	1.51	1.49	1.45
Silver	5-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Silver..Ag..Dissolved	5-Oct-18	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Sodium..Na..Dissolved	5-Oct-18	1.44	1.4	1.38	1.45	1.45	1.49
Sodium..Na..Total	5-Oct-18	1.41	1.4	1.44	1.39	1.38	1.43
Strontium..Sr..Dissolved	5-Oct-18	0.097	0.0961	0.0948	0.0965	0.0946	0.0961
Strontium..Sr..Total	5-Oct-18	0.0993	0.0945	0.0982	0.0987	0.0952	0.097
Sulfate	5-Oct-18	10	10.1	10.1	10.1	10	10.2
Thallium	5-Oct-18	0.0000025	0.0000033	0.0000036	0.0000034	0.000003	0.0000038
Thallium..Tl..Dissolved	5-Oct-18	0.0000021	0.0000021	0.0000025	0.0000026	0.0000028	0.0000023

metric	Date.Sampled	Stoney Creek_l-1mab	Stoney Creek_l-1md	Stoney Creek_l-sh	Stoney Creek_r-1mab	Stoney Creek_r-1md	Stoney Creek_r-sh
Tin..Sn..Dissolved	5-Oct-18	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010
Tin..Sn..Total	5-Oct-18	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020	<0.000020
Titanium..Ti..Dissolved	5-Oct-18	<0.00030	<0.00030	<0.00030	<0.00030	0.0004	<0.00030
Titanium..Ti..Total	5-Oct-18	<0.00050	<0.00050	0.00055	<0.00050	<0.0010	<0.00050
Total.Dissolved.Solids	5-Oct-18						
Total.Kjeldahl.Nitrogen	5-Oct-18	0.053	0.072	0.076	0.072	0.084	0.079
Total.Suspended.Solids	5-Oct-18						
Turbidity	5-Oct-18	0.57	0.59	0.61	0.56	0.51	0.44
Uranium..U..Dissolved	5-Oct-18	0.000436	0.000435	0.000444	0.000436	0.000447	0.00042
Uranium..U..Total	5-Oct-18	0.00041	0.000419	0.000421	0.000417	0.00041	0.000423
Vanadium..V..Dissolved	5-Oct-18	0.000116	0.000121	0.000115	0.000118	0.000124	0.000115
Vanadium..V..Total	5-Oct-18	0.000153	0.000154	0.00016	0.000171	0.00016	0.000159
Zinc	5-Oct-18	0.00061	0.00055	0.00054	0.00064	0.00065	0.00058
Zinc..Zn..Dissolved	5-Oct-18	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Zirconium..Zr..Dissolved	5-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Zirconium..Zr..Total	5-Oct-18	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010

metric	Date.Sampled	Waneta_comp
Alkalinity..Total..as.CaCO3.	3-Oct-18	
Aluminum	3-Oct-18	0.0118
Aluminum..Al..Dissolved	3-Oct-18	0.00668
Ammonia	3-Oct-18	0.0114
Antimony..Sb..Dissolved	3-Oct-18	0.000086
Antimony..Sb..Total	3-Oct-18	0.000081
Arsenic	3-Oct-18	0.000187
Arsenic..As..Dissolved	3-Oct-18	0.000171
Barium..Ba..Dissolved	3-Oct-18	0.0168
Barium..Ba..Total	3-Oct-18	0.017
Beryllium..Be..Dissolved	3-Oct-18	<0.000010
Beryllium..Be..Total	3-Oct-18	<0.000010
Bismuth..Bi..Dissolved	3-Oct-18	<0.0000050
Bismuth..Bi..Total	3-Oct-18	<0.0000050
Boron..B..Dissolved	3-Oct-18	<0.010
Boron..B..Total	3-Oct-18	<0.0050
Bromide..Br.	3-Oct-18	<0.050
Cadmium	3-Oct-18	0.0000146
Cadmium..Cd..Total	3-Oct-18	0.0000211
Calcium..Ca..Dissolved	3-Oct-18	15.6
Calcium..Ca..Total	3-Oct-18	16.5
Chloride..Cl.	3-Oct-18	0.6
Chromium	3-Oct-18	<0.00010

metric	Date.Sampled	Waneta_comp
Chromium..Cr..Dissolved	3-Oct-18	<0.00010
Cobalt..Co..Dissolved	3-Oct-18	0.0000079
Cobalt..Co..Total	3-Oct-18	0.0000113
Conductivity	3-Oct-18	
Copper	3-Oct-18	0.00036
Copper..Cu..Dissolved	3-Oct-18	0.00033
Fluoride..F.	3-Oct-18	0.059
Iron	3-Oct-18	0.0106
Iron..Fe..Dissolved	3-Oct-18	0.0028
Lead	3-Oct-18	0.000088
Lead..Pb..Dissolved	3-Oct-18	0.0000261
Lithium..Li..Dissolved	3-Oct-18	0.00098
Lithium..Li..Total	3-Oct-18	0.001
Magnesium..Mg..Dissolved	3-Oct-18	3.64
Magnesium..Mg..Total	3-Oct-18	3.88
Manganese..Mn..Dissolved	3-Oct-18	0.000733
Manganese..Mn..Total	3-Oct-18	0.00185
Mercury	3-Oct-18	<0.00050
Mercury..Hg..Dissolved	3-Oct-18	<0.00050
Molybdenum..Mo..Dissolved	3-Oct-18	0.000527
Molybdenum..Mo..Total	3-Oct-18	0.000572
Nickel	3-Oct-18	0.000376
Nickel..Ni..Dissolved	3-Oct-18	0.000359
Nitrate	3-Oct-18	0.0753

metric	Date.Sampled	Waneta_comp
Nitrite	3-Oct-18	0.0013
Organic.Carbon	3-Oct-18	1.19
Phosphorus	3-Oct-18	0.0065
Phosphorus..P..Dissolved	3-Oct-18	<0.050
Phosphorus..P..Total..Dissolved	3-Oct-18	0.003
Phosphorus..P..Total.1	3-Oct-18	<0.050
Potassium	3-Oct-18	0.599
Potassium..K..Dissolved	3-Oct-18	0.598
Selenium	3-Oct-18	0.000178
Selenium..Se..Dissolved	3-Oct-18	0.000179
Silicon..Si..Dissolved	3-Oct-18	1.41
Silicon..Si..Total	3-Oct-18	1.41
Silver	3-Oct-18	<0.0000050
Silver..Ag..Dissolved	3-Oct-18	<0.0000050
Sodium..Na..Dissolved	3-Oct-18	1.34
Sodium..Na..Total	3-Oct-18	1.4
Strontium..Sr..Dissolved	3-Oct-18	0.0994
Strontium..Sr..Total	3-Oct-18	0.104
Sulfate	3-Oct-18	10.4
Thallium	3-Oct-18	0.0000306
Thallium..Tl..Dissolved	3-Oct-18	0.0000303
Tin..Sn..Dissolved	3-Oct-18	<0.000010

metric	Date.Sampled	Waneta_comp
Tin..Sn..Total	3-Oct-18	<0.000020
Titanium..Ti..Dissolved	3-Oct-18	<0.00030
Titanium..Ti..Total	3-Oct-18	<0.00050
Total.Dissolved.Solids	3-Oct-18	
Total.Kjeldahl.Nitrogen	3-Oct-18	0.093
Total.Suspended.Solids	3-Oct-18	
Turbidity	3-Oct-18	0.4
Uranium..U..Dissolved	3-Oct-18	0.000447
Uranium..U..Total	3-Oct-18	0.000415
Vanadium..V..Dissolved	3-Oct-18	0.000112
Vanadium..V..Total	3-Oct-18	0.000151
Zinc	3-Oct-18	0.00069
Zinc..Zn..Dissolved	3-Oct-18	<0.0010
Zirconium..Zr..Dissolved	3-Oct-18	<0.00010
Zirconium..Zr..Total	3-Oct-18	<0.00010

APPENDIX D WATER QUALITY QA/QC

Table 1: Water quality assurance / control for samples taken in 2018.

Metric	Date sampled	Sample	New Bridge value[1]	Duplicate value[1]	Percent difference[2]	Minimum detection limit
Aluminum	04-Apr-2018	r-sh	0.00991	0.00874	12.5%	0.000700
Aluminum	04-Oct-2018	r-sh	0.0236	0.0238	0.8%	0.000700
Aluminum	04-Oct-2018	r-md	0.0209	0.0231	10.0%	0.000700
Aluminum	04-Oct-2018	l-sh	0.0221	0.0198	11.0%	0.000700
Aluminum	05-Apr-2018	r-sh	0.00829	0.00821	1.0%	0.000700
Aluminum	17-Jul-2018	r-sh	0.0203	0.0196	3.5%	0.000700
Aluminum	18-Apr-2018	r-sh	0.0255	0.0226	12.1%	0.000700
Aluminum	19-Apr-2018	r-sh	0.0227	0.0189	18.3%	0.000700
Aluminum	22-Mar-2018	r-sh	0.0114	0.0105	8.2%	0.000700
Ammonia	04-Apr-2018	r-sh	0.0289	0.0212	30.7%	0.005000
Ammonia	04-Oct-2018	r-sh	0.0198	0.0188	5.2%	0.005000
Ammonia	04-Oct-2018	r-md	0.0058	0.0056	3.5%	0.005000
Ammonia	04-Oct-2018	l-sh	0.0447	0.0461	3.1%	0.005000
Ammonia	05-Apr-2018	r-sh	0.0194	0.019	2.1%	0.005000
Ammonia	17-Jul-2018	r-sh	0.0101	0.0089	12.6%	0.005000
Ammonia	18-Apr-2018	r-sh	0.0197	0.022	11.0%	0.005000
Ammonia	19-Apr-2018	r-sh	0.021	0.0201	4.4%	0.005000
Ammonia	22-Mar-2018	r-sh	0.0108	0.0091	17.1%	0.005000
Arsenic	04-Apr-2018	r-sh	0.000435	0.000474	8.6%	0.000020
Arsenic	04-Oct-2018	r-sh	0.000562	0.000574	2.1%	0.000020
Arsenic	04-Oct-2018	r-md	0.000169	0.000167	1.2%	0.000020
Arsenic	04-Oct-2018	l-sh	0.000183	0.000187	2.2%	0.000020
Arsenic	05-Apr-2018	r-sh	0.000419	0.000391	6.9%	0.000020
Arsenic	17-Jul-2018	r-sh	0.000302	0.000289	4.4%	0.000020
Arsenic	18-Apr-2018	r-sh	0.000505	0.000516	2.2%	0.000020
Arsenic	19-Apr-2018	r-sh	0.000572	0.000541	5.6%	0.000020
Arsenic	22-Mar-2018	r-sh	0.000346	0.000342	1.2%	0.000020
Cadmium	04-Apr-2018	r-sh	0.000221	0.000249	11.9%	0.000005
Cadmium	04-Oct-2018	r-sh	0.000272	0.000235	14.6%	0.000005
Cadmium	04-Oct-2018	r-md	0.0000088	0.0000092	4.4%	0.000005
Cadmium	04-Oct-2018	l-sh	0.0000078	0.0000063	21.3%	0.000005
Cadmium	05-Apr-2018	r-sh	0.000245	0.00025	2.0%	0.000005
Cadmium	17-Jul-2018	r-sh	0.000117	0.000106	9.9%	0.000005

Metric	Date sampled	Sample	New Bridge value[1]	Duplicate value[1]	Percent difference[2]	Minimum detection limit
Cadmium	18-Apr-2018	r-sh	0.000313	0.000329	5.0%	0.000005
Cadmium	19-Apr-2018	r-sh	0.000261	0.000262	0.4%	0.000005
Cadmium	22-Mar-2018	r-sh	0.000345	0.000337	2.3%	0.000005
Chromium	04-Apr-2018	r-sh	<0.0001	<0.0001	0.0%	0.000100
Chromium	04-Oct-2018	r-sh	<0.0001	<0.0001	0.0%	0.000100
Chromium	04-Oct-2018	r-md	<0.0001	<0.0001	0.0%	0.000100
Chromium	04-Oct-2018	l-sh	<0.0001	<0.0001	0.0%	0.000100
Chromium	05-Apr-2018	r-sh	<0.0001	0.00011	75.0%	0.000100
Chromium	17-Jul-2018	r-sh	<0.0001	<0.0001	0.0%	0.000100
Chromium	18-Apr-2018	r-sh	0.0001	<0.0001	66.7%	0.000100
Chromium	19-Apr-2018	r-sh	<0.0001	<0.0001	0.0%	0.000100
Chromium	22-Mar-2018	r-sh	<0.0001	<0.0001	0.0%	0.000100
Copper	04-Apr-2018	r-sh	0.00069	0.0007	1.4%	0.000100
Copper	04-Oct-2018	r-sh	0.00059	0.00056	5.2%	0.000100
Copper	04-Oct-2018	r-md	0.00034	0.00033	3.0%	0.000100
Copper	04-Oct-2018	l-sh	0.00033	0.00033	0.0%	0.000100
Copper	05-Apr-2018	r-sh	0.00075	0.00075	0.0%	0.000100
Copper	17-Jul-2018	r-sh	0.00049	0.00046	6.3%	0.000100
Copper	18-Apr-2018	r-sh	0.00106	0.00102	3.8%	0.000100
Copper	19-Apr-2018	r-sh	0.00077	0.00072	6.7%	0.000100
Copper	22-Mar-2018	r-sh	0.00078	0.0008	2.5%	0.000100
Iron	04-Apr-2018	r-sh	0.0095	0.0094	1.1%	0.001000
Iron	04-Oct-2018	r-sh	0.0292	0.0293	0.3%	0.001000
Iron	04-Oct-2018	r-md	0.0283	0.0273	3.6%	0.001000
Iron	04-Oct-2018	l-sh	0.0269	0.0254	5.7%	0.001000
Iron	05-Apr-2018	r-sh	0.0094	0.0105	11.1%	0.001000
Iron	17-Jul-2018	r-sh	0.011	0.0093	16.7%	0.001000
Iron	18-Apr-2018	r-sh	0.0285	0.0261	8.8%	0.001000
Iron	19-Apr-2018	r-sh	0.0257	0.022	15.5%	0.001000
Iron	22-Mar-2018	r-sh	0.0107	0.0102	4.8%	0.001000
Lead	04-Apr-2018	r-sh	0.000262	0.000263	0.4%	0.000010
Lead	04-Oct-2018	r-sh	0.000943	0.000916	2.9%	0.000010
Lead	04-Oct-2018	r-md	0.000059	0.00006	1.7%	0.000010
Lead	04-Oct-2018	l-sh	0.000057	0.000061	6.8%	0.000010

Metric	Date sampled	Sample	New Bridge value[1]	Duplicate value[1]	Percent difference[2]	Minimum detection limit
Lead	05-Apr-2018	r-sh	0.0003	0.000272	9.8%	0.000010
Lead	17-Jul-2018	r-sh	0.000396	0.00036	9.5%	0.000010
Lead	18-Apr-2018	r-sh	0.000678	0.000642	5.5%	0.000010
Lead	19-Apr-2018	r-sh	0.00172	0.00162	6.0%	0.000010
Lead	22-Mar-2018	r-sh	0.000689	0.000616	11.2%	0.000010
Mercury	04-Apr-2018	r-sh	<0.0005	<0.0005	9.5%	0.000500
Mercury	04-Oct-2018	r-sh	<0.0005	<0.0005	8.3%	0.000500
Mercury	04-Oct-2018	r-md	<0.0005	<0.0005	0.0%	0.000500
Mercury	04-Oct-2018	l-sh	<0.0005	<0.0005	0.0%	0.000500
Mercury	05-Apr-2018	r-sh	<0.0005	<0.0005	6.0%	0.000500
Mercury	17-Jul-2018	r-sh	<0.0005	<0.0005	3.9%	0.000500
Mercury	18-Apr-2018	r-sh	<0.0005	<0.0005	0.0%	0.000500
Mercury	19-Apr-2018	r-sh	<0.0005	<0.0005	8.3%	0.000500
Mercury	22-Mar-2018	r-sh	<0.0005	<0.0005	6.8%	0.000500
Nickel	04-Apr-2018	r-sh	0.00035	0.00034	2.9%	0.000050
Nickel	04-Oct-2018	r-sh	0.000449	0.000428	4.8%	0.000050
Nickel	04-Oct-2018	r-md	0.000394	0.000393	0.3%	0.000050
Nickel	04-Oct-2018	l-sh	0.000398	0.000424	6.3%	0.000050
Nickel	05-Apr-2018	r-sh	0.000373	0.000359	3.8%	0.000050
Nickel	17-Jul-2018	r-sh	0.000362	0.000354	2.2%	0.000050
Nickel	18-Apr-2018	r-sh	0.000372	0.000358	3.8%	0.000050
Nickel	19-Apr-2018	r-sh	0.000388	0.000348	10.9%	0.000050
Nickel	22-Mar-2018	r-sh	0.000374	0.000345	8.1%	0.000050
Nitrate	04-Apr-2018	r-sh	0.265	0.262	1.1%	0.005000
Nitrate	04-Oct-2018	r-sh	0.176	0.177	0.6%	0.005000
Nitrate	04-Oct-2018	r-md	0.0662	0.0654	1.2%	0.005000
Nitrate	04-Oct-2018	l-sh	0.0863	0.085	1.5%	0.005000
Nitrate	05-Apr-2018	r-sh	0.259	0.258	0.4%	0.005000
Nitrate	17-Jul-2018	r-sh	0.102	0.103	1.0%	0.005000
Nitrate	18-Apr-2018	r-sh	0.245	0.243	0.8%	0.005000
Nitrate	19-Apr-2018	r-sh	0.279	0.279	0.0%	0.005000
Nitrate	22-Mar-2018	r-sh	0.255	0.256	0.4%	0.005000
Nitrite	04-Apr-2018	r-sh	<0.001	<0.001	0.0%	0.001000
Nitrite	04-Oct-2018	r-sh	<0.001	<0.001	0.0%	0.001000

Metric	Date sampled	Sample	New Bridge value[1]	Duplicate value[1]	Percent difference[2]	Minimum detection limit
Nitrite	04-Oct-2018	r-md	<0.001	<0.001	0.0%	0.001000
Nitrite	04-Oct-2018	l-sh	0.0013	0.001	26.1%	0.001000
Nitrite	05-Apr-2018	r-sh	<0.001	<0.001	0.0%	0.001000
Nitrite	17-Jul-2018	r-sh	0.0018	0.0013	32.3%	0.001000
Nitrite	18-Apr-2018	r-sh	<0.001	<0.001	0.0%	0.001000
Nitrite	19-Apr-2018	r-sh	<0.001	<0.001	0.0%	0.001000
Nitrite	22-Mar-2018	r-sh	0.0014	<0.001	94.7%	0.001000
Phosphorus	04-Apr-2018	r-sh	0.0059	0.0067	12.7%	0.002000
Phosphorus	04-Oct-2018	r-sh	0.007	0.0067	4.4%	0.002000
Phosphorus	04-Oct-2018	r-md	0.0065	0.0058	11.4%	0.002000
Phosphorus	04-Oct-2018	l-sh	0.0067	0.0061	9.4%	0.002000
Phosphorus	05-Apr-2018	r-sh	0.0049	0.0052	5.9%	0.002000
Phosphorus	17-Jul-2018	r-sh	0.0049	0.005	2.0%	0.002000
Phosphorus	18-Apr-2018	r-sh	0.0049	0.0046	6.3%	0.002000
Phosphorus	19-Apr-2018	r-sh	0.0045	0.0045	0.0%	0.002000
Phosphorus	22-Mar-2018	r-sh	0.0047	0.0042	11.2%	0.002000
Potassium	04-Apr-2018	r-sh	0.706	0.696	1.4%	0.050000
Potassium	04-Oct-2018	r-sh	0.683	0.692	1.3%	0.050000
Potassium	04-Oct-2018	r-md	0.593	0.594	0.2%	0.050000
Potassium	04-Oct-2018	l-sh	0.611	0.6	1.8%	0.050000
Potassium	05-Apr-2018	r-sh	0.683	0.684	0.1%	0.050000
Potassium	17-Jul-2018	r-sh	0.593	0.589	0.7%	0.050000
Potassium	18-Apr-2018	r-sh	0.773	0.764	1.2%	0.050000
Potassium	19-Apr-2018	r-sh	0.771	0.733	5.1%	0.050000
Potassium	22-Mar-2018	r-sh	0.688	0.663	3.7%	0.050000
Selenium	04-Apr-2018	r-sh	0.00185	0.00185	0.0%	0.000040
Selenium	04-Oct-2018	r-sh	0.00184	0.00199	7.8%	0.000040
Selenium	04-Oct-2018	r-md	0.000174	0.000209	18.3%	0.000040
Selenium	04-Oct-2018	l-sh	0.000176	0.000187	6.1%	0.000040
Selenium	05-Apr-2018	r-sh	0.00193	0.00202	4.6%	0.000040
Selenium	17-Jul-2018	r-sh	0.000759	0.000762	0.4%	0.000040
Selenium	18-Apr-2018	r-sh	0.00235	0.00249	5.8%	0.000040
Selenium	19-Apr-2018	r-sh	0.00206	0.00205	0.5%	0.000040
Selenium	22-Mar-2018	r-sh	0.00172	0.00179	4.0%	0.000040

Metric	Date sampled	Sample	New Bridge value[1]	Duplicate value[1]	Percent difference[2]	Minimum detection limit
Silver	04-Apr-2018	r-sh	<0.000005	<0.000005	0.0%	0.000005
Silver	04-Oct-2018	r-sh	<0.000005	<0.000005	0.0%	0.000005
Silver	04-Oct-2018	r-md	<0.000005	<0.000005	0.0%	0.000005
Silver	04-Oct-2018	l-sh	<0.000005	<0.000005	0.0%	0.000005
Silver	05-Apr-2018	r-sh	<0.000005	<0.000005	0.0%	0.000005
Silver	17-Jul-2018	r-sh	<0.000005	<0.000005	0.0%	0.000005
Silver	18-Apr-2018	r-sh	<0.000005	<0.000005	0.0%	0.000005
Silver	19-Apr-2018	r-sh	<0.000005	<0.000005	0.0%	0.000005
Silver	22-Mar-2018	r-sh	<0.000005	<0.000005	0.0%	0.000005
Sulfate	04-Apr-2018	r-sh	18.1	18.1	0.0%	0.300000
Sulfate	04-Oct-2018	r-sh	18.6	18.5	0.5%	0.300000
Sulfate	04-Oct-2018	r-md	10	9.99	0.1%	0.300000
Sulfate	04-Oct-2018	l-sh	11.1	11	0.9%	0.300000
Sulfate	05-Apr-2018	r-sh	17	16.9	0.6%	0.300000
Sulfate	17-Jul-2018	r-sh	11.7	11.8	0.9%	0.300000
Sulfate	18-Apr-2018	r-sh	19.4	19.4	0.0%	0.300000
Sulfate	19-Apr-2018	r-sh	17.5	17.5	0.0%	0.300000
Sulfate	22-Mar-2018	r-sh	18.1	18.1	0.0%	0.300000
Thallium	04-Apr-2018	r-sh	0.000632	0.00061	3.5%	0.000002
Thallium	04-Oct-2018	r-sh	0.00114	0.00111	2.7%	0.000002
Thallium	04-Oct-2018	r-md	0.0000066	0.0000093	34.0%	0.000002
Thallium	04-Oct-2018	l-sh	0.0000036	0.0000036	0.0%	0.000002
Thallium	05-Apr-2018	r-sh	0.000486	0.000509	4.6%	0.000002
Thallium	17-Jul-2018	r-sh	0.000196	0.0002	2.0%	0.000002
Thallium	18-Apr-2018	r-sh	0.00103	0.00104	1.0%	0.000002
Thallium	19-Apr-2018	r-sh	0.00108	0.0011	1.8%	0.000002
Thallium	22-Mar-2018	r-sh	0.0000578	0.000054	6.8%	0.000002
Total Kjeldahl Nitrogen	04-Apr-2018	r-sh	0.088	0.107	19.5%	0.050000
Total Kjeldahl Nitrogen	04-Oct-2018	r-sh	0.127	0.109	15.3%	0.050000
Total Kjeldahl Nitrogen	04-Oct-2018	r-md	0.076	0.078	2.6%	0.050000
Total Kjeldahl Nitrogen	04-Oct-2018	l-sh	0.132	0.129	2.3%	0.050000
Total Kjeldahl Nitrogen	05-Apr-2018	r-sh	0.088	0.093	5.5%	0.050000
Total Kjeldahl Nitrogen	17-Jul-2018	r-sh	0.083	0.116	33.2%	0.050000
Total Kjeldahl Nitrogen	18-Apr-2018	r-sh	0.113	0.086	27.1%	0.050000

Metric	Date sampled	Sample	New Bridge value[1]	Duplicate value[1]	Percent difference[2]	Minimum detection limit
Total Kjeldahl Nitrogen	19-Apr-2018	r-sh	0.111	0.118	6.1%	0.050000
Total Kjeldahl Nitrogen	22-Mar-2018	r-sh	0.063	0.073	14.7%	0.050000
Total Organic Carbon	04-Apr-2018	r-sh	1.3	1.37	5.2%	0.500000
Total Organic Carbon	04-Oct-2018	r-sh	1.18	1.16	1.7%	0.500000
Total Organic Carbon	04-Oct-2018	r-md	1.36	1.08	23.0%	0.500000
Total Organic Carbon	04-Oct-2018	l-sh	1.12	1.05	6.5%	0.500000
Total Organic Carbon	05-Apr-2018	r-sh	1.21	1.31	7.9%	0.500000
Total Organic Carbon	17-Jul-2018	r-sh	1.48	1.63	9.6%	0.500000
Total Organic Carbon	18-Apr-2018	r-sh	1.65	1.66	0.6%	0.500000
Total Organic Carbon	19-Apr-2018	r-sh	1.82	1.43	24.0%	0.500000
Total Organic Carbon	22-Mar-2018	r-sh	1.21	1.14	6.0%	0.500000
Zinc	04-Apr-2018	r-sh	0.00525	0.00487	7.5%	0.000500
Zinc	04-Oct-2018	r-sh	0.00659	0.00648	1.7%	0.000500
Zinc	04-Oct-2018	r-md	0.00083	0.00092	10.3%	0.000500
Zinc	04-Oct-2018	l-sh	0.00084	0.0009	6.9%	0.000500
Zinc	05-Apr-2018	r-sh	0.00579	0.0056	3.3%	0.000500
Zinc	17-Jul-2018	r-sh	0.00316	0.00314	0.6%	0.000500
Zinc	18-Apr-2018	r-sh	0.00778	0.00747	4.1%	0.000500
Zinc	19-Apr-2018	r-sh	0.00754	0.00741	1.7%	0.000500
Zinc	22-Mar-2018	r-sh	0.00601	0.00589	2.0%	0.000500

[1] Italicized values indicate measurements below the minimum detection limit.

[2] Bolded values indicate measurements with a percentage difference greater than or equal to 50%.

APPENDIX E CHLOROPHYLL A RESULTS

CARO
ANALYTICAL SERVICES

CERTIFICATE OF ANALYSIS

REPORTED TO Ecoscape Environmental Ltd.
#102 - 450 Neave Court
Kelowna, BC V1V 2M2

ATTENTION Kyle Hawes

PO NUMBER
PROJECT Chlorophyll-A
PROJECT INFO

WORK ORDER 8101069

RECEIVED / TEMP 2018-10-11 16:45 / 6°C
REPORTED 2018-10-30 11:07
COC NUMBER B74758

Introduction:

CARO Analytical Services is a testing laboratory full of smart, engaged scientists driven to make the world a safer and healthier place. Through our clients' projects we become an essential element for a better world. We employ methods conducted in accordance with recognized professional standards using accepted testing methodologies and quality control efforts. CARO is accredited by the Canadian Association for Laboratories Accreditation (CALA) to ISO 17025:2005 for specific tests listed in the scope of accreditation approved by CALA.

Big Picture Sidekicks

You know that the sample you collected after snowshoeing to site, digging 5 meters, and racing to get it on a plane so you can submit it to the lab for time sensitive results needed to make important and expensive decisions (whew) is VERY important. We know that too.

We've Got Chemistry

It's simple. We figure the more you enjoy working with our fun and engaged team members; the more likely you are to give us continued opportunities to support you.

Ahead of the Curve

Through research, regulation knowledge, and instrumentation, we are your analytical centre for the technical knowledge you need, BEFORE you need it, so you can stay up to date and in the know.

Work Order Comments:

Due to a laboratory error, the results for ERO-EXP-5-2B and ERO-REF-1-4B are unavailable -ES 10/30/2018

If you have any questions or concerns, please contact me at estclair@caro.ca

Authorized By:

Eilish St.Clair, B.Sc., C.I.T.
Client Service Representative

EStClair

TEST RESULTS

REPORTED TO	Ecoscape Environmental Ltd.	**WORK ORDER**	8101069
PROJECT	Chlorophyll-A	**REPORTED**	2018-10-30 11:07

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-5-5C (8101069-01) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**48.3**	N/A	0.10	µg	2018-10-16	
ERO-EXP-3-3B (8101069-03) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**29.9**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-5B (8101069-04) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**36.1**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-3C (8101069-05) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**11.3**	N/A	0.10	µg	2018-10-16	
ERO-EXP-3-5C (8101069-06) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**70.4**	N/A	0.10	µg	2018-10-16	
ERO-REF-2-3C (8101069-07) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**38.8**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-4A (8101069-08) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**33.9**	N/A	0.10	µg	2018-10-16	
ERO-EXP-3-5A (8101069-09) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**53.8**	N/A	0.10	µg	2018-10-16	
ERO-EXP-4-1C (8101069-10) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-4-1C (8101069-10) | Matrix: Tissue (wet) | Sampled: 2018-10-10, Continued						
General Parameters, Continued						
Chlorophyll a	**23.1**	N/A	0.10	µg	2018-10-16	
ERO-EXP-3-4B (8101069-11) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**31.1**	N/A	0.10	µg	2018-10-16	
ERO-EXP-4-4A (8101069-12) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**12.7**	N/A	0.10	µg	2018-10-16	
ERO-REF-1-5C (8101069-13) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**41.4**	N/A	0.10	µg	2018-10-16	
ERO-REF-1-2C (8101069-14) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**23.6**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-1A (8101069-15) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**29.2**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-1B (8101069-16) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**13.7**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-4B (8101069-17) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**21.5**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-1C (8101069-18) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						

TEST RESULTS

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-5-1C (8101069-18) | Matrix: Tissue (wet) | Sampled: 2018-10-10, Continued						
General Parameters, Continued						
Chlorophyll a	**40.4**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-3A (8101069-19) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**17.1**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-3B (8101069-20) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**10.3**	N/A	0.10	µg	2018-10-16	
ERO-EXP-5-2C (8101069-21) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**32.0**	N/A	0.10	µg	2018-10-18	
ERO-EXP-5-5A (8101069-22) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**26.4**	N/A	0.10	µg	2018-10-18	
ERO-EXP-5-2A (8101069-23) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**25.3**	N/A	0.10	µg	2018-10-18	
ERO-REF-1-4C (8101069-24) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**31.5**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-5B (8101069-25) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**35.2**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-4C (8101069-26) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-4-4C (8101069-26) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**9.95**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-4B (8101069-27) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**14.1**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-5C (8101069-28) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**39.2**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-1B (8101069-29) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**39.2**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-4A (8101069-30) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**22.6**	N/A	0.10	µg	2018-10-18	
ERO-REF-1-5B (8101069-31) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**26.4**	N/A	0.10	µg	2018-10-18	
ERO-REF-1-1C (8101069-32) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**35.6**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-2C (8101069-33) | Matrix: Tissue (wet) | Sampled: 2018-10-10						
General Parameters						
Chlorophyll a	**26.4**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-4B (8101069-34) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-REF-2-4B (8101069-34) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**20.6**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-2A (8101069-35) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**20.1**	N/A	0.10	µg	2018-10-18	
ERO-REF-1-4A (8101069-36) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**26.6**	N/A	0.10	µg	2018-10-18	
ERO-EXP-3-4A (8101069-37) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**37.2**	N/A	0.10	µg	2018-10-18	
ERO-EXP-3-4C (8101069-38) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**44.1**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-3B (8101069-39) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**21.1**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-1A (8101069-40) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**22.9**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-1B (8101069-41) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**11.6**	N/A	0.10	µg	2018-10-18	
ERO-EXP-3-5B (8101069-42) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

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Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-3-5B (8101069-42) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**59.2**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-2C (8101069-43) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**11.6**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-2B (8101069-44) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**11.8**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-2A (8101069-45) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**11.9**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-5A (8101069-46) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**29.6**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-3C (8101069-47) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**13.5**	N/A	0.10	µg	2018-10-18	
ERO-EXP-4-3A (8101069-48) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**14.6**	N/A	0.10	µg	2018-10-18	
ERO-EXP-1-4B (8101069-49) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**51.8**	N/A	0.10	µg	2018-10-18	
ERO-EXP-1-2A (8101069-50) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-1-2A (8101069-50) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**112**	N/A	0.10	µg	2018-10-18	
ERO-EXP-1-1C (8101069-51) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**23.6**	N/A	0.10	µg	2018-10-18	
ERO-EXP-1-1A (8101069-52) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**58.9**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-1A (8101069-53) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**39.3**	N/A	0.10	µg	2018-10-18	
ERO-REF-1-5A (8101069-54) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**34.3**	N/A	0.10	µg	2018-10-18	
ERO-REF-1-3B (8101069-55) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**19.7**	N/A	0.10	µg	2018-10-18	
ERO-REF-1-3A (8101069-56) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**37.0**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-4C (8101069-57) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**36.8**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-1C (8101069-58) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-REF-2-1C (8101069-58) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**18.1**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-5B (8101069-59) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**20.3**	N/A	0.10	µg	2018-10-18	
ERO-REF-2-3B (8101069-60) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**16.5**	N/A	0.10	µg	2018-10-18	
ERO-EXP-5-4C (8101069-62) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**13.7**	N/A	0.10	µg	2018-10-23	
ERO-EXP-3-3A (8101069-64) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**21.7**	N/A	0.10	µg	2018-10-23	
ERO-EXP-2-2C (8101069-65) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**18.8**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-2B (8101069-66) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**28.8**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-4C (8101069-67) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**37.1**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-3B (8101069-68) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

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Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-1-3B (8101069-68) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**18.6**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-1B (8101069-69) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**27.6**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-2C (8101069-70) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**42.0**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-3A (8101069-71) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**24.5**	N/A	0.10	µg	2018-10-23	
ERO-EXP-2-3B (8101069-72) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**70.9**	N/A	0.10	µg	2018-10-23	
ERO-EXP-2-4B (8101069-73) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**97.0**	N/A	0.10	µg	2018-10-23	
ERO-EXP-2-3A (8101069-74) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**64.2**	N/A	0.10	µg	2018-10-23	
ERO-EXP-2-1A (8101069-75) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**47.8**	N/A	0.10	µg	2018-10-23	
ERO-EXP-2-1B (8101069-76) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

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Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-2-1B (8101069-76) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**42.7**	N/A	0.10	µg	2018-10-23	
ERO-EXP-2-2B (8101069-77) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**19.7**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-5B (8101069-78) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**19.2**	N/A	0.10	µg	2018-10-23	
ERO-EXP-3-1B (8101069-79) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**27.5**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-5C (8101069-80) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**47.2**	N/A	0.10	µg	2018-10-23	
ERO-EXP-1-3C (8101069-81) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**48.7**	N/A	0.10	µg	2018-10-25	
ERO-EXP-2-3C (8101069-82) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**60.0**	N/A	0.10	µg	2018-10-25	
ERO-EXP-3-2B (8101069-83) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**133**	N/A	0.10	µg	2018-10-25	
ERO-EXP-2-5C (8101069-84) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

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Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-2-5C (8101069-84) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**42.1**	N/A	0.10	µg	2018-10-25	
ERO-EXP-3-1A (8101069-85) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**34.7**	N/A	0.10	µg	2018-10-25	
ERO-EXP-3-3C (8101069-86) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**34.2**	N/A	0.10	µg	2018-10-25	
ERO-EXP-3-2A (8101069-87) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**116**	N/A	0.10	µg	2018-10-25	
ERO-REF-1-1B (8101069-88) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**24.6**	N/A	0.10	µg	2018-10-25	
ERO-REF-2-3A (8101069-89) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**17.3**	N/A	0.10	µg	2018-10-25	
ERO-REF-1-1A (8101069-90) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**34.3**	N/A	0.10	µg	2018-10-25	
ERO-EXP-2-5A (8101069-91) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**86.1**	N/A	0.10	µg	2018-10-25	
ERO-EXP-1-5A (8101069-92) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-EXP-1-5A (8101069-92) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**57.5**	N/A	0.10	µg	2018-10-25	
ERO-EXP-2-4A (8101069-93) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**184**	N/A	0.10	µg	2018-10-25	
ERO-EXP-2-4C (8101069-94) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**247**	N/A	0.10	µg	2018-10-25	
ERO-REF-1-3C (8101069-95) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**12.5**	N/A	0.10	µg	2018-10-25	
ERO-REF-2-2B (8101069-96) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**45.2**	N/A	0.10	µg	2018-10-25	
ERO-REF-2-5A (8101069-97) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**17.9**	N/A	0.10	µg	2018-10-25	
ERO-REF-1-2B (8101069-98) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**26.3**	N/A	0.10	µg	2018-10-25	
ERO-REF-1-2A (8101069-99) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**22.3**	N/A	0.10	µg	2018-10-25	
ERO-REF-2-5C (8101069-AA) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
ERO-REF-2-5C (8101069-AA) | Matrix: Tissue (wet) | Sampled: 2018-10-11, Continued						
General Parameters, Continued						
Chlorophyll a	**18.1**	N/A	0.10	µg	2018-10-25	
ERO-EXP-3-2C (8101069-AB) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**86.2**	N/A	0.10	µg	2018-10-25	
ERO-EXP-2-2A (8101069-AC) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**66.2**	N/A	0.10	µg	2018-10-25	
ERO-EXP-2-5B (8101069-AD) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**88.5**	N/A	0.10	µg	2018-10-25	
ERO-EXP-2-1C (8101069-AE) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**338**	N/A	0.10	µg	2018-10-25	
ERO-EXP-1-4A (8101069-AF) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**54.9**	N/A	0.10	µg	2018-10-25	
ERO-EXP-3-1C (8101069-AG) | Matrix: Tissue (wet) | Sampled: 2018-10-11						
General Parameters						
Chlorophyll a	**46.9**	N/A	0.10	µg	2018-10-25	

APPENDIX 1: SUPPORTING INFORMATION

REPORTED TO	Ecoscape Environmental Ltd.	**WORK ORDER**	8101069
PROJECT	Chlorophyll-A	**REPORTED**	2018-10-30 11:07

Analysis Description	Method Ref.	Technique	Location
Chlorophyll-A in Tissue (wet)	SM 10200 H (2011)	Spectrophotometry	Kelowna

Glossary of Terms:

RL	Reporting Limit (default)
µg	Micrograms
SM	Standard Methods for the Examination of Water and Wastewater, American Public Health Association

Guidelines Referenced in this Report:

Guidelines for Canadian Drinking Water Quality (Health Canada, Feb 2017)

Note: In some cases, the values displayed on the report represent the lowest guideline and are to be verified by the end user

General Comments:

The results in this report apply to the samples analyzed in accordance with the Chain of Custody document. This analytical report must be reproduced in its entirety. CARO is not responsible for any loss or damage resulting directly or indirectly from error or omission in the conduct of testing. Liability is limited to the cost of analysis. Samples will be disposed of 30 days after the test report has been issued unless otherwise agreed to in writing.

APPENDIX 2: QUALITY CONTROL RESULTS

The following section displays the quality control (QC) data that is associated with your sample data. Groups of samples are prepared in “batches” and analyzed in conjunction with QC samples that ensure your data is of the highest quality. Common QC types include:

- **Method Blank (Blk)**: A blank sample that undergoes sample processing identical to that carried out for the test samples. Method blank results are used to assess contamination from the laboratory environment and reagents.
- **Duplicate (Dup)**: An additional or second portion of a randomly selected sample in the analytical run carried through the entire analytical process. Duplicates provide a measure of the analytical method's precision (reproducibility).
- **Blank Spike (BS)**: A sample of known concentration which undergoes processing identical to that carried out for test samples, also referred to as a laboratory control sample (LCS). Blank spikes provide a measure of the analytical method's accuracy.
- **Matrix Spike (MS)**: A second aliquot of sample is fortified with with a known concentration of target analytes and carried through the entire analytical process. Matrix spikes evaluate potential matrix effects that may affect the analyte recovery.
- **Reference Material (SRM)**: A homogenous material of similar matrix to the samples, certified for the parameter(s) listed. Reference Materials ensure that the analytical process is adequate to achieve acceptable recoveries of the parameter(s) tested.

Each QC type is analyzed at a 5-10% frequency, i.e. one blank/duplicate/spike for every 10-20 samples. For all types of QC, the specified recovery (% Rec) and relative percent difference (RPD) limits are derived from long-term method performance averages and/or prescribed by the reference method.

Analyte	Result	RL	Units	Spike Level	Source Result	% REC	REC Limit	% RPD	RPD Limit	Qualifier
General Parameters, Batch B8J0942										
Blank (B8J0942-BLK1)				Prepared: 2018-10-12, Analyzed: 2018-10-16						
Chlorophyll a	< 0.10	0.10	µg							
General Parameters, Batch B8J0978										
Blank (B8J0978-BLK1)				Prepared: 2018-10-12, Analyzed: 2018-10-18						
Chlorophyll a	< 0.10	0.10	µg							
General Parameters, Batch B8J0979										
Blank (B8J0979-BLK1)				Prepared: 2018-10-12, Analyzed: 2018-10-18						
Chlorophyll a	< 0.10	0.10	µg							
General Parameters, Batch B8J0981										
Blank (B8J0981-BLK1)				Prepared: 2018-10-12, Analyzed: 2018-10-23						
Chlorophyll a	< 0.10	0.10	µg							
General Parameters, Batch B8J0982										
Blank (B8J0982-BLK1)				Prepared: 2018-10-12, Analyzed: 2018-10-25						
Chlorophyll a	< 0.10	0.10	µg							
Blank (B8J0982-BLK2)				Prepared: 2018-10-12, Analyzed: 2018-10-25						
Chlorophyll a	< 0.10	0.10	µg							

8101069

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#102-3677 Highway 97N, Kelowna, BC V1X 5C3
17225 109 Avenue NW, Edmonton, AB T5S 1H7

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CHAIN OF CUSTODY RECORD

COC# B 74758 PAGE 1 OF

RELINQUISHED BY: LAC	DATE:	RECEIVED BY: AC WI	DATE: 10/11
	TIME:		TIME: 16:48

TURNAROUND TIME REQUESTED:
Routine: (5-7 Days) ☑
Rush: 1 Day* ☐ 2 Day* ☐ 3 Day* ☐
Other*
*Contact Lab To Confirm. Surcharge May Apply

REGULATORY APPLICATION: Show on Report ☐
Canadian Drinking Water Quality ☐ BC WQG ☐ BC HWR ☐
BC CSR Soil: WL ☐ AL ☐ PL ☐ RL-LD ☐ RL-HD ☐ CL ☐ IL ☐
BC CSR Water: AW ☐ IW ☐ LW ☐ DW ☐
CCME:
OTHER:

PROJECT NUMBER / INFO:

A: Biohazard	D: Asbestos	G: Strong Odour
B: Cyanide	E: Heavy Metals	H: High Contamination
C: PCBs	F: Flammable	I: Other (please specify*)

REPO~~RT TO:~~
COMPANY: LAC/Ecoscape
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☑ MAIL ☐ OTHER* ☐
DATA FORMAT: EXCEL ☐ WATERTRAX ☐ ESdat ☐
EQuIS ☐ BC EMS ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:

INVOICE TO: SAME AS REPORT TO ☐
COMPANY: Ecoscape
ADDRESS:
CONTACT: Kyle Hawes
TEL/FAX:
DELIVERY METHOD: EMAIL ☑ MAIL ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:
PO #:

** If you would like to sign up for ClientConnect and/or Envirochain, CARO's online service offerings, please check here: ☐

SAMPLED BY:

	CLIENT SAMPLE ID:	MATRIX: DRINKING WATER	MATRIX: OTHER WATER	MATRIX: SOIL	MATRIX: OTHER	# CONTAINERS	SAMPLING: DATE YYYY-MM-DD	SAMPLING: TIME HH:MM	CHLORINATED	FILTERED	PRESERVED	COMMENTS: (e.g. flow/volume media ID/notes)
1	ERO-EXP 5-5C					1	Oct10/2018					
* 2	DEP-REF GE2					↓	↓					
3	ERO-Exp 3-3B											
4	ERO-EXP-5-5B											
5	ERO-EXP-5-3C											
6	ERO-EXP-3-5C											
7	ERO-REF-2-3C											
8	ERO-EXP-5-4A											
9	ERO-EXP-3-5A											
10	ERO-EXP-4-1C											
11	ERO-EXP-3-4B											
12	ERO-EXP-4-4A											

ANALYSES REQUESTED:

	BTEX ☐ VPH ☐ PHC F1 ☐	VOC ☐ VPH ☐	EPH ☐ PHC F2-F4 ☐	PAH ☐ L/HEPH ☐	PHENOLS Chlorinated ☐ Non-Chlor. ☐	PCB ☐ GLYCOLS ☐ HAA ☐	PESTICIDES ☐ ACID HERBICIDES ☐	METALS - WATER TOTAL Hg ☐	METALS - WATER DISSOLVED Hg ☐	METALS - SOIL (SALM) ☐ inc. pH ☐	pH ☐ EC ☐ ALK ☐	TSS ☐ VSS ☐ TDS ☐	BOD ☐ COD ☐	TOG ☐ MOG ☐	FECAL COLIFORMS ☐ HPC ☐	TOTAL COLIFORMS ☐ E. coli ☐	ASBESTOS	chl-a						HOLD	POSSIBLE SAMPLE HAZARD CODE(S)
1																									
2																									
3																									
4																									
5																									
6																									
7																									
8																									
9																									
10																									
11																									
12																									

SHIPPING INSTRUCTIONS: Return Cooler(s) ☐
Supplies Needed:

SAMPLE RETENTION:
30 Days (default) ☐
60 Days ☐ 90 Days ☐
Other (surcharges will apply):

*** OTHER INSTRUCTIONS:**
please express in ug

If you would like to talk to a real live Scientist about your project requirements, please check here: ☐

SAMPLE RECEIPT CONDITION:
COOLER 1 (°C): 5.8 ICE: Y ☐ N ☐
COOLER 2 (°C): ICE: Y ☐ N ☐
COOLER 3 (°C): ICE: Y ☐ N ☐
CUSTODY SEALS INTACT: NA ☐ Y ☐ N ☐

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17225 109 Avenue NW, Edmonton, AB T5S 1H7

CARO BC COC, Rev 2017-0

Page 18 of 25

CHAIN OF CUSTODY RECORD

COC# B 74761 PAGE 2 OF

RELINQUISHED BY:	DATE: TIME:	RECEIVED BY: AC WI	DATE: 10/1 TIME: 11:48

TURNAROUND TIME REQUESTED:
Routine: (5-7 Days) ☑
Rush: 1 Day* ☐ 2 Day* ☐ 3 Day* ☐
Other*
*Contact Lab To Confirm. Surcharge May Apply

REGULATORY APPLICATION: Show on Report ☐
Canadian Drinking Water Quality ☐ BC WQG ☐ BC HWR ☐
BC CSR Soil: WL ☐ AL ☐ PL ☐ RL-LD ☐ RL-HD ☐ CL ☐ IL ☐
BC CSR Water: AW ☐ IW ☐ LW ☐ DW ☐
CCME: OTHER:

PROJECT NUMBER / INFO:

A: Biohazard D: Asbestos G: Strong Odour
B: Cyanide E: Heavy Metals H: High Contamination
C: PCBs F: Flammable I: Other (please specify*)

REPORT TO:
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
DATA FORMAT: EXCEL ☐ WATERTRAX ☐ ESdat ☐ EQuIS ☐ BC EMS ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:

INVOICE TO: SAME AS REPORT TO ☐
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:
PO #:

** If you would like to sign up for ClientConnect and/or Envirochain, CARO's online service offerings, please check here: ☐

SAMPLED BY:

MATRIX: DRINKING WATER, OTHER WATER, SOIL, OTHER
SAMPLING: # CONTAINERS, DATE (YYYY-MM-DD), TIME (HH:MM)
COMMENTS: CHLORINATED, FILTERED, PRESERVED, (e.g. flow/volume media ID/notes)

ANALYSES REQUESTED:
BTEX ☐ VPH ☐ PHC F1 ☐
VOC ☐ VPH ☐
EPH ☐ PHC F2-F4 ☐
PAH ☐ L/HEPH ☐
PHENOLS Chlorinated ☐ Non-Chlor. ☐
PCB ☐ GLYCOLS ☐ HAA ☐
PESTICIDES ☐ ACID HERBICIDES ☐
METALS - WATER TOTAL Hg ☐
METALS - WATER DISSOLVED Hg ☐
METALS - SOIL (SALM) ☐ inc. pH ☐
pH ☐ EC ☐ ALK ☐
TSS ☐ VSS ☐ TDS ☐
BOD ☐ COD ☐
TOG ☐ MOG ☐
FECAL COLIFORMS ☐ HPC ☐
TOTAL COLIFORMS ☐ E. coli ☐
ASBESTOS
chl-a
HOLD
POSSIBLE SAMPLE HAZARD CODE(S)

	CLIENT SAMPLE ID:	# CONTAINERS	DATE	chl-a
13	ERO-REF-1-5C	1	Oct 10/2018	X
14	ERO-REF-1-2C			X
15	ERO-EXP-5-1A			X
16	ERO-EXP-5-1B			X
17	ERO-EXP-5-4B			X
18	ERO-EXP-5-1C			X
19	ERO-EXP-5-3A			X
20	ERO-EXP-5-3B			X
21	ERO-EXP-5-2C			X
22	ERO-EXP-5-5A			X
23	ERO-EXP-5-2A			X
24	ERO-REF-1-4C			X

SHIPPING INSTRUCTIONS: Return Cooler(s) ☐
Supplies Needed:

SAMPLE RETENTION:
30 Days (default) ☐
60 Days ☐ 90 Days ☐
Other (surcharges will apply):

*** OTHER INSTRUCTIONS:**
please express in ug

If you would like to talk to a real live Scientist about your project requirements, please check here: ☐

SAMPLE RECEIPT CONDITION:
COOLER 1 (°C): 5.8 ICE: Y ☐ N ☐
COOLER 2 (°C): ICE: Y ☐ N ☐
COOLER 3 (°C): ICE: Y ☐ N ☐
CUSTODY SEALS INTACT: NA ☐ Y ☐ N ☐

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CARO BC COC, Rev 2017-0

CHAIN OF CUSTODY RECORD

COC# B 74760 PAGE 3 OF

Page 19 of 25

RELINQUISHED BY:	DATE:	RECEIVED BY: AC WI	DATE: 10/11
	TIME:		TIME: 16:4

TURNAROUND TIME REQUESTED:
Routine: (5-7 Days) ☑
Rush: 1 Day* ☐ 2 Day* ☐ 3 Day* ☐
Other*
*Contact Lab To Confirm. Surcharge May Apply

REGULATORY APPLICATION: Show on Report ☐
Canadian Drinking Water Quality ☐ BC WQG ☐ BC HWR ☐
BC CSR Soil: WL ☐ AL ☐ PL ☐ RL-LD ☐ RL-HD ☐ CL ☐ IL ☐
BC CSR Water: AW ☐ IW ☐ LW ☐ DW ☐
CCME: OTHER:

PROJECT NUMBER / INFO:

A: Biohazard
B: Cyanide
C: PCBs
D: Asbestos
E: Heavy Metals
F: Flammable
G: Strong Odour
H: High Contamination
I: Other (please specify*)

REPORT TO:
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
DATA FORMAT: EXCEL ☐ WATERTRAX ☐ ESdat ☐
EQuIS ☐ BC EMS ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:

INVOICE TO: SAME AS REPORT TO ☐
SAME
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:
PO #:

**** If you would like to sign up for ClientConnect and/or Envirochain, CARO's online service offerings, please check here:** ☐

SAMPLED BY:

	CLIENT SAMPLE ID:	MATRIX: DRINKING WATER	OTHER WATER	SOIL	OTHER	# CONTAINERS	SAMPLING: DATE YYYY-MM-DD	TIME HH:MM	CHLORINATED	FILTERED	PRESERVED	COMMENTS: (e.g. flow/volume media ID/notes)	BTEX ☐ VPH ☐ PHC F1 ☐	VOC ☐ VPH ☐	EPH ☐ PHC F2-F4 ☐	PAH ☐ L/HEPH ☐	PHENOLS Chlorinated ☐ Non-Chlor. ☐	PCB ☐ GLYCOLS ☐ HAA ☐	PESTICIDES ☐ ACID HERBICIDES ☐	METALS - WATER TOTAL Hg ☐	METALS - WATER DISSOLVED Hg ☐	METALS - SOIL (SALM) ☐ inc. pH ☐	pH ☐ EC ☐ ALK ☐	TSS ☐ VSS ☐ TDS ☐	BOD ☐ COD ☐	TOG ☐ MOG ☐	FECAL COLIFORMS ☐ HPC ☐	TOTAL COLIFORMS ☐ E. coli ☐	ASBESTOS	chl-a						HOLD	POSSIBLE SAMPLE HAZARD CODE(S)
25	ERO-EXP-4-5B					1	0/10/2018																							X							
26	ERO-EXP-4-4C																													X							
27	ERO-EXP-4-4B																													X							
28	ERO-EXP-4-5C																													X							
29	ERO-REF-2-1B																													X							
30	ERO-REF-2-4A																													X							
31	ERO-REF-1-5B																													X							
32	ERO-REF-1-1C																													X							
33	ERO-REF-2-2C																													X							
34	ERO-REF-2-4B																													X							
35	ERO-REF-2-2A																													X							
36	ERO-REF-1-4A																													X							

SHIPPING INSTRUCTIONS: Return Cooler(s) ☐
Supplies Needed:

SAMPLE RETENTION:
30 Days (default) ☐
60 Days ☐ 90 Days ☐
Other (surcharges will apply):

*** OTHER INSTRUCTIONS:**
pls express results in ug

If you would like to talk to a real live Scientist about your project requirements, please check here: ☐

SAMPLE RECEIPT CONDITION:
COOLER 1 (°C): 5.8 ICE: Y ☐ N ☐
COOLER 2 (°C): ICE: Y ☐ N ☐
COOLER 3 (°C): ICE: Y ☐ N ☐
CUSTODY SEALS INTACT: NA ☐ Y ☐ N ☐

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CARO BC COC, Rev 2017-0

CHAIN OF CUSTODY RECORD

COC# B 74759 PAGE 4 OF

RELINQUISHED BY:	DATE: TIME:	RECEIVED BY: AC wl	DATE: 10/11/1 TIME: 16:45

TURNAROUND TIME REQUESTED:
Routine: (5-7 Days) ☑
Rush: 1 Day* ☐ 2 Day* ☐ 3 Day* ☐
Other*
*Contact Lab To Confirm. Surcharge May Apply

REGULATORY APPLICATION: Show on Report ☐
Canadian Drinking Water Quality ☐ BC WQG ☐ BC HWR ☐
BC CSR Soil: WL ☐ AL ☐ PL ☐ RL-LD ☐ RL-HD ☐ CL ☐ IL ☐
BC CSR Water: AW ☐ IW ☐ LW ☐ DW ☐
CCME:
OTHER:

REPORT TO:
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
DATA FORMAT: EXCEL ☐ WATERTRAX ☐ ESdat ☐
EQuIS ☐ BC EMS ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:

INVOICE TO: SAME AS REPORT TO ☐
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:
PO #:

PROJECT NUMBER / INFO:

A: Biohazard
B: Cyanide
C: PCBs
D: Asbestos
E: Heavy Metals
F: Flammable
G: Strong Odour
H: High Contamination
I: Other (please specify*)

** If you would like to sign up for ClientConnect and/or Envirochain, CARO's online service offerings, please check here: ☐

SAMPLED BY:

ANALYSES REQUESTED:
BTEX ☐ VPH ☐ PHC F1 ☐
VOC ☐ VPH ☐
EPH ☐ PHC F2-F4 ☐
PAH ☐ L/HEPH ☐
PHENOLS Chlorinated ☐ Non-Chlor. ☐
PCB ☐ GLYCOLS ☐ HAA ☐
PESTICIDES ☐ ACID HERBICIDES ☐
METALS - WATER TOTAL ☐ Hg
METALS - WATER DISSOLVED ☐ Hg
METALS - SOIL (SALM) ☐ inc. pH ☐
pH ☐ EC ☐ ALK ☐
TSS ☐ VSS ☐ TDS ☐
BOD ☐ COD ☐
TOG ☐ MOG ☐
FECAL COLIFORMS ☐ HPC ☐
TOTAL COLIFORMS ☐ E. coli ☐
ASBESTOS
Chl-a
HOLD
POSSIBLE SAMPLE HAZARD CODE(S)

	CLIENT SAMPLE ID:	DRINKING WATER	OTHER WATER	SOIL	OTHER	# CONTAINERS	DATE YYYY-MM-DD	TIME HH:MM	CHLORINATED	FILTERED	PRESERVED	COMMENTS: (e.g. flow/volume media ID/notes)	Chl-a	HOLD	POSSIBLE SAMPLE HAZARD CODE(S)
37	ERO-EXP-3-4A					1	Oct 20	2018					X		
38	ERO-EXP-3-4C												X		
39	ERO-EXP-4-3B												X		
40	ERO-EXP-4-1A												X		
41	ERO-EXP-4-1B												X		
42	ERO-EXP-3-5B												X		
43	ERO-EXP-4-2C												X		
44	ERO-EXP-4-2B												X		
45	ERO-EXP-4-2A												X		
46	ERO-EXP-4-5A												X		
47	ERO-EXP-4-3C												X		
48	ERO-EXP-4-3A												X		

SHIPPING INSTRUCTIONS: Return Cooler(s) ☐
Supplies Needed:

SAMPLE RETENTION:
30 Days (default) ☐
60 Days ☐ 90 Days ☐
Other (surcharges will apply):

*** OTHER INSTRUCTIONS:**
please express results in ug

If you would like to talk to a real live Scientist about your project requirements, please check here: ☐

SAMPLE RECEIPT CONDITION:
COOLER 1 (°C): 5.8 ICE: Y ☐ N ☐
COOLER 2 (°C): ICE: Y ☐ N ☐
COOLER 3 (°C): ICE: Y ☐ N ☐
CUSTODY SEALS INTACT: NA ☐ Y ☐ N ☐

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CARO BC COC, Rev 2017-0

CHAIN OF CUSTODY RECORD

COC# B 64893 PAGE 5 OF

RELINQUISHED BY:	DATE: TIME:	RECEIVED BY: AC WI	DATE: 10/11 TIME: 16:4

TURNAROUND TIME REQUESTED:
Routine: (5-7 Days) ☒
Rush: 1 Day* ☐ 2 Day* ☐ 3 Day* ☐
Other*
*Contact Lab To Confirm. Surcharge May Apply

REGULATORY APPLICATION: Show on Report ☐
Canadian Drinking Water Quality ☐ BC WQG ☐ BC HWR ☐
BC CSR Soil: WL ☐ AL ☐ PL ☐ RL-LD ☐ RL-HD ☐ CL ☐ IL ☐
BC CSR Water: AW ☐ IW ☐ LW ☐ DW ☐
CCME: OTHER:

PROJECT NUMBER / INFO:

A: Biohazard D: Asbestos G: Strong Odour
B: Cyanide E: Heavy Metals H: High Contamination
C: PCBs F: Flammable I: Other (please specify*)

REPORT TO:
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
DATA FORMAT: EXCEL ☐ WATERTRAX ☐ ESdat ☐
EQuIS ☐ BC EMS ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:

INVOICE TO: SAME AS REPORT TO ☐
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:
PO #:

**** If you would like to sign up for ClientConnect and/or Envirochain, CARO's online service offerings, please check here:** ☐

SAMPLED BY:

ANALYSES REQUESTED:
BTEX ☐ VPH ☐ PHC F1 ☐
VOC ☐ VPH ☐
EPH ☐ PHC F2-F4 ☐
PAH ☐ L/HEPH ☐
PHENOLS Chlorinated ☐ Non-Chlor. ☐
PCB ☐ GLYCOLS ☐ HAA ☐
PESTICIDES ☐ ACID HERBICIDES ☐
METALS - WATER TOTAL Hg ☐
METALS - WATER DISSOLVED Hg ☐
METALS - SOIL (SALM) ☐ inc. pH ☐
pH ☐ EC ☐ ALK ☐
TSS ☐ VSS ☐ TDS ☐
BOD ☐ COD ☐
TOG ☐ MOG ☐
FECAL COLIFORMS ☐ HPC ☐
TOTAL COLIFORMS ☐ E. coli ☐
ASBESTOS
chl-a
HOLD
POSSIBLE SAMPLE HAZARD CODE(S)

	CLIENT SAMPLE ID:	DRINKING WATER	OTHER WATER	SOIL	OTHER	# CONTAINERS	DATE YYYY-MM-DD	TIME HH:MM	CHLORINATED	FILTERED	PRESERVED	COMMENTS: (e.g. flow/volume media ID/notes)	chl-a	HOLD	POSSIBLE SAMPLE HAZARD CODE(S)
49	ERO-EXP-1-4B					1	02/10/2018						X		
50	ERO-EXP-1-2A					↓	↓						X		
51	ERO-EXP-1-1C												X		
52	ERO-EXP-1-1A												X		
53	ERO-REF-2-1A												X		
54	ERO-REF-1-5A												X		
55	ERO-REF-1-3B												X		
56	ERO-REF-1-3A												X		
57	ERO-REF-2-4C												X		
58	ERO-REF-2-1C												X		
59	ERO-REF-2-5B												X		
60	ERO-REF-2-3B												X		

SHIPPING INSTRUCTIONS: Return Cooler(s) ☐
Supplies Needed:

SAMPLE RETENTION:
30 Days (default) ☐
60 Days ☐ 90 Days ☐
Other (surcharges will apply):

*** OTHER INSTRUCTIONS:**

If you would like to talk to a real live Scientist about your project requirements, please check here: ☐

SAMPLE RECEIPT CONDITION:
COOLER 1 (°C): 5.8 ICE: Y ☐ N ☐
COOLER 2 (°C): ICE: Y ☐ N ☐
COOLER 3 (°C): ICE: Y ☐ N ☐
CUSTODY SEALS INTACT: NA ☐ Y ☐ N ☐

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CARO BC COC, Rev2017-0

CHAIN OF CUSTODY RECORD

COC# B 74762 PAGE 6 OF

RELINQUISHED BY:
DATE:
TIME:
RECEIVED BY: Ac Wl
DATE: 10/11
TIME: 16:4

TURNAROUND TIME REQUESTED:
Routine: (5-7 Days) ☐
Rush: 1 Day* ☐ 2 Day* ☐ 3 Day* ☐
Other*
***Contact Lab To Confirm. Surcharge May Apply**

REGULATORY APPLICATION: Show on Report ☐
Canadian Drinking Water Quality ☐ BC WQG ☐ BC HWR ☐
BC CSR Soil: WL ☐ AL ☐ PL ☐ RL-LD ☐ RL-HD ☐ CL ☐ IL ☐
BC CSR Water: AW ☐ IW ☐ LW ☐ DW ☐
CCME:
OTHER:

PROJECT NUMBER / INFO:

A: Biohazard
B: Cyanide
C: PCBs
D: Asbestos
E: Heavy Metals
F: Flammable
G: Strong Odour
H: High Contamination
I: Other (please specify*)

REPORT TO:
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
DATA FORMAT: EXCEL ☐ WATERTRAX ☐ ESdat ☐
EQuIS ☐ BC EMS ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:

INVOICE TO: SAME AS REPORT TO ☐
SAME
COMPANY:
ADDRESS:
CONTACT:
TEL/FAX:
DELIVERY METHOD: EMAIL ☐ MAIL ☐ OTHER* ☐
EMAIL 1:
EMAIL 2:
EMAIL 3:
PO #:

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SAMPLED BY:

	CLIENT SAMPLE ID:	MATRIX: DRINKING WATER	OTHER WATER	SOIL	OTHER	# CONTAINERS	SAMPLING: DATE YYYY-MM-DD	TIME HH:MM	CHLORINATED	FILTERED	PRESERVED	COMMENTS: (e.g. flow/volume media ID/notes)
61	ERO-EXP-5-2B					1	Oct11/2018					
62	ERO-EXP-5-4C											
63	ERO-REF-1-4B											
64	ERO-EXP-3-3A											
65	ERO-EXP-2-2C											
66	ERO-EXP-1-2B											
67	ERO-EXP-1-4C											
68	ERO-EXP-1-3B											
69	ERO-EXP-1-1B											
70	ERO-EXP-1-2C											
71	ERO-EXP-1-3A											
72	ERO-EXP-2-3B											

ANALYSES REQUESTED:

	CLIENT SAMPLE ID:	BTEX ☐ VPH ☐ PHC F1 ☐	VOC ☐ VPH ☐	EPH ☐ PHC F2-F4 ☐	PAH ☐ L/HEPH ☐	PHENOLS Chlorinated ☐ Non-Chlor. ☐	PCB ☐ GLYCOLS ☐ HAA ☐	PESTICIDES ☐ ACID HERBICIDES ☐	METALS - WATER TOTAL Hg ☐	METALS - WATER DISSOLVED Hg ☐	METALS - SOIL (SALM) ☐ inc. pH ☐	pH ☐ EC ☐ ALK ☐	TSS ☐ VSS ☐ TDS ☐	BOD ☐ COD ☐	TOG ☐ MOG ☐	FECAL COLIFORMS ☐ HPC ☐	TOTAL COLIFORMS ☐ E. coli ☐	ASBESTOS	Chl-a						HOLD	POSSIBLE SAMPLE HAZARD CODE(S)
61	ERO-EXP-5-2B																		X							
62	ERO-EXP-5-4C																		X							
63	ERO-REF-1-4B																		X							
64	ERO-EXP-3-3A																		X							
65	ERO-EXP-2-2C																		X							
66	ERO-EXP-1-2B																		X							
67	ERO-EXP-1-4C																		X							
68	ERO-EXP-1-3B																		X							
69	ERO-EXP-1-1B																		X							
70	ERO-EXP-1-2C																		X							
71	ERO-EXP-1-3A																		X							
72	ERO-EXP-2-3B																		X							

SHIPPING INSTRUCTIONS: Return Cooler(s) ☐
Supplies Needed:

SAMPLE RETENTION:
30 Days (default) ☐
60 Days ☐ 90 Days ☐
Other (surcharges will apply):

*** OTHER INSTRUCTIONS:**
pls express in ug
If you would like to talk to a real live Scientist about your project requirements, please check here: ☐

SAMPLE RECEIPT CONDITION:
COOLER 1 (°C): 5.8 ICE: Y ☐ N ☐
COOLER 2 (°C): ICE: Y ☐ N ☐
COOLER 3 (°C): ICE: Y ☐ N ☐
CUSTODY SEALS INTACT: NA ☐ Y ☐ N ☐

CARO
ANALYTICAL SERVICES

CHAIN OF CUSTODY RECORD

☐ 120-12791 CLARKE PLACE, RICHMOND, BC, V6V 2H1 TEL: 604 279-1499 FAX: 604 279-1599
☐ 102-3677 HIGHWAY 97N, KELOWNA, BC, V1X 5C3 TEL: 250 765-9646 FAX: 250 765-3893

Chain of Custody Number: 42461.39228

PAGE 7 of 9

CLIENT NAME:
ADDRESS:
CITY:
PROV:
POSTAL CODE:
CONTACT:
SAMPLER: SAME
TEL:
FAX:
Email: heather@larratt.net

RELINQUISHED BY: H Larratt	DATE: 10/11/18 TIME: 16:45	RECEIVED BY: AC Wl	
RELINQUISHED BY:	DATE: TIME:	RECEIVED BY:	
PROJECT NAME: AREMP	PROJECT NUMBER:	QUOTE #:	

REPORT DISTRIBUTION:
☐ Mail ☐ Fax ☐ WaterTrax
☐ Email (☑ Excel ☑ PDF)
Email:
☐ Other: heather@larratt.net

TURN-AROUND-TIME:
☐ 1-DAY* ☐ 2-DAY*
☐ 3-DAY* ☑ ROUTINE (4-7 DAYS)
☐ OTHER*:
*Contact Lab to Confirm. Surcharges May Apply

ANALYSIS REQUEST

LAB ID	CLIENT SAMPLE ID	SOIL	WATER	OTHER	#CONTAINERS	DATE	TIME	COMMENTS (i.e. Field Filtered, Source/Distribution)		chl-a																		HOLD
73	ERO-Exp-2-4B	☐	☐	☐	1	Oct 10/2018			☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
74	ERO-Exp-2-3A	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
75	ERO-Exp-2-1A	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
76	ERO-Exp-2-1B	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
77	ERO-Exp-2-2B	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
78	ERO-Exp 1-5B	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
79	ERO-Exp-3-1B	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
80	ERO-Exp-1-5C	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
81	ERO-Exp-1-3C	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
82	ERO-Exp-2-3C	☐	☐	☐					☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		☐	☐	☐					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		☐	☐	☐					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Total Number of Containers

REGULATORY LIMITS:
☐ BC Drinking Water Reg/Act
☐ BCMOE
☐ CCME
☐ Other:

SPECIAL INSTRUCTIONS (

SAMPLE RECEIPT TEMP: 5.4 c
CUSTODY SEAL INTACT: ☐Y ☐N ☐NA

Required Fields Recommended Fields SHADED AREAS: LAB USE ONLY

CARO ANALYTICAL SERVICES

CHAIN OF CUSTODY RECORD

☐ 120-12791 CLARKE PLACE, RICHMOND, BC, V6V 2H TEL: 604 279-1499 FAX: 604 279-1599
☐ 102-3677 HIGHWAY 97N, KELOWNA, BC, V1X 5C3 TEL: 250 765-9646 FAX: 250 765-3893

Chain of Custody Number: 42461.39228

PAGE 8 of 9

CLIENT NAME
ADDRESS:
CITY: **PROV:** **POSTAL CODE:**
CONTACT: **SAMPLER:**
TEL: **FAX:** **Email:** heather@larratt.net

RELINQUISHED BY: H Larratt	DATE: 10/11/18 TIME: 16:45	RECEIVED BY: AC WI
RELINQUISHED BY:	DATE: TIME:	RECEIVED BY:
PROJECT NAME: AREMP	PROJECT NUMBER:	QUOTE #:

REPORT DISTRIBUTION:
☐ Mail ☐ Fax ☐ WaterTrax
☐ Email (☑ Excel ☑ PDF)
Email:
☐ Other: heather@larratt.net

TURN-AROUND-TIME:
☐ 1-DAY* ☐ 2-DAY*
☐ 3-DAY* ☑ ROUTINE (4-7 DAYS)
☐ OTHER*:
*Contact Lab to Confirm. Surcharges May Apply

ANALYSIS REQUEST

LAB ID	CLIENT SAMPLE ID	MATRIX SOIL	MATRIX WATER	MATRIX OTHER	#CONTAINERS	DATE	TIME	COMMENTS (i.e. Field Filtered, Source/Distribution)	Chl-a															☐ ☐				HOLD
83	ERO-EXP-3-2B	☐	☐	☐	1	Oct 10 2018			☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
84	ERO-EXP-2-5C	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
85	ERO-EXP-3-1A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
86	ERO-EXP-3-3C	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
87	ERO-EXP-3-2A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
88	ERO-REF-1-1B	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
89	ERO-REF-2-3A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
90	ERO-REF-1-1A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
91	ERO-EXP-2-5A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
92	ERO-EXP-1-5A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
93	ERO-EXP-2-4A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
94	ERO-EXP-2-4C	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Total Number of Containers

REGULATORY LIMITS:
☐ BC Drinking Water Reg/Act
☐ BCMOE
☐ CCME
☐ Other:

SPECIAL INSTRUCTIONS (

SAMPLE RECEIPT TEMP: 2.1 c

CUSTODY SEAL INTACT: ☐Y ☐N ☐NA

Required Fields **Recommended Fields** **SHADED AREAS:** LAB USE ONLY

CARO
ANALYTICAL SERVICES

CHAIN OF CUSTODY RECORD

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Chain of Custody Number: 42461.39228

PAGE 9 of 9

CLIENT NAME
ADDRESS:
CITY:
PROV:
POSTAL CODE:
CONTACT:
SAMPLER:
TEL:
FAX:
Email:
heather@larratt.net

RELINQUISHED BY: H Larratt	DATE: 10/11/18	TIME: 16:45	RECEIVED BY: Ac Wl
RELINQUISHED BY:	DATE:	TIME:	RECEIVED BY:
PROJECT NAME: AREMP	PROJECT NUMBER:	QUOTE #:	

REPORT DISTRIBUTION:
☐ Mail ☐ Fax ☐ WaterTrax
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TURN-AROUND-TIME:
☐ 1-DAY* ☐ 2-DAY*
☐ 3-DAY* ☑ ROUTINE (4-7 DAYS)
☐ OTHER*:
*Contact Lab to Confirm. Surcharges May Apply

ANALYSIS REQUEST

LAB ID	CLIENT SAMPLE ID	MATRIX SOIL	MATRIX WATER	MATRIX OTHER	#CONTAINERS	DATE	TIME	COMMENTS (i.e. Field Filtered, Source/Distribution)	Chl-a																			HOLD
95	ERO-REF-1-3C	☐	☐	☐	1	06/10/2018			☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
96	ERO-REF-2-2B	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
97	ERO-REF-2-5A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
98	ERO-REF-1-2B	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
99	ERO-REF-1-2A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
100	ERO-REF-2-5C	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
101	ERO-EXP-3-2C	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
102	ERO-EXP-2-2A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
103	ERO-EXP-2-5B	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
104	ERO-EXP-2-1C	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
105	ERO-EXP-1-4A	☐	☐	☐					☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
106	ERO-EXP-3-1C	☐	☐	☐					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

REGULATORY LIMITS:
☐ BC Drinking Water Reg/Act
☐ BCMOE
☐ CCME
☐ Other:

Total Number of Containers

SPECIAL INSTRUCTIONS (

SAMPLE RECEIPT TEMP: 5.4 c

CUSTODY SEAL INTACT: ☐Y ☐N ☐NA

Required Fields Recommended Fields SHADED AREAS: LAB USE ONLY

APPENDIX F SEDIMENT QUALITY DATA

Sediment Quality 2018 Samples.

fraction	analyte	dep-exp-1	dep-exp-2	dep-exp-3	dep-exp-4	dep-exp-5	dep-exp-6	dep-exp-7	dep-ref-1	dep-ref-2	dep-ref-3
0.000	Aluminum	10500	9150	7600	6710	8210	8090	6370	6370	5650	6280
0.002	Aluminum	5460	6600	3960	5860	5600	5050	6100	3820	4100	3910
0.000	Antimony	23.3	66.09	72.8	14.4	41.9	21.5	4.25	0.23	0.23	0.59
0.002	Antimony	14.4	28.5	58.9	25.6	25.2	19.3	3.15	<0.10	<0.10	0.15
0.000	Arsenic	23.6	37.4	16	7.05	23.7	10.5	6.79	2.46	2.220	2.78
0.002	Arsenic	8.66	11	11.1	6.76	7.88	6.64	3.63	1.38	1.07	1.27
0.000	Barium	272	231	194	323	254	156	206	71.40	75.2	66.3
0.002	Barium	166	391	113	274	216	135	143	37.1	45.5	38.70
0.000	Beryllium	0.47	0.44	0.37	0.33	0.41	0.42	0.32	0.36	0.3	0.34
0.002	Beryllium	0.25	0.280	0.2	0.280	0.27	0.25	0.26	0.19	0.19	0.19
0.000	Bismuth	1.43	1.88	0.63	0.62	1.29	0.51	0.35	0.13	0.140	0.18
0.002	Bismuth	0.280	0.26	0.12	0.15	0.15	0.15	0.11	<0.10	<0.10	<0.10
0.000	Boron	<2.0	<2.0	<2.0	2.8	2.4	3.2	<2.0	<2.0	<2.0	<2.0
0.002	Boron	3	10.19	3.1	5.8	5.3	3.4	<2.0	<2.0	<2.0	<2.0
0.000	Cadmium	4.63	10.19	2.029	1.76	7.4	2.15	2.48	0.584	0.580	0.572
0.002	Cadmium	1.68	2.15	0.360	1.41	1.53	0.572	1.42	0.207	0.248	0.165
0.000	Calcium	5600	6230	5780	6660	6990	6710	16600	4400	4250	4910
0.002	Calcium	4590	13000	4400	6910	7700	4330	11300	1970	1750	1860
0.000	Chromium	45.5	56.2	34.4	29.1	44.7	34.29	27.1	23.9	21.1	26.5
0.002	Chromium	21.7	38.70	26.6	30.2	29.3	21.9	28.6	14.4	10.9	13.6
0.000	Cobalt	9.699	12.3	10.7	7.99	11.2	8.49	6.24	4.62	4.18	4.71
0.002	Cobalt	6.84	9.98	5.9	12.4	8.74	6.38	5.88	2.93	2.91	2.99

fraction	analyte	dep-exp-1	dep-exp-2	dep-exp-3	dep-exp-4	dep-exp-5	dep-exp-6	dep-exp-7	dep-ref-1	dep-ref-2	dep-ref-3
0.000	Copper	243	681	416	109	408	158	43.8	13.6	12.4	14.2
0.002	Copper	188	467	251	322	315	165	46.9	5.4	5.89	5.38
0.000	Iron	30100	66400	24800	21800	49500	24600	20900	14500	12800	16600
0.002	Iron	20800	51900	26600	27900	32700	19300	19000	10000	8870	10000
0.000	Lead	526	900	221	84.6	543	134	116	12.6	10.7	15.5
0.002	Lead	194	220	71.8	70.40	129	56	61.9	6.26	7.19	5.54
0.000	Lithium	13.6	9.220	12.3	11.3	11.3	12.8	10.1	12.3	10.3	11.3
0.002	Lithium	8.279	8.41	6.75	10.1	8.31	9.369	10.5	8.84	9.83	8.83
0.000	Magnesium	5020	3330	4350	3930	4210	4750	10200	3950	3550	3770
0.002	Magnesium	2950	2970	2250	3230	2700	2950	8540	2590	2840	2570
0.000	Manganese	260	588	561	273	576	358	241	166	150	168
0.002	Manganese	266	689	298	473	485	301	242	114	115	109
0.000	Mercury	1.149	7.41	1.9	0.414	5.21	0.879	0.422	<0.04	5.5E-	0.185
0.002	Mercury	0.133	0.550	4.200	0.106	0.245	7.599	5.399	<0.04	<0.04	<0.04
0.000	Molybdenum	1.33	4.41	0.97	0.83	2.79	1.35	2.14	0.52	0.51	0.42
0.002	Molybdenum	1.56	5.22	1.5	3.24	2.62	1.6	1.8	0.19	0.17	0.16
0.000	Nickel	27.6	29.3	18.89	15	25.9	19.10	18.60	16	14.5	16.3
0.002	Nickel	12.5	12.9	10.19	11.3	10.9	10.3	15.3	9.01	9.65	8.69
0.000	Phosphorus	1920	1240	1360	1570	1530	1580	1620	1310	1300	1620
0.002	Phosphorus	800	1050	717	882	772	682	900	637	548	584
0.000	Potassium	1470	1000	1220	1030	1170	1280	1050	1100	973	1020
0.002	Potassium	951	1100	661	1010	900	958	1170	772	868	785
0.000	Selenium	1.57	8.73	0.64	0.39	4.12	0.6	0.45	0.42	0.3	0.289
0.002	Selenium	0.43	1.82	0.21	0.37	0.63	0.22	0.22	<0.20	<0.20	<0.20

fraction	analyte	dep-exp-1	dep-exp-2	dep-exp-3	dep-exp-4	dep-exp-5	dep-exp-6	dep-exp-7	dep-ref-1	dep-ref-2	dep-ref-3
0.000	Silver	1.56	3.24	6.14	1.44	3.89	2.62	0.48	<0.10	0.13	0.289
0.002	Silver	0.39	0.82	2.259	1.17	0.5	0.73	0.140	<0.10	<0.10	<0.10
0.000	Sodium	193	162	193	188	197	203	187	181	149	169
0.002	Sodium	175	254	159	236	197	157	201	89	75	86
0.000	Strontium	55.2	54.3	59.7	53.9	54.6	51.7	58.1	47.4	46.1	48.2
0.002	Strontium	31.7	60.9	37.29	51.4	43.2	34.70	43.3	19.2	22.1	25.5
0.000	Sulfur	<1000	9130	<1000	1410	7750	<1000	5590	<1000	<1000	<1000
0.002	Sulfur	<1000	2690	<1000	1310	1360	<1000	1610	<1000	<1000	<1000
0.000	Tellurium	0.27	0.61	0.15	<0.10	0.42	<0.10	<0.10	<0.10	<0.10	<0.10
0.002	Tellurium	<0.10	0.1	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
0.000	Thallium	0.48	1.25	0.22	0.18	0.89	0.2	0.18	0.1	<0.10	<0.10
0.002	Thallium	0.25	0.37	<0.10	0.2	0.22	0.140	0.15	<0.10	<0.10	<0.10
0.000	Thorium	7.43	5.66	8.16	7.97	7.38	8.4	7.21	8.36	7.11	10.1
0.002	Thorium	4.769	4.139	5.44	4.24	4.28	4.76	3.85	3.43	3.46	3.58
0.000	Tin	19.10	113	29.9	9.86	64.59	14	3.4	0.81	0.61	1.100
0.002	Tin	20.2	74.2	31.6	26.7	41.4	18.8	3.83	0.4	0.31	0.34
0.000	Titanium	863	734	724	671	748	731	627	585	530	610
0.002	Titanium	507	573	421	597	511	549	677	416	422	423
0.000	Tungsten	1.54	2.240	0.78	2.42	1.07	1.8	1.74	0.71	0.67	1.07
0.002	Tungsten	1.81	2.54	1.08	1.31	1.44	1.04	0.74	<0.20	<0.20	<0.20
0.000	Uranium	2.27	3.34	2.38	1.69	3.11	3.62	2.57	2.83	1.64	2.36
0.002	Uranium	1.01	1.41	0.841	1.75	1.02	0.93	1.28	0.892	0.585	0.645
0.000	Vanadium	46	36.4	39.1	39.9	42.8	44.2	37.5	31.6	27.3	37.6
0.002	Vanadium	25	28.5	45.7	27.2	27.2	25.4	37.4	22.2	17.8	21.4

fraction	analyte	dep-exp-1	dep-exp-2	dep-exp-3	dep-exp-4	dep-exp-5	dep-exp-6	dep-exp-7	dep-ref-1	dep-ref-2	dep-ref-3
0.000	Zinc	1400	4380	1200	697	2660	803	482	96.2	78.2	92.5
0.002	Zinc	1100	3790	949	1800	2160	902	506	60.8	64.90	56.2
0.000	Zirconium	3	5.9	2.5	2.1	4.400	<2.0	<2.0	<2.0	<2.0	<2.0
0.002	Zirconium	3.1	9.699	2.8	5.4	6.1	3.1	<2.0	<2.0	<2.0	<2.0

APPENDIX G PERIPHYTON TAXONOMIC DATA

Periphyton Taxonomic Codes		
Final Code	Bacillariophyte-Diatoms	Peri Names and alternates
P001	Achnanthidium linearis	Achnanthidium linearis
P002	Achnanthidium minutissima	Achnanthidium minutissima
P003	Achnanthidium spp.	Achnanthidium spp.
P004	Amphora ovalis	Amphora ovalis
P005	Amphora perpusilla	Amphora perpusilla
P006	Amphora pediculus	Amphora pediculus
P007	Amphipleura pellucida	Amphipleura pellucida
P008	Anomoeoneis sp.	Anomoeoneis vitrea
P009	Asterionella formosa	Asterionella formosa
P010	Aulicoseira distans	Aulicoseira distans
P011	Aulacoseira granulata	Aulacoseira granulata
P012	Caloneis silicula	Caloneis silicula
P013	Cocconeis fluviatilis	Cocconeis fluviatilis
P014	Cocconeis placentula	Cocconeis placentula
P015	Cyclotella bodanica	Cyclotella bodanica
P016	Cyclotella comta	Cyclotella comta
P017	Cyclotella glomerata	Cyclotella glomerata
P018	Cyclotella ocellata	Cyclotella ocellata
P019	Cyclotella stelligera	Cyclotella stelligera
P020	Cymbella cistula	Cymbella cistula
P021	Cymbella parva	Cymbella parva
P022	Cymbella turgida	Cymbella turgida
P023	Denticula tenuis	Denticula tenuis
P024	Diatoma hiemale	Diatoma hiemale
P025	Diatoma tenue var elongatum	Diatoma tenue var elongatum
P026	Diatoma vulgare	Diatoma vulgare
P027	Didymosphenia geminata	Didymosphenia geminata
P028	Diploneis elliptica	Diploneis elliptica
P029	Epithemia sp.	Epithemia sp.
P030	Eucocconeis flexella	Eucocconeis flexella
P031	Eucocconeis sp.	Eucocconeis sp.
P032	Eunotia lunaris	Eunotia lunaris
P033	Eunotia pectinalis	Eunotia pectinalis
P034	Fragilaria crotonensis	Fragilaria crotonensis
P035	Fragilaria capucina (intermedia)	Fragilaria capucina (intermedia)
P036	Fragilariforma virescens	Fragilariforma virescens
P037	Frustulia rhomboides	Frustulia rhomboides
P038	Gomphonema ovilaceum	Gomphonema ovilaceum
P039	Gomphonema sp.	Gomphonema sp.
P040	Gyrosigma sp.	Gyrosigma sp.
P041	Hannaea arcus	Hannaea arcus
P042	Meridion anceps	Meridion anceps
P043	Meridion circulare	Meridion circulare
P044	Navicula gastrum	Navicula gastrium
P045	Navicula radiosa	Navicula radiosa

P046	Navicula tripunctata	Navicula tripunctata
P047	Navicula spp.	Navicula spp.
P048	Neidium bisulcatum	Neidium bisulcatum
P049	Neidium spp.	Neidium spp.
P050	Nitzschia acicularis	Nitzschia acicularis
P051	Nitzschia hantzschiana	Nitzschia hantzschiana
P052	Nitzschia obtusa	Nitzschia obtusa
P053	Nitzschia palea	Nitzschia palea
P054	Nitzschia stellata	Nitzschia stellata
P055	Nitzschia - sigmoid sp.?	Nitzschia - sigmoid sp.?
P056	Nitzschia sp.	Nitzschia sp.
P057	Pinnularia sp.	Pinnularia sp.
P058	Pleurosigma sp.	Pleurosigma sp.
P059	Rhoicosphenia curvata	Rhoicosphenia curvata
P060	Rhopalodia gibba	Rhopalodia gibba
P061	Stauroneis phoenicenteron.	Stauroneis phoenicenteron.
P062	Stauroforma exiguiformis	Stauroforma exiguiformis
P063	Staurosira ansata	Staurosira ansata
P064	Staurosira construens v ventor	Staurosira construens v ventor
P065	Staurosira construens v. plumila	Staurosira construens v. plumila
P066	Staurosirella leptostauron	Staurosirella leptostauron
P067	Staurosirella pinnata (cf. Fragilaria pinnata)	Staurosirella pinnata (cf. Fragilaria pinnata)
P068	Stephanodiscus hantzschii	Stephanodiscus hantzschii
P069	Stephanodiscus sp	Stephanodiscus sp
P070	Synedra acus	Synedra acus
P071	Synedra acus var angustissima	Synedra acus var angustissima
P072	Synedra nana	Synedra nana
P073	Synedra ulna	Synedra ulna
P074	Synedra ulna var radians	Synedra ulna var radians
P075	Surirella ovata	Surirella ovata
P076	Surirella angusta	Surirella angustata
P077	Surirella sp.	Surirella sp.
P078	Tabellaria fenestrata	Tabellaria fenestrata
P079	Tabellaria flocculosa	Tabellaria flocculosa
P080	Not Identified Flagellates	Not Identified Flagellates
P081	Chromulina sp.	Chromulina sp
P082	Chroomonas acuta.	Chroomonas acuta.
P083	Chrysochromulina sp.	Chrysochromulina sp.
P084	Chrysococcus sp.	Chrysococcus sp.
P085	Cryptomonas sp.	Cryptomonas sp.
P086	Dinobryon divergens (lorica)	Dinobryon divergens
P087	Dinobryon sertularia (lorica)	Dinobryon sertularia
P088	Kephyrion sp.	Kephyrion sp.
P089	Komma sp.	Komma sp.
P090	Mallomonas sp.	Mallomonas sp.
P091	Ceratium hirudinella	Ceratium hirudinella
P092	Gymnodinium sp.	Gymnodinium sp.
P093	Peridinium sp.	Peridinium sp

P094	Anabaena sp. (filaments)	Anabaena sp. (filaments)
P095	Anacystis cyanea	Anacystis cyanea
P096	Coelosphaerium sp. (spheric colony)	Coelosphaerium sp. (spheric colony)
P097	Gloeotrichia sp.	Gloeotrichia sp.
P098	Limnothrix redekei (filament)	Limnothrix redekei (filament)
P099	Lyngbya sp.	Lyngbya sp. 100 micron length
P100	Merismopedia elegans	Merismopedia elegans
P101	Oscillatoria sp. (4 micron dia)	Oscillatoria 4mi sp. (100 L)
P102	Planktolyngbya limnetica (filament)	Planktolyngbya limnetica 100L)
P103	Planktothrix agardhii (filament)	Planktothrix agardhii (100 L filament)
P104	Planktothrix limnetica (filament)	Planktothrix limnetica (100 L filament)
P105	Pseudanabaena sp. (filament 1.5micron dia)	Pseudanabaena sp. 1.5mi (100 L)
P106	Synechococcus sp.	Synechococcus sp.
P107	Synechocystis sp.	Synechocystis sp
P108	Distigma sp. -flagellate	Distigma sp. -flagellate
P109	Euglena spp. -flagellate	Euglena spp. -flagellate
P110	Trachelomonas sp. -flagellate	Trachelomonas sp. -flagellate
P111	Ankistrodesmus spp.	Ankistrodesmus spp.
P112	Botryococcus sp. (colony)	Botryococcus sp. (colony)
P113	Chlamydocapsa sp.	Chlamydocapsa sp.
P114	Chlorella spp.	Chlorella spp.
P115	Closterium sp.	Closterium sp.
P116	Cosmarium spp.	Cosmarium spp
P117	Dichtyosphaerium sp.	Dichtyosphaerium
P118	Eremosphaera sp. (colony)	Eremosphaera sp. (colony)
P119	Euastrum sp.	Euastrum sp.
P120	Gloeocystis sp. colony	Gloeocystis sp. colony
P121	Hyalotheca sp.	Hyalotheca sp.
P122	Oocystis sp. (cells)	Oocystis sp. (cells)
P123	Pediastrum sp. (colony)	Pediastrum sp.
P124	Planctosphaeria sp. (colony)	Planctosphaeria sp. colony
P125	Scenedesmus sp.	Scenedesmus sp.
P126	Spondylosium sp. (cells - filaments)	Spondylosium sp. (cells - filaments)
P127	Staurastrum sp. (cell)	Staurastrum sp.
P128	Bulbochaete (cells)	Bulbochaete (cells)
P129	Cladophora zonata	Cladophora sp. glomerata?
P130	Draparnaldia sp. glomerata?	Draparnaldia sp. glomerata?
P131	Geminella sp. (I cell)	Geminella sp I cell
P132	Microspora sp.	Microspora sp.
P133	Mougeotia sp.	Mougeotia sp.
P134	Oedogonium sp.	Oedogonium sp.
P135	Stigeoclonium sp.	Stigeoclonium sp.
P136	Spirogyra sp.	Spirogyra sp.
P137	Ulothrix sp. (zonata?)	Ulothrix sp. (zonata)
P138	Zygnema sp.	Zygnema sp.
P139	Aphanothece (saxicola?)	Coccoid Chlorophyta Complex (colony) unidentifiable
P140	pico-flagellates	***moved to D012

P141	Brachysira vitrea	Brachysira vitrea
P142	Hantzschia spp.	Hantzschia spp.
P143	Rhizosolenia sp.	Rhizosolenia sp.
P144	Rossithidium linearis	Rossithidium linearis
P145	Ochromonas sp.	Oochromonas sp.
P146	Anabaenopsis elenkinii	Anabaenopsis elenkinii
P147	Coelastrum sp. (colony)	Coelastrum sp. (colony)
P148	Scourfieldia sp. -flagellate	*** changed to P145 Ochromonas
P149	Stichococcus minutissima	Stichococcus minutissima
P150	Navicula minima (oval)	Navicula minima (oval)
P151	Stauroneis sp.	Stauroneis sp
P152	Gomphosphaeria sp.	Gomphosphaeria sp
P153	Lepocinclis ovum	Lepocinclis ovum
P154	Small euglenoid	Chlamydomonas spp.
P155	Leptolyngbya sp.	Leptolyngbya
P156	amoeba	amoeba
P157	Spirulina sp.	Spirolina
P158	Dactylococcopsis sp.	Dactylococcopsis
P159	Campylodiscus sp.	Campylodiscus sp.
P160	Euglenoid large	Euglenoid (Phacus?)
P161	Peranema sp.	Peranema sp.
P162	Gomphonema parvulum	Gomphonema parvulum
P163	Staurosirella sp.	Staurosirella sp.
P164	Cymbella minuta	Cymbella minuta
P165	Gomphonema minutum	Gomphonema minutum
P166	Aphanocapsa sp.	Aphanocapsa sp.
P167	Caloneis sp.	Caloneis sp.
P168	Achnanthidium exiguum	Achnanthidium exiguum
P169	Amphora sp.	Amphora sp
P170	Frustulia sp.	Frustulia sp.
P171	Diploneis sp.	Diploneis sp.
P172	Cymbella spp.	Cymbella sp.
P173	Glenodinium sp.	Glenodinium sp.
P174	Stigonema ocellata	Stigonema ocellata
P175	Chroococcus sp.	Chroococcus sp.
P176	Cymbolpleura sp.	Cymbolpleura sp.
P177	Encyonema minuta	Encyonema minuta
P178	Gomphoneis minuta	Gomphoneis minuta
P179	Cymatopleura sp.	Cymatopleura sp.
P180	Dinobryon bavaricum	Dinobryon bavaricum
P181	Cyclotella sp. (Wehr)	Cyclotella sp. (Wehr)

P182	Calothrix (fusca?)	Calothrix (fusca?)
P183	Phacus (trimarginatus?)	Phacus (trimarginatus?)
P184	Navicula lancelota	Navicula lancelota
P185	Cycolotella ocellata+comta=rossi	Cycolotella ocellata+comta=rossi
P186	Bodo sp.	Bodo sp.
P187	Eunotia spp.	Eunotia spp.
P188	Komvophoron minutissima	Komvophoron minutissima
P189	Gomphonema acuminata	Gomphonema acuminata
P190	Heterococcus (subaerial)	Heterococcus (subaerial)
P191	Fischerella sp.	Fischerella sp.
P192	Synedra cyclopum	Synedra cyclopum
P193	Cymbella caespitosum (Encyonema caespitosum)	Cymbella caespitosum (Encyonema caespitosum)
P194	Mastogloia sp.	Mastogloia sp.
P195	Crucigenia tetrapedia	Crucigenia tetrapedia
P196	Rhodophyceae	Rhodophyceae
P197	Epithemia turgida	Epithemia turgida
P198	Aphanizomenon sp. (cells)	Aphanizomenon sp. (cells)
P199	Tetraedron sp.	Tetraedron sp.
P200	Gloeotila sp.	Gloeotila sp.
P201	Unidentified coccoid green	Unidentified coccoid green
P202	Cymbella microcephala (E. microcephala)	Cymbella microcephala (E. microcephala)
P203	Cymbella ventricosa	Cymbella ventricosa
P204	Cymbella sp. lrg	Cymbella sp. lrg
P205	Gomphoneis spp.	Gomphoneis spp.
P206	Homeothrix sp. (janthina?)	Homeothrix sp. (janthina?)
P207	Diatoma mesodon	Diatoma mesodon
P208	Oscillatoria limnosa	Oscillatoria limnosa
P209	Navicula cryptocephala	Navicula cryptocephala
P210	Cymbella excisiformis (Encyonema excisiformis)	Cymbella excisiformis (Encyonema excisiformis)
P211	Audouinella sp.	Audouinella sp.
P212	Phormidium autumnale	Phormidium autumnale
P213	Hydrurus foetidus or sp.	Hydrurus foetidus or sp.
P214	Chamaesiphon incrustans	Chamaesiphon incrustans
P215	Gloeocapsa sp.	Gloeocapsa sp.

APPENDIX H DEPOSITIONAL PERIPHYTON STATISTICAL OUTPUTS

Table A1 ANOVA summary table for tot.abun depositional sites.

term	df	sumsq	meansq	statistic	p.value	form
x$year	2.000	1.380	0.689	18.200	<0.001	aov(value~year+ref_exp)
x$ref_exp	1.000	0.040	0.040	1.060	0.313	aov(value~year+ref_exp)
Residuals	26.000	0.984	0.038			aov(value~year+ref_exp)

Table A2 Tukey HSD ANOVA summary table for tot.abun depositional sites.

year	diff	lwr	upr	p adj
2015-2012	0.479	0.262	0.695	<0.001
2018-2012	0.426	0.209	0.642	<0.001
2018-2015	-0.053	-0.269	0.163	0.817

Table A3 ANOVA summary table for tot.biov depositional sites.

term	df	sumsq	meansq	statistic	p.value	form
x$year	2.000	1.650	0.823	15.400	<0.001	aov(value~year+ref_exp)
x$ref_exp	1.000	0.000	0.000	0.000	0.999	aov(value~year+ref_exp)
Residuals	26.000	1.390	0.054			aov(value~year+ref_exp)

Table A4 Tukey HSD ANOVA summary table for tot.biov depositional sites.

year	diff	lwr	upr	p adj
2015-2012	0.503	0.246	0.760	<0.001
2018-2012	0.491	0.233	0.748	<0.001
2018-2015	-0.012	-0.270	0.245	0.992

Table A5 ANOVA summary table for eff.species depositional sites.

term	df	sumsq	meansq	statistic	p.value	form
x$year	2.000	278.000	139.000	16.500	<0.001	aov(value~year+ref_exp)
x$ref_exp	1.000	25.200	25.200	2.980	0.0961	aov(value~year+ref_exp)
Residuals	26.000	220.000	8.460			aov(value~year+ref_exp)

Table A6 Tukey HSD ANOVA summary table for eff.species depositional sites.

year	diff	lwr	upr	p adj
2015-2012	-7.360	-10.600	-4.130	<0.001
2018-2012	-2.640	-5.880	0.587	0.124
2018-2015	4.720	1.490	7.950	0.00339

APPENDIX I EROSIONAL PERIPHYTON STATISTICAL OUTPUTS

Table A7 ANOVA summary table for Erosional Site Pairs for 2018 Chl-a (mg/cm^2)

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	1.561	0.260	8.002	<0.001
Residuals	28.000	0.911	0.033		

Table A8 Tukey HSD for Erosional Site Pairs for 2018 Chl-a (mg/cm^2)

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	0.297	-0.065	0.658	0.164
area	Ero Exp 3 : Ero Exp 1	0.059	-0.303	0.420	0.998
area	Ero Exp 4 : Ero Exp 1	-0.387	-0.749	-0.025	0.030
area	Ero Exp 5 : Ero Exp 1	-0.238	-0.600	0.124	0.386
area	Ero Ref 1 : Ero Exp 1	-0.179	-0.541	0.183	0.703
area	Ero Ref 2 : Ero Exp 1	-0.211	-0.573	0.151	0.527
area	Ero Exp 3 : Ero Exp 2	-0.238	-0.600	0.124	0.387
area	Ero Exp 4 : Ero Exp 2	-0.684	-1.045	-0.322	<0.001
area	Ero Exp 5 : Ero Exp 2	-0.535	-0.897	-0.173	0.001
area	Ero Ref 1 : Ero Exp 2	-0.475	-0.837	-0.114	0.004
area	Ero Ref 2 : Ero Exp 2	-0.508	-0.870	-0.146	0.002
area	Ero Exp 4 : Ero Exp 3	-0.446	-0.807	-0.084	0.009
area	Ero Exp 5 : Ero Exp 3	-0.297	-0.659	0.065	0.163
area	Ero Ref 1 : Ero Exp 3	-0.237	-0.599	0.124	0.390
area	Ero Ref 2 : Ero Exp 3	-0.270	-0.632	0.092	0.250
area	Ero Exp 5 : Ero Exp 4	0.149	-0.213	0.511	0.844
area	Ero Ref 1 : Ero Exp 4	0.208	-0.154	0.570	0.543
area	Ero Ref 2 : Ero Exp 4	0.176	-0.186	0.538	0.718
area	Ero Ref 1 : Ero Exp 5	0.059	-0.302	0.421	0.998
area	Ero Ref 2 : Ero Exp 5	0.027	-0.335	0.389	1.000
area	Ero Ref 2 : Ero Ref 1	-0.032	-0.394	0.329	1.000

Table A9 ANOVA summary table for Erosional Site Pairs for 2018 Chl-a (µg/L)

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	1.561	0.260	8.002	<0.001
Residuals	28.000	0.911	0.033		

Table A10 Tukey HSD for Erosional Site Pairs for 2018 Chl-a (µg/L)

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	0.297	-0.065	0.658	0.164
area	Ero Exp 3 : Ero Exp 1	0.059	-0.303	0.420	0.998
area	Ero Exp 4 : Ero Exp 1	-0.387	-0.749	-0.025	0.030
area	Ero Exp 5 : Ero Exp 1	-0.238	-0.600	0.124	0.386
area	Ero Ref 1 : Ero Exp 1	-0.179	-0.541	0.183	0.703
area	Ero Ref 2 : Ero Exp 1	-0.211	-0.573	0.151	0.527
area	Ero Exp 3 : Ero Exp 2	-0.238	-0.600	0.124	0.387
area	Ero Exp 4 : Ero Exp 2	-0.684	-1.045	-0.322	<0.001
area	Ero Exp 5 : Ero Exp 2	-0.535	-0.897	-0.173	0.001
area	Ero Ref 1 : Ero Exp 2	-0.475	-0.837	-0.114	0.004
area	Ero Ref 2 : Ero Exp 2	-0.508	-0.870	-0.146	0.002
area	Ero Exp 4 : Ero Exp 3	-0.446	-0.807	-0.084	0.009
area	Ero Exp 5 : Ero Exp 3	-0.297	-0.659	0.065	0.163
area	Ero Ref 1 : Ero Exp 3	-0.237	-0.599	0.124	0.390
area	Ero Ref 2 : Ero Exp 3	-0.270	-0.632	0.092	0.250
area	Ero Exp 5 : Ero Exp 4	0.149	-0.213	0.511	0.844
area	Ero Ref 1 : Ero Exp 4	0.208	-0.154	0.570	0.543
area	Ero Ref 2 : Ero Exp 4	0.176	-0.186	0.538	0.718
area	Ero Ref 1 : Ero Exp 5	0.059	-0.302	0.421	0.998
area	Ero Ref 2 : Ero Exp 5	0.027	-0.335	0.389	1.000

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Ref 2 : Ero Ref 1	-0.032	-0.394	0.329	1.000

Table A11 ANOVA summary table for Erosional Site Pairs for 2018 Effective Species

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	0.368	0.061	6.727	<0.001
Residuals	28.000	0.255	0.009		

Table A12 Tukey HSD for Erosional Site Pairs for 2018 Effective Species

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	-0.297	-0.488	-0.105	<0.001
area	Ero Exp 3 : Ero Exp 1	-0.067	-0.258	0.125	0.921
area	Ero Exp 4 : Ero Exp 1	0.007	-0.185	0.198	1.000
area	Ero Exp 5 : Ero Exp 1	-0.113	-0.304	0.079	0.519
area	Ero Ref 1 : Ero Exp 1	-0.018	-0.210	0.174	1.000
area	Ero Ref 2 : Ero Exp 1	0.013	-0.179	0.205	1.000
area	Ero Exp 3 : Ero Exp 2	0.230	0.038	0.422	0.011
area	Ero Exp 4 : Ero Exp 2	0.304	0.112	0.495	<0.001
area	Ero Exp 5 : Ero Exp 2	0.184	-0.007	0.376	0.065
area	Ero Ref 1 : Ero Exp 2	0.279	0.087	0.470	0.001
area	Ero Ref 2 : Ero Exp 2	0.310	0.118	0.502	<0.001
area	Ero Exp 4 : Ero Exp 3	0.074	-0.118	0.265	0.880
area	Ero Exp 5 : Ero Exp 3	-0.046	-0.237	0.146	0.987
area	Ero Ref 1 : Ero Exp 3	0.049	-0.143	0.240	0.982
area	Ero Ref 2 : Ero Exp 3	0.080	-0.112	0.272	0.835
area	Ero Exp 5 : Ero Exp 4	-0.119	-0.311	0.072	0.450
area	Ero Ref 1 : Ero Exp 4	-0.025	-0.217	0.167	1.000
area	Ero Ref 2 : Ero Exp 4	0.006	-0.185	0.198	1.000

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Ref 1 : Ero Exp 5	0.095	-0.097	0.286	0.705
area	Ero Ref 2 : Ero Exp 5	0.126	-0.066	0.317	0.391
area	Ero Ref 2 : Ero Ref 1	0.031	-0.160	0.223	0.998

Table A13 ANOVA summary table for Erosional Site Pairs for 2018 Shannon's Evenness

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	0.093	0.015	8.986	<0.001
Residuals	28.000	0.048	0.002		

Table A14 Tukey HSD for Erosional Site Pairs for 2018 Shannon's Evenness

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	-0.133	-0.216	-0.050	<0.001
area	Ero Exp 3 : Ero Exp 1	-0.033	-0.116	0.050	0.861
area	Ero Exp 4 : Ero Exp 1	0.030	-0.053	0.113	0.910
area	Ero Exp 5 : Ero Exp 1	-0.014	-0.097	0.069	0.998
area	Ero Ref 1 : Ero Exp 1	0.019	-0.064	0.102	0.989
area	Ero Ref 2 : Ero Exp 1	0.014	-0.069	0.097	0.998
area	Ero Exp 3 : Ero Exp 2	0.100	0.017	0.183	0.011
area	Ero Exp 4 : Ero Exp 2	0.163	0.080	0.246	<0.001
area	Ero Exp 5 : Ero Exp 2	0.119	0.036	0.202	0.002
area	Ero Ref 1 : Ero Exp 2	0.152	0.069	0.235	<0.001
area	Ero Ref 2 : Ero Exp 2	0.147	0.064	0.230	<0.001
area	Ero Exp 4 : Ero Exp 3	0.063	-0.020	0.146	0.233
area	Ero Exp 5 : Ero Exp 3	0.019	-0.064	0.103	0.988
area	Ero Ref 1 : Ero Exp 3	0.052	-0.031	0.136	0.436
area	Ero Ref 2 : Ero Exp 3	0.047	-0.036	0.131	0.554
area	Ero Exp 5 : Ero Exp 4	-0.044	-0.127	0.040	0.644

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Ref 1 : Ero Exp 4	-0.011	-0.094	0.073	1.000
area	Ero Ref 2 : Ero Exp 4	-0.016	-0.099	0.067	0.996
area	Ero Ref 1 : Ero Exp 5	0.033	-0.050	0.116	0.864
area	Ero Ref 2 : Ero Exp 5	0.028	-0.055	0.111	0.933
area	Ero Ref 2 : Ero Ref 1	-0.005	-0.088	0.078	1.000

Table A15 ANOVA summary table for Erosional Site Pairs for 2018 Species Richness

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	0.081	0.013	2.462	0.049
Residuals	28.000	0.153	0.005		

Table A16 Tukey HSD for Erosional Site Pairs for 2018 Species Richness

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	-0.042	-0.190	0.106	0.971
area	Ero Exp 3 : Ero Exp 1	0.021	-0.127	0.169	0.999
area	Ero Exp 4 : Ero Exp 1	-0.090	-0.238	0.058	0.480
area	Ero Exp 5 : Ero Exp 1	-0.121	-0.269	0.028	0.170
area	Ero Ref 1 : Ero Exp 1	-0.090	-0.238	0.058	0.478
area	Ero Ref 2 : Ero Exp 1	-0.033	-0.181	0.116	0.992
area	Ero Exp 3 : Ero Exp 2	0.063	-0.085	0.211	0.826
area	Ero Exp 4 : Ero Exp 2	-0.048	-0.196	0.100	0.942
area	Ero Exp 5 : Ero Exp 2	-0.079	-0.227	0.069	0.629
area	Ero Ref 1 : Ero Exp 2	-0.048	-0.197	0.100	0.941
area	Ero Ref 2 : Ero Exp 2	0.009	-0.139	0.157	1.000
area	Ero Exp 4 : Ero Exp 3	-0.111	-0.259	0.037	0.245
area	Ero Exp 5 : Ero Exp 3	-0.142	-0.290	0.007	0.068
area	Ero Ref 1 : Ero Exp 3	-0.111	-0.259	0.037	0.244

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Ref 2 : Ero Exp 3	-0.054	-0.202	0.095	0.908
area	Ero Exp 5 : Ero Exp 4	-0.031	-0.179	0.118	0.994
area	Ero Ref 1 : Ero Exp 4	-0.000	-0.148	0.148	1.000
area	Ero Ref 2 : Ero Exp 4	0.057	-0.091	0.206	0.876
area	Ero Ref 1 : Ero Exp 5	0.030	-0.118	0.179	0.994
area	Ero Ref 2 : Ero Exp 5	0.088	-0.060	0.236	0.506
area	Ero Ref 2 : Ero Ref 1	0.058	-0.090	0.206	0.875

Table A17 ANOVA summary table for Erosional Site Pairs for 2018 Total Abundance

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	1.348	0.225	9.176	<0.001
Residuals	28.000	0.685	0.024		

Table A18 Tukey HSD for Erosional Site Pairs for 2018 Total Abundance

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	0.286	-0.028	0.600	0.092
area	Ero Exp 3 : Ero Exp 1	-0.006	-0.320	0.308	1.000
area	Ero Exp 4 : Ero Exp 1	-0.329	-0.643	-0.015	0.036
area	Ero Exp 5 : Ero Exp 1	-0.241	-0.555	0.073	0.222
area	Ero Ref 1 : Ero Exp 1	-0.259	-0.573	0.054	0.157
area	Ero Ref 2 : Ero Exp 1	-0.164	-0.478	0.150	0.649
area	Ero Exp 3 : Ero Exp 2	-0.292	-0.606	0.021	0.080
area	Ero Exp 4 : Ero Exp 2	-0.615	-0.929	-0.301	<0.001
area	Ero Exp 5 : Ero Exp 2	-0.527	-0.841	-0.213	<0.001
area	Ero Ref 1 : Ero Exp 2	-0.546	-0.860	-0.232	<0.001
area	Ero Ref 2 : Ero Exp 2	-0.450	-0.764	-0.136	0.002
area	Ero Exp 4 : Ero Exp 3	-0.322	-0.636	-0.009	0.041

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 5 : Ero Exp 3	-0.235	-0.548	0.079	0.248
area	Ero Ref 1 : Ero Exp 3	-0.253	-0.567	0.061	0.177
area	Ero Ref 2 : Ero Exp 3	-0.158	-0.471	0.156	0.688
area	Ero Exp 5 : Ero Exp 4	0.088	-0.226	0.402	0.971
area	Ero Ref 1 : Ero Exp 4	0.069	-0.245	0.383	0.992
area	Ero Ref 2 : Ero Exp 4	0.165	-0.149	0.479	0.643
area	Ero Ref 1 : Ero Exp 5	-0.019	-0.333	0.295	1.000
area	Ero Ref 2 : Ero Exp 5	0.077	-0.237	0.391	0.985
area	Ero Ref 2 : Ero Ref 1	0.096	-0.218	0.410	0.957

Table A19 ANOVA summary table for Erosional Site Pairs for 2018 Total Biovolume

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	2.637	0.439	4.778	0.002
Residuals	28.000	2.575	0.092		

Table A20 Tukey HSD for Erosional Site Pairs for 2018 Total Biovolume

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	0.093	-0.515	0.701	0.999
area	Ero Exp 3 : Ero Exp 1	-0.144	-0.753	0.464	0.988
area	Ero Exp 4 : Ero Exp 1	-0.482	-1.090	0.127	0.193
area	Ero Exp 5 : Ero Exp 1	-0.130	-0.738	0.479	0.993
area	Ero Ref 1 : Ero Exp 1	-0.518	-1.126	0.091	0.136
area	Ero Ref 2 : Ero Exp 1	-0.696	-1.304	-0.087	0.017
area	Ero Exp 3 : Ero Exp 2	-0.237	-0.846	0.371	0.873
area	Ero Exp 4 : Ero Exp 2	-0.575	-1.183	0.034	0.074
area	Ero Exp 5 : Ero Exp 2	-0.223	-0.831	0.386	0.903
area	Ero Ref 1 : Ero Exp 2	-0.611	-1.219	-0.002	0.049

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Ref 2 : Ero Exp 2	-0.789	-1.397	-0.180	0.005
area	Ero Exp 4 : Ero Exp 3	-0.337	-0.946	0.271	0.585
area	Ero Exp 5 : Ero Exp 3	0.015	-0.594	0.623	1.000
area	Ero Ref 1 : Ero Exp 3	-0.373	-0.982	0.235	0.469
area	Ero Ref 2 : Ero Exp 3	-0.551	-1.160	0.057	0.095
area	Ero Exp 5 : Ero Exp 4	0.352	-0.256	0.961	0.537
area	Ero Ref 1 : Ero Exp 4	-0.036	-0.644	0.573	1.000
area	Ero Ref 2 : Ero Exp 4	-0.214	-0.822	0.395	0.918
area	Ero Ref 1 : Ero Exp 5	-0.388	-0.996	0.221	0.424
area	Ero Ref 2 : Ero Exp 5	-0.566	-1.174	0.043	0.081
area	Ero Ref 2 : Ero Ref 1	-0.178	-0.786	0.430	0.965

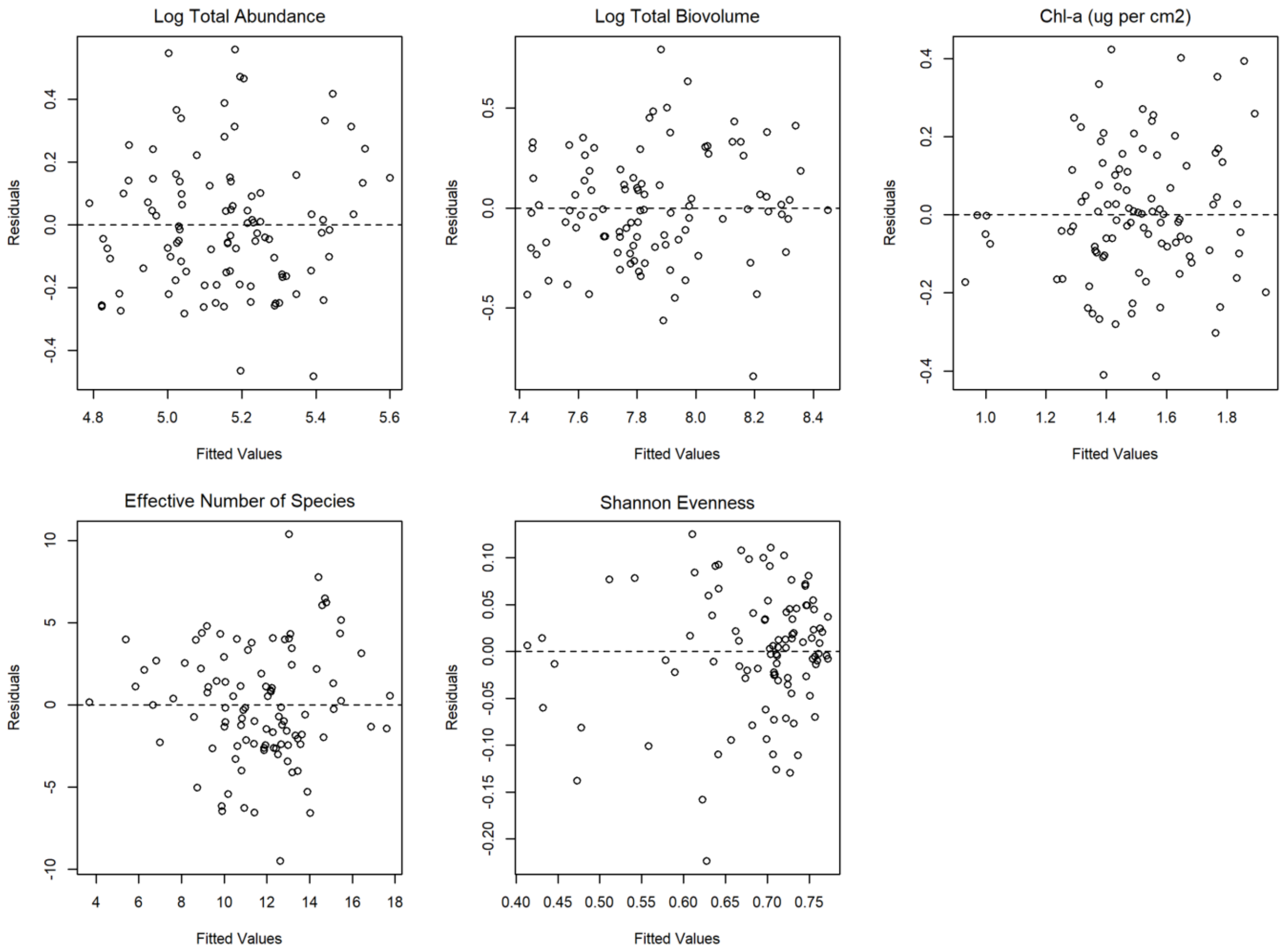


Figure A1 **Residual plots for periphyton models of abundance, biovolume, chl-a, effective number of species and Shannon Evenness.**

Table A21 Formulae used for periphyton linear mixed effects models.

Model Formula
Total Abundance (log) ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + Ref / Exp:Year + (1 | Area)
Total Biovolume (log) ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + Ref / Exp:Year + (1 | Area : Year)
Chorophyll-a (log) ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + Ref / Exp:Year + (1 | Area : Year) + (1 | Area)
Effective Species ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + Ref / Exp:Year + (1 | Area)
Shannon's Equitability ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + Ref / Exp:Year + (1 | Area : Year)

Table A22 Summary of plausible models identified using model averaging (those with a delta AIC <3) with pseudo-R2 values and coefficients for all periphyton erosional samples.

Response	X.Intercept.	D50 (cm)	Reference	Average Velocity (m/s)	Water Temperature	Year (2012)	ref_exp.Year	R.2	df	AICc	delta	weight
Chl-a (ug per cm2)	1.610	0.131				+		0.405	7.000	-9.030	0.000	0.334
Chl-a (ug per cm2)	1.610	0.131		-0.019		+		0.405	8.000	-6.790	2.250	0.109
Chl-a (ug per cm2)	1.610	0.121			-0.061	+		0.405	8.000	-6.770	2.260	0.108
Chl-a (ug per cm2)	1.620	0.129	+			+		0.404	8.000	-6.530	2.500	0.096
Effective Number of Species	13.500			-2.800	-1.520	+		0.307	7.000	553.000	0.000	0.193
Effective Number of Species	13.400			-2.710		+		0.290	6.000	553.000	0.012	0.192
Effective Number of Species	13.400	1.080		-2.920	-1.830	+		0.322	8.000	553.000	0.259	0.170
Effective Number of Species	13.300	0.833		-2.770		+		0.298	7.000	554.000	1.200	0.106
Effective Number of Species	13.600		+	-2.830	-1.400	+		0.307	8.000	555.000	2.360	0.059
Effective Number of Species	13.600		+	-2.700		+		0.290	7.000	555.000	2.400	0.058
Effective Number of Species	13.500	1.020	+	-2.980	-1.710	+		0.323	9.000	555.000	2.490	0.056
Log Total Abundance	5.290			0.081		+		0.323	6.000	7.370	0.000	0.148
Log Total Abundance	5.270					+		0.307	5.000	7.380	0.015	0.147
Log Total Abundance	5.280	0.063		0.081		+		0.334	7.000	8.150	0.781	0.100
Log Total Abundance	5.270	0.063				+		0.318	6.000	8.160	0.786	0.100
Log Total Abundance	5.290			0.086	0.050	+		0.328	7.000	9.020	1.650	0.065
Log Total Abundance	5.270				0.037	+		0.310	6.000	9.280	1.910	0.057
Log Total Abundance	5.290		+			+		0.308	6.000	9.560	2.190	0.050
Log Total Abundance	5.300		+	0.076		+		0.323	7.000	9.690	2.320	0.046
Log Total Abundance	5.280	0.065		0.087	0.055	+		0.339	8.000	9.720	2.350	0.046
Log Total Abundance	5.260	0.064			0.040	+		0.321	7.000	10.000	2.660	0.039
Log Total Abundance	5.290	0.062	+			+		0.319	7.000	10.400	2.990	0.033
Log Total Biovolume	7.610	0.220	+			+	+	0.373	9.000	67.300	0.000	0.373
Log Total Biovolume	7.620	0.220	+	0.038		+	+	0.377	10.000	69.300	1.940	0.142
Shannon Evenness	0.686			-0.047	-0.050			0.404	5.000	-198.000	0.000	0.303
Shannon Evenness	0.686			-0.049				0.382	4.000	-197.000	1.430	0.148

Response	X.Intercept.	D50 (cm)	Reference	Average Velocity (m/s)	Water Temperature	Year (2012)	ref_exp.Year	R.2	df	AICc	delta	weight
Shannon Evenness	0.686	0.001		-0.047	-0.050			0.404	6.000	-196.000	2.260	0.098
Shannon Evenness	0.683		+	-0.046	-0.049			0.404	6.000	-196.000	2.280	0.097

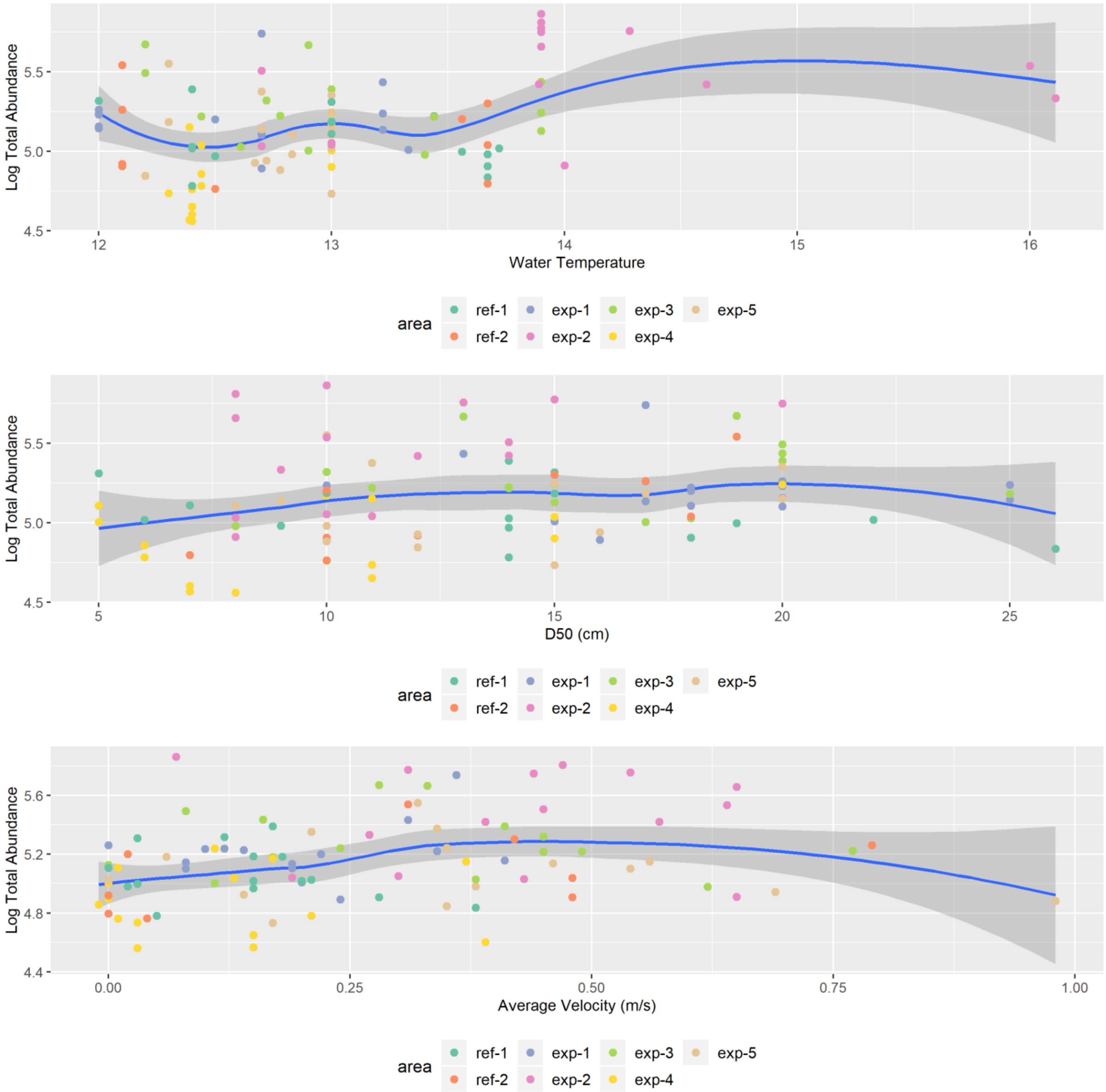


Figure A2 **Explanatory variables and Log Total Abundance grouped by erosional areas for 2012, 2015 and 2018 periphyton samples.**

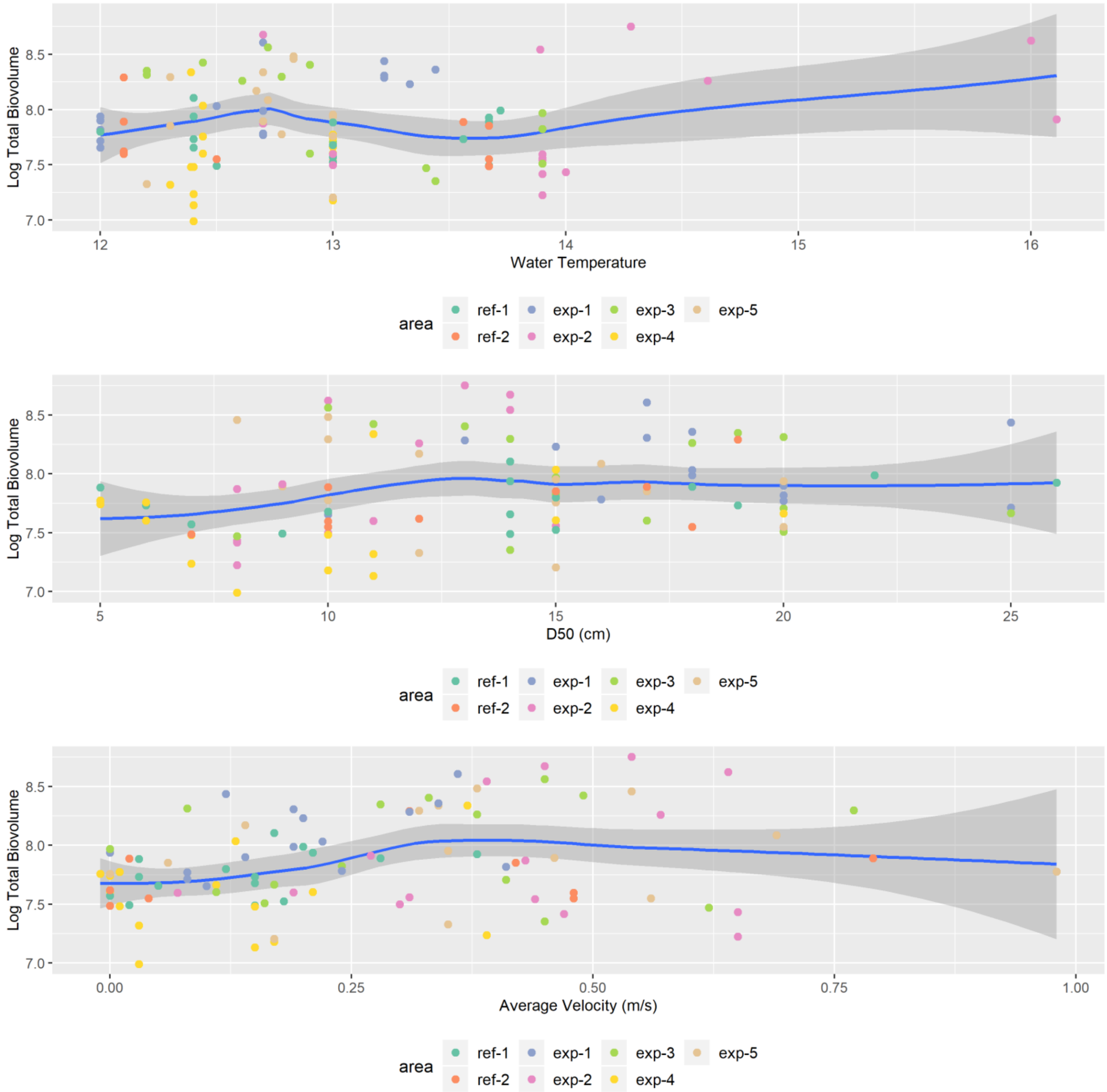


Figure A3 Explanatory variables and Log Total Biovolume grouped by erosional areas for 2012, 2015 and 2018 periphyton samples.

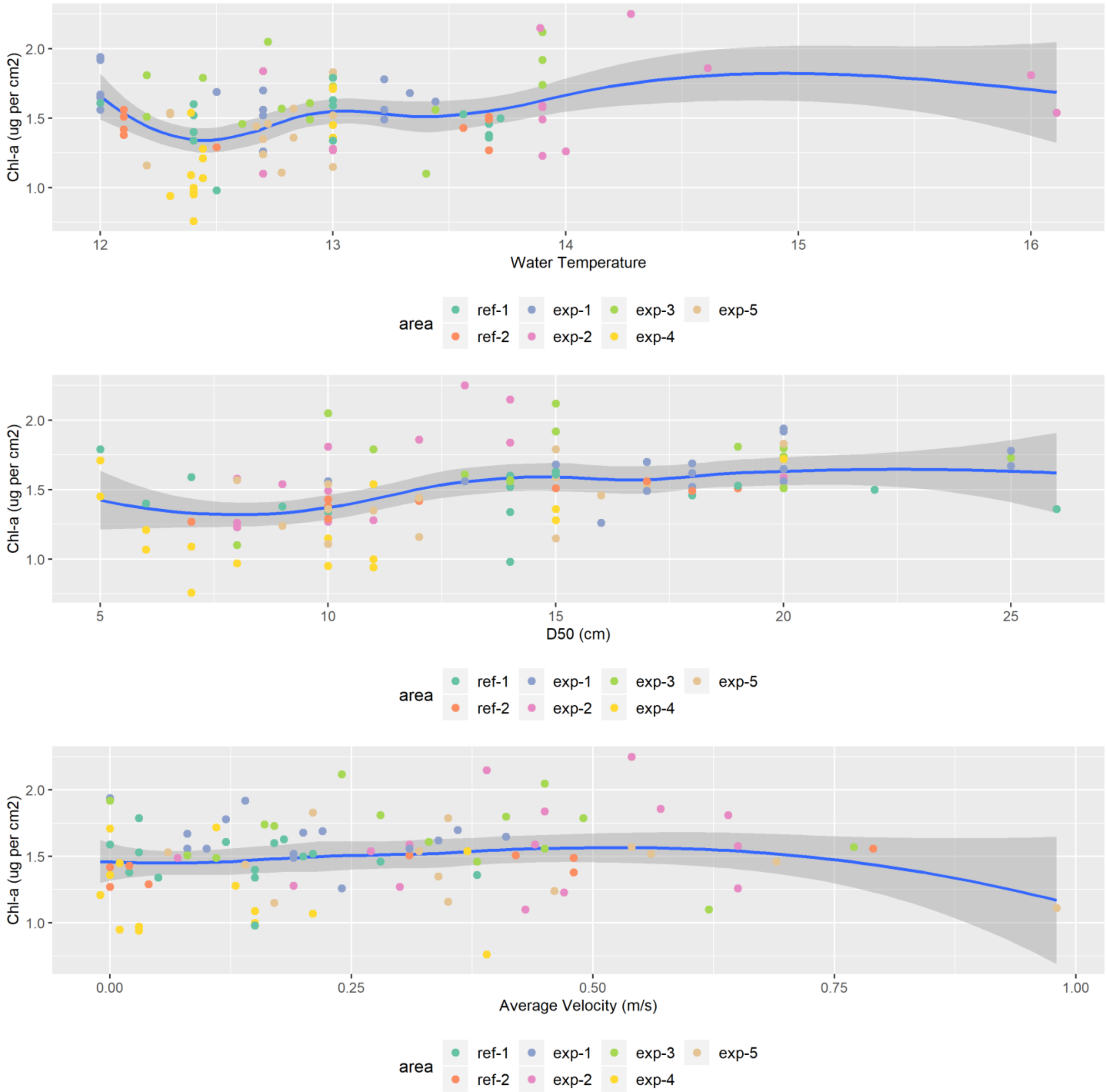


Figure A4 **Explanatory variables and Chl-a (ug per cm2) grouped by erosional areas for 2012, 2015 and 2018 periphyton samples.**

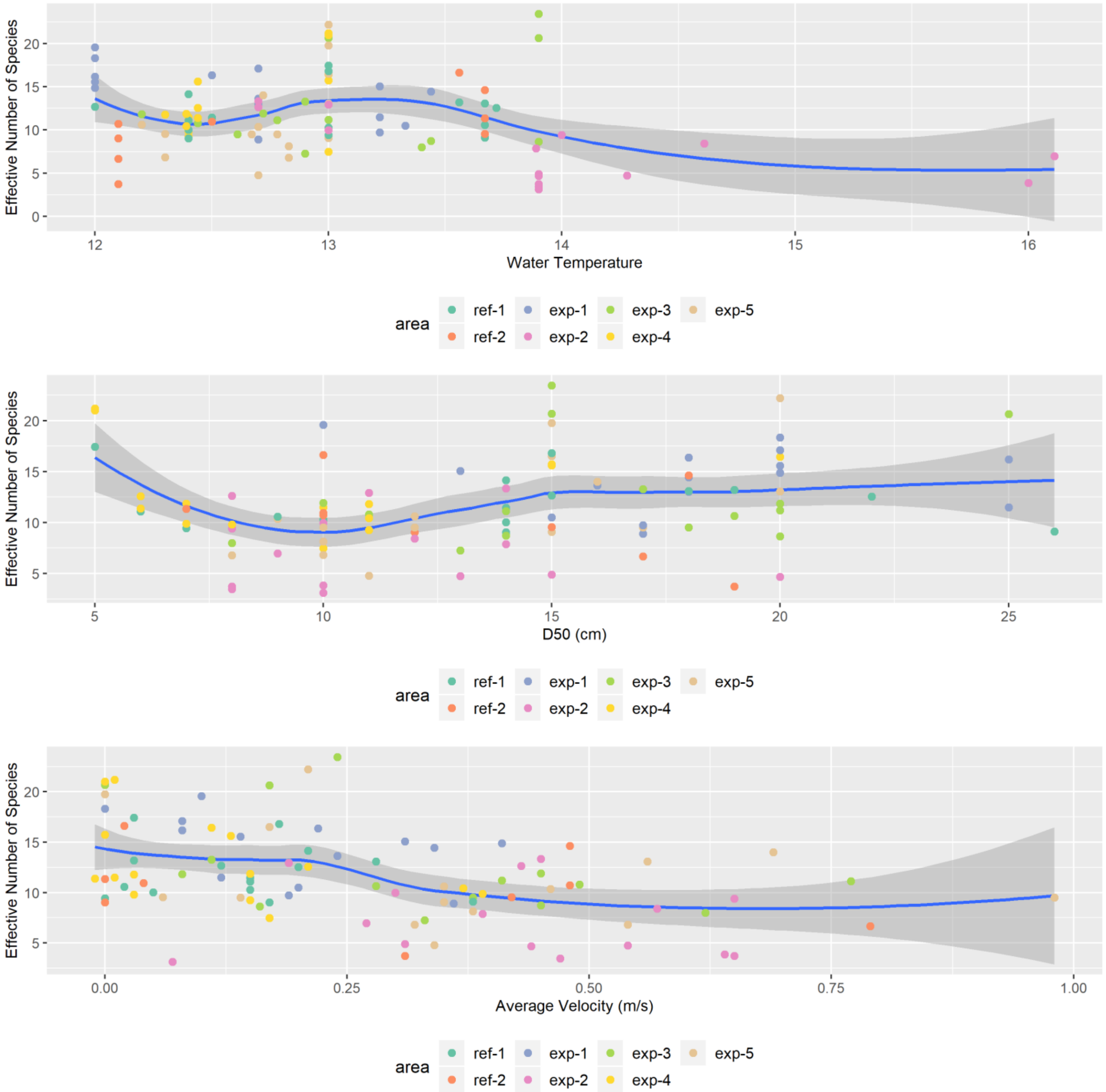


Figure A5 **Explanatory variables and effective number of species grouped by erosional areas for 2012, 2015 and 2018 periphyton samples.**

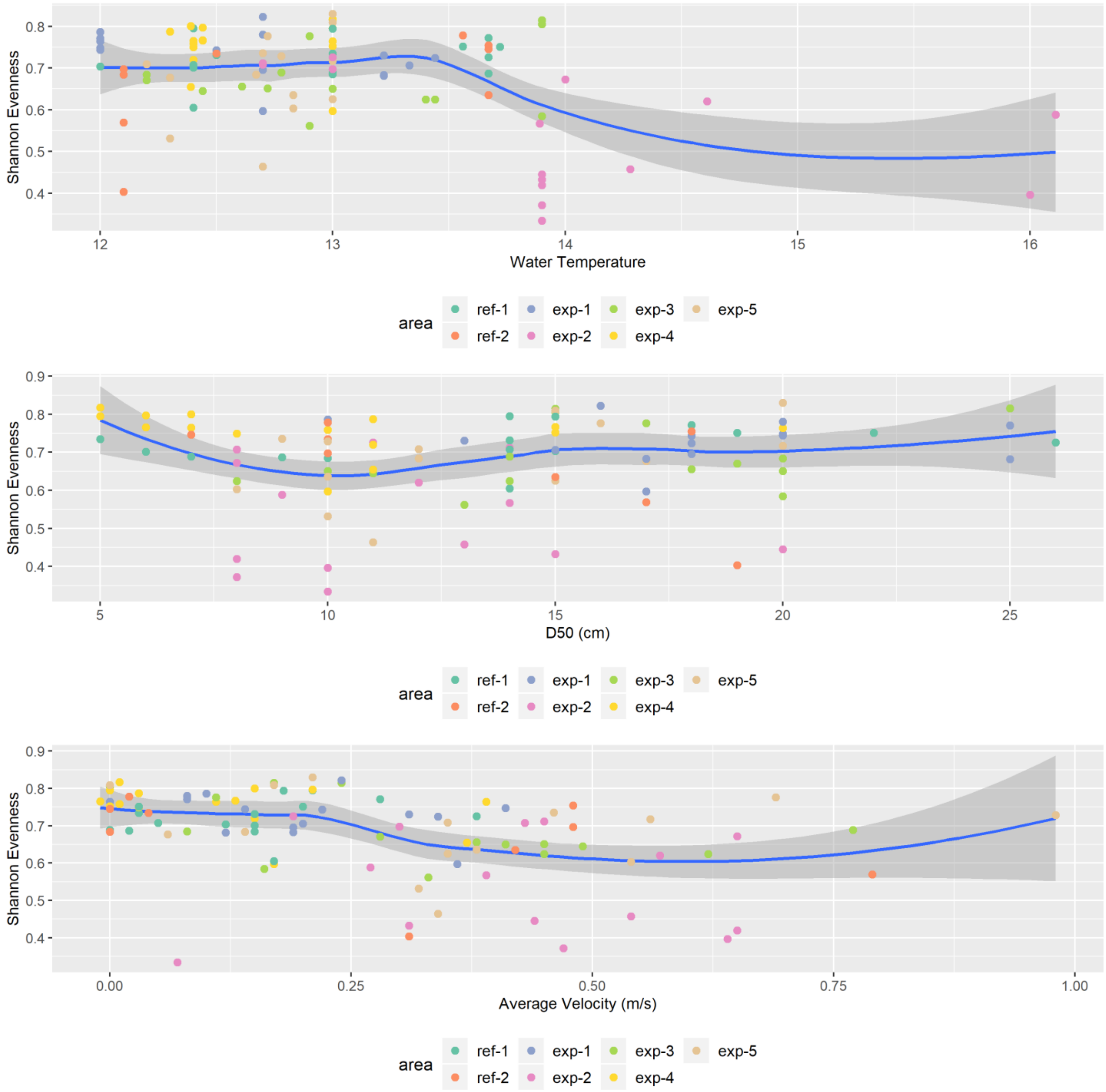


Figure A6 Explanatory variables and Shannon Evenness grouped by erosional areas for 2012, 2015 and 2018 periphyton samples.

APPENDIX J BENTHIC INVERTEBRATE TAXONOMY AND METRICS

Table J1: Benthic metrics at Depositional Exposure site 1

		Sample
	Metric	**DEP-EXP-1**
Richness Measures		
	Species Richness	57
	EPT Richness	8
	Total Abundance	1213
	Total Biomass	190
Diversity / Evenness Measures		
	Effective Species Number	13.56
	Shannon's Equitability	0.64
	Shannon's H	2.61
Dominance Measures		
	1st Dominant Taxon	Pisidiidae
	1st Dominant Abundance	313
	2nd Dominant Taxon	Naididae
	2nd Dominant Abundance	243
	3rd Dominant Taxon	Hydropsychidae
	3rd Dominant Abundance	205
	% 1st Dominant Taxon	25.80
	% 2nd Dominant Taxon	20.03
	% 3rd Dominant Taxon	16.90

		Sample
	Metric	DEP-EXP-1
Community composition		
	% Chironomidae	15.00
	% EPT	21.85
	% Gastropoda	5.19
	% Macrophyte Hervibore	0.00
	% Oligochaeta	20.03
Functional group composition		
	% Collector-Filterer	54.00
	% Collector-Gatherer	31.41
	% Other	37.92
	% Omnivore	1.24
	% Parasite	0.00
	% Piercer Herbivore	0.00
	% Predator	6.18
	% Scraper	6.60
	% Shredder	0.00
	% Shredder Herbivore	0.00
	% Unclassified	0.58
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J2: Benthic metrics at Depositional Exposure site 2

		Sample
	Metric	**DEP-EXP-2**
Richness Measures		
	Species Richness	42
	EPT Richness	5
	Total Abundance	945
	Total Biomass	112
Diversity / Evenness Measures		
	Effective Species Number	9.63
	Shannon's Equitability	0.61
	Shannon's H	2.27
Dominance Measures		
	1st Dominant Taxon	Pisidiidae
	1st Dominant Abundance	261
	2nd Dominant Taxon	Margaritiferidae
	2nd Dominant Abundance	219
	3rd Dominant Taxon	Naididae
	3rd Dominant Abundance	198
	% 1st Dominant Taxon	27.62
	% 2nd Dominant Taxon	23.17
	% 3rd Dominant Taxon	20.95
Community composition		

		Sample
	Metric	DEP-EXP-2
	% Chironomidae	9.84
	% EPT	1.48
	% Gastropoda	9.95
	% Macrophyte Hervibore	0.00
	% Oligochaeta	20.95
Functional group composition		
	% Collector-Filterer	52.91
	% Collector-Gatherer	26.03
	% Other	57.78
	% Omnivore	0.74
	% Parasite	0.00
	% Piercer Herbivore	0.00
	% Predator	6.88
	% Scraper	11.75
	% Shredder	0.11
	% Shredder Herbivore	0.00
	% Unclassified	1.59
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table HJ: Benthic metrics at Depositional Exposure site 3

		Sample
	Metric	**DEP-EXP-3**
Richness Measures		
	Species Richness	48
	EPT Richness	7
	Total Abundance	959
	Total Biomass	329
Diversity / Evenness Measures		
	Effective Species Number	19.34
	Shannon's Equitability	0.77
	Shannon's H	2.96
Dominance Measures		
	1st Dominant Taxon	Chironomidae
	1st Dominant Abundance	358
	2nd Dominant Taxon	Margaritiferidae
	2nd Dominant Abundance	127
	3rd Dominant Taxon	Pisidiidae
	3rd Dominant Abundance	119
	% 1st Dominant Taxon	37.33
	% 2nd Dominant Taxon	13.24
	% 3rd Dominant Taxon	12.41
Community composition		

		Sample
	Metric	DEP-EXP-3
	% Chironomidae	37.33
	% EPT	1.46
	% Gastropoda	20.33
	% Macrophyte Hervibore	0.00
	% Oligochaeta	8.76
Functional group composition		
	% Collector-Filterer	29.09
	% Collector-Gatherer	29.41
	% Other	32.12
	% Omnivore	1.25
	% Parasite	0.10
	% Piercer Herbivore	0.00
	% Predator	14.60
	% Scraper	24.82
	% Shredder	0.00
	% Shredder Herbivore	0.00
	% Unclassified	0.73
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J3: Benthic metrics at Depositional Exposure site 4

		Sample
	Metric	DEP-EXP-4
Richness Measures		
	Species Richness	36
	EPT Richness	1
	Total Abundance	732
	Total Biomass	1380
Diversity / Evenness Measures		
	Effective Species Number	9.64
	Shannon's Equitability	0.63
	Shannon's H	2.27
Dominance Measures		
	1st Dominant Taxon	Naididae
	1st Dominant Abundance	309
	2nd Dominant Taxon	Chironomidae
	2nd Dominant Abundance	121
	3rd Dominant Taxon	Valvatidae
	3rd Dominant Abundance	94
	% 1st Dominant Taxon	42.21
	% 2nd Dominant Taxon	16.53
	% 3rd Dominant Taxon	12.84
Community composition		

		Sample
	Metric	**DEP-EXP-4**
	% Chironomidae	16.53
	% EPT	0.14
	% Gastropoda	21.86
	% Macrophyte Hervibore	0.00
	% Oligochaeta	42.21
Functional group composition		
	% Collector-Filterer	13.80
	% Collector-Gatherer	54.37
	% Other	19.26
	% Omnivore	0.14
	% Parasite	0.55
	% Piercer Herbivore	0.00
	% Predator	7.10
	% Scraper	23.77
	% Shredder	0.00
	% Shredder Herbivore	0.00
	% Unclassified	0.27
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J4: Benthic metrics at Depositional Exposure site 5

		Sample
	Metric	DEP-EXP-5
Richness Measures		
	Species Richness	47
	EPT Richness	7
	Total Abundance	2053
	Total Biomass	626
Diversity / Evenness Measures		
	Effective Species Number	10.26
	Shannon's Equitability	0.60
	Shannon's H	2.33
Dominance Measures		
	1st Dominant Taxon	Naididae
	1st Dominant Abundance	887
	2nd Dominant Taxon	Chironomidae
	2nd Dominant Abundance	248
	3rd Dominant Taxon	Valvatidae
	3rd Dominant Abundance	229
	% 1st Dominant Taxon	43.21
	% 2nd Dominant Taxon	12.08
	% 3rd Dominant Taxon	11.15
Community composition		

		Sample
	Metric	**DEP-EXP-5**
	% Chironomidae	12.08
	% EPT	1.51
	% Gastropoda	25.09
	% Macrophyte Hervibore	0.00
	% Oligochaeta	43.21
Functional group composition		
	% Collector-Filterer	11.59
	% Collector-Gatherer	55.43
	% Other	18.12
	% Omnivore	0.83
	% Parasite	0.58
	% Piercer Herbivore	0.00
	% Predator	5.89
	% Scraper	25.47
	% Shredder	0.10
	% Shredder Herbivore	0.00
	% Unclassified	0.10
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J5: Benthic metrics at Depositional Exposure site 6

		Sample
	Metric	DEP-EXP-6
Richness Measures		
	Species Richness	41
	EPT Richness	10
	Total Abundance	355
	Total Biomass	147
Diversity / Evenness Measures		
	Effective Species Number	14.30
	Shannon's Equitability	0.72
	Shannon's H	2.66
Dominance Measures		
	1st Dominant Taxon	Pisidiidae
	1st Dominant Abundance	97
	2nd Dominant Taxon	Naididae
	2nd Dominant Abundance	55
	3rd Dominant Taxon	Margaritiferidae
	3rd Dominant Abundance	43
	% 1st Dominant Taxon	27.32
	% 2nd Dominant Taxon	15.49
	% 3rd Dominant Taxon	12.11
Community composition		

		Sample
	Metric	DEP-EXP-6
	% Chironomidae	11.27
	% EPT	6.76
	% Gastropoda	20.85
	% Macrophyte Hervibore	0.00
	% Oligochaeta	15.49
Functional group composition		
	% Collector-Filterer	40.85
	% Collector-Gatherer	21.69
	% Other	45.63
	% Omnivore	2.54
	% Parasite	0.00
	% Piercer Herbivore	0.00
	% Predator	5.07
	% Scraper	26.20
	% Shredder	1.13
	% Shredder Herbivore	0.00
	% Unclassified	2.54
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J6: Benthic metrics at Depositional Exposure site 7

		Sample
	Metric	**DEP-EXP-7**
Richness Measures		
	Species Richness	44
	EPT Richness	5
	Total Abundance	1344
	Total Biomass	615
Diversity / Evenness Measures		
	Effective Species Number	10.34
	Shannon's Equitability	0.62
	Shannon's H	2.34
Dominance Measures		
	1st Dominant Taxon	Isopoda
	1st Dominant Abundance	656
	2nd Dominant Taxon	Naididae
	2nd Dominant Abundance	168
	3rd Dominant Taxon	Lymnaeidae
	3rd Dominant Abundance	100
	% 1st Dominant Taxon	48.81
	% 2nd Dominant Taxon	12.50
	% 3rd Dominant Taxon	7.44

	Metric	Sample DEP-EXP-7
Community composition		
	% Chironomidae	4.46
	% EPT	1.41
	% Gastropoda	12.43
	% Macrophyte Hervibore	0.00
	% Oligochaeta	12.50
Functional group composition		
	% Collector-Filterer	8.63
	% Collector-Gatherer	70.54
	% Other	69.20
	% Omnivore	0.97
	% Parasite	0.07
	% Piercer Herbivore	0.00
	% Predator	4.17
	% Scraper	15.55
	% Shredder	0.00
	% Shredder Herbivore	0.00
	% Unclassified	0.07
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J7: Benthic metrics at Depositional Reference site 1

		Sample
	Metric	DEP-REF-1
Richness Measures		
	Species Richness	49
	EPT Richness	9
	Total Abundance	1813
	Total Biomass	172
Diversity / Evenness Measures		
	Effective Species Number	12.48
	Shannon's Equitability	0.65
	Shannon's H	2.52
Dominance Measures		
	1st Dominant Taxon	Naididae
	1st Dominant Abundance	529
	2nd Dominant Taxon	Chironomidae
	2nd Dominant Abundance	354
	3rd Dominant Taxon	Pisidiidae
	3rd Dominant Abundance	317
	% 1st Dominant Taxon	29.18
	% 2nd Dominant Taxon	19.53
	% 3rd Dominant Taxon	17.48
Community composition		

		Sample
	Metric	DEP-REF-1
	% Chironomidae	19.53
	% EPT	10.20
	% Gastropoda	3.86
	% Macrophyte Hervibore	0.00
	% Oligochaeta	29.18
Functional group composition		
	% Collector-Filterer	24.49
	% Collector-Gatherer	47.16
	% Other	37.23
	% Omnivore	4.91
	% Parasite	0.22
	% Piercer Herbivore	0.00
	% Predator	13.40
	% Scraper	8.94
	% Shredder	0.06
	% Shredder Herbivore	0.00
	% Unclassified	0.83
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J8: Benthic metrics at Depositional Reference site 2

		Sample
	Metric	DEP-REF-2
Richness Measures		
	Species Richness	51
	EPT Richness	7
	Total Abundance	3728
	Total Biomass	548
Diversity / Evenness Measures		
	Effective Species Number	8.50
	Shannon's Equitability	0.54
	Shannon's H	2.14
Dominance Measures		
	1st Dominant Taxon	Naididae
	1st Dominant Abundance	1330
	2nd Dominant Taxon	Isopoda
	2nd Dominant Abundance	997
	3rd Dominant Taxon	Pisidiidae
	3rd Dominant Abundance	431
	% 1st Dominant Taxon	35.68
	% 2nd Dominant Taxon	26.74
	% 3rd Dominant Taxon	11.56
Community composition		

		Sample
	Metric	DEP-REF-2
	% Chironomidae	10.35
	% EPT	1.26
	% Gastropoda	6.38
	% Macrophyte Hervibore	0.00
	% Oligochaeta	35.68
Functional group composition		
	% Collector-Filterer	16.87
	% Collector-Gatherer	71.89
	% Other	46.33
	% Omnivore	0.62
	% Parasite	0.16
	% Piercer Herbivore	0.00
	% Predator	3.51
	% Scraper	6.57
	% Shredder	0.13
	% Shredder Herbivore	0.00
	% Unclassified	0.24
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J9: Benthic metrics at Depositional Reference site 3

		Sample
	Metric	DEP-REF-3
Richness Measures		
	Species Richness	41
	EPT Richness	3
	Total Abundance	1122
	Total Biomass	161
Diversity / Evenness Measures		
	Effective Species Number	10.15
	Shannon's Equitability	0.62
	Shannon's H	2.32
Dominance Measures		
	1st Dominant Taxon	Naididae
	1st Dominant Abundance	467
	2nd Dominant Taxon	Pisidiidae
	2nd Dominant Abundance	229
	3rd Dominant Taxon	Margaritiferidae
	3rd Dominant Abundance	135
	% 1st Dominant Taxon	41.62
	% 2nd Dominant Taxon	20.41
	% 3rd Dominant Taxon	12.03
Community composition		

		Sample
	Metric	DEP-REF-3
	% Chironomidae	7.31
	% EPT	0.53
	% Gastropoda	8.47
	% Macrophyte Hervibore	0.00
	% Oligochaeta	47.15
Functional group composition		
	% Collector-Filterer	32.44
	% Collector-Gatherer	51.87
	% Other	36.54
	% Omnivore	0.71
	% Parasite	0.00
	% Piercer Herbivore	0.00
	% Predator	5.44
	% Scraper	8.56
	% Shredder	0.00
	% Shredder Herbivore	0.00
	% Unclassified	0.98
Biotic Indices		
	Hilsenhoff Biotic Index	NA

Table J10: Benthic metrics at Erosional Exposure site 1

		Sample				
	Metric	**ERO-EXP-1-1**	**ERO-EXP-1-2**	**ERO-EXP-1-3**	**ERO-EXP-1-4**	**ERO-EXP-1-5**
Richness Measures						
	Species Richness	22	29	35	20	26
	EPT Richness	11	11	14	11	16
	Total Abundance	10680	1640	2634	5741	14700
	Total Biomass	17174	573	37670	6777	14297
Diversity / Evenness Measures						
	Effective Species Number	3.59	10.33	10.06	5.12	4.32
	Shannon's Equitability	0.41	0.69	0.65	0.55	0.45
	Shannon's H	1.28	2.34	2.31	1.63	1.46
Dominance Measures						
	1st Dominant Taxon	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae
	1st Dominant Abundance	9480	830	1553	4300	12220
	2nd Dominant Taxon	Ephemerellidae	Ephemerellidae	Ephemerellidae	Ephemerellidae	Ephemerellidae
	2nd Dominant Abundance	300	265	431	871	1440
	3rd Dominant Taxon	Sperchontidae	Hygrobatidae	Hydrobiidae	Leptoceridae	Baetidae
	3rd Dominant Abundance	280	200	108	171	260
	% 1st Dominant Taxon	88.76	50.61	58.96	74.90	83.13
	% 2nd Dominant Taxon	2.81	16.16	16.36	15.17	9.80
	% 3rd Dominant Taxon	2.62	12.20	4.10	2.98	1.77

		Sample				
	Metric	**ERO-EXP-1-1**	**ERO-EXP-1-2**	**ERO-EXP-1-3**	**ERO-EXP-1-4**	**ERO-EXP-1-5**
Community composition						
	% Chironomidae	0.75	6.10	4.06	1.48	0.68
	% EPT	94.57	71.04	82.12	95.28	97.55
	% Gastropoda	0.19	2.44	5.28	1.50	0.41
	% Macrophyte Hervibore	0.00	0.30	0.00	0.00	0.00
	% Oligochaeta	0.00	0.61	0.30	0.00	0.00
Functional group composition						
	% Collector-Filterer	88.95	50.61	58.96	74.90	83.40
	% Collector-Gatherer	4.31	22.87	24.03	17.16	10.61
	% Other	4.49	19.82	8.24	1.74	1.36
	% Omnivore	0.75	2.74	2.35	2.23	1.63
	% Parasite	0.00	0.00	0.00	0.00	0.00
	% Piercer Herbivore	0.00	0.00	0.30	0.00	0.00
	% Predator	4.87	18.60	7.33	3.73	2.72
	% Scraper	0.56	4.88	6.45	1.74	1.50
	% Shredder	0.19	0.00	0.00	0.00	0.00
	% Shredder Herbivore	0.00	0.00	0.00	0.00	0.00
	% Unclassified	0.37	0.00	0.57	0.24	0.14
Biotic Indices						
	Hilsenhoff Biotic Index	4.14	4.45	4.03	3.65	3.74

Table J11: Benthic metrics at Erosional Exposure site 2

		Sample				
	Metric	**ERO-EXP-2-1**	**ERO-EXP-2-2**	**ERO-EXP-2-3**	**ERO-EXP-2-4**	**ERO-EXP-2-5**
Richness Measures						
	Species Richness	29	23	19	20	22
	EPT Richness	16	13	11	13	13
	Total Abundance	24720	12360	10000	13520	13100
	Total Biomass	14519	5401	5894	8841	7793
Diversity / Evenness Measures						
	Effective Species Number	4.23	4.05	3.67	3.54	4.10
	Shannon's Equitability	0.43	0.45	0.44	0.42	0.46
	Shannon's H	1.44	1.40	1.30	1.26	1.41
Dominance Measures						
	1st Dominant Taxon	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae
	1st Dominant Abundance	19740	9780	8440	11300	10460
	2nd Dominant Taxon	Ephemerellidae	Ephemerellidae	Brachycentridae	Brachycentridae	Chironomidae
	2nd Dominant Abundance	2720	860	380	1040	720
	3rd Dominant Taxon	Chironomidae	Chironomidae	Chironomidae	Ephemerellidae	Ephemerellidae
	3rd Dominant Abundance	1040	620	300	560	720
	% 1st Dominant Taxon	79.85	79.13	84.40	83.58	79.85
	% 2nd Dominant Taxon	11.00	6.96	3.80	7.69	5.50
	% 3rd Dominant Taxon	4.21	5.02	3.00	4.14	5.50

		Sample				
	Metric	ERO-EXP-2-1	ERO-EXP-2-2	ERO-EXP-2-3	ERO-EXP-2-4	ERO-EXP-2-5
Community composition						
	% Chironomidae	4.21	5.02	3.00	1.78	5.50
	% EPT	94.09	92.07	95.00	96.60	93.44
	% Gastropoda	0.32	1.13	0.40	0.15	0.15
	% Macrophyte Hervibore	0.00	0.00	0.00	0.00	0.00
	% Oligochaeta	0.00	0.32	0.00	0.00	0.00
Functional group composition						
	% Collector-Filterer	79.94	79.13	84.80	83.58	80.31
	% Collector-Gatherer	14.81	11.97	6.20	2.96	12.37
	% Other	1.38	1.46	1.60	1.48	0.92
	% Omnivore	0.89	0.65	4.60	8.14	3.51
	% Parasite	0.00	0.00	0.00	0.00	0.00
	% Piercer Herbivore	0.00	0.00	0.00	0.00	0.00
	% Predator	3.24	2.59	2.00	4.29	2.44
	% Scraper	0.81	5.34	2.20	0.59	0.31
	% Shredder	0.00	0.00	0.00	0.00	0.15
	% Shredder Herbivore	0.00	0.00	0.00	0.00	0.00
	% Unclassified	0.32	0.32	0.20	0.44	0.92
Biotic Indices						
	Hilsenhoff Biotic Index	3.78	3.87	3.86	3.71	3.91

Table J12: Benthic metrics at Erosional Exposure site 3

		Sample				
	Metric	**ERO-EXP-3-1**	**ERO-EXP-3-2**	**ERO-EXP-3-3**	**ERO-EXP-3-4**	**ERO-EXP-3-5**
Richness Measures						
	Species Richness	20	21	23	17	14
	EPT Richness	15	12	11	11	12
	Total Abundance	16160	13900	11160	9940	8020
	Total Biomass	11319	9211	5816	6420	3705
Diversity / Evenness Measures						
	Effective Species Number	3.15	3.30	4.65	3.84	3.00
	Shannon's Equitability	0.38	0.39	0.49	0.47	0.42
	Shannon's H	1.15	1.19	1.54	1.34	1.10
Dominance Measures						
	1st Dominant Taxon	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae
	1st Dominant Abundance	14500	12620	8980	8300	7220
	2nd Dominant Taxon	Chironomidae	Ephemerellidae	Ephemerellidae	Ephemerellidae	Ephemerellidae
	2nd Dominant Abundance	420	420	880	600	320
	3rd Dominant Taxon	Ephemerellidae	Chironomidae	Chironomidae	Baetidae	Brachycentridae
	3rd Dominant Abundance	420	180	300	480	200
	% 1st Dominant Taxon	89.73	90.79	80.47	83.50	90.02
	% 2nd Dominant Taxon	2.60	3.02	7.89	6.04	3.99
	% 3rd Dominant Taxon	2.60	1.29	2.69	4.83	2.49

	Metric	Sample				
		ERO-EXP-3-1	ERO-EXP-3-2	ERO-EXP-3-3	ERO-EXP-3-4	ERO-EXP-3-5
Community composition						
	% Chironomidae	2.60	1.29	2.69	2.01	0.25
	% EPT	97.28	96.55	94.27	96.78	99.00
	% Gastropoda	0.00	0.43	0.18	0.00	0.00
	% Macrophyte Hervibore	0.00	0.00	0.00	0.00	0.00
	% Oligochaeta	0.00	0.00	0.00	0.00	0.00
Functional group composition						
	% Collector-Filterer	89.85	91.08	81.72	84.71	90.02
	% Collector-Gatherer	6.19	4.46	10.75	12.07	3.24
	% Other	0.12	1.73	2.87	1.21	0.75
	% Omnivore	1.73	1.29	1.43	1.21	2.74
	% Parasite	0.00	0.00	0.00	0.00	0.00
	% Piercer Herbivore	0.00	0.00	0.00	0.00	0.00
	% Predator	0.87	1.87	2.33	0.40	2.74
	% Scraper	1.24	1.29	3.41	1.41	1.25
	% Shredder	0.00	0.00	0.00	0.00	0.00
	% Shredder Herbivore	0.00	0.00	0.00	0.00	0.00
	% Unclassified	0.12	0.00	0.36	0.20	0.00
Biotic Indices						
	Hilsenhoff Biotic Index	3.92	3.97	3.82	3.91	3.83

Table J13: Benthic metrics at Erosional Exposure site 4

		Sample				
	Metric	**ERO-EXP-4-1**	**ERO-EXP-4-2**	**ERO-EXP-4-3**	**ERO-EXP-4-4**	**ERO-EXP-4-5**
Richness Measures						
	Species Richness	32	35	38	36	28
	EPT Richness	13	12	9	12	13
	Total Abundance	857	1994	616	1870	6820
	Total Biomass	985	1039	1142	936	3753
Diversity / Evenness Measures						
	Effective Species Number	13.22	10.95	18.38	14.74	4.92
	Shannon's Equitability	0.74	0.67	0.80	0.75	0.48
	Shannon's H	2.58	2.39	2.91	2.69	1.59
Dominance Measures						
	1st Dominant Taxon	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae
	1st Dominant Abundance	442	1268	122	905	5220
	2nd Dominant Taxon	Leptoceridae	Leptoceridae	Hydrobiidae	Hygrobatidae	Ephemerellidae
	2nd Dominant Abundance	85	113	116	140	920
	3rd Dominant Taxon	Chironomidae	Chironomidae	Leptoceridae	Leptoceridae	Chironomidae
	3rd Dominant Abundance	68	101	54	130	220
	% 1st Dominant Taxon	51.58	63.59	19.81	48.40	76.54
	% 2nd Dominant Taxon	9.92	5.67	18.83	7.49	13.49
	% 3rd Dominant Taxon	7.93	5.07	8.77	6.95	3.23

		Sample				
	Metric	ERO-EXP-4-1	ERO-EXP-4-2	ERO-EXP-4-3	ERO-EXP-4-4	ERO-EXP-4-5
Community composition						
	% Chironomidae	7.93	5.07	6.49	6.68	3.23
	% EPT	67.68	75.23	31.49	62.03	93.55
	% Gastropoda	5.83	7.82	37.34	17.11	0.88
	% Macrophyte Hervibore	0.00	0.00	0.00	0.00	0.00
	% Oligochaeta	0.00	0.30	0.00	0.00	0.00
Functional group composition						
	% Collector-Filterer	54.49	64.84	23.38	50.80	77.42
	% Collector-Gatherer	7.12	6.57	15.26	9.09	14.96
	% Other	18.55	11.58	24.68	14.17	2.35
	% Omnivore	10.39	5.67	8.77	6.95	0.59
	% Parasite	0.00	0.00	0.00	0.00	0.00
	% Piercer Herbivore	0.00	0.00	0.00	0.00	0.00
	% Predator	17.74	7.87	10.06	12.30	3.23
	% Scraper	9.80	13.79	40.91	19.79	2.35
	% Shredder	0.00	0.00	0.00	0.00	0.00
	% Shredder Herbivore	0.00	0.00	0.00	0.27	0.00
	% Unclassified	0.47	1.25	1.62	0.80	1.47
Biotic Indices						
	Hilsenhoff Biotic Index	4.85	4.52	5.75	5.04	3.65

Table J14: Benthic metrics at Erosional Exposure site 5

		Sample				
	Metric	**ERO-EXP-5-1**	**ERO-EXP-5-2**	**ERO-EXP-5-3**	**ERO-EXP-5-4**	**ERO-EXP-5-5**
Richness Measures						
	Species Richness	46	18	20	21	31
	EPT Richness	14	12	10	10	11
	Total Abundance	1388	14220	3405	3370	2038
	Total Biomass	1425	11620	1076	936	1525
Diversity / Evenness Measures						
	Effective Species Number	24.47	2.93	3.91	4.94	13.56
	Shannon's Equitability	0.84	0.37	0.45	0.52	0.76
	Shannon's H	3.20	1.07	1.36	1.60	2.61
Dominance Measures						
	1st Dominant Taxon	Chironomidae	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hydropsychidae
	1st Dominant Abundance	204	13280	2975	2730	811
	2nd Dominant Taxon	Hygrobatidae	Ephemerellidae	Ephemerellidae	Ephemerellidae	Chironomidae
	2nd Dominant Abundance	152	580	100	170	336
	3rd Dominant Taxon	Lymnaeidae	Glossosomatidae	Chironomidae	Chironomidae	Simuliidae
	3rd Dominant Abundance	148	80	99	160	289
	% 1st Dominant Taxon	14.70	93.39	87.37	81.01	39.79
	% 2nd Dominant Taxon	10.95	4.08	2.94	5.04	16.49
	% 3rd Dominant Taxon	10.66	0.56	2.91	4.75	14.18

		Sample				
	Metric	**ERO-EXP-5-1**	**ERO-EXP-5-2**	**ERO-EXP-5-3**	**ERO-EXP-5-4**	**ERO-EXP-5-5**
Community composition						
	% Chironomidae	14.70	0.42	2.91	4.75	16.49
	% EPT	17.87	99.16	94.19	88.72	55.99
	% Gastropoda	36.89	0.00	0.23	0.30	2.89
	% Macrophyte Hervibore	0.00	0.00	0.00	0.00	0.00
	% Oligochaeta	2.02	0.00	0.23	0.30	0.59
Functional group composition						
	% Collector-Filterer	10.66	93.53	89.07	81.60	54.27
	% Collector-Gatherer	17.87	3.52	3.64	9.20	10.45
	% Other	28.53	0.42	2.44	5.93	24.04
	% Omnivore	3.46	0.56	1.70	1.78	4.32
	% Parasite	0.00	0.00	0.00	0.00	0.00
	% Piercer Herbivore	0.00	0.00	0.00	0.00	0.00
	% Predator	20.75	1.27	1.70	5.04	10.99
	% Scraper	45.82	0.84	2.17	2.37	12.17
	% Shredder	0.00	0.14	0.00	0.00	0.00
	% Shredder Herbivore	0.00	0.00	0.00	0.00	0.00
	% Unclassified	1.44	0.14	1.70	0.00	7.80
Biotic Indices						
	Hilsenhoff Biotic Index	6.28	3.95	4.00	4.10	4.55

Table J15: Benthic metrics at Erosional Reference site 1

		Sample				
	Metric	**ERO-REF-1-1**	**ERO-REF-1-2**	**ERO-REF-1-3**	**ERO-REF-1-4**	**ERO-REF-1-5**
Richness Measures						
	Species Richness	19	37	20	14	41
	EPT Richness	11	7	13	9	10
	Total Abundance	4270	1748	9040	6815	1347
	Total Biomass	2635	8493	7061	4187	263
Diversity / Evenness Measures						
	Effective Species Number	5.49	11.31	3.46	2.93	16.06
	Shannon's Equitability	0.58	0.67	0.41	0.41	0.75
	Shannon's H	1.70	2.43	1.24	1.08	2.78
Dominance Measures						
	1st Dominant Taxon	Hydropsychidae	Hygrobatidae	Hydropsychidae	Hydropsychidae	Hygrobatidae
	1st Dominant Abundance	3351	428	7880	6258	391
	2nd Dominant Taxon	Hydrobiidae	Pisidiidae	Ephemerellidae	Ephemerellidae	Ephemerellidae
	2nd Dominant Abundance	313	296	620	272	183
	3rd Dominant Taxon	Ephemerellidae	Naididae	Baetidae	Hydrobiidae	Chironomidae
	3rd Dominant Abundance	214	264	280	86	151
	% 1st Dominant Taxon	78.48	24.49	87.17	91.83	29.03
	% 2nd Dominant Taxon	7.33	16.93	6.86	3.99	13.59
	% 3rd Dominant Taxon	5.01	15.10	3.10	1.26	11.21

		Sample				
	Metric	ERO-REF-1-1	ERO-REF-1-2	ERO-REF-1-3	ERO-REF-1-4	ERO-REF-1-5
Community composition						
	% Chironomidae	0.00	2.97	0.66	0.43	11.21
	% EPT	87.33	4.35	98.23	96.64	27.02
	% Gastropoda	8.22	8.47	0.00	1.26	13.88
	% Macrophyte Hervibore	0.00	0.00	0.00	0.00	0.00
	% Oligochaeta	0.00	15.10	0.00	0.00	2.82
Functional group composition						
	% Collector-Filterer	78.48	20.82	87.83	91.83	13.59
	% Collector-Gatherer	7.68	28.60	9.51	1.89	28.58
	% Other	4.45	69.11	1.11	1.67	45.06
	% Omnivore	1.17	1.37	0.66	0.41	0.30
	% Parasite	0.00	0.00	0.00	0.00	0.00
	% Piercer Herbivore	0.00	0.00	0.00	0.00	0.00
	% Predator	3.26	29.98	1.55	4.40	39.57
	% Scraper	9.41	18.76	0.22	1.47	16.70
	% Shredder	0.00	0.00	0.00	0.00	0.00
	% Shredder Herbivore	0.00	0.00	0.00	0.00	0.00
	% Unclassified	0.00	0.46	0.22	0.00	1.26
Biotic Indices						
	Hilsenhoff Biotic Index	4.30	7.44	3.84	4.00	5.74

Table J16: Benthic metrics at Erosional Reference site 2

		Sample				
	Metric	**ERO-REF-2-1**	**ERO-REF-2-2**	**ERO-REF-2-3**	**ERO-REF-2-4**	**ERO-REF-2-5**
Richness Measures						
	Species Richness	18	17	18	35	28
	EPT Richness	9	11	9	7	6
	Total Abundance	12040	22020	17400	2001	1325
	Total Biomass	6699	9452	13939	468	799
Diversity / Evenness Measures						
	Effective Species Number	4.69	3.75	4.11	7.88	11.06
	Shannon's Equitability	0.54	0.47	0.49	0.58	0.72
	Shannon's H	1.55	1.32	1.41	2.06	2.40
Dominance Measures						
	1st Dominant Taxon	Hydropsychidae	Hydropsychidae	Hydropsychidae	Hygrobatidae	Hygrobatidae
	1st Dominant Abundance	10360	20700	16180	1005	344
	2nd Dominant Taxon	Baetidae	Ephemerellidae	Ephemerellidae	Planorbidae	Hydrobiidae
	2nd Dominant Abundance	540	860	440	241	233
	3rd Dominant Taxon	Ephemerellidae	Baetidae	Baetidae	Corixidae	Planorbidae
	3rd Dominant Abundance	520	100	300	182	178
	% 1st Dominant Taxon	86.05	94.01	92.99	50.22	25.96
	% 2nd Dominant Taxon	4.49	3.91	2.53	12.04	17.58
	% 3rd Dominant Taxon	4.32	0.45	1.72	9.10	13.43

		Sample				
	Metric	**ERO-REF-2-1**	**ERO-REF-2-2**	**ERO-REF-2-3**	**ERO-REF-2-4**	**ERO-REF-2-5**
Community composition						
	% Chironomidae	1.33	0.27	0.34	3.55	4.30
	% EPT	96.01	99.09	97.93	5.95	6.19
	% Gastropoda	0.17	0.09	0.80	17.04	35.55
	% Macrophyte Hervibore	0.00	0.00	0.00	0.00	0.00
	% Oligochaeta	0.00	0.00	0.00	1.15	1.43
Functional group composition						
	% Collector-Filterer	86.38	94.19	93.10	2.50	2.79
	% Collector-Gatherer	9.80	2.91	4.25	6.50	7.40
	% Other	2.49	0.54	0.92	72.31	52.53
	% Omnivore	0.83	0.54	0.11	1.60	1.43
	% Parasite	0.00	0.00	0.00	0.00	0.00
	% Piercer Herbivore	0.00	0.00	0.00	0.00	0.00
	% Predator	2.16	2.09	0.57	68.72	37.21
	% Scraper	0.83	0.18	1.38	19.79	48.08
	% Shredder	0.00	0.00	0.00	0.00	0.00
	% Shredder Herbivore	0.00	0.00	0.00	0.00	0.00
	% Unclassified	0.00	0.09	0.57	0.90	3.09
Biotic Indices						
	Hilsenhoff Biotic Index	4.47	4.33	4.29	7.32	7.13

APPENDIX K DEPOSITIONAL BENTHIC INVERTEBRATES STATISTICAL OUTPUTS

Table A23 ANOVA summary table for tot.abun depositional sites benthic invertebrates.

term	df	sumsq	meansq	statistic	p.value	form
x$year	2.000	0.214	0.107	0.596	0.558	aov(value~year+ref_exp)
x$ref_exp	1.000	0.343	0.343	1.920	0.178	aov(value~year+ref_exp)
Residuals	27.000	4.840	0.179			aov(value~year+ref_exp)

Table A24 ANOVA summary table for perc.Chironomidae depositional sites benthic invertebrates.

term	df	sumsq	meansq	statistic	p.value	form
x$year	2.000	0.246	0.123	0.419	0.662	aov(value~year+ref_exp)
x$ref_exp	1.000	0.490	0.490	1.670	0.207	aov(value~year+ref_exp)
Residuals	27.000	7.920	0.293			aov(value~year+ref_exp)

Table A25 ANOVA summary table for perc.EPT depositional sites benthic invertebrates.

term	df	sumsq	meansq	statistic	p.value	form
x$year	2.000	0.979	0.490	1.260	0.3	aov(value~year+ref_exp)
x$ref_exp	1.000	0.000	0.000	0.001	0.975	aov(value~year+ref_exp)
Residuals	27.000	10.500	0.389			aov(value~year+ref_exp)

Table A26 ANOVA summary table for eff.species depositional sites benthic invertebrates.

term	df	sumsq	meansq	statistic	p.value	form
x$year	2.000	157.000	78.700	7.040	0.00347	aov(value~year+ref_exp)
x$ref_exp	1.000	20.800	20.800	1.860	0.184	aov(value~year+ref_exp)
Residuals	27.000	302.000	11.200			aov(value~year+ref_exp)

Table A27 Tukey HSD ANOVA summary table for eff.species depositional benthic invertebrate.

year	diff	lwr	upr	p adj
2015-2012	2.840	-0.786	6.460	0.147
2018-2012	5.470	1.850	9.100	0.0024
2018-2015	2.640	-1.070	6.350	0.201

APPENDIX L EROSIONAL BENTHIC INVERTEBRATES STATISTICAL OUTPUTS

Table A28 ANOVA summary table for Erosional Site Pairs for 2018 Effective Species

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	0.856	0.143	2.522	0.044
Residuals	28.000	1.584	0.057		

Table A29 Tukey HSD for Erosional Site Pairs for 2018 Effective Species

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	-0.192	-0.669	0.286	0.858
area	Ero Exp 3 : Ero Exp 1	-0.234	-0.711	0.243	0.709
area	Ero Exp 4 : Ero Exp 1	0.274	-0.204	0.751	0.547
area	Ero Exp 5 : Ero Exp 1	0.071	-0.406	0.548	0.999
area	Ero Ref 1 : Ero Exp 1	0.018	-0.460	0.495	1.000
area	Ero Ref 2 : Ero Exp 1	-0.024	-0.501	0.454	1.000
area	Ero Exp 3 : Ero Exp 2	-0.043	-0.520	0.435	1.000
area	Ero Exp 4 : Ero Exp 2	0.465	-0.012	0.942	0.060
area	Ero Exp 5 : Ero Exp 2	0.263	-0.215	0.740	0.593
area	Ero Ref 1 : Ero Exp 2	0.209	-0.268	0.686	0.802
area	Ero Ref 2 : Ero Exp 2	0.168	-0.309	0.645	0.918
area	Ero Exp 4 : Ero Exp 3	0.508	0.031	0.985	0.031
area	Ero Exp 5 : Ero Exp 3	0.305	-0.172	0.782	0.420
area	Ero Ref 1 : Ero Exp 3	0.252	-0.225	0.729	0.638
area	Ero Ref 2 : Ero Exp 3	0.211	-0.267	0.688	0.797
area	Ero Exp 5 : Ero Exp 4	-0.203	-0.680	0.275	0.824
area	Ero Ref 1 : Ero Exp 4	-0.256	-0.733	0.221	0.620
area	Ero Ref 2 : Ero Exp 4	-0.297	-0.774	0.180	0.451
area	Ero Ref 1 : Ero Exp 5	-0.053	-0.531	0.424	1.000
area	Ero Ref 2 : Ero Exp 5	-0.095	-0.572	0.383	0.995
area	Ero Ref 2 : Ero Ref 1	-0.041	-0.518	0.436	1.000

Table A30 ANOVA summary table for Erosional Site Pairs for 2018 EPT Richness

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	0.149	0.025	4.225	0.004
Residuals	28.000	0.164	0.006		

Table A31 Tukey HSD for Erosional Site Pairs for 2018 EPT Richness

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	0.023	-0.131	0.176	0.999
area	Ero Exp 3 : Ero Exp 1	-0.011	-0.165	0.142	1.000
area	Ero Exp 4 : Ero Exp 1	-0.027	-0.180	0.127	0.998
area	Ero Exp 5 : Ero Exp 1	-0.042	-0.195	0.112	0.976
area	Ero Ref 1 : Ero Exp 1	-0.104	-0.258	0.050	0.355
area	Ero Ref 2 : Ero Exp 1	-0.180	-0.334	-0.027	0.014
area	Ero Exp 3 : Ero Exp 2	-0.034	-0.188	0.120	0.991
area	Ero Exp 4 : Ero Exp 2	-0.049	-0.203	0.104	0.945
area	Ero Exp 5 : Ero Exp 2	-0.064	-0.218	0.090	0.835
area	Ero Ref 1 : Ero Exp 2	-0.127	-0.280	0.027	0.160
area	Ero Ref 2 : Ero Exp 2	-0.203	-0.356	-0.049	0.004
area	Ero Exp 4 : Ero Exp 3	-0.015	-0.169	0.138	1.000
area	Ero Exp 5 : Ero Exp 3	-0.030	-0.184	0.124	0.996
area	Ero Ref 1 : Ero Exp 3	-0.093	-0.246	0.061	0.491
area	Ero Ref 2 : Ero Exp 3	-0.169	-0.322	-0.015	0.024
area	Ero Exp 5 : Ero Exp 4	-0.015	-0.168	0.139	1.000
area	Ero Ref 1 : Ero Exp 4	-0.077	-0.231	0.076	0.687
area	Ero Ref 2 : Ero Exp 4	-0.153	-0.307	0.000	0.050
area	Ero Ref 1 : Ero Exp 5	-0.062	-0.216	0.091	0.851
area	Ero Ref 2 : Ero Exp 5	-0.139	-0.292	0.015	0.097

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Ref 2 : Ero Ref 1	-0.076	-0.230	0.077	0.698

Table A32 ANOVA summary table for Erosional Site Pairs for 2018 Hilsenhoff Biotic index

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	0.093	0.015	2.504	0.046
Residuals	28.000	0.173	0.006		

Table A33 Tukey HSD for Erosional Site Pairs for 2018 Hilsenhoff Biotic index

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	-0.018	-0.176	0.139	1.000
area	Ero Exp 3 : Ero Exp 1	-0.011	-0.169	0.146	1.000
area	Ero Exp 4 : Ero Exp 1	0.072	-0.086	0.229	0.772
area	Ero Exp 5 : Ero Exp 1	0.052	-0.105	0.210	0.936
area	Ero Ref 1 : Ero Exp 1	0.089	-0.069	0.246	0.565
area	Ero Ref 2 : Ero Exp 1	0.126	-0.031	0.284	0.183
area	Ero Exp 3 : Ero Exp 2	0.007	-0.150	0.165	1.000
area	Ero Exp 4 : Ero Exp 2	0.090	-0.067	0.248	0.546
area	Ero Exp 5 : Ero Exp 2	0.071	-0.087	0.228	0.783
area	Ero Ref 1 : Ero Exp 2	0.107	-0.050	0.265	0.346
area	Ero Ref 2 : Ero Exp 2	0.145	-0.013	0.302	0.088
area	Ero Exp 4 : Ero Exp 3	0.083	-0.074	0.241	0.637
area	Ero Exp 5 : Ero Exp 3	0.064	-0.094	0.221	0.855
area	Ero Ref 1 : Ero Exp 3	0.100	-0.057	0.258	0.426
area	Ero Ref 2 : Ero Exp 3	0.137	-0.020	0.295	0.118
area	Ero Exp 5 : Ero Exp 4	-0.020	-0.177	0.138	1.000
area	Ero Ref 1 : Ero Exp 4	0.017	-0.140	0.174	1.000
area	Ero Ref 2 : Ero Exp 4	0.054	-0.103	0.212	0.925

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Ref 1 : Ero Exp 5	0.037	-0.121	0.194	0.989
area	Ero Ref 2 : Ero Exp 5	0.074	-0.084	0.231	0.749
area	Ero Ref 2 : Ero Ref 1	0.037	-0.120	0.195	0.988

Table A34 ANOVA summary table for Erosional Site Pairs for 2018 Percent EPT

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	1.060	0.177	1.354	0.267
Residuals	28.000	3.652	0.130		

Table A35 ANOVA summary table for Erosional Site Pairs for 2018 Shannon's Evenness

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	0.139	0.023	2.622	0.038
Residuals	28.000	0.248	0.009		

Table A36 Tukey HSD for Erosional Site Pairs for 2018 Shannon's Evenness

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	-0.090	-0.279	0.099	0.738
area	Ero Exp 3 : Ero Exp 1	-0.099	-0.288	0.090	0.643
area	Ero Exp 4 : Ero Exp 1	0.100	-0.089	0.289	0.637
area	Ero Exp 5 : Ero Exp 1	0.018	-0.171	0.207	1.000
area	Ero Ref 1 : Ero Exp 1	0.006	-0.183	0.195	1.000
area	Ero Ref 2 : Ero Exp 1	0.010	-0.179	0.199	1.000
area	Ero Exp 3 : Ero Exp 2	-0.009	-0.198	0.180	1.000
area	Ero Exp 4 : Ero Exp 2	0.190	0.001	0.379	0.049
area	Ero Exp 5 : Ero Exp 2	0.108	-0.081	0.297	0.552
area	Ero Ref 1 : Ero Exp 2	0.096	-0.093	0.285	0.675
area	Ero Ref 2 : Ero Exp 2	0.100	-0.089	0.289	0.638

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 4 : Ero Exp 3	0.199	0.010	0.388	0.034
area	Ero Exp 5 : Ero Exp 3	0.117	-0.072	0.306	0.456
area	Ero Ref 1 : Ero Exp 3	0.105	-0.083	0.294	0.577
area	Ero Ref 2 : Ero Exp 3	0.109	-0.080	0.298	0.540
area	Ero Exp 5 : Ero Exp 4	-0.082	-0.271	0.107	0.811
area	Ero Ref 1 : Ero Exp 4	-0.094	-0.282	0.095	0.701
area	Ero Ref 2 : Ero Exp 4	-0.090	-0.279	0.099	0.736
area	Ero Ref 1 : Ero Exp 5	-0.012	-0.201	0.177	1.000
area	Ero Ref 2 : Ero Exp 5	-0.008	-0.197	0.181	1.000
area	Ero Ref 2 : Ero Ref 1	0.004	-0.185	0.192	1.000

Table A37 ANOVA summary table for Erosional Site Pairs for 2018 Species Richness

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	0.184	0.031	1.900	0.116
Residuals	28.000	0.451	0.016		

Table A38 ANOVA summary table for Erosional Site Pairs for 2018 Total Abundance

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	3.064	0.511	3.741	0.007
Residuals	28.000	3.822	0.137		

Table A39 Tukey HSD for Erosional Site Pairs for 2018 Total Abundance

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Exp 2 : Ero Exp 1	0.429	-0.313	1.170	0.538
area	Ero Exp 3 : Ero Exp 1	0.342	-0.399	1.083	0.763
area	Ero Exp 4 : Ero Exp 1	-0.492	-1.234	0.249	0.376
area	Ero Exp 5 : Ero Exp 1	-0.185	-0.926	0.556	0.984

Term	Comparison	Estimate	Conf (low)	Conf (high)	Adjusted p Value
area	Ero Ref 1 : Ero Exp 1	-0.160	-0.901	0.582	0.993
area	Ero Ref 2 : Ero Exp 1	0.099	-0.642	0.841	0.999
area	Ero Exp 3 : Ero Exp 2	-0.087	-0.828	0.655	1.000
area	Ero Exp 4 : Ero Exp 2	-0.921	-1.662	-0.180	0.008
area	Ero Exp 5 : Ero Exp 2	-0.614	-1.355	0.127	0.156
area	Ero Ref 1 : Ero Exp 2	-0.588	-1.330	0.153	0.191
area	Ero Ref 2 : Ero Exp 2	-0.329	-1.070	0.412	0.793
area	Ero Exp 4 : Ero Exp 3	-0.835	-1.576	-0.093	0.020
area	Ero Exp 5 : Ero Exp 3	-0.527	-1.269	0.214	0.299
area	Ero Ref 1 : Ero Exp 3	-0.502	-1.243	0.240	0.355
area	Ero Ref 2 : Ero Exp 3	-0.243	-0.984	0.499	0.940
area	Ero Exp 5 : Ero Exp 4	0.307	-0.434	1.049	0.839
area	Ero Ref 1 : Ero Exp 4	0.333	-0.408	1.074	0.784
area	Ero Ref 2 : Ero Exp 4	0.592	-0.149	1.333	0.186
area	Ero Ref 1 : Ero Exp 5	0.026	-0.716	0.767	1.000
area	Ero Ref 2 : Ero Exp 5	0.285	-0.457	1.026	0.881
area	Ero Ref 2 : Ero Ref 1	0.259	-0.482	1.000	0.920

Table A40 ANOVA summary table for Erosional Site Pairs for 2018 Total Biomass

Term	Df	Sum of Squares	Mean of Squares	Statistic	p Value
area	6.000	2.985	0.497	2.133	0.081
Residuals	28.000	6.530	0.233		

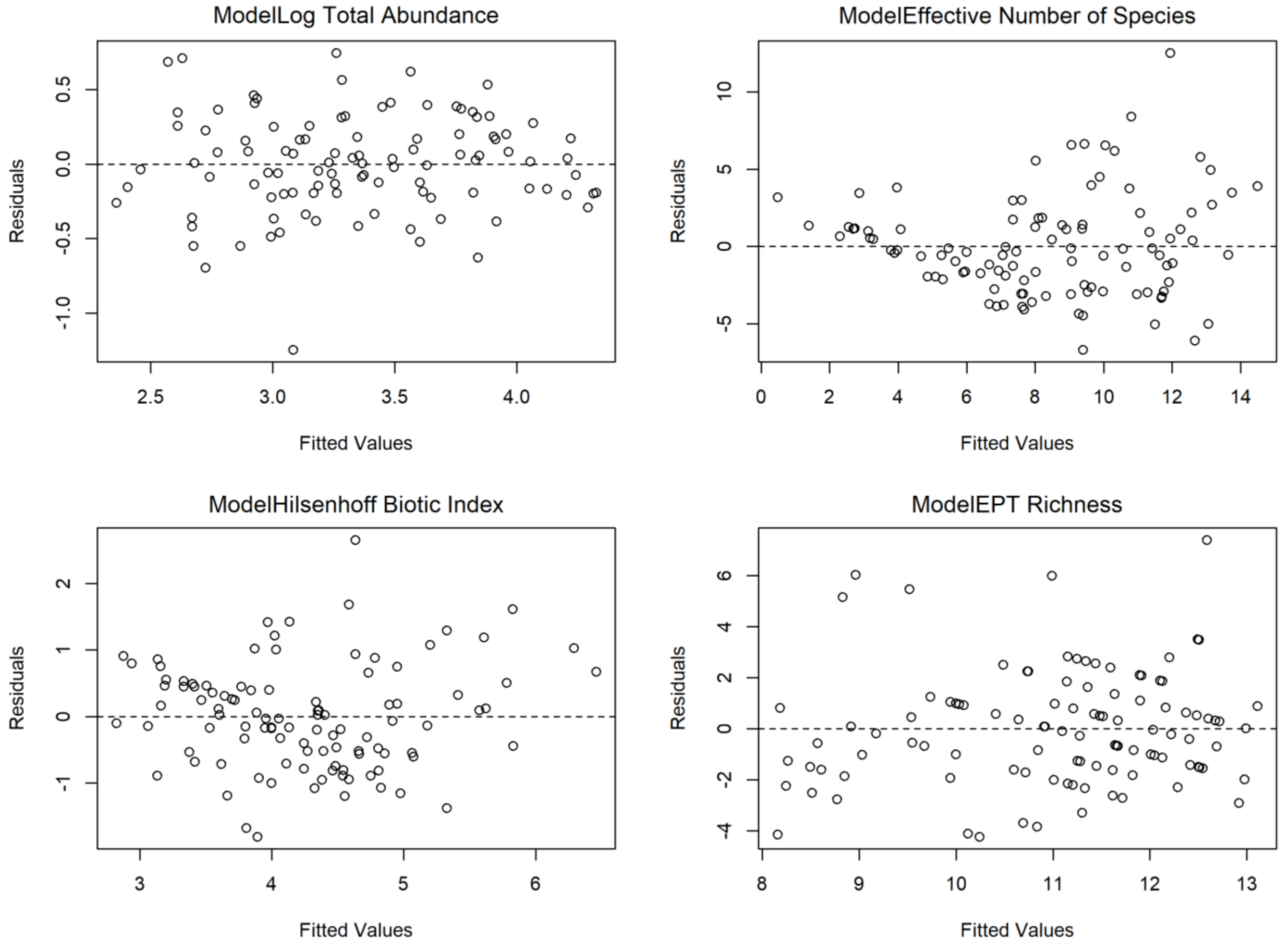


Figure A7 Residual plots for invertebrate models of abundance, effective number of species, Hilsenhoff Biotic Index and EPT Richness.

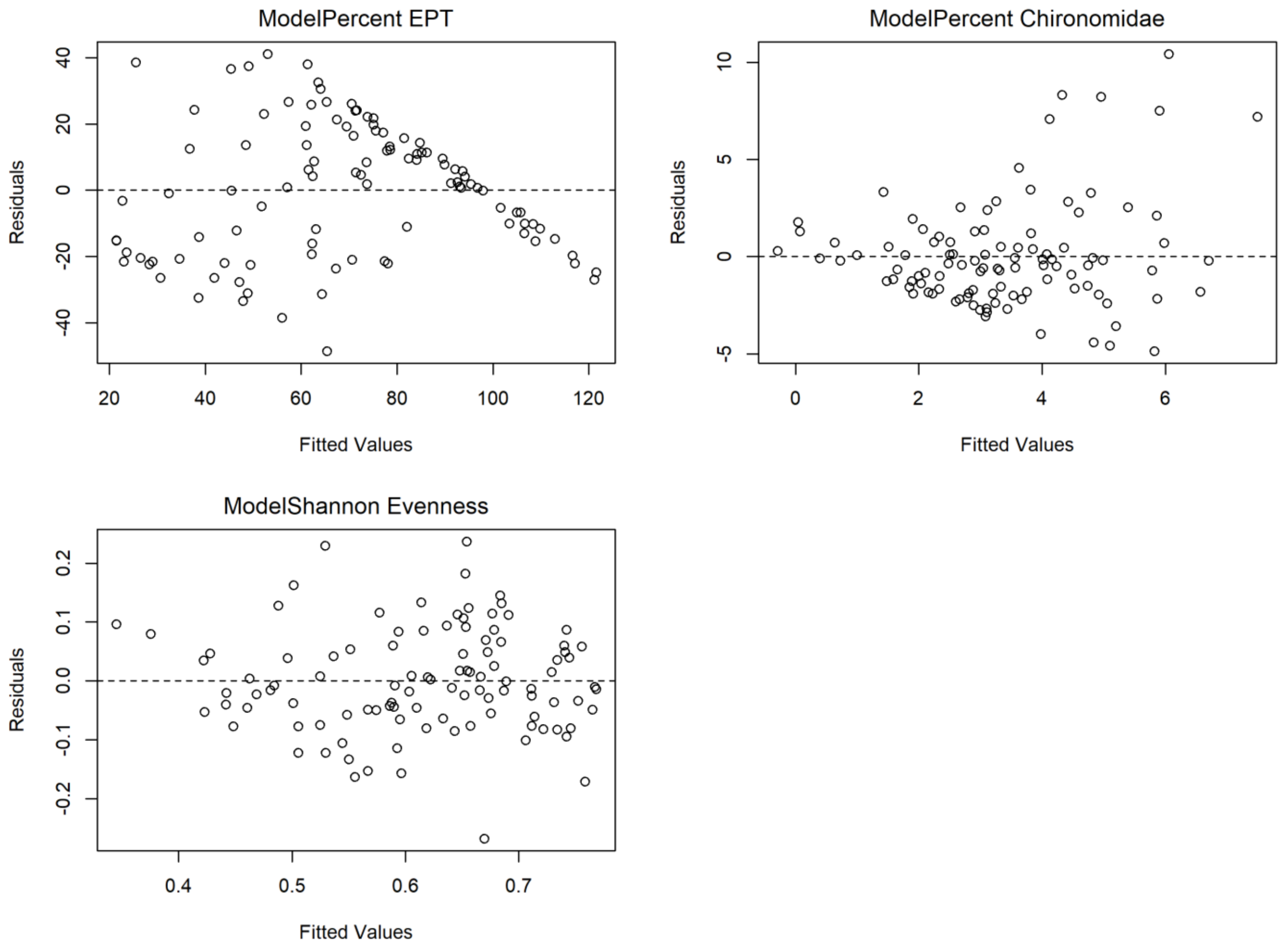


Figure A8 Residual plots for invertebrate models of percent EPT, percent Chironomidae and Shannon Evenness.

Table A41 Formulae used for benthic linear mixed effects models.

Model Formula
Total Abundance (log) ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + (1 | Area)
Effective Species ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + (1 | Area : Year)
HilsenHoff Biotic Index ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + (1 | Area)
EPT Richness ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + (1 | Area : Year)
EPT (%) ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + (1 | Area)
Chironomidae (%) ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year + (1 | Area : Year)
Shannon's Equitability ~ Water Temperature + Substrate Size + Velocity + Ref / Exp + Year

Table A42 Summary of plausible models identified using model averaging (those with a delta AIC <3) with pseudo-R2 values and coefficients for all erosional samples.

Response	X.Intercept.	D50 (cm)	Reference	Average Velocity (m/s)	Water Temperature	Year (2012)	R.2	df	AICc	delta	weight
Effective Number of Species	8.330	-1.990		-5.030	-2.080		0.448	6.000	565.000	0.000	0.567
Effective Number of Species	8.330	-2.000	+	-5.020	-2.060		0.447	7.000	567.000	2.420	0.169
EPT Richness	11.700		+	0.978			0.182	5.000	490.000	0.000	0.176
EPT Richness	11.600	0.725	+	0.933			0.198	6.000	491.000	0.106	0.167
EPT Richness	11.700	0.756	+				0.176	5.000	491.000	0.767	0.120
EPT Richness	11.700		+				0.158	4.000	491.000	0.828	0.116
EPT Richness	11.700		+	0.992	0.036		0.181	6.000	493.000	2.330	0.055
EPT Richness	11.600	0.737	+	0.927	0.120		0.198	7.000	493.000	2.440	0.052
EPT Richness	11.900		+			+	0.179	6.000	493.000	2.610	0.048
EPT Richness	12.000		+	0.962		+	0.196	7.000	493.000	2.710	0.045
EPT Richness	11.700	0.782	+		0.308		0.178	6.000	493.000	2.710	0.045
EPT Richness	11.700		+		0.251		0.159	5.000	493.000	2.830	0.043
Hilsenhoff Biotic Index	3.860	-0.397	+	-1.140		+	0.450	8.000	272.000	0.000	0.504
Hilsenhoff Biotic Index	3.860	-0.398	+	-1.130	-0.038	+	0.450	9.000	275.000	2.350	0.156
Hilsenhoff Biotic Index	3.820		+	-1.170		+	0.421	7.000	275.000	2.960	0.115
Log Total Abundance	3.430	0.328		0.427		+	0.624	7.000	101.000	0.000	0.599

Response	X.Intercept.	D50 (cm)	Reference	Average Velocity (m/s)	Water Temperature	Year (2012)	R.2	df	AICc	delta	weight
Log Total Abundance	3.430	0.328		0.426	-0.014	+	0.624	8.000	103.000	2.360	0.184
Log Total Abundance	3.420	0.329	+	0.425		+	0.623	8.000	104.000	2.550	0.167
Percent Chironomidae	3.370			-1.890			0.119	4.000	539.000	0.000	0.245
Percent Chironomidae	3.370	-0.708		-1.810			0.130	5.000	540.000	0.993	0.149
Percent Chironomidae	3.180			-2.020		+	0.139	6.000	542.000	2.080	0.087
Percent Chironomidae	3.370			-1.890	-0.010		0.119	5.000	542.000	2.240	0.080
Percent Chironomidae	3.400		+	-1.900			0.119	5.000	542.000	2.250	0.079
Percent EPT	73.900	19.300	+	39.100	7.990		0.588	7.000	943.000	0.000	0.378
Percent EPT	73.900	19.200	+	40.000			0.574	6.000	944.000	1.140	0.213
Percent EPT	77.800	18.300	+	40.200		+	0.587	8.000	945.000	2.470	0.110
Shannon Evenness	0.626	-0.045		-0.149	-0.066	+	0.556	7.000	-196.000	0.000	0.343
Shannon Evenness	0.616	-0.046		-0.154	-0.081		0.535	5.000	-195.000	0.137	0.320
Shannon Evenness	0.627	-0.045	+	-0.149	-0.066	+	0.556	8.000	-193.000	2.290	0.109
Shannon Evenness	0.617	-0.046	+	-0.154	-0.081		0.536	6.000	-193.000	2.320	0.107

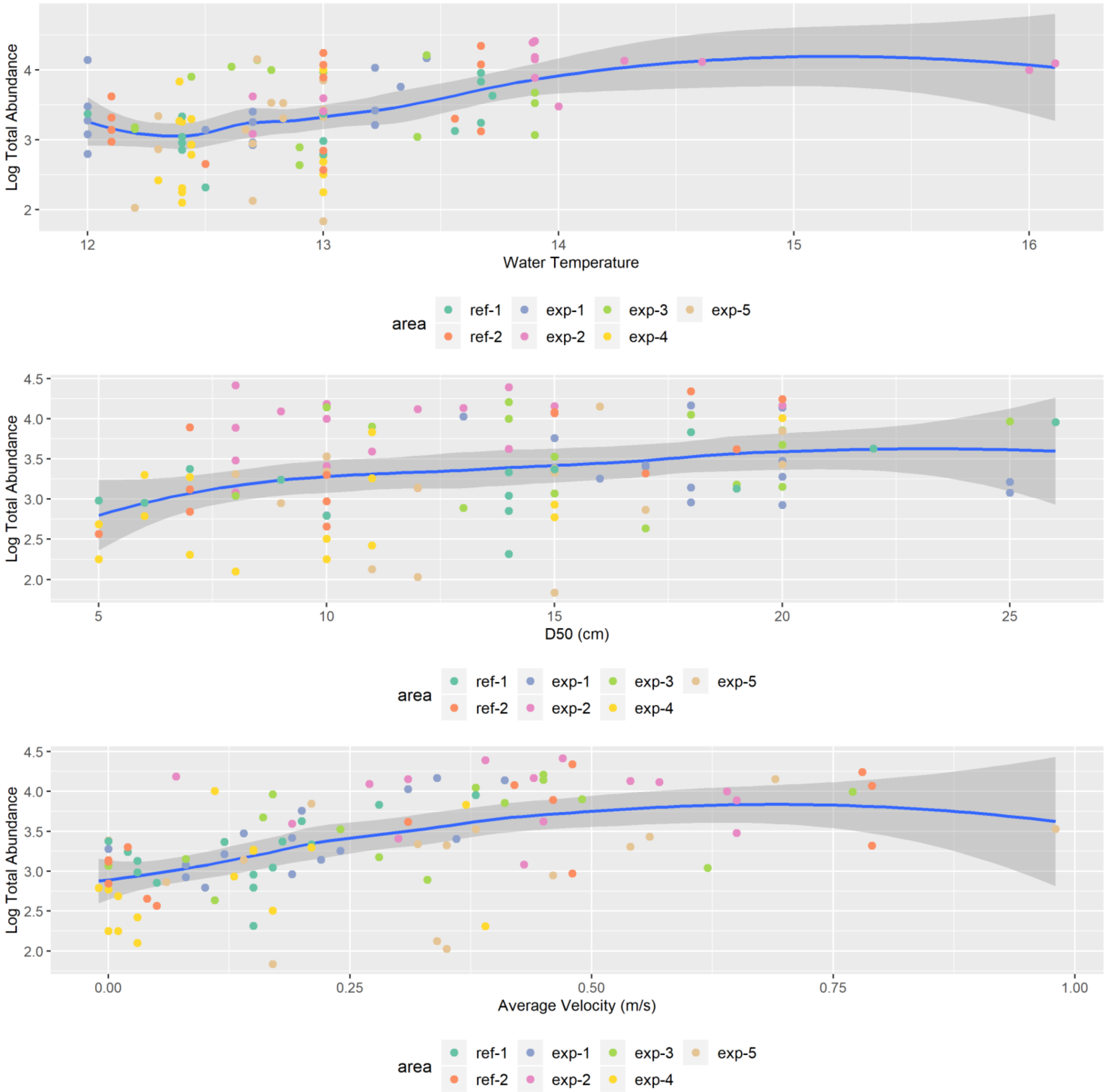


Figure A9 Explanatory variables and Log Total Abundance grouped by erosional areas for 2012, 2015 and 2018 invertebrate samples.

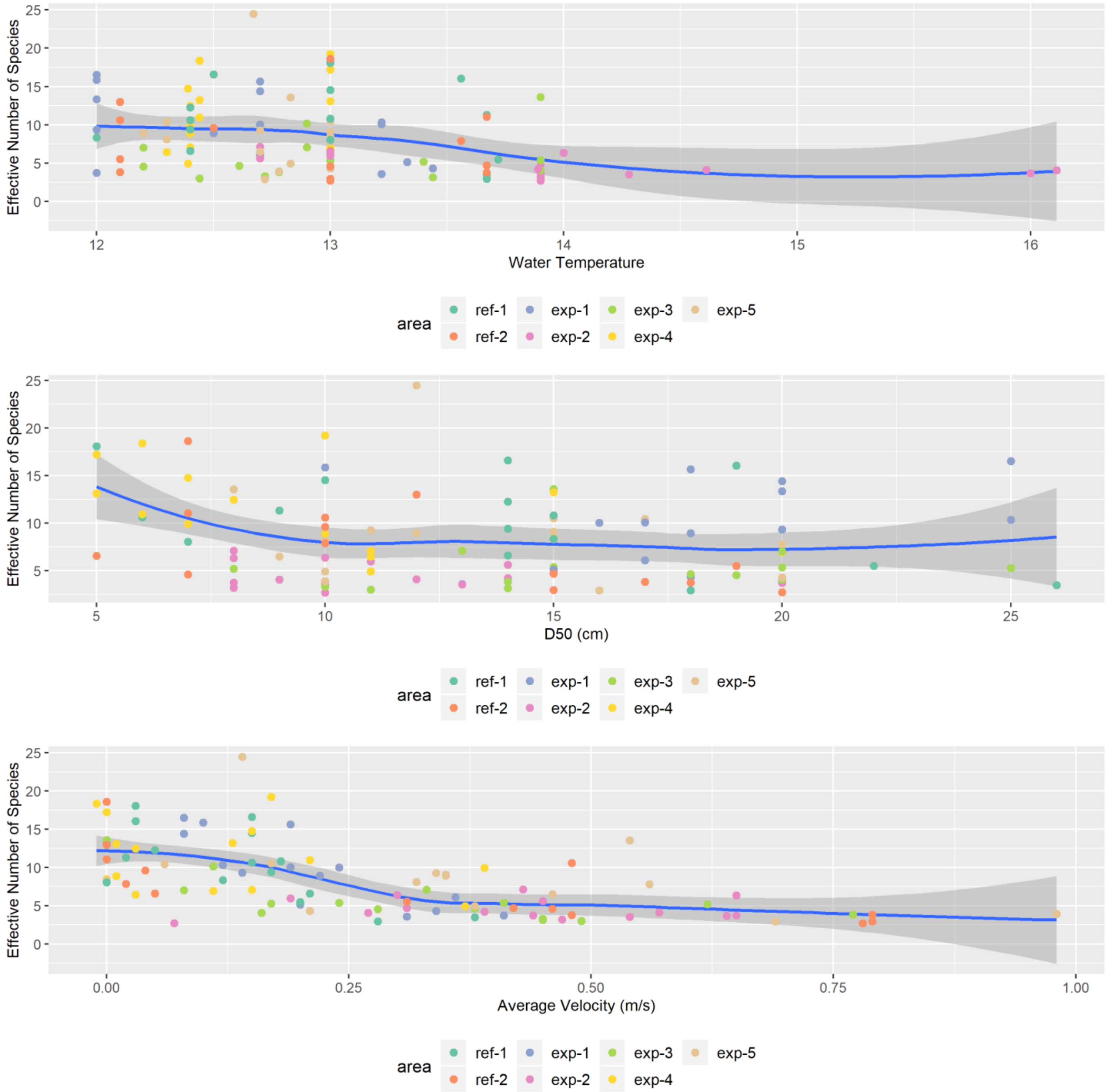


Figure A10 **Explanatory variables and effective number of species grouped by erosional areas for 2012, 2015 and 2018 invertebrate samples.**

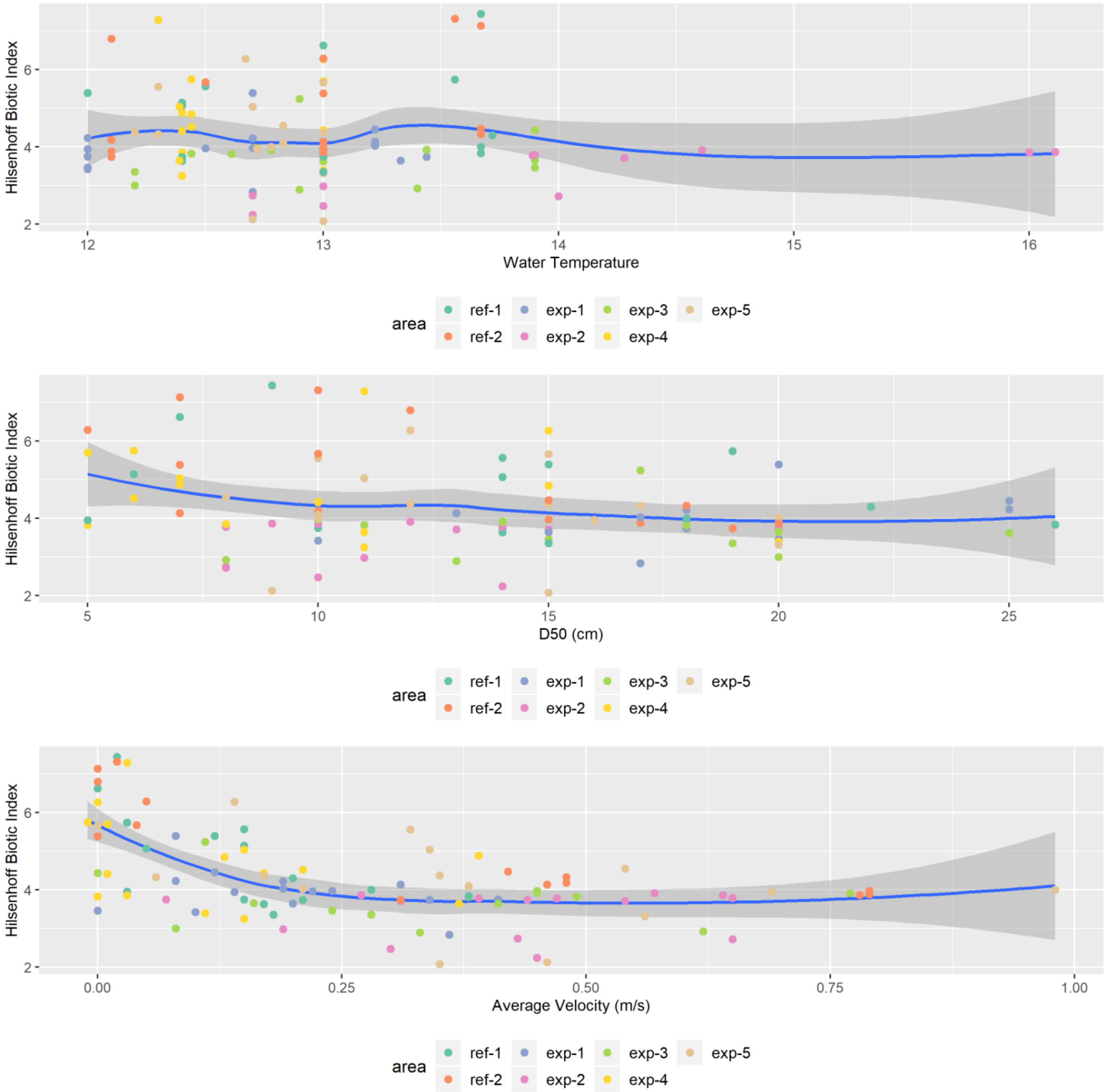


Figure A11 Explanatory variables and Hilsenhoff Biotic Index grouped by erosional areas for 2012, 2015 and 2018 invertebrate samples.

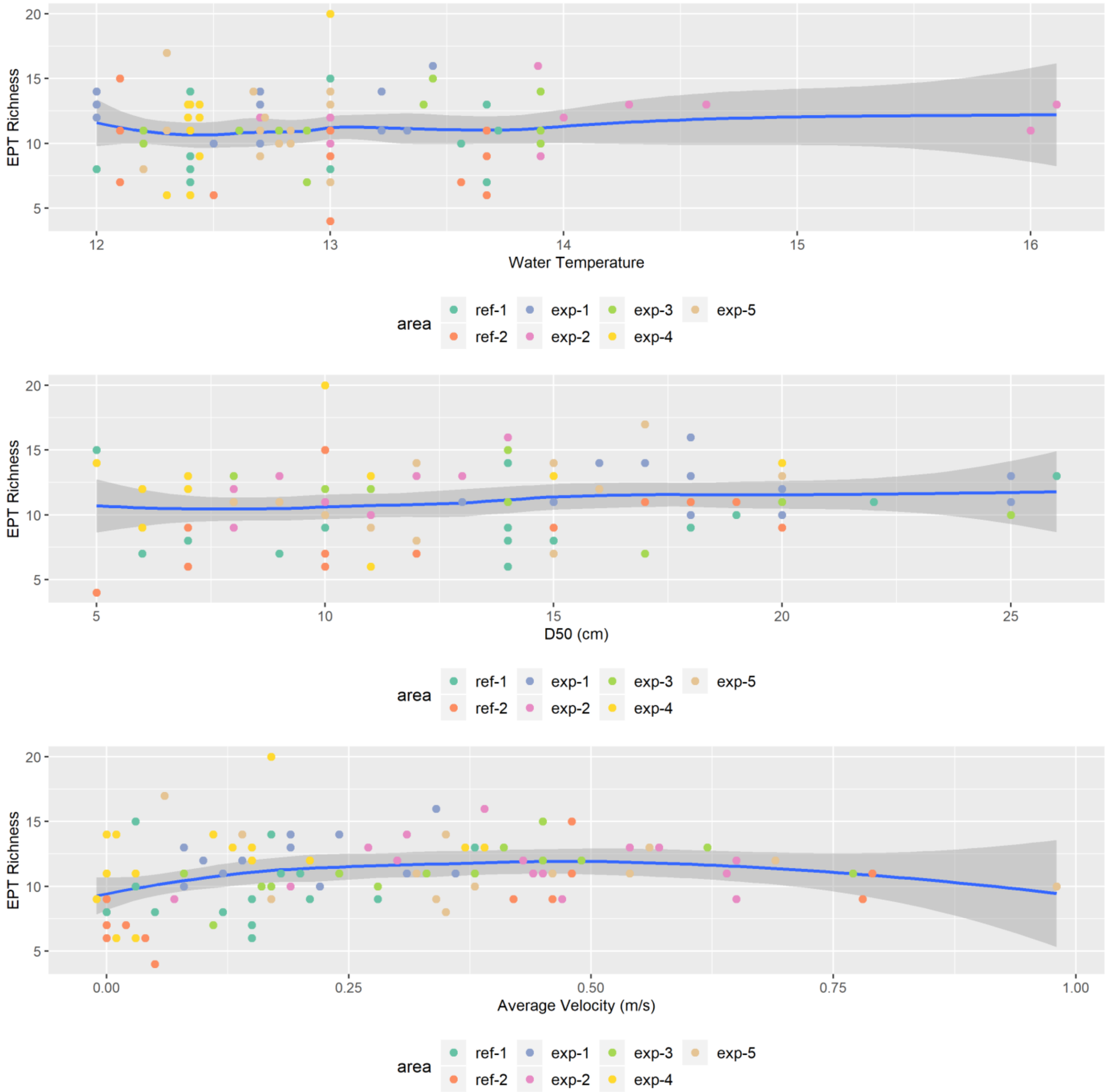


Figure A12 **Explanatory variables and EPT Richness grouped by erosional areas for 2012, 2015 and 2018 invertebrate samples.**

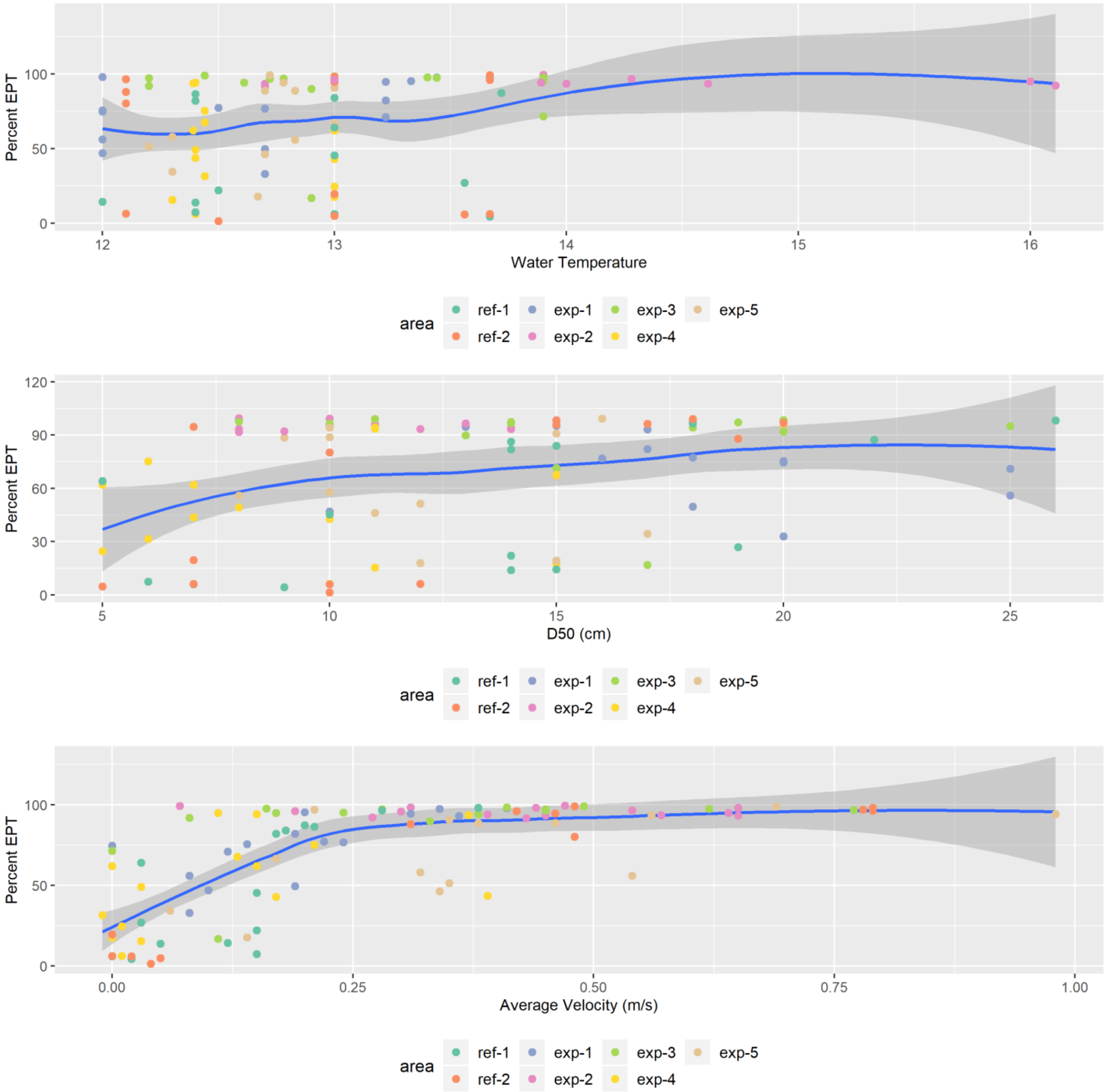


Figure A13 Explanatory variables and Percent EPT grouped by erosional areas for 2012, 2015 and 2018 invertebrate samples.

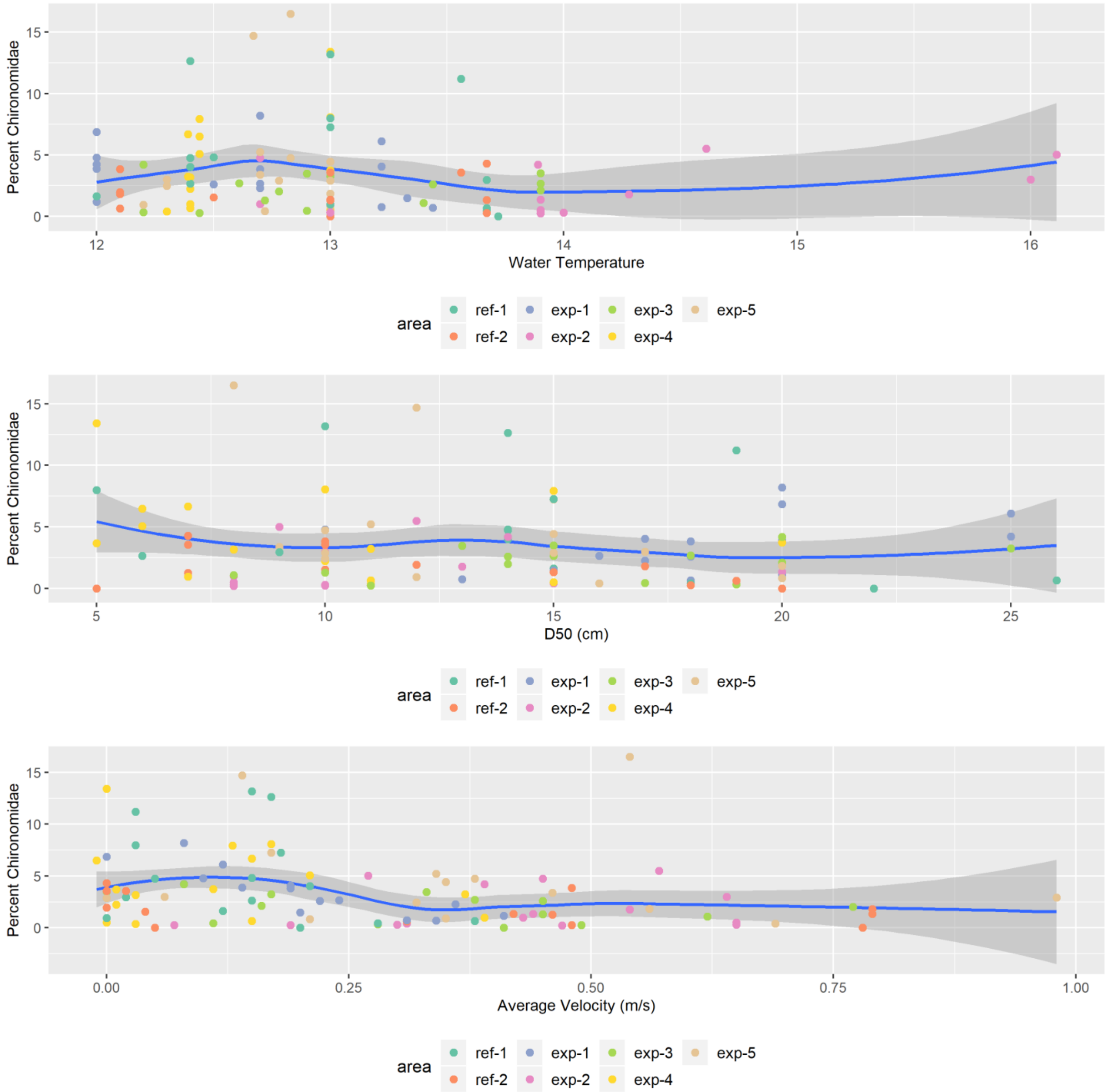


Figure A14 Explanatory variables and Percent Chironomidae grouped by erosional areas for 2012, 2015 and 2018 invertebrate samples.

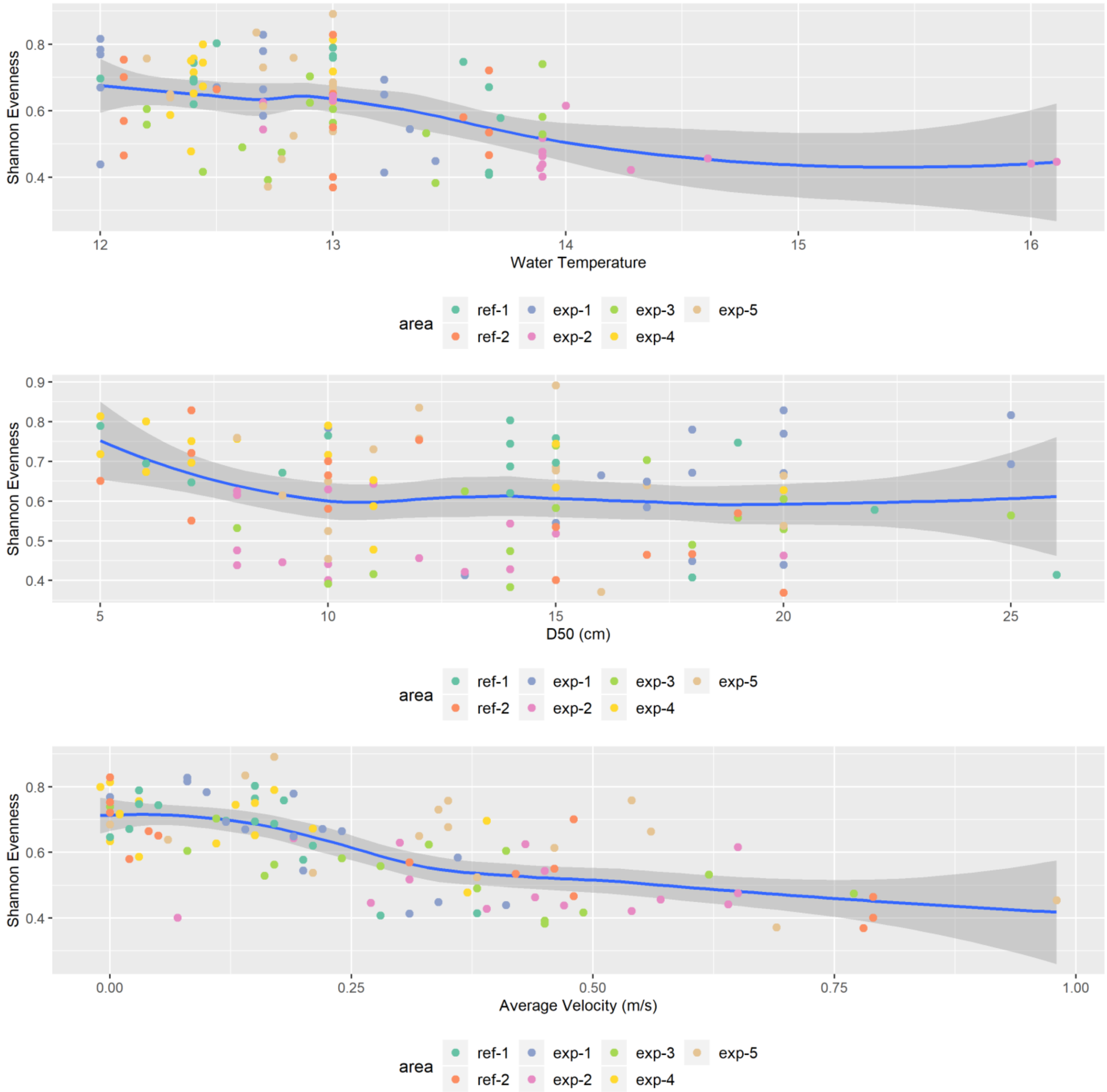


Figure A15 **Explanatory variables and Shannon Evenness grouped by erosional areas for 2012, 2015 and 2018 invertebrate samples.**

APPENDIX M WATER QUALITY SUPPLEMENTAL RESULTS

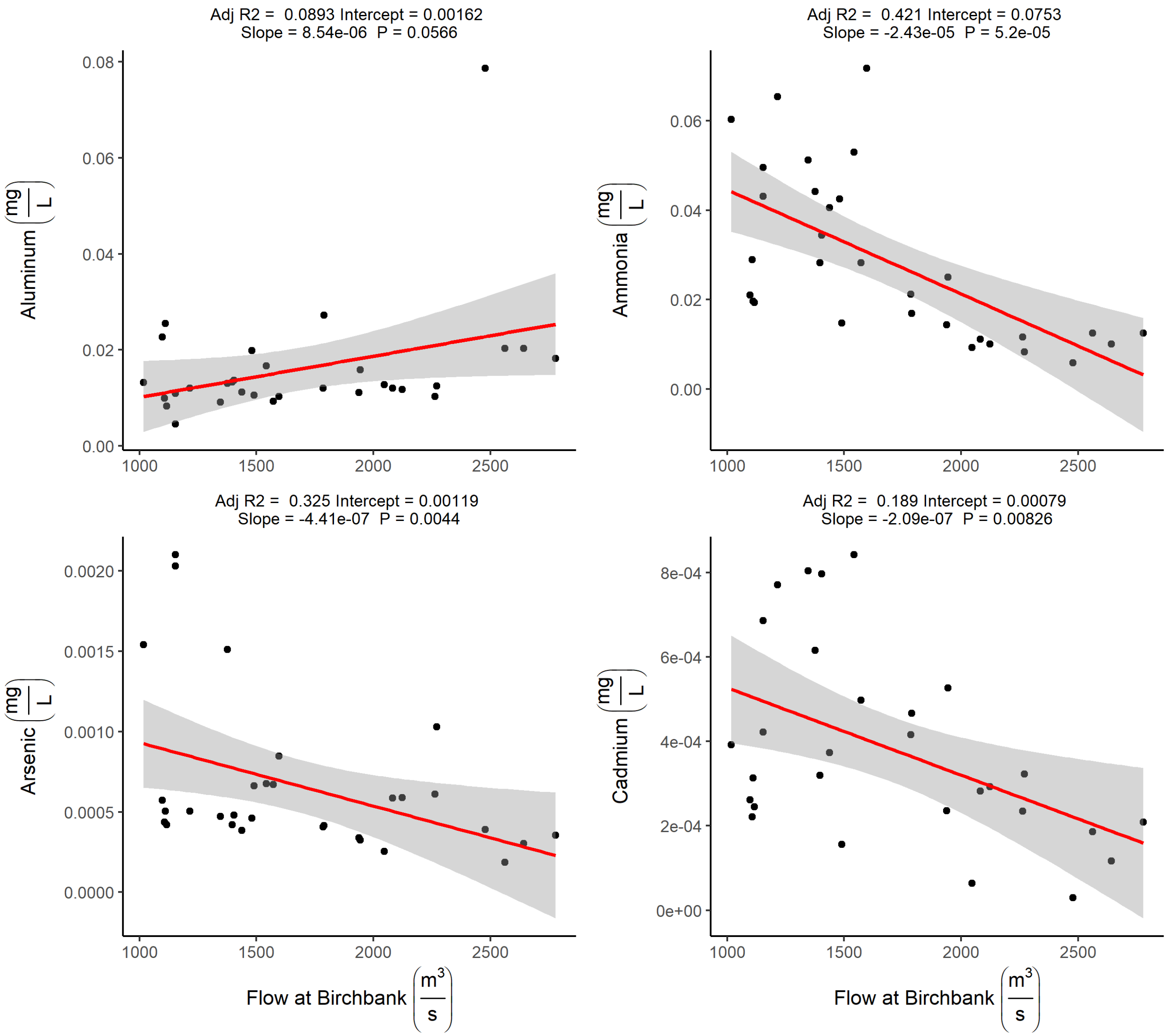


Figure A16 **Scatter plots of Aluminum, Ammonia, Arsenic and Cadmium concentrations at different flow rates as measured at the Birchbank site. Red line indicates least squares regression line.**

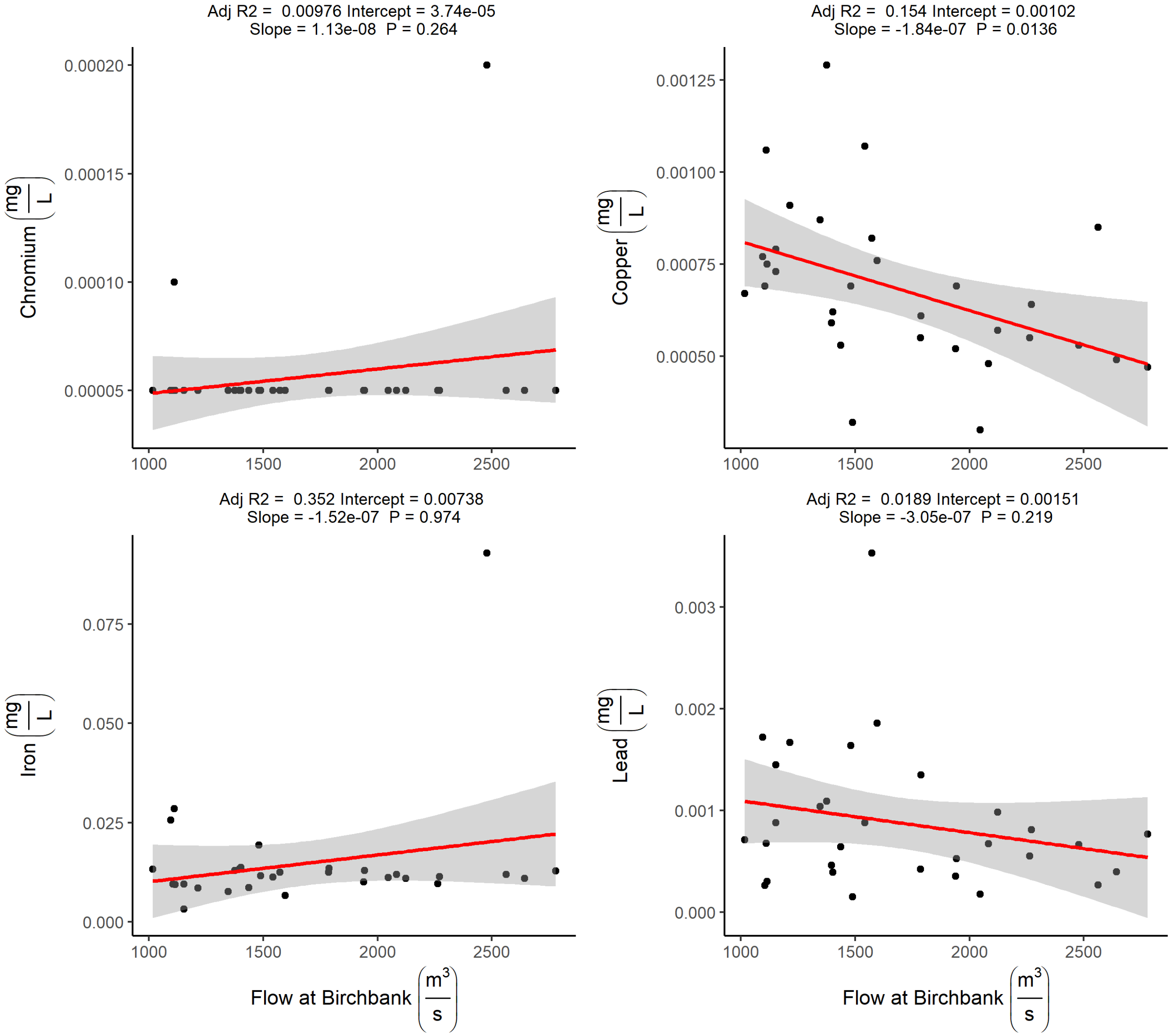


Figure A17 Scatter plots of Chromium, Copper, Iron and Lead concentrations at different flow rates as measured at the Birchbank site. Red line indicates least squares regression line.

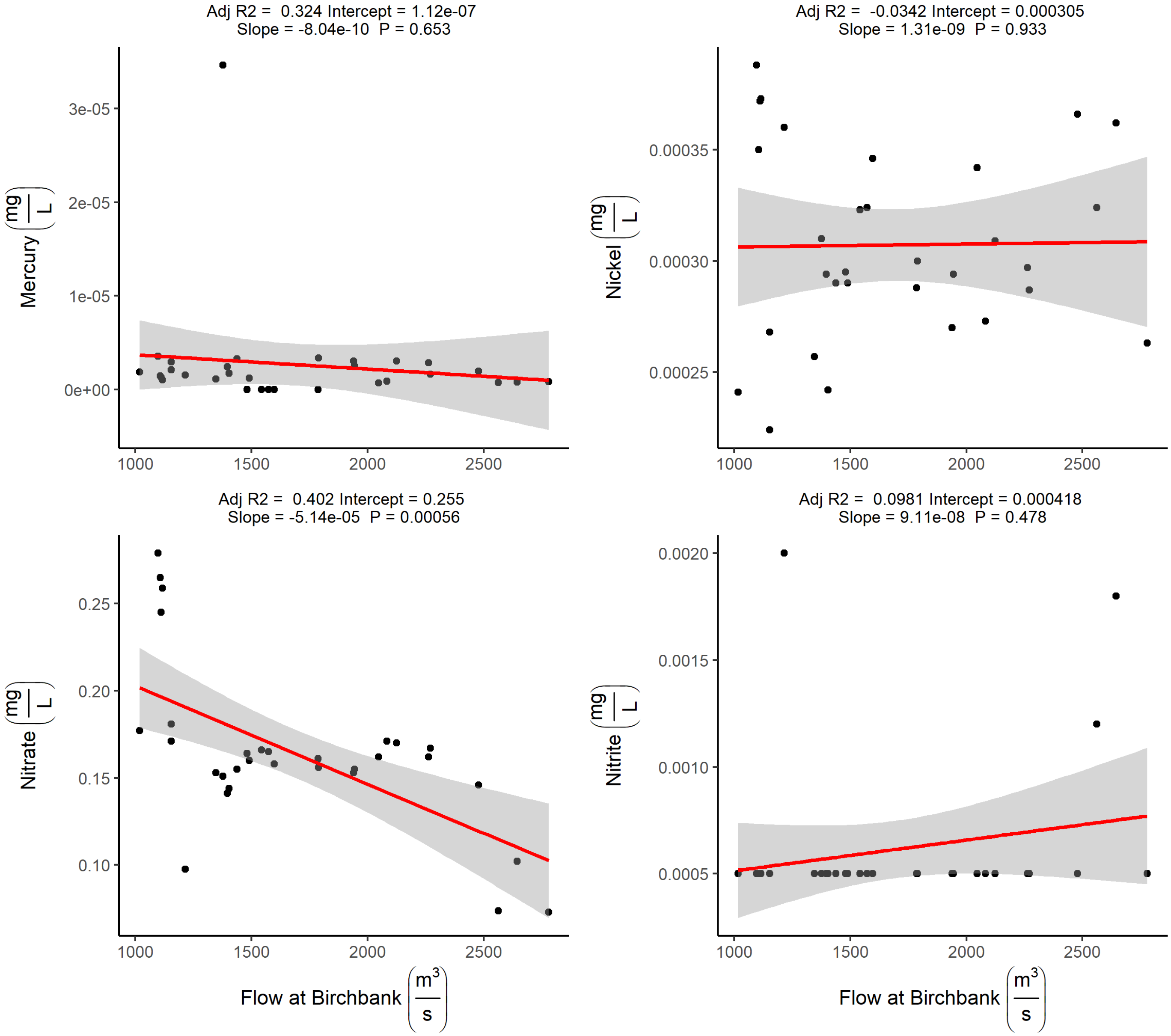


Figure A18 Scatter plots of Mercury, Nickel, Nitrate and Nitrite concentrations at different flow rates as measured at the Birchbank site. Red line indicates least squares regression line.

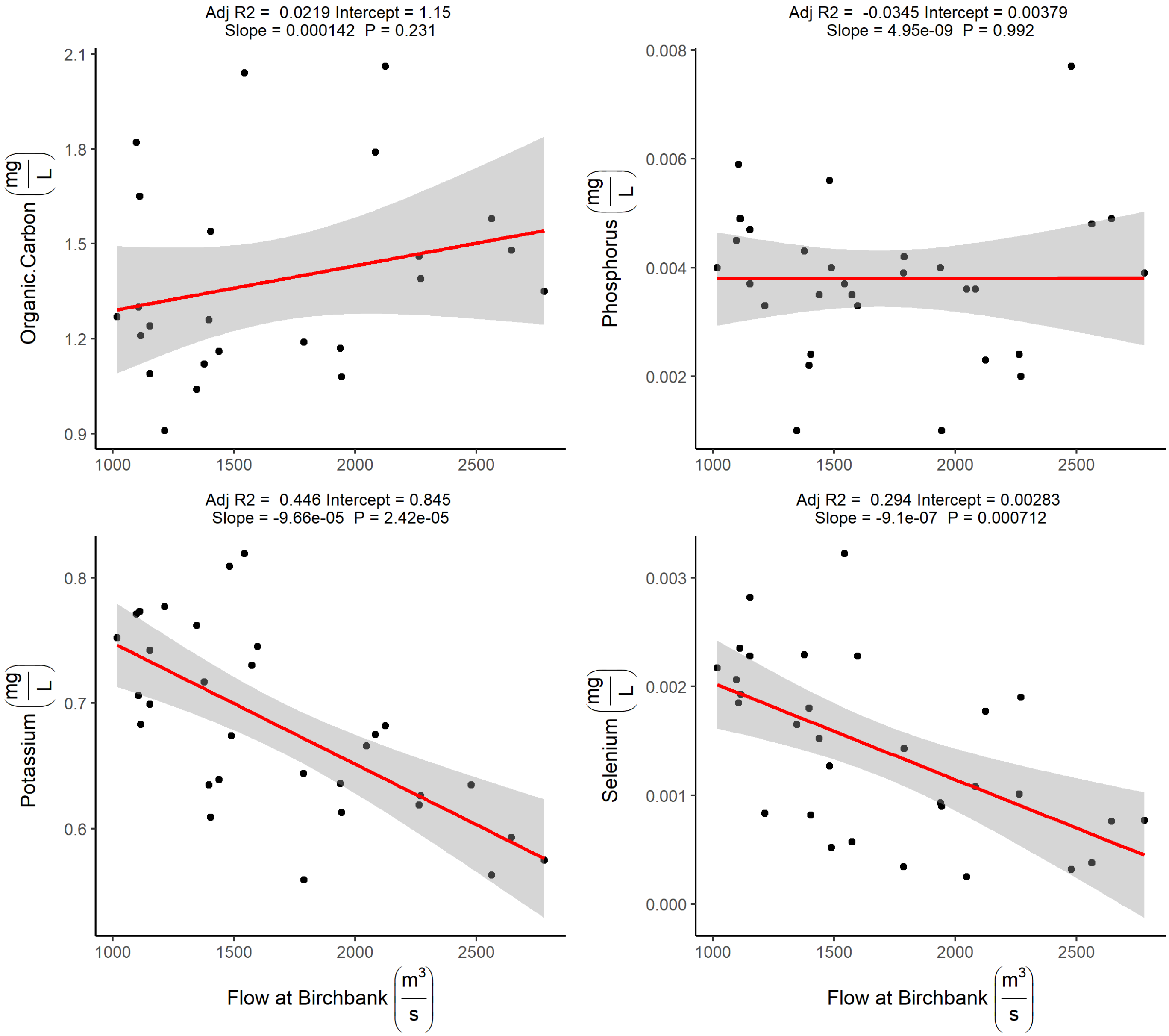


Figure A19 Scatter plots of Organic.Carbon, Phosphorus, Potassium and Selenium concentrations at different flow rates as measured at the Birchbank site. Red line indicates least squares regression line.

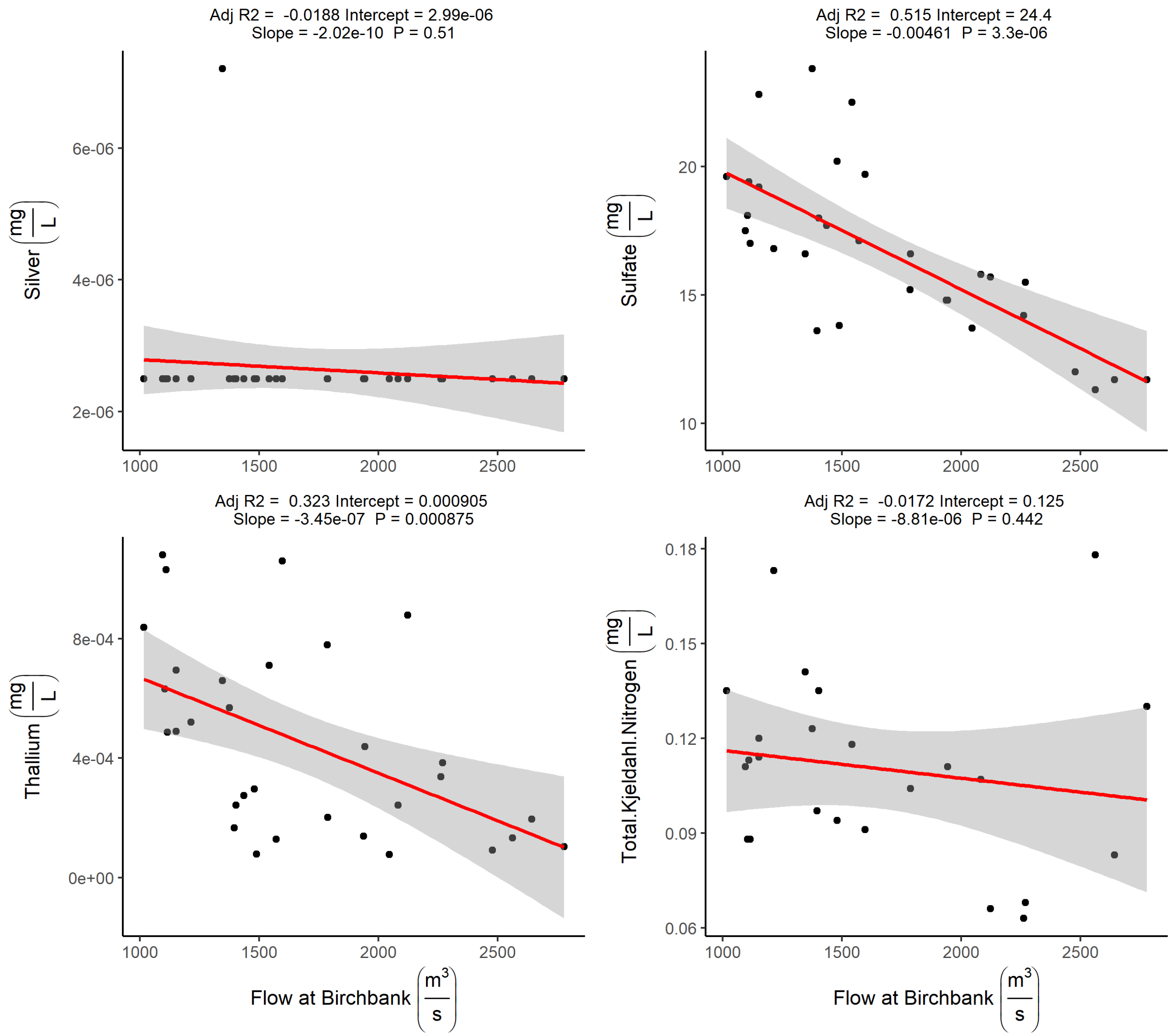


Figure A20 Scatter plots of Silver, Sulfate, Thallium and Total.Kjeldahl.Nitrogen concentrations at different flow rates as measured at the Birchbank site. Red line indicates least squares regression line.

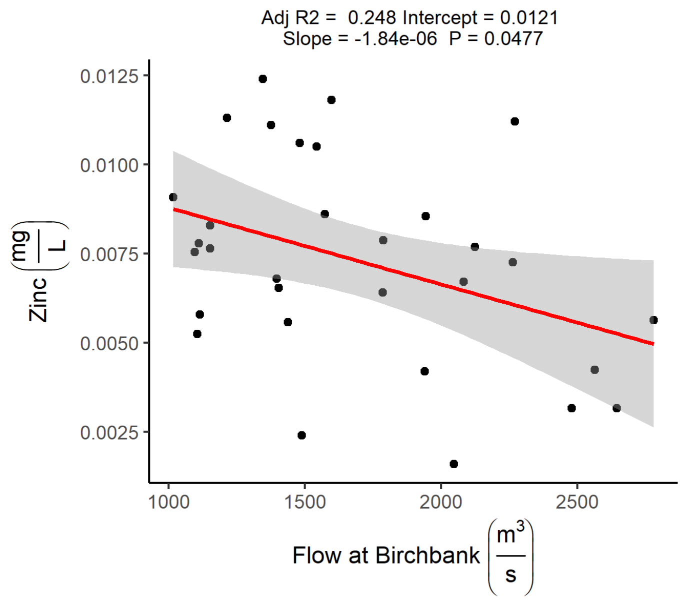


Figure A21 Scatter plot of Zinc concentrations at different flow rates as measured at the Birchbank site. Red line indicates least squares regression line.

Table A43 Regression coefficients summary table for analytes of interest of flow and effluent loadings.

Term	Estimate	Std. Error	t Value	p Value	Analyte
Intercept	1.62e-03	0.008	0.214	0.832	Aluminum
Flow at Birchbank	8.54e-06	0.000	1.986	0.0566	Aluminum
Intercept	7.53e-02	0.010	7.503	<0.001	Ammonia
Flow at Birchbank	-2.43e-05	0.000	-4.770	<0.001	Ammonia
Loading Sum	-1.03e-04	0.000	-1.617	0.117	Ammonia
Intercept	1.19e-03	0.000	4.711	<0.001	Arsenic
Flow at Birchbank	-4.41e-07	0.000	-3.098	0.0044	Arsenic
Loading Sum	1.33e-04	0.000	2.941	0.0065	Arsenic
Intercept	7.90e-04	0.000	5.206	<0.001	Cadmium
Flow at Birchbank	-2.09e-07	0.000	-2.859	0.00826	Cadmium
Loading Sum	-2.28e-04	0.000	-0.715	0.481	Cadmium
Intercept	3.74e-05	0.000	2.137	0.0411	Chromium
Flow at Birchbank	1.13e-08	0.000	1.138	0.264	Chromium

Term	Estimate	Std. Error	t Value	p Value	Analyte
Intercept	1.02e-03	0.000	7.800	<0.001	Copper
Flow at Birchbank	-1.84e-07	0.000	-2.633	0.0136	Copper
Loading Sum	-3.01e-05	0.000	-0.482	0.633	Copper
Intercept	7.38e-03	0.008	0.952	0.349	Iron
Flow at Birchbank	-1.52e-07	0.000	-0.032	0.974	Iron
Loading Sum	1.69e-03	0.000	3.984	<0.001	Iron
Intercept	1.51e-03	0.000	3.434	0.00187	Lead
Flow at Birchbank	-3.05e-07	0.000	-1.258	0.219	Lead
Loading Sum	-4.00e-05	0.000	-0.949	0.351	Lead
Intercept	1.12e-07	0.000	0.033	0.974	Mercury
Flow at Birchbank	-8.04e-10	0.000	-0.455	0.653	Mercury
Loading Sum	3.89e-04	0.000	3.952	<0.001	Mercury
Intercept	3.05e-04	0.000	11.119	<0.001	Nickel
Flow at Birchbank	1.31e-09	0.000	0.084	0.933	Nickel
Intercept	2.55e-01	0.023	11.130	<0.001	Nitrate
Flow at Birchbank	-5.14e-05	0.000	-3.893	<0.001	Nitrate
Loading Sum	-9.86e-04	0.001	-1.763	0.0887	Nitrate
Intercept	4.18e-04	0.000	1.907	0.0668	Nitrite
Flow at Birchbank	9.11e-08	0.000	0.720	0.478	Nitrite
Loading Sum	1.06e-05	0.000	1.975	0.0582	Nitrite
Intercept	1.15e+00	0.201	5.700	<0.001	Organic.Carbon
Flow at Birchbank	1.42e-04	0.000	1.231	0.231	Organic.Carbon
Intercept	3.79e-03	0.001	4.293	<0.001	Phosphorus
Flow at Birchbank	4.95e-09	0.000	0.010	0.992	Phosphorus
Intercept	8.45e-01	0.034	24.898	<0.001	Potassium
Flow at Birchbank	-9.66e-05	0.000	-5.017	<0.001	Potassium
Intercept	2.83e-03	0.000	6.412	<0.001	Selenium
Flow at Birchbank	-9.10e-07	0.000	-3.802	<0.001	Selenium

Term	Estimate	Std. Error	t Value	p Value	Analyte
Loading Sum	3.22e-05	0.000	0.655	0.518	Selenium
Intercept	2.99e-06	0.000	5.617	<0.001	Silver
Flow at Birchbank	-2.02e-10	0.000	-0.668	0.51	Silver
Intercept	2.44e+01	1.415	17.263	<0.001	Sulfate
Flow at Birchbank	-4.61e-03	0.001	-5.736	<0.001	Sulfate
Intercept	9.05e-04	0.000	5.419	<0.001	Thallium
Flow at Birchbank	-3.45e-07	0.000	-3.725	<0.001	Thallium
Loading Sum	7.92e-05	0.000	2.044	0.0505	Thallium
Intercept	1.25e-01	0.020	6.395	<0.001	Total.Kjeldahl.Nitrogen
Flow at Birchbank	-8.81e-06	0.000	-0.782	0.442	Total.Kjeldahl.Nitrogen
Intercept	1.21e-02	0.002	7.460	<0.001	Zinc
Flow at Birchbank	-1.84e-06	0.000	-2.071	0.0477	Zinc
Loading Sum	-1.48e-04	0.000	-2.430	0.0217	Zinc

Table A44 Mann Kendall results for spring flow-weighted R-sh water quality samples.

Analyte	Site	Tau	p Value	n
Aluminum	Birchbank	-0.586	0.095	7
Aluminum	New Bridge	-0.524	0.133	7
Aluminum	Old Bridge	-0.333	0.368	7
Aluminum	Stoney Creek	-0.238	0.548	7
Aluminum	Waneta	-0.143	0.764	7
Ammonia	Birchbank	1.000	1.000	7
Ammonia	New Bridge	-0.143	0.764	7
Ammonia	Old Bridge	-0.048	1.000	7
Ammonia	Stoney Creek	0.143	0.764	7
Ammonia	Waneta	0.333	0.368	7
Arsenic	Birchbank	0.333	0.368	7
Arsenic	New Bridge	-0.048	1.000	7

Analyte	Site	Tau	p Value	n
Arsenic	Old Bridge	-0.143	0.764	7
Arsenic	Stoney Creek	0.048	1.000	7
Arsenic	Waneta	0.143	0.764	7
Cadmium	Birchbank	0.333	0.368	7
Cadmium	New Bridge	-0.238	0.548	7
Cadmium	Old Bridge	-0.143	0.764	7
Cadmium	Stoney Creek	0.714	0.036	7
Cadmium	Waneta	0.048	1.000	7
Chromium	Birchbank	-0.535	0.211	7
Chromium	New Bridge	-0.066	1.000	7
Chromium	Old Bridge	0.206	0.638	7
Chromium	Stoney Creek	-0.206	0.638	7
Chromium	Waneta	-0.411	0.272	7
Copper	Birchbank	-0.524	0.133	7
Copper	New Bridge	0.143	0.764	7
Copper	Old Bridge	0.238	0.548	7
Copper	Stoney Creek	-0.429	0.230	7
Copper	Waneta	-0.143	0.764	7
Iron	Birchbank	-0.143	0.764	7
Iron	New Bridge	-0.333	0.368	7
Iron	Old Bridge	0.333	0.368	7
Iron	Stoney Creek	0.048	1.000	7
Iron	Waneta	-0.143	0.764	7
Lead	Birchbank	-0.195	0.649	7
Lead	New Bridge	-0.333	0.368	7
Lead	Old Bridge	-0.143	0.764	7
Lead	Stoney Creek	-0.429	0.230	7
Lead	Waneta	-0.333	0.368	7
Mercury	Birchbank	-0.461	0.254	7
Mercury	New Bridge	0.238	0.548	7

Analyte	Site	Tau	p Value	n
Mercury	Old Bridge	-0.429	0.230	7
Mercury	Stoney Creek	-0.333	0.368	7
Mercury	Waneta	-0.048	1.000	7
Nickel	Birchbank	-0.238	0.548	7
Nickel	New Bridge	-0.143	0.764	7
Nickel	Old Bridge	-0.143	0.764	7
Nickel	Stoney Creek	-0.524	0.133	7
Nickel	Waneta	-0.238	0.548	7
Nitrate	Birchbank	-0.053	1.000	7
Nitrate	New Bridge	0.488	0.172	7
Nitrate	Old Bridge	0.195	0.649	7
Nitrate	Stoney Creek	-0.098	0.879	7
Nitrate	Waneta	0.098	0.879	7
Nitrite	Birchbank	1.000	1.000	7
Nitrite	New Bridge	0.535	0.211	7
Nitrite	Old Bridge	0.535	0.211	7
Nitrite	Stoney Creek	-0.535	0.211	7
Nitrite	Waneta	1.000	1.000	7
Phosphorus	Birchbank	-0.333	0.368	7
Phosphorus	New Bridge	-0.143	0.764	7
Phosphorus	Old Bridge	-0.429	0.230	7
Phosphorus	Stoney Creek	-0.429	0.230	7
Phosphorus	Waneta	-0.333	0.368	7
Potassium	Birchbank	0.333	0.368	7
Potassium	New Bridge	0.048	1.000	7
Potassium	Old Bridge	0.238	0.548	7
Potassium	Stoney Creek	0.238	0.548	7
Potassium	Waneta	0.238	0.548	7
Selenium	Birchbank	0.524	0.133	7
Selenium	New Bridge	0.143	0.764	7

Analyte	Site	Tau	p Value	n
Selenium	Old Bridge	0.619	0.072	7
Selenium	Stoney Creek	0.619	0.072	7
Selenium	Waneta	0.714	0.036	7
Silver	Birchbank	1.000	1.000	7
Silver	New Bridge	<0.001	1.000	7
Silver	Old Bridge	0.178	0.803	7
Silver	Stoney Creek	<0.001	1.000	7
Silver	Waneta	1.000	1.000	7
Sulfate	Birchbank	0.333	0.368	7
Sulfate	New Bridge	0.048	1.000	7
Sulfate	Old Bridge	0.098	0.879	7
Sulfate	Stoney Creek	0.333	0.368	7
Sulfate	Waneta	0.390	0.288	7
Thallium	Birchbank	0.524	0.133	7
Thallium	New Bridge	0.524	0.133	7
Thallium	Old Bridge	0.238	0.548	7
Thallium	Stoney Creek	0.524	0.133	7
Thallium	Waneta	0.333	0.368	7
Zinc	Birchbank	0.333	0.368	7
Zinc	New Bridge	-0.048	1.000	7
Zinc	Old Bridge	0.524	0.133	7
Zinc	Stoney Creek	0.429	0.230	7
Zinc	Waneta	0.429	0.230	7

APPENDIX N FALL 2018 WATER QUALITY PLOTS

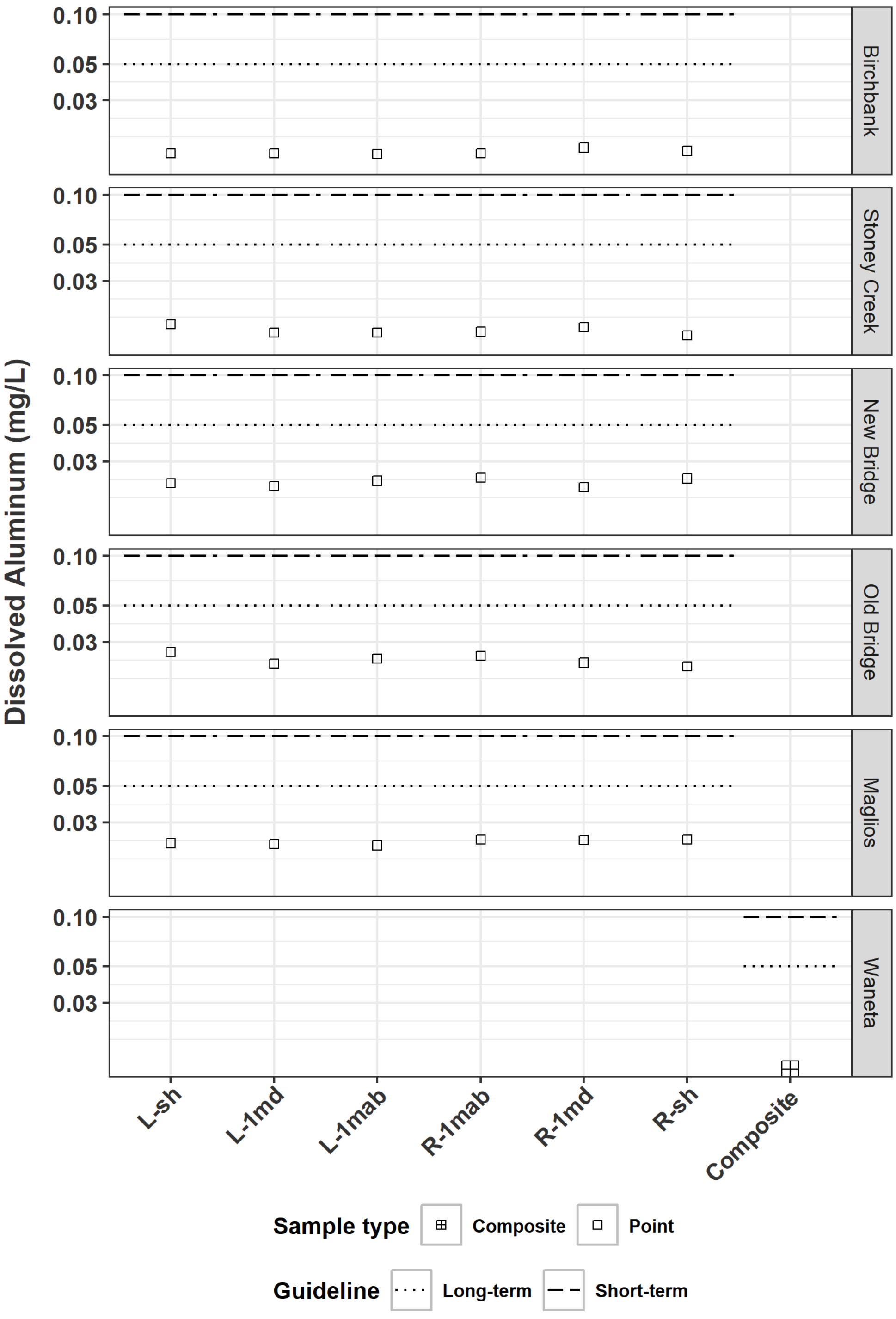


Figure A22 Box plots of total Aluminum measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

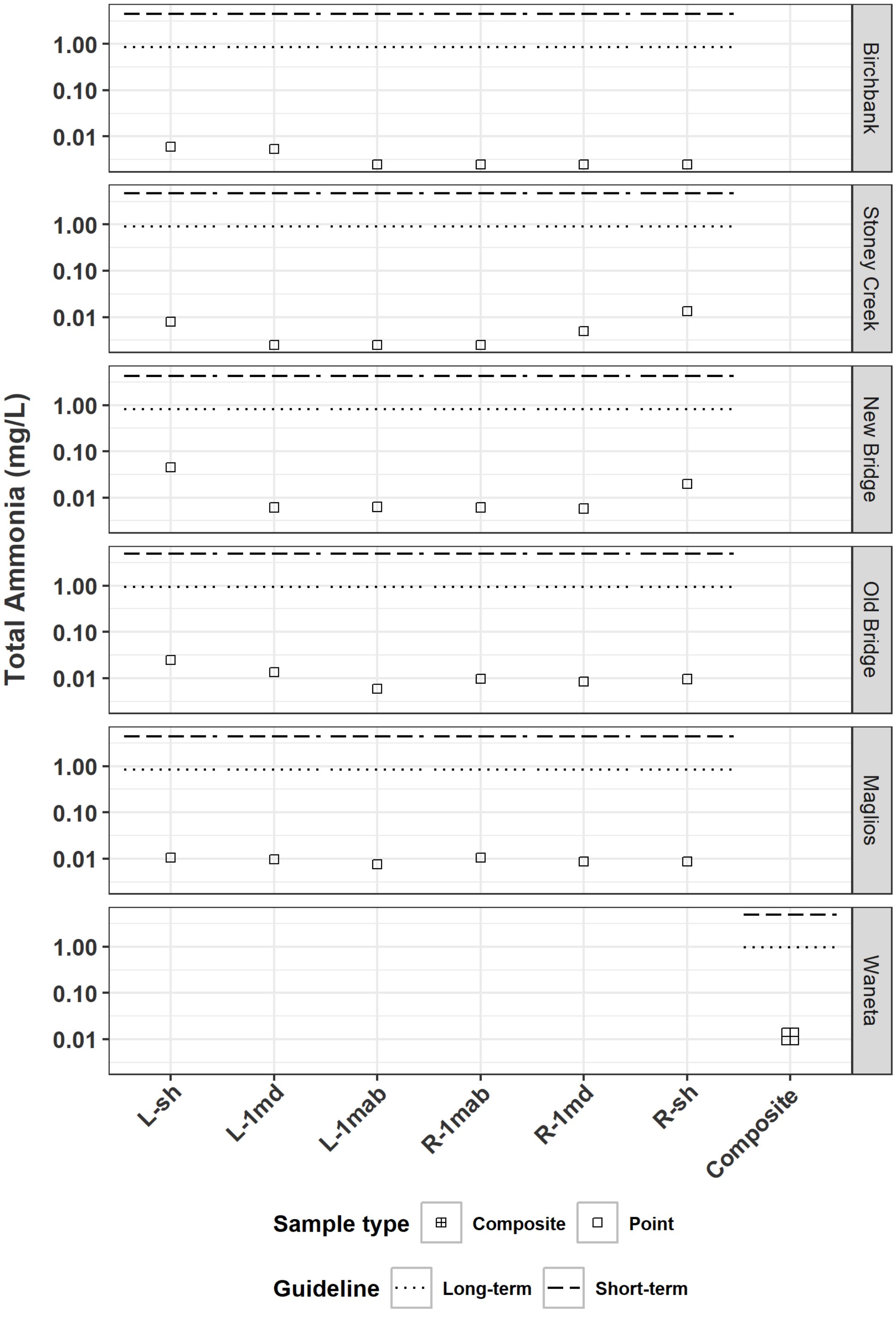


Figure A23 Box plots of total Ammonia measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

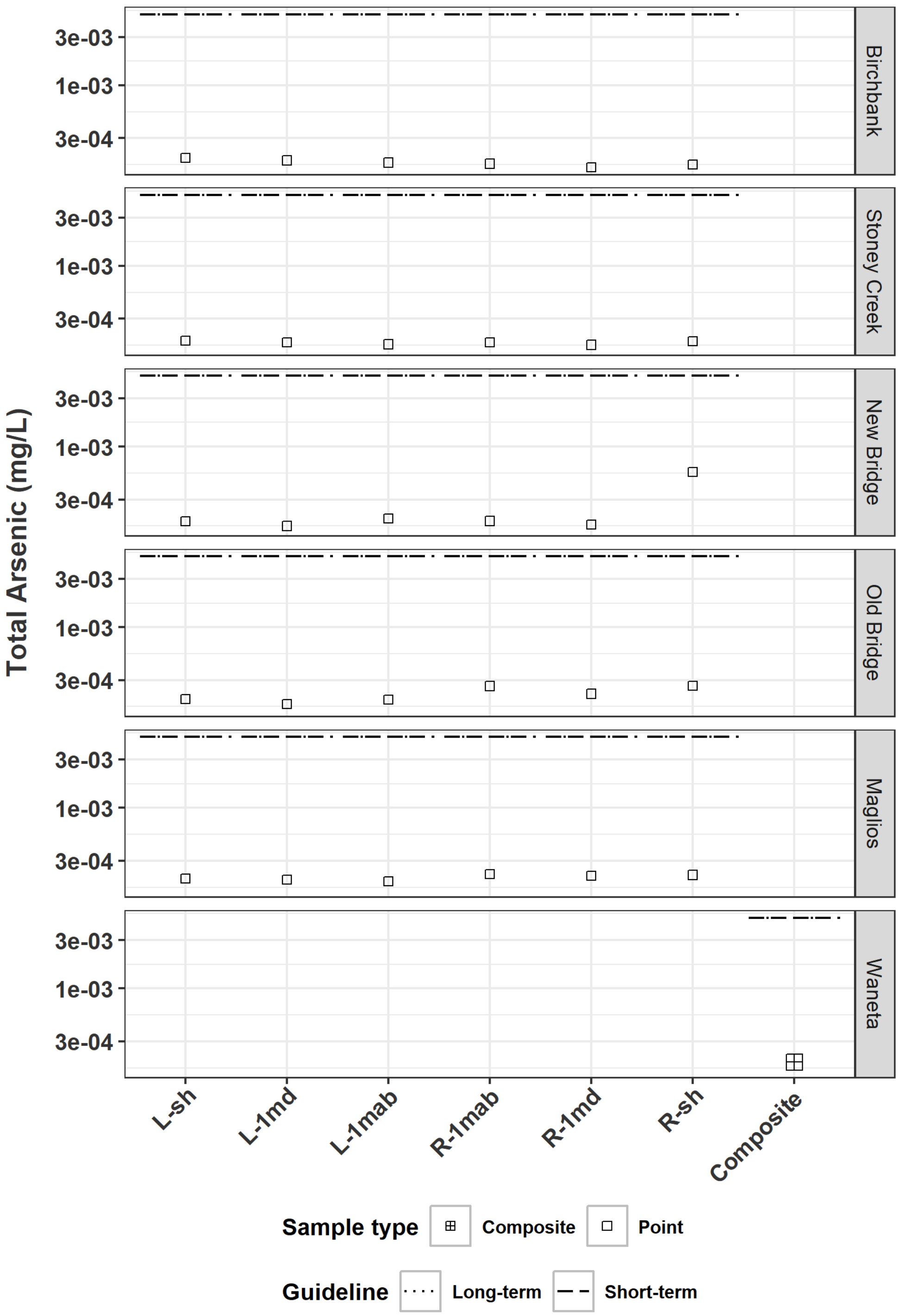


Figure A24 **Box plots of total Arsenic measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.**

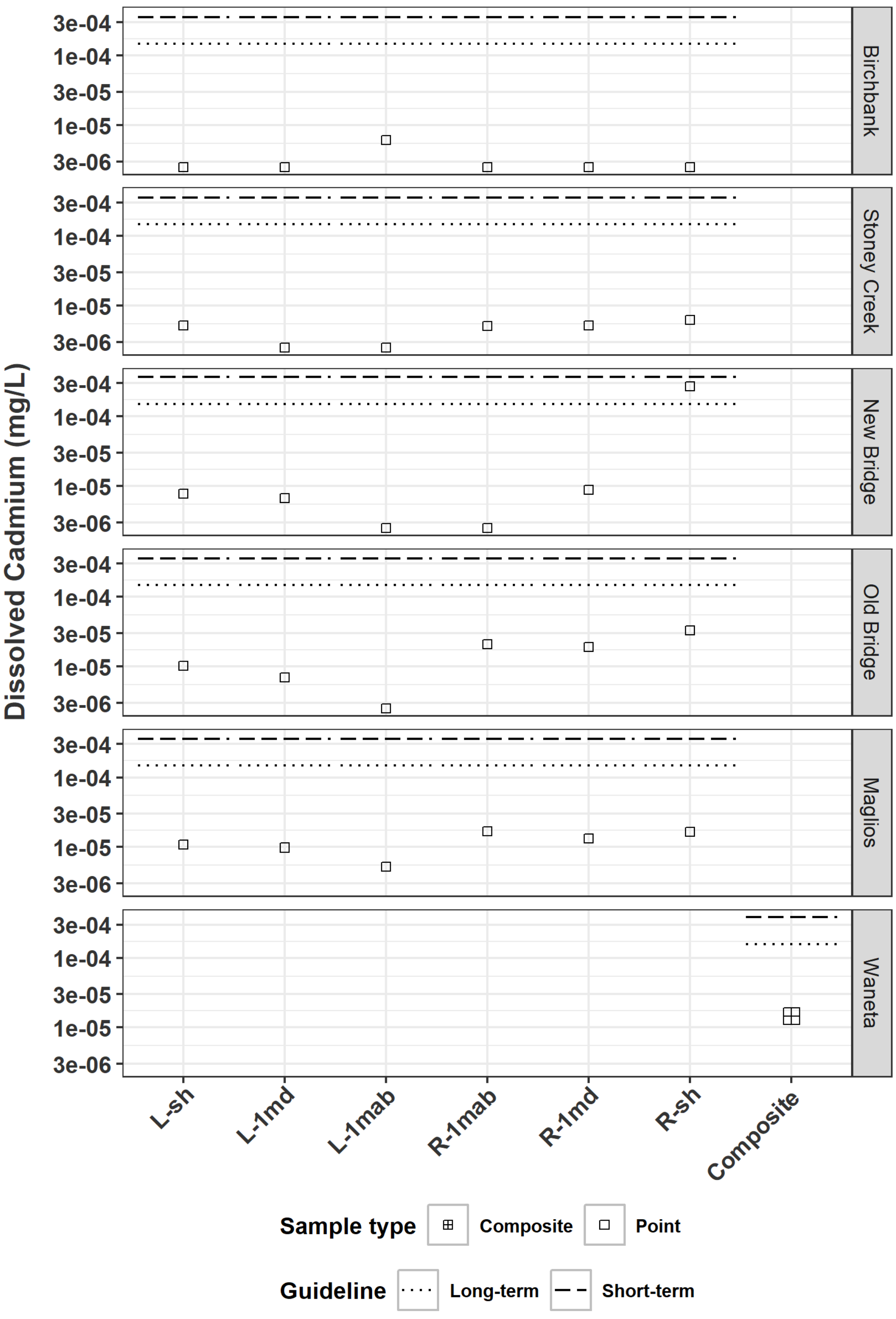


Figure A25 **Box plots of total Cadmium measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.**

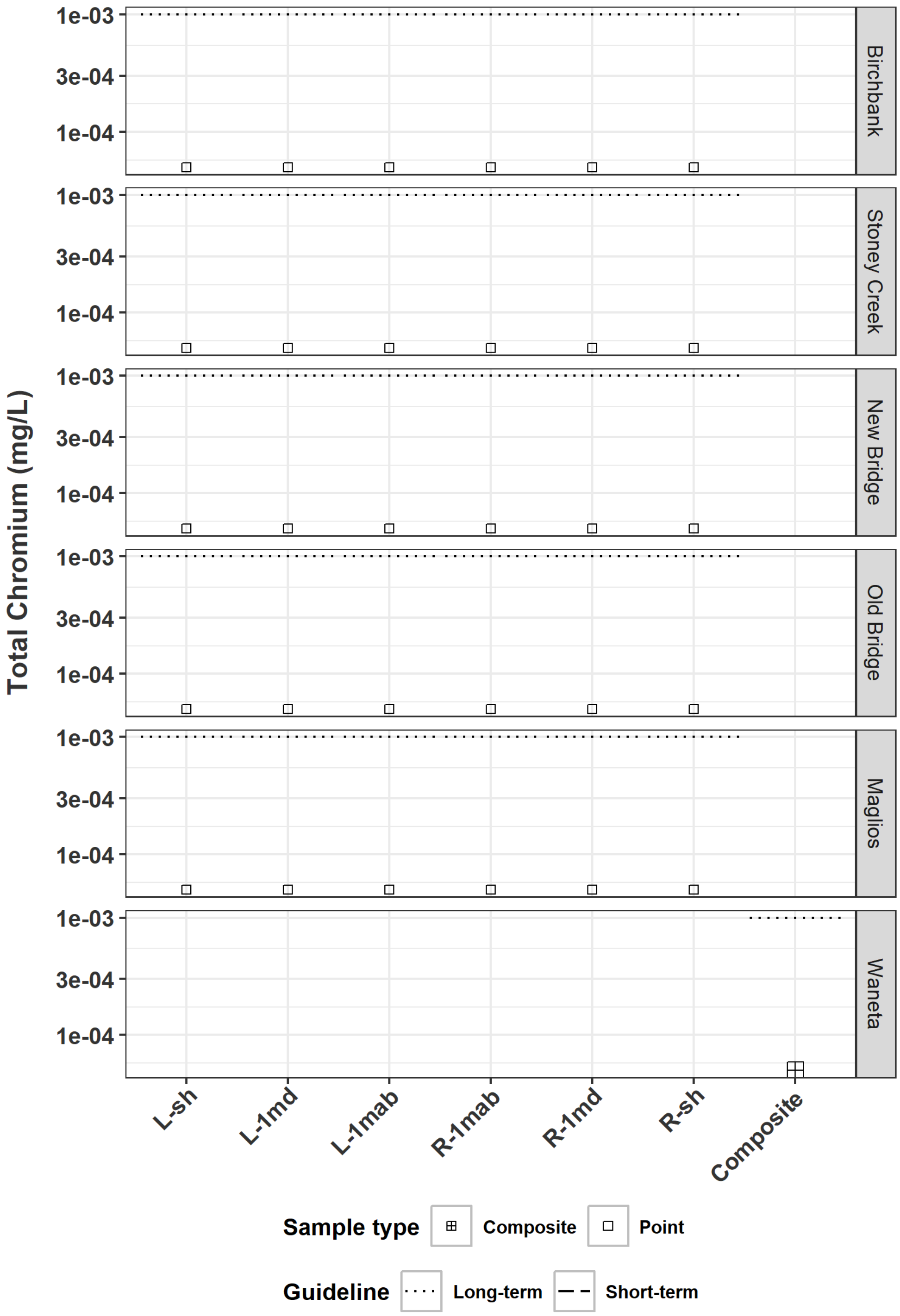


Figure A26 Box plots of total Chromium measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

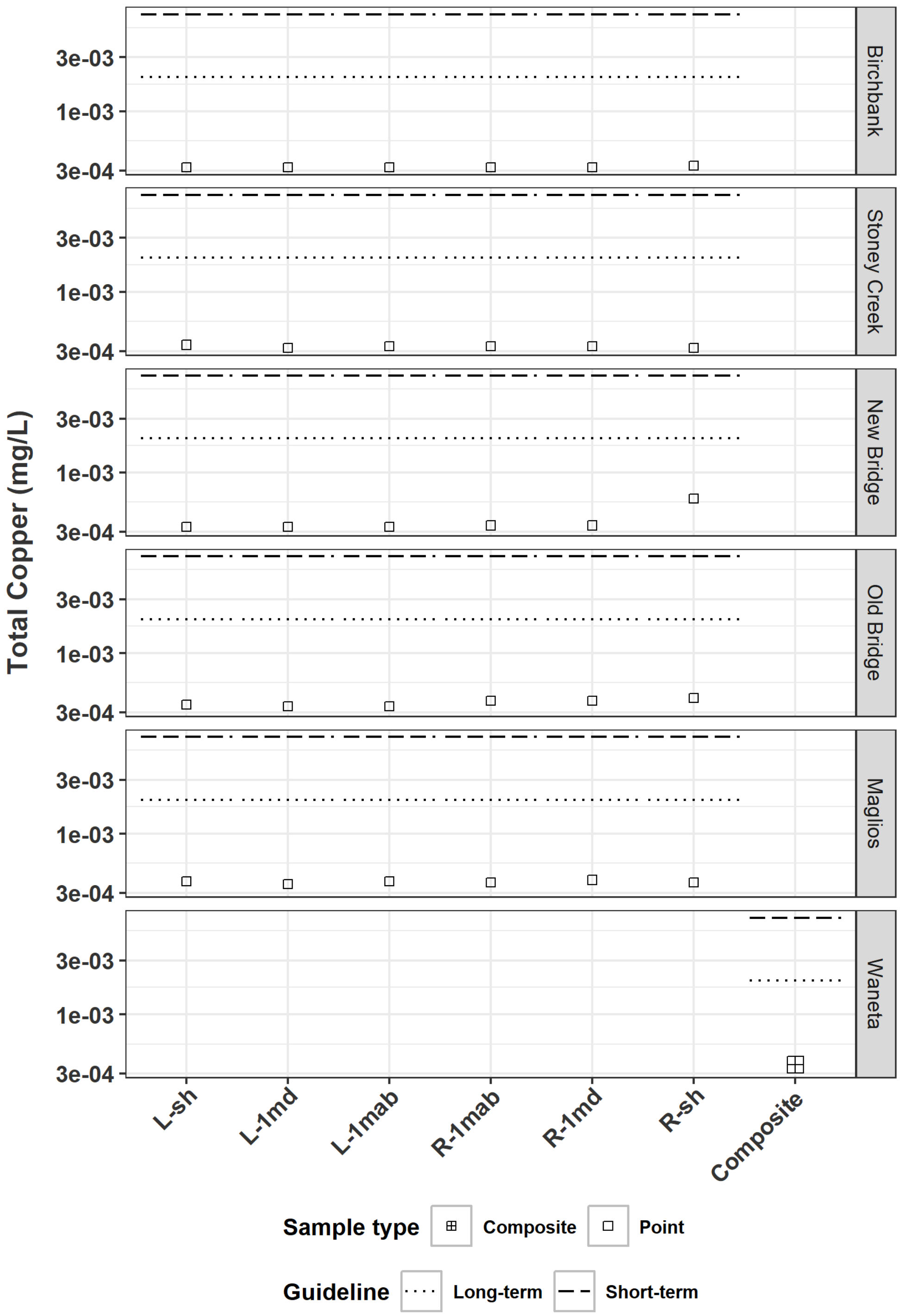


Figure A27 Box plots of total Copper measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

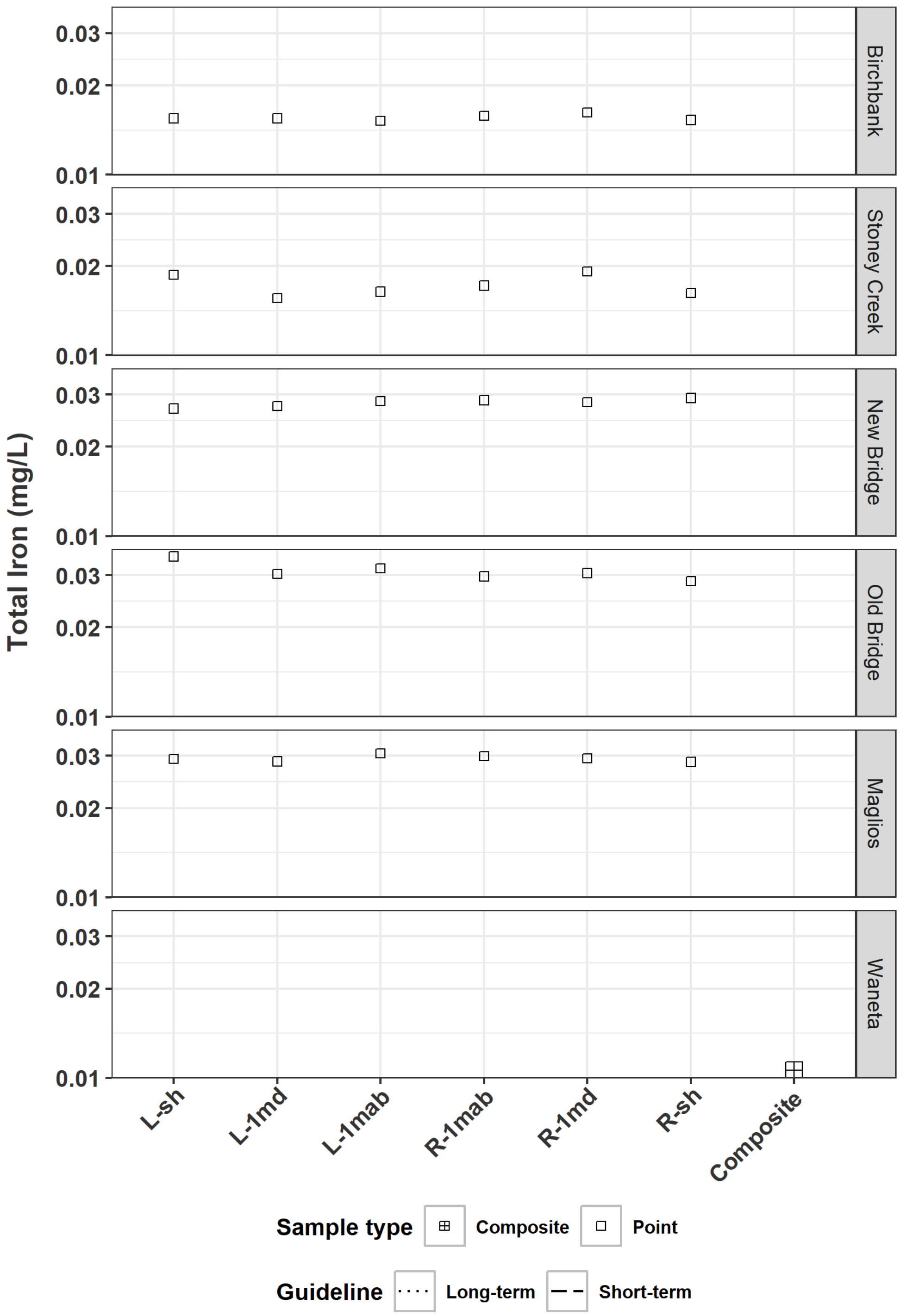


Figure A28 Box plots of total Iron measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

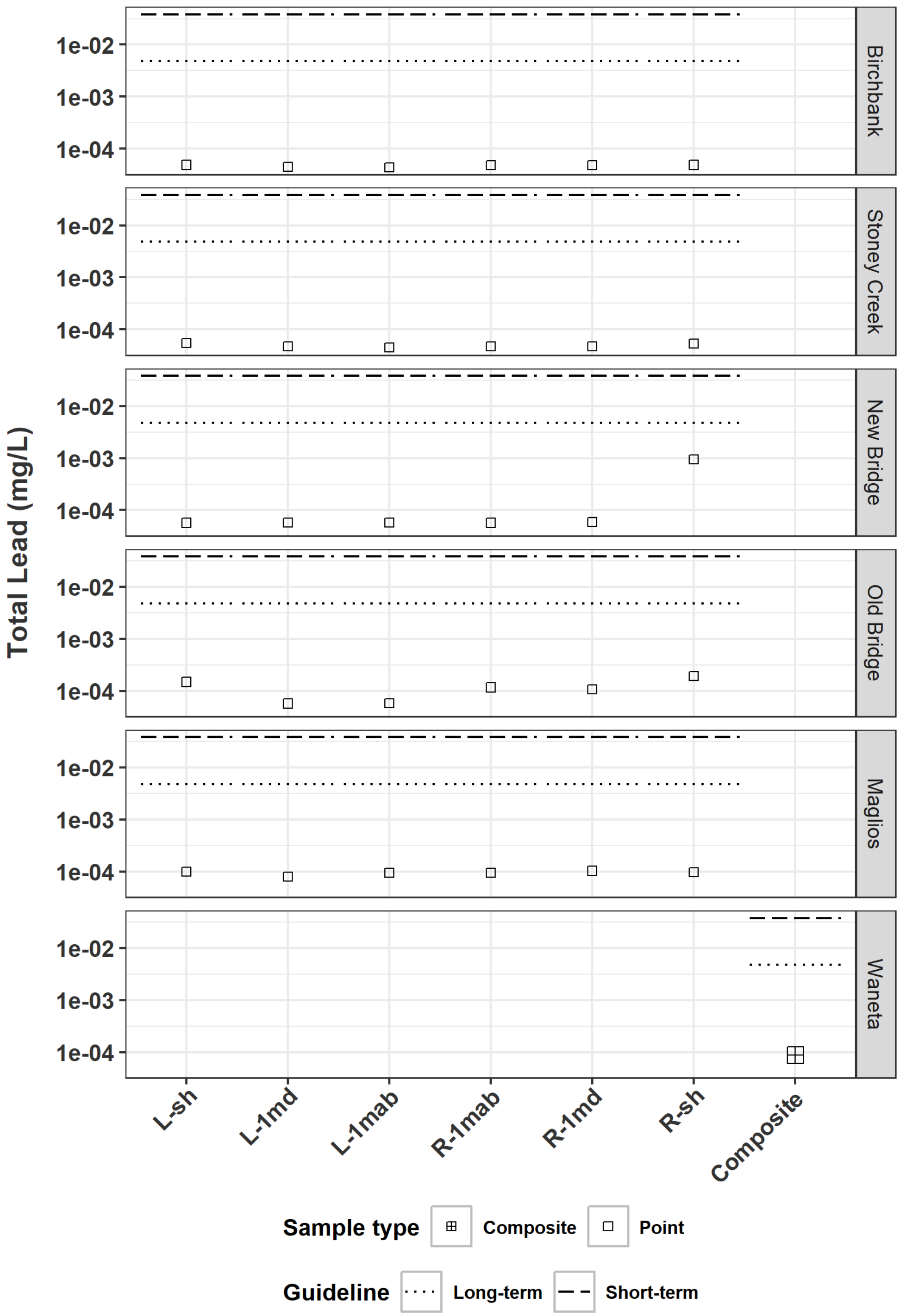


Figure A29 Box plots of total Lead measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

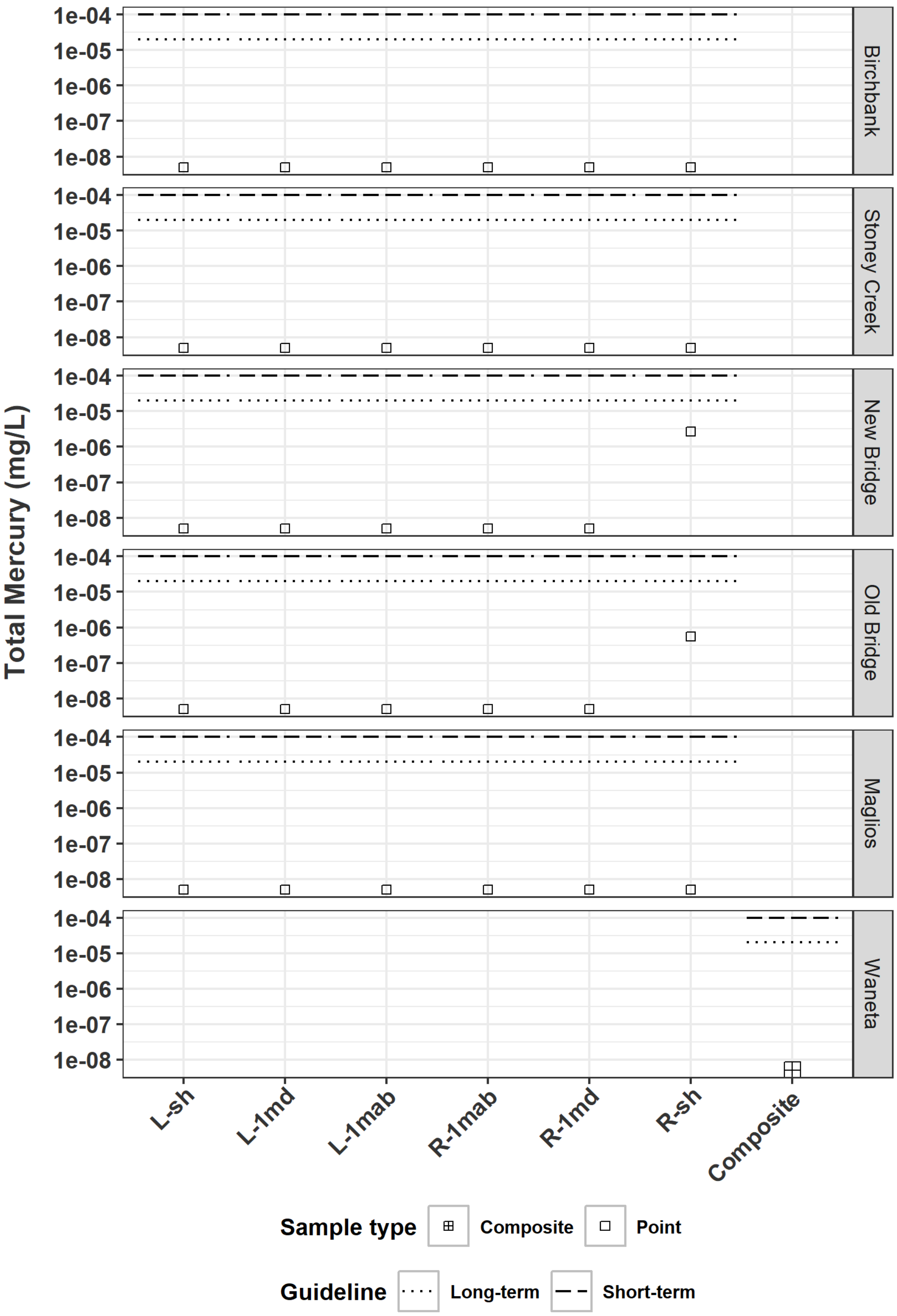


Figure A30 Box plots of total Mercury measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

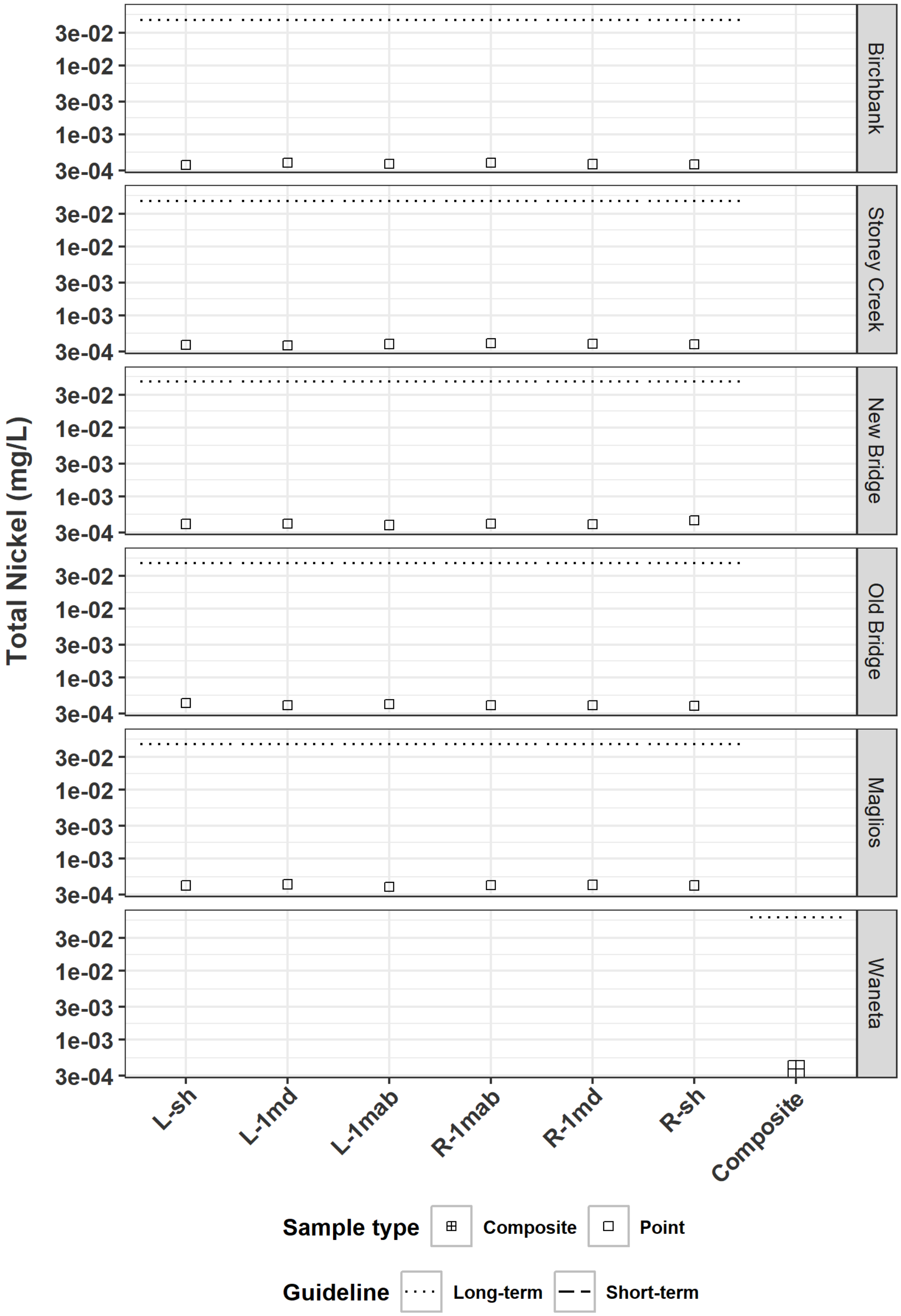


Figure A31 Box plots of total Nickel measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

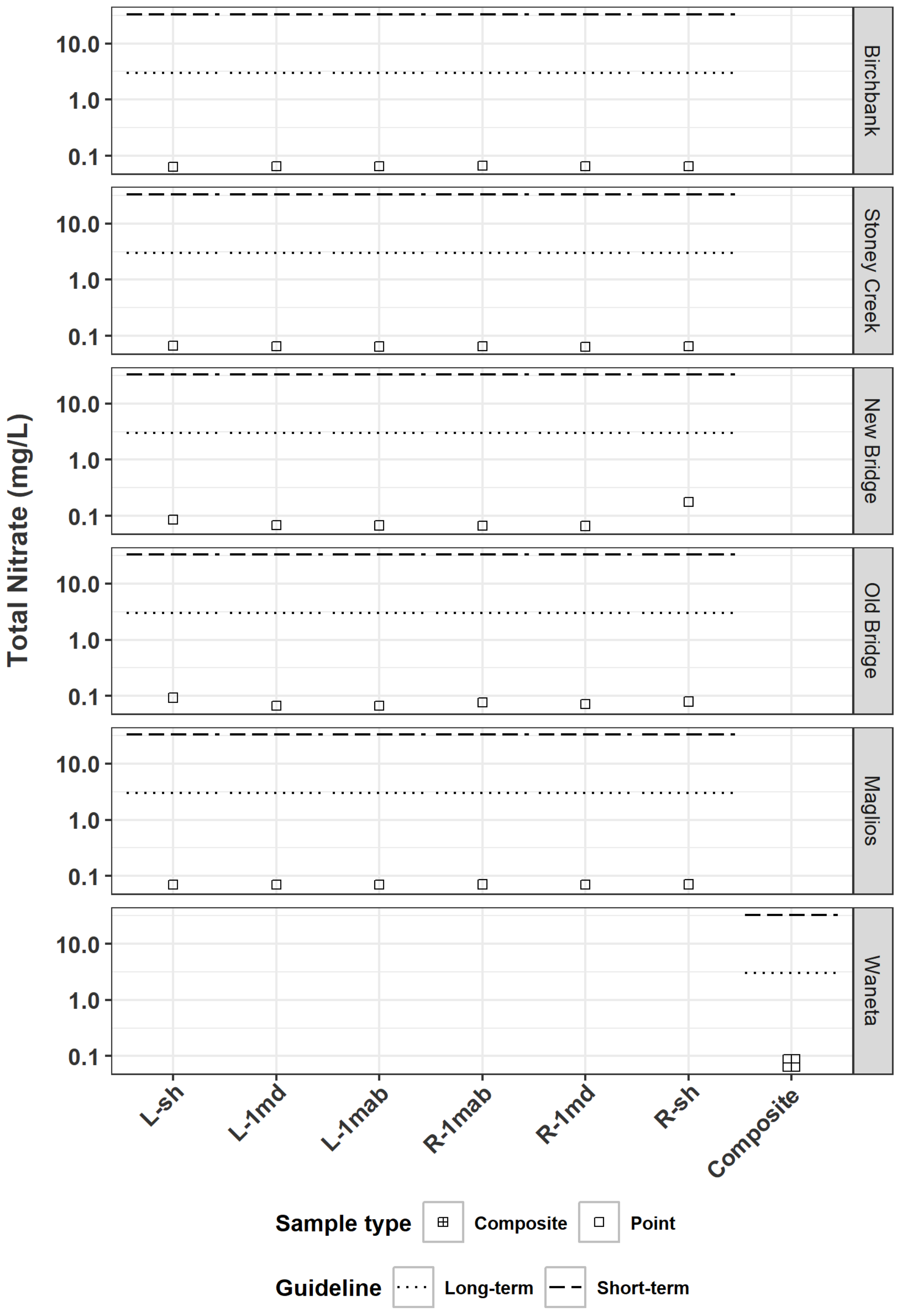


Figure A32 Box plots of total Nitrate measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

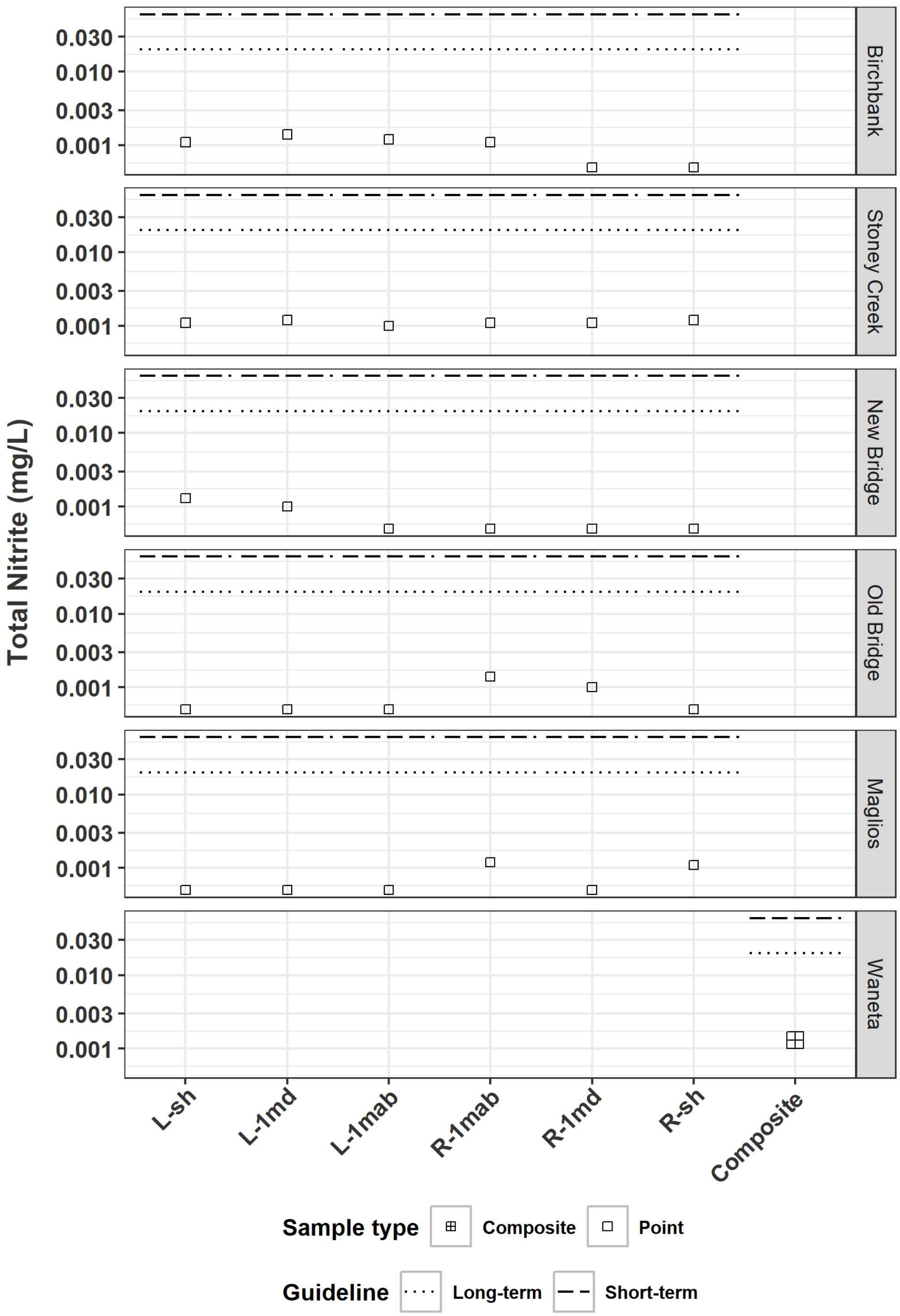


Figure A33 Box plots of total Nitrite measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

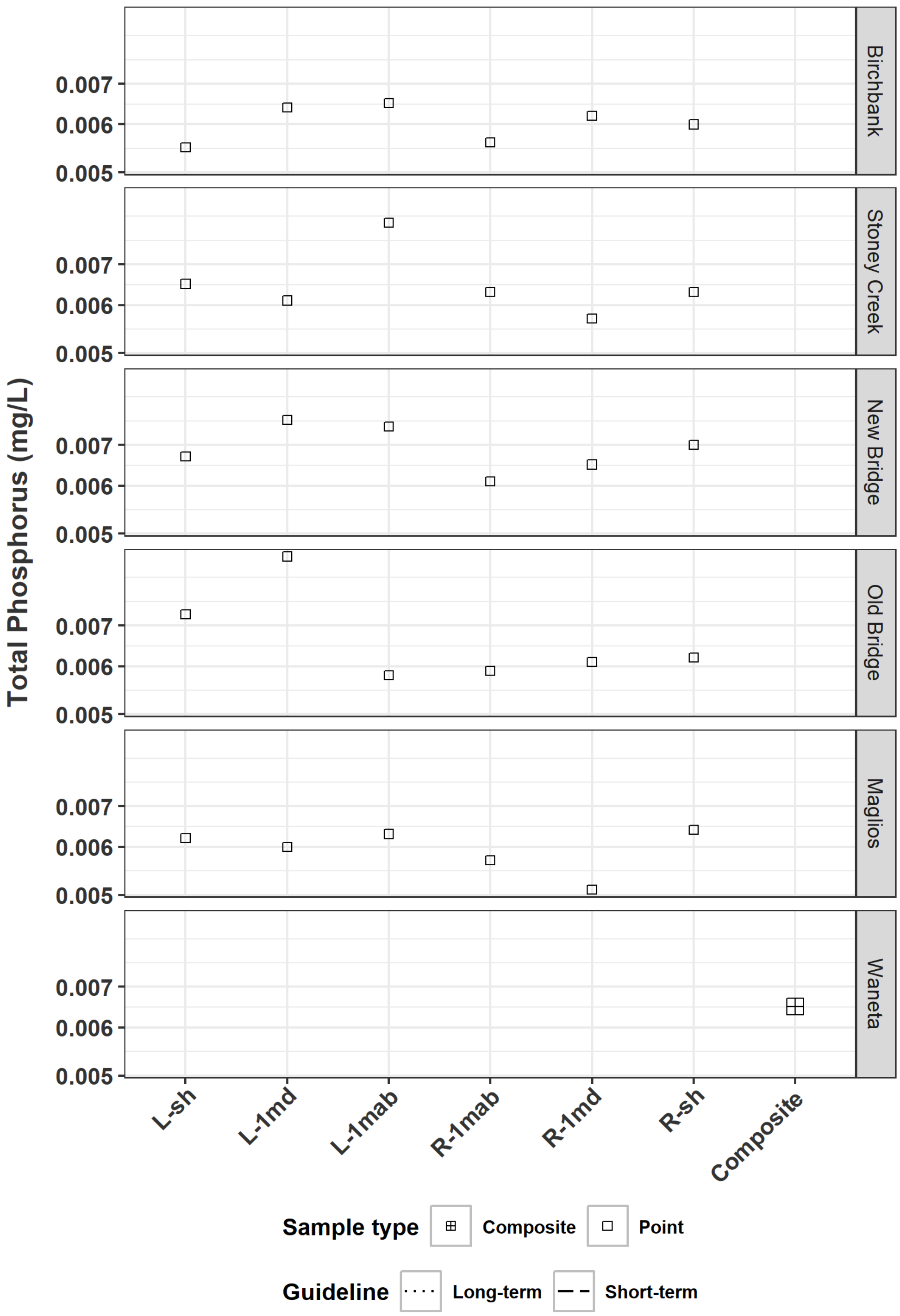


Figure A34 Box plots of total Phosphorus measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

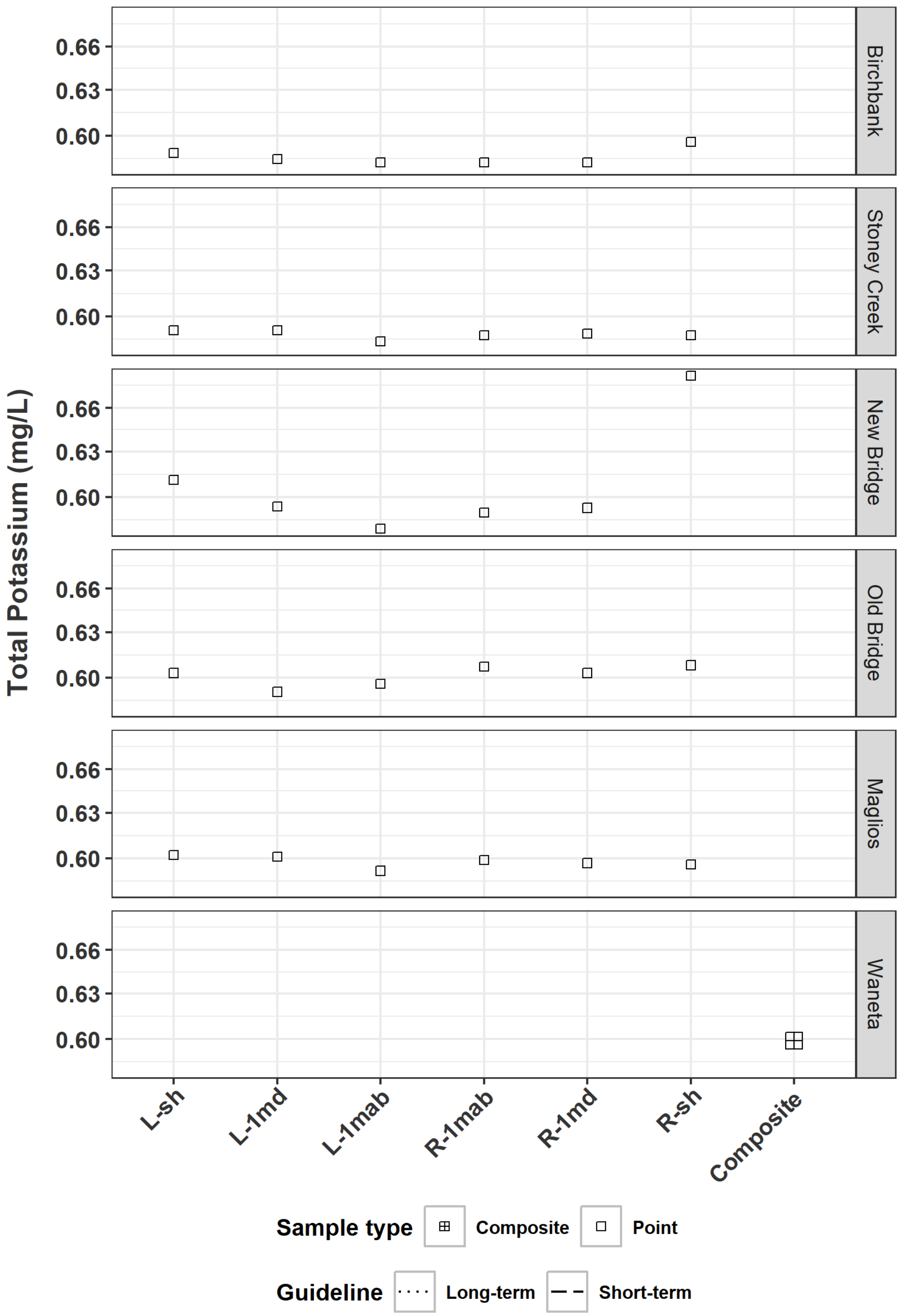


Figure A35 Box plots of total Potassium measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

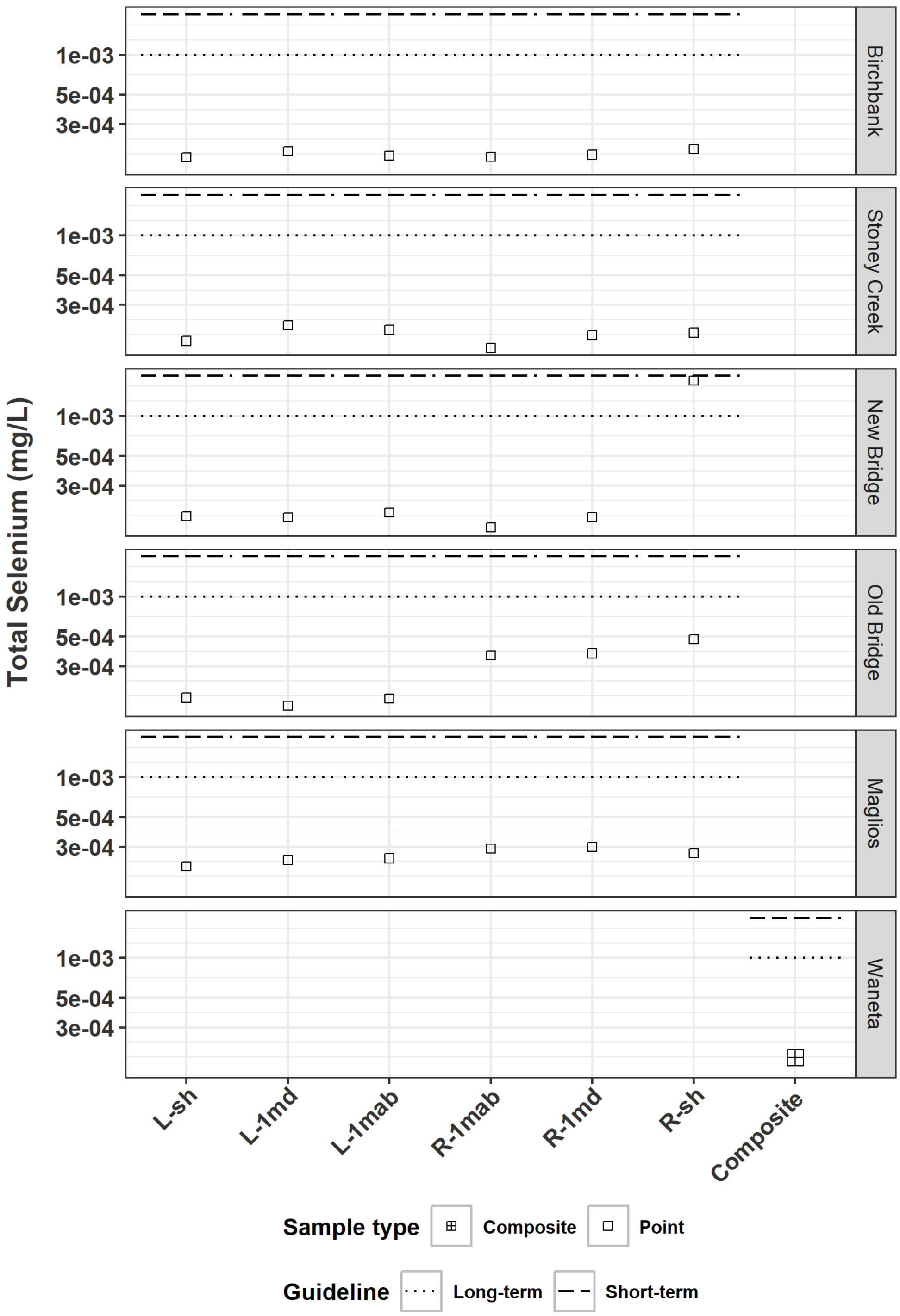


Figure A36 **Box plots of total Selenium measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.**

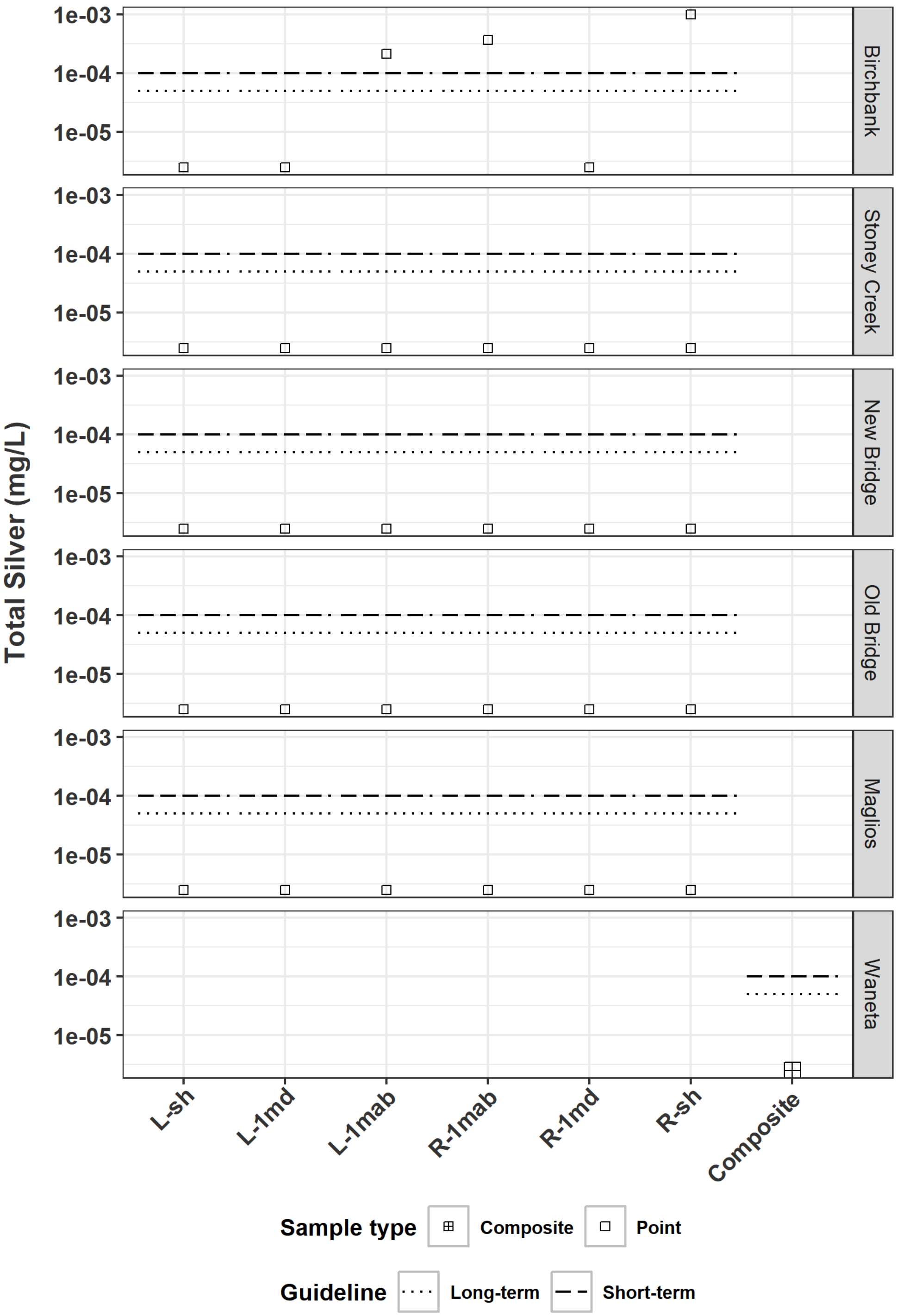


Figure A37 Box plots of total Silver measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

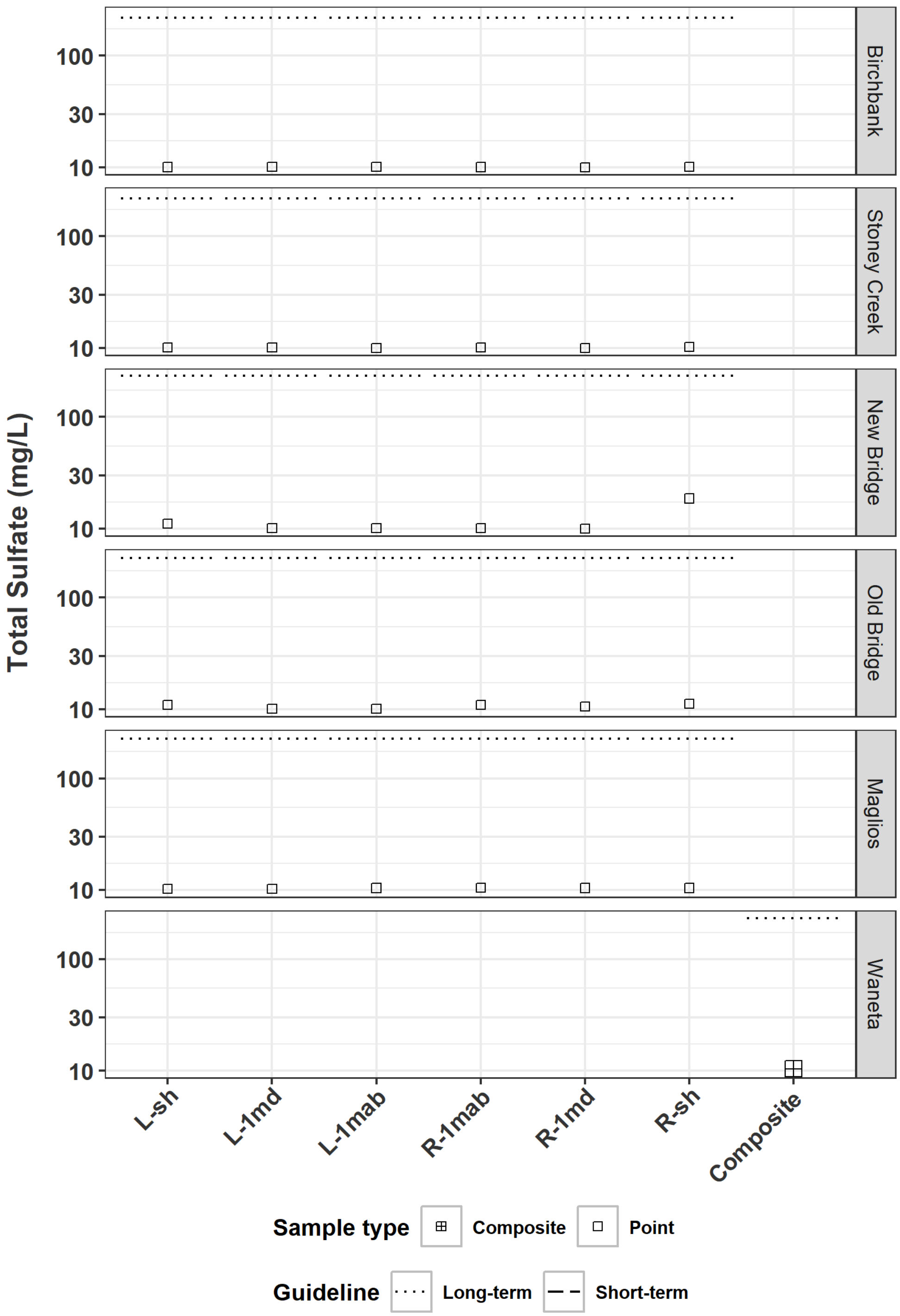


Figure A38 Box plots of total Sulfate measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

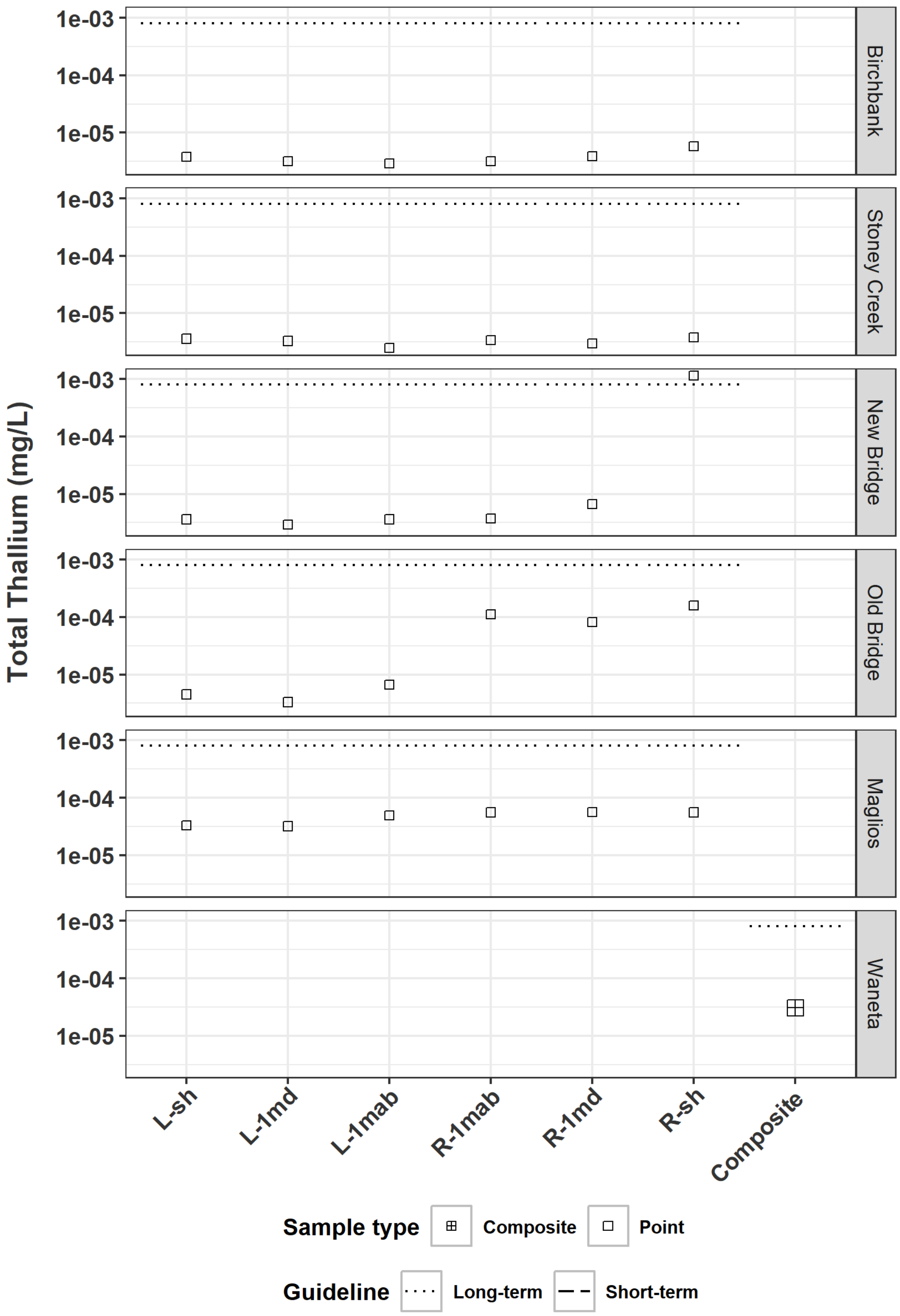


Figure A39 **Box plots of total Thallium measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.**

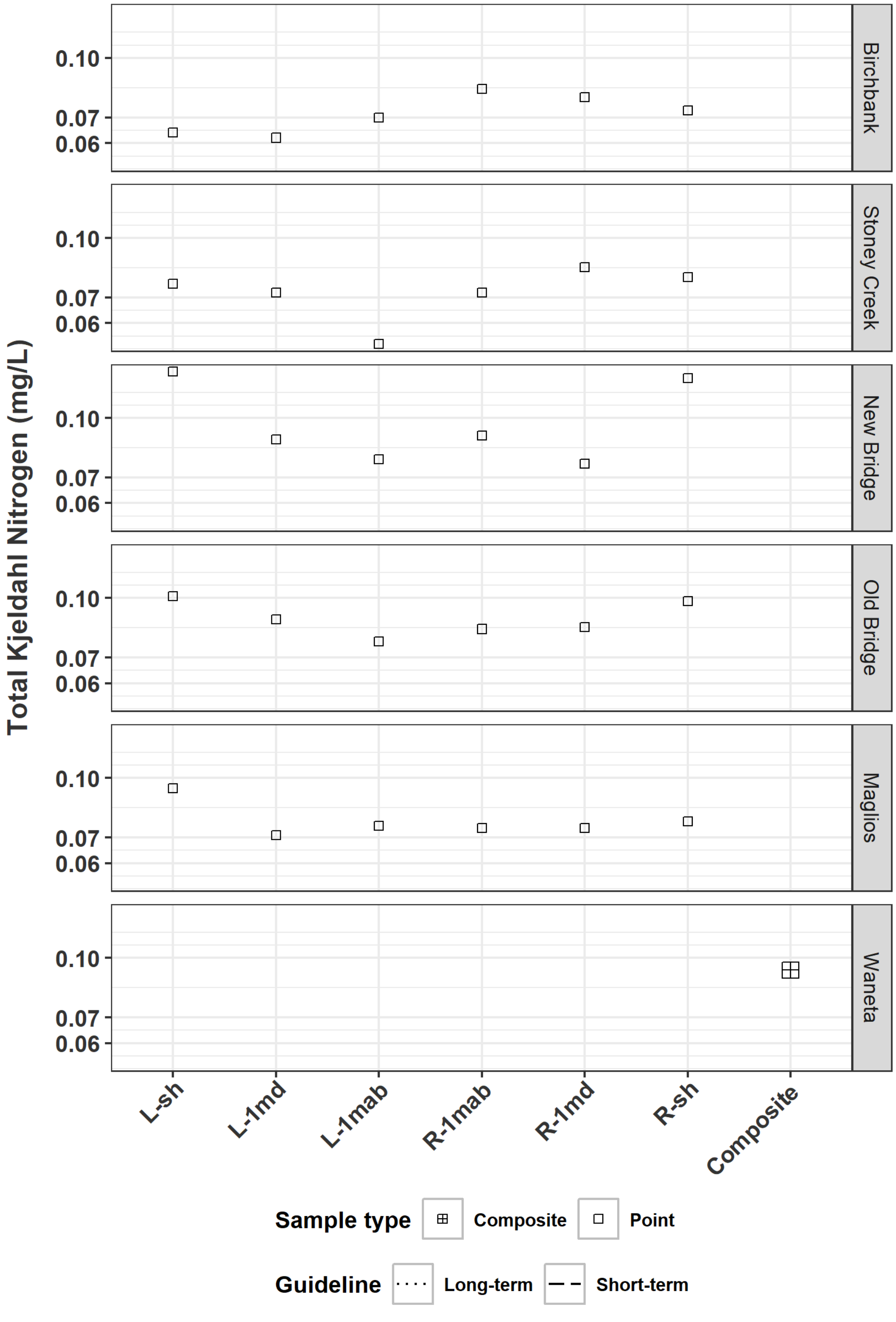


Figure A40 Box plots of total Total Kjeldahl Nitrogen measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

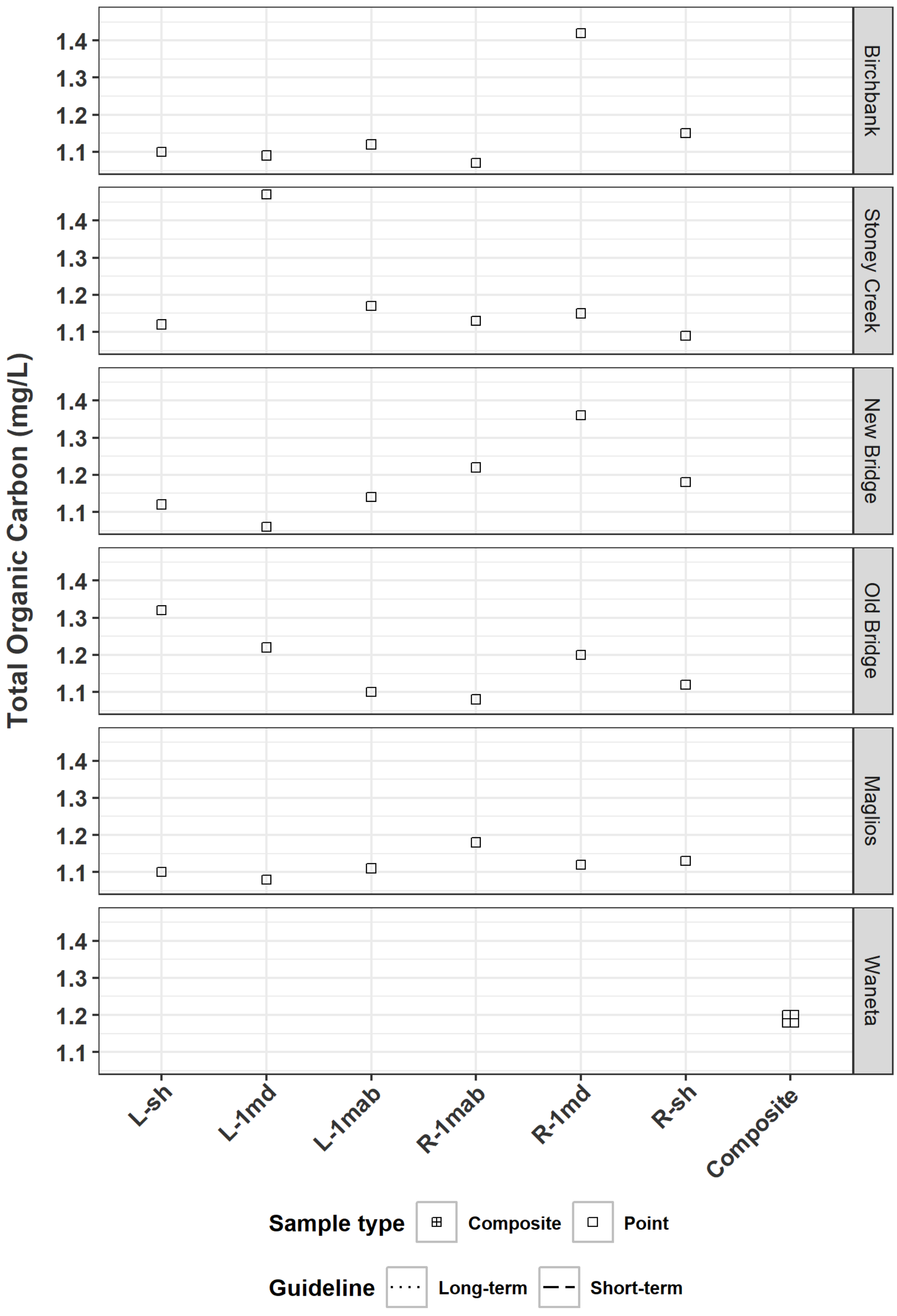


Figure A41 Box plots of total Total Organic Carbon measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

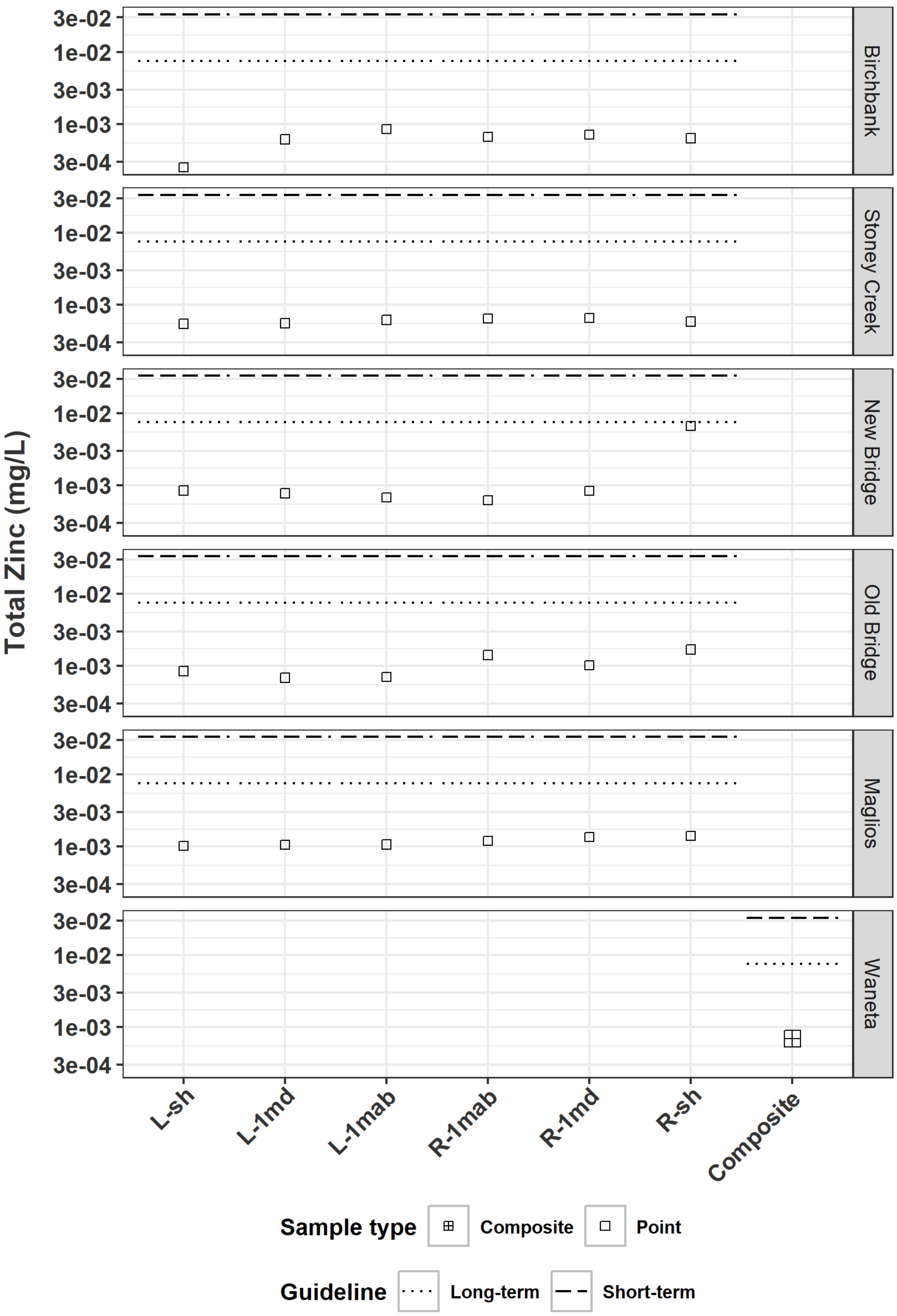


Figure A42 Box plots of total Zinc measured in the LCR during fall 2018 transect sampling. The channel position designations are L-sh left-shallow, L-1md left 1 m deep, L-1mab left 1 meter above bed, and the same for Right.

APPENDIX O SEDIMENT QUALITY SUPPLEMENTAL RESULTS

Table A45 Paired t-test comparison of 2mm and 0.063mm for sediment metal concentrations 2018.

Analyte	t Stat	p Value	Mean of differences	Standard error
Aluminum	5.690	<0.001	2 447.000	430.072
Antimony	1.657	0.132	7.000	4.225
Arsenic	2.641	0.027	7.311	2.768
Barium	1.280	0.233	28.960	22.629
Beryllium	8.400	<0.001	0.140	0.017
Boron	<0.001	0.059	-1.940	0.900
Cadmium	2.693	0.025	2.264	0.841
Calcium	1.010	0.339	1 032.000	1 021.358
Chromium	4.341	0.002	10.690	2.463
Cobalt	2.015	0.075	1.518	0.753
Copper	0.898	0.392	32.743	36.452
Iron	2.517	0.033	5 493.000	2 182.390
Lead	2.403	0.040	174.131	72.451
Lithium	3.981	0.003	2.530	0.636
Magnesium	7.100	<0.001	1 347.000	189.731
Manganese	0.650	0.532	24.900	38.318
Mercury	2.192	0.056	1.638	0.747
Molybdenum	<0.001	0.327	-0.279	0.269
Nickel	5.895	<0.001	9.045	1.534
Phosphorus	9.345	<0.001	747.800	80.024
Potassium	2.869	0.019	213.800	74.532
Selenium	1.902	0.090	1.331	0.700
Silver	2.987	0.015	1.368	0.458
Sodium	1.029	0.330	19.300	18.757
Strontium	4.634	0.001	15.990	3.451
Sulfur	1.923	0.087	1 691.000	879.149
Thallium	2.089	0.066	0.207	0.099
Thorium	8.341	<0.001	3.583	0.430
Tin	0.780	0.456	3.860	4.951
Titanium	4.756	0.001	172.700	36.313

Analyte	t Stat	p Value	Mean of differences	Standard error
Uranium	6.617	<0.001	1.544	0.233
Vanadium	3.886	0.004	10.460	2.692
Zinc	0.339	0.742	50.000	147.416

APPENDIX P SEDIMENT METALS PRINCIPAL COMPONENT ANALYSIS

Sediment Quality PCA

18-2411.1

Luke Crevier

Started: August 27 2019 - Most recent: Wed Jan 12 10:42:44 2022

Contents

Load libraries

```
require(ggplot2)
require(plyr)
require(stringr)
require(openxlsx)
require(vegan)
require(vegetarian)
require(tidyverse)
require(reshape2)
require(ggrepel)
require(gridExtra)
require(data.table)
require(Hmisc)
require(RPostgreSQL)
require(stringr)
require(psych)
require(grid)
```

Load Data

Load master data files

```
fChlaExcel <- "M:/Projects/2018/18-2411.1 - Teck AREMP - Interpretation/Data_AREMP/Sediment_Quality/WD1_

sedsRaw <- read.xlsx(fChlaExcel, sheet = "Sediment Metals")
```

Munging

delete 2003 data

```
sedsRaw = sedsRaw %>% filter(year != 2003)
```

Filter for metals of interest

```
MOI <- c(
  "Arsenic",
  "Cadmium",
  "Chromium",
  "Copper",
  "Lead",
  "Mercury",
  "Selenium",
  "Thallium",
  "Zinc"
)

sedsMOI <- sedsRaw %>% filter(analyte %in% MOI, !duplicate)
```

```
sedsMOI %>%
  group_by(label, analyte, value_text) %>% filter(n() > 1)
```

```
## # A tibble: 6 x 13
## # Groups:   label, analyte, value_text [3]
##   label           year dep_ero ref_exp site  CII_Dist fraction analyte duplicate
##   <chr>          <dbl> <chr>   <chr>   <chr>    <dbl>    <dbl> <chr>   <lgl>
## 1 2018-dep-ref-1  2018 dep     ref     1       -28291 0.000063 Mercury FALSE
## 2 2018-dep-ref-1  2018 dep     ref     1       -28291 0.002    Mercury FALSE
## 3 2018-dep-ref-3  2018 dep     ref     3        -8238 0.000063 Thalli~ FALSE
## 4 2018-dep-ref-3  2018 dep     ref     3        -8238 0.002    Thalli~ FALSE
## 5 2018-dep-ref-2  2018 dep     ref     2       -12833 0.000063 Thalli~ FALSE
## 6 2018-dep-ref-2  2018 dep     ref     2       -12833 0.002    Thalli~ FALSE
## # ... with 4 more variables: value_text <chr>, value <dbl>, dl <chr>,
## #   season <chr>
```

Drop unneeded variables

Note: Need to keep fraction or there are 'duplicate' rows for the conversion to wide due to the multiple fraction sizes present in 2018

```
sedsClean <- sedsMOI %>% select(label, analyte, value, fraction)
```

Convert to wide

```
sedsWide <- sedsClean %>%
  spread(analyte, value)

sedsWide
```

```
##             label fraction Arsenic Cadmium Chromium Copper   Lead Mercury
## 1  2012-dep-exp-1       NA    7.10   1.700     19.0 120.00 170.00   0.190
## 2  2012-dep-exp-2       NA   14.00   0.500     39.0 670.00 100.00   0.120
## 3  2012-dep-exp-3       NA   11.00   1.100     31.0 370.00 160.00   0.210
## 4  2012-dep-exp-4       NA    7.00   0.500     24.0 180.00  62.00   0.080
## 5  2012-dep-exp-5       NA    9.60   1.100     30.0 320.00 130.00   0.160
## 6  2012-dep-exp-6       NA    5.90   0.710     25.0 250.00  83.00   0.070
## 7  2012-dep-exp-7       NA    4.90   1.200     34.0 100.00  73.00   0.050
## 8  2012-dep-ref-1       NA    0.80   0.230     18.0   5.80   7.80   0.001
## 9  2012-dep-ref-2       NA    1.10   0.300     15.0   6.30   9.90   0.001
## 10 2012-dep-ref-3       NA    0.60   0.090     15.0   4.00   4.90   0.001
## 11 2015-dep-exp-1       NA    6.00   1.390     20.8  95.90 160.00   0.230
## 12 2015-dep-exp-2       NA    5.50   0.540     19.1 161.00 141.00   0.130
## 13 2015-dep-exp-3       NA   14.10   0.570     36.6 514.00 136.00   0.120
## 14 2015-dep-exp-4       NA    5.20   0.460     22.5 139.00  48.90   0.080
## 15 2015-dep-exp-5       NA    5.90   1.120     26.3 196.00 109.00   0.250
## 16 2015-dep-exp-6       NA    4.10   0.520     20.7 176.00  52.80   0.170
## 17 2015-dep-exp-7       NA    3.60   2.810     31.2  36.00  91.90   0.140
## 18 2015-dep-ref-1       NA    0.90   0.190     11.9   5.40   6.80   0.050
## 19 2015-dep-ref-2       NA    1.00   0.170     10.0   5.10   7.30   0.025
```

```
## 20 2015-dep-ref-3       NA    0.80   0.110     15.6   5.10   7.00   0.025
## 21 2018-dep-exp-1  6.3e-05   23.60   4.630     45.5 243.00 526.00   1.150
## 22 2018-dep-exp-1  2.0e-03    8.66   1.680     21.7 188.00 194.00   0.133
## 23 2018-dep-exp-2  6.3e-05   37.40  10.200     56.2 681.00 900.00   7.410
## 24 2018-dep-exp-2  2.0e-03   11.00   2.150     38.7 467.00 220.00   0.550
## 25 2018-dep-exp-3  6.3e-05   16.00   2.030     34.4 416.00 221.00   1.900
## 26 2018-dep-exp-3  2.0e-03   11.10   0.361     26.6 251.00  71.80   0.042
## 27 2018-dep-exp-4  6.3e-05    7.05   1.760     29.1 109.00  84.60   0.415
## 28 2018-dep-exp-4  2.0e-03    6.76   1.410     30.2 322.00  70.40   0.106
## 29 2018-dep-exp-5  6.3e-05   23.70   7.400     44.7 408.00 543.00   5.210
## 30 2018-dep-exp-5  2.0e-03    7.88   1.530     29.3 315.00 129.00   0.245
## 31 2018-dep-exp-6  6.3e-05   10.50   2.150     34.3 158.00 134.00   0.879
## 32 2018-dep-exp-6  2.0e-03    6.64   0.573     21.9 165.00  56.00   0.076
## 33 2018-dep-exp-7  6.3e-05    6.79   2.480     27.1  43.80 116.00   0.423
## 34 2018-dep-exp-7  2.0e-03    3.63   1.420     28.6  46.90  61.90   0.054
## 35 2018-dep-ref-1  6.3e-05    2.46   0.585     23.9  13.60  12.60   0.020
## 36 2018-dep-ref-1  2.0e-03    1.38   0.208     14.4   5.40   6.26   0.020
## 37 2018-dep-ref-2  6.3e-05    2.22   0.581     21.1  12.40  10.70   0.055
## 38 2018-dep-ref-2  2.0e-03    1.07   0.248     10.9   5.89   7.19   0.020
## 39 2018-dep-ref-3  6.3e-05    2.78   0.573     26.5  14.20  15.50   0.185
## 40 2018-dep-ref-3  2.0e-03    1.27   0.165     13.6   5.38   5.54   0.020
##    Selenium Thallium   Zinc
## 1      0.60     0.40  650.0
## 2      1.00     0.05 4200.0
## 3      0.80     0.20 2200.0
## 4      0.01     0.10  930.0
## 5      0.80     0.20 2400.0
## 6      0.60     0.20 1400.0
## 7      0.01     0.20  780.0
## 8      0.01     0.05   71.0
## 9      0.01     0.05   70.0
## 10     0.01     0.05   38.0
## 11     0.25     0.30  645.0
## 12     0.25     0.05 1190.0
## 13     0.25     0.05 2550.0
## 14     0.25     0.10  770.0
## 15     0.60     0.20 1160.0
## 16     0.25     0.20  793.0
## 17     0.25     0.20  594.0
## 18     0.25     0.05   59.0
## 19     0.25     0.05   48.0
## 20     0.25     0.05   31.0
## 21     1.57     0.48 1400.0
## 22     0.43     0.25 1100.0
## 23     8.73     1.25 4380.0
## 24     1.82     0.37 3790.0
## 25     0.64     0.22 1200.0
## 26     0.21     0.05  949.0
## 27     0.39     0.18  697.0
## 28     0.37     0.20 1800.0
## 29     4.12     0.89 2660.0
## 30     0.63     0.22 2160.0
## 31     0.60     0.20  803.0
## 32     0.22     0.14  902.0
```

```
## 33     0.45     0.18  482.0
## 34     0.22     0.15  506.0
## 35     0.42     0.10   96.2
## 36     0.10     0.05   60.8
## 37     0.30     0.05   78.2
## 38     0.10     0.05   64.9
## 39     0.29     0.05   92.5
## 40     0.10     0.05   56.2
```

Split datasets into two

Make df with only 2mm fractions

```
sedsWide$fraction[is.na(sedsWide$fraction)] <- 2.0e-03

seds2mm <- sedsWide %>% filter(is.na(fraction) | fraction == 2.0e-03)

row.names(seds2mm) <- seds2mm$label

seds2mm <- seds2mm %>% select(-label, -fraction)

seds2mm
```

```
##                 Arsenic Cadmium Chromium Copper   Lead Mercury Selenium Thallium
## 2012-dep-exp-1    7.10   1.700     19.0 120.00 170.00   0.190     0.60     0.40
## 2012-dep-exp-2   14.00   0.500     39.0 670.00 100.00   0.120     1.00     0.05
## 2012-dep-exp-3   11.00   1.100     31.0 370.00 160.00   0.210     0.80     0.20
## 2012-dep-exp-4    7.00   0.500     24.0 180.00  62.00   0.080     0.01     0.10
## 2012-dep-exp-5    9.60   1.100     30.0 320.00 130.00   0.160     0.80     0.20
## 2012-dep-exp-6    5.90   0.710     25.0 250.00  83.00   0.070     0.60     0.20
## 2012-dep-exp-7    4.90   1.200     34.0 100.00  73.00   0.050     0.01     0.20
## 2012-dep-ref-1    0.80   0.230     18.0   5.80   7.80   0.001     0.01     0.05
## 2012-dep-ref-2    1.10   0.300     15.0   6.30   9.90   0.001     0.01     0.05
## 2012-dep-ref-3    0.60   0.090     15.0   4.00   4.90   0.001     0.01     0.05
## 2015-dep-exp-1    6.00   1.390     20.8  95.90 160.00   0.230     0.25     0.30
## 2015-dep-exp-2    5.50   0.540     19.1 161.00 141.00   0.130     0.25     0.05
## 2015-dep-exp-3   14.10   0.570     36.6 514.00 136.00   0.120     0.25     0.05
## 2015-dep-exp-4    5.20   0.460     22.5 139.00  48.90   0.080     0.25     0.10
## 2015-dep-exp-5    5.90   1.120     26.3 196.00 109.00   0.250     0.60     0.20
## 2015-dep-exp-6    4.10   0.520     20.7 176.00  52.80   0.170     0.25     0.20
## 2015-dep-exp-7    3.60   2.810     31.2  36.00  91.90   0.140     0.25     0.20
## 2015-dep-ref-1    0.90   0.190     11.9   5.40   6.80   0.050     0.25     0.05
## 2015-dep-ref-2    1.00   0.170     10.0   5.10   7.30   0.025     0.25     0.05
## 2015-dep-ref-3    0.80   0.110     15.6   5.10   7.00   0.025     0.25     0.05
## 2018-dep-exp-1    8.66   1.680     21.7 188.00 194.00   0.133     0.43     0.25
## 2018-dep-exp-2   11.00   2.150     38.7 467.00 220.00   0.550     1.82     0.37
## 2018-dep-exp-3   11.10   0.361     26.6 251.00  71.80   0.042     0.21     0.05
## 2018-dep-exp-4    6.76   1.410     30.2 322.00  70.40   0.106     0.37     0.20
## 2018-dep-exp-5    7.88   1.530     29.3 315.00 129.00   0.245     0.63     0.22
## 2018-dep-exp-6    6.64   0.573     21.9 165.00  56.00   0.076     0.22     0.14
## 2018-dep-exp-7    3.63   1.420     28.6  46.90  61.90   0.054     0.22     0.15
## 2018-dep-ref-1    1.38   0.208     14.4   5.40   6.26   0.020     0.10     0.05
```

```
## 2018-dep-ref-2    1.07   0.248     10.9   5.89   7.19   0.020     0.10     0.05
## 2018-dep-ref-3    1.27   0.165     13.6   5.38   5.54   0.020     0.10     0.05
##                  Zinc
## 2012-dep-exp-1  650.0
## 2012-dep-exp-2 4200.0
## 2012-dep-exp-3 2200.0
## 2012-dep-exp-4  930.0
## 2012-dep-exp-5 2400.0
## 2012-dep-exp-6 1400.0
## 2012-dep-exp-7  780.0
## 2012-dep-ref-1   71.0
## 2012-dep-ref-2   70.0
## 2012-dep-ref-3   38.0
## 2015-dep-exp-1  645.0
## 2015-dep-exp-2 1190.0
## 2015-dep-exp-3 2550.0
## 2015-dep-exp-4  770.0
## 2015-dep-exp-5 1160.0
## 2015-dep-exp-6  793.0
## 2015-dep-exp-7  594.0
## 2015-dep-ref-1   59.0
## 2015-dep-ref-2   48.0
## 2015-dep-ref-3   31.0
## 2018-dep-exp-1 1100.0
## 2018-dep-exp-2 3790.0
## 2018-dep-exp-3  949.0
## 2018-dep-exp-4 1800.0
## 2018-dep-exp-5 2160.0
## 2018-dep-exp-6  902.0
## 2018-dep-exp-7  506.0
## 2018-dep-ref-1   60.8
## 2018-dep-ref-2   64.9
## 2018-dep-ref-3   56.2
```

Concatenate label and fraction to use as rownames

```
row.names(sedsWide) <- with(sedsWide, paste(label, fraction))

sedsAll <- sedsWide %>% select(-label, -fraction)

sedsAll
```

```
##                        Arsenic Cadmium Chromium Copper   Lead Mercury Selenium
## 2012-dep-exp-1 0.002      7.10   1.700     19.0 120.00 170.00   0.190     0.60
## 2012-dep-exp-2 0.002     14.00   0.500     39.0 670.00 100.00   0.120     1.00
## 2012-dep-exp-3 0.002     11.00   1.100     31.0 370.00 160.00   0.210     0.80
## 2012-dep-exp-4 0.002      7.00   0.500     24.0 180.00  62.00   0.080     0.01
## 2012-dep-exp-5 0.002      9.60   1.100     30.0 320.00 130.00   0.160     0.80
## 2012-dep-exp-6 0.002      5.90   0.710     25.0 250.00  83.00   0.070     0.60
## 2012-dep-exp-7 0.002      4.90   1.200     34.0 100.00  73.00   0.050     0.01
## 2012-dep-ref-1 0.002      0.80   0.230     18.0   5.80   7.80   0.001     0.01
## 2012-dep-ref-2 0.002      1.10   0.300     15.0   6.30   9.90   0.001     0.01
```

```
## 2012-dep-ref-3 0.002      0.60   0.090     15.0   4.00   4.90   0.001     0.01
## 2015-dep-exp-1 0.002      6.00   1.390     20.8  95.90 160.00   0.230     0.25
## 2015-dep-exp-2 0.002      5.50   0.540     19.1 161.00 141.00   0.130     0.25
## 2015-dep-exp-3 0.002     14.10   0.570     36.6 514.00 136.00   0.120     0.25
## 2015-dep-exp-4 0.002      5.20   0.460     22.5 139.00  48.90   0.080     0.25
## 2015-dep-exp-5 0.002      5.90   1.120     26.3 196.00 109.00   0.250     0.60
## 2015-dep-exp-6 0.002      4.10   0.520     20.7 176.00  52.80   0.170     0.25
## 2015-dep-exp-7 0.002      3.60   2.810     31.2  36.00  91.90   0.140     0.25
## 2015-dep-ref-1 0.002      0.90   0.190     11.9   5.40   6.80   0.050     0.25
## 2015-dep-ref-2 0.002      1.00   0.170     10.0   5.10   7.30   0.025     0.25
## 2015-dep-ref-3 0.002      0.80   0.110     15.6   5.10   7.00   0.025     0.25
## 2018-dep-exp-1 6.3e-05   23.60   4.630     45.5 243.00 526.00   1.150     1.57
## 2018-dep-exp-1 0.002      8.66   1.680     21.7 188.00 194.00   0.133     0.43
## 2018-dep-exp-2 6.3e-05   37.40  10.200     56.2 681.00 900.00   7.410     8.73
## 2018-dep-exp-2 0.002     11.00   2.150     38.7 467.00 220.00   0.550     1.82
## 2018-dep-exp-3 6.3e-05   16.00   2.030     34.4 416.00 221.00   1.900     0.64
## 2018-dep-exp-3 0.002     11.10   0.361     26.6 251.00  71.80   0.042     0.21
## 2018-dep-exp-4 6.3e-05    7.05   1.760     29.1 109.00  84.60   0.415     0.39
## 2018-dep-exp-4 0.002      6.76   1.410     30.2 322.00  70.40   0.106     0.37
## 2018-dep-exp-5 6.3e-05   23.70   7.400     44.7 408.00 543.00   5.210     4.12
## 2018-dep-exp-5 0.002      7.88   1.530     29.3 315.00 129.00   0.245     0.63
## 2018-dep-exp-6 6.3e-05   10.50   2.150     34.3 158.00 134.00   0.879     0.60
## 2018-dep-exp-6 0.002      6.64   0.573     21.9 165.00  56.00   0.076     0.22
## 2018-dep-exp-7 6.3e-05    6.79   2.480     27.1  43.80 116.00   0.423     0.45
## 2018-dep-exp-7 0.002      3.63   1.420     28.6  46.90  61.90   0.054     0.22
## 2018-dep-ref-1 6.3e-05    2.46   0.585     23.9  13.60  12.60   0.020     0.42
## 2018-dep-ref-1 0.002      1.38   0.208     14.4   5.40   6.26   0.020     0.10
## 2018-dep-ref-2 6.3e-05    2.22   0.581     21.1  12.40  10.70   0.055     0.30
## 2018-dep-ref-2 0.002      1.07   0.248     10.9   5.89   7.19   0.020     0.10
## 2018-dep-ref-3 6.3e-05    2.78   0.573     26.5  14.20  15.50   0.185     0.29
## 2018-dep-ref-3 0.002      1.27   0.165     13.6   5.38   5.54   0.020     0.10
##                        Thallium   Zinc
## 2012-dep-exp-1 0.002        0.40  650.0
## 2012-dep-exp-2 0.002        0.05 4200.0
## 2012-dep-exp-3 0.002        0.20 2200.0
## 2012-dep-exp-4 0.002        0.10  930.0
## 2012-dep-exp-5 0.002        0.20 2400.0
## 2012-dep-exp-6 0.002        0.20 1400.0
## 2012-dep-exp-7 0.002        0.20  780.0
## 2012-dep-ref-1 0.002        0.05   71.0
## 2012-dep-ref-2 0.002        0.05   70.0
## 2012-dep-ref-3 0.002        0.05   38.0
## 2015-dep-exp-1 0.002        0.30  645.0
## 2015-dep-exp-2 0.002        0.05 1190.0
## 2015-dep-exp-3 0.002        0.05 2550.0
## 2015-dep-exp-4 0.002        0.10  770.0
## 2015-dep-exp-5 0.002        0.20 1160.0
## 2015-dep-exp-6 0.002        0.20  793.0
## 2015-dep-exp-7 0.002        0.20  594.0
## 2015-dep-ref-1 0.002        0.05   59.0
## 2015-dep-ref-2 0.002        0.05   48.0
## 2015-dep-ref-3 0.002        0.05   31.0
## 2018-dep-exp-1 6.3e-05      0.48 1400.0
## 2018-dep-exp-1 0.002        0.25 1100.0
```

```
## 2018-dep-exp-2 6.3e-05     1.25 4380.0
## 2018-dep-exp-2 0.002       0.37 3790.0
## 2018-dep-exp-3 6.3e-05     0.22 1200.0
## 2018-dep-exp-3 0.002       0.05  949.0
## 2018-dep-exp-4 6.3e-05     0.18  697.0
## 2018-dep-exp-4 0.002       0.20 1800.0
## 2018-dep-exp-5 6.3e-05     0.89 2660.0
## 2018-dep-exp-5 0.002       0.22 2160.0
## 2018-dep-exp-6 6.3e-05     0.20  803.0
## 2018-dep-exp-6 0.002       0.14  902.0
## 2018-dep-exp-7 6.3e-05     0.18  482.0
## 2018-dep-exp-7 0.002       0.15  506.0
## 2018-dep-ref-1 6.3e-05     0.10   96.2
## 2018-dep-ref-1 0.002       0.05   60.8
## 2018-dep-ref-2 6.3e-05     0.05   78.2
## 2018-dep-ref-2 0.002       0.05   64.9
## 2018-dep-ref-3 6.3e-05     0.05   92.5
## 2018-dep-ref-3 0.002       0.05   56.2
```

Check Shapiro

For 2mm (2012, 2015, 2018-2mm)

```
shapChecker <- function(df_) {
  data.frame(t(apply(df_, 2, function(x){
    res = shapiro.test(x)
    return(unlist(res[names(res)[1:3]]))
  })), stringsAsFactors = FALSE)
}

shap2mm <- shapChecker(seds2mm)

shap2mm
```

```
##                statistic.W              p.value                      method
## Arsenic  0.922267625175274   0.0307237200119629 Shapiro-Wilk normality test
## Cadmium  0.881853725087408  0.00311036551822731 Shapiro-Wilk normality test
## Chromium 0.966022774960039    0.436810611487647 Shapiro-Wilk normality test
## Copper    0.86922537018697  0.00161011213619583 Shapiro-Wilk normality test
## Lead     0.917115865747217   0.0225912740286698 Shapiro-Wilk normality test
## Mercury  0.802316559210049 7.22733051712454e-05 Shapiro-Wilk normality test
## Selenium 0.769896319214142 1.94207160951879e-05 Shapiro-Wilk normality test
## Thallium 0.825366740105936  0.00019712488453015 Shapiro-Wilk normality test
## Zinc     0.838212617644639 0.000354701019498722 Shapiro-Wilk normality test
```

Some departures from normality. Check with log transformation, and sqrt

```
violators <- (shap2mm %>%
  rownames_to_column("analyte") %>%
```

```
  filter(as.numeric(p.value) < 0.05) %>%
  select(analyte))[,1]

violators
```

```
## [1] "Arsenic"  "Cadmium"  "Copper"   "Lead"     "Mercury"  "Selenium" "Thallium"
## [8] "Zinc"
```

Filter for violating analytes

```
toTrans <- seds2mm %>%
  select(one_of(violators))

toTrans
```

```
##                Arsenic Cadmium Copper   Lead Mercury Selenium Thallium   Zinc
## 2012-dep-exp-1    7.10   1.700 120.00 170.00   0.190     0.60     0.40  650.0
## 2012-dep-exp-2   14.00   0.500 670.00 100.00   0.120     1.00     0.05 4200.0
## 2012-dep-exp-3   11.00   1.100 370.00 160.00   0.210     0.80     0.20 2200.0
## 2012-dep-exp-4    7.00   0.500 180.00  62.00   0.080     0.01     0.10  930.0
## 2012-dep-exp-5    9.60   1.100 320.00 130.00   0.160     0.80     0.20 2400.0
## 2012-dep-exp-6    5.90   0.710 250.00  83.00   0.070     0.60     0.20 1400.0
## 2012-dep-exp-7    4.90   1.200 100.00  73.00   0.050     0.01     0.20  780.0
## 2012-dep-ref-1    0.80   0.230   5.80   7.80   0.001     0.01     0.05   71.0
## 2012-dep-ref-2    1.10   0.300   6.30   9.90   0.001     0.01     0.05   70.0
## 2012-dep-ref-3    0.60   0.090   4.00   4.90   0.001     0.01     0.05   38.0
## 2015-dep-exp-1    6.00   1.390  95.90 160.00   0.230     0.25     0.30  645.0
## 2015-dep-exp-2    5.50   0.540 161.00 141.00   0.130     0.25     0.05 1190.0
## 2015-dep-exp-3   14.10   0.570 514.00 136.00   0.120     0.25     0.05 2550.0
## 2015-dep-exp-4    5.20   0.460 139.00  48.90   0.080     0.25     0.10  770.0
## 2015-dep-exp-5    5.90   1.120 196.00 109.00   0.250     0.60     0.20 1160.0
## 2015-dep-exp-6    4.10   0.520 176.00  52.80   0.170     0.25     0.20  793.0
## 2015-dep-exp-7    3.60   2.810  36.00  91.90   0.140     0.25     0.20  594.0
## 2015-dep-ref-1    0.90   0.190   5.40   6.80   0.050     0.25     0.05   59.0
## 2015-dep-ref-2    1.00   0.170   5.10   7.30   0.025     0.25     0.05   48.0
## 2015-dep-ref-3    0.80   0.110   5.10   7.00   0.025     0.25     0.05   31.0
## 2018-dep-exp-1    8.66   1.680 188.00 194.00   0.133     0.43     0.25 1100.0
## 2018-dep-exp-2   11.00   2.150 467.00 220.00   0.550     1.82     0.37 3790.0
## 2018-dep-exp-3   11.10   0.361 251.00  71.80   0.042     0.21     0.05  949.0
## 2018-dep-exp-4    6.76   1.410 322.00  70.40   0.106     0.37     0.20 1800.0
## 2018-dep-exp-5    7.88   1.530 315.00 129.00   0.245     0.63     0.22 2160.0
## 2018-dep-exp-6    6.64   0.573 165.00  56.00   0.076     0.22     0.14  902.0
## 2018-dep-exp-7    3.63   1.420  46.90  61.90   0.054     0.22     0.15  506.0
## 2018-dep-ref-1    1.38   0.208   5.40   6.26   0.020     0.10     0.05   60.8
## 2018-dep-ref-2    1.07   0.248   5.89   7.19   0.020     0.10     0.05   64.9
## 2018-dep-ref-3    1.27   0.165   5.38   5.54   0.020     0.10     0.05   56.2
```

Rerun shapiro test with transformations

```
shapTransformChecker <- function(df_) {
  df_ <- data.frame(apply(df_, 2, function(x) {
    noTrans = shapiro.test(x)
    resLog = shapiro.test(log10(x))
    resSqrt = shapiro.test(sqrt(x))
    resSqr = shapiro.test(x^2)
    resRecip = shapiro.test(1/x)
    resExp = shapiro.test(exp(x))

    y = as.numeric(x)

    lenLogi = all(y > 0 & y < 1)

    print(lenLogi)

    if (lenLogi > 3) {
      resArc = shapiro.test(asin(sqrt(x)))
    } else {
      resArc = NA
    }


    out <-
      data.frame(
        noTrans = unlist(noTrans),
        logTrans = unlist(resLog),
        sqrtTrans = unlist(resSqrt),
        sqrTrans = unlist(resSqr),
        recipTrans = unlist(resRecip),
        expTrans = unlist(resExp),
        arcTrans = unlist(resArc)
        )
    return(out)
  }), stringsAsFactors = FALSE) #%>%
  # rownames_to_column("metric")# %>%
  # gather(key, value, -metric)
  newColNames <- rownames(df_)
  newRowNames <- colnames(df_)

    tdf <- transpose(df_)
  names(tdf) <- newColNames
  rownames(tdf) <- newRowNames

  tdf <- tdf %>% rownames_to_column(var = "analyte") %>%
    mutate(analyte = gsub("\\..*", "", analyte))

  return(tdf)
}

shap2mmTransform <- shapTransformChecker(toTrans)
```

```
## [1] FALSE
## [1] FALSE
```

```
## [1] FALSE
## [1] FALSE
## [1] TRUE
## [1] FALSE
## [1] TRUE
## [1] FALSE
```

```
shap2mmTransform
```

```
##     analyte       statistic.W              p.value                      method
## 1   Arsenic 0.922267625175274   0.0307237200119629 Shapiro-Wilk normality test
## 2   Arsenic 0.877691394460626  0.00249633573150726 Shapiro-Wilk normality test
## 3   Arsenic 0.925706662432565   0.0378090678045172 Shapiro-Wilk normality test
## 4   Arsenic 0.797353006569579 5.86904905707444e-05 Shapiro-Wilk normality test
## 5   Arsenic 0.745154368460901 7.61149181751914e-06 Shapiro-Wilk normality test
## 6   Arsenic 0.309761465592363 8.53275961357887e-11 Shapiro-Wilk normality test
## 7   Arsenic              <NA>                 <NA>                        <NA>
## 8   Cadmium 0.881853725087408  0.00311036551822731 Shapiro-Wilk normality test
## 9   Cadmium 0.958102935890069    0.276825235038072 Shapiro-Wilk normality test
## 10  Cadmium 0.947083584144167    0.141163718660792 Shapiro-Wilk normality test
## 11  Cadmium 0.685974989185053 9.81454932602564e-07 Shapiro-Wilk normality test
## 12  Cadmium 0.787310102793917  3.8823785392984e-05 Shapiro-Wilk normality test
## 13  Cadmium 0.614985484281849  1.1176465137952e-07 Shapiro-Wilk normality test
## 14  Cadmium              <NA>                 <NA>                        <NA>
## 15   Copper  0.86922537018697  0.00161011213619583 Shapiro-Wilk normality test
## 16   Copper 0.828967692779905 0.000231913483086182 Shapiro-Wilk normality test
## 17   Copper 0.916513995227668   0.0218002324766021 Shapiro-Wilk normality test
## 18   Copper 0.636016599897667 2.06925169483465e-07 Shapiro-Wilk normality test
## 19   Copper 0.667710251375561 5.46518640106387e-07 Shapiro-Wilk normality test
## 20   Copper 0.179615252483381 7.76637672584594e-12 Shapiro-Wilk normality test
## 21   Copper              <NA>                 <NA>                        <NA>
## 22     Lead 0.917115865747217   0.0225912740286698 Shapiro-Wilk normality test
## 23     Lead 0.828996178240984 0.000232213358981591 Shapiro-Wilk normality test
## 24     Lead 0.905632929122083   0.0115664130794796 Shapiro-Wilk normality test
## 25     Lead 0.804020944082125 7.76769075779759e-05 Shapiro-Wilk normality test
## 26     Lead 0.695633448738366 1.34870265527694e-06 Shapiro-Wilk normality test
## 27     Lead 0.179615252484767 7.76637672603273e-12 Shapiro-Wilk normality test
## 28     Lead              <NA>                 <NA>                        <NA>
## 29  Mercury 0.802316559210049 7.22733051712454e-05 Shapiro-Wilk normality test
## 30  Mercury 0.827316034238414 0.000215210085990214 Shapiro-Wilk normality test
## 31  Mercury 0.965260124907435    0.418802075383921 Shapiro-Wilk normality test
## 32  Mercury 0.435154447861089 1.17816107571408e-09 Shapiro-Wilk normality test
## 33  Mercury  0.38510411626545  3.9563528359793e-10 Shapiro-Wilk normality test
## 34  Mercury 0.725436945730848 3.74039566580745e-06 Shapiro-Wilk normality test
## 35  Mercury              <NA>                 <NA>                        <NA>
## 36 Selenium 0.769896319214142 1.94207160951879e-05 Shapiro-Wilk normality test
## 37 Selenium 0.830470546869527 0.000248310864915508 Shapiro-Wilk normality test
## 38 Selenium 0.925973575532745   0.0384256826549496 Shapiro-Wilk normality test
## 39 Selenium 0.441996439332278 1.37454622895757e-09 Shapiro-Wilk normality test
## 40 Selenium 0.505439439420905 6.11978564581107e-09 Shapiro-Wilk normality test
## 41 Selenium 0.523721423173238  9.6327180490395e-09 Shapiro-Wilk normality test
## 42 Selenium              <NA>                 <NA>                        <NA>
## 43 Thallium 0.825366740105936  0.00019712488453015 Shapiro-Wilk normality test
## 44 Thallium 0.809045897429996 9.62567530860643e-05 Shapiro-Wilk normality test
```

```
## 45 Thallium 0.831659845531881 0.000262158794091281 Shapiro-Wilk normality test
## 46 Thallium 0.716125066780228 2.70157025160958e-06 Shapiro-Wilk normality test
## 47 Thallium  0.73739073260309 5.73337999646998e-06 Shapiro-Wilk normality test
## 48 Thallium 0.814276211293667 0.000120698883147288 Shapiro-Wilk normality test
## 49 Thallium              <NA>                 <NA>                        <NA>
## 50     Zinc 0.838212617644639 0.000354701019498722 Shapiro-Wilk normality test
## 51     Zinc 0.865634739181274  0.00134149554823743 Shapiro-Wilk normality test
## 52     Zinc 0.925216194805859   0.0367026445711844 Shapiro-Wilk normality test
## 53     Zinc 0.592077108053476 5.84969342347126e-08 Shapiro-Wilk normality test
## 54     Zinc 0.692501820533717  1.2158358066221e-06 Shapiro-Wilk normality test
## 55     Zinc               NaN                  NaN Shapiro-Wilk normality test
## 56     Zinc              <NA>                 <NA>                        <NA>
##    data.name
## 1          x
## 2   log10(x)
## 3    sqrt(x)
## 4        x^2
## 5        1/x
## 6     exp(x)
## 7       <NA>
## 8          x
## 9   log10(x)
## 10   sqrt(x)
## 11       x^2
## 12       1/x
## 13    exp(x)
## 14      <NA>
## 15         x
## 16  log10(x)
## 17   sqrt(x)
## 18       x^2
## 19       1/x
## 20    exp(x)
## 21      <NA>
## 22         x
## 23  log10(x)
## 24   sqrt(x)
## 25       x^2
## 26       1/x
## 27    exp(x)
## 28      <NA>
## 29         x
## 30  log10(x)
## 31   sqrt(x)
## 32       x^2
## 33       1/x
## 34    exp(x)
## 35      <NA>
## 36         x
## 37  log10(x)
## 38   sqrt(x)
## 39       x^2
## 40       1/x
## 41    exp(x)
```

```
## 42      <NA>
## 43         x
## 44  log10(x)
## 45   sqrt(x)
## 46       x^2
## 47       1/x
## 48    exp(x)
## 49      <NA>
## 50         x
## 51  log10(x)
## 52   sqrt(x)
## 53       x^2
## 54       1/x
## 55    exp(x)
## 56      <NA>
```

Pull out effective transformations

```
shap2mmTransform %>% filter(as.numeric(p.value) > 0.05)
```

```
##   analyte       statistic.W           p.value                      method
## 1 Cadmium 0.958102935890069 0.276825235038072 Shapiro-Wilk normality test
## 2 Cadmium 0.947083584144167 0.141163718660792 Shapiro-Wilk normality test
## 3 Mercury 0.965260124907435 0.418802075383921 Shapiro-Wilk normality test
##   data.name
## 1  log10(x)
## 2   sqrt(x)
## 3   sqrt(x)
```

Transform Cadmium and Mercury according to the appropriate transformations

```
seds2mm$Cadmium <- log10(seds2mm$Cadmium)
seds2mm$Mercury <- sqrt(seds2mm$Mercury)
```

For all samples, all years

```
shapAll <- shapChecker(sedsAll)
shapAll
```

```
##                statistic.W               p.value                      method
## Arsenic   0.78282411046024 3.02774779020635e-06 Shapiro-Wilk normality test
## Cadmium  0.613364473430415 4.78361342983019e-09 Shapiro-Wilk normality test
## Chromium 0.962412158187357    0.202364425340044 Shapiro-Wilk normality test
## Copper    0.86024838362152 0.000161126880971918 Shapiro-Wilk normality test
## Lead     0.628783922752634 7.90279710830037e-09 Shapiro-Wilk normality test
## Mercury  0.382739302437782 8.91926237329066e-12 Shapiro-Wilk normality test
## Selenium 0.416562294454812 1.99957533078252e-11 Shapiro-Wilk normality test
## Thallium 0.610522894440252 4.36715460176784e-09 Shapiro-Wilk normality test
## Zinc     0.822952852353462 2.11518287526166e-05 Shapiro-Wilk normality test
```

Almost all violate assumptions of normality (save for Chromium). Try a slew of transformations

Rerun shapiro with a variety of transformations

```
shapAllTransform <- shapTransformChecker(sedsAll)
```

```
## [1] FALSE
## [1] FALSE
## [1] FALSE
## [1] FALSE
## [1] FALSE
## [1] FALSE
## [1] FALSE
## [1] FALSE
## [1] FALSE
```

```
shapAllTransform
```

```
##     analyte       statistic.W              p.value                      method
## 1   Arsenic  0.78282411046024 3.02774779020635e-06 Shapiro-Wilk normality test
## 2   Arsenic 0.951074192782039   0.0825706519382216 Shapiro-Wilk normality test
## 3   Arsenic 0.937812416472195   0.0291965171216729 Shapiro-Wilk normality test
## 4   Arsenic 0.458848695641011 5.75060069347352e-11 Shapiro-Wilk normality test
## 5   Arsenic 0.735888742741288 3.98292462268763e-07 Shapiro-Wilk normality test
## 6   Arsenic 0.147031386042912 6.63994245578217e-14 Shapiro-Wilk normality test
## 7   Arsenic              <NA>                 <NA>                        <NA>
## 8   Cadmium 0.613364473430415 4.78361342983019e-09 Shapiro-Wilk normality test
## 9   Cadmium 0.981062061673135    0.728874772033741 Shapiro-Wilk normality test
## 10  Cadmium 0.851557786294791 9.81700033512879e-05 Shapiro-Wilk normality test
## 11  Cadmium 0.336573177556338 3.11062762472805e-12 Shapiro-Wilk normality test
## 12  Cadmium 0.749445383723317 6.98920810150854e-07 Shapiro-Wilk normality test
## 13  Cadmium 0.161659012128103 8.72944193218351e-14 Shapiro-Wilk normality test
## 14  Cadmium              <NA>                 <NA>                        <NA>
## 15 Chromium 0.962412158187357    0.202364425340044 Shapiro-Wilk normality test
## 16 Chromium 0.984107609078972    0.836056139759614 Shapiro-Wilk normality test
## 17 Chromium 0.987985170415235    0.941440947020392 Shapiro-Wilk normality test
## 18 Chromium 0.841257313344343 5.55756056510419e-05 Shapiro-Wilk normality test
## 19 Chromium 0.900388015578874  0.00196209476623998 Shapiro-Wilk normality test
## 20 Chromium 0.147038015868654 6.64076076231977e-14 Shapiro-Wilk normality test
## 21 Chromium              <NA>                 <NA>                        <NA>
## 22   Copper  0.86024838362152 0.000161126880971918 Shapiro-Wilk normality test
## 23   Copper 0.865945266969127 0.000224781157570306 Shapiro-Wilk normality test
## 24   Copper 0.925490033859286   0.0115079587859075 Shapiro-Wilk normality test
## 25   Copper 0.638268331618323 1.08347404740213e-08 Shapiro-Wilk normality test
## 26   Copper 0.672880833530897 3.59304793782194e-08 Shapiro-Wilk normality test
## 27   Copper 0.147034713677455 6.64035316608055e-14 Shapiro-Wilk normality test
## 28   Copper              <NA>                 <NA>                        <NA>
## 29     Lead 0.628783922752634 7.90279710830037e-09 Shapiro-Wilk normality test
## 30     Lead 0.913697801590334  0.00490637805620298 Shapiro-Wilk normality test
## 31     Lead 0.871172732491399 0.000306911044035495 Shapiro-Wilk normality test
## 32     Lead 0.336236848144926 3.08744073747064e-12 Shapiro-Wilk normality test
```

```
## 33     Lead 0.708522185576776 1.34699945642886e-07 Shapiro-Wilk normality test
## 34     Lead               NaN                  NaN Shapiro-Wilk normality test
## 35     Lead              <NA>                 <NA>                        <NA>
## 36  Mercury 0.382739302437782 8.91926237329066e-12 Shapiro-Wilk normality test
## 37  Mercury 0.938463619627986    0.030701475558589 Shapiro-Wilk normality test
## 38  Mercury 0.648564562280412 1.53544707956723e-08 Shapiro-Wilk normality test
## 39  Mercury 0.249890274098743 4.91324572575007e-13 Shapiro-Wilk normality test
## 40  Mercury 0.336544399615037 3.10863652507236e-12 Shapiro-Wilk normality test
## 41  Mercury 0.172370893280604 1.06894726084409e-13 Shapiro-Wilk normality test
## 42  Mercury              <NA>                 <NA>                        <NA>
## 43 Selenium 0.416562294454812 1.99957533078252e-11 Shapiro-Wilk normality test
## 44 Selenium 0.879261108354297 0.000502763043645358 Shapiro-Wilk normality test
## 45 Selenium 0.734368317686705 3.74356410394193e-07 Shapiro-Wilk normality test
## 46 Selenium 0.217024997382107 2.53972788898289e-13 Shapiro-Wilk normality test
## 47 Selenium 0.447834520415199 4.34409068208895e-11 Shapiro-Wilk normality test
## 48 Selenium 0.149677461843238 6.97507253002708e-14 Shapiro-Wilk normality test
## 49 Selenium              <NA>                 <NA>                        <NA>
## 50 Thallium 0.610522894440252 4.36715460176784e-09 Shapiro-Wilk normality test
## 51 Thallium 0.864339044634494  0.00020450363124278 Shapiro-Wilk normality test
## 52 Thallium  0.79120775258207 4.46472039800098e-06 Shapiro-Wilk normality test
## 53 Thallium 0.339289109946122 3.30468649111598e-12 Shapiro-Wilk normality test
## 54 Thallium 0.766567239716525 1.46010034916531e-06 Shapiro-Wilk normality test
## 55 Thallium 0.469014329952192 7.47593014398745e-11 Shapiro-Wilk normality test
## 56 Thallium              <NA>                 <NA>                        <NA>
## 57     Zinc 0.822952852353462 2.11518287526166e-05 Shapiro-Wilk normality test
## 58     Zinc 0.886299956092517  0.00078191602073473 Shapiro-Wilk normality test
## 59     Zinc 0.926357165469653   0.0122710251776188 Shapiro-Wilk normality test
## 60     Zinc 0.580326717718719 1.70246597523304e-09 Shapiro-Wilk normality test
## 61     Zinc 0.695772205781097 8.30378269415843e-08 Shapiro-Wilk normality test
## 62     Zinc               NaN                  NaN Shapiro-Wilk normality test
## 63     Zinc              <NA>                 <NA>                        <NA>
##    data.name
## 1          x
## 2   log10(x)
## 3    sqrt(x)
## 4        x^2
## 5        1/x
## 6     exp(x)
## 7       <NA>
## 8          x
## 9   log10(x)
## 10   sqrt(x)
## 11       x^2
## 12       1/x
## 13    exp(x)
## 14      <NA>
## 15         x
## 16  log10(x)
## 17   sqrt(x)
## 18       x^2
## 19       1/x
## 20    exp(x)
## 21      <NA>
## 22         x
```

```
## 23  log10(x)
## 24   sqrt(x)
## 25       x^2
## 26       1/x
## 27    exp(x)
## 28      <NA>
## 29         x
## 30  log10(x)
## 31   sqrt(x)
## 32       x^2
## 33       1/x
## 34    exp(x)
## 35      <NA>
## 36         x
## 37  log10(x)
## 38   sqrt(x)
## 39       x^2
## 40       1/x
## 41    exp(x)
## 42      <NA>
## 43         x
## 44  log10(x)
## 45   sqrt(x)
## 46       x^2
## 47       1/x
## 48    exp(x)
## 49      <NA>
## 50         x
## 51  log10(x)
## 52   sqrt(x)
## 53       x^2
## 54       1/x
## 55    exp(x)
## 56      <NA>
## 57         x
## 58  log10(x)
## 59   sqrt(x)
## 60       x^2
## 61       1/x
## 62    exp(x)
## 63      <NA>
```

Pull out any effective transformations

```
shapAllTransform %>% filter(as.numeric(p.value) > 0.05)
```

```
##    analyte       statistic.W            p.value                      method
## 1  Arsenic 0.951074192782039 0.0825706519382216 Shapiro-Wilk normality test
## 2  Cadmium 0.981062061673135  0.728874772033741 Shapiro-Wilk normality test
## 3 Chromium 0.962412158187357  0.202364425340044 Shapiro-Wilk normality test
## 4 Chromium 0.984107609078972  0.836056139759614 Shapiro-Wilk normality test
## 5 Chromium 0.987985170415235  0.941440947020392 Shapiro-Wilk normality test
```

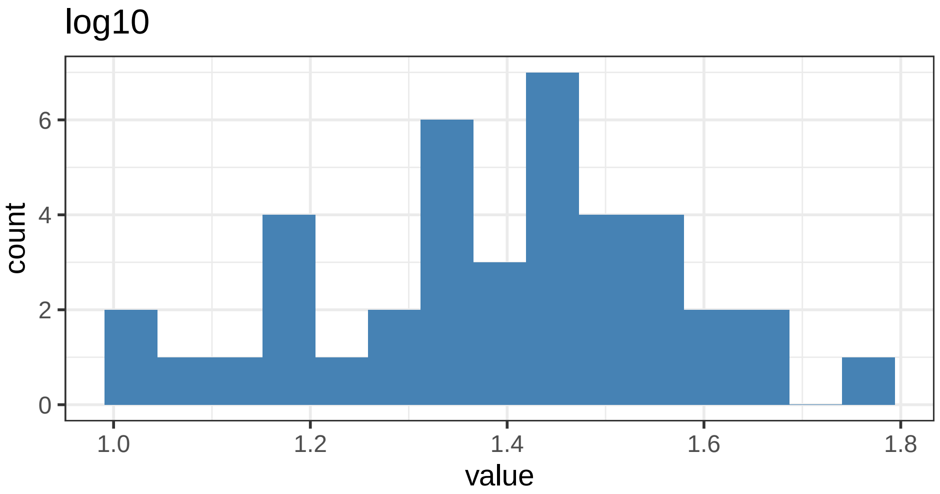
```
##   data.name
## 1  log10(x)
## 2  log10(x)
## 3         x
## 4  log10(x)
## 5   sqrt(x)
```

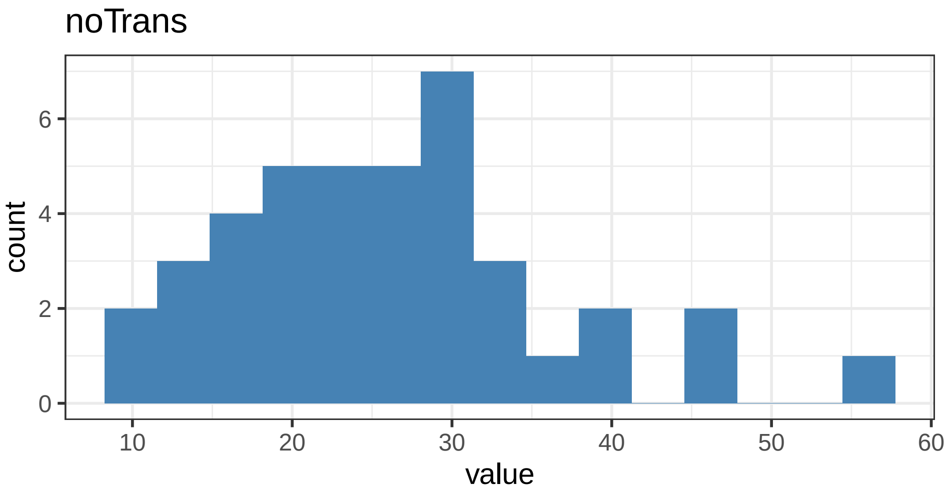
Only Arsenic and Cadmium can be transformed. Chromium is also potentially improved- check histogram for a visual check.

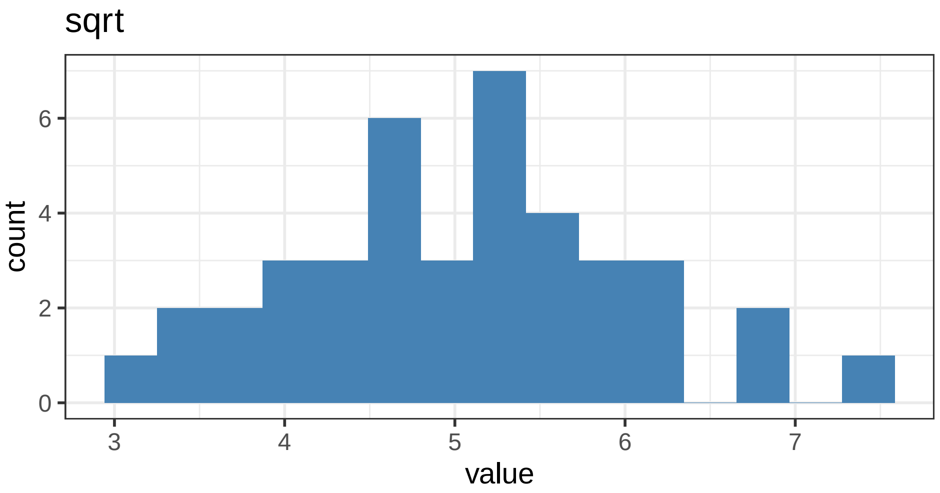
```
toHist <- data.frame(
  noTrans = sedsAll$Chromium,
  log10 = log10(sedsAll$Chromium),
  sqrt = sqrt(sedsAll$Chromium)
) %>%
  gather(transformation, value)
```

```
plotList <- dlply(toHist, "transformation", function(df_) {
  ttl = unique(df_$transformation)
  p <- ggplot(df_, aes(x = value)) +
    geom_histogram(bins = 15, fill = "steelblue") +
    ggplot2::ggtitle(label = ttl) + theme_bw()
})

threePlots <- lapply(plotList, ggplotGrob)

threePlots <- do.call(rbind, threePlots)
```

```
grid.newpage()
grid.draw(threePlots)
```







Somewhat subjective, but the sqrt transformation appears closes to normal visually. This is supported by a high p-value in the shapiro wilks test for that transformation.

Transform Arsenic, Cadmium, Chromium

```
shapAllTransform %>% filter(as.numeric(p.value) > 0.05)
```

```
##    analyte       statistic.W            p.value                      method
## 1  Arsenic 0.951074192782039 0.0825706519382216 Shapiro-Wilk normality test
## 2  Cadmium 0.981062061673135  0.728874772033741 Shapiro-Wilk normality test
## 3 Chromium 0.962412158187357  0.202364425340044 Shapiro-Wilk normality test
## 4 Chromium 0.984107609078972  0.836056139759614 Shapiro-Wilk normality test
## 5 Chromium 0.987985170415235  0.941440947020392 Shapiro-Wilk normality test
##   data.name
## 1  log10(x)
## 2  log10(x)
## 3         x
## 4  log10(x)
## 5   sqrt(x)
```

```
sedsAll$Arsenic <- log10(sedsAll$Arsenic)
sedsAll$Cadmium <- log10(sedsAll$Cadmium)
sedsAll$Chromium <- sqrt(sedsAll$Chromium)
```

Standardize values

2mm

```
seds2mmStd <- data.frame(apply(seds2mm, 2, function(col) {
  mCol = mean(col)
  sdCol = sd(col)

  z = (col - mCol) / sdCol
}))
```

All

```
sedsAllStd <- data.frame(apply(sedsAll, 2, function(col) {
  mCol = mean(col)
  sdCol = sd(col)

  z = (col - mCol) / sdCol
}))
```

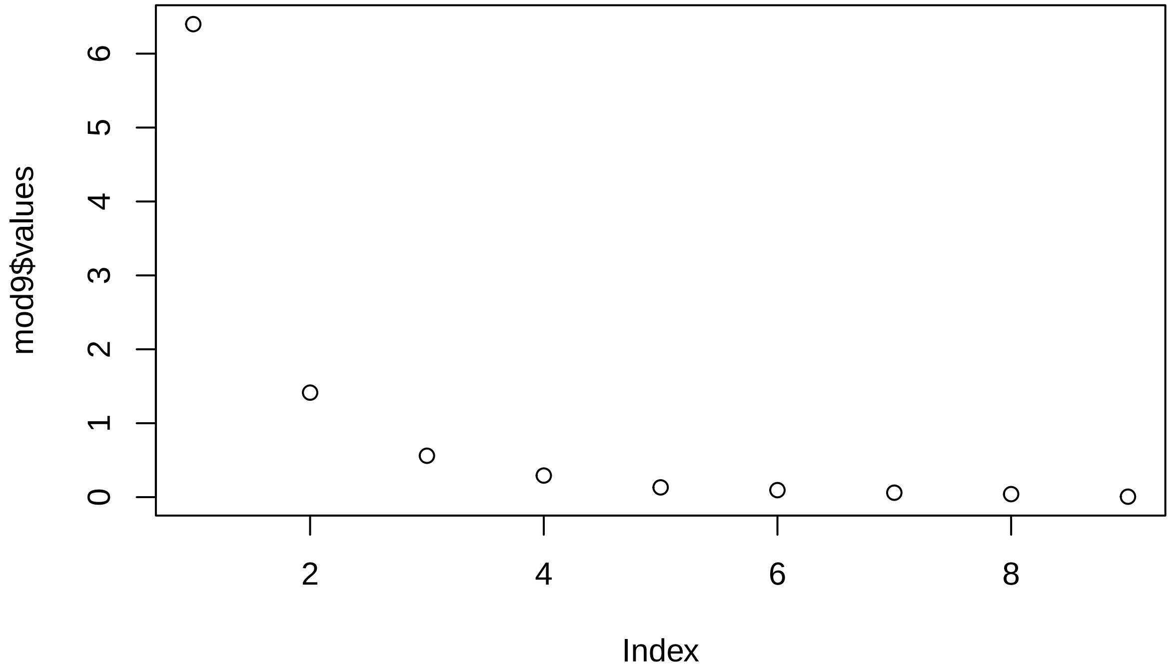
Run PCA

For 2mm fractions only

```
mod9 = principal(seds2mmStd, nfactors = 9, scores = TRUE)
round(mod9$values, 1)
```

```
## [1] 6.4 1.4 0.6 0.3 0.1 0.1 0.1 0.0 0.0
```

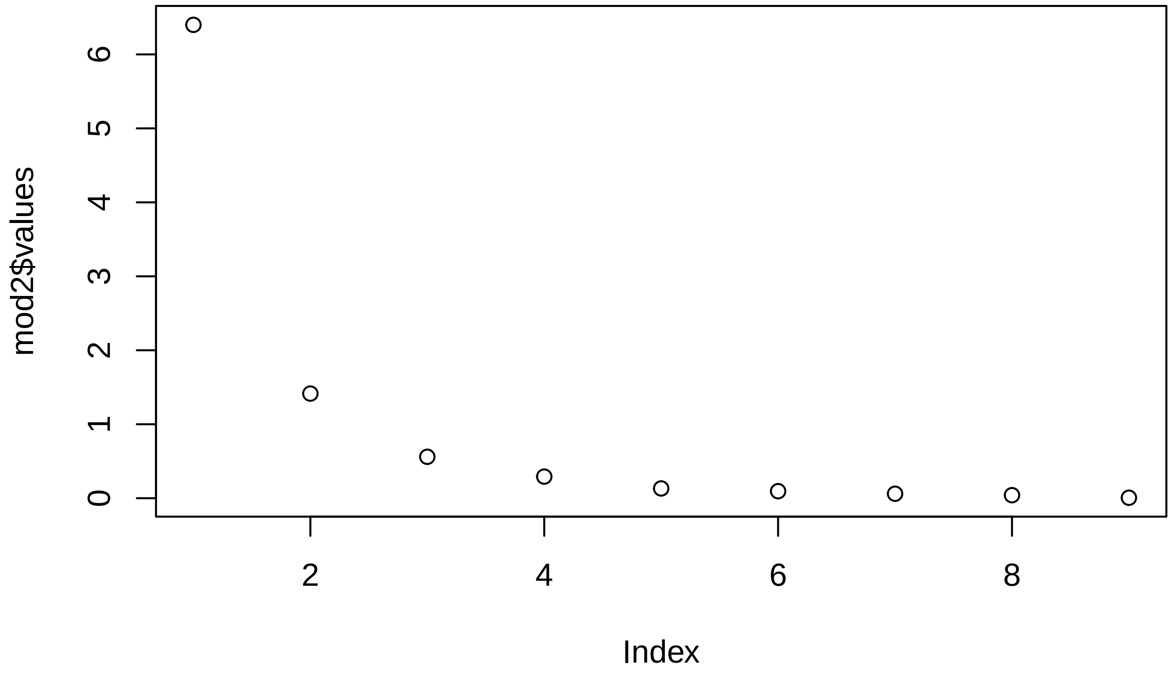
```
plot(mod9$values)
```



```
mod2 <- principal(seds2mmStd, nfactors = 2, scores = TRUE)
round(mod2$values, 1)
```

```
## [1] 6.4 1.4 0.6 0.3 0.1 0.1 0.1 0.0 0.0
```

```
plot(mod2$values)
```



Output

Loadings

```
outDir <- "M:/Projects/2018/18-2411.1 - Teck AREMP - Interpretation/Data_AREMP/Sediment_Quality/WD5_PCA

seds2mmLoadings <- data.frame(matrix(
  as.numeric(mod2$loadings),
  attributes(mod2$loadings)$dim,
  dimnames = attributes(mod2$loadings)$dimnames
))

write.csv(seds2mmLoadings, paste0(outDir, "loadings_sed_2mm_2019.csv"))
```

Scores

```
df1.2mm <- data.frame(label1 = rownames(seds2mmStd), round(mod2$scores[, c(1:2)], 2))
df1.2mm
```

```
##                         label1   RC1   RC2
## 2012-dep-exp-1 2012-dep-exp-1 -0.91  2.16
```

```
## 2012-dep-exp-2 2012-dep-exp-2  3.13 -1.36
## 2012-dep-exp-3 2012-dep-exp-3  1.11  0.58
## 2012-dep-exp-4 2012-dep-exp-4  0.10 -0.41
## 2012-dep-exp-5 2012-dep-exp-5  0.96  0.45
## 2012-dep-exp-6 2012-dep-exp-6  0.22  0.19
## 2012-dep-exp-7 2012-dep-exp-7 -0.29  0.37
## 2012-dep-ref-1 2012-dep-ref-1 -0.76 -1.01
## 2012-dep-ref-2 2012-dep-ref-2 -0.85 -0.90
## 2012-dep-ref-3 2012-dep-ref-3 -0.75 -1.32
## 2015-dep-exp-1 2015-dep-exp-1 -0.83  1.67
## 2015-dep-exp-2 2015-dep-exp-2  0.06 -0.09
## 2015-dep-exp-3 2015-dep-exp-3  2.10 -0.95
## 2015-dep-exp-4 2015-dep-exp-4 -0.09 -0.33
## 2015-dep-exp-5 2015-dep-exp-5 -0.01  0.88
## 2015-dep-exp-6 2015-dep-exp-6 -0.39  0.35
## 2015-dep-exp-7 2015-dep-exp-7 -0.68  1.14
## 2015-dep-ref-1 2015-dep-ref-1 -0.85 -0.71
## 2015-dep-ref-2 2015-dep-ref-2 -0.87 -0.83
## 2015-dep-ref-3 2015-dep-ref-3 -0.69 -1.01
## 2018-dep-exp-1 2018-dep-exp-1 -0.19  1.28
## 2018-dep-exp-2 2018-dep-exp-2  1.69  2.04
## 2018-dep-exp-3 2018-dep-exp-3  0.80 -0.97
## 2018-dep-exp-4 2018-dep-exp-4  0.49  0.26
## 2018-dep-exp-5 2018-dep-exp-5  0.61  0.84
## 2018-dep-exp-6 2018-dep-exp-6 -0.05 -0.14
## 2018-dep-exp-7 2018-dep-exp-7 -0.53  0.37
## 2018-dep-ref-1 2018-dep-ref-1 -0.79 -0.85
## 2018-dep-ref-2 2018-dep-ref-2 -0.92 -0.76
## 2018-dep-ref-3 2018-dep-ref-3 -0.80 -0.93
```

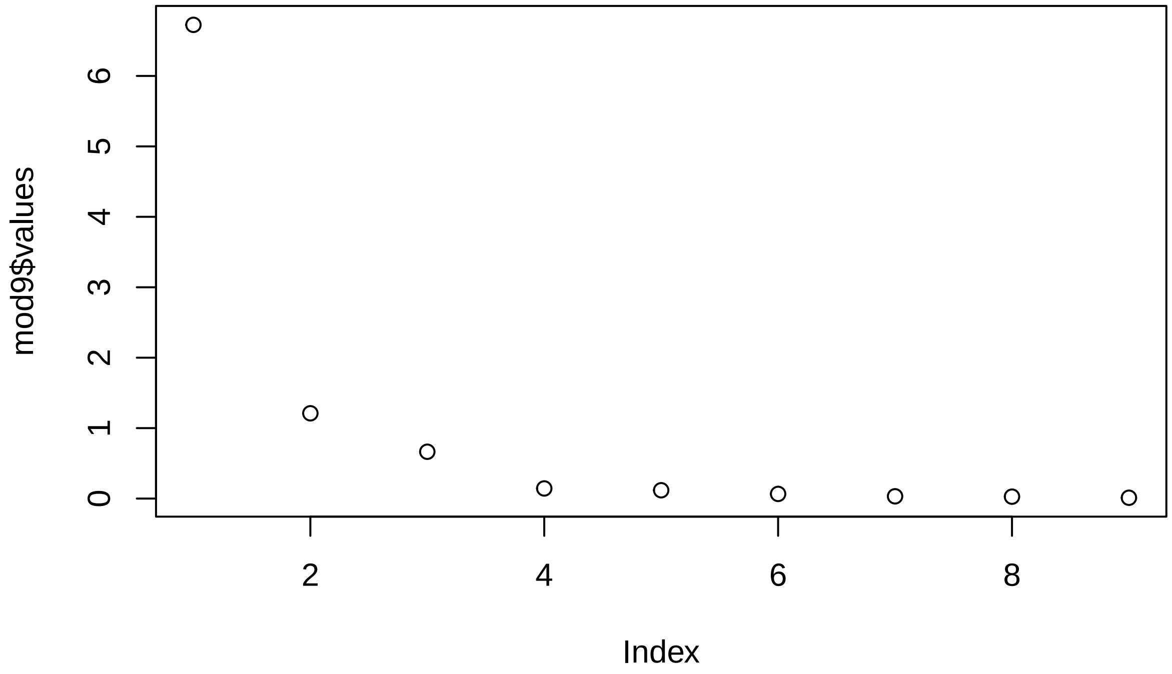
```
write.csv(df1.2mm, paste0(outDir, "pcs_sed_metals_2mm_2019.csv"), row.names = FALSE)
```

For all fractions

```
mod9 = principal(sedsAllStd, nfactors = 9, scores = TRUE)
round(mod9$values, 1)
```

```
## [1] 6.7 1.2 0.7 0.1 0.1 0.1 0.0 0.0 0.0
```

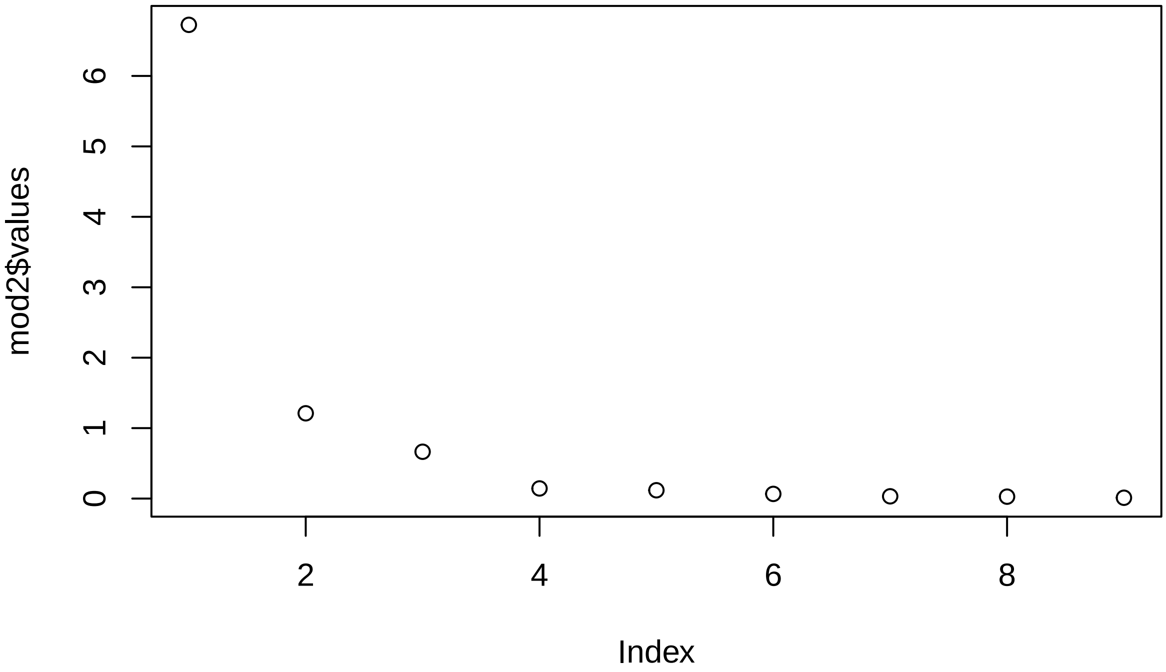
```
plot(mod9$values)
```



```
mod2 <- principal(sedsAllStd, nfactors = 2, scores = TRUE)
round(mod2$values, 1)
```

```
## [1] 6.7 1.2 0.7 0.1 0.1 0.1 0.0 0.0 0.0
```

```
plot(mod2$values)
```



Output

Loadings

```
outDir <- "M:/Projects/2018/18-2411.1 - Teck AREMP - Interpretation/Data_AREMP/Sediment_Quality/WD5_PCA
sedsAllLoadings <- data.frame(matrix(
  as.numeric(mod2$loadings),
  attributes(mod2$loadings)$dim,
  dimnames = attributes(mod2$loadings)$dimnames
))
write.csv(sedsAllLoadings, paste0(outDir, "loadings_sed_allfrac_2019.csv"))
```

Scores

```
df1.All <- data.frame(label1 = rownames(sedsAllStd), round(mod2$scores[, c(1:2)], 2))
df1.All
```

```
##                                         label1   RC1   RC2
## 2012-dep-exp-1 0.002     2012-dep-exp-1 0.002  0.38 -0.28
## 2012-dep-exp-2 0.002     2012-dep-exp-2 0.002 -1.36  2.49
## 2012-dep-exp-3 0.002     2012-dep-exp-3 0.002 -0.45  1.12
```

```
## 2012-dep-exp-4 0.002     2012-dep-exp-4 0.002 -0.54  0.20
## 2012-dep-exp-5 0.002     2012-dep-exp-5 0.002 -0.46  1.03
## 2012-dep-exp-6 0.002     2012-dep-exp-6 0.002 -0.33  0.35
## 2012-dep-exp-7 0.002     2012-dep-exp-7 0.002 -0.30  0.20
## 2012-dep-ref-1 0.002     2012-dep-ref-1 0.002 -0.12 -1.25
## 2012-dep-ref-2 0.002     2012-dep-ref-2 0.002 -0.12 -1.22
## 2012-dep-ref-3 0.002     2012-dep-ref-3 0.002 -0.09 -1.56
## 2015-dep-exp-1 0.002     2015-dep-exp-1 0.002  0.18 -0.25
## 2015-dep-exp-2 0.002     2015-dep-exp-2 0.002 -0.35 -0.01
## 2015-dep-exp-3 0.002     2015-dep-exp-3 0.002 -1.12  1.78
## 2015-dep-exp-4 0.002     2015-dep-exp-4 0.002 -0.40 -0.09
## 2015-dep-exp-5 0.002     2015-dep-exp-5 0.002 -0.16  0.24
## 2015-dep-exp-6 0.002     2015-dep-exp-6 0.002 -0.21 -0.20
## 2015-dep-exp-7 0.002     2015-dep-exp-7 0.002 -0.01 -0.08
## 2015-dep-ref-1 0.002     2015-dep-ref-1 0.002 -0.01 -1.49
## 2015-dep-ref-2 0.002     2015-dep-ref-2 0.002 -0.01 -1.55
## 2015-dep-ref-3 0.002     2015-dep-ref-3 0.002 -0.06 -1.46
## 2018-dep-exp-1 6.3e-05 2018-dep-exp-1 6.3e-05  0.94  0.92
## 2018-dep-exp-1 0.002     2018-dep-exp-1 0.002 -0.01  0.22
## 2018-dep-exp-2 6.3e-05 2018-dep-exp-2 6.3e-05  4.90  0.87
## 2018-dep-exp-2 0.002     2018-dep-exp-2 0.002 -0.12  1.73
## 2018-dep-exp-3 6.3e-05 2018-dep-exp-3 6.3e-05  0.09  0.97
## 2018-dep-exp-3 0.002     2018-dep-exp-3 0.002 -0.73  0.52
## 2018-dep-exp-4 6.3e-05 2018-dep-exp-4 6.3e-05 -0.12  0.15
## 2018-dep-exp-4 0.002     2018-dep-exp-4 0.002 -0.53  0.87
## 2018-dep-exp-5 6.3e-05 2018-dep-exp-5 6.3e-05  2.86  0.57
## 2018-dep-exp-5 0.002     2018-dep-exp-5 0.002 -0.37  0.91
## 2018-dep-exp-6 6.3e-05 2018-dep-exp-6 6.3e-05  0.00  0.44
## 2018-dep-exp-6 0.002     2018-dep-exp-6 0.002 -0.40  0.06
## 2018-dep-exp-7 6.3e-05 2018-dep-exp-7 6.3e-05  0.06 -0.07
## 2018-dep-exp-7 0.002     2018-dep-exp-7 0.002 -0.16 -0.17
## 2018-dep-ref-1 6.3e-05 2018-dep-ref-1 6.3e-05 -0.13 -0.66
## 2018-dep-ref-1 0.002     2018-dep-ref-1 0.002 -0.14 -1.23
## 2018-dep-ref-2 6.3e-05 2018-dep-ref-2 6.3e-05 -0.18 -0.75
## 2018-dep-ref-2 0.002     2018-dep-ref-2 0.002 -0.05 -1.43
## 2018-dep-ref-3 6.3e-05 2018-dep-ref-3 6.3e-05 -0.23 -0.54
## 2018-dep-ref-3 0.002     2018-dep-ref-3 0.002 -0.13 -1.32
```

```
write.csv(df1.All, paste0(outDir, "pcs_sed_metals_allfrac_2019.csv"), row.names = FALSE)
```

Plotting

2mm

Check axis contribution

```


seds2mmLoadings %>% rownames_to_column("analyte") %>% filter(RC1 > 0.7) %>% select(-RC2)
```

PC1

```
##    analyte       RC1
## 1  Arsenic 0.8897532
## 2 Chromium 0.8081070
## 3   Copper 0.9725674
## 4     Zinc 0.9444389
```

```
PC1Lab_2mm <- "PC1 (As, Cr, Cu, Zn)"
```

```
seds2mmLoadings %>% rownames_to_column("analyte") %>% filter(RC2 > 0.7) %>% select(-RC1)
```

PC2

```
##    analyte       RC2
## 1  Cadmium 0.8621776
## 2     Lead 0.7780649
## 3  Mercury 0.7944435
## 4 Thallium 0.9612692
```

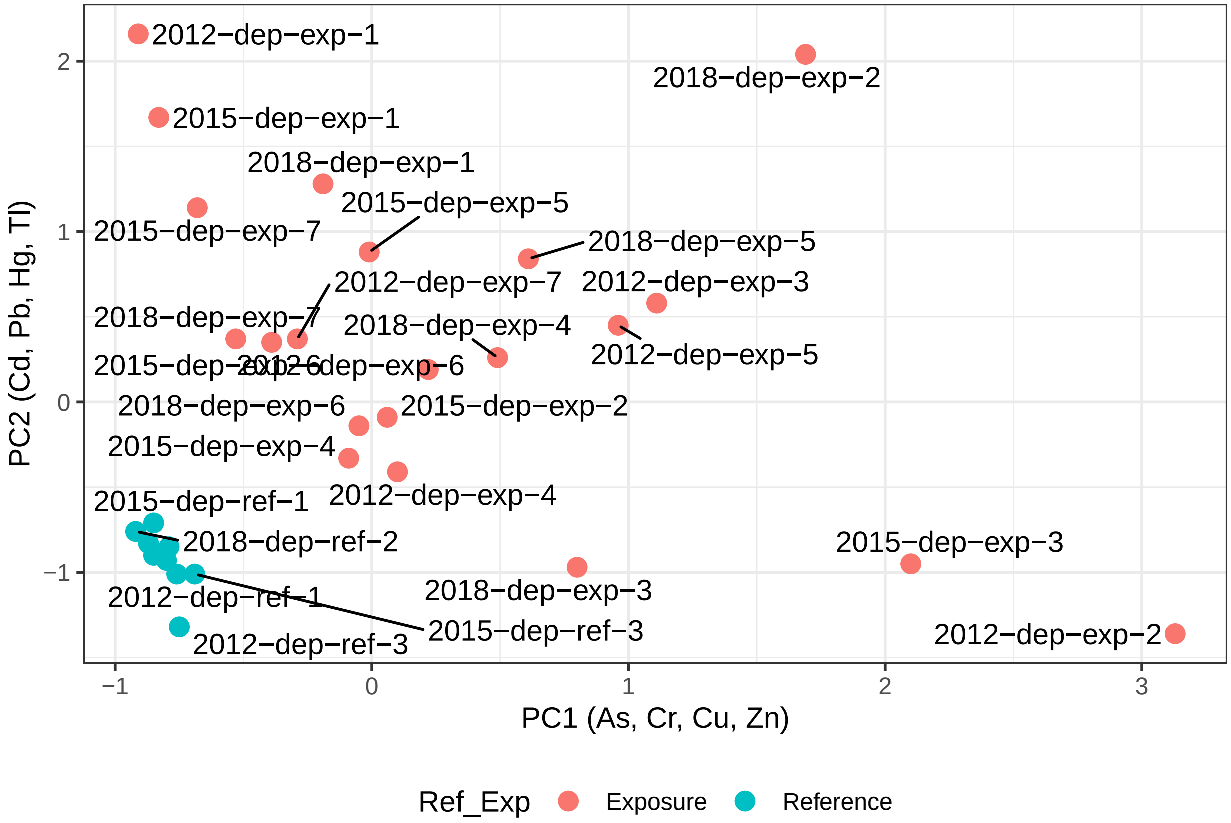
```
PC2Lab_2mm <- "PC2 (Cd, Pb, Hg, Tl)"
```

```
cleanAndPlot <- function(ld, scr, xlab_, ylab_) {
  ## extract reference and exposure
  scr$site_type=rep("Null",nrow(scr))
  scr$site_type[grep("ref",scr$label1)]="Reference"
  scr$site_type[grep("exp",scr$label1)]="Exposure"
  names(scr)[4]="Ref_Exp"

  ggplot(data = ld, aes (RC1,RC2)) +
    theme_bw() +
    geom_point (data = scr, (aes (RC1, RC2,colour=Ref_Exp)),size=3) +
    # subset according to optimal position
    geom_text_repel(scr,mapping=aes(x=RC1,y=RC2,label=label1)) +
    theme (legend.position="bottom") +
    xlab(xlab_) +
    ylab(ylab_)
}
```

Plot

```
p2mm <- cleanAndPlot(
  ld = seds2mmLoadings,
  scr = df1.2mm,
  xlab_ = PC1Lab_2mm,
  ylab_ = PC2Lab_2mm
)

p2mm
```

```
## Warning: ggrepel: 4 unlabeled data points (too many overlaps). Consider
## increasing max.overlaps
```



```
png(
  filename = paste0(outDir, "pca_sed_metals_2mm_2019.png"),
  width = 8,
  height = 6,
  units = "in",
  res = 200,
  pointsize = 12
)
plot(p2mm)
```

```
## Warning: ggrepel: 1 unlabeled data points (too many overlaps). Consider
## increasing max.overlaps
```

```
dev.off()
```

```
## pdf
##   2
```

All fractions

Check axis contribution

```
sedsAllLoadings %>% rownames_to_column("analyte") %>% filter(RC1 > 0.7) %>% select(-RC2)
```

PC1

```
##    analyte       RC1
## 1     Lead 0.8538192
## 2  Mercury 0.9349863
## 3 Selenium 0.9077398
## 4 Thallium 0.9137886
```

```
PC1Lab_all <- "PC1 (Pb, Hg, Se, Tl)"
```

```
sedsAllLoadings %>% rownames_to_column("analyte") %>% filter(RC2 > 0.7) %>% select(-RC1)
```

PC2

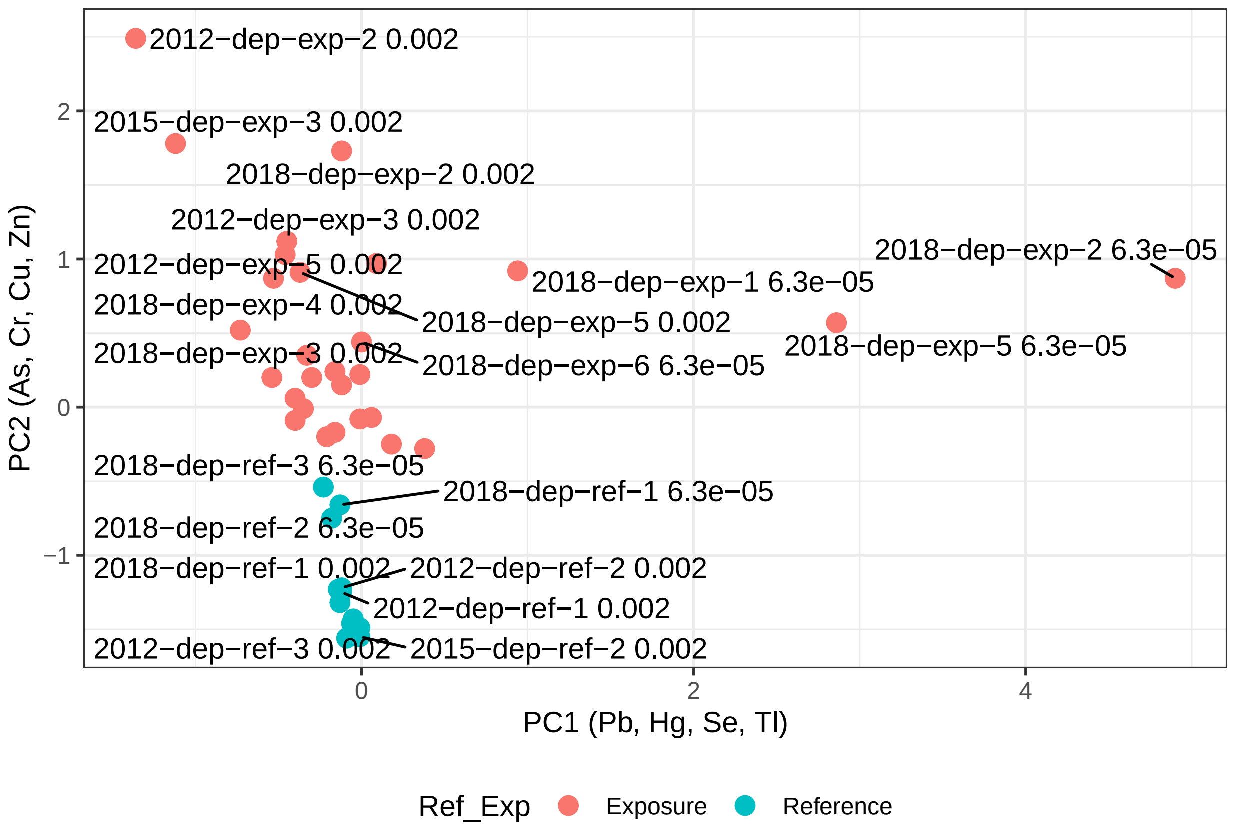
```
##    analyte       RC2
## 1  Arsenic 0.8887471
## 2 Chromium 0.8382634
## 3   Copper 0.8844007
## 4     Zinc 0.8574915
```

```
PC2Lab_all <- "PC2 (As, Cr, Cu, Zn)"
```

Plot

```
pAll <- cleanAndPlot(
  ld = sedsAllLoadings,
  scr = df1.All,
  xlab_ = PC1Lab_all,
  ylab_ = PC2Lab_all
)

pAll
```

```
## Warning: ggrepel: 20 unlabeled data points (too many overlaps). Consider
## increasing max.overlaps
```



```
png(
  filename = paste0(outDir, "pca_sed_metals_all_2019.png"),
  width = 8,
  height = 6,
  units = "in",
  res = 200,
  pointsize = 12
)
plot(pAll)
```

```
## Warning: ggrepel: 11 unlabeled data points (too many overlaps). Consider
## increasing max.overlaps
```

```
dev.off()
```

```
## pdf
##   2
```