Passive Sampling Results for Polycyclic Aromatic Hydrocarbons and Selected Metals in the Yukon River Watershed, Yukon Territory

A report prepared by

The Institute for Watershed Science at Trent University

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The Yukon River Inter-Tribal Watershed Council

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Acknowledgements

The Yukon River Inter-Tribal Watershed Council (YRITWC) is an Indigenous grassroots organization, consisting of 70 First Nations and Tribes, dedicated to the protection and preservation of the Yukon River Watershed. The YRITWC accomplishes this by providing Tribes in Alaska and First Nations in Canada in the Yukon Watershed with technical assistance. We facilitate the development and exchange of information, coordinate efforts between Tribes and First Nations, undertake research, and provide training, education and awareness programs to promote the health of the Watershed and its Indigenous peoples. Listed below are supporters and contributors to this project.

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Passive Sampling Results for Polycyclic Aromatic Hydrocarbons and selected Metals in the Yukon River Watershed, Yukon Territory

Introduction

Previous sampling in the Yukon River watershed completed by the Yukon River Inter-Tribal Watershed Council (YRITWC) in 2013 showed that concentrations of some elements (i.e., arsenic, cadmium, iron, lead and selenium) and hydrocarbons were present in water at concentrations that exceeded the water quality guidelines of the Council of Canadian Ministers of the Environment (CCME) for the protection of aquatic life at several sites that were identified by community members as being potentially contaminated. Through these research activities, the First Nations have identified two priorities: 1) the development of concrete action to address contaminants in water, aquatic life and human health, and 2) continued monitoring of suspected contaminated sites in their traditional territories. While addressing these two priorities, YRITWC staff recognized that water quality sampling methods must be enhanced to ensure that contaminants in water are being detected and accurately measured to ensure that ecosystem and human health is sustained in First Nations traditional territories.

This study was undertaken to obtain quantitative data on water quality parameters and contaminant levels in order to generate critical baseline data on potentially toxic contaminants that may be related to human activities and natural occurrences. Passive sampling is an excellent monitoring technique for determining time weighted average (TWA) concentrations of aquatic contaminants over the period of deployment. This method is superior to "grab" sampling techniques that provide data on conditions at the moment of sampling. Moreover, the passive samplers concentrate the contaminants over time so that even trace contaminants can be detected. Semi-permeable membrane devices (SPMDs) are appropriate sampling devices for monitoring hydrophobic contaminants that are freely dissolved in water, such as Polycyclic Aromatic Hydrocarbons (PAHs). Diffuse gradients in thin-films (DGTs) passively accumulate labile metal species in water. Using these two sampling technologies, TWA concentrations of PAHs and metals can be calculated.

Materials and Methods

The SPMDs and DGTs were prepared according to the procedures described by Hoque et al. (2014) and Guéguen et al. (2011), respectively. They were shipped to the YRITWC in Whitehorse, and deployed at the sampling sites between September and November of 2014. The SPMDs and DGTS were deployed at 9 locations in the Yukon River watershed (Figure 1) between September 16th and October 10th, 2014. The SPMD deployment periods ranged from a maximum of 32 days at Mica Creek to a minimum of 8 days at Yukon River Site A (Table 1). The DGT deployment periods ranged from a maximum of 33 days at Yukon River Site B to 20 days at Bonanza Creek (Table 1).

U.S. Geological Survey Samples

During the open water season in 2014 (May – October), the YRITWC with three Yukon First Nations collected water samples from Mayo, Dawson, and Whitehorse.

During the passive sampler installations, nutrient samples and dissolved organic carbon samples were collected at each site. These samples were sent to the USGS lab in Boulder, Colorado for analysis. This

report does not include the data analysis from USGS since this report is being released prior to obtaining USGS results. The YRITWC and USGS will be releasing this information at a later date.

YSI Professional Plus and YSI 650 were both used in the field by the YRITWC. First Nations were supplied with YSI Professional Plus meters. Additionally, field parameter data can be found at http://yukon.fieldscope.org.

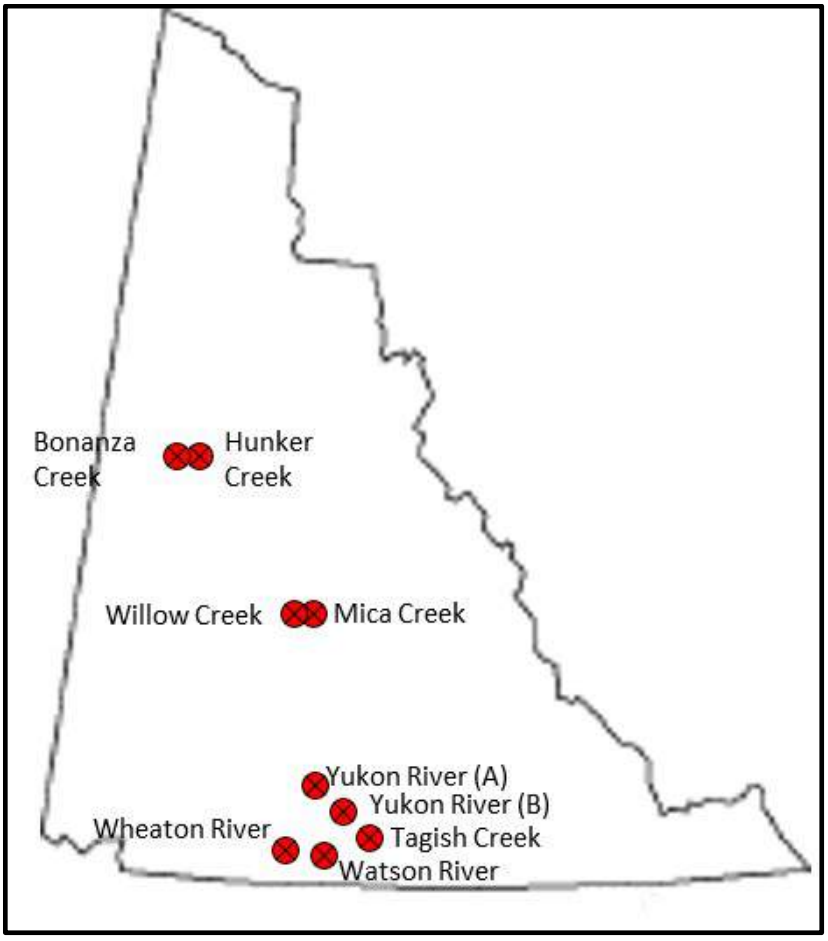


Figure 1. Location of Yukon Territory monitoring sites

Figure 2. Location of Bonanza Creek and Hunker Creek monitoring sites.

Figure 3. Location of Willow Creek and Mica Creek monitoring sites.

Figure 3. Location of Yukon River, Tagish Creek, Watson River and Wheaton Creek monitoring sites.

The SPMDs were deployed in triplicate in a shroud consisting of a 30" section of 3" diameter snap lock aluminum stove piping that was solvent washed prior to deployment to remove any residual PAHs from the manufacturing process. Triplicate SPMDs were installed in each pipe, and the pipe was suspended in the water column in flowing water. The DGTs were mounted to a plexiglass plate in triplicate, and installed upstream of the SPMDs to avoid any contamination from the piping and metal fittings. Deployment periods can be seen in Table 1, and varied from site to site.

Table 1. Deployment periods for SPMD and DGT samplers in Yukon River Watershed

Sample Location	SPMD Deployment Period (Days)	DGT Deployment Period (Days)
Mica Creek	32	32
Watson River	14	26
Wheaton River	14	26
Tagish Creek	17	N/A
Willow Creek	20	30
Hunker Creek	19	N/A
Bonanza Creek	19	20
Yukon River Site A	23	32
Yukon River Site B	8	33

The SPMD and DGT samplers were removed from the river by YRITWC staff, placed in amber glass jars, and shipped back to Trent University for analysis. The SPMDs were extracted at Trent University using the procedures described by Hoque et al. (2014), and the extracts were shipped for analysis of PAHs and the Performance Reference Compound (PRC) to the Great Lakes Institute for Environmental Research (GLIER) Analytical Organic Laboratory at the University of Windsor. The PRC was PCB congener 14, which was spiked into the SPMDs to measure loss over the deployment period. The US EPA priority PAH compounds listed in Table 2 and the PRC concentrations in the extracts were determined using a Hewlett Packard model 6890 gas chromatograph with a model 5973 mass selective detector (i.e. GC-MSD) operated in electron ionization (EI) mode with selected ion monitoring (SIM) using a quadrupole analyzer. The estimated TWA concentrations of PAHs in the SPMDs were calculated using previously determined sampling rates (R_s) calculated in lab-based experiments (Røe Utvik et al. 1999). The sampling rates were adjusted according to data on the loss of the PRC during the deployment period using methods previously described by Hoque et al. (2014). The DGTs were extracted and analyzed at Trent University using an ICP-OES (Varian Vista MPX), and the resulting accumulated mass of metal in the DGTs was converted to an estimated TWA concentration using the methods described by Guéguen et al. (2011).

Table 2. US EPA Priority PAH Compounds

PAH Compound
Naphthalene
Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo(a)anthracene
Chrysene/Triphenylene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Indeno(1,2,3-cd)pyrene
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene

The estimated TWA concentrations of PAHs and metals were compared to two different water quality standards, CCME Canadian water quality guidelines for the protection of aquatic life, and the YRITWC's Yukon River Watershed Plan (YRWP) and its water quality standards for the Yukon River. The CCME's guidelines for the protection of aquatic life were developed to protect freshwater and marine life from human stressors such as chemical compounds. These guidelines are based on current scientifically defensible toxicological data for each parameter. These guidelines provide a science-based benchmark for a nationally consistent level of protection for aquatic life in Canada (CCME 1999). The water quality standards for the Yukon River were developed and approved by the First Nation and Tribal governments of the Yukon River watershed, working with the Yukon River Inter-Tribal Watershed Council. These

water quality standards were designed to protect the chemical, physical, biological and cultural integrity of surface waters in the Yukon River watershed. The standards are ground in and consistent with water quality rules and standards that have been established under the U.S. Clean Water Act (YRITWC 2013).

Results

pH

The Canadian Guidelines for the Protection of Aquatic Life established a range of acceptable pH values from 6.5-9.0 (CCME, 1999). All of the field measurements of pH are between and meet the guidelines expect for one occasion at Bonanza Creek on October 28, 2014 (see table 3 and figure 1).

Dissolved Oxygen

The Canadian Guidelines for the Protection of Aquatic Life state the following lowest acceptable dissolved oxygen concentrations (CCME, 1999):

- For cold water biota: early life stages = 9.5 mg/L
- For cold water biota: other life stages = 6.5 mg/L

All of the measurements of dissolved oxygen at these 9 sampling sites are between and meet the guidelines.

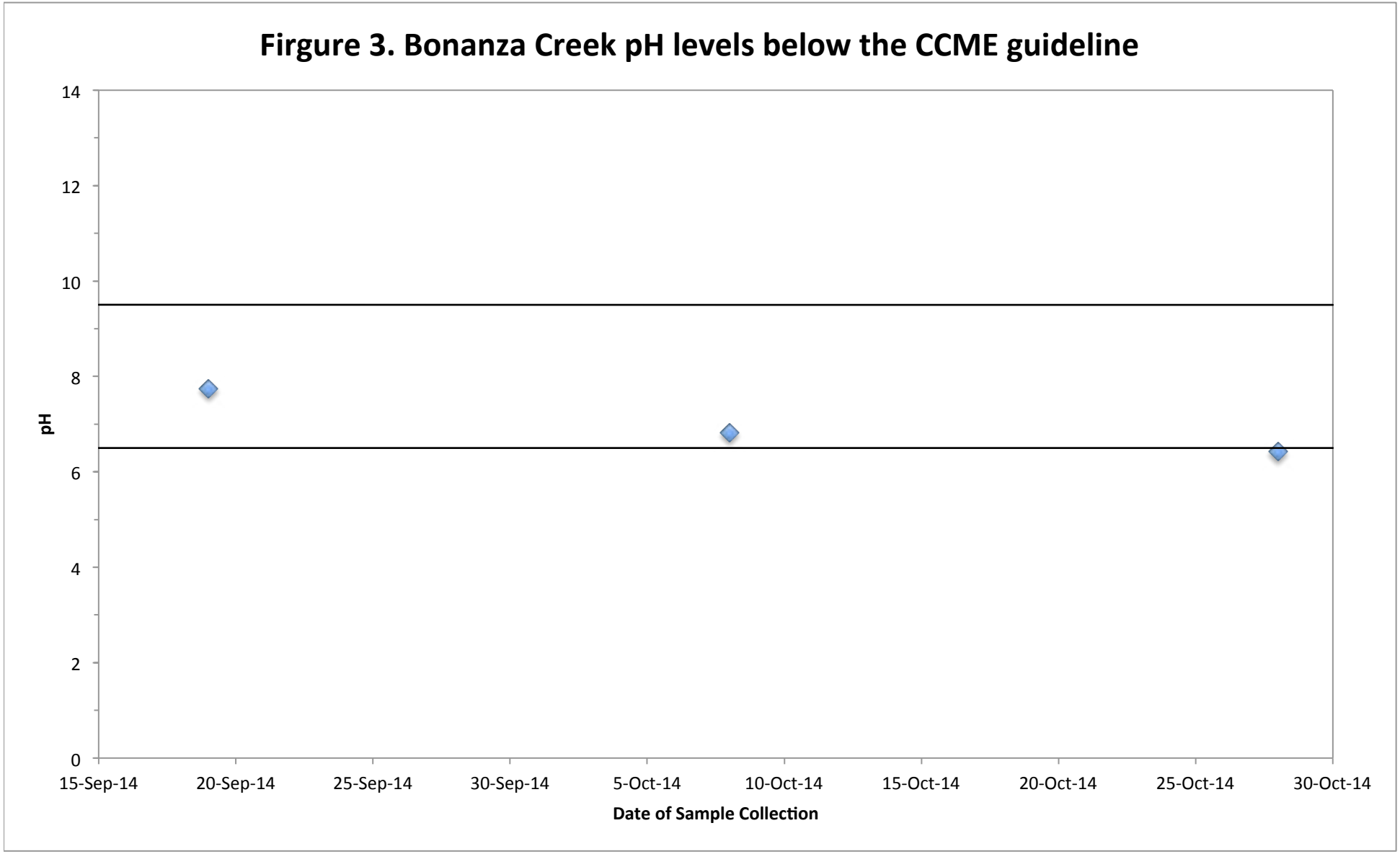
Bonanza Creek

Estimated TWA concentrations of PAHs and metals in Bonanza Creek can be seen in Appendix 2. Trace concentrations of 6 of the 16 PAH compounds were found. Acenaphthene (0.000007 µg/L), Fluorene (0.0003 µg/L), Phenanthrene (0.0010 µg/L), Anthracene (0.0005 µg/L), Fluoranthene (0.0011 µg/L), and Pyrene (0.0010 µg/L) were detected. The remaining 10 PAHs, which have higher molecular weight, were not detected at this site. All of the PAH compounds that were detected were present at concentrations orders of magnitude lower than the YRWP or CCME guidelines for the respective compounds. Metal concentrations ranged from a high of 4.72 µg/L for Zinc to a low of 0.008 µg/L for Cobalt. Bonanza Creek had the lowest concentration of Copper (0.01 µg/L), and Nickel (0.04 µg/L) compared to the other 8 sample locations. None of the metals exceed YRWP or CCME guidelines, with most metals lower than the guidelines by several orders of magnitude.

Table 3. Bonanza Creek field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
19/09/2014	14.03	110.2	7.74	217	4.73
08/10/2014	20.04	137.4	6.82	n/a	0.1
28/10/2014	17.8	118.5	6.43	n/a	0.4
Average =	17.29	122.0	7.00	217	1.74
Standard deviation =	3.04	13.9	0.67	n/a	2.59
# of measurements =	3				

Firgure 3. Bonanza Creek pH levels below the CCME guideline



Hunker Creek

Estimated TWA concentrations of PAHs in Hunker Creek can be seen in Appendix 3. Trace concentrations of 7 PAHs were found, Acenaphthylene (0.0006 µg/L), Acenaphthene (0.0020 µg/L), Fluorene (0.0024 µg/L), Phenanthrene (0.0092 µg/L), Anthracene (0.0009 µg/L), Fluoranthene (0.0121 µg/L) and Pyrene (0.0086 µg/L). There were no exceedances of the YRITWC or CCME guidelines for PAH compounds, and in most cases the estimated PAH concentrations measured in Hunker Creek were an order of magnitude lower than any of the guidelines. The DGT sampler that was deployed in Hunker Creek was lost, and therefore analysis of metals concentrations was not possible.

Table 4. Hunker Creek field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
19/09/2014	13.38	106.2	8.06	320	5.2
08/10/2014	18.74	130.0	7.45	n/a	0.3
28/10/2014	17.45	120.0	7.17	n/a	0
Average =	16.52	118.7	7.56	320	1.8
Standard deviation =	2.80	12.0	0.46	n/a	2.9
# of measurements =	3				

Willow Creek

Estimated TWA concentrations of PAHs and metals in Willow Creek can be seen in Appendix 4. Trace concentrations of 3 PAHs were found, Acenaphthene (0.0006 µg/L), Fluorene (0.0009 µg/L), and Phenanthrene (0.0043 µg/L). There were no exceedances of the YRWP or CCME guidelines for PAH compounds. PAH concentrations measured in Willow Creek were orders of magnitude lower than any of the guidelines. The estimated copper concentration was 2.96 µg/L at Willow Creek. This is the highest copper concentration relative to the other study sites, and it exceeded the CCME Aquatic Life Guideline of 2.35 µg/L. However, the copper concentrations are far below the Aquatic Life Chronic exposure criteria that were adopted by the YRWP of 9 µg/L. Willow Creek's estimated manganese concentrations of 36.62 µg/L were significantly higher than at other sites in this study. However, they did not exceed YRITWC Human Health Criteria: Water and Organism standard of 50 µg/L. Note that there are no guidelines CCME or YRWP aquatic life guidelines for manganese. All of the other metal concentrations were significantly lower than the CCME or YRWP guidelines.

Table 5. Willow Creek field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
18/09/2014	12.95	105.3	7.72	197	5.73
07/10/2014	15.10	105.8	8.38	105	0.81
06/11/2014	16.29	114.1	7.15	168	0.39
Average =	14.78	108.4	7.75	157	2.31
Standard deviation =	1.69	4.9	0.62	47	2.97
# of measurements =	3				

Mica Creek

Estimated TWA concentrations of PAHs and metals in Mica Creek can be seen in Appendix 5. Trace concentrations of Acenaphthylene (0.0002 µg/L), Acenaphthene (0.0002 µg/L), Fluorene (0.0002 µg/L) and Anthracene (0.0002 µg/L) were found. There were no exceedances of the YRITWC or CCME guidelines for PAH compounds. Estimated PAH concentrations for Mica Creek were orders of magnitude lower than any of the guidelines. The metal concentrations in Mica Creek were also all well below the YRWP and CCME guidelines (Table 5).

Table 6. Mica Creek field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
07/10/2014	15.99	116.3	7.72	130	2.20
06/11/2014	16.66	113.9	7.62	56	-0.12
Average =	16.33	115.1	7.67	93	1.04
Standard deviation =	0.47	1.7	0.07	52	1.64
# of measurements =	2				

Yukon River (Site A)

Estimated TWA concentrations of PAHs and metals in the Yukon River at Site A can be seen in Appendix 6. Trace concentrations of Naphthalene (0.09 µg/L), Acenaphthylene (0.0005 µg/L), Fluorene (0.0002 µg/L) and Fluoranthene (0.0008 µg/L) were detected. The four PAH compounds that were detected were present at estimated concentrations orders of magnitude lower than the YRWMP or CCME guidelines for the respective compounds. This site has the highest zinc concentration relative to the other sites in this study. The 33.15 µg/L estimated concentration exceeds the CCME Aquatic Life Guidelines, but is still far below the Aquatic Life Chronic exposure criteria that were adopted by the YRWMP of 110 µg/L. All of the other metal concentrations are a minimum of an order of magnitude lower than the lowest CCME or YRWMP guideline.

Table 7. Yukon River (Site A) field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
13/06/2014	12.32	112.0	7.85	n/a	10.8
18/06/2014	11.90	104.7	7.77	47	9.68
17/07/2014	11.38	116.7	8.47	n/a	15.8
22/07/2014	10.98	111.1	8.23	n/a	15.4
25/09/2014	11.89	101.5	7.41	63	8.40
26/09/2014	12.74	116.4	8.29	n/a	9.6
01/10/2014	error	111.0	7.46	n/a	8.1
03/10/2014	12.70	103.4	7.63	64	6.20
04/11/2014	14.01	104	7.74	69	2.50
Average =	12.24	109.0	7.87	61	9.6
Standard deviation =	0.94	5.7	0.38	10	4.2
# of measurements =	9				

Yukon River (Site B)

Estimated TWA concentrations of PAHs and metals in the Yukon River at Site B can be seen in Appendix 7. The SPMDs that were deployed in Yukon River at Site B showed trace concentrations of Naphthalene (0.01 µg/L) and Acenaphthylene (0.00002 µg/L), both of which were present at estimated concentrations orders of magnitude lower than the YRWP or CCME guidelines. The metal concentrations in the Yukon River at Site B were all also well below the CCME and YRWP guidelines for metals.

Table 8. Yukon River (Site B) field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
11/06/2014	12.89	116.7	8.38	n/a	10.7
18/06/2014	11.65	108.0	8.05	52	11.92
18/07/2014	11.16	114.4	8.18	n/a	16.4
22/07/2014	11.17	116.1	7.86	n/a	15.3
25/09/2014	12.86	113.2	8.28	64	9.80
26/09/2014	13.79	121.3	7.67	n/a	9.1
02/10/2014	15.77	129.9	7.61	66	7.25
04/11/2014	14.39	107.3	7.89	64	2.97
24/02/2015	15.55	107.4	7.11	n/a	0
04/03/2015	15.54	105.9	6.64	59	0
Average =	13.48	114.0	7.77	61	8.34
Standard deviation =	1.81	7.5	0.54	6	5.81
# of measurements =	10				

Tagish Creek

Estimated TWA of PAHs in Tagish Creek can be seen in Appendix 8. Trace concentrations of Naphthalene (0.06 µg/L), Acenaphthylene (0.0005 µg/L), Acenaphthene (0.0036 µg/L), Fluorene (0.0054 µg/L), Phenanthrene (0.0160 µg/L), and Anthracene (0.0011 µg/L) were detected. This site had the highest concentrations of Acenaphthene, Fluorene, Phenanthrene and Anthracene relative the 8 other study sites. However, there were no exceedances of the YRWP or CCME guidelines for PAH compounds, and in most cases the PAH concentrations measured in Tagish Creek were more than an order of magnitude lower than the guidelines. A DGT sampler was not deployed in Tagish Creek, and therefore analysis of metals concentrations was not possible.

Table 9. Tagish Creek field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
16/09/2014	11.88	108.5	8.36	265.4	11.26
03/10/2014	14.01	107.4	8.60	194	4.01
Average =	12.945	108.0	8.48	229.7	7.64
Standard deviation =	1.51	0.8	0.17	50.5	5.13
# of measurements =	2				

Wheaton River

Estimated TWA concentrations of PAHs and metals in the Wheaton River can be seen in Appendix 9. There were only 2 PAHs detected in the Wheaton River, 0.000009 µg/L of Acenaphthene and 0.00001 µg/L Anthracene. These trace amount are well below the YRITWC and CCME guidelines for PAH compounds. The metal concentrations in the Wheaton River are also substantially less the YRWP and CCME guidelines.

Table 10. Wheaton River field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
26/09/2014	11.99	91.3	7.94	55	3.91
05/11/2014	14.57	101.6	8.18	68	0.43
Average =	13.28	96.45	8.06	62	2.17
Standard deviation =	1.82	7.3	0.17	9	2.46
# of measurements =	2				

Watson River

Estimated TWA concentrations of PAHs and metals in Watson River can be seen in Appendix 10. Trace concentrations of 6 PAHs were found, Naphthalene (0.12 µg/L), Acenaphthylene (0.0004 µg/L), Acenaphthene (0.0008 µg/L), Fluorene (0.0007 µg/L), Phenanthrene (0.0025 µg/L), and Anthracene (0.0003 µg/L). There were no exceedances of the YRWP or CCME guidelines for PAH compounds. PAH concentrations measured in Watson Creek were at least an order of magnitude less than any of the guidelines. The Watson River zinc concentrations were relatively high at 25.34 µg/L. This was the second largest zinc concentration of the study sites, but is still less than the CCME Aquatic Life Guideline which is 30 µg/L. All of the other metal concentrations in Watson River are well below the CCME or YRWP guidelines.

Table 11. Watson River field parameters

Date	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Field pH	Field Conductivity (µS/cm)	Water Temperature (°C)
26/09/2014	12.39	92.5	8.12	102	3.16
05/11/2014	18.42	128.5	8.07	133	0.43
Average =	15.41	110.5	8.10	118	1.80
Standard deviation =	4.26	25.5	0.04	22	1.93
# of measurements =	2				

Conclusions

The above research has helped establish baseline data on PAHs and metals at the nine study sites. This research has established that a number PAH compounds are dissolved in water in the watershed, but, the estimated concentrations of these compounds rarely exceeded 1 ng/L. None of the study sites in which PAH compounds were detected had concentrations that exceeded the CCME's water quality guidelines for the protection of aquatic life or the YRWP water quality standards. It should be noted that the PAH compounds that were detected in the SPMDs were all relatively low molecular weight compounds that have greater water solubility than the higher molecular weight compounds. None of these compounds are recognized human carcinogens. More work would be needed to determine the origin of these hydrocarbons, which could come from spills of gasoline or oil, boat traffic, atmospheric deposition, creosoted wood structures, road runoff or natural geological deposits.

Similarly the metal concentrations were generally well below the CCME's water quality guidelines for the protection of aquatic life and the YRWP water quality standards. There were two exceedances of the CCME guidelines. The Yukon River (Site A) had 33.15 µg/L of zinc, which exceeds the CCME Aquatic Life Guidelines, but is still far below the Aquatic Life Chronic exposure criteria that was adopted by the YRWP of 110 µg/L. Willow Creek's 2.96 µg/L copper concentration exceeds the CCME Aquatic Life Guideline of 2.35 µg/L, but is also below the low the YRWP aquatic life chronic exposure criteria of 9 µg/L.

It is important to note that the passive samplers were deployed in the fall of 2014 when the water temperatures were low. Passive samplers and especially SPMDs are susceptible to reductions in sampling rates as a result of low water temperatures. This was compensated for in the SPMDs by correcting for losses of the PRC compound during the deployment period. However, to provide more certainty for the data, it would be prudent to conduct these monitoring efforts during warmer months when water temperatures are elevated above 15^{o}C.

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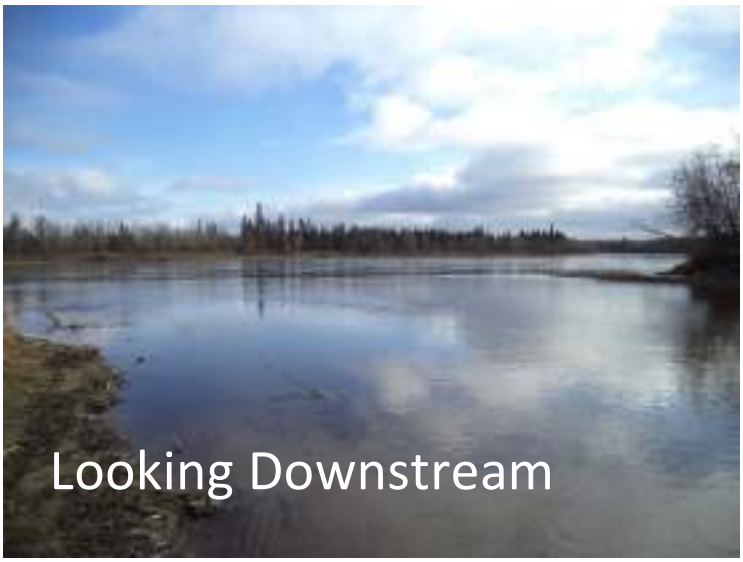
Appendix 1. Site Descriptions

Water Body: Mica Creek at the mouth

Site Name: mccfq1b

Traditional Territory: Selkirk First Nation

Coordinates: 62.81644°N, -136.56728°W



Water Body: Tagish Creek

Site Name: tccfa1b

Traditional Territory: Carcross/Tagish First Nation

Coordinates: 60.31525°N, -134.2865°W

Water Body: Watson River

Site Name: wacfa1b

Traditional Territory: Carcross/Tagish First Nation

Coordinates: 60.18229°N, -134.73766°W

Water Body: Wheaton River

Site Name: whcfa1b

Traditional Territory: Carcross/Tagish First Nation

Coordinates: 60.20707°N, -135.28229°W

Looking Downstream from the bridge

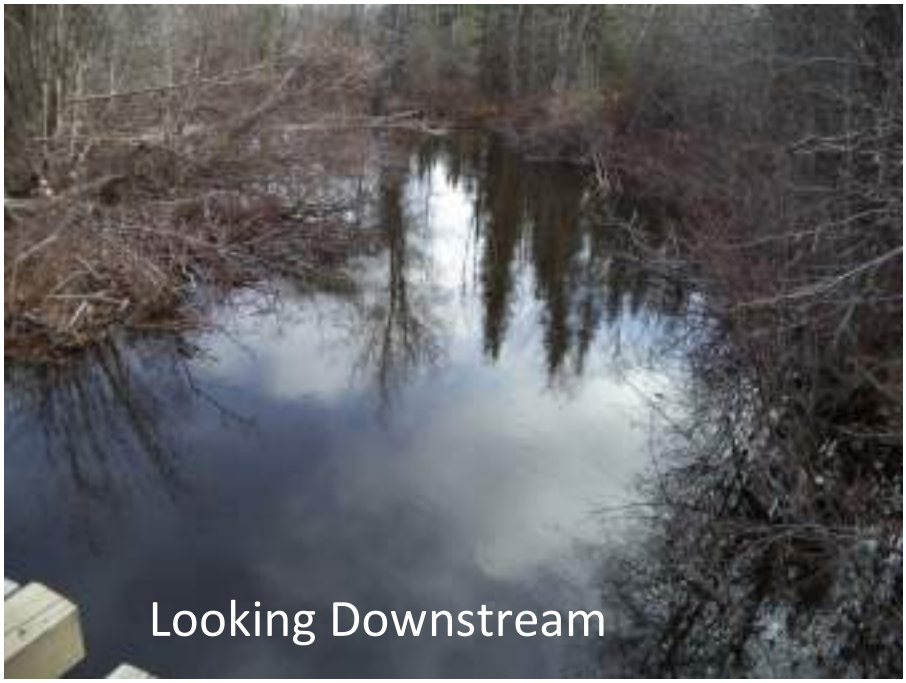
Looking Upstream

Water Body: Willow Creek near the bridge

Site Name: wicfq1b

Traditional Territory: Selkirk First Nation

Coordinates: 66.83692°N, -136.62122°W



Water Body: Yukon River above Whitehorse

Site Name: yuyxy1a

Traditional Territory: Kwanlin Dun First Nation & Ta'an Kwach'an Council

Coordinates: 60.57644°N, -134.67908°W

Water Body: Yukon River below Whitehorse

Site Name: yuyxy1b

Traditional Territory: Kwanlin Dun First Nation & Ta'an Kwach'an Council

Coordinates: 60.83984°N, -135.18117°W

Water Body: Hunker Creek near the Klondike Highway

Site Name: huyda1b

Traditional Territory: Tr'ondëk Hwëch'in First Nation

Coordinates: 64.0304°N, - 139.17671°W

Water Body: Bonanza Creek

Site Name: boyda1b

Traditional Territory: Tr'ondëk Hwëch'in First Nation

Coordinates: 64.03075°N, -139.38847°W

Appendix 2. Bonanza Creek PAH and Metal Concentrations

Class	Parameter	Bonanza Creek Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	ND						1.1
	Acenaphthylene	ND						5.8
	Acenaphthene	0.000007	95	99				
	Fluorene	0.0003	390	530				3
	Phenanthrene	0.0010						0.4
	Anthracene	0.0005	2900	4000				0.012
	Fluoranthene	0.0011	14	14				0.04
	Pyrene	0.0010	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						
Metals	Aluminum (^{27}Al)	0.41			750	87	50-200#	100#
	Vanadium (^{51}V)	0.082						
	Manganese (^{55}Mn)	0.90	50	100				
	Iron (^{56}Fe)	4.51	300			1000	300	300
	Cobalt (^{59}Co)	0.008						
	Nickel (^{60}Ni)	0.04	140	170	470	52	100	95.58*
	Copper (^{65}Cu)	0.01	1300		13	9	1300	2.35*
	Zinc (^{66}Zn)	4.72	2100	2600	120	110		30
	Cadmium (^{111}Cd)	0.008			2	0.25	5	0.09
	Lead (^{208}Pb)	0.034			65*	2.5*	15	3.18

* ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)

Appendix 3. Hunker Creek PAH Concentrations

Class	Parameter	Hunter Creek Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	ND						1.1
	Acenaphthylene	0.0006						5.8
	Acenaphthene	0.0020	95	99				
	Fluorene	0.0024	390	530				3
	Phenanthrene	0.0092						0.4
	Anthracene	0.0009	2900	4000				0.012
	Fluoranthene	0.0121	14	14				0.04
	Pyrene	0.0086	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						

ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)

Appendix 4. Willow Creek PAH and Metal Concentrations

Class	Parameter	Willow Creek Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	ND						1.1
	Acenaphthylene	ND						5.8
	Acenaphthene	0.0006	95	99				
	Fluorene	0.0009	390	530				3
	Phenanthrene	0.0043						0.4
	Anthracene	ND	2900	4000				0.012
	Fluoranthene	ND	14	14				0.04
	Pyrene	ND	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						
Metals	Aluminum (^{27}Al)	1.01			750	87	50-200#	100#
	Vanadium (^{51}V)	0.045						
	Manganese (^{55}Mn)	36.62	50	100				
	Iron (^{56}Fe)	6.80	300			1000	300	300
	Cobalt (^{59}Co)	0.177						
	Nickel (^{60}Ni)	0.46	140	170	470	52	100	95.58*
	Copper (^{65}Cu)	2.96	1300		13	9	1300	2.35*
	Zinc (^{66}Zn)	4.78	2100	2600	120	110		30
	Cadmium (^{111}Cd)	0.024			2	0.25	5	0.09
	Lead (^{208}Pb)	0.007			65*	2.5*	15	3.18

ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)

Appendix 5. Mica Creek PAH and Metal Concentrations

Class	Parameter	Mica Creek Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	ND						1.1
	Acenaphthylene	0.0002						5.8
	Acenaphthene	0.0002	95	99				
	Fluorene	0.0002	390	530				3
	Phenanthrene	ND						0.4
	Anthracene	0.0002	2900	4000				0.012
	Fluoranthene	ND	14	14				0.04
	Pyrene	ND	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						
Metals	Aluminum (^{27}Al)	0.90			750	87	50-200#	100#
	Vanadium (^{51}V)	0.086						
	Manganese (^{55}Mn)	2.49	50	100				
	Iron (^{56}Fe)	5.12	300			1000	300	300
	Cobalt (^{59}Co)	0.010						
	Nickel (^{60}Ni)	0.24	140	170	470	52	100	95.58*
	Copper (^{65}Cu)	1.23	1300		13	9	1300	2.35*
	Zinc (^{66}Zn)	4.30	2100	2600	120	110		30
	Cadmium (^{111}Cd)	0.008			2	0.25	5	0.09
	Lead (^{208}Pb)	0.004			65*	2.5*	15	3.18

ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)

Appendix 6.Yukon River (Site A) PAH and Metal Concentrations

Class	Parameter	Yukon River (Site A) Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	0.09						1.1
	Acenaphthylene	0.0005						5.8
	Acenaphthene	ND	95	99				
	Fluorene	0.0002	390	530				3
	Phenanthrene	ND						0.4
	Anthracene	ND	2900	4000				0.012
	Fluoranthene	0.0008	14	14				0.04
	Pyrene	ND	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						
Metals	Aluminum (^{27}Al)	0.24			750	87	50-200#	100#
	Vanadium (^{51}V)	0.115						
	Manganese (^{55}Mn)	0.28	50	100				
	Iron (^{56}Fe)	0.74	300			1000	300	300
	Cobalt (^{59}Co)	0.002						
	Nickel (^{60}Ni)	0.09	140	170	470	52	100	95.58*
	Copper (^{65}Cu)	0.88	1300		13	9	1300	2.35*
	Zinc (^{66}Zn)	33.15	2100	2600	120	110		30
	Cadmium (^{111}Cd)	0.010			2	0.25	5	0.09
	Lead (^{208}Pb)	0.032			65*	2.5*	15	3.18

ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)

Appendix 7.Yukon River (Site B) PAH and Metal Concentrations

Class	Parameter	Yukon River (Site B) Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	0.01						1.1
	Acenaphthylene	0.00002						5.8
	Acenaphthene	ND	95	99				
	Fluorene	ND	390	530				3
	Phenanthrene	ND						0.4
	Anthracene	ND	2900	4000				0.012
	Fluoranthene	ND	14	14				0.04
	Pyrene	ND	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						
Metals	Aluminum (^{27}Al)	3.67			750	87	50-200#	100#
	Vanadium (^{51}V)	0.069						
	Manganese (^{55}Mn)	0.86	50	100				
	Iron (^{56}Fe)	5.88	300			1000	300	300
	Cobalt (^{59}Co)	0.006						
	Nickel (^{60}Ni)	0.07	140	170	470	52	100	95.58*
	Copper (^{65}Cu)	0.41	1300		13	9	1300	2.35*
	Zinc (^{66}Zn)	18.12	2100	2600	120	110		30
	Cadmium (^{111}Cd)	0.005			2	0.25	5	0.09
	Lead (^{208}Pb)	0.037			65*	2.5*	15	3.18

ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)

Appendix 8. Tagish Creek PAH Concentrations

Class	Parameter	Tagish Creek Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	0.06						1.1
	Acenaphthylene	0.0005						5.8
	Acenaphthene	0.0036	95	99				
	Fluorene	0.0054	390	530				3
	Phenanthrene	0.0160						0.4
	Anthracene	0.0011	2900	4000				0.012
	Fluoranthene	ND	14	14				0.04
	Pyrene	ND	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						

ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)

Appendix 9.Wheaton River PAH and Metal Concentrations

Class	Parameter	Wheaton Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	ND						1.1
	Acenaphthylene	ND						5.8
	Acenaphthene	0.000009	95	99				
	Fluorene	ND	390	530				3
	Phenanthrene	ND						0.4
	Anthracene	0.00001	2900	4000				0.012
	Fluoranthene	ND	14	14				0.04
	Pyrene	ND	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						
Metals	Aluminum (^{27}Al)	1.62			750	87	50-200#	100#
	Vanadium (^{51}V)	0.100						
	Manganese (^{55}Mn)	2.78	50	100				
	Iron (^{56}Fe)	3.21	300			1000	300	300
	Cobalt (^{59}Co)	0.005						
	Nickel (^{60}Ni)	0.06	140	170	470	52	100	95.58*
	Copper (^{65}Cu)	0.20	1300		13	9	1300	2.35*
	Zinc (^{66}Zn)	13.92	2100	2600	120	110		30
	Cadmium (^{111}Cd)	0.020			2	0.25	5	0.09
	Lead (^{208}Pb)	0.025			65*	2.5*	15	3.18

ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)

Appendix 10.Watson River PAH and Metal Concentrations

Class	Parameter	Watson River Concentration (µg/L)	Human Health Criteria: Water + Organism (µg/L)	Human Health Criteria: Organism Only (µg/L)	Aquatic Life Acute Criteria (µg/L)	Aquatic Life Chronic Criteria (µg/L)	Water Supply Maximum Contaminant Level (µg/L)	CCME Aquatic Life Guidelines (µg/L)
Polycyclic Aromatic Hydrocarbons	Naphthalene	0.12						1.1
	Acenaphthylene	0.0004						5.8
	Acenaphthene	0.0008	95	99				
	Fluorene	0.0007	390	530				3
	Phenanthrene	0.0025						0.4
	Anthracene	0.0003	2900	4000				0.012
	Fluoranthene	ND	14	14				0.04
	Pyrene	ND	290	400				0.025
	Benzo(a)anthracene	ND	0.0013	0.0018				0.018
	Chrysene/Triphenylene	ND	0.0013	0.0018				
	Benzo(b)fluoranthene	ND	0.0013	0.0018				
	Benzo(k)fluoranthene	ND	0.0013	0.0018				
	Benzo(a)pyrene	ND	0.0013	0.0018				0.015
	Indeno(1,2,3-cd)pyrene	ND	0.0013	0.0018				
	Dibenzo(a,h)anthracene	ND	0.0013	0.0018				
	Benzo(g,h,i)perylene	ND						
Metals	Aluminum (^{27}Al)	10.09			750	87	50-200#	100#
	Vanadium (^{51}V)	0.131						
	Manganese (^{55}Mn)	5.27	50	100				
	Iron (^{56}Fe)	16.90	300			1000	300	300
	Cobalt (^{59}Co)	0.032						
	Nickel (^{60}Ni)	0.14	140	170	470	52	100	95.58*
	Copper (^{65}Cu)	0.69	1300		13	9	1300	2.35*
	Zinc (^{66}Zn)	25.34	2100	2600	120	110		30
	Cadmium (^{111}Cd)	0.017			2	0.25	5	0.09
	Lead (^{208}Pb)	0.086			65*	2.5*	15	3.18

ND = Not Detected, *= Hardness dependent (100mg/L used), # = pH dependent (pH of 8 used)