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Screening for PAHs and Metals in the Puget Sound Basin at Aquatic Habitats Adjacent to Mainline Railroad Tracks

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Cover photo:
A wetland at Golden Gardens Park taken by Randy Coots

Screening for PAHs and Metals in the Puget Sound Basin at Aquatic Habitats Adjacent to Mainline Railroad Tracks

by

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Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area:

WRIAs
- 1 – Nooksack
- 7 – Snohomish
- 8 – Cedar/Samish
- 12 – Chambers/Clover

HUC 8 numbers
- Nooksack – 17110004
- Snohomish – 17110011
- Puget Sound – 17110019

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Abstract

The Washington State Department of Ecology (Ecology) and others have identified polycyclic aromatic hydrocarbons (PAHs) as an impact to Puget Sound's water quality in a number of studies (Norton et al., 2011; Davies et al., 2012; Sandvik, 2013).

Railroad operations account for many possible sources of PAHs in addition to creosote-treated railroad ties. This study establishes baseline levels of PAHs and metals in soil, sediment, and water near mainline railroad lines in the Puget Sound basin.

This study found levels of PAHs and metals in a majority of the soils and sediments sampled. Monitoring immediately adjacent to railroad lines would provide a better baseline for PAHs and other parameters sampled for this study.

Introduction

Background

The Washington State Department of Ecology (Ecology) and others have identified polycyclic aromatic hydrocarbons (PAHs) as harmful to the water quality of Puget Sound (Norton et al., 2011; Davies et al., 2012; Sandvik, 2013).

Between 2007 and 2011, Ecology and other groups conducted the Puget Sound Toxics Loading Analysis (PSTLA) (Norton et al., 2011). Based on data collected from the Washington State Department of Transportation, the PSTLA study found that 794 miles of rail line run through the Puget Sound study area. The study also estimated that railroad ties leach 43 metric tons of creosote each year.

The PSTLA study reported that PAHs were present in a number of areas in the Puget Sound basin. These PAHs were concentrated enough that:

- The negative effects could be documented.
- The levels were above criteria used to protect aquatic organisms and their consumers.

Subsequently in 2012, Ecology released a PAH Chemical Action Plan (CAP) describing uses and releases within Washington State (Davies et al., 2012). Washington State uses the CAP to manage the threat of persistent, bioaccumulative, and toxic chemicals (PBTs).

Considered the "worst of the worst," PBTs remain in the environment for a long time and can be transported long distances moving between air, land, and water media. PAHs are a group of compounds that have been identified as PBTs.

The majority of PAHs come from two different sources: half from combustion emissions and about one-third from creosote-treated wood products (Norton et al., 2011). Other potential sources of PAHs released into the environment include coal and petroleum/fuel spills.

Recognizing the high (>80%) likelihood for release of PAHs to land from railroad ties statewide, the PAH Chemical Action Plan recommended a mapping exercise be conducted to evaluate where railroads intersect with sensitive aquatic areas (Davies et al. 2012). Sensitive aquatic areas near active railroads in Washington State were defined as:

- Areas with railroads near streams supporting salmonids.
- Areas of Priority Habitat and Species (PHS).
- Wetlands included in the Northwest Wetland Inventory (NWI).

Ecology conducted the mapping work in 2013 entitled, Location of Creosote-Treated Railroad Lines Near Sensitive Near-Shore Aquatic Habitats in Washington State, (Sandvik, 2013). This evaluation combined mapping of aerial photography and GIS data layers to identify railroad track locations within 300 feet of "sensitive aquatic habitat." The study recommended that the information be used to conduct environmental sampling to determine if PAHs are affecting "sensitive aquatic habitat."

Creosote is made up largely of PAHs, and creosote-treated wood railroad ties still represent the majority of ties used in railroad operations. Railroad operations consist of a number of other possible sources of PAHs in addition to the creosote-treated railroad ties. PAHs are also significant components of fossil fuels, so coal and oil are potentially PAH sources to the environment. Metals also play a role in railroad activities in addition to their being contaminants in coal and crude oil.

In 2013, Ecology's Environmental Assessment Program (EAP) received a grant from the National Estuary Program (NEP) to carry out monitoring of PAH levels along railroad lines.

In September 2014, Ecology began working with a group of stakeholders, including BNSF, UPRR, Tacoma Rail, Western Wood Preservers Institute, and Oregon State University to develop a study to assess whether elevated PAH levels are present in sensitive aquatic areas near railways with creosote-treated ties.

Based on input from stakeholders, Ecology drafted a study outline focusing on maintenance operations where treated railroad ties were being replaced since the stakeholder group felt these areas had the highest potential for PAH release.

Unfortunately, due to a lack of participation, permission, and feedback from railroad stakeholders, the study was modified to sample less representative sample areas in publically accessible locations. It was crucial that monitoring be conducted because the deadline for using NEP project funds was fast approaching.

Sampling of less representative areas was completed in 2016. Sites sampled were 50 – 200 feet down gradient from railroad lines in publically accessible areas.

Study Area and Surroundings

This study was conducted using funding from the National Estuary Program (NEP); due to the funding source, Puget Sound's drainages, wetlands, and waterways were targeted for site selection. This study used publicly owned lands in the Puget Sound basin to access study sites where surface water was located near the railroad right-of-way. General locations of study sites are shown in Figure 1.

History of study area

Around the mid-1800s logging started in the Puget Sound. Seattle was known for being the area's largest port for trade and shipbuilding, and Tacoma was known for smelting of gold, silver, copper, and lead ores. Along with the establishment of the railroad, the majority of regional industry and development was located on Puget Sound's east side. The Puget Sound has over 794 miles of railway (Norton et al., 2011).

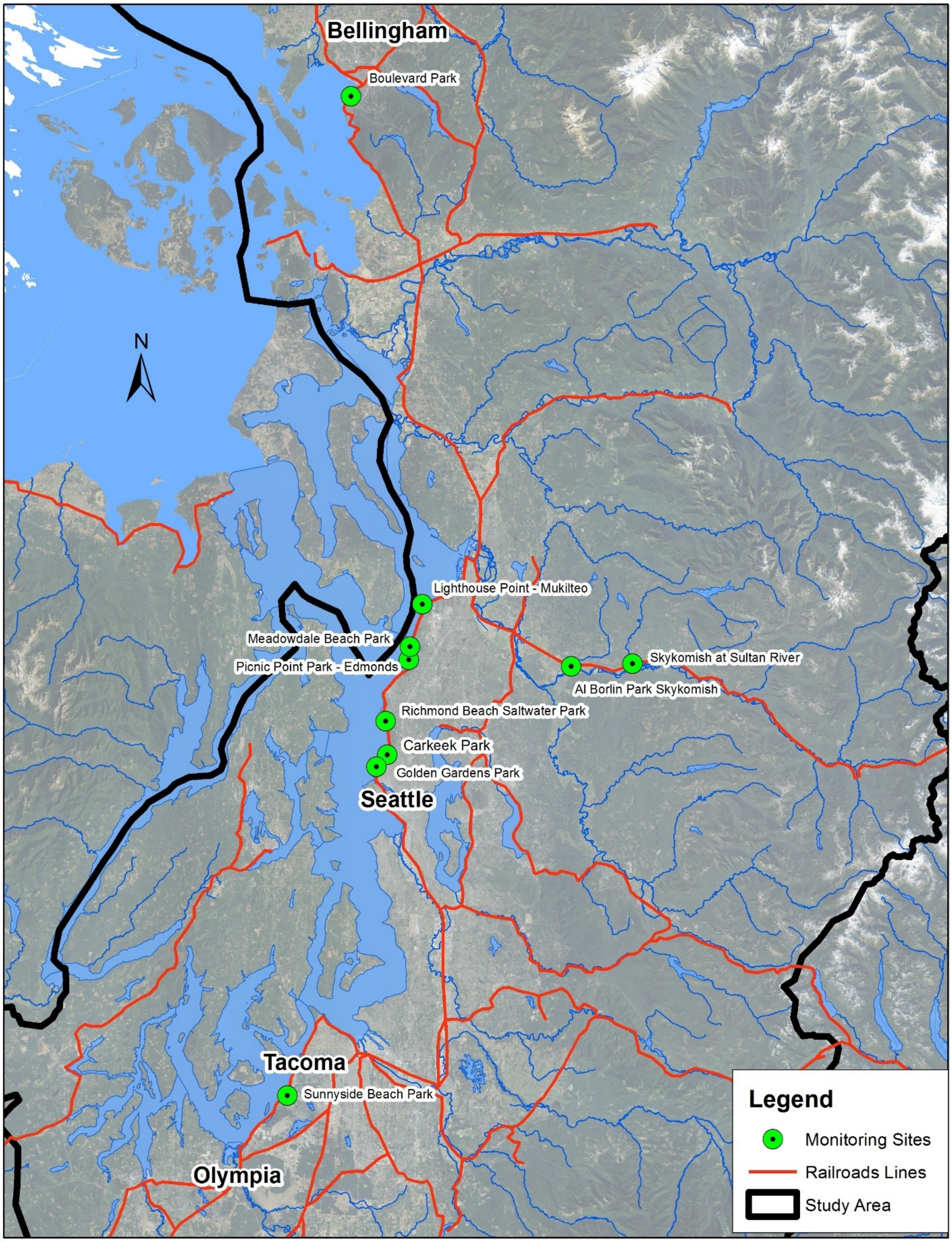

Figure 1. Sample site locations for the screening study of PAH and metals near rail lines.

Study Parameters

Parameters of interest for this study include Poly Aromatic Hydrocarbons (PAHs), Total Petroleum Hydrocarbons-diesel & waste oil (TPH-dx), and metals. For sediment and soil samples, companion total organic carbon (TOC) and grain size were also analyzed. TOC in sediment can moderate toxic effects of PAHs (NYSDEC, 2014); higher TOC content in sediment means there is larger available surface area to adsorb toxics. Some numeric sediment criteria require TOC normalized PAH concentrations for comparison. Ancillary parameters for water samples included dissolved organic carbon (DOC) and hardness. A complete list of study parameters can be found in Appendix B. Water quality criteria for parameters monitored in this study can be found in Appendix F.

Project Description

Study design and methods for this study are described in the Quality Assurance Project Plan (Coots, 2016). This study determined current concentrations of PAHs and metals within the Puget Sound basin near mainline railroad lines and adjacent to surface water. Ecology's Environmental Assessment Program (EAP) conducted the study. Soil, sediment, and water samples were collected within the Puget Sound basin at ten sites. Sample sites selected were located on publically owned land within 50 – 200 feet of a mainline railroad right-of-way and adjacent to fresh surface water.

Sediment and soil samples were analyzed for PAHs, TPH-dx, and metals along with TOC and grain size. Freshwater samples collected from surface waters were also analyzed for PAHs, metals, hardness, and dissolved organic carbon (DOC). Manchester Environmental Laboratory (MEL) conducted the chemical analyses of sediment, soil, and water. The grain size analysis was contracted out to Materials Testing and Consulting, Inc.

Project Goal and Objectives

The original intent of this study was to characterize PAH release before and after creosote railroad tie maintenance operations (replacement). Due to lack of access to railroad lines, the project goals and objectives were modified to conduct monitoring in publically owned areas near and downgradient of the railroad.

Study data will serve as a baseline to compare future conditions in these areas; data will also help in assessing possible environmental damages and degradation due to railroad accidents including spills and increased railroad traffic.

The specific goal of the modified study was to determine current levels of PAHs and metals within railroad corridors near aquatic habitats in the Puget Sound basin.

Specific objectives of the modified study were to:

- Collect soil, sediment, and freshwater water samples downgradient of mainline railroad tracks adjacent to surface waters around the Puget Sound on publically owned land. Analyze samples for PAHs, metals, TPH, TOC, DOC, hardness, and grain size.
- Establish current PAH and metal levels in soils and sediments downgradient of mainline railroad lines for future comparisons.

Study Methods

Study Overview

For this study, soil samples were collected at ten locations near surface water and mainline railroad tracks (within 50 – 200 feet). At two of the ten locations, sediment and water samples were also collected: Al Borlin Park in Monroe (ABP) and the Skykomish River at Sultan (SSR). Appendix B lists all specific study parameters analyzed.

Sampling Locations and Frequency

General sample site locations are shown in Figure 1 (above) and are listed below in Table 1. A sampling scheme detailing how sampling was generally conducted at each site can be found in Figure 2. Appendix C includes a brief description of each site and an aerial photo with sample collection sites identified. Table 1 also lists the adjacent water body, property ownership, and a latitude and longitude for the site. All sample locations were accessed through city, county, or state parks. Each study location was sampled on one occasion.

In general, sample sites were chosen based on public accessibility, proximity to railroad lines, and availability of matrices for sampling.

Table 1. Study sites and locations.

Location	Adjacent Water Body	Property Ownership	Latitude[1]	Longitude[1]
Al Borlin Park – ABP	Skykomish River at Monroe	City of Monroe	47.8549	-121.9607
Skykomish at Sultan River -SSR	Skykomish River at Sultan	City of Sultan/Private	47.8607	-121.8189
Boulevard Park – BVP	Bellingham Bay	City of Bellingham	48.7322	-122.5019
Lighthouse Park – LHP	Possession Sound	City of Mukilteo	47.9467	-122.3070
Meadowdale Beach Park – MBP	Northern Puget Sound	Snohomish County	47.8599	-122.3353
Picnic Point Park – PPP	Northern Puget Sound	Snohomish County	47.8803	-122.3338
Carkeek Park – CKP	Central Puget Sound	City of Seattle	47.7121	-122.3801
Golden Gardens Park – GGP	Central Puget Sound	City of Seattle	47.6926	-122.4042
Richmond Beach Park – RBP	Central Puget Sound	King County	47.7639	-122.3857
Sunnyside Beach Park – SBP	Southern Puget Sound	City of Steilacoom	47.1790	-122.5894

[1] = NAD83(HARN)

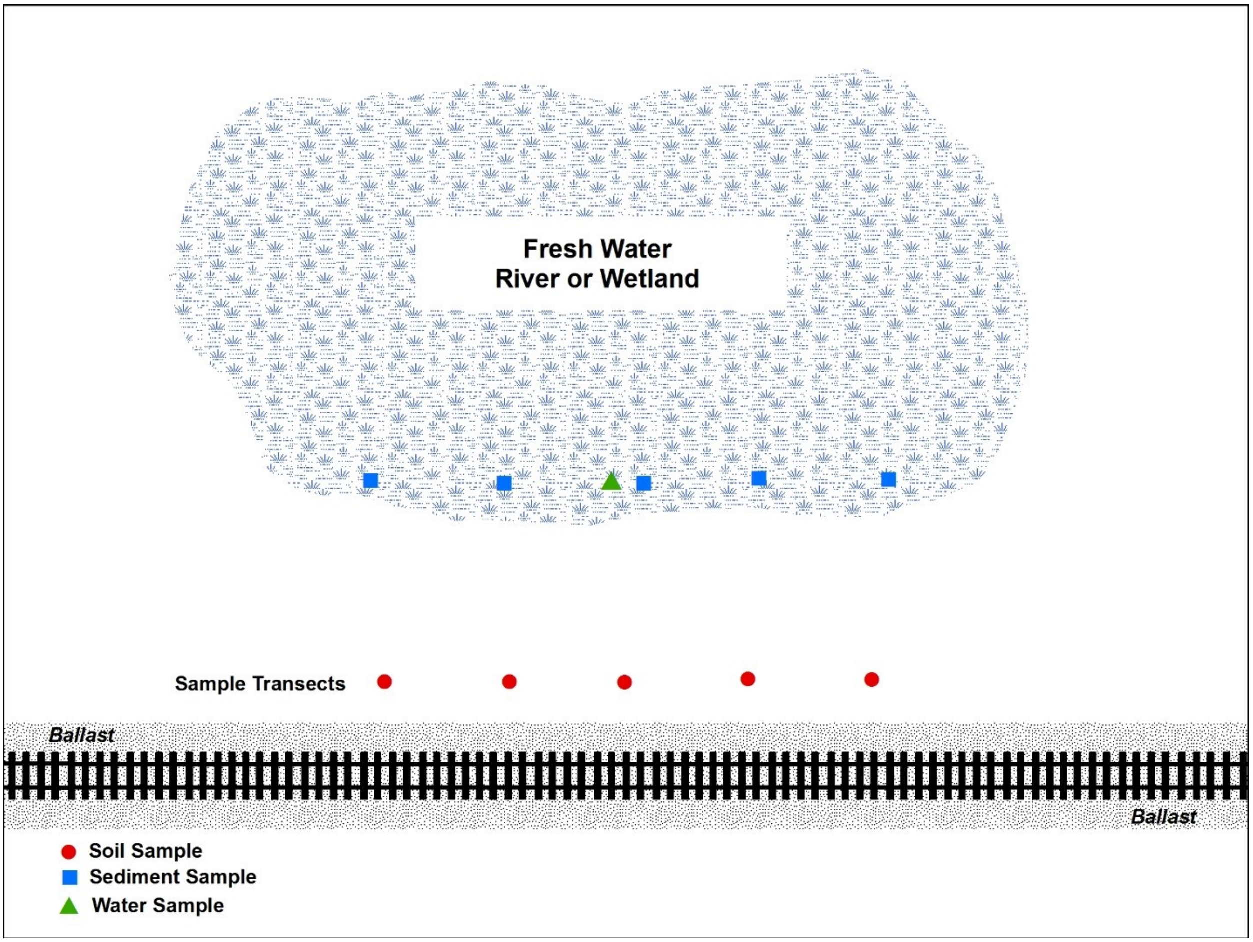

Figure 2. Sampling scheme.

Lab Procedures

Table 2 presents the list of analytes, matrices, reporting limits, sample preparation methods, and analytical methods for study site samples.

Table 2. Analytical methods and reporting limits for the study.

Analyte	Matrix	Reporting Limit	Sample Prep Method	Analytical Method
Soil or Sediment				
PAHs	Soil or Sediment	1 – 5 µg/kg	EPA 3541/3620[2]	EPA 8270D SIM[2] Isotopic Dilution
Metals[1]	Soil or Sediment	0.1 µg/kg[^]	EPA 3050[2]	EPA 6020A/7471B[^,2]
TPH-Diesel	Soil or Sediment	50 mg/kg	NWTPH-DX[5]	
TOC	Soil or Sediment	0.1%	PSEP-TOC, Combustion NDIR[3]	
Grain Size	Soil or Sediment	0.1%	PSEP 1986, Sieve and Pipet[3]	
Water				
PAHs	Water	0.05 µg/L	EPA 3535[2]	EPA 8270 SIM Isotopic Dilution[2]
Metals	Water	0.1 – 5 µg/L[*]	Filter 0.45 um, H_2SO_4 preserve	EPA 200.8/245.1[*, 2]
Hardness as $CaCO_3$	Water	0.3 mg/L	H_2SO_4 preserve	SM 2340B[4]
DOC	Water	1.0 mg/L	Filter 0.45 um	SM 5310C[4]

[1] Soil/sediment samples were analyzed as “total recoverable metals,” while water samples were analyzed as “dissolved metals.”

[2] https://www.epa.gov/measurements-modeling/collection-methods%236

[3] https://fortress.wa.gov/ecy/publications/documents/1509046.pdf

[4] https://www.standardmethods.org/

[5] https://fortress.wa.gov/ecy/publications/documents/97602.pdf

[^] Hg soil is 0.0036 mg/kg wet weight, EPA 7471B

[*] Hg is 0.05 µg/L, EPA 245.1

Laboratory Data Quality Assessment

Results were reviewed for qualitative and quantitative accuracy following the National Functional Guidelines for Organic Data Review under the Contract Laboratory Program (USEPA, 1999). Written case narratives assessing the quality of the data reports are provided by Ecology’s Manchester Environmental Laboratory (MEL). These narratives include:

- Descriptions of the analytical methods.
- A review of sample holding times.
- Instrument calibration checks.
- Blank results.
- Surrogate recoveries.
- Matrix spike recoveries.
- Laboratory control samples.

Case narratives and complete data reports can be obtained by request from the report author.

The quality assurance (QA) review verified that laboratory performance met most quality control (QC) specifications outlined in the analytical methods. The quality of the data reported here is appropriate for the intended uses. To verify that results generated for the study were of the quality needed, control sample results were compared to data quality objectives established in the Quality Assurance Project Plan for this study (Coots, 2016).

Sample Holding

Soil, sediment, and surface water samples were collected for the study and analyzed for PAHs, TPH-dx, metals, TOC, DOC, hardness, and grain size. Samples were stored in laboratory-provided sample bottles certified for the intended analyses. Immediately following collection, samples were placed in coolers containing water and ice; they were kept in the dark through the rest of each sample day. At the conclusion of the sample day, samples were driven back to Ecology Headquarters in Lacey. The following morning, Ecology's courier transported the coolers containing the study samples to MEL for analysis.

Samples were maintained under chain-of-custody from the time of collection throughout the analytical process. Preparation and analysis of all study samples was completed within the specific recommended method holding-time limits.

The grain size samples were repackaged by MEL staff and shipped to the contract laboratory, Materials Testing and Consulting, Inc. (MTC). The contract analyses were also completed within the methods recommended holding-time limit for grain size.

PAHs, Alkylated PAHs, TPH-dx, and Metals Data Quality

PAH and Alkylated PAH Data Quality

PAH samples were extracted by modifying methods SW3535A for water and SW3541 for sediment and soils. Cleanup procedures were completed by modifications to method SW3620C and the samples were analyzed by a modification of method SW8270DSIM. This analysis for PAHs is referred to by the MEL as the "NOAA PAH method." It includes the EPA's 16 priority pollutant PAHs, a standard list of alkylated PAHs, and a number of other PAHs.

Quality assurance for the PAH analyses in all sample matrices included surrogate recovery, laboratory blanks, spiked blanks, blank spike duplicates, sample duplicates, matrix spikes, and matrix spike duplicates. Analysis of a standard reference material (SRM) was included for sediment.

TPH Data Quality

The laboratory used method SW3541 (modified) for extraction and method NWTPH-DX (Northwest Total Petroleum Hydrocarbons – Diesel) for analysis of TPHD (Total Petroleum Hydrocarbons Diesel) in soils and sediment. The analyst noted that the sample results most closely matched lube oil. Results were reported as lube oil, as this was the most likely candidate.

Metals Data Quality

As seen in Table 2, the laboratory followed EPA 3050B for sample preparation and EPA 6020A for the analysis of metals in soil and sediment. For surface water, the laboratory followed EPA 200.8 for the analysis of trace metals. Mercury was prepared and analyzed using EPA 7471B (soil and sediment) and EPA 245.1 (surface water).

Hardness was calculated using Standard Method 2340B and prepared and analyzed using EPA 7471B (soil and sediment) and EPA 245.1 (surface water).

Instruments used for metals and ancillary parameter analyses (grain size, hardness, DOC, and TOC) were calibrated using proper methods. Initial and subsequent verification, blank checks, and standard residuals were within acceptable limits.

Quality assurance for the metals analyses included method blanks, laboratory control samples (LCS), duplicates, matrix spikes (MS), matrix spike duplicates (MS/MSD), and internal standards. All quality control samples met acceptance limits with the exception of MS/MSD recoveries for two samples: one for copper, chromium, and nickel and the other for zinc. Both samples were outside of the acceptance limits.

Data Analysis and Assessment Methods

Data qualifiers used for this study include the following:

J = positively identified and estimated.
NJ = tentatively identified and the associated numerical value represents an approximate concentration.
U = not detected at or above the reporting limit.

Each site’s mean concentrations were summed to determine site totals for each parameter group in order to compare the concentrations of PAHs and metals throughout the study area. Results that were positively identified or qualified “J” (estimated) or “NJ” (approximated) were used in the summed total. Results that were qualified “U” (not detected) were not included in the total summed concentrations.

The results and discussion section focuses on analytes detected throughout the study area. For each analyte presented in summary tables, statistics were calculated for the maximum, average, median, and standard deviation. Some parameters had a significant number of qualified and non-detected results. To summarize data for these parameters, the following rules were applied:

- **Maximum concentrations** – Maximum concentrations only included values not qualified or positively identified “J” by the laboratory analyst.
- **Average concentrations** – Positively identified “J” results and tentatively identified “NJ” results were used at full value. Non-detected “U” results were used at one-half the reporting limit for calculating average concentrations. Using one-half of the reporting limit assumes the concentration is not zero, but is above the detection limit and below the reporting limit. Average concentrations are not qualified in the summary table unless all results were qualified as non-detects (“U”).

- **Median concentrations and standard deviation** – The same rules used in calculating and treating average concentration qualifiers apply for median concentrations and the standard deviation of the dataset. Median concentrations and the standard deviation are only qualified if the median value is calculated using a dataset with all non-detects (“U”).

Results and Discussion

A summary of analyte detection statistics for this study is provided below and briefly discussed. For detailed concentration results, see Appendix A. Sampling was conducted from September 19 – 28, 2017.

Discussions of the results that follow are first organized based on the sample matrices of soil, sediment, and surface water, then by the specific parameters analyzed for each. Data assessment and summing methods are described in the previous methods section.

When available, existing data from Ecology's Environmental Information Management database and other studies were cited and compared to study results and discussed.

Soil

PAHs in Soil

Table 3 presents a detection summary for individual Poly Aromatic Hydrocarbon (PAH) analytes in soils classified as low molecular weight PAHs (LPAHs) and heavy molecular weight PAHs (HPAHs). Analyte detection frequency for PAHs on the priority pollutant list along with the maximum, average, and median concentrations are shown for each. More information regarding carcinogenicity to humans, toxicity to animals and aquatic life, uses, and the natural or anthropogenic sources for each PAH is provided in Appendix E, Table E-1.

Table 3. Summary of PAHs detected in soil.

pp PAH	Detections (n/52)[1]	Maximum concentration (µg/kg)[1]	Average concentration (µg/kg)[2]	Median concentration (µg/kg)[2]	SD (µg/kg)	Detection Frequency (%)
LPAHs						
Acenaphthene	28	18.3	3.0	1.6	4.9	54
1,1'-Biphenyl	52	17.1	3.0	1.9	3.2	100
1,6,7-Trimethylnaphthalene	27	39.8J	5.8	1.1	10.5	52
1-Methylnaphthalene	45	37.1	4.7	4.9	13.0	87
1-Methylphenanthrene	47	28.4	8.2	4.2	10.6	90
2,6-Dimethylnaphthalene	33	28.5	5.0	2.4	6.9	63
2-Chloronaphthalene	No detections					
2-Methylfluoranthene	43	90.9	8.6	4.7	14.7	83
2-Methylnaphthalene	33	78	8.7	4.87	13.04	63
2-Methylphenanthrene	52	62.2	9.7	5.4	12.9	100
3,6-dimethylphenanthrene	10	3.9	1.1	0.5	1.8	19
4-Methyldibenzothiophene	32	21.4	2.0	1.0	3.2	62
9H-Fluorene, 1-methyl-	25	13.1	1.4	0.5	2.0	48
Acenaphthylene	32	70.1	6.3	2.3	12.5	62
Anthracene	50	192J	15.6	5.8	34.7	96
Benzo[e]pyrene	52	641	59.1	27.2	112.4	100
Carbazole	32	53.8 J	5.5	2.5	9.4	62
Dibenzofuran	48	75.8	6.0	2.6	11.8	92
Dibenzothiophene	40	67.7	3.44	1.5	9.6	77
Fluorene	47	30	3.9	2.1	5.5	90
Naphthalene	52	87.2	12.5	7.0	14.5	100
Phenanthrene	52	342	40.8	24.7	62.6	100

pp PAH	Detections (n/52)[1]	Maximum concentration (µg/kg)[1]	Average concentration (µg/kg)[2]	Median concentration (µg/kg)[2]	SD (µg/kg)	Detection Frequency (%)
HPAHs						
Benzo[a]anthracene*	52	327	35.5	16.9	64.5	100
5-Methylchrysene*	No detections					
Benzo(a)pyrene*	52	464 J	46.7	24.8	82.7	100
Benzo(b)fluoranthene*	52	596	62.9	33.1	111.1	100
Benzo(ghi)perylene	52	498 J	46.2	25.8	86.4	100
Benzo(k)fluoranthene*	49	717	58.9	23.4	124.9	94
Benzo[e]pyrene*	52	641	59.1	27.2	112.4	100
Chrysene*	52	626	73.1	34.4	124.4	100
Dibenzo(a,h)anthracene*	44	161 J	13.5	7.7	25.9	85
Fluoranthene	51	617	73.0	41.1	120.0	98
Indeno(1,2,3-cd)pyrene*	51	353 J	24.9	13.1	52.2	98
Perylene	48	146 J	15.9	8.4	27.0	92
Pyrene	51	643	71.5	37.3	122.0	98
Retene	52	180	32.7	7.7	50.1	100
Detection Total	1502 of 1872 (80% Detection)					

Bold* = Carcinogenic PAHs

[1] = Includes positively identified "J" or "NJ" qualified results. When all results were qualified "U," concentration is flagged U. Maximum concentrations included values not qualified, positively identified "J," or tentatively identified "NJ" by the laboratory analyst.

[2] = Includes positively identified "J," "NJ," and half of the "U" qualified results.

The LPAHs are generally more volatile and water soluble than the HPAHs. The HPAHs are more persistent than the LPAHs as they resist breakdown and tend to remain in the environment longer. The carcinogenic PAHs (cPAHs) are a sub-group of the HPAHs (see items bolded with asterisks in Table 3).

There were 1,872 soil samples taken for analysis of PAHs. MEL detected PAHs in 1,502 of the samples from the ten sites, averaging an 80% rate of detection for PAHs in soils. The average detection frequency for the LPAH analyses was 71%, while the average detection frequency for the HPAHs was 90%. As an indicator of the potential to impact human health, the cPAHs had a detection frequency of 86%. The higher detection frequency for the HPAHs was somewhat expected; the LPAHs are more volatile, while the HPAHs are more resistant to breakdown.

The highest PAH concentrations were dominated by two of the ten sites sampled for the study: Carkeek Park (CKP) in Seattle and Boulevard Park (BVP) located in Bellingham.

Figure 3 presents the highest average PAH sample concentrations for each site. Analytes with less significant concentrations were not included in the figure to increase readability. As seen in the figure, Carkeek Park and Boulevard Park had consistently higher concentrations of average soil PAHs than all other sites monitored.

The only exception was for the Retene analyte at Lighthouse Park (LHP) located along Possession Sound in Mukilteo. Samples of soil were collected from LHP at a landscaped area of the park, and included the removal of a layer of “beauty bark.” Retene is ubiquitous in environments with coniferous forests and is a marker for soft wood combustion.

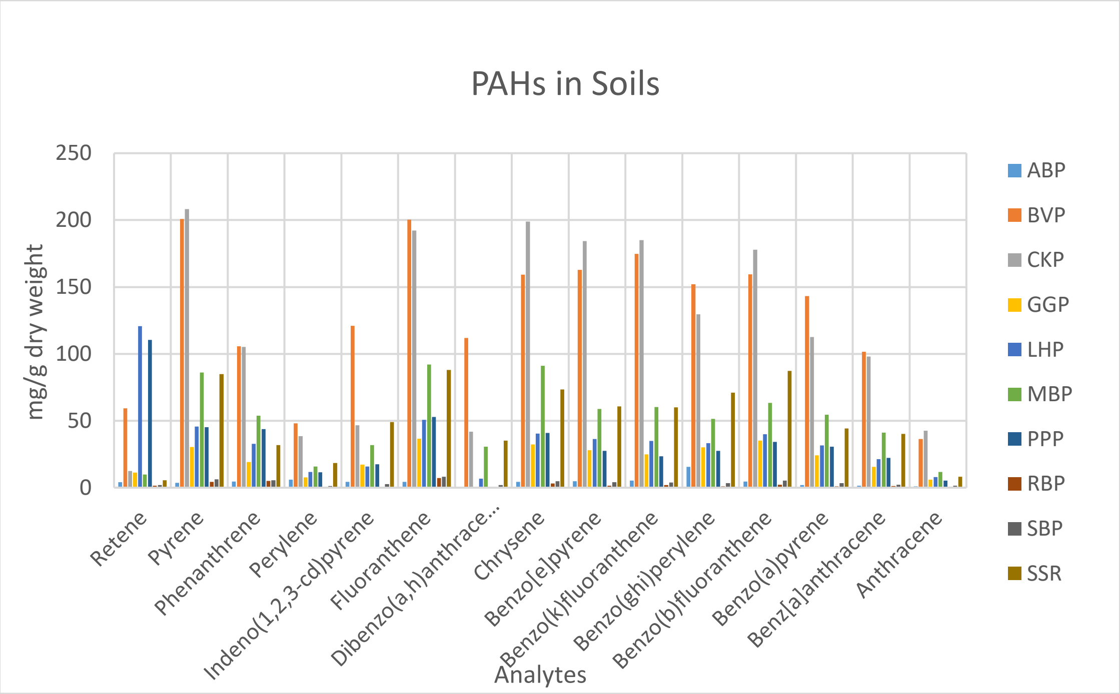

Figure 3. Highest average soil PAH concentrations.

The 2-chloronaphthalene analyte had no detections at any of the sites. Considering the many reported uses for 2-chloronaphthalene (see Appendix E, Table E-2), it was surprising to have no detections for the study.

Alkylated PAHs in Soil

Soils were analyzed for a group of 19 alkylated PAHs. A summary of detections is presented in Table 4. The analyte list for the alkylated PAHs is shown in Appendix B, Table B-1. Results are shown in Appendix A. The alkylated PAHs did not have certified analytical standards for the analyses. This lead to “NJ” (tentatively identified) qualification of almost all detected analyses. Only four of the possible 988 alkylated PAH results were reported as positively identified (“not qualified”).

The majority of the reported detections were qualified “NJ” or the analyte was “tentatively identified.” The number shown is approximate. There were 988 soil samples taken for analysis of alkylated PAHs. MEL reported detections for 621 alkylated PAHs from the ten sampling sites, averaging roughly a 63% rate of detection.

Table 4. Summary of alkylated PAHs detected in soil from the 2016 study.

Alkylated PAHs	Detections (n/52)[1]	Maximum concentration (µg/kg)[1]	Average concentration (µg/kg)[2]	Median concentration (µg/kg)[2]	SD (µg/kg)[2]	Detection frequency (%)
C1-Chrysenes	50	357 NJ	58.52	38.45	77.47	96
C1-Dibenzothiophenes	20	72.2 NJ	10.65	7.17	14.02	39
C1-Fluoranthene/Pyrene	48	578 NJ	74.55	38.3	109.36	92
C1-Fluorenes	38	144 NJ	14.34	7.99	21.56	73
C1-Naphthalenes	51	78.7 NJ	15.31	8.96	17.39	98
C1-Phenanthrenes/Anthracenes	48	204 NJ	32.88	19.75	42.16	92
C2-Naphthalenes	23	117 NJ	21.03	7.65	30.18	44
C2-Chrysenes	28	182 NJ	13.59	3.01	30.32	54
C2-Dibenzothiophenes	31	55.9 NJ	6.9	4.17	9.73	60
C2-Fluorenes	20	40 NJ	6.14	1.02	8.46	38
C2-Phenanthrenes/Anthracenes	47	152 NJ	31.09	17.8	36	90
C3-Naphthalenes	51	165 NJ	24.72	10.03	38.8	98
C3-Chrysenes	18	148 NJ	11.03	1.02	27.79	35
C3-Dibenzothiophenes	21	114 NJ	5.29	1.02	16.09	40
C3-Fluorenes	17	20.3 NJ	2.84	1.02	4.1	33
C3-Phenanthrenes/Anthracenes	31	293 NJ	17.14	4.03	49.24	60
C4-Naphthalenes	23	29.9 NJ	3.83	1.02	5.88	44
C4-Chrysenes	6	49.9 NJ	2.4	1.01	6.88	12
C4-Phenanthrenes/Anthracenes	45	180 NJ	36.07	8.27	52.6	87
Detection Total	621 of 988					

[1] = Includes positively identified "J" or "NJ" qualified results. Maximum concentrations included values not qualified, positively identified "J," or tentatively identified "NJ" by the laboratory analyst.
[2] = Includes positively identified "J," "NJ," and half of the "U" qualified results.

Alkyl PAHs are most often described as being more water soluble and more toxic than their parent compounds. When doing damage assessments for petroleum products, PAHs and alkyl PAHs are the most important analytes for assessment. Crude oil accounts for up to 85% PAHs.

The highest alkylated PAH concentrations were found at two of the ten sites sampled for the study: Carkeek Park (CKP) in Seattle and Boulevard Park (BVP) in Bellingham. Concentrations of alkylated PAHs followed similar trends as their parent compounds for each site.

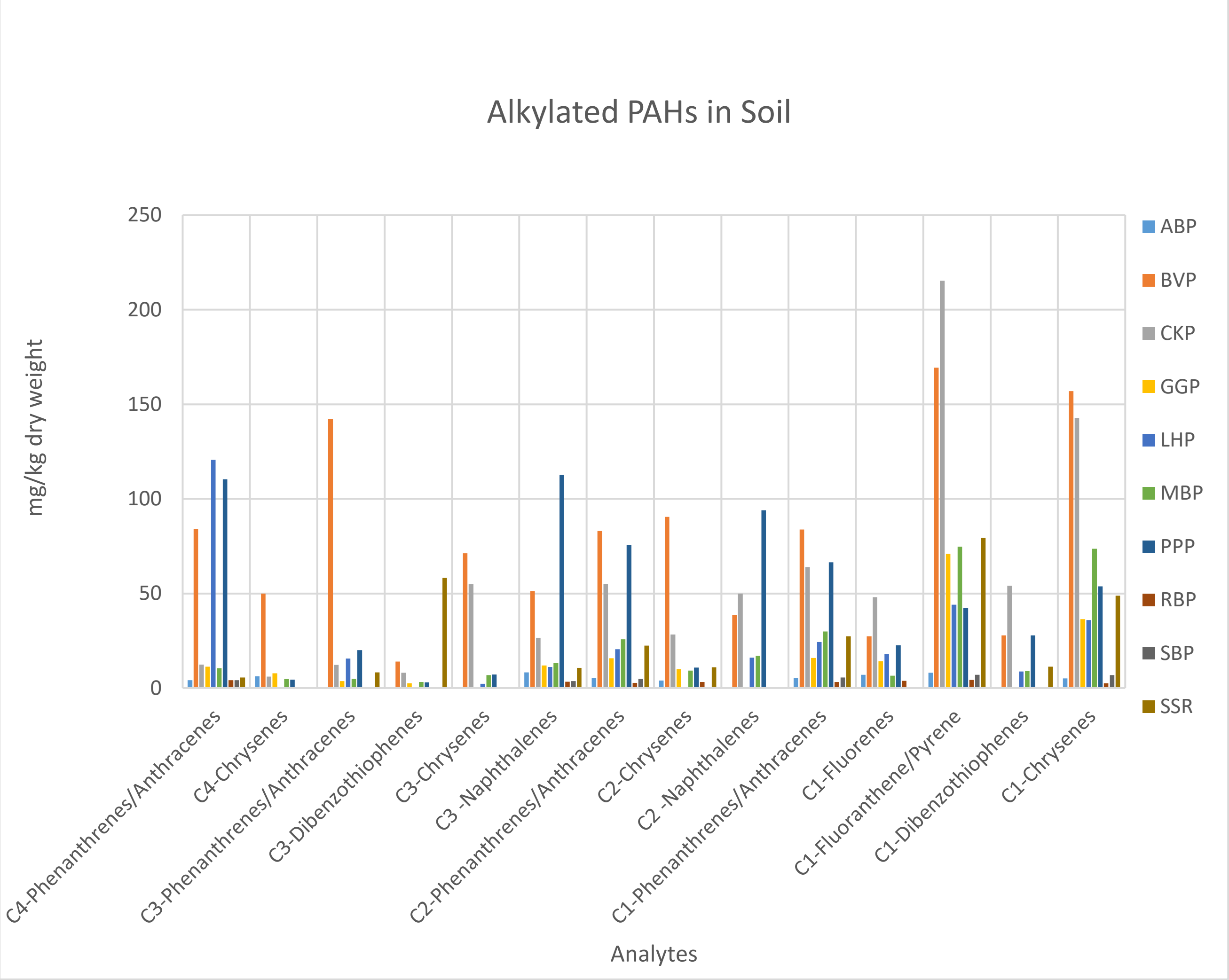

Figure 4. Highest average alkylated PAH concentrations in soil.

Total Petroleum Hydrocarbons (TPH-dx) in Soil

A summary of detection frequencies for diesel hydrocarbons in soil can be found in Table 5. MEL stated that the detected values were primarily a form of lube oil. Lube oil was detected in study area soils at a frequency of 56%.

Table 5. Summary of TPHD detected in soil.

Hydrocarbons-dx	Detections (n/52)	Maximum concentration (µg/kg)	Average concentration (µg/kg)[1]	Median concentration (µg/kg)[1]	SD (µg/kg)[1]	Detection Frequency (%)
Lube oil	29	1610	267	130	341	56

[1] = Half the value of "U" qualified results were used for calculating average, median, and standard deviation.

The maximum concentration in the study area was found at Boulevard Park (BVP) followed by Golden Gardens Park (GGP), Carkeek Park (CKP), and Lighthouse Park (LHP).

Metals in Soil

A summary of detection frequencies for the 13 metals can be found in Table 6. There were 676 soil samples taken for analysis of metals. MEL detected metals in 614 of the samples from the ten sites, averaging a 91% rate of detection.

Table 6. Summary of metals detected in soil.

Metals	**Detections (n/52)[1]**	**Maximum concentration (mg/kg)[1]**	**Average concentration (mg/kg)[2]**	**Median concentration (mg/kg)[2]**	**SD (mg/kg)[2]**	**Detection Frequency (%)**
Antimony – Sb	47	1.87	0.51	0.52	0.36	90%
Arsenic – As	52	20.8	6.17	4.52	5	100%
Beryllium – Be	52	0.4	0.23	0.25	0.07	100%
Cadmium – Cd	48	0.4	0.16	0.16	0.1	92%
Chromium – Cr	52	53.3	29.54	27.4	9.21	100%
Copper – Cu	52	53.6	25.72	24.6	13.34	100%
Lead – Pb	52	110	21.26	13.55	22.68	100%
Mercury – Hg	52	0.11	0.04	0.41	0.03	100%
Nickel – Ni	52	64	31.6	31.25	8.05	100%
Selenium – Se	42	0.63	0.35	0.36	0.15	81%
Silver – Ag	36	0.51	0.09	0.06	0.09	70%
Thallium – Tl	25	0.09	0.05	0.02	0.02	48%
Zinc – Zn	52	188	66.33	59.75	33.84	100%
Detection Total	614 of 676					

[1] = Includes positively identified and "J" qualified results. Maximum concentrations included values not qualified, positively identified "J," or tentatively identified "NJ" by the laboratory analyst.
[2] = Includes positively identified, "J" and half of the "U" qualified results.

To put the study's metals findings into perspective, results were compared to findings from the Ecology study, *Natural Background Soil Metals Concentrations in Washington State* (San Juan, 1994). The 90th percentile concentrations (in mg/kg) of samples taken in the Puget Sound were used as a comparison.

As seen in Figure 5 below, levels of arsenic, lead, copper, and zinc were found to be higher for this study in comparison to the 90th percentile natural background soil concentrations found in the 1994 study – approximately two-fold higher for arsenic and lead.

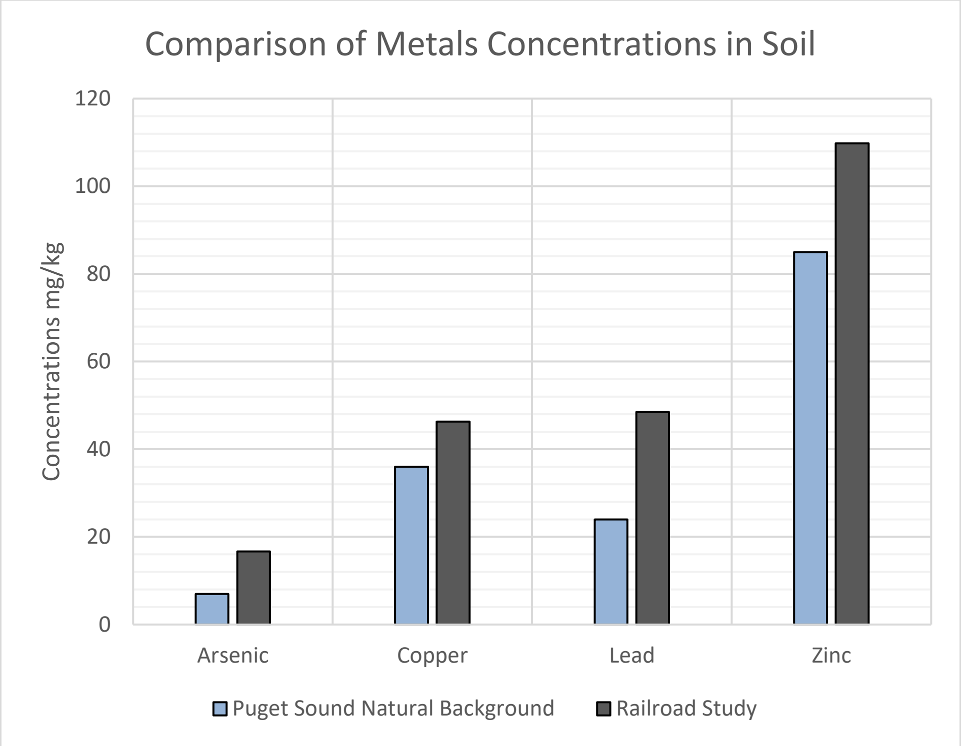

Figure 5. Comparison of metals concentration results from Railroad Study and Puget Sound Natural Background study.

Sediment

Freshwater sediment samples were obtained from two of the ten sites where soil was collected:
- Al Borlin Park (ABP) in Monroe at the east end of town.
- Skykomish River (SSR) at the confluence with the Sultan River in Sultan.

This section discusses sediment results, provides a summary of the detection frequency, and gives the maximum, average, and median study concentration for each analyte.

PAHs and Alkylated PAHs in Sediment

PAHs in Sediment

Table 7 provides a detection summary for individual priority pollutant PAH analytes in sediments along with their maximum, average, and median concentrations. More information regarding carcinogenicity to humans, toxicity to animals and aquatic life, uses, and the natural or anthropogenic sources for each PAH is provided in Appendix E, Table E-1.

Table 7. PAH in sediment detection summary.

ppPAHs	**Detections (n/7)[1]**	**Maximum concentration (µg/kg)[1]**	**Average concentration (µg/kg)[2]**	**Median concentration (µg/kg)[2]**	**Detection frequency[1]**
LPAHs					
1,1'-Biphenyl	7	1.9 J	1.2	1.1	100%
1,6,7-Trimethylnaphthalene	7	3.4	1.9	1.9	100%
1-Methylphenanthrene	5	2.87 NJ	1.1	0.9	71%
2,6-Dimethylnaphthalene	7	2.6	1.6	1.5	100%
2-Methylfluoranthene	No Detection				
4-Methyldibenzothiophene	No Detection				
9H-Fluorene, 1-methyl-	6	1.2 NJ	0.8	.7	86%
Acenaphthene	1	2.0	1.0	1.0	14%
Acenaphthylene	No Detection				
Anthracene	7	1.7	0.9	0.7	100%
Fluorene	7	3.3	1.6	1.0	100%
Naphthalene	7	3.9	2.7	2.5	100%
Phenanthrene	7	14.5	7.4	6.5	100%
1-Methylnaphthalene	7	2.1 NJ	1.2	0.4	100%
2-Methylnaphenanthrene	7	2.7	1.4	1.34	100%
2-Chloronaphthalene	No Detection				
Dibenzofuran	7	3.4	1.7	1.32	100%
Carbazole	No Detection				
3,6-dimethylphenanthrene	No Detection				
HPAHs					
5-Methylchrysene	No Detection				
Benzo[a]anthracene*	7	2.4	1.3	0.9	100%
Benzo(a)pyrene*	6	1.9 J	1.1	1.0	86%
Benzo(b)fluoranthene*	7	6.3	3.3	2.3	100%
Benzo[e]pyrene*	7	3.8	2.0	1.5	100%
Benzo(k)fluoranthene*	7	3.5	2.1	1.5	100%
Benzo(ghi)perylene	5	6.3	4.2	2.43	71%
Chrysene*	7	7.0	3.6	2.3	100%
Dibenzo(a,h)anthracene*	1	1.4 NJ	0.9	.8	14%
Fluoranthene	7	13.9	6.9	4.2	100%
Indeno(1,2,3-cd)pyrene*	6	2.3 NJ	1.4	1.3	86%
Perylene	7	35.3	21.9	9.2	100%
Pyrene	7	10.1	5.0	3.3	100%
Retene	7	32.5	14.5	10.2	100%
Detection Total	**161 of 231 (70% Detection)**				

Bold* = carcinogenic PAHs

[1] = Includes positively identified, "J" or "NJ" qualified results. When all results were qualified U, concentration is flagged U. Maximum concentrations included values not qualified, positively identified "J," or tentatively identified "NJ" by the laboratory analyst.

[2] = Includes positively identified "J," "NJ," and half of the "U" qualified results.

There were 168 sediment samples taken for the analysis of PAHs. MEL detected PAHs in 122 of the samples, averaging a 70% rate of detection for PAHs in sediments (Table 7). The detection frequency for the LPAHs was 60%, while the detection frequency for HPAHs was 83%. As an indicator of the potential to impact human health, the cPAHs had a detection frequency of 86%.

Higher detection frequency for the HPAHs was somewhat expected; the LPAHs are much more volatile, while the HPAHs are more resistant to break-down. More information regarding carcinogenicity to humans, toxicity to animals and aquatic life, uses, and sources for each PAH is provided in Appendix E, Table E-2.

Alkylated PAHs in Sediment

Results for the group of 19 alkylated PAHs analyzed in sediments are shown in Table 8. As explained earlier in this report, the majority of alkylated PAH detections were qualified as "tentatively identified" (NJ). There were 133 sediment samples taken for the analysis of alkylated PAHs. MEL detected alkylated PAHs in 82 of the samples from the two sampling sites, averaging a 62% rate of detection.

Table 8. Alkylated PAHs in sediment detection summary.

Alkylated PAHs	Detections (n/7)[1]	Maximum concentration (µg/kg)[1]	Average concentration (µg/kg)[2]	Median concentration (µg/kg)[2]	SD (µg/kg)[2]	Detection Frequency (%)
C1-Chrysenes	7	6.7 NJ	4.7	3.8	1.5	100
C1-Dibenzothiophenes	1	65.9 NJ	14.3	8.0	23.1	14
C1-Fluoranthene/ Pyrene	7	20.9 NJ	11.0	8.6	5.8	100
C1-Fluorenes	7	17.4 NJ	11.0	10.1	3.1	100
C1-Naphthalenes	7	8.6 NJ	5.3	5.44	1.7	100
C1-Phenanthrenes/ Anthracenes	7	9.1 NJ	6.1	5.82	2.2	100
C2-Naphthalenes	No Detects					
C2-Chrysenes	5	4.6 NJ	2.4	2.4	1.3	71
C2-Dibenzothiophenes	1	2.4 NJ	1.2	1.0	0.5	14
C2-Fluorenes	1	9.8 NJ	2.3	1.0	3.3	14
C2-Phenanthrenes/ Anthracenes	7	10.2 NJ	6.1	5.8	1.9	100
C3-Naphthalenes	7	13.4 NJ	8.8	8.4	2.7	100
C3-Chrysenes	No Detects					
C3-Dibenzothiophenes	No Detects					
C3-Fluorenes	2	5.4 NJ	1.8	1	1.7	29
C3-Phenanthrenes/ Anthracenes	4	5.0 NJ	2.7	2.4	1.8	57
C4-Naphthalenes	6	4.9 NJ	2.7	2.5	1.2	86
C4-Chrysenes	6	10.5 NJ	4.8	5.2	3.9	86
C4-Phenanthrenes/ Anthracenes	7	32.5	18	14.5	10.19	100
Detection Total	82 of 133					

[1] = Includes positively identified "J," or "NJ" qualified results. When all results were qualified "U," concentration is flagged U.
[2] = Includes positively identified "J," "NJ" and half of the "U" qualified results.

As described in the PAHs in Soil section, alkylated PAHs "are most often described as being more water soluble and more toxic than their parent compounds."

TPH-dx in Sediment

The diesel fraction of total petroleum hydrocarbons (TPH-dx) is specific to the diesel range of hydrocarbons and semi-volatile petroleum products. No positive identification could be made with the analysis. Due to the small sample size and lack of positive detections, summary statistics were not calculated for this analyte.

Metals in Sediment

A summary of detection frequencies for the 13 metals in sediment can be found in Table 9. There were 91 sediment samples taken for analysis of metals. MEL detected metals in 87 of the samples from two sampling sites, averaging a 96% rate of detection.

Table 9. Metals in sediment detection summary.

pp Metals	Detections (n/7)[1]	Maximum concentration (mg/kg)[1]	Average concentration (mg/kg)[2]	Median concentration (mg/kg)[2]	SD (mg/kg)[2]	Detection Frequency (%)
Antimony – Sb	7	0.64	0.44	0.42	0.11	100
Arsenic – As	7	18.2	11.66	10.9	2.93	100
Beryllium – Be	7	0.367	0.27	0.25	0.05	100
Cadmium – Cd	7	0.19	0.14	0.13	0.03	100
Chromium – Cr	7	5.82	4.07	39.6	8.28	100
Copper – Cu	7	52.2	39.36	38.6	6.46	100
Lead – Pb	7	8.36	6.28	5.68	1.18	100
Mercury – Hg	7	0.05	0.04	0.04	0.01	100
Nickel – Ni	7	49.6	34.9	33.4	6.08	100
Selenium – Se	7	0.63	0.49	0.49	0.07	100
Silver – Ag	3	0.062	0.04	0.025	0.017	43
Thallium – Tl	7	0.09	0.06	0.06	0.01	100
Zinc – Zn	7	88.3	63.41	59.7	11.21	100
Detection Total	87 of 91					

[1] = Includes positively identified, “J” qualified results.
[2] = Includes positively identified, “J,” “NJ,” and half of the “U” qualified results.

Surface Water

Freshwater samples were collected and analyzed from two sample sites, Al Borlin Park (ABP) in Monroe at the east end of town, and the Skykomish River (SSR) at the confluence with the Sultan River in Sultan. Surface water sample analysis included: pp PAHs, pp metals, DOC, and hardness.

PAHs in Surface Water

PAHs were not detected in surface water at either site. Detection limits for surface water PAH analyses are listed in Table 2.

Metals in Surface Water

A summary of detection frequencies for the 13 metals in surface water is shown in Table 10. Metals were analyzed as dissolved. Only six metals were detected in the surface water samples: arsenic, chromium, copper, lead, nickel, and zinc. The overall detection frequency was 40%.

Table 10. Dissolved metals in surface water detection summary.

pp Metals	Detections (n/6)	Maximum concentration (µg/L)[1]	Average concentration (µg/L)[1]	Median concentration (µg/L)[1]	SD (µg/L)[1]	Detection Frequency (%)
Antimony – Sb	0	0.1 U	0.1 U	0.1 U	1.52E-17	0
Arsenic – As	6	1.09	0.882	0.88	0.21	100
Beryllium – Be	0	0.05 U	0.05 U	0.05 U	7.60E-18	0
Cadmium – Cd	0	0.01 U	0.01 U	0.01 U	0.00E+00	0
Chromium – Cr	6	0.18	0.16	0.17	0.02	100
Copper – Cu	6	1.53	0.98	0.99	0.58	100
Lead – Pb	3	0.36	0.021	0.02	0.01	50
Mercury – Hg	0	0.03 U	0.03 U	0.03 U	3.80E-18	100
Nickel – Ni	6	0.58	0.33	0.32	0.22	100
Selenium – Se	0	0.05 U	0.05 U	0.05 U	7.60E-18	0
Silver – Ag	0	0.01 U	0.01 U	0.01 U	0.00E+00	0
Thallium – Tl	0	0.05 U	0.05 U	0.05 U	7.60E-18	0
Zinc – Zn	4	8.5	3.27	2.75	3.05	67
Detection Total	31 0f 78					

[1] = Includes non-detected values qualified "U" using half of the detected value. (When all results are qualified as "U," statistics concentrations in the table are qualified "U.")

Conclusions

PAHs

- PAHs were found ubiquitously throughout the study area in soils and sediment, but not detected in the two adjacent freshwater bodies tested.
- The heavier weight PAHs were detected more frequently and at higher concentrations than the lighter weight, more volatile PAHs in soils and sediment.
- The more persistent, bioaccumulative, and toxic alkylated PAHs were detected in 62% of samples; they were found at lower concentrations than their parent compounds, but were tentatively identified through lab analysis.

Metals

- Metals were found in all three matrices throughout the study area, detected at a frequency of 97% in sediment, 91% in soil, and 40% in water.
- Among the metals, zinc was found at the highest concentration in soil, sediment, and water.
- Copper, nickel, chromium, and arsenic were detected frequently for all matrices.
- The metal concentrations found in this study were higher than the 90th percentile of natural background soil metals concentrations found in the study *Natural Background Soil Metals Concentrations in Washington State* (San Juan, 1994).

TPH-dx

- Diesel hydrocarbons were found in the form of “lube oil” in soils, but not in sediment at a detectable level.

Recommendations

Results of this 2016 study support the following recommendations:

- Sampling should be done immediately adjacent to the railway in order to provide a better characterization of PAHs and other pollutants associated with the railway.
- Sites found to have elevated metals (above the 90th percentile Puget Sound natural background levels) should be studied further to better determine toxic contributions from the railroad in comparison to upslope land use.
- Railway traffic at the time of the study should be quantified at each site to compare changes in future PAH and metals concentrations in relation to railway traffic.
- Due to the low concentrations of PAHs, metals, and TPH-dx in surface water, future monitoring efforts should primarily target upland soils and with a secondary focus on sediments.

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Appendices

Appendix A. Analyte Results

Analyte concentrations for this study are provided below and briefly discussed.

Discussions of the results that follow are first organized based on the sample matrices of soil, sediment, and surface water, then by the specific sites and parameters analyzed for each.

Data assessment and summing methods are described in the methods section of the main body of this report.

Soil

Priority Pollutant Polycyclic Aromatic Hydrocarbons (PAH) in Soil

Table A-1 presents the priority pollutant (pp) PAHs in soil reported for the study. Total PAH concentrations were calculated for the low molecular weight PAHs (LPAHs), high molecular weight PAHs (HPAHs), total pp PAHs and carcinogenic PAHs for each study site. Five soil samples were collected for each study site. The site's mean concentrations were summed to determine site totals. As described earlier in the *Data Analysis and Assessment Methods* section of this report, results that were positively identified or qualified "J" (estimated) or "NJ" (approximated) were used in the summed total. Results that were qualified "U" (not detected) were not included in the total summed concentrations.

Table A-1 Priority pollutant LPAHs, HPAHs, and carcinogenic PAHs in soil (µg/kg, dry weight).

Location	pp LPAH [1]	pp HPAH[2]	Total pp PAHs[3]	Total cPAHs[4]
Richmond Beach Park – RBP	10.9 J	19.8 J	30.7 J	9.16 J
Sunnyside Beach Park – SBP	8.70 J	37.0 J	45.7 J	22.4 J
Al Borlin Park – ABP	9.76	32.6	42.4	18.5
Golden Gardens Park – GGP	36	234 J	270	142 J
Lighthouse Park – LHP	65.7	302	368	176
Picnic Point Park – PPP	72.4	294	366	169
Skykomish at Sultan – SSR	49.3	554	603	339
Meadowdale Beach Park – MBP	90.7	551 J	642	329 J
Carkeek Park – CKP	222 J	1318 J	1540 J	880 J
Boulevard Park – BVP	182 J	1420 J	1602 J	880 J

J: Analyte positively identified; value is an estimate.

[1] number of samples taken = 6

[2] number of samples taken = 10

[3] number of samples taken = 16

[4] number of samples taken = 6

Other Standard Non-pp, Other Requested, and Alkylated PAHs in Soil

Table A-2 below shows study results for the eight "other standard non-priority pollutant PAHs," the 11 "other requested PAHs," and the 19 alkylated PAHs analyzed from soil. Data are presented as total concentrations for detected and tentatively identified compounds, and were calculated using the mean concentration of five samples for each site.

For the analyses of the alkylated PAHs MEL did not have the analyte standards available for the development and verification of a standard curve. As seen in Table A-2, results were qualified as "NJ" or the presence of the analyte has been "tentatively identified" and the associated numerical value represents the "approximate concentration."

Table A-2. Other standard, other requested, and alkylated non-priority pollutant PAHs in soil (µg/kg, dry weight).

Location	Other Standard Non-pp PAHs		Other Requested PAHs		Alkylated PAHs	
Richmond Beach Park – RBP	2.51	J	3.29	J	20.8	NJ
Sunnyside Beach Park – SBP	4.13	J	6.92	J	27.1	NJ
Al Borlin Park – ABP	13.1	J	10.6	J	60.6	NJ
Golden Gardens Park – GGP	26	J	33.8		196	NJ
Lighthouse Park – LHP	147		52		344	NJ
Picnic Point Park – PPP	174	J	135	J	722	NJ
PAHSkykomish at Sultan – SSR	34.4		84.8		253	NJ
Meadowdale Beach Park – MBP	46.1	J	91.3		311	NJ
Carkeek Park – CKP	86.4	J	242	J	750	NJ
Boulevard Park – BVP	172	J	259	J	1025	NJ

J: Analyte positively identified; value is an estimate.
NJ: Analyte tentatively identified.

Total Petroleum Hydrocarbons (TPH-dx) in Soil

The diesel fraction of total petroleum hydrocarbons (TPH-dx) was measured in soil (Table A-3). This analysis is specific to the diesel range of hydrocarbons and semi-volatile petroleum products. The analyst described the compound as closest to "lube oil."

Table A-3. TPH-dx (lube oil) reported for soils (mg/kg, dry weight).

Location	TPH-dx
Richmond Beach Park – RBP	38.0 U
Sunnyside Beach Park – SBP	38.4 U
Al Borlin Park – ABP	47.0 U
Golden Gardens Park – GGP	**613**
Lighthouse Park – LHP	**551**
Picnic Point Park – PPP	**270**
Skykomish at Sultan – SSR	**237**
Meadowdale Beach Park – MBP	**171**
Carkeek Park – CKP	**593**
Boulevard Park – BVP	**762**

Bolded values indicate detected results.
U: Not detected at the detection limit shown.

Metals in Soil

Soil samples were analyzed as "total recoverable metals." Mean concentrations are shown for all 13 metals from each of the ten sample sites in Table A-4. Figures showing the metals results are available in Appendix C.

Table A-4. Priority pollutant metals in soils (mg/kg, dry weight).

Metals	SSR	SBP	RBP	PPP	MBP	LHP	GGP	CKP	BVP	ABP	Study Mean[1]
Antimony	0.70	0.17	0.08	**1.05**	0.51	0.52	0.46	0.55	0.60	0.55	0.52
Arsenic	**17.0**	2.74	2.05	5.25	2.76	5.47	6.44	2.66	5.07	13.7	6.31
Beryllium	0.29	0.21	0.18	0.29	0.15	0.26	**0.29**	0.11	0.28	0.27	0.23
Cadmium	0.24	0.08	0.05	0.26	0.08	0.21	0.20	0.09	**0.28**	0.14	0.16
Chromium	**42.8**	24.4	25.8	36.6	18.3	32.9	32.5	19.4	26.9	39.4	29.9
Copper	**45.6**	13.3	10.9	30.1	14.2	28.3	28.3	18.4	31.7	43.3	26.4
Lead	38.1	7.07	3.92	**40.0**	29.4	15.5	17.8	34.5	20.4	7.34	21.4
Mercury	0.06	0.01	0.01	**0.08**	0.02	0.05	0.06	0.03	0.05	0.05	0.04
Nickel	34.6	26.7	39.7	**41.2**	21.6	33.0	35.3	23.3	30.0	33.6	31.9
Selenium	0.50	0.29	0.24	0.43	0.18	0.36	0.43	0.26U	**0.51**	0.50	0.36
Silver	0.07	0.05U	0.05U	**0.20**	0.12	0.09	0.06	0.15	0.08	0.07	0.09
Thallium	0.07	0.05U	0.05U	0.04	0.05U	0.05	0.06	0.05U	**0.08**	0.07	0.05
Zinc	83.9	54.5	30.7	84.4	47.1	83.8	**95.3**	45.9	87.4	60.4	67.3

Bold: Highest study pp metal result.

[1]: For calculating study means, non-detected values ("U") used half of the value of the result shown.

Sample Sites: SSR: Skykomish River at Sultan; SBP: Sunnyside Beach Park; RBP: Richmond Beach Park; PPP: Picnic Point Park; MBP: Meadowdale Beach Park; LHP: Lighthouse Park; GGP: Golden Gardens Park; CKP: Carkeek Park; BVP: Boulevard Park; ABP: Al Borlin Park.

Total Organic Carbon and Grain Size in Soil

Total organic carbon (TOC) and fines are reported as a mean percent for each study location (Table A-5). The result reported for each site is the mean of the five subsamples collected at each soil site. Grain size measurements for the study are reported as a percent fines. Fines are defined as the total percent of all silts and clays within a sample.

Table A-5. Total organic carbon and fines reported for soils (%).

Location	TOC	Fines
Richmond Beach Park – RBP	0.45	0.90
Sunnyside Beach Park – SBP	0.36	2.04
Al Borlin Park – ABP	0.74	28.9
Golden Gardens Park – GGP	4.54	11.8
Lighthouse Park – LHP	4.96	19.5
Picnic Point Park – PPP	4.76	10.9
Skykomish at Sultan – SSR	2.41	24.7
Meadowdale Beach Park – MBP	2.16	2.83
Carkeek Park – CKP	7.51	1.47
Boulevard Park – BVP	4.47	12.2

Sediment

Freshwater sediment samples were collected and analyzed from two of the ten sample sites where soil was collected for analysis. Only two sites were selected due to the availability of surface water at sites for collection. Samples were collected from Al Borlin Park (ABP) in Monroe at the east end of town, and the Skykomish River (SSR) at the confluence with the Sultan River in Sultan.

Priority Pollutant PAHs in Sediment

Table A-6 shows the PAH concentrations reported in sediment. Total concentrations are presented for the priority pollutant (pp) PAHs.

Table A-6. Priority pollutant lower molecular weight PAHs (LPAHs), high molecular weight PAHs (HPAHs), and carcinogenic PAHs (cPAHs) in sediment (µg/kg, dry weight).

Location	pp LPAH[1]	pp HPAH[2]	Total pp PAHs [3]	Total cPAHs[4]
Al Borlin Park – ABP	12.4	15.8	28.2	8.43
Skykomish at Sultan – SSR	4.65	42.8	47.5	18.7

[1] number of samples = 6
[2] number of samples = 10
[3] number of samples = 16
[4] number of samples = 6

Other Non-Priority Pollutant and Alkylated PAHs in Sediment

Table A-7 shows other non-priority pollutant standard and requested PAHs analyzed from sediment for the study. Data are presented as total concentrations for all other non-pp PAHs analyzed. A total sum for pp PAHs and non-pp PAHs analyzed for the study is also shown. Due to the tentative identification and the concentration of alkylated PAHs being approximated, they were not included in other PAH totals but totaled separately.

Table A-7. Other non-pp PAHs, total pp and non-pp PAHs, and alkylated PAHs in sediment (µg/kg, dry weight).

Location	Other non-pp PAHs	Total pp and non-pp PAHs	Alkylated PAHs
Skykomish at Sultan – SSR	47.7	95.2	92.4 NJ
Al Borlin Park – ABP	49.7	77.9	100 NJ

NJ: Analyte tentatively identified.

TPH-dx in Sediment

Table A-8 presents the results for the analysis of TPH-dx in sediment. This analysis is specific to the diesel range of hydrocarbons and semi-volatile petroleum products. The analyst described the sample compounds as closest to "lube oil" in their constituents. No positive identification could be made with the analysis.

Table A-8. Mean TPH-dx reported from sediment (mg/kg, dry weight).

Location	TPH-dx
Al Borlin Park – ABP	91.9 U
Skykomish at Sultan – SSR	64.8 U

U: Not detected at the detection limit shown.

Metals in Sediment

The pp metals analyses for the sediment samples were analyzed as “total recoverable metals.” In Table A-9, the pp metals results from sediment are shown for all 13 metals from the two sample sites (ABP and SSR).

Table A-9. Priority pollutant metals in sediment (mg/kg, dry weight).

pp Metal	ABP	SSR	Study Mean[1]
Antimony	0.47	0.35	0.41
Arsenic	12.2	10.4	11.3
Beryllium	0.27	0.25	0.26
Cadmium	0.14	0.13	0.14
Chromium	43.3	34.4	38.8
Copper	40.8	35.9	38.3
Lead	6.02	6.91	6.46
Mercury	0.04	0.032	0.04
Nickel	36.8	30.3	33.5
Selenium	0.50	0.46	0.48
Silver	0.04	0.05 U	0.04
Thallium	0.07	0.06	0.062
Zinc	64.3	61.2	62.8

ABP: Al Borlin Park
SSR: Skykomish River at Sultan
[1]: For calculating study means, non-detected values (“U”) used half of the value of the result shown.
U: Not detected at the detection limit shown.

Total Organic Carbon and Grain Size in Sediment

Table A-10 presents total organic carbon (TOC) and grain size/fines (silts and clay) reported in sediment for the study.

Results are reported as a mean percent for each of the two study locations. The single result reported for each of the two sites is a mean of the five subsamples collected from ABP and two subsamples collected from SSR.

Table A-10. Total organic carbon and fines reported for sediment (%).

Location	TOC	Mean Fines Per Site (%)
Al Borlin Park – ABP	1.14	15.0
Skykomish at Sultan – SSR	0.62	39.2

Surface Water

Freshwater was collected and analyzed from two of the ten sample sites where soil and sediment were also collected: Al Borlin Park (ABP) in Monroe and Skykomish at Sultan River (SSR) in

Sultan. Only two sites were selected due to the availability of surface water at sites for collection. The analyses of surface water samples included pp PAHs, pp metals, DOC, and hardness.

Priority Pollutant PAHs in Surface Water

The surface water samples had no detections of PAHs. To get a sense of how low of a detection limit the analyst was able to achieve, Table A-11 lists the range of detection limits reported for the LPAHs, HPAHs, and other requested PAHs.

Table A-11. Detection limits reported for PAHs in surface water (µg/L, ppb).

PAH Group	ABP	SSR
LPAHs	0.0510U – 0.0521U	0.0513U – 0.0549U
HPAHs	0.0510U – 0.0521U	0.0513U – 0.0549U
Standard non pp PAHs	0.0510U – 0.0521U	0.0513U – 0.0549U
(4-Methyldibenzothiophene)[1]	1.02U – 1.04U	1.03U – 1.10U

[1]: 4-Methyldibenzothiophene is listed separately due to higher detection limits than other PAHs.
U: Not detected at the detection limit shown.

Alkylated PAHs in Surface Water

No detections were reported for the alkylated PAH analyses. The detection limits the analyst was able to achieve are listed below in Table A-12.

Table A-12. Detection limits reported for alkylated PAHs in surface water (µg/L, ppb).

	ABP	SSR
Alkylated PAHs	0.0510U – 0.0521U	0.0513U – 0.0549 U

U: Not detected at the detection limit shown.

Metals in Surface Water

All 13 of the metals in surface water samples were analyzed as “dissolved” and the results are presented in Table A-13. The study mean is also included in Table A-13.

Table A-13. Dissolved metals in surface water (µg/L).

pp Metal	ABP	SSR	Study Mean[1]
Antimony – Sb	20.0 U	20.0 U	20.0 U
Arsenic – As	**1.07**	**0.70**	**0.89**
Beryllium – Be	0.10 U	0.10 U	0.10 U
Cadmium – Cd	0.20 U	0.20 U	0.20 U
Chromium – Cr	**0.17**	**0.15**	**0.16**
Copper – Cu	**1.51**	**0.45**	**0.98**
Lead – Pb	**0.03**	0.20 U	**0.07**
Mercury – Hg	0.05 U	0.05 U	0.05 U
Nickel – Ni	**0.54**	**0.13**	**0.34**
Selenium – Se	0.20 U	0.20 U	0.20 U
Silver – Ag	0.20 U	0.20 U	0.20 U
Thallium – Tl	0.10 U	0.10 U	0.10 U
Zinc – Zn	**5.6**	**0.97**	**3.3**

Bold: Value exceeds a water quality criterion.
ABP: Al Borlin Park
SSR: Skykomish River at Sultan
[1]: For calculating study means non-detected values (“U”) used half of the value of the result shown.

Dissolved Organic Carbon and Hardness in Surface Water

Table A-14 presents the study results for dissolved organic carbon (DOC) and hardness reported in surface water.

Table A-14. DOC and hardness in surface water (mg/L).

Location	DOC	Hardness
Al Borlin Park – ABP	3.2	24.3
Skykomish at Sultan – SSR	1.1	16.5

Appendix B. Study Parameters and Parameter Descriptions

Table B-1. Study analytes included the following organic compounds, metals, and conventionals.

PAHs	Alkyl PAHs	Metals	Other
Acenaphthene[1]	C1-Chrysenes	Antimony (Sb)	TOC
Acenaphthylene[1]	C1-Dibenzothiophenes	Arsenic (As)	DOC
Anthracene[1]	C1-Flouranthene/Pyrene	Beryllium (Be)	Hardness
Flourene[1]	C1-Flourenes	Cadmium (Cd)	Grain Size
Naphthalene[1]	C1-Naphthalenes	Chromium (Cr)	
Phenanthrene[1]	C1-Phenanthrenes/Anthracenes	Copper (Cu)	
Benzo[a]anthracene[2*]	C2-Naphthalenes	Lead (Pb)	
Benzo(a)pyrene[2*]	C2-Chrysenes	Mercury (Hg)	
Benzo(b)flouranthene[2*]	C2-Dibenzothiophenes	Nickel (Ni)	
Benzo(k)flouranthene[2*]	C2-Flourenes	Selenium (Se)	
Benzo(ghi)perylene[2]	C2-Phenanthrenes/Anthracenes	Silver (Ag)	
Chrysene[2]	C3-Naphthalenes	Thallium (Tl)	
Dibenzo(a,h)anthracene[2*]	C3-Chrysenes	Zinc (Zn)	
Flouranthene[2]	C3-Dibenzothiophenes		
Indeno(1,2,3-cd)pyrene[2*]	C3-Flourenes		
Pyrene[2]	C3-Phenanthrenes/Anthracenes		
1,1'-Biphenyl	C4-Naphthalenes		
1,6,7-Trimethylnaphthalene	C4-Chrysenes		
1-Methylnaphthalene	C4-Phenanthrenes/Anthracenes		
1-Methylphenanthrene			
2,6-Dimethylnaphthalene			
2-Chloronaphthalene			
2-Methylflouranthene			
2-Methylnaphthalene			
2-Methylphenanthrene			
4-Methyldibenzothiophene			
5-Methylchrysene			
9H-Flourene, 1-methyl-			
Benzo[e]pyrene			
3,6-dimethylphenanthrene			
Dibenzofuran			
Dibenzothiophene			
Carbazole			
Perylene			
Retene			

[1] = LPAH
[2] = HPAH
Bold* = carcinogenic PAHs

Poly Aromatic Hydrocarbons, Alkylated PAHs, Total Petroleum Hydrocarbons, and Metals

Priority Pollutant PAHs

Poly Aromatic Hydrocarbons (PAHs) are a group of around 10,000 compounds characterized by two or more aromatic (benzene) rings of carbon and hydrogen. In the environment, PAHs are almost always found as a mixture. Of the numerous possible compounds, 16 have been the focus of the majority of research and are considered priority pollutants (pp) by the United States Environmental Protection Agency (USEPA) under the federal Clean Water Act (e-CFR, 2016). The International Agency for Research on Cancer (IARC) suggests that several are known as possible or probable carcinogens for humans (IARC, 2010). The pp PAHs are usually divided into three groups: low molecular weight polycyclic aromatic hydrocarbons (LPAHs), high molecular weight polycyclic aromatic hydrocarbons (HPAHs), and carcinogenic polycyclic aromatic hydrocarbons (cPAHs). The 16 pp PAHs are listed below:

Low Molecular Weight PAHs (LPAHs)
Acenaphthene
Acenaphthylene
Anthracene
Fluorene
Naphthalene
Phenanthrene

High Molecular Weight PAHs (HPAHs)
Benzo(a)anthracene*
Benzo(a)pyrene*
Benzo(b)fluoranthene*
Benzo(k)fluoranthene*
Benzo(g,h,i)perylene
Chrysene*
Dibenzo(a,h)anthracene*
Fluoranthene
Indeno(1,2,3-c,d)pyrene*
Pyrene

*Designated as probable human carcinogens (cPAHs) by EPA.

The LPAHs are generally more water-soluble and volatile than the HPAHs. The HPAHs tend to be more resistant to oxidation, reduction, and vaporization. The LPAHs have significant acute toxicity to aquatic organisms, whereas the HPAHs do not. While the HPAHs do not exhibit toxicity to aquatic organisms like the LPAHs, seven of the ten HPAHs make up the cPAH group designated as probable human carcinogens.

Alkylated PAHs

Alkylated PAHs are more abundant, generally persist for a longer time, and are sometimes more toxic than the parent PAH. Alkyl substitution usually decreases water solubility, while also tending to bioaccumulate to a greater degree. Within a PAH family series, toxicity increases with increasing alkyl substitution. Alkyl substituted PAHs may have more phototoxicity potential compared to the parent or unsubstituted compounds (Irwin et al., 1997). These characteristics could be considered more of a toxic threat to the environment than their parent PAH compounds, even though they have no water quality criteria (Appendix F).

Selected alkylated PAHs were also measured in addition to the EPA's 16 pp PAHs described above. Targeted alkylated PAHs are from the EPA's 16 pp PAHs, or parent PAH compounds, that have one or more alkyl group attachments. A number of petroleum-related PAHs have alkyl group substitution on their ring structure. These alkyl groups generally have one to four saturated carbon atoms that can make many structural isomers and homologs possible for each PAH family. Crude oils contain primarily the alkyl homologs of aromatic compounds and relatively small quantities of the unsubstituted parent aromatic structures (Irwin et al., 1997). The target alkylated PAHs are listed below:

Alkylated PAHs

- C1-Naphthalenes
- C2-Naphthalenes
- C3-Naphthalenes
- C4-Naphthalenes
- C1-Fluorenes
- C2-Fluorenes
- C3-Fluorenes
- C1-Dibenzothiophenes
- C2-Dibenzothiophenes
- C3-Dibenzothiophenes
- C1-Phenanthrenes/Anthracenes
- C2-Phenanthrenes/Anthracenes
- C3-Phenanthrenes/Anthracenes
- C4-Phenanthrenes/Anthracenes
- C1-Fluoranthene/Pyrene
- C1-Chrysenes
- C2-Chrysenes
- C3-Chrysenes
- C4-Chrysenes

The abundance, persistence, and potential toxicity of alkylated PAHs are a concern for the environment. While alkyl PAHs do not have water quality criteria, their presence in combination with other toxic contaminants can provide information on the potential toxicity at a site while also establishing a baseline for future comparison.

Total Petroleum Hydrocarbons

In addition to the analyses for PAHs and alkylated PAHs, the diesel fraction of total petroleum hydrocarbons (TPH-dx) was measured in soil and sediments. This analysis is more specific to semi-volatile petroleum products and the diesel range of hydrocarbons. While there isn't a total PAH criterion available in the Sediment Management Standards (SMS), there is a freshwater TPH criterion.

Metals

The study monitored for 13 metals, all of which are on the priority pollutant list. Five are known human carcinogens, while four others are suspected carcinogens. Soil and sediment samples were analyzed as "total recoverable metals," while water samples were analyzed as "dissolved metals." The target metals are listed below:

Metals

- Antimony (Sb)[2]
- Arsenic (As)[1]
- Beryllium (Be)[1]
- Cadmium (Cd)[1]
- Chromium (Cr)[1]
- Copper (Cu)
- Lead (Pb)[2]
- Mercury (Hg)[2]
- Nickel (Ni)[1]
- Selenium (Se)
- Silver (Ag)
- Thallium (Tl)[2]
- Zinc (Zn)

[1] Known human carcinogen

[2] Suspected human carcinogen

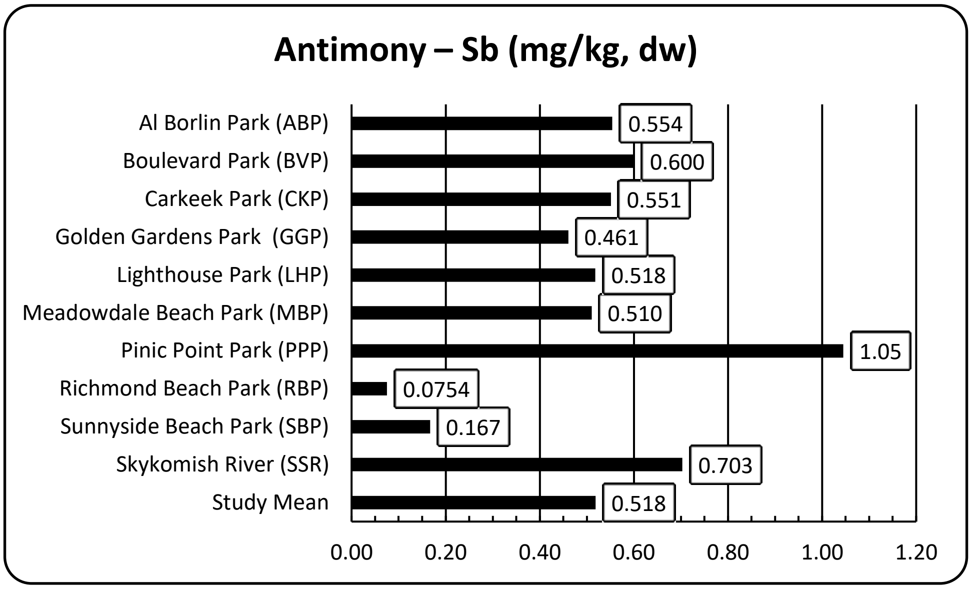
Sources of Poly Aromatic Hydrocarbons (PAHs) and Metals

Many potential PAH and metals sources along rail corridors are associated with trains and their tracks. Creosote has been reported to contain over 30 PAHs and a total PAH content of up to 85% by weight (WHO, 2004). Other sources of PAHs can vary. Some are created naturally; others are man-made. PAHs are created and released during low-temperature burning of materials such as coal, gas, oil, or garbage (organics). Releases to the air are thought to be mostly from volcanoes, forests fires, residential wood burning, and exhaust from cars and trucks. Direct sources to surface water are through industrial discharges, waste treatment plants, and stormwater. PAHs can also be released to soils at hazardous waste sites (ATSDR, 1995). Along rail corridors, metals are a product of friction between the wheel and rails as well as the wheel and brake pads. There are also metals in some fluids and greases (Wilkomirski et al., 2012). Metal impurities are also associated with coal and crude oil.

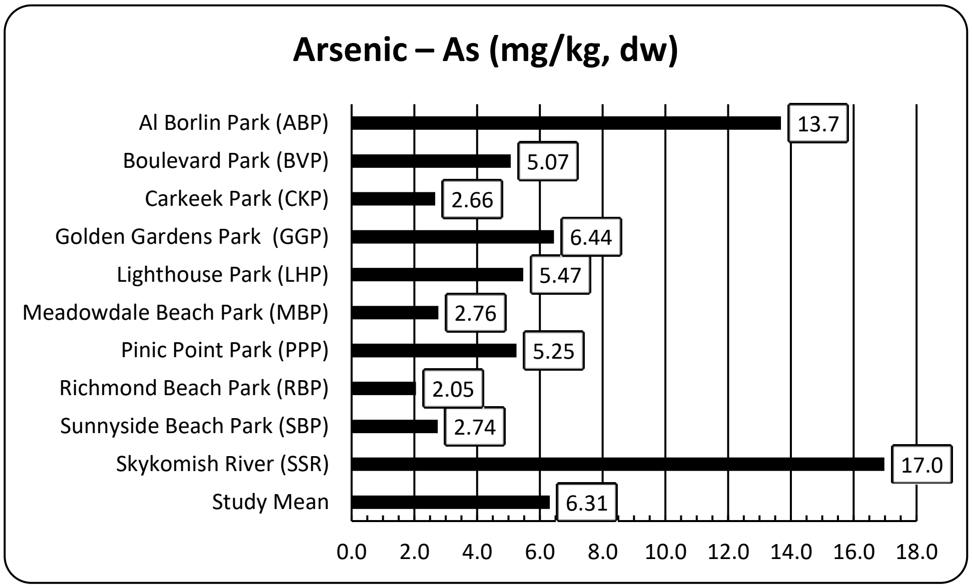
Total annual releases of PAHs to the Puget Sound basin are estimated at 310,000 kg/year (Davies et al., 2012) The majority of PAHs come from two different sources: half from combustion emissions and about one-third from creosote-treated wood products (Norton et al., 2011). Other potential sources of PAHs released into the environment include coal and petroleum/fuel spills.

The Puget Sound Toxics Loading Assessment (PSTLA) reported estimates of annual loading for selected metals through major pathways to the Puget Sound (Norton et al., 2011). Median annual range estimates of total mercury and total cadmium loads were 0.21 and 0.28 metric tons, respectively. Median annual loads reported for total lead, total arsenic, total copper, and total zinc were 7.0, 18, 45, and 170 metric tons per year, respectively.

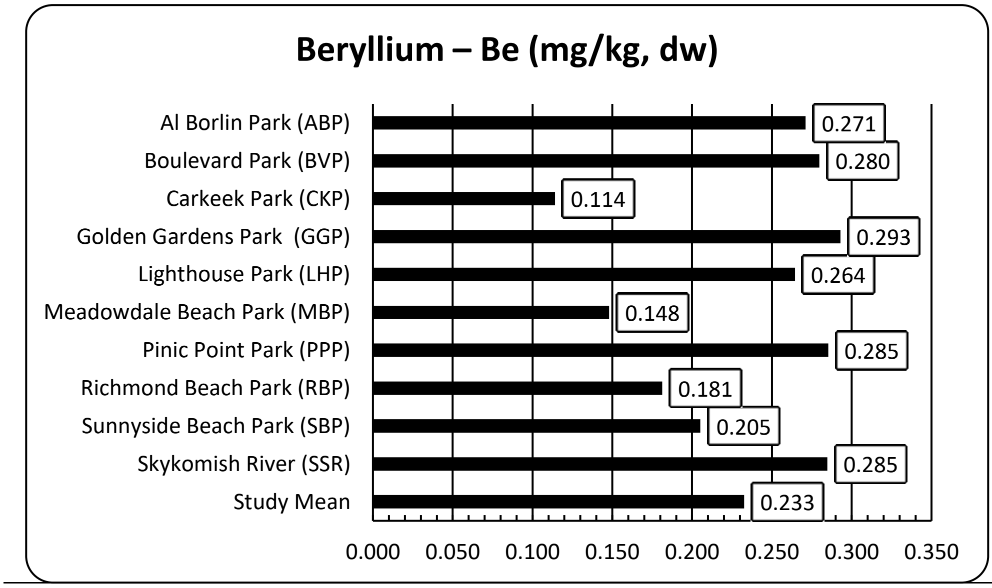
Appendix C. Metals Figures for Soils



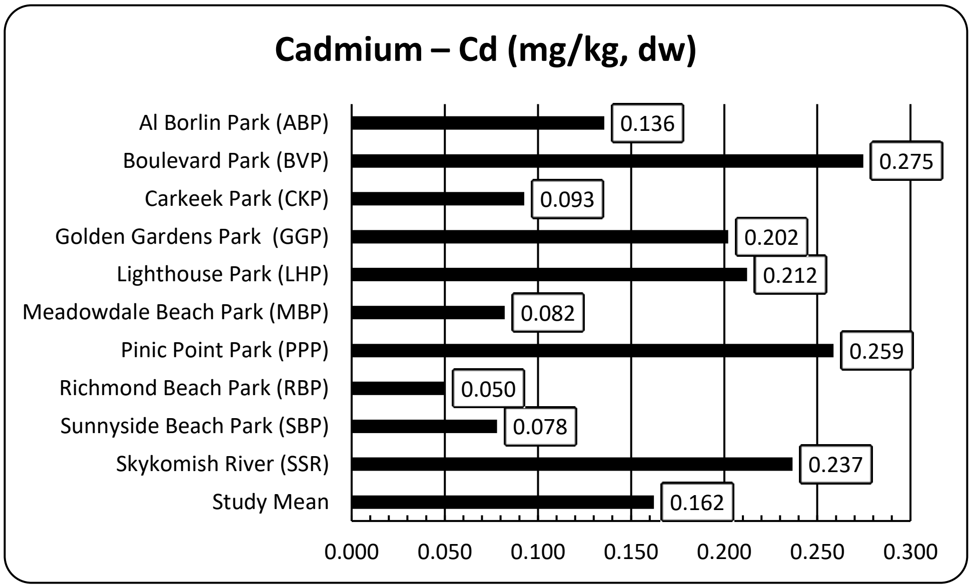
Antimony – Sb (mg/kg, dw)



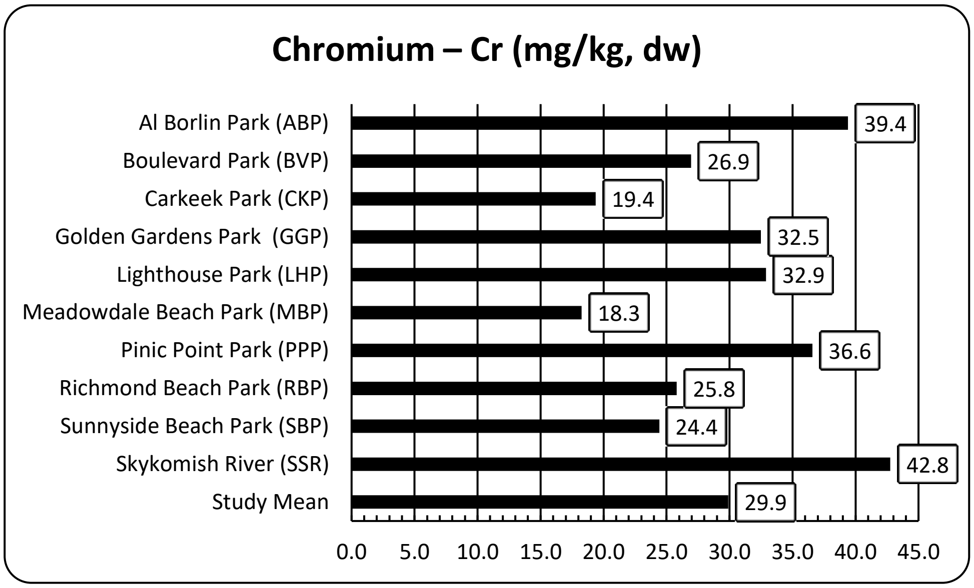
Arsenic – As (mg/kg, dw)



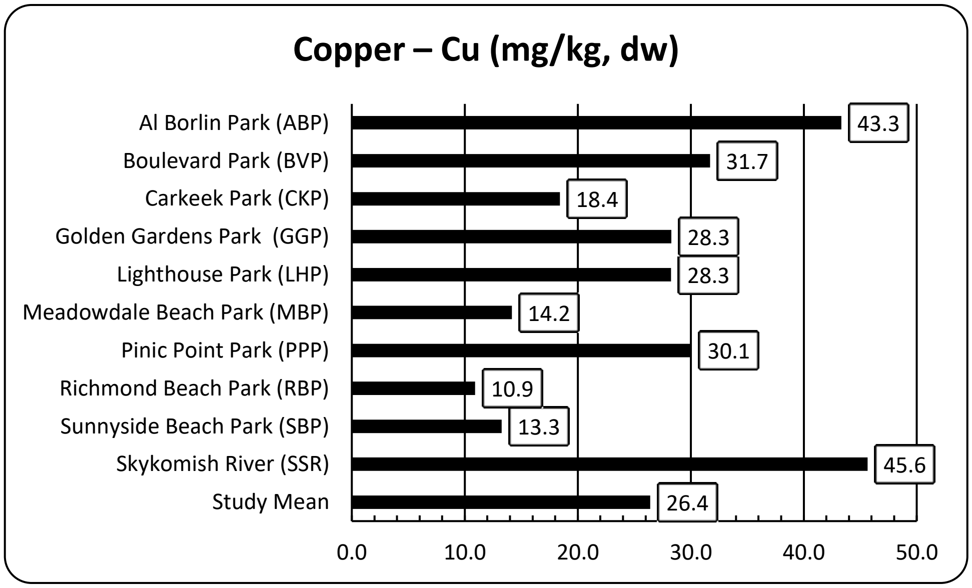
Beryllium – Be (mg/kg, dw)



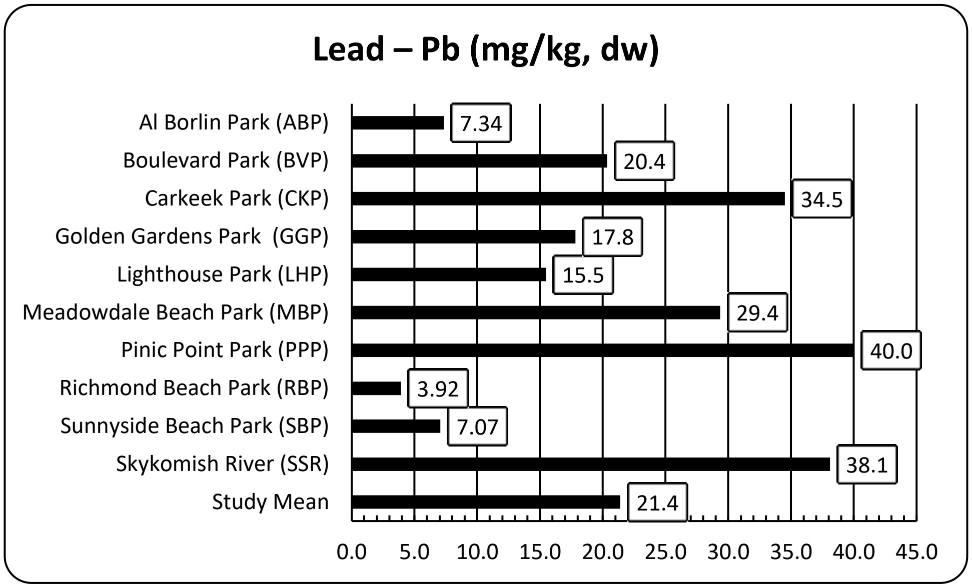
Cadmium – Cd (mg/kg, dw)

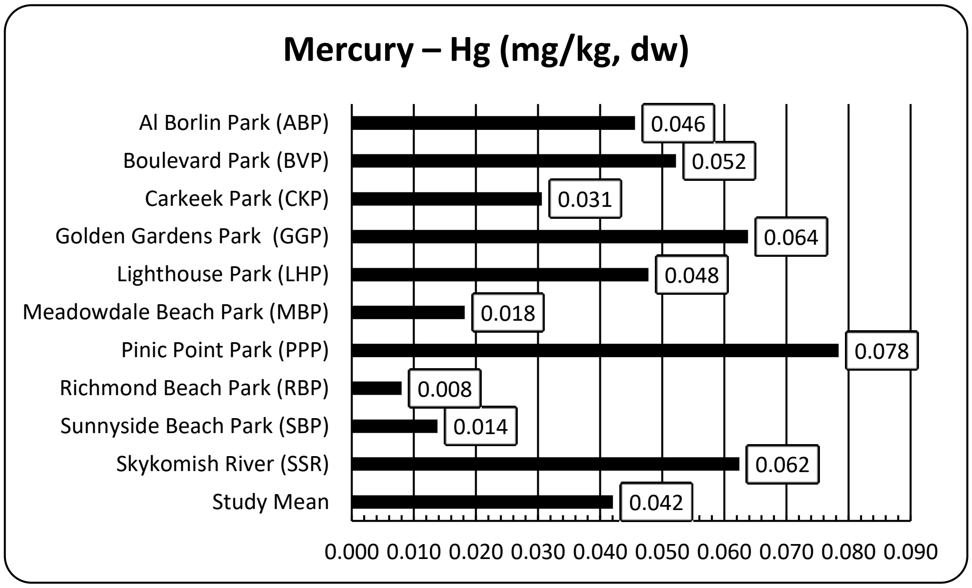


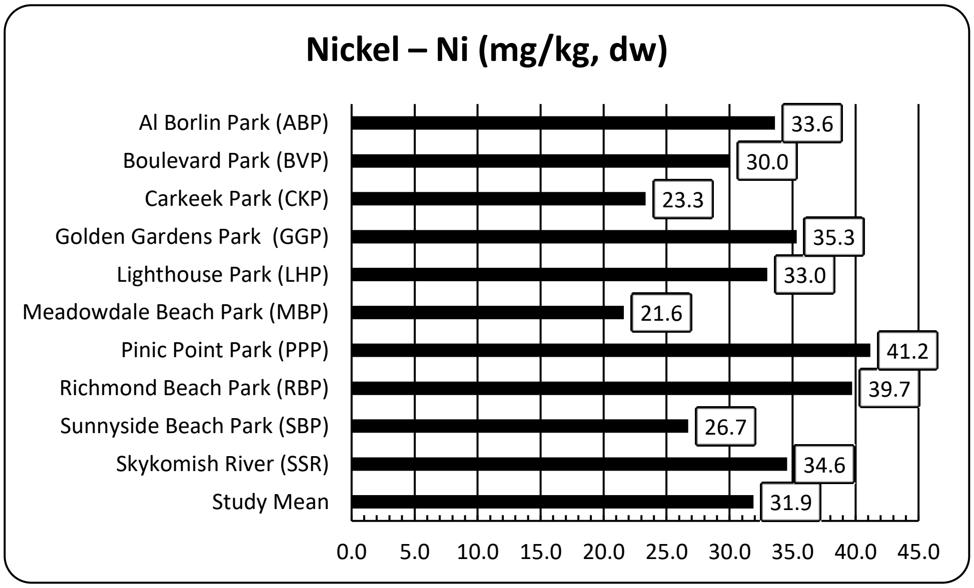
Chromium – Cr (mg/kg, dw)

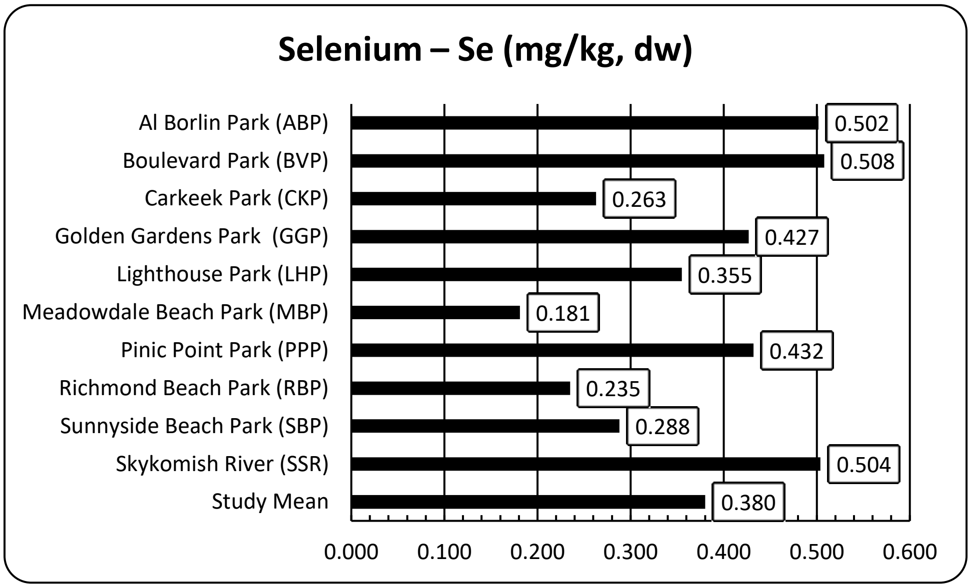


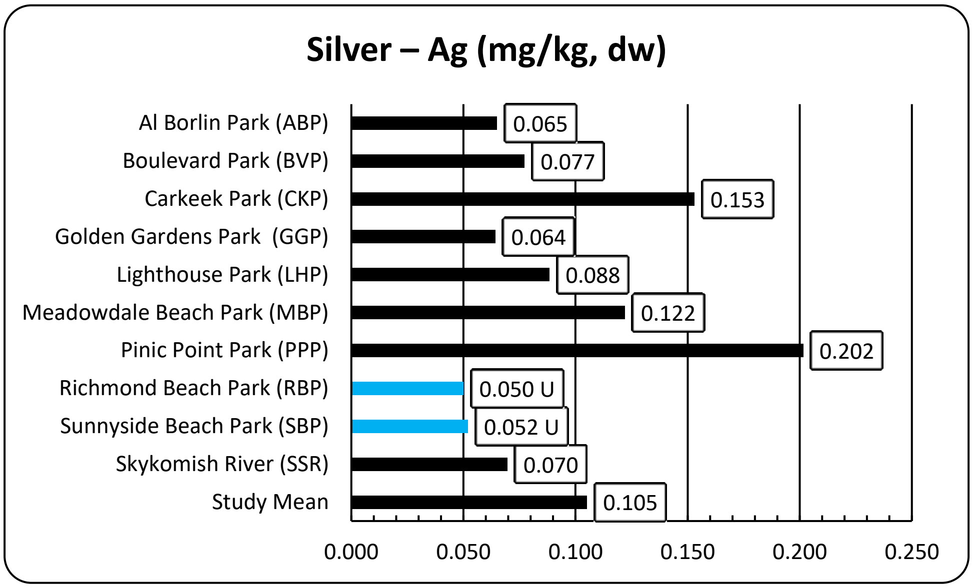
Copper – Cu (mg/kg, dw)

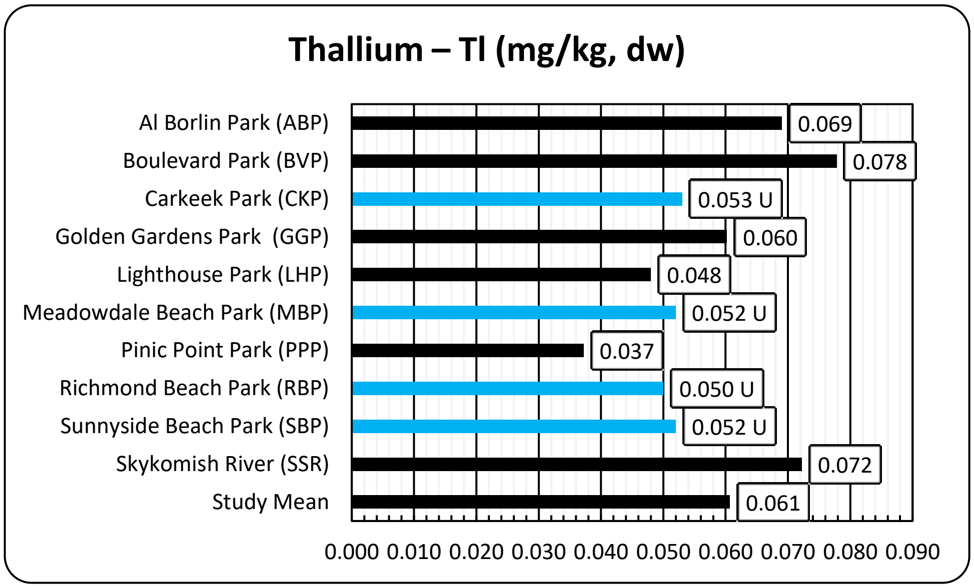

Lead – Pb (mg/kg, dw)

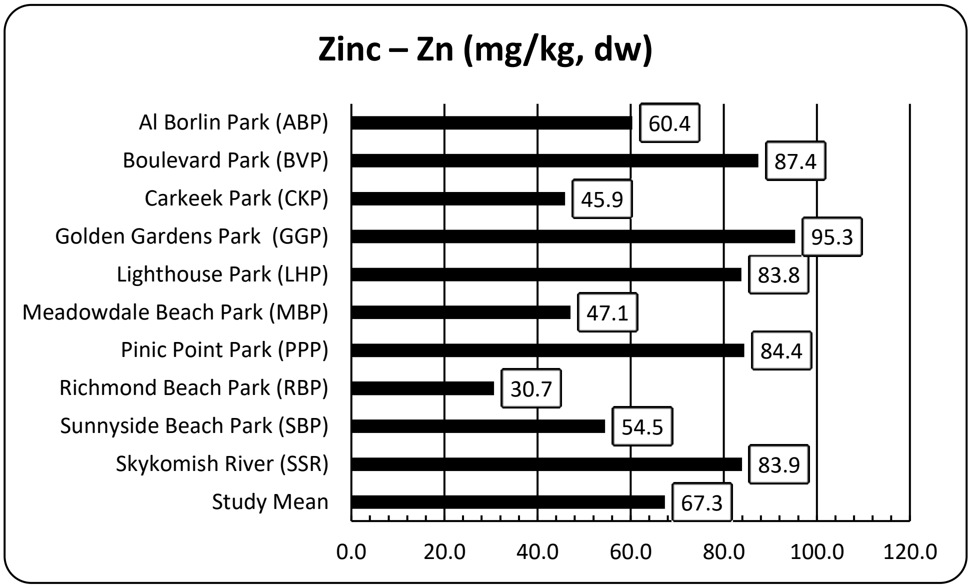

Mercury – Hg (mg/kg, dw)


Nickel – Ni (mg/kg, dw)


Selenium – Se (mg/kg, dw)
Al Borlin Park (ABP)
Boulevard Park (BVP)
Carkeek Park (CKP)
Golden Gardens Park (GGP)
Lighthouse Park (LHP)
Meadowdale Beach Park (MBP)
Pinic Point Park (PPP)
Richmond Beach Park (RBP)
Sunnyside Beach Park (SBP)
Skykomish River (SSR)
Study Mean
0.502
0.508
0.263
0.427
0.355
0.181
0.432
0.235
0.288
0.504
0.380
0.000
0.100
0.200
0.300
0.400
0.500
0.600


Silver – Ag (mg/kg, dw)
Al Borlin Park (ABP)
Boulevard Park (BVP)
Carkeek Park (CKP)
Golden Gardens Park (GGP)
Lighthouse Park (LHP)
Meadowdale Beach Park (MBP)
Pinic Point Park (PPP)
Richmond Beach Park (RBP)
Sunnyside Beach Park (SBP)
Skykomish River (SSR)
Study Mean
0.065
0.077
0.153
0.064
0.088
0.122
0.202
0.050 U
0.052 U
0.070
0.105
0.000
0.050
0.100
0.150
0.200
0.250


Thallium – Tl (mg/kg, dw)
Al Borlin Park (ABP)
Boulevard Park (BVP)
Carkeek Park (CKP)
Golden Gardens Park (GGP)
Lighthouse Park (LHP)
Meadowdale Beach Park (MBP)
Pinic Point Park (PPP)
Richmond Beach Park (RBP)
Sunnyside Beach Park (SBP)
Skykomish River (SSR)
Study Mean
0.069
0.078
0.053 U
0.060
0.048
0.052 U
0.037
0.050 U
0.052 U
0.072
0.061
0.000
0.010
0.020
0.030
0.040
0.050
0.060
0.070
0.080
0.090


Zinc – Zn (mg/kg, dw)
Al Borlin Park (ABP)
Boulevard Park (BVP)
Carkeek Park (CKP)
Golden Gardens Park (GGP)
Lighthouse Park (LHP)
Meadowdale Beach Park (MBP)
Pinic Point Park (PPP)
Richmond Beach Park (RBP)
Sunnyside Beach Park (SBP)
Skykomish River (SSR)
Study Mean
60.4
87.4
45.9
95.3
83.8
47.1
84.4
30.7
54.5
83.9
67.3
0.0
20.0
40.0
60.0
80.0
100.0
120.0

Appendix D. Sample Site Descriptions

Al Borlin Park in Monroe (ABP)

Al Borlin Park is located along Monroe's eastern city limits and includes about 90 acres of land. Separating Woods Creek and the Skykomish River from Highway 2 down to the confluence, a portion of the park is locally known as Buck Island. The park is closed during the wet season due to flooding potential. Soils samples were collected from the base of the exposed bank along the overflow channel running parallel with the BNSF railroad tracks connecting the Skykomish River and Woods Creek. Water and sediment samples were collected from the overflow channel just down gradient from the soils samples (see Figure 1 and D-1 below). At the time of sampling, the overflow channel was not receiving surface flow from the Skykomish River but was hydraulically connected through substrate gravels within the reach. During higher river discharge the overflow channel is a flow-through from the Skykomish River to Woods Creek.

Figure D-1. Al Borlin Park, Monroe.

Latitude: 47.8550 Longitude: -121.9583

Skykomish River at Sultan (SSR)

Sampling was conducted on the Skykomish River on the west side of the city of Sultan just upstream of the confluence with the Sultan River (see Figure 1 and D-2 below). Historically, the Sultan area was known for logging, mining, and farming. Mining included metallic elements such as gold, silver, and arsenic. With the introduction of the railroad to the Sultan area came access to smelting. To the west of Sultan, Everett had one of the only two arsenic smelters in the nation. The samples collected for the study were taken from private property along the Skykomish River just upstream of the confluence with the Sultan River. The property owner described the site as historically used as a lumber mill.

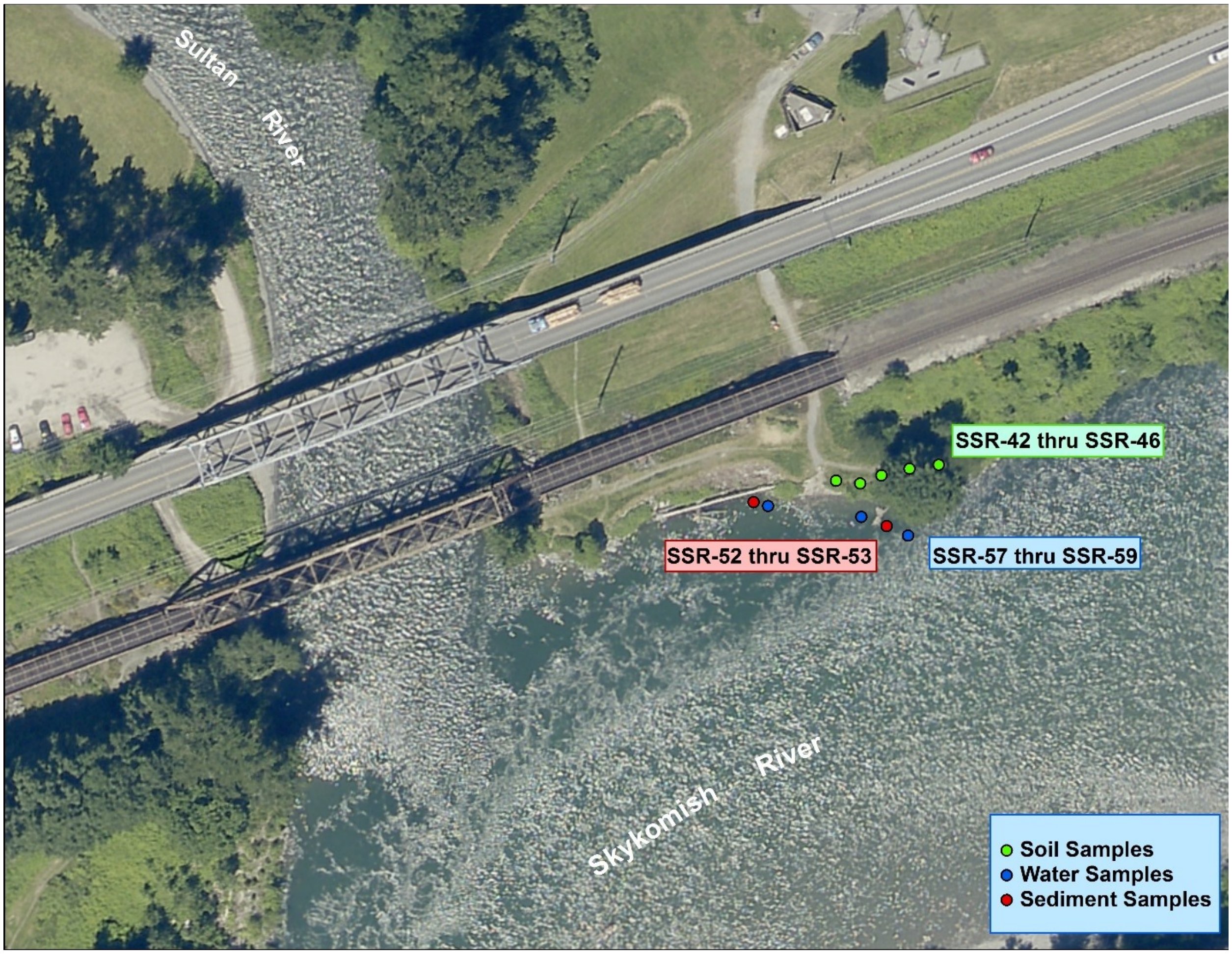


Figure D-2. Skykomish River at Sultan.

Latitude: 47:8607 Longitude: -121.8189

Boulevard Park, Bellingham (BVP)

Boulevard Park opened the summer of 1980 along northeastern Bellingham Bay (Figure 1). In 1884, a lumber mill was built on pilings that extended out into the bay, located below the rail line in the lower park area. The mill burned down in 1925. A coal gasification plant was established in 1890 called Bellingham Bay Gas Company that remained open until 1956. The railroad line that runs through the site supplied timber and coal for both the lumber mill and the gasification plant (DeSitter, 2011). Originally, the rail system was known as the Fairhaven & Northern Railway, currently owned by BNSF. The land area of the park is artificial and was filled for development of the lumber mill. Old concrete chunks originally used as fill were replaced with rock, boulders, and sand in the upper beach (Servais, 2013). All sample locations for this site except the southernmost site (BVP-55) were from surface soils reworked during the development of the park (see Figure D-3). The BVP-55 site was at the edge of what looked like a naturally cut shoreline bank at the southern extent of the park.

Figure D-3. Boulevard Park, Bellingham.

Latitude: 48.7322 Longitude: -122.5019

Lighthouse Park, Mukilteo (LHP)

Lighthouse Park is on Possession Sound within the city of Mukilteo. The park includes about 14.5 acres of land located just west and south of Washington State's Mukilteo Ferry Terminal (Figure 1). Ferry services are to Clinton on Whidbey Island. Washington State Parks first developed Lighthouse Park in the 1950's on a tidal fill. In 2003, it was deeded to the city of Mukilteo. The park is named for the historical wooden Mukilteo Light Station (still on site today) that opened in 1906. In 1855, the Point Elliott Treaty was signed on this beach ceding lands from Des Moines to Arlington in exchange for federal recognition and rights of the Tulalip Reservation (Riddle, 2007). The park has a sandy beach, a public boat launch, the lighthouse, and a shoreline walkway. This area of Mukilteo is considered "Old Town," where the city originally developed. Newer economic development for Mukilteo has shifted away from the waterfront; although in 2015, a new ferry terminal and transportation center began construction. Soil samples for the study were collected on city property inside the park fence separating the park from the rail line (Figure D-4).

Figure D-4. Lighthouse Park, Mukilteo.

Latitude: 47.9467 Longitude: -122.3070

Picnic Point Park, Snohomish County (PPP)

Picnic Point Park is located within the city of Edmonds on northern Puget Sound (Figure 1). It is a small general-use park developed for picnicking and beach activities. Picnic tables and charcoal cookers are available for park users. From the parking lot, you traverse a large overpass built in 1982 above the rail line on an elevated footbridge. To the west of the park, views are of the northern Puget Sound and the southern tip of Whidbey Island. North of the park at a distance of about 800 yards is where multiple ship wrecks in different states of salvage are located at the site of a now-defunct shipyard. The most visible intact wreck is the Pacific Queen, a wooden ship often mistaken for a minesweeper due to the wooden hull structure. The ship was intended for demolition metal salvage and brought to the site following a sinking in Tacoma in 1957 and raised again for heavy internal item removal in 1958 (Baar, 2015). The beach is currently closed to shellfish harvest due to Department of Health sampling in the area. Large sewage treatment outfalls and stormwater runoff are concerns in the populated urban area. Soil samples were collected along a linear track starting in the wooded area to the north from the footbridge overpass (Figure D-5).

Figure D-5. Picnic Point Park, Snohomish County.

Latitude: 47.8803 Longitude: -122.3338

Meadowdale Beach Park, Snohomish County (MBP)

The way to get to Meadowdale Beach Park is by hiking down a ravine from the trailhead beginning at a parking lot at 6026 156th St. SW, in Edmonds. Getting to the park beach involves a one and a quarter-mile long walk down a trail, dropping 425 feet from the trailhead to a grassy picnic and play area, and sandy beach (Figure 1). Lund's Gulch Creek parallels the trail, and then runs through the park discharging into Puget Sound. The county park sits on 108 acres of a once private Meadowdale Country Club. The club closed in the late 1960's. Snohomish County acquired the land in 1968 to develop a park with beach access. The park was closed from 1979 to 1988 until an emergency access road could be built. Access to the beach is through a tunnel/culvert that contains Lund Gulch Creek under the rail line. The tunnel leading to the beach is an area of excessive sedimentation from Lund Gulch Creek. Sedimentation through the tunnel area has made fish passage a difficult issue for maintaining public access (Snohomish County, 2017). Study samples were collected from the edge of the grassy area south of the tunnel opening (Figure D-6).

Figure D-6. Meadowdale Beach Park, Snohomish County.

Latitude: 47.8604 Longitude: -122.3355

Carkeek Park, Seattle (CKP)

Carkeek Park was originally established north of Sand Point in 1918. Named for an English building contractor Morgan J. Carkeek, the park land was gifted to Seattle. This 216 acre park currently includes Pipers Creek, Mohlendorph Creek, Venema Creek, and a number of small streamlets, as well as play and picnic areas, shelters, hiking trails, and the beach. The park moved to its current location (Figure 1) in the Broadview neighborhood of northwest Seattle when the original site at Sand Point was condemned for conversion to a Naval Air Station in 1928. The park land was bought by the city using donations from the Carkeek family (WTA, 2017). From the parking lot, you traverse a large overpass above the rail line on an elevated footbridge. Hand carry boat access is located south of the overpass, while boat arrival by water is restricted. Some of the prior uses of the park area include a brickyard, a sawmill, a commercial fish trap, and a site for camp buildings for the Civilian Conservation Corps. It was also used as an archery range and a model airplane field (Noonan, 2002). Soil samples were collected from the edge of the grassy area south of the footbridge overpass (Figure D-7).

Figure D-7. Carkeek Park, Seattle.

Latitude: 47.7171 Longitude: -122.3801

Golden Gardens Park, Seattle (GGP)

Golden Gardens Park was created in 1907 by real estate developer Harry Treat to attract buyers as an end-of-the-line "amusement park" for his trolley through remote real estate additions around Seattle. The northern area of the park was historically referred to as Meadow Point by the US Coast Guard who used it as the site of a shipyard until 1913. Located in Ballard on Puget Sound, Golden Gardens Park includes 87 acres situated just north of Shilshole Bay Marina (Figure 1). One of Seattle's most popular parks, known for the great views of Puget Sound and the Olympic Mountains, the park also includes two wetlands (Seattle Parks, 2017). Common park activities include but are not limited to picnics, playground use, beach walks, hiking trails, fishing from a pier, basketball, and boating. An off-leash dog area in the north park is also a popular activity. Only two Seattle parks are designated for bonfires on the beach, Golden Gardens and Alki. Soil samples for the study were collected in the wooded area along the fence separating the park from the railroad line in the north park area (Figure D-8).

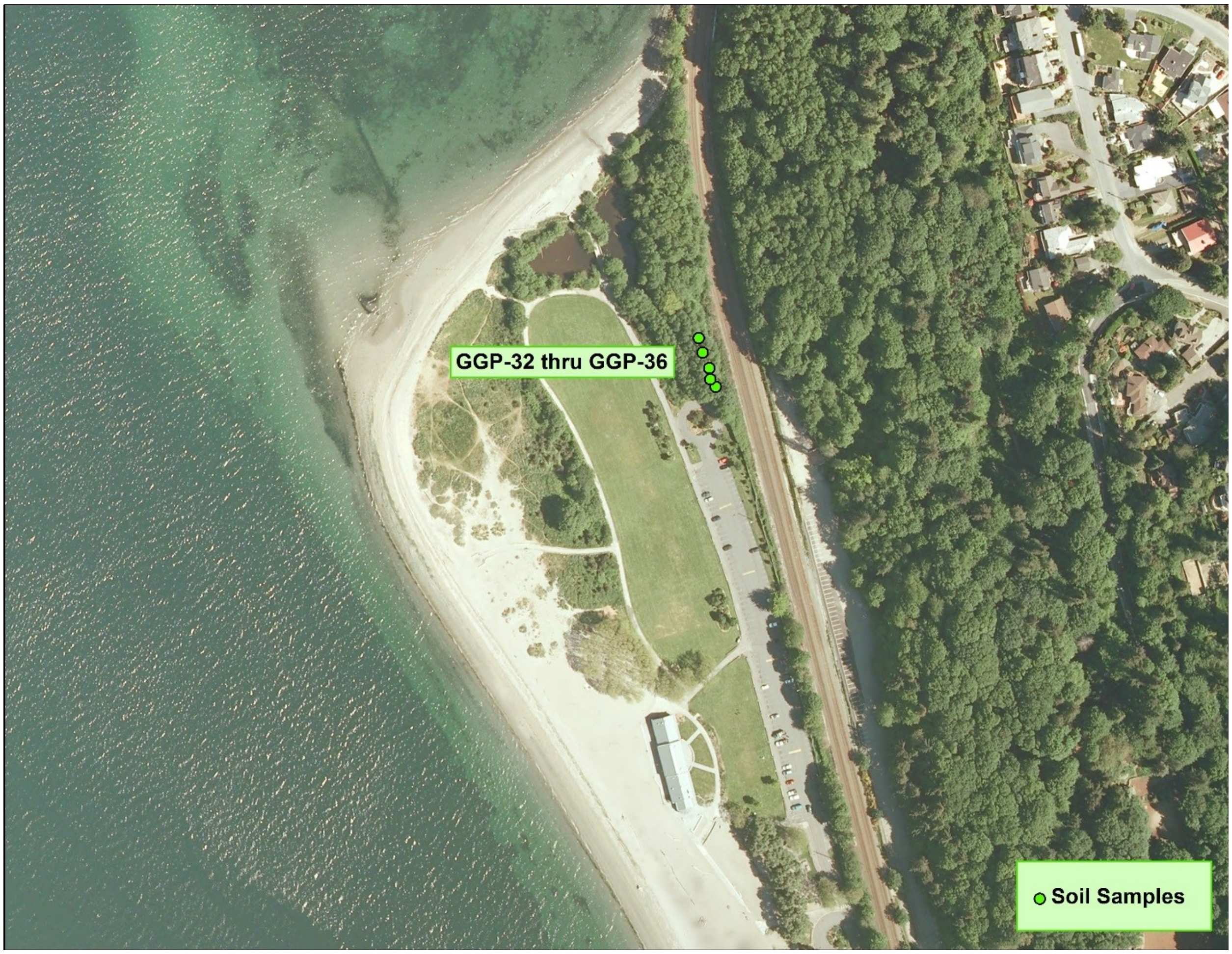


Figure D-8. Golden Gardens Park, Seattle.

Latitude: 47.6926 Longitude: -122.4042

Richmond Beach Saltwater Park, King County (RBP)

In one of the oldest areas of Shoreline, C.W. Smith bought 63 acres of land in 1889. This area is now called Richmond Beach. Richmond Beach Saltwater Park is located on central Puget Sound within Richmond Beach (Figure 1). Entrance to the park is down a steep grade to a parking lot. The park is known for views of Puget Sound and the Olympic Mountains. Beach access is by way of an overpass footbridge crossing the railroad line to a mile-long grey sand beach. The Great Northern Railroad first made way to Richmond Beach in 1891. The Pioneer Sand and Gravel Company sluiced sand and gravel from the site's hillside by fire hose to the base of the bluff to what is now Richmond Beach Saltwater Park. Barges loaded and carried away sorted gravel, while a long gone wooden dock was a popular fishing spot for locals. Remnant sands from the sand and gravel company created the sandy beach for the area park users (RBCA, 2017). The Great Northern Railroad sold the 37 acres of land to King County in 1959 to develop a swimming beach. Richmond Beach became a part of Shoreline in 1994, and in 1995 King County began the process of passing the land to the city of Seattle (Parent Map, 2007). Soil samples were collected from the area just south of the footbridge overpass in grey sand soils (Figure D-9).

Figure D-9. Richmond Beach Park, King County.

Latitude: 47.7639 Longitude: -122.3857

Sunnyside Beach Park, Steilacoom (SBP)

When Washington was still a territory in 1854, Steilacoom was incorporated as the oldest town in Washington. Situated on southern Puget Sound, Sunnyside Beach Park (Figure 1) is one of two Steilacoom parks having shoreline access. Sunnyside Beach Park is located about a mile south of Chambers Creek and is known for the amazing views of Puget Sound, the Narrows Bridge, south sound islands (Ketron, Fox, McNeil, and Anderson), and the Olympic Mountains. Port Steilacoom (founded in 1851) and a neighboring Steilacoom City were merged to form what is now Steilacoom. In the early days of Steilacoom, the port served Fort Nisqually and was considered a way station between Canada and San Francisco (Sailor, 2015). Steilacoom has two ferries from its downtown area: one to McNeil Island that requires Department of Corrections business and another to Anderson and Ketron Islands. Currently, activities at the park include swimming, beach combing, sand activities, playground toys, picnicking, and grilling. Grey sands make up the beach at Sunnyside Beach Park, which is also known for being a great diving location for beginners. Soil samples collected for the study were collected from the northern area of the park at the bank cut just above the beach. Soil samples were composed mostly of grey sand (Figure D-10).

Figure D-10. Sunnyside Beach Park, Steilacoom.

Latitude: 47.1790 Longitude: -122.5894

Appendix E. PAH Carcinogenicity, Uses, and Sources

Priority Pollutant PAH Carcinogenicity, Uses, and Sources

Table E-1. Carcinogenicity, uses, and sources for priority pollutant PAHs.

Priority Pollutant PAH	Carcinogenic/Animal Toxic	Uses	Source(s)
Acenaphthene	Not classified/Aquatic toxic	Production of dyes, plastics, and pharmaceuticals. Insecticide and fungicide.	Coal tar, tobacco smoke, and gasoline exhaust.
Acenaphthylene	Not classified/Not acutely aquatic toxic	Production of dyes, pigments, soaps, pesticides, and plastics.	Vehicle exhaust, coal, coal tar (2%), asphalt, wildfires, agriculture/trash burning, hazardous waste sites.
Anthracene	Not classified/Aquatic toxic	Production of red dye alizarin. Wood preservatives, insecticides, herbicides, rodenticides, coatings.	Coal tar, residues of thermal pyrolysis, incomplete combustion of fossil fuels.
Fluorene	Not classified/Aquatic toxic	Chemical intermediate. Petroleum component.	Incomplete combustion of fossil fuels.
Naphthalene	Possible carcinogen/Animal toxic/Aquatic toxic	Chemical intermediate. Insecticide (carbaryl), pest repellant, mothballs, dyes, resins, leather tanning agents.	Tobacco and wood smoke, fossil fuel products, coal tar, crude oil, asphalt, forest fires.
Phenanthrene	Carcinogen/Aquatic toxic	Production of dyes, plastics, pharmaceuticals, insecticides, and fungicides. To make bile acids, cholesterol, and steroids.	Coal tar pitches, vehicle exhaust, bile acids, cholesterol and steroids, coal, crude oil and natural gas processing, tobacco smoke.
Benz[a]anthracene* **H**PAHs	Probable carcinogen/Aquatic toxic	Some research needs. Chemical intermediate during manufacturing.	Coal tar, roasted coffee, tobacco smoke.
Benzo(a)pyrene*	Carcinogen/Animal toxic/Aquatic toxic	Produced through incomplete combustion, no uses.	Incomplete combustion of organic matter, coal tar, tobacco smoke,

Priority Pollutant PAH	Carcinogenic/Animal Toxic	Uses	Source(s)
			some foods (e.g., grilled meats).
Benzo(b)fluoranthene*	Probable carcinogen/Animal toxic/Aquatic toxic	Research needs.	Formed by burning gas, garbage, and any plant or animal material. Also in creosote. Most releases to air.
Benzo(k)fluoranthene*	Probable carcinogen/Animal toxic/Aquatic toxic	Research needs.	Formed by burning gas, garbage, and any plant or animal material. In tobacco smoke, coal tar, coal and oil combustion, used motor and crude oils.
Benzo(ghi)perylene	Not classifiable/Very aquatic toxic	Research needs.	No known commercial production. In crude oil/coal tar. From forest fires, volcanic activity, and asphalt fumes.
Chrysene*	Carcinogen/Animal carcinogen/Very aquatic toxic	In wood preservatives and coal tar pitch.	Coal tar pitch, creosote, smoke and soot from burning organic material. Wood and coal burning for heat.
Dibenzo(a,h)anthracene *	Probable Carcinogen/Animal carcinogen/Very aquatic toxic	Research chemical. Not produced commercially.	Coke ovens, forest fires, fossil fuels, engine exhaust, tobacco smoke, soot, coal tar, peat deposits, coal exhaust, smoke, soot, coal tar, and peat.
Fluoranthene	Not classifiable/Has shown phototoxicity	Not produced commercially.	Coal tar and petroleum-derived asphalt. Incomplete combustion of coal, gas, wood, garbage, or other organic materials like tobacco.

Priority Pollutant PAH	Carcinogenic/Animal Toxic	Uses	Source(s)
Indeno(1,2,3-cd)pyrene*	Probable carcinogen/Animal carcinogen/Aquatic toxic	Not produced commercially.	Incomplete combustion of organic matter. Exhaust, tobacco smoke, coal tar and coal tar pitch, soot, and petroleum asphalt. No commercial use.
Pyrene	Not classified/Very aquatic toxic	Dyes, auto care products, laundry and dishwashing products, personal care, water treatment products, and pesticides.	Incomplete combustion of organic matter and coal tar. Not produced commercially. Tobacco smoke.

Table E-2 Carcinogenicity, uses and sources for standard non-priority pollutant PAHs.

PAH	Carcinogenic/Animal Toxic	Uses	Source(s)
1-Methylnaphthalene	Studies lacking to determine/Animal and aquatic toxic	Development of chemicals, dyes, resins, and a flavoring ingredient.	Burning of wood, tobacco, and fossil fuels. Also discharges of moth repellants, toilet deodorants. Also manufactured for specific uses.
2-Methylnaphthalene	Studies lacking to determine/ Animal and aquatic toxic	Making dyes, resins, and vitamin K.	Petroleum, coal, burning tobacco and wood. In tar, and asphalt. Also manufactured for specific uses.
2-Chloronaphthalene	Not classifiable for humans/Aquatic toxic	Dyes, solvents, wood preservative, cable insulation, engine oil additive, capacitors.	Created for chemical use. Landfill leachate. Waste incineration.
Dibenzofuran	Not classifiable for humans or animals/ Aquatic toxic	Chemical synthesis, insecticide also in creosote, a dye carrier, and polymer production.	Coal tar, creosote, fly ash, and heat transfer oils. Incomplete combustion of coal, fuels, and heat transfer oils.
Carbazole	Not classifiable for humans/Aquatic toxic	Biomarkers for geology, production of violet pigments (#23).	Crude oil, coal tar, tobacco smoke, and production of anthracene.
3,6-Dimethylphenanthrene	Data not available/ Very aquatic toxic	Laboratory research use.	Lab developed. Burning of wood, diesel, and tobacco.
Retene	Cytotoxic to human lung cells/Very aquatic toxic	Indicator of wood waste/ combustion, and crude oil fingerprinting diagnosis. .	Fresh oil, coal/diesel exhaust, pulp/paper mill effluents, coal tars, and wood burning.
Perylene	Not classifiable for humans/Possible photo-toxicity for aquatics	Light-emitting diodes, blue fluorescence, dyes, photoconductor.	Created for uses listed. Incomplete burning of coal, oil, gas, wood, garbage, and other organics.

Table E-3. Carcinogenicity, uses, and sources for other requested PAHs.

PAH	Carcinogenic/ Animal Toxic	Uses	Source(s)
1,1'-Biphenyl	Suggestive evidence of carcinogenic potential	Heat transfer fluids, precursor to fungicide, organic syntheses, dye carrier, preservative.	Coal tar (creosote), crude oil, and natural gas.
2,6-Dimethylnaphthalene	Very aquatic toxic	Starter of high-performance polyester fibers and films (commercially important).	Produced for commercial use. Low levels in crude oil and coal tar.
1,6,7-Trimethylnaphthalene	Possible carcinogen[1]/ Aquatic toxic	Laboratory standards.	Created for laboratory use.
9H-Fluorene, 1-methyl-	Not listed/Aquatic toxic	Used by cosmetic and pharmaceutical industries.	Coal tar and diesel emissions. Created for uses listed.
Dibenzothiophene	Not listed/Very aquatic toxic	Used by cosmetic and pharmaceutical industries. Chemical intermediate.	Component of fossil fuels. Created for uses listed.
1-Methylphenanthrene	Suspected carcinogen/ Very aquatic toxic	Used in diagnostic ratios for fingerprinting petroleum.	Petroleum and sedimentary organic matter, tobacco smoke, and combustion effluents.
2-Methylphenanthrene	Suspected carcinogen/ Very aquatic toxic	Used in diagnostic ratios for fingerprinting petroleum.	Aging of petroleum and sedimentary organic matter.
4-Methyldibenzothiophene	Suspected carcinogenic	None found except for research needs.	Constituent of rhubarb rhizomes.
2-Methylfluoranthene	Limited information/ Animal carcinogenic	Anti-infection and anti-bacterial agents.	Tobacco smoke and other combustion. Pollutant from polystyrene plastic.
Benzo[e]pyrene	Suspected carcinogen/ Very aquatic toxic	No commercial production or known uses except for experimental research.	Constituent of coal tar pitch. Combustion effluents and incomplete burning of coal, oil, gas, and organics. Soot, smoke, and exhaust.

PAH	Carcinogenic/ Animal Toxic	Uses	Source(s)
5-Methylchrysene	Carcinogenic/ Aquatic toxic	No commercial production or known use other than laboratory use.	Incomplete combustion of organic matter or coal. Found primarily in gasoline exhaust and tobacco smoke.

[1] = No studies on 1,6,7-Trimethylnaphthalene. Used information for naphthalene. Generally, alkyl substituted PAHs are more toxic than the parent compound.

Appendix F. Regulatory Criteria

Regulatory Criteria

Few Washington State upland soils criteria exist for the study parameters. The Model Toxics Control Act (MTCA) found in 173-340 WAC (Table 740-1) establishes soil clean-up level requirements that provide limits for TPH-dx (diesel), three PAHs (benzene, benzo(a)pyrene, and naphthalene), and five metals (As, Cd, Cr(VI), Pb, and Hg).

The Washington State sediment cleanup levels in WAC 173-204-563 apply to freshwater sediments based on protection of the benthic community from toxicity. These Sediment Management Standards (SMS) chemical criteria have not established acute or chronic adverse effect objectives, but assume values below the sediment cleanup concentration corresponds to sediment quality resulting in no adverse effects to the benthic community. Sediment criteria are detailed in Table F-1. Soil criteria are detailed in Table F-2.

There are no water quality criteria that address total PAHs. In water, 11 of the 16 priority pollutant PAH water criteria are from the Washington Toxics Rule (WTR) for human health and are listed in Table F-3. There currently are no specific water quality criteria for alkylated PAHs.

Table F-1. Washington State sediment regulatory criteria for PAHs and metals.

Analyte	Regulatory Criteria	Carcinogen/ Non-carcinogen	Criterion Concentration
Total PAHs	SMS*	NA	17,000 µg/kg, dw
TPH-dx (Diesel)	SMS*	NA	340 mg/kg, dw
Arsenic	SMS*	NA	14 mg/kg, dw
Cadmium	SMS*	NA	2.1 mg/kg, dw
Chromium	SMS*	NA	72 mg/kg, dw
Copper	SMS*	NA	400 mg/kg, dw
Lead	SMS*	NA	360 mg/kg, dw
Mercury	SMS*	NA	0.66 mg/kg, dw
Nickel	SMS*	NA	26 mg/kg, dw
Selenium	SMS*	NA	11 mg/kg, dw
Silver	SMS*	NA	0.57 mg/kg, dw
Zinc	SMS*	NA	3200 mg/kg, dw

* Sediment Management Standards (SMS), sediment cleanup objectives (SCO).

Table F-2. Washington State soil regulatory criteria for PAHs and metals.

Analyte	Regulatory Criteria	Carcinogen/ Non-carcinogen	Criterion Concentration
TPH-dx (Diesel)	MTCA*	NA	2,000 mg/kg^
Benzene	MTCA*	C	0.03 mg/kg
Benzo(a)pyrene	MTCA*	C	0.1 mg/kg
Naphthalenes	MTCA*	P	5 mg/kg
Arsenic	MTCA*	C	20 mg/kg
Cadmium	MTCA*	C	2 mg/kg
Chromium (VI)	MTCA*	C	19 mg/kg
Lead	MTCA*	S	250 mg/kg
Mercury (inorganic)	MTCA*	S	2 mg/kg

* Model Toxics Control Act (MTCA), Method “A” soil cleanup levels
^ TPH criterion is the MTCA diesel range organics criterion.

Table F-3. Washington State freshwater regulatory criteria for PAHs and metals.

Analyte	Regulatory Criteria	Carcinogen/ Non-carcinogen	Criterion Concentration	Analyte Notes
Anthracene[1]	WTR	NC	100 µg/L	LPAH
Fluorene[1]	WTR	NC	10 µg/L	LPAH
Benzo(a)anthracene[2]	WTR	C	0.00016 µg/L	HPAH
Benzo(a)pyrene[2]	WTR	C	0.000016ug/L	HPAH
Benzo(b)fluoranthene[2]	WTR	C	0.00016 µg/L	HPAH
Benzo(k)fluoranthene[2]	WTR	C	0.0016 µg/L	HPAH
Chrysene[2]	WTR	C	0.016 µg/L	HPAH
Dibenzo(a,h)anthracene[2]	WTR	C	0.000016 µg/L	HPAH
Fluoranthene[2]	WTR	NC	6 µg/L	HPAH
Indeno(1,2,3-c,d)pyrene[2]	WTR	C	0.00016 µg/L	HPAH
Pyrene[2]	WTR	NC	310 µg/L	HPAH
Antimony	WTR	NC	6 µg/L	–
Arsenic	WTR	C	0.018 µg/L	–
Nickel	WTR	NC	80 µg/L	–
Thallium	WTR	NC	1.7 µg/L	–
Arsenic	WAC	C	190.0 µg/L	–
Cadmium	WAC	C	$<(CF)(e^{(0.7852[\ln(hardness)]-0.3490)})$	CF is the conversion factor for cadmium. CF=1.101672 – [(ln hardness)(0.041838)].
Chromium (VI)	WAC	C	10.0 µg/L	Conversion factor for total chromium to dissolved chromium is 0.962.
Copper	WAC	NC	$<(0.960)(e^{(0.8545[\ln(hardness)]-1.465)})$	
Lead	WAC	S	$<(CF)(e^{1.273[\ln(hardness)]-4.705)})$	CF is the conversion factor for lead. CF=1.46203 – [(ln hardness)(0.145712)].
Mercury	WAC	S	0.012 µg/L	Based on total recoverable.
Nickel	WAC	NC	$<(0.997)(e^{(0.8460[\ln(hardness)]+1.1645)})$	–
Selenium	WAC	NC	5.0 µg/L	Based on total recoverable.
Silver	WAC	NC	$<(0.85)(e^{(1.72[\ln(hardness)]-6.52)})$	Acute criterion only, no chronic value.
Zinc	WAC	NC	$<(0.986)(e^{(0.8473[\ln(hardness)]+0.7614)})$	–

WTR: Washington Toxics Rule 40 CFR 131.45 – for human health, freshwater-water and organisms.
WAC: Washington Administrative Code – WAC 173-201A, for the protection of aquatic life, chronic. Values are the chronic criterion unless otherwise noted.

NA: Not applicable.
NC: Non-carcinogenic.
C: Carcinogenic.
P: Possible human carcinogen.
S: Suspected human carcinogen.

Appendix G. Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Carcinogenic: Potential to cause cancer in organisms.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Dissolved Organic Carbon (DOC): Measure of the amount of organic carbon dissolved in a waterbody.

High Molecular Weight PAH (HPAH): Polycyclic Aromatic Hydrocarbon rings containing five or more aromatic rings, thus heavier in molecular weight and more persistent in the environment. Most PAHs with carcinogenic effects on organisms are also persistent HPAH.

Low Molecular Weight PAH (LPAH): Polycyclic Aromatic Hydrocarbon rings containing 4 or less aromatic rings, thus lighter, more volatile, and less persistent in the environment than HPAHs.

PAH: Polycyclic aromatic hydrocarbon (PAHs) are formed with carbon and hydrogen (hydrocarbons) found in coal and tar deposits and released through incomplete combustion of organic matter. Molecularly, their structure is composed by the arrangement of aromatic rings. PAHs have become a concern due to their release in the environment and subsequent impact to organisms through carcinogenic and toxic effects.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Salmonid: Fish that belong to the family *Salmonidae*. Species of salmon, trout, or char.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snowmelt.

Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

TPHD: Diesel fraction of total petroleum hydrocarbons.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

DOC	Dissolved Organic Carbon
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	US Environmental Protection Agency
HPAH	High Molecular Weight PAHs
LPAH	Low Molecular Weight PAHs
MEL	Manchester Environmental Laboratory
MTCA	Model Toxics Control Act
PBT	persistent, bioaccumulative, and toxic substance
pp	priority pollutants
SMS	Sediment Management Standards
SOP	Standard operating procedure
TOC	Total Organic Carbon
TPHD	Total Petroleum Hydrocarbons Diesel
WAC	Washington Administrative Code
WTR	Washington Toxics Rule
WRIA	Water Resource Inventory Area

Units of Measurement

°C	degree centigrade
dw	dry weight
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
mg	milligram
mg/kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mL	milliliters
ng/kg	nanograms per kilogram (parts per trillion)
ng/L	nanograms per liter (parts per trillion)
NTU	nephelometric turbidity units
µg/kg	micrograms per kilogram (parts per billion)
µg/L	micrograms per liter (parts per billion)