



DEPARTMENT OF THE ARMY

PINE BLUFF ARSENAL
10020 KABRICH CIRCLE
PINE BLUFF AR 71602-9500

April 3, 2018

SUBJECT: Mercury Site-specific Bioaccumulation Factor Study Plan

David Miller
Enforcement Analyst
Arkansas Department of Environmental Quality
5301 Northshore Drive
North Little Rock, AR 72118-5317

Dear Mr. Miller,

Attached is the "Study Plan for a Mercury Bioaccumulation Study in Phillips Creek, Pine Bluff Arsenal." The attached plan contains detail on sampling and analytical information that was added to the conceptual plan previously submitted to ADEQ included as an appendix to "Plan to Achieve Compliance with the Whole Effluent Toxicity and Mercury Limits at Outfall 01C, Third Year Progress Report, Pine Bluff Arsenal Permit AR0001678, January 23, 2018." The contents of the study plan were discussed in a conference call between Pine Bluff Arsenal Environmental Management and ADEQ on March 8, 2018.

If you have any questions, please don't hesitate to contact Mr. Kevin Dorman, Restoration Manager at 870-540-2806 or via e-mail to kevin.d.dorman2.civ@mail.mil.

Sincerely,

A handwritten signature in black ink that reads "Doug McKim".

Doug McKim,
Chief Environmental Compliance Division
Risk Management and Regulatory Affairs

Study Plan

Mercury Bioaccumulation Study in Phillips Creek, Pine Bluff Arsenal

Pine Bluff Arsenal

Pine Bluff, Arkansas



April 2018

Study Plan for a Mercury Bioaccumulation Study in Phillips Creek, Pine Bluff Arsenal

Introduction

As documented in the report *Plan to Achieve Compliance with the Mercury Limit at Outfall 01C, Second Year Progress Report* (PBA 2017), the total recoverable mercury discharged from Outfall 01C has not been in compliance with the final effluent limits since the effective date of the Permit. Mercury within Site 11 appears to become mobilized during rain events as evidenced by the relatively higher concentrations of mercury measured in the streams that discharge to the Runoff Control Impoundment (RCI) during rain events. The association of mercury mobilization with rain events is also reflected in the mercury concentrations in Outfall 01C effluent over the time period April 2008 to January 2017. Peak mercury concentrations are observed during the wetter months and lower mercury concentrations occur during the drier months. Based on discussions with the Arkansas Department of Environmental Quality (ADEQ) and the U.S. Environmental Protection Agency (USEPA), Pine Bluff Arsenal (PBA) decided to pursue a site-specific bioaccumulation factor (BAF) in conjunction with improvement in the operational performance of the RCI as a settling basin to achieve compliance with the mercury limit at Outfall 01C (PBA 2017).

The RCI discharges to an intermittent stream which then flows into Phillips Creek approximately 1 mile upstream from Phillips Creek's confluence with the Arkansas River. Mercury is a bioaccumulative chemical and is typically measured in fish as an indicator to exposure to humans. Mercury levels in fish living Phillips Creek do not increase downstream of the discharge from the RCI. In each of five years mercury was measured in fish from Phillips Creek, whole body concentrations in the downstream stations PC4–PC7 were similar to the three sites upstream of the influence of the RCI, stations PC1–PC3 (Table 3, PBA 2017) (Figure 1). These mercury tissue concentrations are slightly higher than mercury concentrations in fish collected from nearby waters, including Yellow Lake and the Arkansas River at Locks 4 and 5, indicating slightly elevated mercury occurs upstream of the point where the RCI effluent enters Phillips Creek (Table 4, PBA 2017).

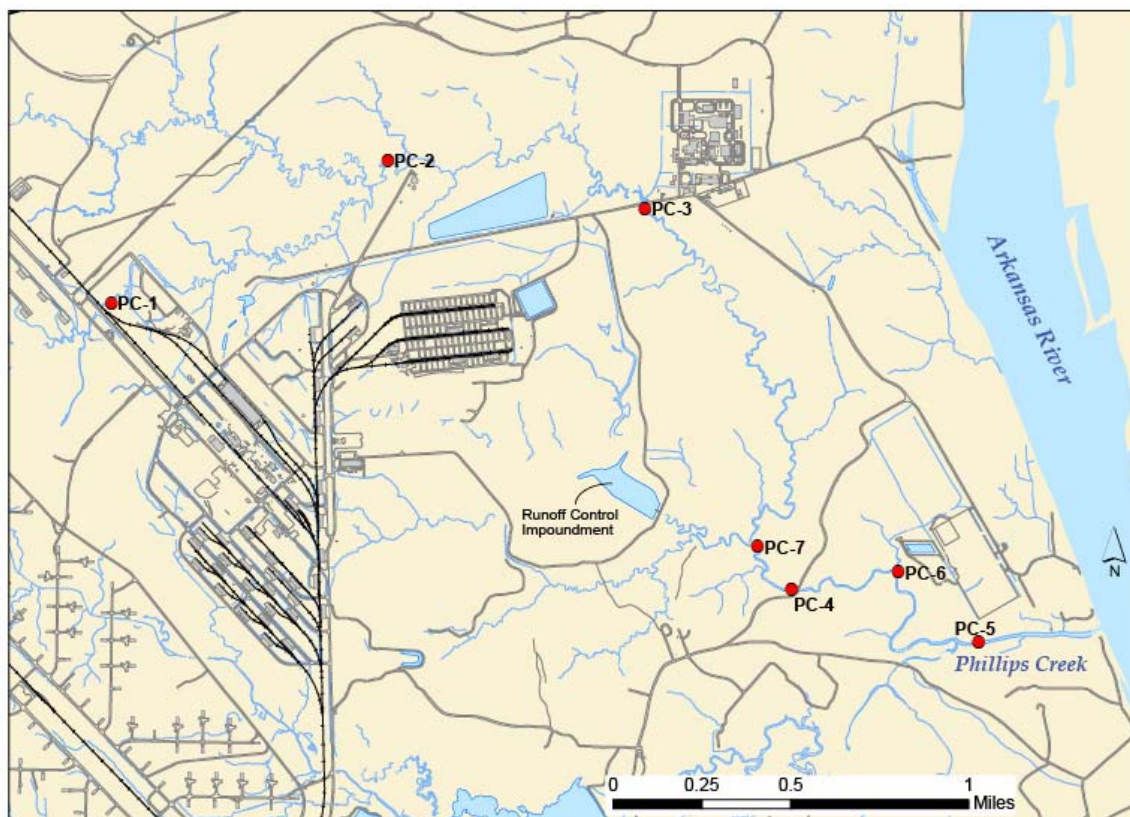


Figure 1. Sampling locations for mercury in Phillips Creek.

Bioaccumulation Factors for Mercury

A bioaccumulation factor (BAF) is calculated from the total concentration of chemical in the wet tissue of an aquatic organism, and the total concentration of the chemical in the ambient water at the sampling site. For mercury, the bioaccumulation factor is most commonly calculated from the tissue and water concentrations of methylmercury, the bioaccumulative form of this metal:

$$\text{Total BAF} = \text{BAF}'_{i,T} = \frac{C_t}{C_w}$$

where:

C_t = concentration of methylmercury in aquatic organism
($\mu\text{g}/\text{kg}$ wet tissue weight)

C_w = concentration of methylmercury in water ($\mu\text{g}/\text{L}$)

A site-specific BAF based on data obtained from field-collected samples of tissue from aquatic organisms that people eat and water from the water body of concern—referred to as a “field-measured site-specific BAF”—is the most direct and most relevant measure of bioaccumulation. It is also the preferred approach, according to USEPA’s mercury implementation document (USEPA 2010). The bioaccumulation methodology used in the 2000 Human Health Methodology (USEPA 2010) encourages developing site-specific BAFs because USEPA recognizes that BAFs vary not only between chemicals and trophic levels, but also among different ecosystems and waterbodies; that is, among sites. Site-specific BAFs can be determined for water bodies and water body segments receiving point source discharges such as industrial or municipal effluents (USEPA 2010), and should also be related to the home range (or foraging range) of the aquatic organism of interest.

Geometric mean chemical concentrations are used for each phase in the calculation of the total BAF (Equation 1), since multiple samples of biota and water will be collected to characterize chemical concentrations at the site. Total mercury concentrations are commonly substituted for methylmercury concentrations in fish tissue because 80-100% of the mercury found in the edible portions of trophic level (TL) 3 and 4 freshwater fish greater than three years of age is in the form of methylmercury (USEPA 2010). Methylmercury concentrations in water can be measured in either filtered or unfiltered samples; Riva-Murray (2013) found that either was acceptable for deriving a BAF.

To express the methylmercury tissue concentration-based criterion (TRC) as a water concentration, the TRC in fish tissue is translated to a methylmercury concentration in the water column using a BAF (USEPA 2010):

$$AWQC = \frac{TRC}{BAF}$$

where:

$AWQC$ = water concentration-based ambient water quality criterion for methylmercury in milligrams per liter (mg/L)
 TRC = tissue residue concentration; the water quality criterion for methylmercury in fish tissue in mg/kg

This conceptual plan has been designed to provide the data necessary to derive a site-specific methylmercury BAF for Phillips Creek downstream from the RCI discharge, as well as an ambient water quality criterion (AWQC) for methylmercury in this water body.

A methylmercury AWQC can be translated into a total mercury water criterion by converting the concentration of methylmercury in water to the equivalent concentration of total mercury. This step can be necessary because although the BAF is typically based on the concentration of methylmercury in water, the assessment of water quality is typically based on an evaluation of total mercury concentrations since other forms of mercury are converted to methylmercury in the environment. As a result, a relationship between (dissolved or total recoverable) methylmercury and (dissolved or total recoverable) mercury in the water needs to be developed. NPDES permits and other water quality-based pollution control activities traditionally rely on the total recoverable concentration of mercury, not the dissolved methylmercury form. A translator (to convert methylmercury water concentrations to total mercury water concentrations) is also required to calculate a water quality standard. The translator is calculated as:

$$\text{Water concentration translator} = \frac{\text{methylmercury concentration}}{\text{total mercury concentration}}$$

This study will provide the data necessary to derive a methylmercury (MeHg) to total mercury (TotHg) translator.

PBA has collected some site-specific preliminary data to assess the feasibility of the BAF approach for achieving compliance (PBA 2016; PBA 2017). Data collected between 2009 and 2014 are summarized in Table 1. Based on paired measurements of total mercury concentrations in fish and water samples from Phillips Creek sampling locations PC4-PC7 (Figure 1) downstream of the RCI, BAFs for total mercury in trophic level 3 fish were in the range of 675 to 23,700 L/kg. Using the tissue-based criterion of 0.3 mg /kg and the geometric mean BAF of 4,403 L/kg based on the total mercury concentrations in fish and water in Table 1, a translated total mercury water value of 0.068 µg/L was calculated for the site. However, this value is uncertain because (1) a BAF based on total mercury in water is not preferred and (2) the 1-4 water samples collected at each sampling location may not be representative of the long-term mercury exposure leading to bioaccumulation in Phillips Creek.

Table 1. Total mercury bioaccumulation data for Phillips Creek downstream of the RCI for August 2009 through December 2014.

Sampling Location	Date	species	Tissue TotHg, µg/kg	Water TotHg, µg/L	BAF
PC4	Aug 2009	green sunfish	537	0.086	6,244
	Oct 2010	bluegill sunfish	686.5	0.05	13,730
	Oct 2011	green sunfish	949.5	0.04	23,738
	Dec 2014	green sunfish	652.5	0.099	6,608
PC5	Aug 2009	green sunfish	613	0.21	2,919
	Oct 2010	bluegill sunfish	280	0.104	2,692
	Oct 2011	bluegill sunfish	254	0.178	1,427
	Dec 2014	bluegill, warmouth	59.5	0.0881	675
PC6	Dec 2014	bluegill sunfish	239	0.0738	3,238
PC7	Dec 2014	bluegill sunfish	483	0.0581	8,313
Geometric mean concentrations			383	0.0871	4,402

The data in Table 1 confirm that total mercury water concentrations vary both seasonally and spatially, and the total mercury BAFs calculated from these data are highly variable.

In September 2016, PBA collected additional site-specific data to assess the feasibility of the BAF approach. In addition to total mercury (TotHg), water samples were analyzed for methyl mercury (MeHg), in both filtered (“dissolved”) and unfiltered fractions. These data are summarized in Table 2. The data provide additional characterization of methylmercury exposure, in terms of the percentage of total mercury in the methylated form, and revealed potential spatial and temporal variability in the measurements of mercury exposure. BAFs for methylmercury in trophic level 3 fish were in the range of 81,100 to 135,000 L/kg. Using the tissue-based criterion of 0.3 mg/kg, the geometric mean BAF of 81,680 L/kg based on the methylmercury concentrations in fish and water in Table 2, and a translator of 0.0938, a translated total mercury water value of 0.039 µg/L was calculated for the site. Again, however, the single water sample collected at each sampling location may not be representative of the long-term mercury exposure leading to bioaccumulation in Phillips Creek.

Table 2. Total mercury and methylmercury bioaccumulation data for Phillips Creek downstream of the RCI, September 2016.

Sampling Location	Species	Tissue TotHg $\mu\text{g}/\text{kg}$	Water Concentrations (ng/L)				MeHg BAF
			TotHg (unfiltered)	TotHg (filtered)	MeHg (unfiltered)	MeHg (filtered)	
PC4	green sunfish (n=11)	605	42.1	11.7	10.6	6.11	99,018
PC5	longear sunfish (tentative)	344	-	-	-	-	-
	bluegill sunfish (tentative)	104					-
PC6	bluegill (n=1)	206	152	45.4	10.4	8.01	25,718
	green sunfish (n=3)	650					81,149
	green sunfish (n=3)	712					88,889
PC7	green sunfish	572	52.7	17.7	7.83	5.68	100,704
	green sunfish	765					134,683
	sunfish (mixed; n=3)	553					97,359
Geometric mean concentrations		543	69.6	21.1	9.52	6.53	81,680

The water concentration data in Table 2 show that total mercury is predominantly non-filtered (i.e., particulate) in Phillips Creek, while methylmercury is predominantly filtered (i.e., “dissolved”). Significant fractions of mercury are measured in the methylated form, for both the filtered and unfiltered samples. BAFs based on methylmercury (Table 2) were less variable than BAFs based on total mercury (Table 1).

Fish sampling

Fish will be collected using a backpack electrofishing unit. Fish sampling will be based on composite samples of like-sized (<25% variation in length) single species of fish (USEPA 2010). Skin-off fillets are the preferred tissue type for sampling of most fish, according to USEPA, however skin-on fillets will be used in this study. Given the small size of fish in Phillips Creek (see below), it is assumed fishermen will not remove the skin prior to consumption. As noted above, total mercury analysis is acceptable for adult TL 3 and 4 fish.

Three replicate composites for each trophic level will be collected at each sampling location. Composite fish samples will be collected at the four established sampling locations in Phillips Creek downstream of the RCI discharge, PC4–PC7. A 4-5 fish composite is an ideal sample and will be the target number of fish for each replicate in this study. The total number of fish needed per site is therefore 12-15. It is likely that 12-15 fish of one species of similar size will not be available at a site during a sampling event. When this occurs (i.e., insufficient number of target species at target size), the following priority sequence will be:

- 1st priority: 3 replicate composite samples of one fish species (e.g., green sunfish) of similar size with each replicate composite sample consisting of 4-5 fish.
- 2nd priority: 3 replicate composite samples of fish (2 or 3 species) of similar size with each replicate consisting of 4-5 fish; three species example - one replicate composite sample of 4-5 green sunfish, one replicate sample of 4-5 bluegill sunfish, and one replicate sample of 4-5 longear sunfish.
- 3rd priority: 1 or 2 (preferred) replicate composite samples of 1 (preferred) or 2 fish species with each composite consisting of 4-5 fish.

The length, weight, and age of any fish used in deriving the field-measured BAF will be measured and recorded because current information suggests that variability in methylmercury accumulation is dependent on fish age and size (USEPA 2001a). This information helps normalize the BAF to a standardized fish size within the range of fish sizes and species known to be consumed by the human population of interest. Length-normalized and standardized fish mercury concentrations reduce within-site BAF variability (Scudder Eikenberry, 2015).

Trophic level will also be determined for all fish, by taking into account its life stage, its diet, and the food web structure at the study location. Life history information should be adequate to determine trophic level of sampled fish species; however, information from the study site (or similar sites) is preferred when evaluating trophic status.

EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1* (USEPA 2000b, Section 6.1.1.5), provides recommendations for how frequently to sample fish tissue. If program resources are sufficient, this guidance recommends biennial sampling of fish in water bodies where recreational or subsistence harvesting is commonly practiced. Also, fish sampling will be done during the period when the target species is most frequently harvested or caught. In fresh waters, the guidance recommends that the most desirable sampling period is from late summer to early fall (August to October). Bi-annual sampling is suggested, with a goal to repeat sampling of each species in 2 rounds of sampling.

Fish species sampled for determining a site-specific BAF should be commonly consumed in the study area. However, Phillips Creek does not contain fish of suitable size for fishermen to

pursue and fishermen have never been observed utilizing the creek. Based on the collection of fish measured during electrofishing sampling in Phillips Creek, the vast majority of game fish are in the 3 to 5 inch size range, which is typically considered too small for fisherman (see Figure 2). In addition, no TL 4 fish have been collected in Phillips Creek during several years of reconnaissance sampling. PBA proposes to target green sunfish, a TL 3 species, as the fish to be used in the BAF calculation following the sampling design given in Table 3. If green sunfish are not available at a site during a sampling event, an alternative fish species (as discussed above) of similar trophic status will be collected.

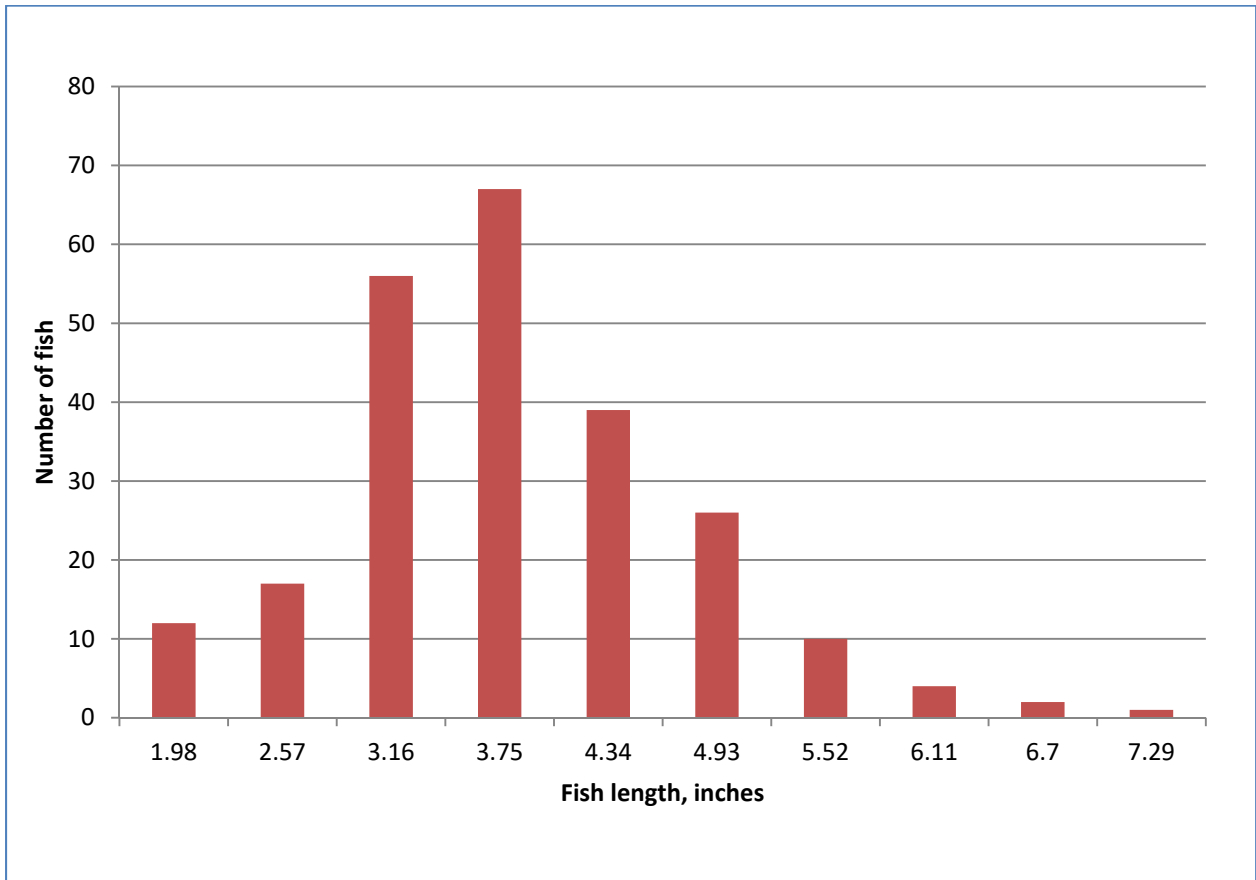


Figure 2. Size Frequency of Fish Collected in Phillips Creek from 2010 – 2014 Using Backpack Electrofishing Equipment. Sample number (N) = 234 Fish Composed of 133 Green Sunfish; 77 Bluegill; 14 Longear Sunfish; 5 Warmouth Sunfish; 5 Yellow Bullhead.

Water sampling

The goal of water sampling is to measure methylmercury water concentrations used to derive a BAF that reflects the average exposure of aquatic organisms that resulted in the concentration measured in their tissue (USEPA 2010). Concentrations of methylmercury in a

water body vary seasonally and diurnally because of a variety of biological and physical factors (USEPA 2010). The sampling program addresses potential temporal and spatial variability and that allows estimation of average exposure conditions.

A probabilistic sampling design is suggested by USEPA (2010) guidance. However, this is not appropriate or practical in Phillips Creek, due to the small overall size of the water body. In addition, significant differences in mercury water concentrations have been sporadically observed in Phillips Creek, in 2016 as well as earlier years. These observations are unexplained, and may be related to spatial and temporal patterns in the delivery of mercury from the watershed. Because of this, water sampling will be in each segment/pool of Phillips Creek downstream from the RCI, specifically sampling locations PC4-PC7. The Arkansas River constitutes a distinctly different water body and "site" from Phillips Creek, so sampling in the river is not proposed in this plan.

Unfiltered methylmercury sampling is recommended; unfiltered total mercury and total suspended solids will also be sampled. Continuing the analysis of filtered methylmercury and total mercury concentrations may be useful, especially when sampling during high flows and will be done in this study. Filtering of the water samples will be done at the analytical laboratory. Previous analysis has indicated that there is no meaningful difference in measurements if the water samples are filtered on site at the time of sampling or at the laboratory. Based on guidance offered in Riva-Murray et al. (2013), water sampling should be conducted seasonally (i.e., every 3 months), including both the months of August and September. Additionally, water should be sampled during wet weather and/or periods of high stream flow (e.g., 80th percentile flow and higher). A summary of the sampling design for water is given in Table 3.

To estimate average water concentrations, a rating curve approach is proposed for this study. Mercury concentrations are correlated to stream flow, so knowledge of daily stream flow for the period of interest allows representative average exposure concentrations to be calculated. For this, daily flows are required; either measured in-stream or estimated from a USGS gauge in a nearby watershed of similar size to Phillips Creek. In-stream flow measurement will be done during each sampling event using a flow meter at PC4. To estimate daily stream flow over the course of the study, a water level logger will be installed at PC4. In addition, there are several active USGS gauges within 25 miles of PBA, including Hurricane Creek below Sheridan, AR (Site Number 07363400; drainage area 261 square miles) and Saline River near Sheridan, AR (Site Number 07363200; drainage area 1,120 square miles). Stream flow measured at one of these gauges will be used to estimate daily flows in Phillips Creek as a comparison to the in-stream measurements.

Analytical procedures

Fish

Fish samples will be filleted on-site at the time of collection, placed in a Ziplock bag with proper identification and placed on wet ice. On the day of collection, fish samples will be shipped overnight on wet ice to GLEC's laboratory in Traverse City. Upon receipt of field-prepared fillets at GLEC's Traverse City laboratory, the tissue samples will be assigned a unique lab ID and stored in a -20 C freezer until the time of processing. The fillets will be homogenized using either a small blender or mortar and pestle. Tissue is ground and mixed until a uniform texture is achieved. The homogenized tissue is transferred to a pre-cleaned jar, labeled with the appropriate Lab ID and returned to the -15°C freezer until shipment to the laboratory performing the analysis. For shipment to the analytical laboratory, the jars are individually wrapped in bubble wrap and shipped via overnight courier in a cooler packed with dry ice. Analysis of mercury in tissue samples will be done at Brooks Applied Labs in Bothell WA.

Water

See Tables 4 and 5 for analytical methods, sample containers, preservatives, and holding times for water sample measurements. Analysis of mercury in water samples will be also done at Brooks Applied Labs. For the water and tissue results, the analytical lab will provide a Level II deliverable which includes a case narrative or cover letter, sample results summary, QA sample summary, work order receipt report, and chain-of-custody form(s).

Table 3. Summary of sampling design for site-specific mercury/methylmercury bioaccumulation study for Phillips Creek downstream of the RCI.

Sampling location	Media	Parameter	Sampling schedule					
			Apr-18	May-18	Aug-18	Sep-18	Oct-18	Nov-18
PC-7	water	TotHg (u)	1	1	1	1		1
		TotHg (f)	1	1	1	1		1
		MeHg(u)	1	1	1	1		1
		MeHg(f)	1	1	1	1		1
		TSS	1	1	1	1		1
	fish (4-5 fish composites)	TotHg			3		3	
		Length			12-15		12-15	
		Weight			12-15		12-15	
		Age			12-15		12-15	
PC-4	water	TotHg (u)	1	1	1	1		1
		TotHg (f)	1	1	1	1		1
		MeHg(u)	1	1	1	1		1
		MeHg(f)	1	1	1	1		1
		TSS	1	1	1	1		1
	fish (4-5 fish composites)	TotHg			3		3	
		Length			12-15		12-15	
		Weight			12-15		12-15	
		Age			12-15		12-15	
PC-6	water	TotHg (u)	1	1	1	1		1
		TotHg (f)	1	1	1	1		1
		MeHg(u)	1	1	1	1		1
		MeHg(f)	1	1	1	1		1
		TSS	1	1	1	1		1
	fish (4-5 fish composites)	TotHg			3		3	
		Length			12-15		12-15	
		Weight			12-15		12-15	
		Age			12-15		12-15	
PC-5	water	TotHg (u)	1	1	1	1		1
		TotHg (f)	1	1	1	1		1
		MeHg(u)	1	1	1	1		1
		MeHg(f)	1	1	1	1		1
		TSS	1	1	1	1		1
	fish (4-5 fish composites)	TotHg			3		3	
		Length			12-15		12-15	
		Weight			12-15		12-15	
		Age			12-15		12-15	
Field	water	TotHg (u)	1	1	1	1		1

Sampling location	Media	Parameter	Sampling schedule					
			Apr-18	May-18	Aug-18	Sep-18	Oct-18	Nov-18
blanks		TotHg (f)	1	1	1	1		1
		MeHg(u)	1	1	1	1		1
		MeHg(f)	1	1	1	1		1
		TSS	1	1	1	1		1
Trip blanks	water	TotHg (u)	1	1	1	1		1
		TotHg (f)	1	1	1	1		1
		MeHg(u)	1	1	1	1		1
		MeHg(f)	1	1	1	1		1
Duplicates	water	TotHg (u)	1	1	1	1		1
		TotHg (f)	1	1	1	1		1
		MeHg(u)	1	1	1	1		1
		MeHg(f)	1	1	1	1		1
		TSS	1	1	1	1		1
	fish	TotHg			1		1	
Total Number of Analyses	water	TotHg (u)	7	7	7	7		7
		TotHg (f)	7	7	7	7		7
		MeHg(u)	7	7	7	7		7
		MeHg(f)	7	7	7	7		7
		TSS	6	6	6	6		6
	fish	TotHg			13		13	

Table 4. Analytical Methods, Method Detection Level (MDL), Reporting Limit (RLs) for Analyses of Phillips Creek Samples

Analyte	MDL	RL	Units
TotHg in water by EPA Method 1631E	0.13	0.40	ng/L
MeHg in water by EPA Method 1630	0.023	0.050	ng/L
Total Hg in tissue	0.16	0.40	ng/g
Total Suspended Solids	1	5	mg/L
YSI or Hydrolab multiparameter water quality meter (GLEC or GBMc SOP FLD)			
Temperature	NA	NA	°C
pH	NA	NA	Standard Units
Dissolved oxygen	NA	NA	mg/L
Specific conductance	NA	NA	µS/cm

Table 5. Sample Containers, Preservatives, and Holding Times

Analyte	Matrix	Method	Bottle Types	Volume/ Mass	Holding Time	Preservative	Shipping	Storage
Ultra-trace Filtration	water	Brooks Applied SOP #BAL-0301	Various	Various	48 hours	0-4°C dark immediately	Cool & away from sunlight	Cool at ≤ 6°C but not frozen
Total Hg	water	EPA 1631E	FLPE or glass bottle with FLPE lined lids	125 mL	90 days	BrCl in lab within 28 days of collection (oxidation in the original sample bottle)	Cool & away from sunlight	Cool at ≤ 6°C but not frozen
Methyl Hg	water	EPA 1630	FLPE or glass bottle with FLPE lined lids	250 mL	6 months	Ship cool (0-4 °C) with no headspace and dark immediately; filter/preserve upon receipt at lab	Cool & away from sunlight	Cool at ≤ 6°C but not frozen
Total and Methyl Hg	Wet tissue	Various	4-oz. glass or plastic wide mouth jars, ziptype plastic bags, or plastic wrap	10 g	1 year	0-4 °C during shipment; ≤ -15 °C in lab	Cool & away from sunlight	≤ -15 °C
Total Suspended Solids (TSS)	water	160.2	HDPE plastic	250 mL	7 days	Laboratory filtration	Cool at ≤ 6°C but not frozen	Cool at ≤ 6°C but not frozen

References

Pine Bluff Arsenal. 2017. Plan to Achieve Compliance with the Mercury Limit at Outfall 01C, Second Year Progress Report, Pine Bluff Arsenal. Pine Bluff Arsenal, Pine Bluff, Arkansas. Document date: January 31, 2017.

Pine Bluff Arsenal. 2016. Plan to Achieve Compliance with the Mercury Limit at Outfall 01C, First Year Progress Report, Pine Bluff Arsenal. Pine Bluff Arsenal, Pine Bluff, Arkansas. Document date: January 28, 2016.

Riva-Murray, K., Bradley, P.M., Scudder Eikenberry, B.C., Knightes, C.D., Journey, C.A., Brigham, M.E. and D. T. Button. 2013. Optimizing Stream Water Mercury Sampling for Calculation of Fish Bioaccumulation Factors. *Environ. Sci. Technol.*, 47 (11):5904–5912.

Scudder Eikenberry, B.C., Riva-Murray, K., Knightes, C.D., Journey, C.A., Chasar, L.C., Brigham, M.E. and P.M. Bradley. 2015. Optimizing Fish Sampling for Fish-mercury Bioaccumulation Factors. *Chemosphere*, 135:467-473.

USEPA. 2000. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000)*. Office of Water, Washington, DC.

USEPA, 2000 (b). *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000). Technical Support Document Volume 1: Risk Assessment*. Office of Science and Technology, Office of Water. Washington, DC. EPA-822-B-00-005. August.

USEPA. 2010. *Guidance for Implementing the January 2001 Methylmercury Water Quality Criterion*. Office of Science and Technology, Office of Water. Washington, D.C. EPA-823-R-10-001. April 2010.