Atmospheric Deposition of PCBs in the Spokane River Watershed

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Cover photo: Atmospheric deposition samplers on the roof of the Spokane Clean Air Agency Building. Photo by Brandee Era-Miller.

Atmospheric Deposition of PCBs in the Spokane River Watershed

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Abstract

In 2016 and 2017 Ecology's Environmental Assessment Program investigated atmospheric deposition of polychlorinated biphenyls (PCBs) in the Spokane area. Quarterly seasonal bulk (wet + dry) deposition samples were obtained via passive samplers at three existing air quality monitoring sites. Each location represents a different land use type: (1) Turnbull National Wildlife Refuge (NWR): regional background, (2) Monroe Street: urban-residential, and (3) Augusta Avenue: urban-commercial.

PCB flux (ng/m^2-day) results for bulk deposition showed a pattern of increasing values from Turnbull NWR (lowest) to Monroe Street to Augusta Avenue (highest). PCB fluxes were comparable to monitoring results from areas with similar land uses near Seattle, Washington.

Principal component analysis indicated that all three bulk deposition sites had congener patterns that were unique to their location. Homologue analysis showed that the urban sites contained more of the higher-chlorinated congeners compared to the Turnbull NWR regional background site.

A proof-of-concept study for dry deposition collection methods found that particulate matter ≤10 microns (PM10) filters cannot be used to accurately characterize PCBs and assess PCB trends because of significant losses of lighter-weight congeners.

Several dry deposition samples were collected with a polyurethane foam (PUF) and filter method during a week-long period of regional wildfires. All results showed similar congener patterns, suggesting that they came predominately from the same source.

PCB flux to the Spokane area from the Spokane Waste to Energy facility was modeled using the AERMOD modeling system and on-site PCB emission data, meteorology, land surface, and building information. The model simulation estimated that the facility accounted for about 2% of the measured PCB bulk deposition at the study sites.

Introduction

The Spokane River is listed on the federal Clean Water Act 303(d) list as impaired for polychlorinated biphenyls (PCBs). The Department of Ecology (Ecology) first documented PCB contamination in the Spokane River in the early 1980s (Hopkins et al., 1985). Since that time, numerous studies and cleanup activities to address PCB contamination have been conducted and are ongoing in the Spokane River watershed (Serdar et al., 2011; LimnoTech, 2015). PCBs are currently being addressed through Ecology's water quality permitting program, which includes the efforts of the Spokane River Regional Toxics Task Force (SRRTTF).

PCBs have been studied in surface water, stormwater, groundwater, sediment, and fish, as well as discharge from permitted facilities in the Spokane River watershed. However, atmospheric deposition has not been studied in this watershed, and it represents a gap in our understanding of PCB sources.

Several recent Ecology documents have also highlighted the need for toxics atmospheric deposition data in the Spokane River, eastern Washington, and the state at large. These Ecology documents include the Statewide PCB Chemical Action Plan (Davies, 2015) and internal technical memos on the state of the science of toxics in atmospheric deposition in Washington (Hobbs, 2015; Era-Miller, 2011).

The purpose of this study is to fill this important data gap regarding PCBs in atmospheric deposition in the Spokane River watershed. The study was designed to address the following questions:

- What are the atmospheric concentrations of PCBs in Spokane and how do they compare to western Washington and to urban areas nationwide?
- How does seasonality affect the atmospheric deposition of PCBs in the Spokane River watershed?
- Are permitted air sources, such as the Spokane Waste to Energy (WTE) Incinerator, a significant contributor to PCBs in the Spokane River watershed?
- How much of the PCB loading in urban stormwater from Spokane comes from atmospheric sources? Can data from this project be used in concert with PCB data from the city of Spokane's stormwater basin monitoring program to estimate this loading?

Study Area

The Spokane River, shown in Figure 1, begins in Idaho at the outlet of Lake Coeur d'Alene and flows west through Washington for 112 miles to the Columbia River. The Spokane River watershed encompasses over 6,000 square miles in Washington and Idaho (Serdar et al., 2011). The river flows through the smaller cities of Coeur d'Alene and Post Falls, Idaho, before flowing through Washington and the urban and industrial areas of the Spokane Valley and Spokane. Other cities include Liberty Lake in Washington, Hayden Lake in Idaho, and smaller communities upstream of Lake Coeur d'Alene.

The Spokane River watershed is located in a transition area between the scablands of the Columbia Basin to the west, coniferous forests and mountainous regions to the north and east, and Palouse hills to the south. The Spokane area receives an average of 16.5 inches of precipitation annually. It is affected by the rain shadow from the Cascade Mountains and thus receives roughly half of Seattle's annual rainfall (36.2 inches). Temperatures in Spokane tend to be extreme, with warm summers and cold winters. Much of the winter precipitation falls as snow, particularly at higher elevations.

The Spokane River sits atop the western portion of the Spokane Valley–Rathdrum Prairie Aquifer. There is significant surface and groundwater exchange between the river and the aquifer. Spring snowmelt and rainfall dominate flows in the Spokane River from April through June, whereas most of the inputs to the river from July through September are from groundwater.

The Spokane River has seven major dams that create reservoirs behind them. From upstream to downstream they are Post Falls Dam, Upriver Dam, Upper Falls Dam, Monroe Street Dam, Nine Mile Dam, Long Lake Dam, and Little Falls Dam (Fig. 1).

With the exception of Lake Coeur D'Alene and Lake Spokane, *direct* deposition of PCBs to the surface of the Spokane River is likely to be minimal, due to the river's small surface area relative to the basin area. The impact to the Spokane River from PCBs delivered to Lake Coeur D'Alene from atmospheric inputs are generally accounted for in river concentrations at the state line (Serdar et al., 2011; LimnoTech, 2015).

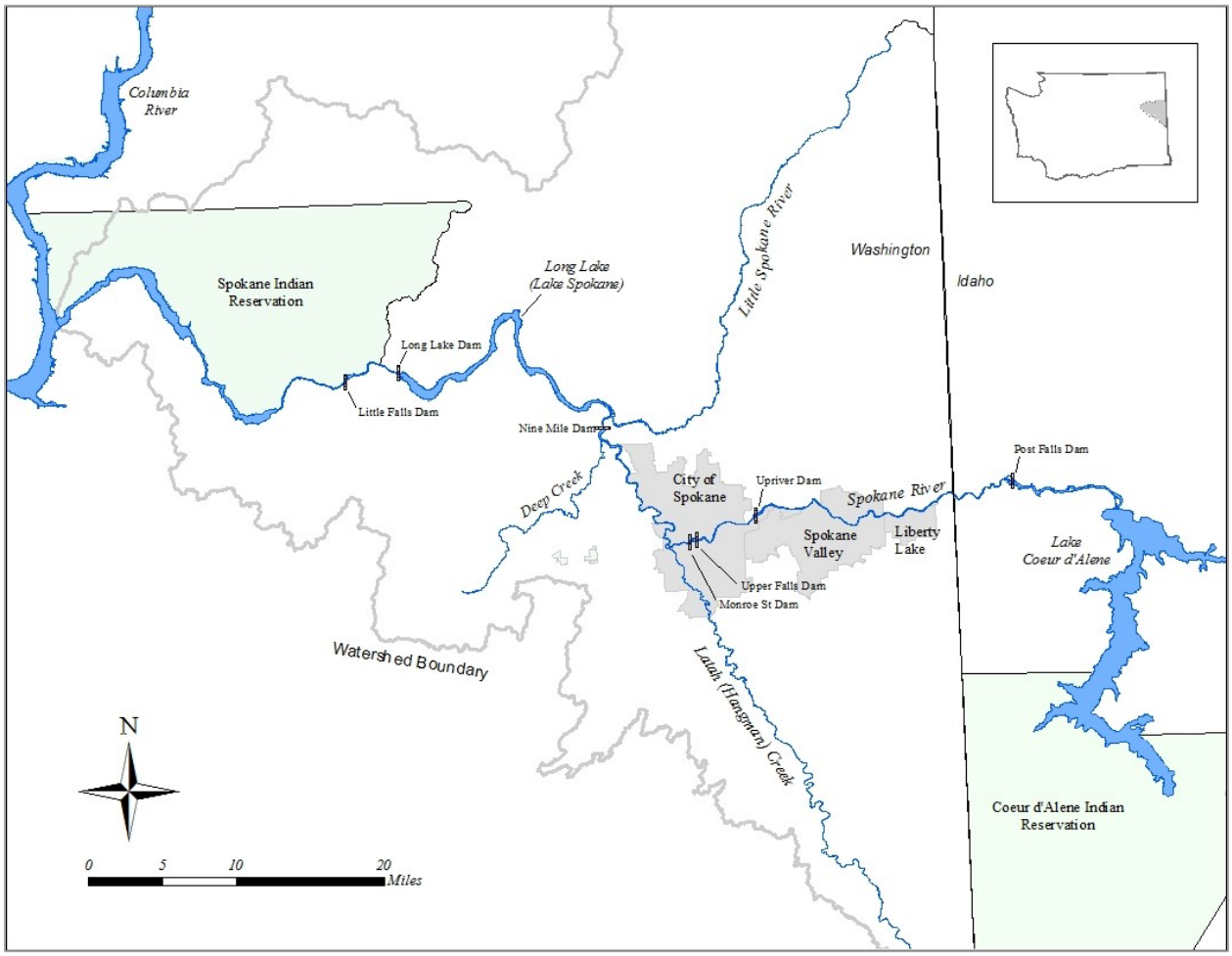


Figure 1. Spokane River Basin.

Methods

Study Design

The study design is thoroughly described in the Quality Assurance Project Plan for the project (Era-Miller and Wong, 2016). Because of the study's limited number of sampling sites, it should be considered a pilot study for atmospheric PCBs in the Spokane River watershed. The study design consisted of three major components:

- Quarterly seasonal sampling for bulk (dry + wet) deposition
- Proof-of-concept study for dry deposition sampling methods
- Plume dispersion modeling of the Waste to Energy (WTE) Facility

High resolution gas chromatography/mass spectrometry (GC/MS) PCB congener method EPA 1668c (EPA, 2010) was used for analysis of all bulk and dry deposition samples.

Bulk Atmospheric Deposition

Bulk atmospheric deposition is the sum total of both wet deposition (precipitation) and dry deposition. Contaminants in wet and dry deposition originate from both gaseous and particulate forms in the atmosphere. Water droplets can form on airborne contaminants via condensation, nucleation, or gas dissolution in clouds. Falling precipitation scavenges airborne particles and aerosols (Coleman et al., 2001). Dry particulates fall out and gases adsorb onto vegetation, soil, and the organic film layers that form on the impervious surfaces (Diamond et al., 2000; Hobbs, 2015).

Bulk deposition for this study was collected with passive samplers on a quarterly basis (3-month deployment periods) for one year at two urban locations and at a regional background location in the Spokane River watershed (Fig. 2, Table 1). All three locations are established air quality monitoring stations that are owned and operated by either Ecology or the Spokane Regional Clean Air Agency (SRCAA).

Table 1. Monitoring location information.

Station name	Owner	Land use type	Deposition collected
Augusta Avenue	SRCAA	urban-commercial	bulk and dry
Monroe Street	Ecology	urban-residential	bulk
Turnbull National Wildlife Refuge	SRCAA	regional background	bulk

SRCAA: Spokane Regional Clean Air Agency.

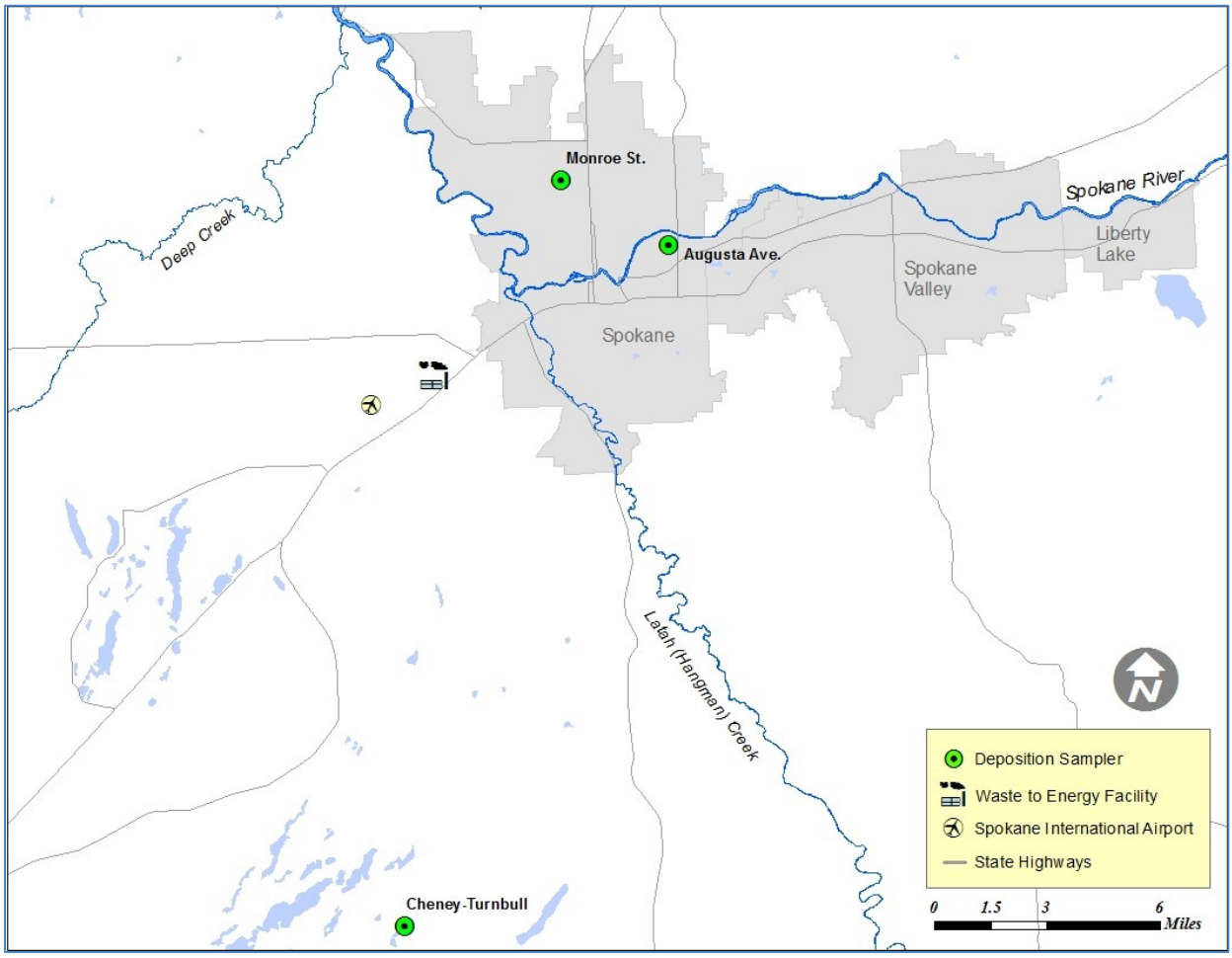


Figure 2. Monitoring locations for this study.

Bulk atmospheric samplers consisted of 33.7-cm-diameter brushed stainless steel bowls with a 5-cm-diameter hole cut through the bottom. The bowls were supported by a tapered aluminum box fastened atop a refrigerator (Fig. 3). Stainless steel funnels were spot-welded to the bottom of the stainless steel bowls. Each bowl and funnel was connected to the sampling container inside the refrigerator below with ½-inch Teflon tubing. Holes were drilled through the top of the refrigerator for the Teflon tubing.

Stainless steel Cornelius kegs were used for the sampling containers. These kegs are typically used for brewing and have both an intake and pressurized outlet. They can hold up to 20 liters. A 20-liter canister can accommodate at least 8 inches of precipitation over a 3-month sampling period (8 inches = ~18 liters with a 34-cm diameter sampling bowl). During collection, the kegs resided inside the refrigerator for insulation from extreme temperatures. During the cold months, heat tape was wrapped around the outsides of the funnels, inside the aluminum box, and around the sampler kegs to prevent freezing and the buildup of snow on top of the aluminum box. Stainless steel bird spikes were screwed onto the top of the aluminum box surrounding the sample bowls to deter birds.

With the height of the refrigerator and aluminum box combined, the bulk deposition samplers were approximately 6 feet high. The stainless steel bowl-and-funnel design and the overall

sampler height is similar to the bulk deposition samplers used for the Puget Sound and Duwamish River air deposition studies (Brandenberger et al., 2010; King County, 2015).

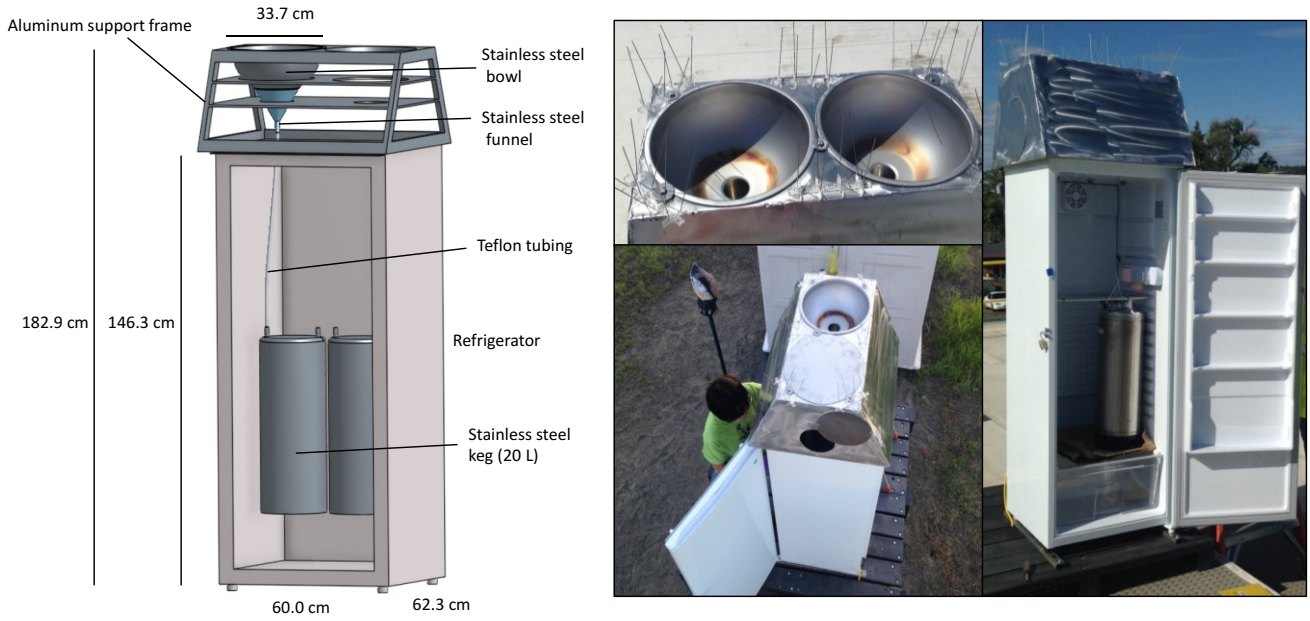


Figure 3. Schematic and photos of a bulk deposition sampler.

Bulk Deposition Collection Procedures

Field sampling methods used for this study were adapted from King County's Standard Operation Procedure (SOP) for air deposition sample collection (KCEL, 2011). King County staff involved in the atmospheric deposition studies in Duwamish River watershed were also consulted in the development of the Quality Assurance Project Plan for this study (Era-Miller and Wong, 2016).

During sample collection, 500 mL of reagent water from the laboratory conducting the PCB congener analyses (ALS Global) was used to clean adhering debris on the sampler bowl, along with a natural bristle brush. Sample volume was determined by weighing the sampler keg before and after collection and subtracting the weight of the 500 mL of rinse water (500 grams) from the weight of the collected sample keg. Kegs were checked for PCB contamination (proofed) by the laboratory each sampling quarter.

The Ecology decontamination SOP EAP090 (*Standard Operating Procedure for Decontaminating Field Equipment for Sampling Toxics in the Environment*; Friese, 2014) was used for decontamination of all collection equipment. The decontamination procedure includes a hot water rinse, brushing with Liquinox soap, hot water rinse, rinse with deionized water, dry under clean fume hood, acetone rinse, dry again, hexane rinse, and finally dry again under fume hood. Once dry, collection items were covered with aluminum foil until deployment in the field.

Dry Deposition

Proof-of-Concept

A proof-of-concept study for dry deposition collection methods was conducted in late January through mid-February of 2017 at the Augusta Avenue (urban-commercial) monitoring station. The objective was to test the efficacy of using PM10 (particulate matter ≤10 microns) filters from high-volume sampling for PCB analysis compared to high-volume polyurethane foam (PUF) sampling. Since SRCAA samples PM10 every six days at the Augusta site and has several years' worth of archived filters, the goal was to see if these archived samples could provide any useful PCB trend information.

Neither the PM10 nor the PUF samples from the winter 2017 proof-of-concept study were deemed usable for the purposes of reporting accurate PCB results. The PUF samples had significant background contamination in the PUF/XAD-2 sampling media prepared by the laboratory. The PM10 filters showed poor recovery of PCBs, showing that they could not be used to provide meaningful PCB data.

The analytical laboratory, ALS Global (ALS), offered to conduct an in-kind second round of PUF sampling due to the contamination issues with the PUF/XAD-2 sampling media. Thus, Ecology conducted a second round of PUF sampling at the Augusta Avenue monitoring site on several dates in the summer of 2017. The PM10 component was not included in the additional summer sampling since it proved to not be useful for PCB analysis.

All of the PM10 and PUF sampling events were conducted as 24-hour events. For the proof-of-concept study, PM10 and PUF sampling was performed in tandem during three events on January 31, February 6, and February 17, 2017. The summer PUF sampling was carried out during three 24-hour events that straddled two calendar days starting at 1:00 p.m. on the first day. The dates were August 29–30, 2017; September 2–3, 2017; and September 5–6, 2017.

PM10 High Volume Sampling

SRCAA follows the procedures laid out by the Ecology's Air Quality Program (AQP) for High Volume PM10 sampling (Rauh, 1993). PM10 high-volume air samplers are constructed according to the guidelines outlined in 40 CFR Appendix J to Part 50 (EPA, 2000) and the collection method is designated as a federal reference method. More information on PM10 samplers can be found online (Tisch Environmental, n.d.).

SRCAA staff run their PM10 samplers for a 24-hour period every six days, according to EPA's established schedule. They archive each 8 × 10–inch quartz microfiber PM10 filter sample (Fig. 4). The PM10 sampler's flow rate is 1.13 m^3/min., and with a sample run time of 24 hours, the total volume of air sampled is about 1,627 m^3. The 24-hour average PM10 mass concentration for the Augusta Avenue monitoring station has had a mean value of 21 $\mu g/m^3$ for the past five years. This averages out to approximately 0.03 grams of mass per filter (Rowe, personal communication).

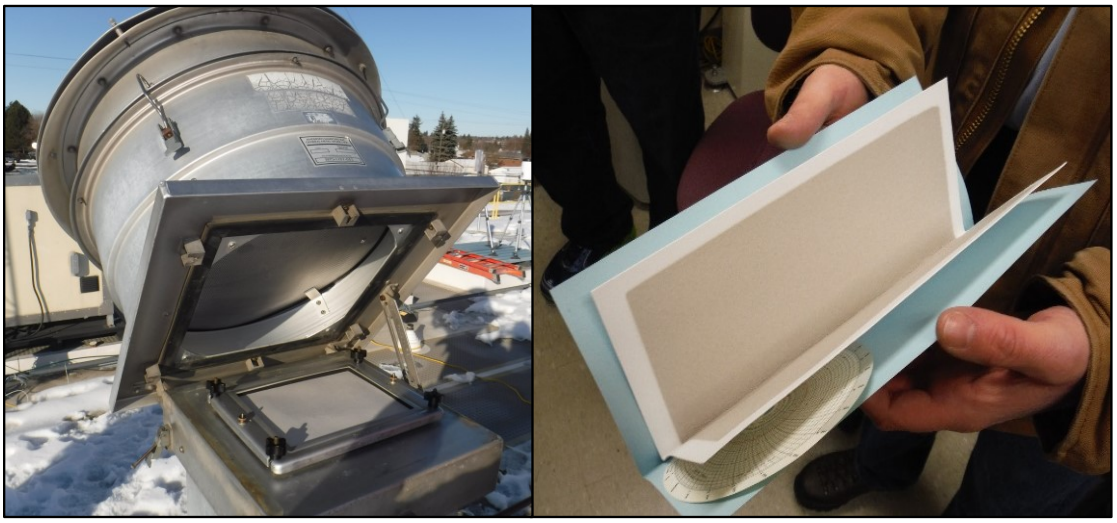


Figure 4. PM10 sampler head (left) and PM10 filter sample (right).

PUF High Volume Sampling

Ecology researchers rented a PUF sampler from Tisch Environmental and located it on the roof of the SRCAA building next to the PM10 samplers at the Augusta Avenue site. Sampling methods followed EPA's Compendium Method TO-4A for determining toxic organic compounds in ambient air (EPA, 1999). More information on PUF samplers can be found online (Tisch Environmental, n.d.).

As recommended by EPA, Ecology's PUF sampling included both a quartz fiber filter and glass cartridge filled with a "PUF sandwich" that included two layers of PUF media and a layer of XAD-2 resin beads in the center (Fig. 5). ALS provided the quartz fiber filters and glass cartridge with the absorption media.

Figure 5. PUF sampler head (left) and PUF glass cartridge and filter sample (right).

Laboratory Procedures

Bulk Deposition

At ALS, the bulk deposition samples were thoroughly mixed and then 1.8-liter aliquot of sample was used for analysis of PCB congeners using method EPA 1668c (EPA, 2010). A second 1.8-liter aliquot was used to conduct a duplicate analysis. An equivalent percentage of the solvent rinse from the sample keg was divided evenly among each of the split samples to account for PCBs that might have adhered to the inside walls of the keg.

To measure potential loss of PCBs occurring from volatilization and other processes, a keg containing 10 liters of lab reagent water spiked by ALS with labeled PCB compounds was deployed alongside the sample collection kegs during the first and second quarters.

Sample kegs were batch proofed for PCBs by ALS each quarter prior to deployment. The amber bottles containing deionized water used for sample collection were also batch proofed quarterly.

Dry Deposition

PM10

PM10 filters were shipped from SRCAA to ALS for blank analysis to characterize any background contamination in the filters. Filters were spiked with surrogate compounds to measure any losses during field collection. The spiked filters were used by SRCAA to perform the PM10 sampling for the proof-of-concept study at the Augusta Avenue monitoring site.

PUF

ALS provided the quartz fiber filters and glass cartridge with the "PUF sandwich" absorption media. The absorption media were also spiked with surrogate compounds to measure any losses during field collection.

Calculations

Bulk Deposition Flux

To standardize results so that they can be compared among sites and to data collected in other studies, PCB concentrations in bulk deposition samples were converted to flux. The following equation is used to convert PCB concentrations to flux:

$$\textit{Concentration (ng/L)} \times \textit{(Precipitation volume (L) + Sample rinse volume (L))} / \textit{Funnel area (m}^2\textit{)} / \textit{Deployment duration (days)} = \textit{Flux (ng/m}^2\textit{-day)}$$

Dry Deposition

The PUF sampler used for the study was the TE-1000, rented from Tisch Environmental. The sampler came with a calibrated orifice transfer standard that was used to calibrate the sampler on-site prior to sampling. The calculation for determining sampler flow is outlined in EPA's Compendium Method TO-4A for determining toxic organic compounds in ambient air (EPA,

1999). We used a spreadsheet developed by Ecology's Air Quality Program Northwest Regional Office to calculate sampler flow (m^3/minute), air sample volume (m^3), and PCB air concentrations (pg/m^3). See Appendix A for the calculation spreadsheets. Average air temperatures and pressures for each monitoring event were downloaded from Weather Underground (www.wunderground.com) for the nearby Felts Field weather station.

PCB Summing

For summing of total PCBs and homologs, non-detected congeners were assigned a value of zero. If only non-detections composed the total value, then the total was reported as "ND" for "not detected." Totals were assigned a qualifier of "J" (estimated) if more than 10% of the result value was composed of congeners containing "J" qualifiers.

Qualifier Definitions

Definitions for the data quality qualifiers are as follows:

- **J**: The analyte was positively identified. The reported result is an estimate.
- **NJ**: There is evidence that the analyte is present in the sample. The reported result for the tentatively identified analyte is an estimate.
- **U**: The analyte was not detected at or above the reported result.
- **UJ**: The analyte was not detected at or above the reported estimate.
- **NUJ**: There is evidence that the analyte is present in the sample. The tentatively identified analyte was not detected at or above the reported estimate.

Censoring for Method Blank Contamination

Individual PCB congeners were censored using three different censoring levels for PCB contamination present in the laboratory method blank (MB). Censoring congeners against positively identified compounds in the MB results accounts for any PCB contamination directly from the analytical process. Homologue totals and total PCBs were calculated using three different MB censoring levels for congeners. A congener is considered a non-detection (U, UJ, or NUJ) if the concentration is:

1. **Less than three times** the concentration of the associated MB.
2. **Less than five times** the concentration of the associated MB.
3. **Less than ten times** the concentration of the associated MB.

Results for all three censoring levels are shown in Appendix B. Censoring at less than three times the MB is used for reporting in the *Results* and *Discussion* sections of this report.

Waste to Energy Facility Plume Dispersion Modeling

Ecology's AQP conducted plume dispersion modeling and analysis of the city of Spokane's Waste to Energy (WTE) facility as a possible source of PCBs in atmospheric deposition to the Spokane area. AQP utilized the American Meteorological Society/U.S. Environmental Protection Agency Regulatory Model (AERMOD v16216r [EPA, 2016]) to simulate the transport, dispersion, and deposition of PCBs released from WTE from May 11, 2016, to May 11, 2017. The PCB bulk deposition study occurred within this time frame. AQP also assessed the representativeness of this one-year period by running AERMOD for 5 years using meteorological data from 2011 to 2015.

Emission data were obtained from reports of source sampling tests performed from 2011 to 2017. Other important pollutant and building information was taken from 1991 and 2001 dispersion modeling done for health risk assessment studies (ETI, 1991; PTC, 2001). Meteorological data were obtained from the Spokane International Airport. AERMOD-simulated concentrations and deposition (total, dry, and wet) estimates covered a domain of 900 km^2, centered on the emission source at the WTE. Model outputs of 24-hour, monthly, and whole-period averages were compared against the 1-year field study period for the three monitoring sites. Methods are fully discussed in the modeling and analysis report (Appendix D).

Data Quality

The study data were reviewed by the report authors, analytical chemists, and Manchester Environmental Laboratory (MEL). MEL provided a Stage 2b validation of the PCB congener data as described in EPA's *Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use* (EPA, 2009). The majority of the study data were found to meet the laboratory measurement quality objectives (MQOs) outlined in the Quality Assurance Project Plan for this study (Era-Miller and Wong, 2016) and shown in Table 2. These MQOs are specific to method EPA 1668c and pertain to both the dry and bulk deposition (aqueous) sample matrices.

Table 2. Measurement quality objectives and results for this study.

	Lab control samples (% recovery)	Lab duplicate samples (RPD)	Surrogate recoveries (% recovery)
MQO limits	50 – 150[†]	≤50%	25 – 150[a]
Sampling event	Percent of Data Meeting MQOs		
Bulk Dep. – Qtr. 1	100	100	100
Bulk Dep. – Qtr. 2	100	99	88
Bulk Dep. – Qtr. 3	100	NA	100
Bulk Dep. – Qtr. 4	56	NC	99
Dry Dep. – Summer	93	NA	97

[†] Per Method for Ongoing Precision and Recovery (OPR), internal standards, and labeled compounds.
[a] labeled congeners.
MQO: Measurement quality objective.
NC: not calculated due to the low number of detections in the duplicate sample.
NA: data not analyzed.
RPD: Relative percent difference.

Bulk Deposition

Multiple types of bulk deposition sampling system quality assurance/quality control (QA/QC) samples were analyzed during the study. These included proofing of sampling containers and laboratory reagent water, analysis of laboratory method blanks, sampling equipment blanks, field replicates, field spike samples, and collection efficiency wipe samples.

Proofing

After ALS decontaminated the 20 liter sample kegs, additional solvent was rinsed through all the kegs, composited, then analyzed for PCBs. The 1-liter amber glass bottles with laboratory reagent water were also proofed for PCBs. The amber bottles were used to transport the laboratory reagent water for bulk deposition sample collection. The total PCB results for the proofed containers along with their associated laboratory method blank (MB) results are shown in Table 3. These concentrations were relatively low compared to the equipment blank and bulk

deposition samples, suggesting that none of the containers had background PCB concentrations that would cause significant contamination of the environmental samples.

Table 3. Total PCB results for proofed containers and associated method blanks.

Sampling event	20-L keg (pg)	MB 20-L keg (pg)	1-L amber (pg)	MB 1-L amber (pg)
Quarter 1	17	2	33	25
Quarter 2	38	54	185	216
Quarter 3	100	59	74	90
Quarter 4	--	--	45	183

MB: method blank
-- data not available

Method Blanks

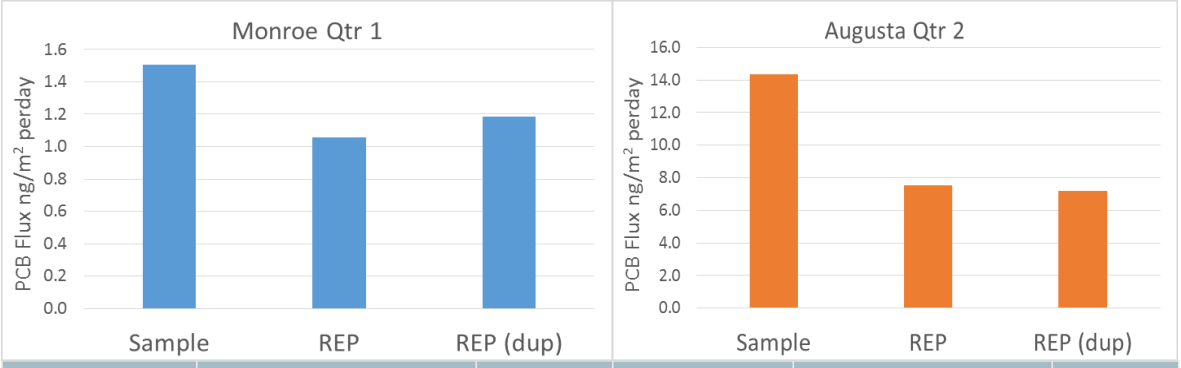
Laboratory MBs are run with every analytical batch. MB results account for PCB contamination from the analytical process. Samples were censored against the laboratory MBs as described earlier in the *Calculations* section of this report.

Equipment Blanks

We ran 0.5 – 1.0 liter of laboratory reagent (deionized) water through the bulk deposition collection system each quarter to mimic the sample collection process. The collection system included the 20-liter sampling kegs, collection funnels, Teflon tubing, and natural bristle brushes. Results for the equipment blank samples are discussed in the *Results* section of this report (see Table 6), but were generally between one and three orders of magnitude lower than the study samples, representing an acceptable level of background contamination. The equipment blank sample for quarter 3 was inadvertently lost by the laboratory, and no results could be reported.

Field Replicates

Field replicates were taken as side-by-side samples at one rotating location each quarter. All the field replicate results were variable during the study, while the laboratory duplicates were fairly precise, suggesting that the majority of the variability came from either the sampling technique or the environment or both. Results for the field replicate samples are further discussed in the *Results* (see Table 6) and *Discussion* sections of this report. The relative percent difference (RPD) between the flux values of the field replicates and laboratory duplicates for the same location are shown in Figure 6 for quarters 1 and 2. No laboratory duplicate was analyzed during quarter 3. The sample for Turnbull National Wildlife Refuge (NWR) during quarter 4 (Sample ID: 1705077-3) was considered to be an outlier and not reliable. The field replicate sample for Turnbull quarter 4 (Sample ID: 1705077-4) was used as the primary sample, thus no RPD could be calculated.



Result 1	Result 2	RPD
Sample	Replicate	35%
Replicate	Replicate (dup)	12%

Result 1	Result 2	RPD
Sample	Replicate	62%
Replicate	Replicate (dup)	5%

Figure 6. Difference between total PCB flux values for field replicates and laboratory duplicates. RPD: relative percent difference; dup: laboratory duplicate.

Sample Outlier

Sample 1705077-3 (from the Turnbull station for quarter 4) had a total PCB concentration that was inconsistent with the first three quarters, in which results were the lowest for Turnbull relative to the other monitoring locations. The Turnbull field replicate for quarter 4 (1705077-4) followed previous observations, having lower tPCB concentrations than the other monitoring sites. Congener distributions in sample 1705077-3 were also different from any of the samples in the study. For these reasons, we consider sample 1705077-3 to be an outlier and do not consider it in our interpretation of regional atmospheric deposition of PCBs.

Field Spikes

Field spikes were deployed during the first and second quarter of the study to measure potential loss of PCBs occurring from volatilization and other processes, such as adhesion to the sample kegs during deployment. The field spike sample recoveries were acceptable and ranged from

54% – 117%, indicating that losses due to a three month deployment in the field were not a concern.

Efficiency Wipes

Solvent-soaked wipes were used to measure bulk deposition removal efficiency on the stainless steel sample funnels directly after collection in the field. The PCB mass on the wipe was compared to the PCB mass in the associated sample. Removal efficiencies of PCBs from the surface of the sample collection bowls ranged from 96.4% – 99.7% (Table 4).

Table 4. Bulk deposition collection bowl PCB removal efficiency.

Sampling quarter	Station	tPCB mass wipe (pg)	tPCB mass sample (pg)	PCB removal efficiency (%)
2	Monroe	40	14,964	99.7
3	Monroe	426	28,277	98.5
3	Turnbull	118	24,542	99.5
3	Turnbull	127	20,954	99.4
4	Augusta	426	11,807	96.4
4	Monroe	359	10,172	96.5

Dry Deposition

As described in the *Methods* section of this report, results from both the PM10 and PUF samples from the winter 2017 proof-of-concept study were deemed unusable. The following data quality discussion refers only to the summer 2017 PUF sampling.

Quality assurance/quality control (QA/QC) samples for the PUF sampling included proofing of PUF/XAD-2 absorption material and analysis of a field blank and laboratory method blank. The concentrations of total PCBs in all the QA/QC samples were orders of magnitude lower than the high concentrations found in the environmental samples (Table 5). The field blank sample, which accounts for background contamination from the entire sampling system (field and laboratory), was two orders of magnitude lower than the environmental samples.

Table 5. Dry deposition quality assurance/quality control results compared to field samples.

Sample type	tPCB mass (pg)
PUF/XAD-2 proof	280
Method blank	33
Field blank	1,240
Field sample – event 1	213,000
Field sample – event 2	189,000
Field sample – event 3	114,000

Waste to Energy Facility Plume Dispersion Modeling

Ecology's Air Quality Program provided internal peer review of the modeling results. The American Meteorological Society/U.S. Environmental Protection Agency Regulatory Model (AERMOD v16216r [EPA, 2016]) was used for the modeling, and all input data came from published reports or peer-reviewed sources. See Appendix D for the full report.

Results

Bulk Deposition

Total PCB results are provided in Table 6 by mass (pg), concentration in parts per quadrillion (pg/L) and part per trillion (ng/L), and flux rate (ng/m^2-day). Equipment blank, field replicate, and laboratory duplicate results are also included. PCB results in Table 6, Figure 7, and the body of the report were censored on a per congener basis at three times the laboratory method blank (MB). Appendix B shows the full congener data censored at three, five, and ten times the MB, along with homologue pattern graphs shown with censoring at three and ten times the MB.

Figure 7 shows a general trend of increasing total PCB flux values among monitoring locations. Lowest values were at Turnbull NWR, the regional background site, and highest values were at Augusta Avenue (the urban-commercial site). Field replicate and laboratory duplicate values were averaged for Figure 7.

Augusta Avenue had the highest total PCB flux for the study during the second quarter (mid-August to mid-November, 2016) with an average of 10.8 ng/m^2-day (Fig. 7). The mean rural and urban-residential values from a study conducted in the Duwamish River watershed by King County (2011 – 2013) are displayed in Figure 7 for comparison (King County, 2015).

Table 6. Total PCB bulk deposition results.

Quarter	Sample Name	MEL ID	Deployment	Retrieval	Days	Total volume (L)	tPCB Mass (pg)	Sample volume (L)	tPCB (pg/L)	tPCB (ng/L)	Flux (ng/m^2-day)
1	Equipment blank	1608070-1	5/6/16	--	--	1.0	957	0.95	1007	1.0	--
1	Turnbull	1608070-4	5/11/16	8/11/16	90	8.1	3099	7.63	406	0.4	0.41
1	Monroe	1608070-2	5/12/16	8/10/16	90	7.3	11242	6.77	1661	1.7	1.51
1	Monroe (rep)	1608070-3	5/12/16	8/10/16	90	7.3	7874	6.81	1156	1.2	1.06
1	Monroe (rep) Dup	--	5/12/16	8/10/16	90	7.3	8864	6.81	1302	1.3	1.19
1	Augusta	1608070-5	5/11/16	8/11/16	89.8	8.3	20331	7.8	2607	2.6	2.71
2	Equipment blank	1611056-1	8/16/16	--	--	0.47	923	0.47	1964	2.0	--
2	Turnbull	1611056-3	8/11/16	11/16/16	96.7	17.3	7129	16.8	425	0.4	0.85
2	Monroe	1611056-2	8/10/16	11/16/16	98.1	16.7	14964	16.2	925	0.9	1.77
2	Augusta	1611056-4	8/11/16	11/16/16	97.1	15.5	120034	15.0	8008	8.0	14.3
2	Augusta (rep)	1611056-5	8/11/16	11/16/16	97.1	15.7	63183	15.2	4168	4.2	7.55
2	Augusta (rep) Dup	--	8/11/16	11/16/16	97.1	15.7	60227	15.2	3962	4.0	7.20
3	Turnbull	1702021-3	11/16/16	2/15/17	91.2	10.8	24542	10.3	2394	2.4	3.17
3	Turnbull (rep)	1702021-5	11/16/16	2/15/17	91.2	10.8	20954	10.3	2030	2.0	2.71
3	Monroe	1702021-2	11/16/16	2/15/17	90.8	11.6	28277	11.1	2554	2.6	3.66
3	Augusta	1702021-1	11/16/16	2/16/17	91.8	11.3	30329	11.3	2675	2.7	3.71
4	Equipment blank	1705077-1	2/23/17	--	--	0.54	94	0.5	174	0.2	--
4	Turnbull*	1705077-3	2/15/17	5/11/17	84.9	16.4	37231	15.86	2347	2.3	5.08
4	Turnbull (rep)	1705077-4	2/15/17	5/11/17	84.9	16.8	452	16.28	28	0.03	0.06
4	Turnbull (rep) Dup	--	2/15/17	5/11/17	84.9	16.8	446	16.28	27	0.03	0.06
4	Monroe	1705077-2	2/15/17	5/11/17	85.0	17.4	10172	16.9	602	0.6	1.38
4	Augusta	1705077-5	2/16/17	5/11/17	84.1	13.8	11807	13.3	888	0.9	1.64

MEL ID: Manchester Environmental Laboratory sample ID; rep: replicate sample deployed side-by-side in the field;Dup: duplicate aliquot sample taken at the laboratory;* Turnbull sample 1705077-3 is an outlier.

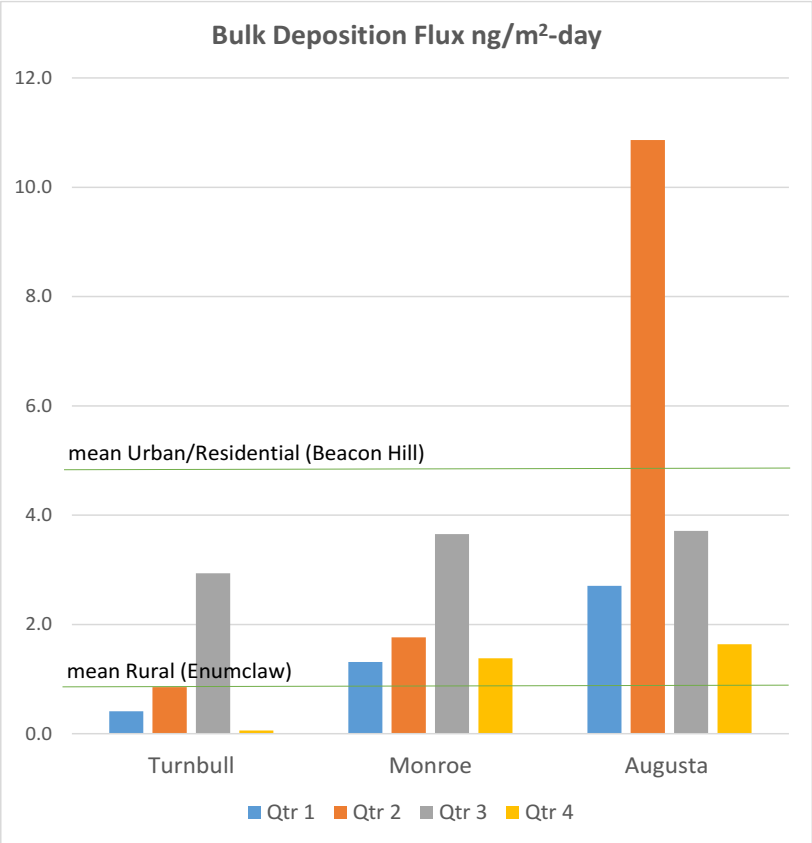


Figure 7. Bulk deposition total PCB flux results.
Source: King County (2015).

Equipment Blank Correction

As previously stated, bulk deposition PCB congener results were censored at three times the laboratory MB to account for background PCB contamination from the laboratory. In order to characterize the possible effects of background contamination from sample collection and field activities, the equipment blank total PCB mass concentrations (pg) were subtracted from the sample total PCB mass concentrations prior to flux calculations. Table 7 shows that this blank correction exercise generally did not substantially reduce flux values compared to the non-blank corrected flux values, indicating that the majority of the PCBs in the samples were from the environment and not the sampling system. Since there was no usable equipment blank result for the third quarter of sampling, an average of the blank results for the other quarters was used.

Table 7. Bulk deposition flux with and without equipment blank correction.

Site	Quarter 1 Flux (ng/m²-day) Result	Quarter 1 Flux (ng/m²-day) BC	Quarter 1 % of result	Quarter 2 Flux (ng/m²–day) Result	Quarter 2 Flux (ng/m²–day) BC	Quarter 2 % of result	Quarter 3 Flux (ng/m²–day) Result	Quarter 3 Flux (ng/m²–day) BC	Quarter 3 % of result	Quarter 4 Flux (ng/m²–day) Result	Quarter 4 Flux (ng/m²–day) BC	Quarter 4 % of result
Turnbull	0.4	0.3	69%	0.9	0.7	87%	2.9	2.9	97%	0.06	0.05	79%
Monroe	1.3	1.2	90%	1.8	1.7	94%	3.7	3.6	98%	1.4	1.4	99%
Augusta	2.7	2.6	95%	10.9	10.8	99%	3.7	3.6	98%	1.6	1.6	99%

BC: blank-corrected result

Environmental Data

Weather patterns and other environmental conditions have a profound effect on atmospheric deposition (King County, 2015). Environmental variables include precipitation, temperature, wind direction, wind speed, particulate matter in the air, landscape, and land use. Precipitation, temperature, wind, and air particulate conditions during the study period are presented below.

Precipitation

Quarterly bulk deposition sample volumes and precipitation data from Felts Field airport are shown in Table 8. Felts Field is located 3 miles northeast of the Augusta Avenue monitoring location. Precipitation was estimated for all three monitoring locations based on sample volumes. Total precipitation for the study period was approximately 24 inches at both Felts Field and at the Spokane International Airport. The average precipitation for Spokane is about 16.5 inches annually. The month of October 2016 was the wettest month ever recorded for Spokane (NOAA, 2016).

Table 8. Quarterly precipitation during bulk deposition collection.

Location	Quarter 1 precipitation 5/11/16 – 8/11/16 volume (L)	Quarter 1 precipitation 5/11/16 – 8/11/16 (in.)*	Quarter 2 precipitation 8/12/16 – 11/17/16 volume (L)	Quarter 2 precipitation 8/12/16 – 11/17/16 (in.)*	Quarter 3 precipitation 11/18/16 – 2/15/17 volume (L)	Quarter 3 precipitation 11/18/16 – 2/15/17 (in.)*	Quarter 4 precipitation 2/16/17 – 5/10/17 volume (L)	Quarter 4 precipitation 2/16/17 – 5/10/17 (in.)*
Turnbull	**7.63**	*3.38*	**16.79**	*7.44*	**10.25/10.32**	*4.54/4.57*	**15.86/16.28**	*7.02/7.21*
Monroe	**6.77/6.81**	*3.00/3.02*	**16.18**	*7.17*	**11.07**	*4.90*	**16.90**	*7.48*
Augusta	**7.80**	*3.45*	**14.99/15.16**	*6.64/6.71*	**11.34**	*5.02*	**13.30**	*5.89*
Felts Field	--	**3.53**	--	**7.50**	--	**5.92**	--	**7.01**

*Precipitation (inches) for the three monitoring locations are estimates calculated from precipitation volume. The Felts Field data are from measured precipitation.

Temperature

Daily high and low temperatures at Felts Field Airport during the bulk deposition study period are shown with the historical daily average high and low temperatures for Spokane in Figure 8. The highest high for the study period was 99°F and the lowest low was –1°F.

Daily temperature statistics and daily precipitation from the Spokane International Airport are graphed together in Figure 9 to show the combined seasonal variability of these two major environmental factors during quarterly bulk deposition sampling.

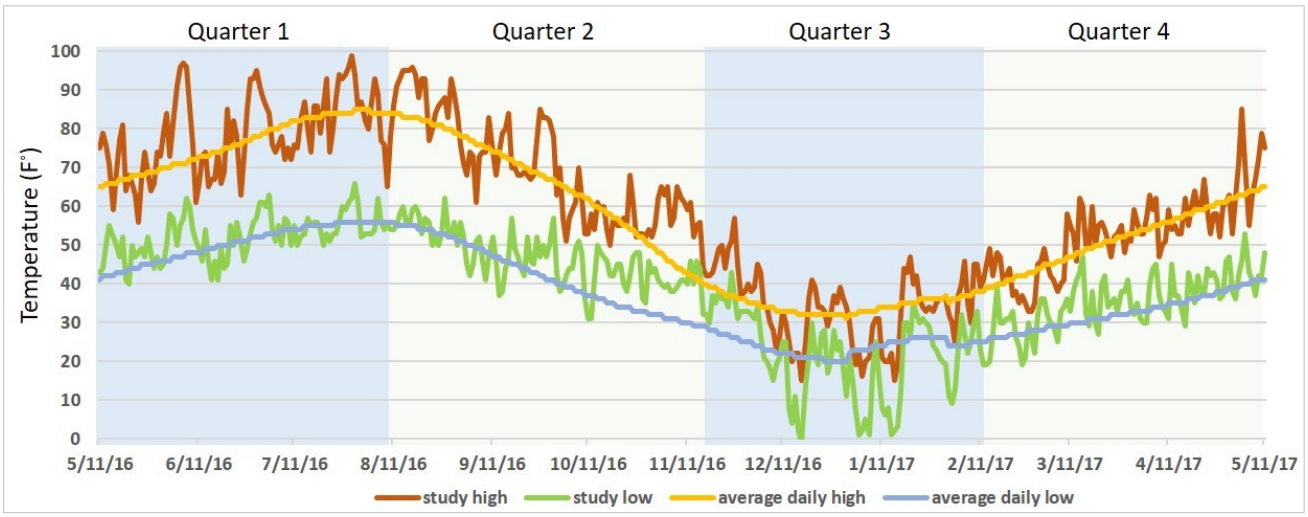


Figure 8. Daily high and low temperatures at Felts Field during bulk deposition collection, along with historical averages for Spokane. Sources: Felts Field data from Weather Underground (www.wunderground.com); historical averages from Intellicast (www.intellicast.com).

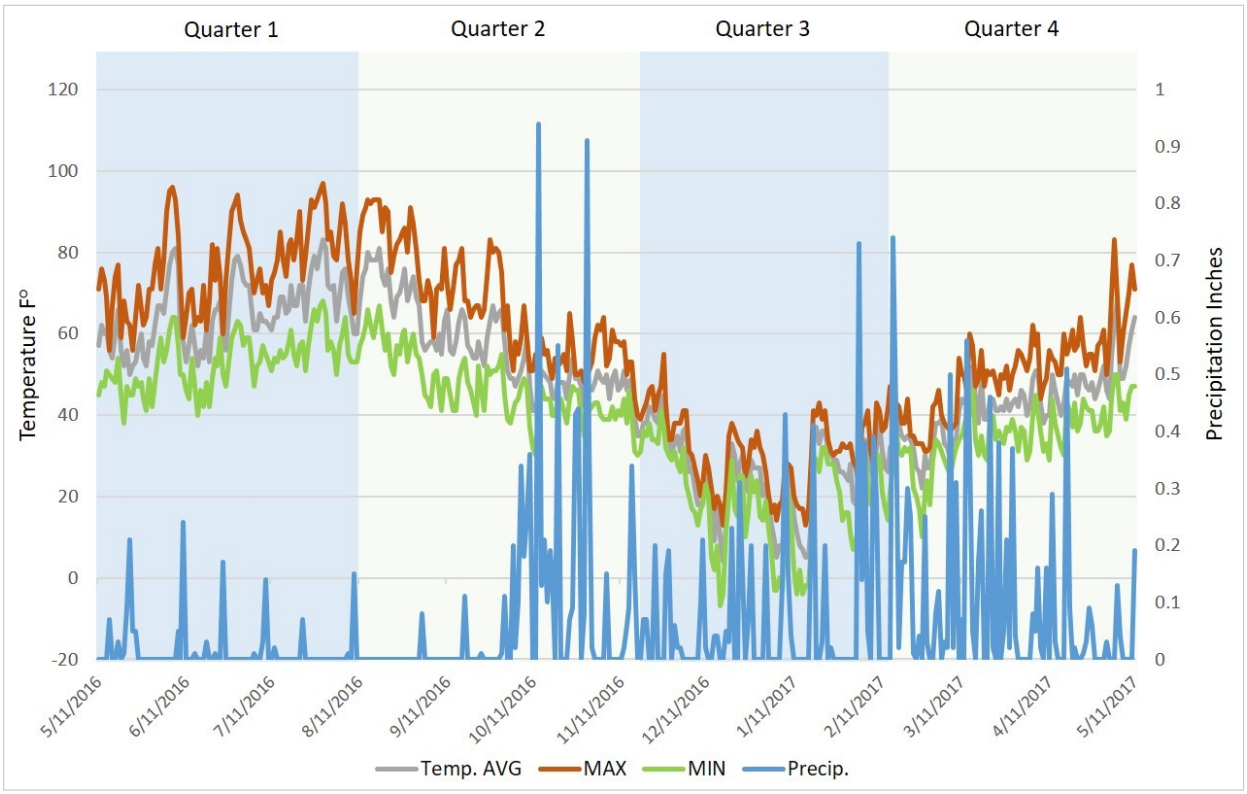


Figure 9. Temperature and precipitation at the Spokane International Airport during bulk deposition collection. Source: National Oceanic and Atmospheric Administration.

Wind Direction and Speed

Wind direction and wind speed in the Spokane area varies throughout the year, though wind direction is predominately from the southwest. Wind direction during the quarterly bulk deposition sampling followed this pattern. Quarterly wind roses for the Augusta Avenue monitoring site, the Spokane International Airport, and Felts Field Airport are shown in Appendix C.

PM2.5 and PM10

Particulate matter ≤2.5 microns (PM2.5) was measured hourly at the Monroe and Augusta air quality monitoring stations during the bulk deposition sampling (Fig. 10). Particulate matter ≤10 microns (PM10) was also measured hourly at the Turnbull and Augusta stations (Fig. 11).

The particulate matter data in Figures 10 and 11 are shown as daily averages and were downloaded from Ecology's air quality monitoring website at https://fortress.wa.gov/ecology/enviwa. The monitoring devices used at these stations are the Beta Attenuation Monitor (BAM_PM25 and BAM_PM10), Nephelometer (N_PM25), and the TEOM 1400a (T_PM10) (Ecology, 2015).

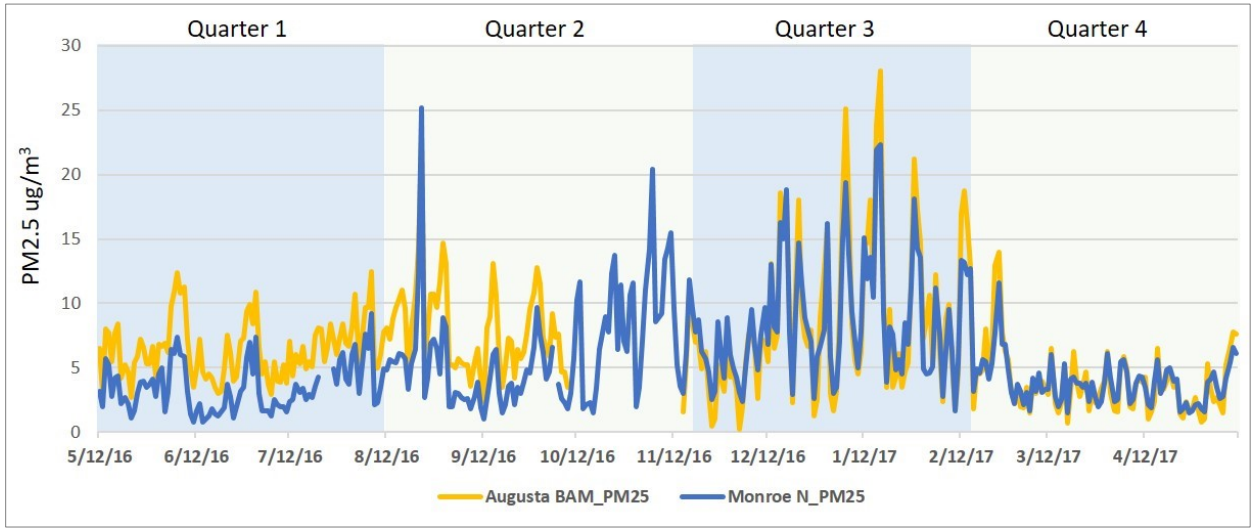


Figure 10. Daily average particulate matter ≤2.5 microns (PM2.5) at the Augusta and Monroe air quality monitoring stations.

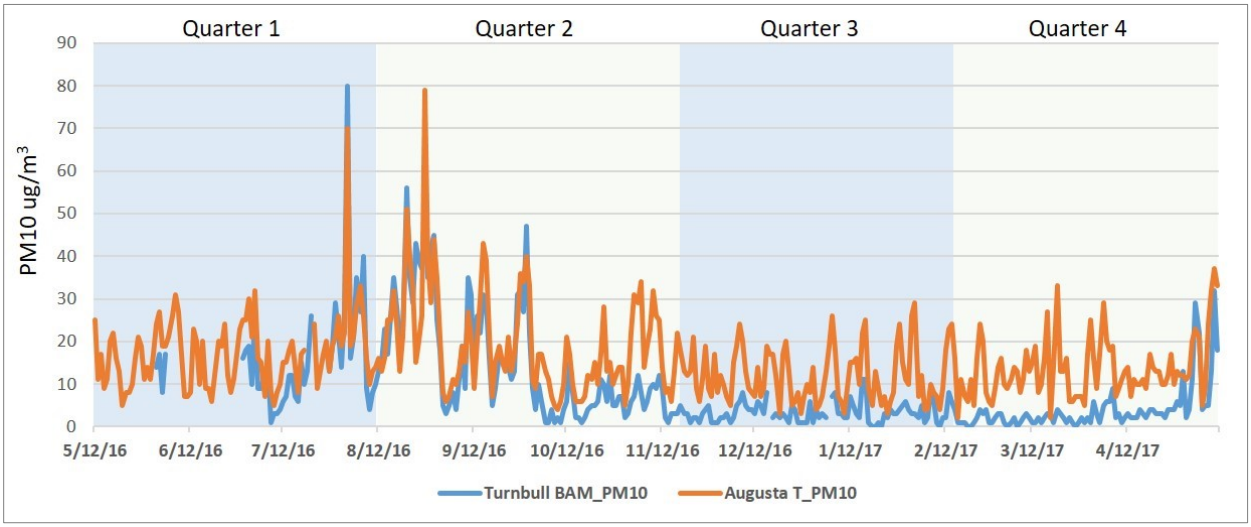


Figure 11. Daily average particulate matter ≤10 microns (PM10) at the Turnbull and Augusta air quality monitoring stations.

Dry Deposition

Proof-of-Concept Study

A proof-of-concept study for dry deposition collection methods was conducted in late January through mid-February of 2017 at the Augusta Avenue (urban-commercial) monitoring station. The objective was to test the efficacy of using PM10 filters for high-volume sampling of atmospheric PCBs compared to the more traditional method of using of high-volume PUF sampling. Since the Spokane Regional Clean Air Agency (SRCAA) samples PM10 every six days at the Augusta site and has several years' worth of archived filters, we wanted to know if these archived samples could provide any useful PCB trend information.

The PM10 filter samples had extremely low or no recovery of the mono- through hepta-chlorinated congeners, suggesting that they could not be used to provide meaningful PCB data. EPA's Compendium Method TO-4A for determining toxic organic compounds in ambient air supports this finding in stating that the volatility of compounds such as PCBs prevents efficient collection on filter media alone (EPA, 1999). Thus, EPA recommends using both a filter and PUF media together for efficient capture.

In addition to the low recovery of congeners in the PM10 samples, there was significant background contamination in the PUF/XAD-2 sampling media that overwhelmed the signal of the di- through penta-chlorinated congeners in the PUF samples. Consequently, the PUF samples from the winter 2017 (proof-of-concept) sampling did not generate usable PCB data.

Summer PUF Sampling

Ecology conducted a second round of PUF sampling in summer 2017. Three 24-hour high-volume PUF samples were obtained at the Augusta Avenue (urban-commercial) monitoring site from late August through early September. Total PCB concentrations (pg/m^3) are shown in Table 9.

Table 9. Total PCB results for summer 2017 PUF dry deposition sampling.

2017 Sampling Events	Volume (m^3)	tPCB mass (pg)	tPCB concentration (pg/m^3)
Event 1: Aug. 29–30	242	212,734	880
Event 2: Sept. 2–3	297	189,662	639
Event 3: Sept. 5–6	252	114,373	454

All three PUF sampling events coincided with a period of poor air quality from high PM2.5 levels due to numerous regional wildfires. The SRCAA stated that the 2017 wildfire season was officially the worst that they have on record and that the Spokane area saw its highest concentrations of PM2.5 over the longest duration in 2017 (SRCAA, 2017).

Figure 12 shows the daily average PM2.5 levels from June 1 to October 1, 2017. All three PUF sampling events occurred when PM2.5 levels were elevated, but the third sampling event captured peak PM2.5 conditions.

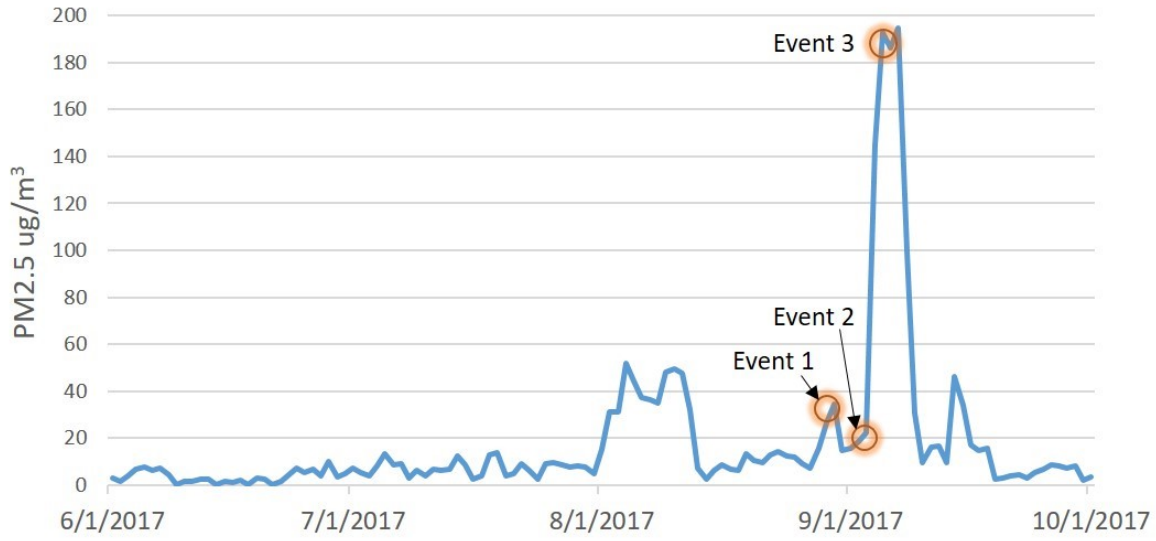


Figure 12. Daily average PM2.5 levels and PUF sampling events at the Augusta Avenue monitoring station during the 2017 fire season.

Figure 13 is a graph of hourly PM2.5 levels during each PUF sampling event and shows the condition of the sample filters after each event. Sampling event 3 had the highest PM2.5 levels, but the lowest total PCB concentrations compared to events 1 and 2. Sampling event 1 had the highest total PCB concentration, about double that of event 3, indicating that increased PM2.5 levels from wildfire smoke didn't necessarily correlate with increased concentrations of PCBs.

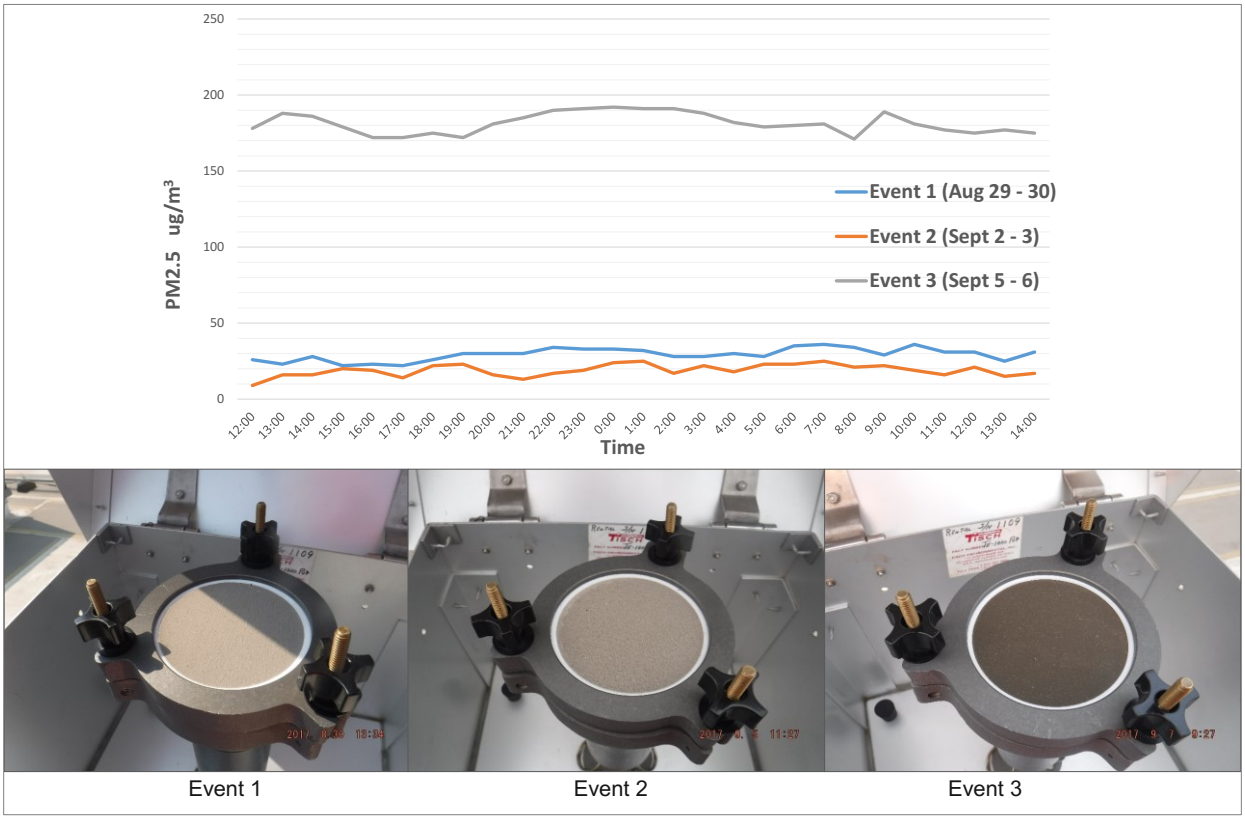


Figure 13. PM2.5 data (top) and photos of PUF filters after sampling wildfire smoke (bottom).

Congener patterns for the PUF sampling events are presented in Figure 14. Sampling events 1 and 2 appear to have identical patterns. Event 3 is similar to the first two events except for congeners -001 through -004 and congener -038, which are circled in red on Figure 14. This suggests that all three samples came predominately from the same source.

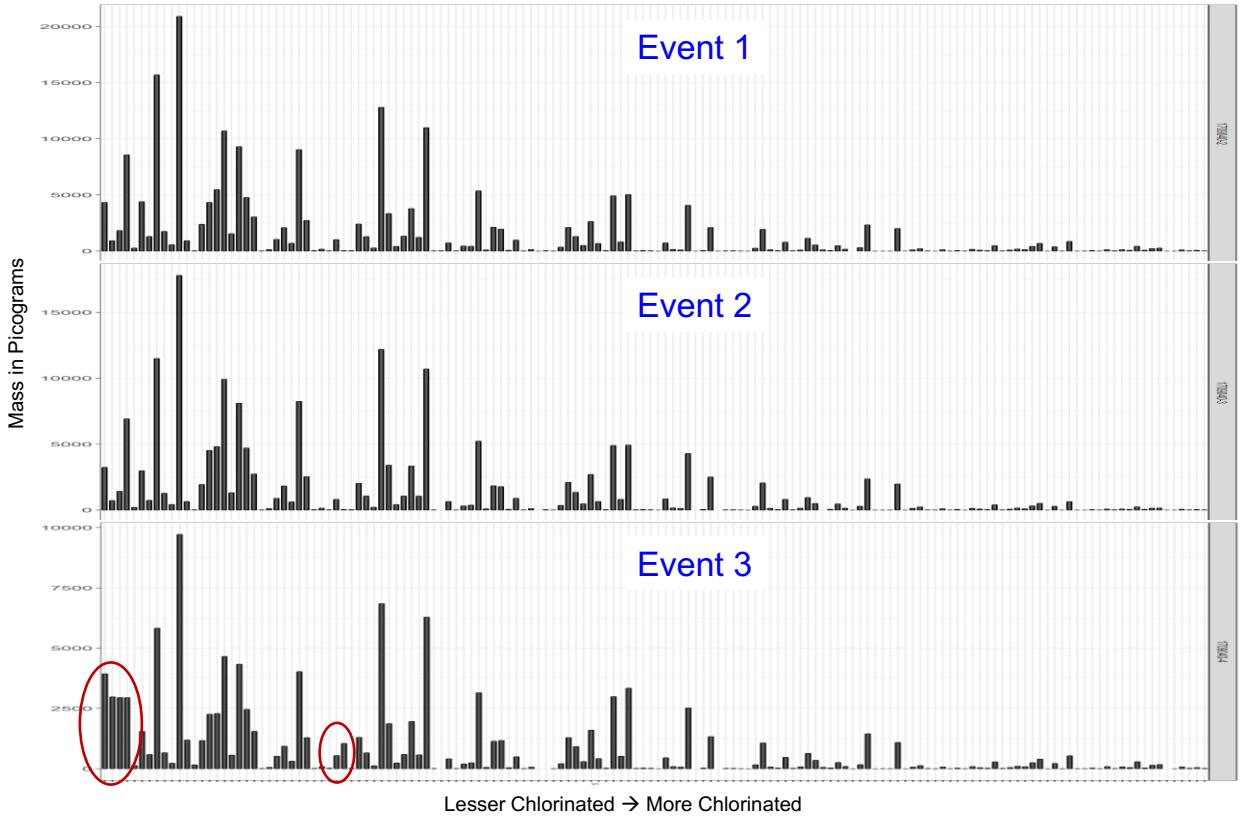


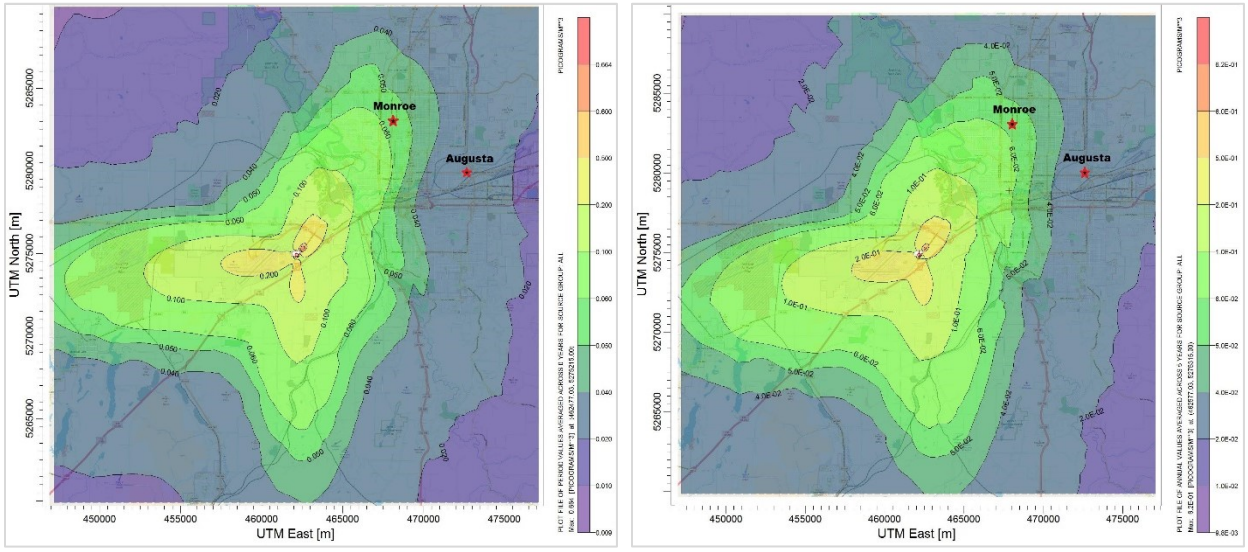
Figure 14. PCB congener patterns in wildfire smoke–dominated PUF samples.
Areas of dissimilar patterns are circled in Event 3.

Waste to Energy Facility Plume Dispersion Modeling

Ecology's Air Quality Program (AQP) conducted plume dispersion modeling and analysis of the city of Spokane's Waste to Energy (WTE) facility as a possible source of PCBs in atmospheric deposition to the Spokane area. Results are summarized below. See Appendix D for the full modeling report.

Modeling results for the 1-year PCB bulk deposition study (Fig. 15a) and a 5-year case study (Fig. 15b) show that highest annual PCB concentrations (pg/m^3) were located over the northeastern, south, and the west-southwestern region in about a 2-mile radius from the emission source. As can be seen from the figures, the two urban air quality monitoring sites of Augusta and Monroe are outside the areas with the highest PCB concentrations.

In general, the 5-year modeling case shows concentrations over a larger area than the 1-year field study case, while the overall plume distribution is similar. Quantitatively, the 5-year modeling results are about 16% higher in concentration and 20% higher in bulk deposition than the 1-year field study period modeling results (Table 10). The comparison between 1-year and 5-year model runs highlights the importance of using a longer period of meteorological data to avoid basing decisions on less representative conditions.



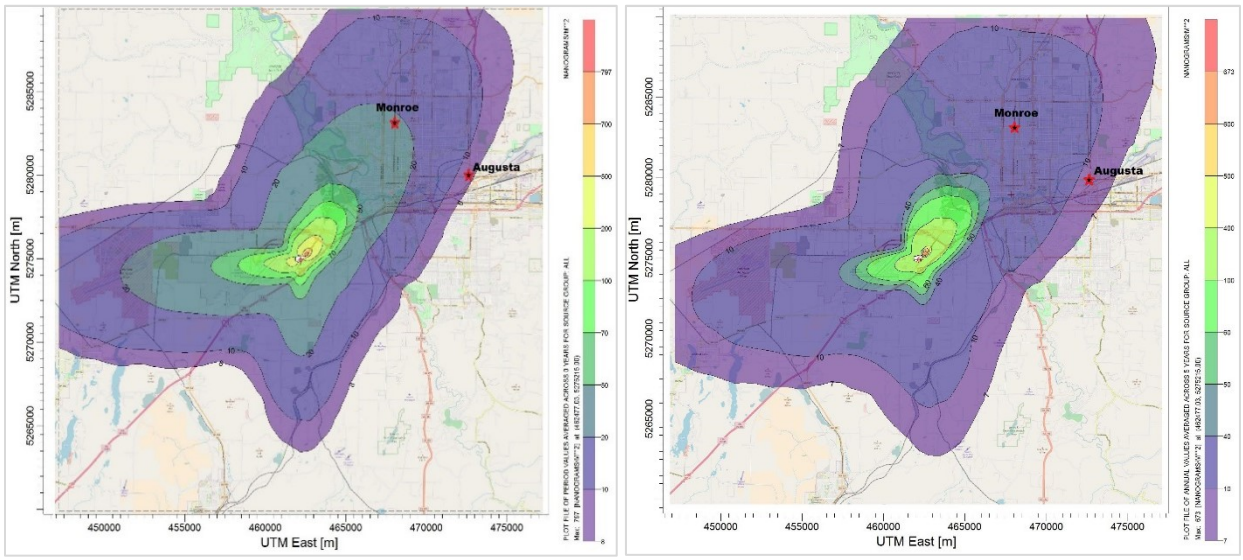
(a) (b)

Figure 15. Modeled average annual PCB concentration distribution from the Spokane Waste to Energy stack. (a) One-year field measurement case study (May 11, 2016, to May 11, 2017). (b) Regulatory 5-year modeling study (January 2011 to December 2015). Coordinates are in the UTM system (m) and concentration is in picograms per cubic meter (pg/m^3).

Table 10. AERMOD's modeled 24-hour average PCB concentration and deposition at Spokane's Waste to Energy facility.

Modeling period	Concentration (pg/m^3)	Total deposition (ng/m^2)	Dry deposition (ng/m^2)	Wet deposition (ng/m^2)
1 year	2.431	11.056	10.987	6.204
5 years	2.826	13.277	13.273	11.389

The qualitative plots of both the 1-year study and the 5-year period show that total (bulk) deposition across the domain has a similar distribution (Figs. 16a, b). The modeled deposition over the Spokane urban sites of Augusta and Monroe are very low compared to the measured concentrations and fluxes at the monitoring sites. From Figure 16a, the Augusta site is situated within the 8 – 10 ng/m^2-year (0.02 – 0.03 ng/m^2-day) contour of modeled deposition values, while Monroe is within the 20 – 50 ng/m^2-year (0.05 – 0.14 ng/m^2-day) contour. On the other hand, observed bulk deposition values at these two sites vary from 1.2 to 10.9 ng/m^2-day (see Table 11).



(a) (b)

Figure 16. Modeled average annual total (bulk) deposition distribution from the Spokane Waste to Energy stack. (a) One-year field measurement case study (May 11, 2016, to May 11, 2017). (b) Regulatory 5-year modeling study (January 2011 to December 2015). Coordinates are in the UTM system (m) and deposition is in nanograms per square meter (ng/m^2).

Table 11. AERMOD modeled and observed quarterly total (bulk) deposition data for three monitoring sites for May 11, 2016, to May 11, 2017.

Site	Site type	Data type	Quarter 1 (5/11/16 – 8/10/16) (ng/m^2-day)	Quarter 2 (8/11/16 – 11/16/16) (ng/m^2-day)	Quarter 3 (11/17/16 – 2/15/17) (ng/m^2-day)	Quarter 4 (2/16/17 – 5/11/17) (ng/m^2-day)
Augusta	Commercial	Model	0.025	0.023	0.015	0.030
		Observed	2.610	10.920	3.710	1.670
Monroe	Residential	Model	0.062	0.060	0.041	0.074
		Observed	1.240	1.740	3.660	1.380
Turnbull	Regional background	Model	0.004	0.007	0.011	0.004
		Observed	0.370	0.850	2.940	0.060

Discussion

Bulk Deposition of PCBs in Spokane

Bulk atmospheric deposition flux can be defined as the sum amount of a contaminant in both dry and wet deposition that has accumulated on the surface of a defined area over a specific period of time (e.g., ng/m^2-day). Atmospheric flux values can be used to estimate the atmospheric loading of a chemical to land surface and eventually, via runoff processes, to surface water.

The annual average flux values for the Spokane bulk deposition samples are within a similar range to the average flux values found in similar land use types (i.e., rural, urban-commercial, and urban-residential) in the Duwamish River watershed, near Seattle (Fig. 17). Because the sampling methods for the Spokane study were adapted from King County, the data between these studies is comparable. The main difference is that King County collected samples on a more frequent basis during the year (n = 5 – 15) and for shorter deployment periods (7 – 29 days). King County found high variability between the different land use types that were sampled (e.g., 1.12 ng/m^2-day for the rural site in Enumclaw to 80.0 ng/m^2-day at the urban transportation site in Georgetown).

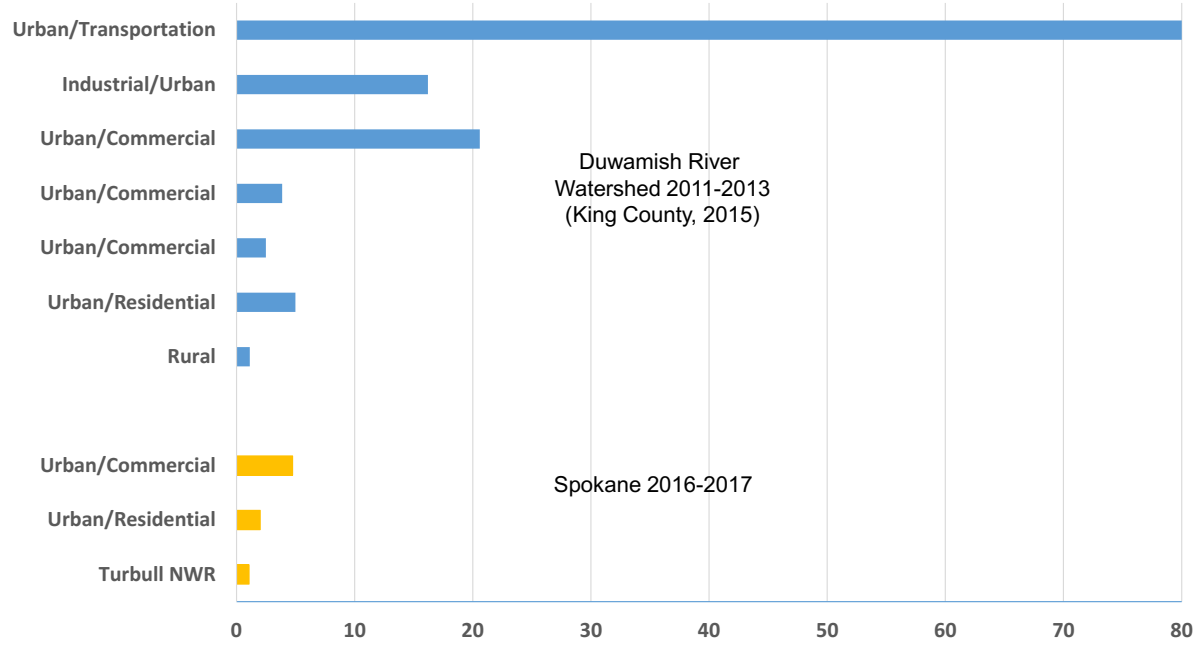


Figure 17. Average total PCB flux (ng/m^2-day) for Spokane and the Duwamish River watershed (King County, 2015).

The general trend of increasing total PCB flux values moving from Turnbull NWR, the regional background site, to Monroe (urban-residential) and then to Augusta (urban-commerical) is not surprising, because the trend of urban areas having higher PCB concentrations than rural and remote areas is strongly supported by the scientific literature (Holsen et al., 1991; Park et al., 2001; Diamond et al., 2010). Urban areas in general are often major sources of PCBs in the atmosphere, especially when temperatures are elevated and the wind comes from urban and industrialized areas (Holsen et al., 1991; Park et al., 2001; King County, 2015).

Site-Specific Congener Patterns in Bulk Deposition

Principal component analysis (PCA) was used to explore similarities and differences in PCB congener patterns in bulk deposition samples between monitoring sites and quarterly seasonal sampling events. The goal of PCA is to reduce the complexity of a large, multiple-variable data set without losing information. A plot of the first two principal components is an effective way of showing the chemical similarity of samples, where points closer together are more chemically similar than points further away (Fig. 18). There is separation between the Turnbull, Monroe, and Augusta monitoring site samples along principal component 1 (PC1). This means that samples from the same locations grouped together because they exhibited similar congener distribution patterns.

In Figure 18, the Turnbull sample from quarter 4 (Sample ID: 1705077-3) is circled and shaded below the monitoring site groupings. It is considered an outlier. Equipment blank samples were included in the PCA and generally did not group with the monitoring sites. Figure 18 shows the equipment blank sample in close proximity to the Turnbull quarter 4 sample, which supports the outlier status of the Turnbull quarter 4 sample.

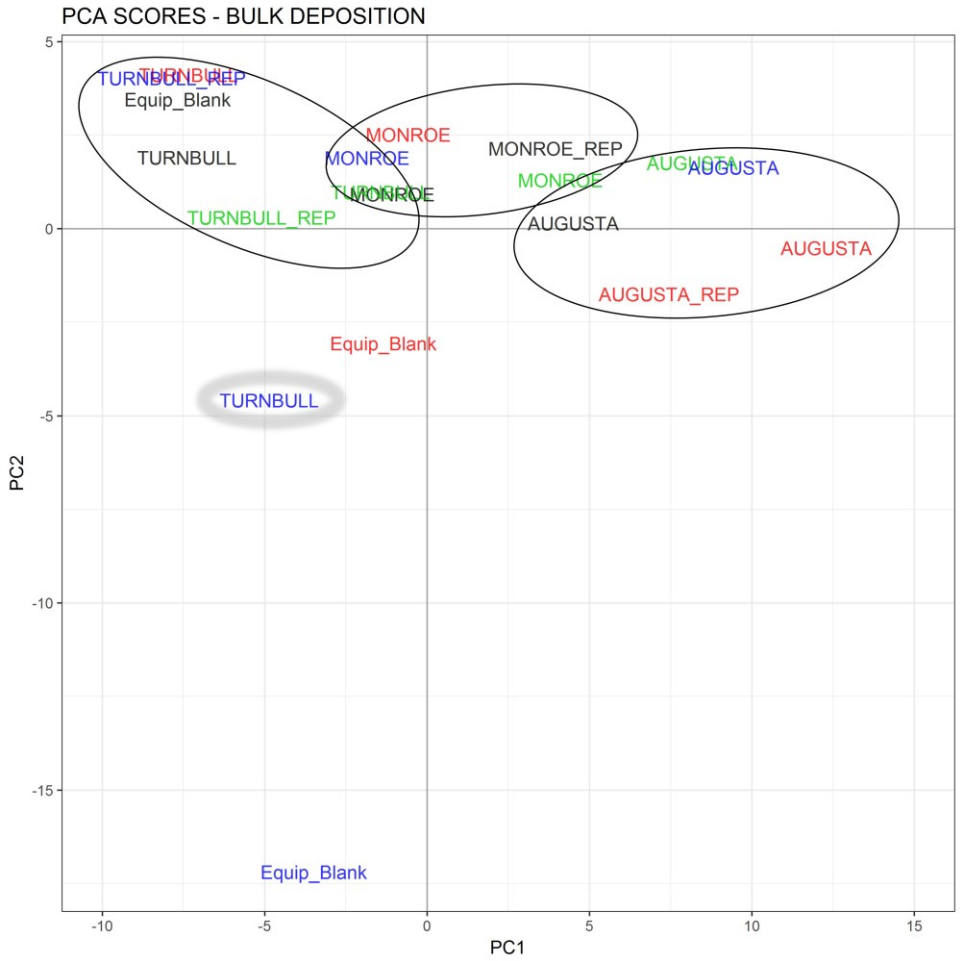


Figure 18. Principal Component Analysis (PCA) ordination plot for PCB congeners in the bulk deposition study.

Homologue analysis of the bulk deposition samples (Appendix B, Figs. B-1 through B-4) indicated that more of the higher-chlorinated congeners dominated at the Monroe Street and Augusta Avenue urban sites compared to the regional reference site at Turnbull. King County found similar results during their bulk deposition studies from 2011 to 2013. The rural site at Enumclaw had a small contribution or absence of higher-chlorinated congeners (> hexa-CB) compared to the suburban and urban sites (King County, 2015).

Modeled PCBs from Waste to Energy Versus Measured PCBs

Figure 19 compares the modeled PCBs for the Spokane WTE facility to the measured results in bulk deposition from each of the study sites. The modeled values for the Spokane WTE Facility are less than 2% of the measured values for the four quarters of the study period. In other words, the monitored deposition values are about two orders of magnitude higher than the modeled values for the WTE facility. These quantitative and qualitative comparisons show that the PCB contribution from the Spokane WTE facility is very low. Past AERMOD sensitivity analysis studies suggested that the model generally overestimates observations, especially during calm and/or low wind speeds (Perry et al., 2005; Duoxing et al., 2007). Therefore, the modeling

results are likely upper bounds of what the Spokane WTE facility could contribute to the observed deposition, implying that there must be other contributing PCB sources in the region.

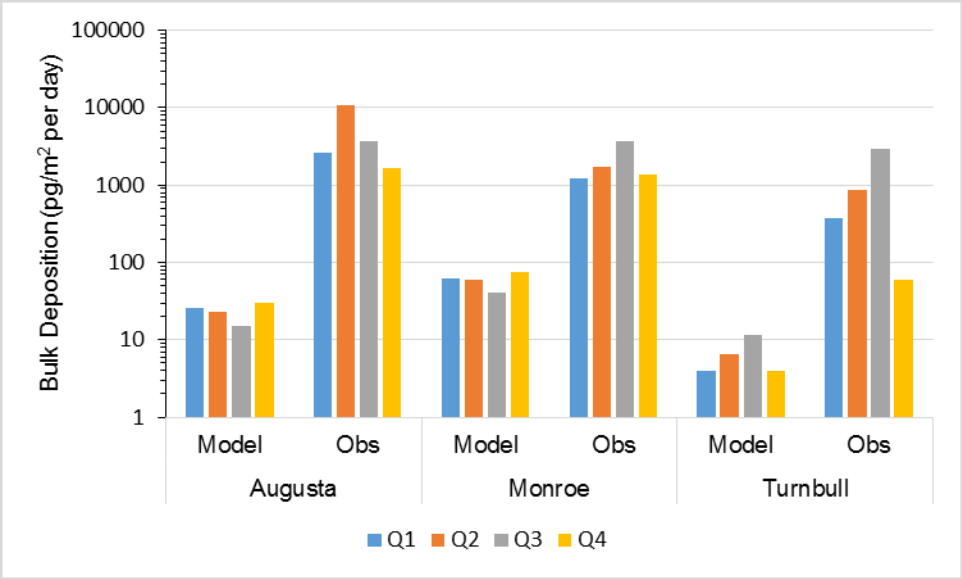


Figure 19. Comparison of modeled quarterly bulk PCB deposition from the Spokane Waste to Energy facility ("Model") and quarterly total PCB measurements at three sites ("Obs").
Note the logarithmic scale for the y axis. Q1 = 5/11/2017 – 8/10/2016; Q2 = 8/11/2016 – 11/16/2017; Q3 = 11/17/2016 – 2/15/2017; Q4 = 2/16/2017 – 5/11/2017).

Contribution of Atmospheric PCBs to Stormwater in the Cochran Basin

Questions that the Spokane PCB atmospheric deposition study sought to address were:

- How much of the PCB loading in urban stormwater from Spokane comes from atmospheric sources?

- Can data from this project be used in concert with PCB data from the city of Spokane's stormwater basin monitoring program to estimate this loading?

We didn't have time to address this question for the report. However, it could still be done in the future.

The Monroe Street air quality monitoring station is located within Spokane's Cochran stormwater basin. The City collected and analyzed PCB congeners and flow in the Cochran basin four times during the bulk atmospheric deposition study (2016 – 2017) as part of their stormwater monitoring program (City of Spokane, 2015; Donovan, personal communication).

PCB bulk deposition flux data from the Monroe Street station could be used to estimate the atmospheric contribution of PCBs to stormwater in the Cochran basin. Any such modeling results would be estimates, but they could provide some useful data regarding the general impact of atmospheric PCBs to stormwater.

PCBs in Wildfire Smoke

We conducted additional dry deposition monitoring at Augusta Avenue in the summer of 2017. Our intent was to replace sampling for the compromised samples collected in the winter of 2017 (as part of the proof-of-concept study). In addition, we decided that having some high-quality dry deposition data for the Spokane area would help to fill the data gap regarding PCBs in atmospheric deposition.

The Augusta Avenue monitoring location represents an urban-commercial land use and airshed. However, the dry deposition samples collected in the summer of 2017 at Augusta Avenue may be more representative of regional wildfire inputs. A scientific literature search revealed little information on PCBs in wildfire smoke. One study from Norway found significant enhancements of PCBs in atmospheric samples taken in July 2004, when a large plume of smoke from boreal forest fires in Alaska and Canada traveled over Svalbard (Eckhardt et al., 2007). But the researchers analyzed for only 32 congeners, making it difficult to compare congener patterns between the Svalbard study and the Spokane study.

To provide context for the wildfire smoke–dominated dry deposition data at the Augusta Avenue site, data were compared with total PCB concentrations from several other urban areas in the northeastern United States (Fig. 20). PCBs in the wildfire smoke–dominated samples appear to be generally higher than PCBs in remote rural and suburban areas, but lower than PCBs in the highly urbanized Chicago area (Hoff et al., 1996; Franz and Eisenreich, 1998; Tasdemir et al., 2004).

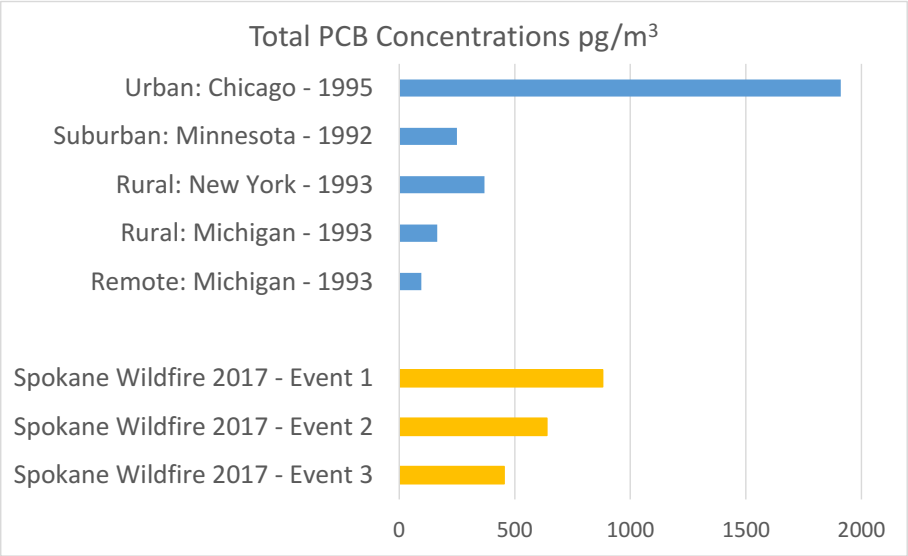


Figure 20. Total atmospheric PCB concentrations in Spokane compared to other states.

Air Mass Movement

Back trajectories of the air masses moving over the Augusta Avenue sampling site during the summer 2017 PUF sampling events were modeled by Ecology's AQP using the National Oceanic and Atmospheric Administration's (NOAA) HYSPLIT model (Stein et al., 2015; Rolph et al., 2017). Wind roses were also created for the 24-hour PUF sampling events using AERMET wind rose products and surface wind data from the Spokane International Airport.

A back trajectory shows the past path of small particles in an air mass as they move through time and space in three dimensions (includes vertical movement) using a model such as HYSPLIT. Together, back trajectories and wind roses tell a story of where air masses originate and what conditions may have affected deposition of atmospheric pollutants at a given place and time.

A full interpretation and discussion regarding the effect that air mass movement had on the summer of 2017 PUF sampling PCB results is beyond the scope of the current study, however, some general observations are provided below for each of the three monitoring events.

Event 1 (August 29 – 30, 2017)

Figure 21 shows that the air masses located at 500 m above ground level at the start (Fig. 21a) and at the end (Fig. 21b) of sampling event 1 originated from the southeast corner of Washington. The vertical movement of the air mass towards the end of the sampling event (Fig. 21b) is one of subsidence or downward movement. Subsidence can concentrate particulates in an air mass by pushing them down towards the land surface. The wind rose (Fig. 21c) indicates that surface wind direction was southwesterly (flowing from the southwest) for approximately half of the time and easterly (flowing from the east) for the other half. Sampling event 1 had the highest total PCB concentrations at 880 pg/m^3 (Table 8).

Event 2 (September 2 – 3, 2017)

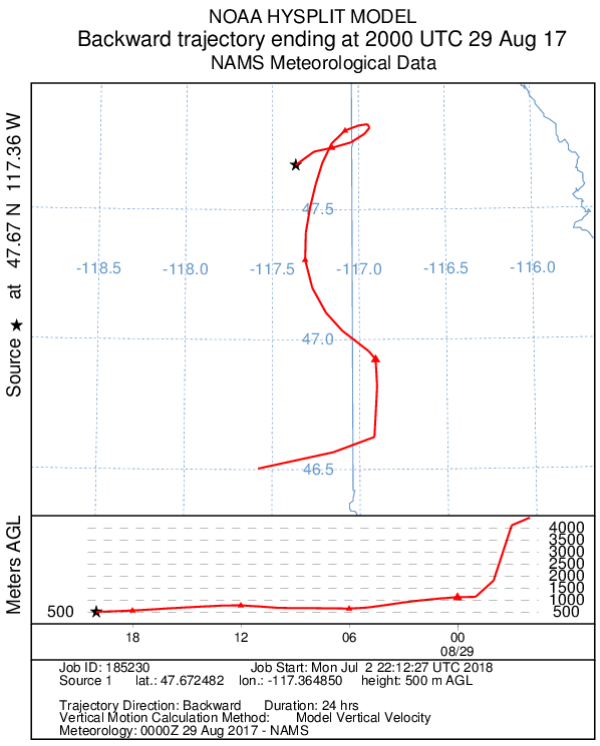
The 500-m-elevation air mass trajectories (Fig. 22a, b), which were generally westerly, did not match the surface wind rose northeasterly direction (Fig. 23) for sampling event 2. The air mass trajectories were therefore plotted again, but at a 50-m elevation (Fig. 22c, d), to see if there were different wind patterns happening closer to the land surface. Comparison of the 50-m and 500-m trajectories indicated major differences in wind conditions happening at the land surface versus above 500 m. Similar to air masses at 500 m for event 1, the air masses at 50 m for event 2 also appeared to mostly originate from southeast of Spokane. Vertical data (Fig. 22b) towards the end of event 2 showed subsidence followed by a dramatic uplift in air mass movement. Total PCBs were 639 pg/m^3 for this event (Table 8).

Event 3 (September 5 – 6, 2017)

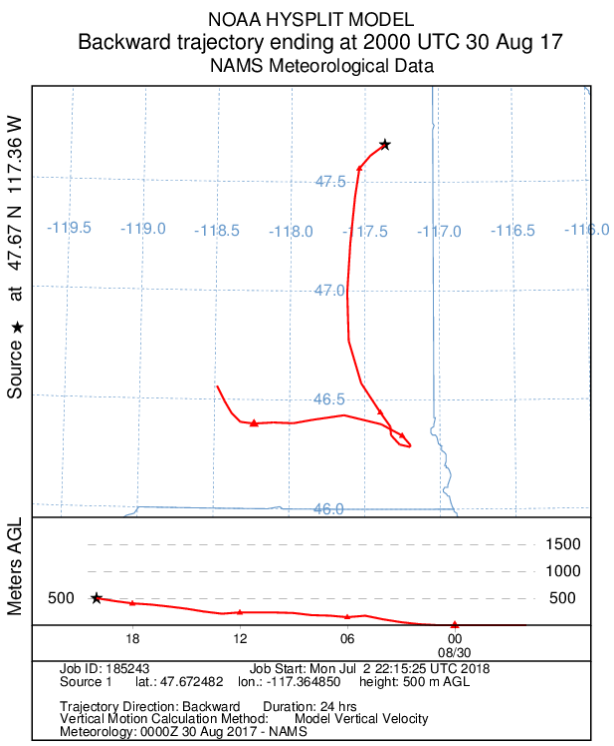
Figure 24 shows that the 500-m-elevation air mass trajectories for sampling event 3 were dramatically different from events 1 and 2, with a dominant flow from the northeast and air masses originating in Idaho, Montana, and likely Canada. The wind rose (Fig. 24c) shows that surface winds were also northeasterly. Vertical data (Fig. 24a, b) indicate uplift towards both the beginning and the end of sampling. Sampling event 3 had the lowest total PCBs (454 pg/m^3) and the highest PM2.5 (Table 9, Fig. 13).

Did Air Mass Movement Affect PCB Concentrations and PM2.5 in Dry Deposition?

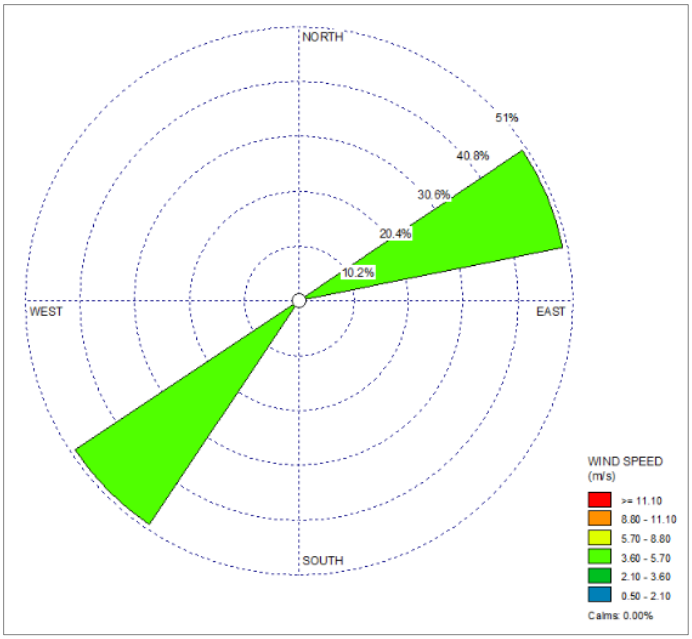
All three sampling events exhibited highly similar congener patterns, suggesting that they came predominately from the same source. There were wildfires burning all over the Pacific Northwest at the time of sampling, and the entire state was inundated with smoke. However, total PCB concentrations for sampling event 1 were twice that of event 3, even though PM2.5 was dramatically higher in event 3. Analysis of air mass back trajectories and wind roses from all three events suggest that the air mass for event 3 came from the more remote areas of Idaho, Montana, and Canada, where wildfires were also burning at the time. So, even though PM2.5 was highest during event 3, the source of PM2.5 was smoke from fires in remote forests. Back trajectories for events 1 and 2 showed air masses originating from the southwest and southeast. Event 1 also had a substantial vertical downward movement of subsidence, where gaseous-phase contaminants could have been effectively concentrated. This subsidence could explain the higher PCB concentrations in event 1.



*a) Event 1; 24-hr back trajectory ending at the **start** of PUF sampling (8/29/17 at noon) – starting at **500** meters vertical.*

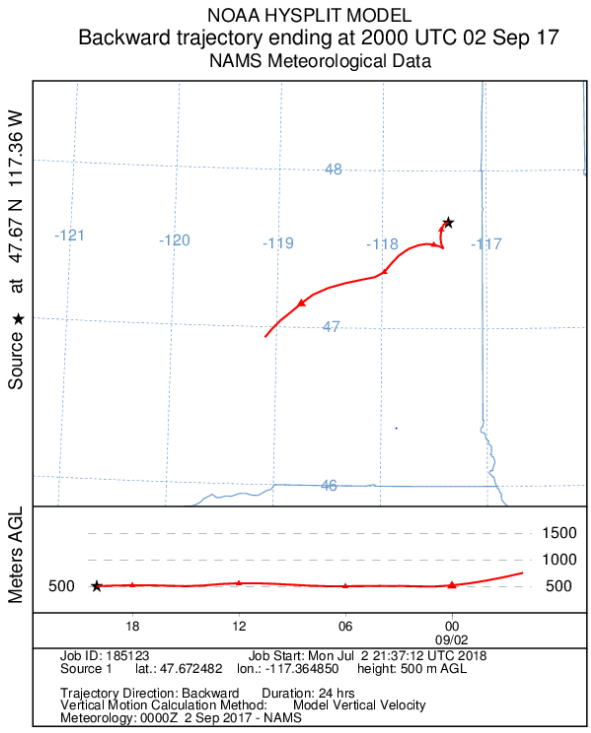


*b) Event 1; 24-hour back trajectory ending at the **end** of PUF sampling (8/30/17 at noon) – starting at **500** meters vertical.*

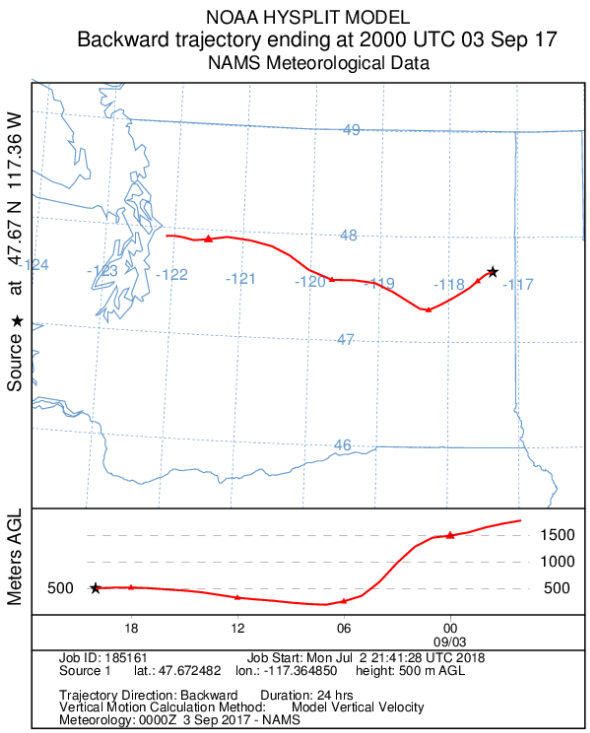


c) Event 1; 24-hour wind rose from the Spokane International Airport.

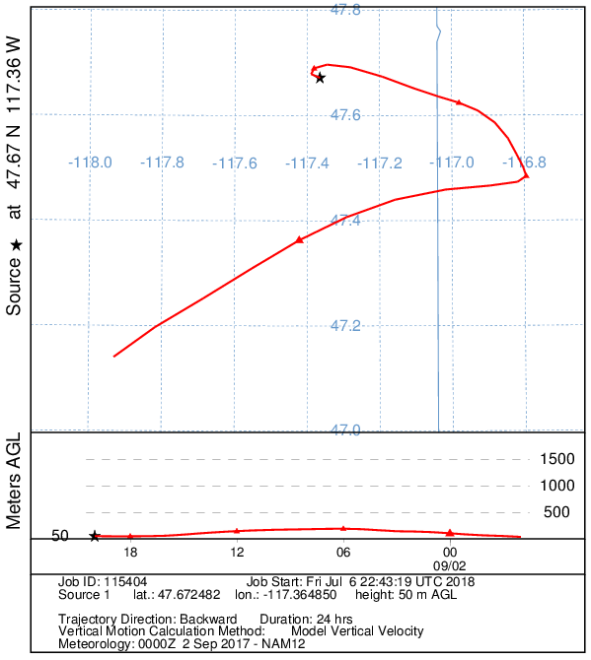
Figure 21. Back trajectories and surface wind rose for Augusta Avenue PUF sampling event 1 (August 29 – 30, 2017). AGL = above ground level.



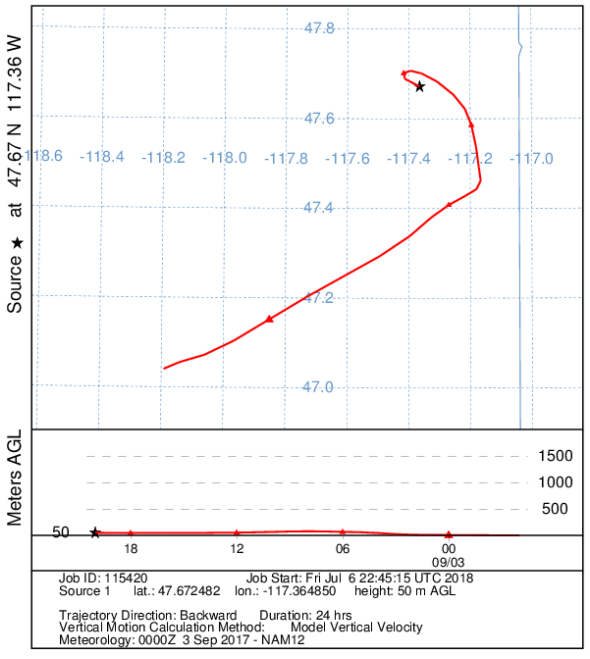
a) Event 2; *24-hr back trajectory ending at the **start** of PUF sampling (9/2/17 at noon) – starting at **500** meters vertical.*



*b) Event 2; 24-hour back trajectory ending at the **end** of PUF sampling (9/3/17 at noon) – starting at **500** meters vertical.*



c) Event 2; *24-hr back trajectory ending at the **start** of PUF sampling (9/2/17 at noon) – starting at **50** meters vertical.*



*d) Event 2; 24-hour back trajectory ending at the **end** of PUF sampling (9/3/17 at noon) – starting at **50** meters vertical.*

Figure 22. Back trajectories for Augusta Avenue PUF sampling event 2 (September 2 – 3, 2017). AGL = above ground level.

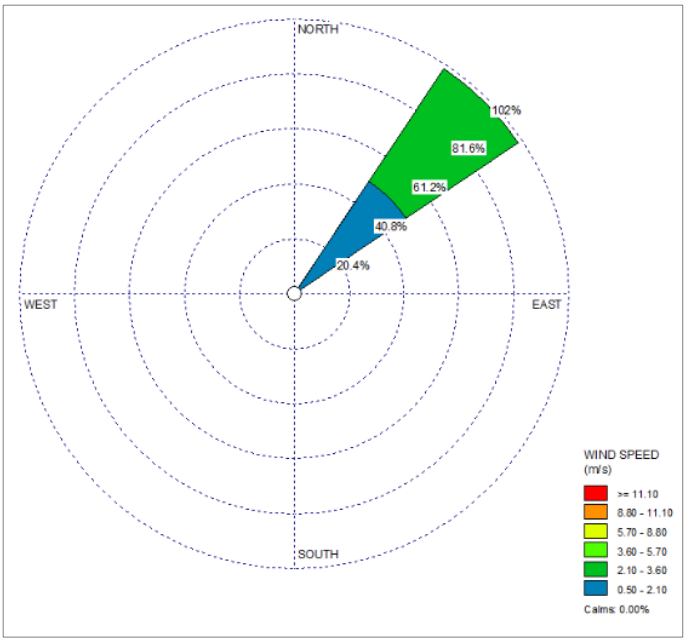
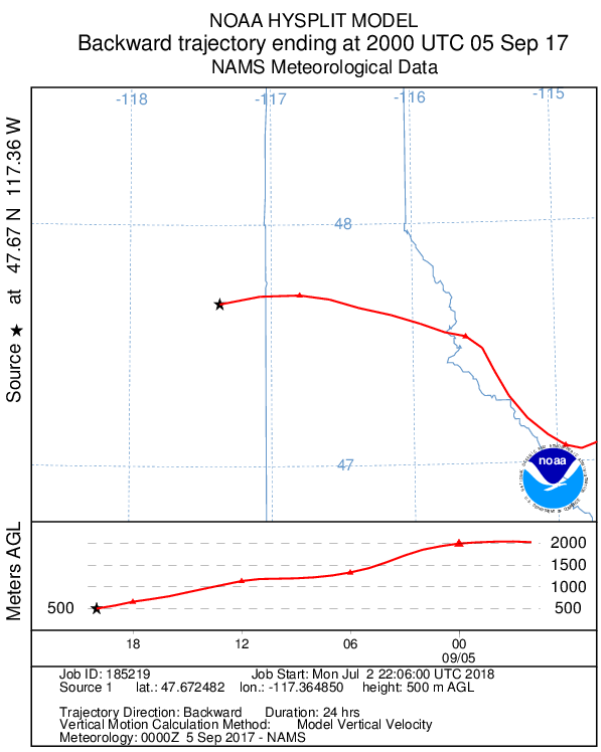
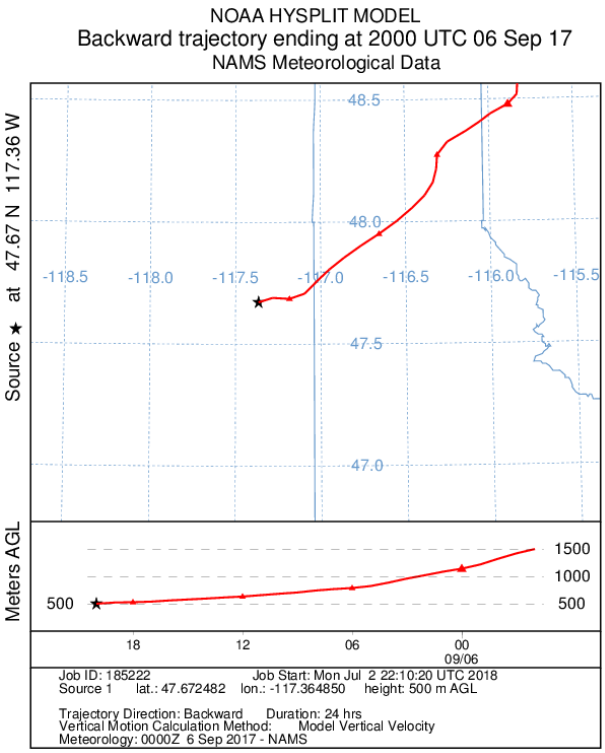


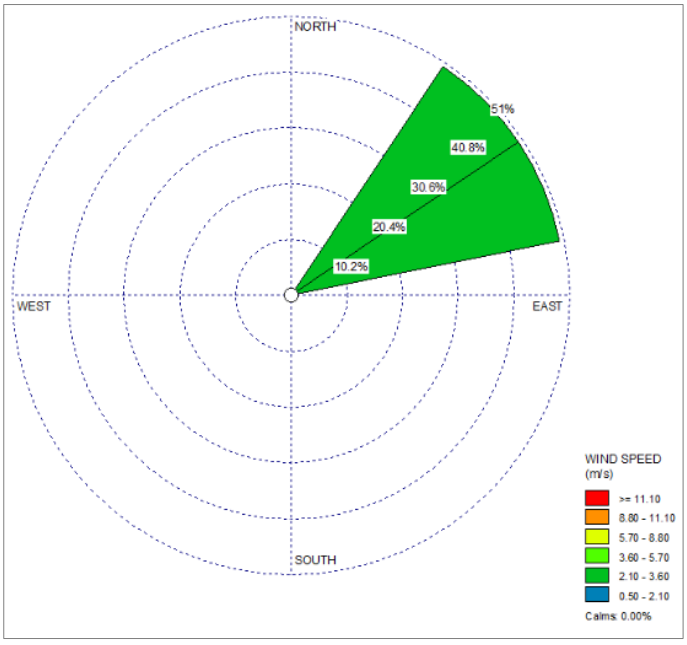
Figure 23. Surface wind rose from the Spokane International Airport for PUF sampling event 2 (September 2 – 3, 2017).



*a) Event 3; 24-hr back trajectory ending at the **start** of PUF sampling (9/5/17 at noon) – starting at 500 meters vertical.*



*b) Event 3; 24-hour back trajectory ending at the **end** of PUF sampling (9/6/17 at noon) – starting at 500 meters vertical.*



c) Event 3; 24-hour wind rose from the Spokane International Airport.

Figure 24. Back trajectories and surface wind rose for Augusta Avenue PUF sampling event 3 (September 5 – 6, 2017). AGL = above ground level.

Conclusions

This study supports the following conclusions:

Bulk Deposition

- PCB analysis of bulk atmospheric deposition samples collected in the Spokane area on a quarterly basis (2016 – 2017) denoted a general trend of increasing total PCB flux values among monitoring sites. The lowest values were from Turnbull NWR, the regional background site, and the highest values were from Augusta Avenue (urban-commercial).

- Spokane-area atmospheric PCB flux measurements were comparable to measurements representing similar land uses in the Duwamish River watershed near Seattle, Washington.

- Principal Component Analysis indicated that all three bulk atmospheric monitoring sites had unique congener patterns that were endemic to each location. Homologue analysis showed that the Monroe Street and Augusta Avenue sites had more of the higher-chlorinated congeners compared to Turnbull.

- Total PCB concentrations in bulk deposition field replicate samples (deployed side-by-side) revealed a significant level of variability, indicating that PCBs in atmospheric deposition may be patchy and erratic in the environment.

Dry Deposition

- The dry deposition proof-of-concept study for PM10 filters and PUF/XAD-2 samples showed that PM10 filters cannot be used to accurately characterize PCBs and assess PCB trends.

- Three 24-hour dry deposition PUF samples were collected at the Augusta Avenue site during a period of intense regional wildfire conditions. All three samples exhibited highly similar congener patterns, suggesting that they came predominately from the same source. However, total PCB concentrations for sampling event 1 were twice that of event 3, even though particulate matter ≤2.5 microns was dramatically higher in event 3. Analysis of air mass back trajectories and wind roses from all the sampling events suggest that air mass movement is an important factor influencing PCB concentrations in dry deposition samples.

- Total PCB concentrations (pg/m^3) in the dry deposition samples collected during wildfire conditions at an urban site in Spokane were higher than rural and suburban concentrations in the northeastern United States, but lower than the highly urbanized areas of Chicago, Illinois.

PCBs from the Waste to Energy Facility

- The Spokane Waste to Energy facility was found to be a very minor source of PCBs in atmospheric deposition in the Spokane area.

Recommendations

Results of this study support the following recommendations:

- The Spokane River atmospheric deposition study for PCBs (2016 – 2017) was a pilot study and as such produced a limited set of data. Expansion of this work could include the following:

    - Field replicates for bulk deposition deployed side-by-side showed significant variability in total PCB concentrations. To better characterize this variability, field replicates should be used at as many future monitoring stations as the analytical budget allows.

    - To better understand PCB flux in the Spokane area and across different land uses, the study could be expanded to include more existing air quality monitoring stations. Sampling additional locations within commercial, industrial, and transportation corridors could show more between-site variability and higher PCB fluxes, as seen in the King County studies in the Duwamish River basin (King County, 2015).

    - Conducting shorter-term collections (e.g., 1 – 3 weeks) of bulk deposition at a few select monitoring stations could help us describe the temporal variability of PCB concentrations in the greater Spokane area, as well as the relationships between PCB flux and environmental variables such as particulate matter, temperature, precipitation, wind direction, and wind speed.

    - Dry deposition sampling using PUF/XAD-2 filters conducted seasonally would help characterize PCB congener patterns during different environmental conditions. The current study had usable data taken only during a period of regional wildfire conditions.

- PCB bulk deposition flux data from the Monroe Street monitoring site could be used to estimate the atmospheric contribution of PCBs to stormwater in Spokane's Cochran stormwater basin. The city collected and analyzed four stormwater samples for PCBs during the same time frame as this atmospheric deposition study.

References

Brandenberger, J.M., P. Louchouarn, L.-J. Kuo, E.A. Crecelius, V. Cullinan, G.A. Gill, C. Garland, J. Williamson, and R. Dhammapala, 2010. Control of Toxic Chemicals in Puget Sound, Phase 3: Study of Atmospheric Deposition of Air Toxics to the Surface of Puget Sound. Prepared for the Washington State Department of Ecology, Air Quality Program, with Pacific Northwest National Laboratory and Naval Facilities Engineering Command. Washington State Department of Ecology, Olympia. Publication No. 10-02-012. https://fortress.wa.gov/ecy/publications/SummaryPages/1002012.html.

City of Spokane, 2015. Draft Quality Assurance Project Plan – Cochran Basin DO TMDL Stormwater Sampling. Prepared by the City of Spokane Wastewater Management for the Washington State Department of Ecology Water Quality Program. Spokane, Washington.

Colman, J.A., K.C. Rice, and T.C. Willoughby, 2001. Methodology and Significance of Studies of Atmospheric Deposition in Highway Runoff. U.S. Geological Survey Open-File Report 01-259. https://pubs.usgs.gov/of/2001/ofr01-259.

Davies, H., 2015. PCB Chemical Action Plan. Washington State Department of Ecology, Olympia. Publication No. 15-07-002. https://fortress.wa.gov/ecy/publications/documents/1507002.pdf.

Diamond, M., S. Gingrich, K. Fertuck, B. McCarry, G. Stern, B. Billeck et al., 2000. Evidence for organic film on an impervious urban surface: Characterization and potential teratogenic effects. Environmental Science and Technology 34: 2900–2908.

Diamond, M., L. Melymuk, S. Csiszar, and M. Robson, 2010. Estimation of PCB stocks, emissions, and urban fate: Will our policies reduce concentrations and exposure? Environmental Science and Technology 44: 2777–2783.

Donovan, J., 2018. Personal communication with Jeff Donovan, Environmental Analyst for the City of Spokane, Washington.

Duoxing, Yang, C. Gangcai, and Y. Yunjiang, 2007. Inter-comparison of AERMOD and ISC3 modeling results to the Alaska tracer field experiment. Chinese Journal of Geochemistry 26: 182–185.

Eckhardt, S., K. Breivik, S. Mano, and A. Stohl, 2007. Record high peaks in PCB concentrations in the Artic atmosphere due to long-range transport of biomass burning emissions. Atmospheric Chemistry and Physics 7: 4527–4536.

Ecology, 2015. Washington Ambient Air Monitoring Network – Quality Assurance Plan. Washington State Department of Ecology, Air Quality Program. Olympia. Publication No. 99-201 (Revised 11/2015). https://fortress.wa.gov/ecy/publications/documents/99201.pdf.

EPA [United States Environmental Protection Agency], 1999. Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, 2nd Edition. Center for Environmental Research Information, Office of Research and Development. U.S. Environmental Protection Agency, Cincinnati. EPA/625/R-96/010b. https://www3.epa.gov/ttnamti1/files/ambient/airtox/tocomp99.pdf.

EPA [United States Environmental Protection Agency], 2000. Reference Method for the Determination of Particulate Matter as PM10 in the Atmosphere. 40 *Code of Federal Regulations* Appendix J to Part 50. https://www.gpo.gov/fdsys/granule/CFR-2000-title40-vol2/CFR-2000-title40-vol2-part50-appJ.

EPA [United States Environmental Protection Agency], 2009. Guidance for Labeling Externally Validated Laboratory Analytical Data for Superfund Use. Office of Solid Waste and Emergency Response, Washington DC. EPA/540/R-08/005.

EPA [United States Environmental Protection Agency], 2010. Method 1668C: Chlorinated Biphenyl Congeners in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS. https://www.epa.gov/sites/production/files/2015-09/documents/method_1668c_2010.pdf.

EPA [United States Environmental Protection Agency], 2016. AERMOD Modeling System, Version Date 16216. Air Quality Dispersion Modeling – Preferred and Recommended Models. Support Center for Regulatory Atmospheric Modeling (SCRAM). https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod.

Era-Miller, B., 2011. Technical Memo: Toxics Atmospheric Deposition in Eastern Washington State – Literature Review. Prepared for Elaine Snouwaert, Water Quality Program, Washington State Department of Ecology, Spokane. November 15, 2011. Project Code 10-124.

Era-Miller, B., and S. Wong, 2016. Quality Assurance Project Plan: Spokane River Atmospheric Deposition Study for PCBs. Washington State Department of Ecology, Olympia. Publication No. 16-03-112. https://fortress.wa.gov/ecy/publications/SummaryPages/1603112.html.

ETI [Environmental Toxicology International, Inc.], 1991. Spokane Regional Solid Waste Disposal Project Dispersion Modeling Analysis. 21907 64th Ave., W Suite 230, Mountlake Terrace, Washington 98043.

Franz, T., and S. Eisenreich, 1998. Snow scavenging of polychlorinated biphenyls and polycyclic aromatic hydrocarbons in Minnesota. Environmental Science and Technology 32: 1771–1778.

Friese, M., 2014. Standard Operating Procedure for Decontaminating Field Equipment for Sampling Toxics in the Environment. SOP EAP090. Washington State Department of Ecology, Olympia.

Hobbs, W., 2015. Technical Memo: Statewide Atmospheric Deposition Review and Scoping Study. Prepared for Cheryl Niemi, Susan Braley, and Melissa Gildersleeve, Water Quality Program, Washington State Department of Ecology, Olympia. July 29, 2015. Project Code 15-041.

Hoff, R., W. Strachan, C. Sweet, C. Chan, M. Shackleton, T. Bidleman, K. Brice, D. Burniston, S. Cussion, D. Gatz, K. Harlin, and W. Schroeder, 1996. Atmospheric deposition of toxic chemicals to the Great Lakes: A review of data through 1994. Atmospheric Environment 30: 3505–3527.

Holsen, T., K. Noll, S. Liu, and W. Lee, 1991. Dry deposition of polychlorinated biphenyls in urban areas. Environmental Science and Technology 25: 1075–1081.

Hopkins, B., D. Clark, M. Schlender, and M. Stinson, 1985. Basic Water Monitoring Program: Fish Tissue and Sediment Sampling for 1984. Washington State Department of Ecology, Olympia. Publication No. 85-7. https://fortress.wa.gov/ecy/publications/summarypages/857.html.

KCEL [King County Environmental Laboratory], 2011. Standard Operating Procedure for Air Deposition Sample Collection. King County Environmental Laboratory, Seattle. SOP # 243v0.

King County, 2015. Lower Duwamish Waterway Source Control: Supplemental Bulk Atmospheric Deposition Study Final Data Report. Prepared by Jenée Colton, Martin Grassley, and Richard Jack, King County Department of Natural Resources and Parks, Water and Land Resources Division, Science and Technical Support Section, Seattle.

LimnoTech, 2015. Spokane River Regional Toxics Task Force Phase 2 Technical ActivitiesReport: Identification of Potential Unmonitored Dry Weather Sources of PCBs to the Spokane River. Prepared for Spokane River Regional Toxics Task Force, Spokane, Washington. August, 2015.

NOAA [National Oceanic and Atmospheric Administration], 2016. Climate Data Online Search. National Oceanic and Atmospheric Administration, National Centers for Environmental Information. Accessed July 27, 2018. https://www.ncdc.noaa.gov/cdo-web/search.

Park, J.S., T. Wade, and S. Sweet, 2001. Atmospheric deposition of organochlorine contaminants to Galveston Bay, Texas. Atmospheric Environment 35: 3315–3324.

Perry, Steven G., A.J. Cimorelli, R.J. Paine, R.W. Brode, J.C. Weil, A.Venkatram, R.B. Wilson, R.F. Lee, and W.D. Peters, 2005. AERMOD: A dispersion model for industrial source applications. Part II: Model performance against 17 field study databases. Journal of Applied Meteorology 44: 694–708.

PTC [Pioneer Technologies Corporation], 2001. Data Evaluation and Reduction. Chapter 2 *in* Final Spokane Waste-To-Energy Facility Human Health Risk Assessment. Report submitted to the City of Spokane – Spokane Technical Oversight Committee. Pioneer Technologies Corporation, Olympia, Washington. [Air quality model and emission rate and deposition data.]

Rauh, Stan, 1993. High Volume PM_{10} Volumetric Flow Controlled Procedures. Publication 95-201D. Air Quality Program, Washington State Department of Ecology, Olympia.

Rolph, G., A. Stein, and B. Stunder, 2017. Real-time environmental applications and display sYstem: READY. Environmental Modelling & Software 95: 210–228. https://doi.org/10.1016/j.envsoft.2017.06.025.

Rowe, M., 2016. Personal communication with Mark Rowe, Spokane Regional Clean Air Agency, Spokane, Washington.

Serdar, D., B. Lubliner, A. Johnson, and D. Norton, 2011. Spokane River PCB Source Assessment, 2003–2007. Washington State Department of Ecology, Olympia. Publication No. 11-03-013. https://fortress.wa.gov/ecy/publications/summarypages/1103013.html.

SRCAA [Spokane Regional Clean Air Agency], 2017. https://spokanecleanair.org/news/1212/a-recap-of-wildfire-smoke-levels-in-august-and-september-2017.

Stein, A.F., R.R. Draxler, G.D. Rolph, B.J.B. Stunder, M.D. Cohen, and F. Ngan, 2015. NOAA's HYSPLIT atmospheric transport and dispersion modeling system. Bulletin of the American Meteorological Society 96: 2059–2077. http://dx.doi.org/10.1175/BAMS-D-14-00110.1.

Tasdemir, Y., N. Vardar, M. Odabasi, T.M. Holsen, 2004. Concentrations and gas/particle partitioning of PCBs in Chicago. Environmental Pollution. 131:35 – 44.

Tisch Environmental, n.d. PM10 High Volume Air Sampler. Accessed October 25, 2018. https://tisch-env.com/high-volume-air-sampler/pm10.

Tisch Environmental, n.d. Polyurethane Foam (PUF) Pesticide Samplers. Accessed October 25, 2018. https://tisch-env.com/pesticide-samplers/PUF.

Appendices

Appendix A. Dry Deposition PCB Flux Calculation Spreadsheets

Calibrated Orifice Standard Information:

Orifice ID	2420
m (orifice)	9.66308
b (orifice)	-0.00827

Date	Actual Temperature(C)	Actual Pressure (mmHg)
8/29/2017	25.6	759.968

Magnehelic, Std (inH2O)	Orifice Manometer, Act (inH20)	Orifice Manometer (Qstd) = X	Magnehelic, Act (FLOW corr) = Y
20	2.6	0.168	4.47
30	3.6	0.197	5.47
40	4.5	0.220	6.32
50	5.3	0.239	7.06
60	6.1	0.256	7.74
70	6.9	0.272	8.36

m (sampler)	**36.98**
b (sampler)	**-1.77**
R2 (sampler)	**0.999**

Sample Date	Avg Temperature(C)	Avg Pressure (mmHg)
8/29 - 8/30 2017	26.5	757.5

Avg Magnehelic, Std (inH2O)	Sampler Flow, Std (m3/min)
21.5	**0.173**

Hours operated
23.31
Minutes operated
1398.6
Sampler flow x time = VOLUME (m^3)
241.7

Total PCBs (pg)	PCB Concentration pg/m^3
212734	880
	PCB Concentration ng/m^3
	0.9

Figure A-1. Dry deposition concentration calculation spreadsheet for sampling event 1 (8/29/17 – 8/30/17).

Calibrated Orifice Standard Information:

Orifice ID	2420
m (orifice)	9.66308
b (orifice)	-0.00827

Date	Actual Temperature(C)	Actual Pressure (mmHg)
8/29/2017	25.6	759.968

Magnehelic, Std (inH2O)	Orifice Manometer, Act (inH20)	Orifice Manometer (Qstd) = X	Magnehelic, Act (FLOW corr) = Y
20	2.6	0.168	4.47
30	3.6	0.197	5.47
40	4.5	0.220	6.32
50	5.3	0.239	7.06
60	6.1	0.256	7.74
70	6.9	0.272	8.36

m (sampler)	**36.98**
b (sampler)	**-1.77**
R2 (sampler)	**0.999**

Sample Date	Avg Temperature(C)	Avg Pressure (mmHg)
9/2 - 9/3 2017	23.7	760.9

Avg Magnehelic, Std (inH2O)	Sampler Flow, Std (m3/min)
33	0.204

Total PCBs (pg)	PCB Concentration pg/m^3
189662	639
	PCB Concentration ng/m^3
	0.6

Hours operated
24.27
Minutes operated
1456.2
Sampler flow x time = VOLUME (m^3)
296.7

Figure A-2. Dry deposition concentration calculation spreadsheet for sampling event 2 (9/2/17 – 9/3/17).

Calibrated Orifice Standard Information:

Orifice ID	2420
m (orifice)	9.66308
b (orifice)	-0.00827

Calibration Date	Actual Temperature(C)	Actual Pressure (mmHg)
8/29/2017	25.6	759.968

Magnehelic, Std (inH2O)	Orifice Manometer, Act (inH20)	Orifice Manometer (Qstd) = X	Magnehelic, Act (FLOW corr) = Y
20	2.6	0.168	4.47
30	3.6	0.197	5.47
40	4.5	0.220	6.32
50	5.3	0.239	7.06
60	6.1	0.256	7.74
70	6.9	0.272	8.36

m (sampler)	**36.98**
b (sampler)	**-1.77**
R2 (sampler)	**0.999**

Sample Date	Avg Temperature(C)	Avg Pressure (mmHg)
9/5 - 9/6 2017	20.5	762.7

Avg Magnehelic, Std (inH2O)	Sampler Flow, Std (m3/min)
21	**0.173**

Hours operated
24.26
Minutes operated
1455.6
Sampler flow x time = VOLUME (m^3)
251.9

Total PCBs (pg)	PCB Concentration pg/m^3
114373	454
	PCB Concentration ng/m^3
	0.5

Figure A-3. Dry deposition concentration calculation spreadsheet for sampling event 3 (9/5/17 – 9/6/17).

Appendix B. Bulk Deposition PCB Data

Table B-1. Quarterly bulk deposition mass (pg) at three, five, and ten times the laboratory method blank.

Table B-1 is available only online, linked to this report:
https://fortress.wa.gov/ecy/publications/SummaryPages/1903003.html.

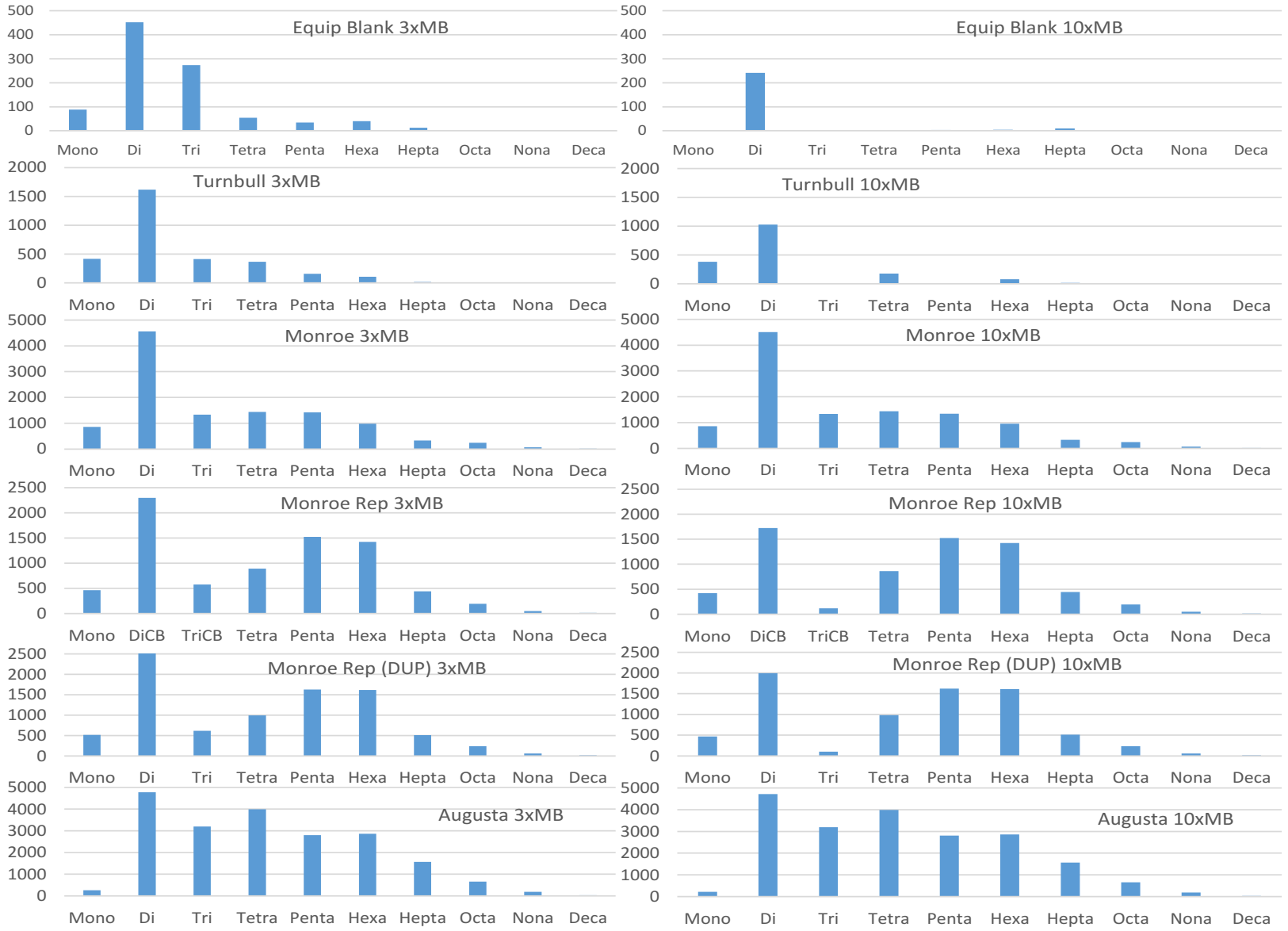


Figure B-1. Quarter 1 bulk deposition mass (pg) PCB homologues, censored at three and ten times the method blank (MB).

Figure B-2. Quarter 2 bulk deposition mass (pg) PCB homologues, censored at three and ten times the method blank (MB).

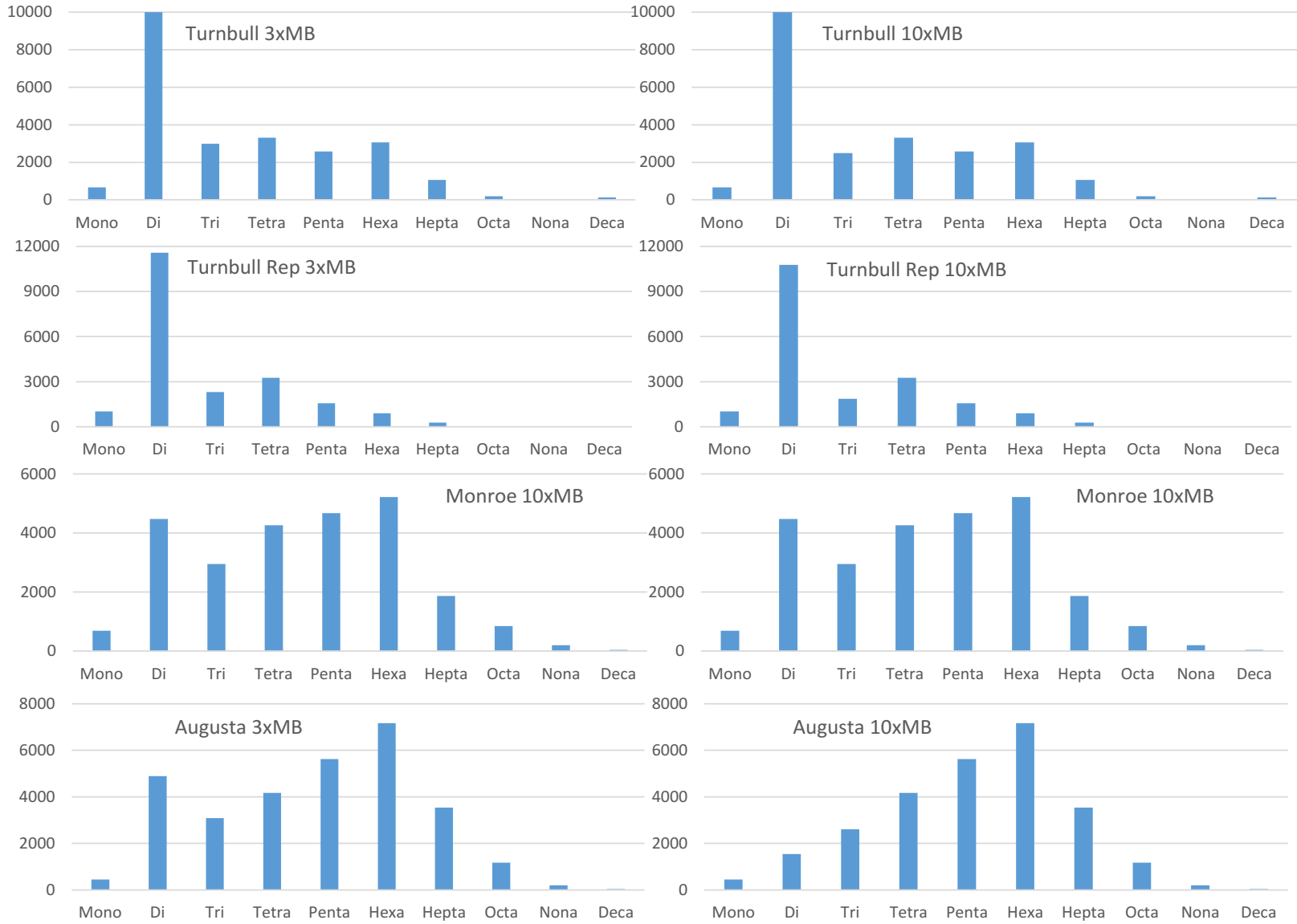


Figure B-3. Quarter 3 bulk deposition mass (pg) PCB homologues, censored at three and ten times the method blank (MB).

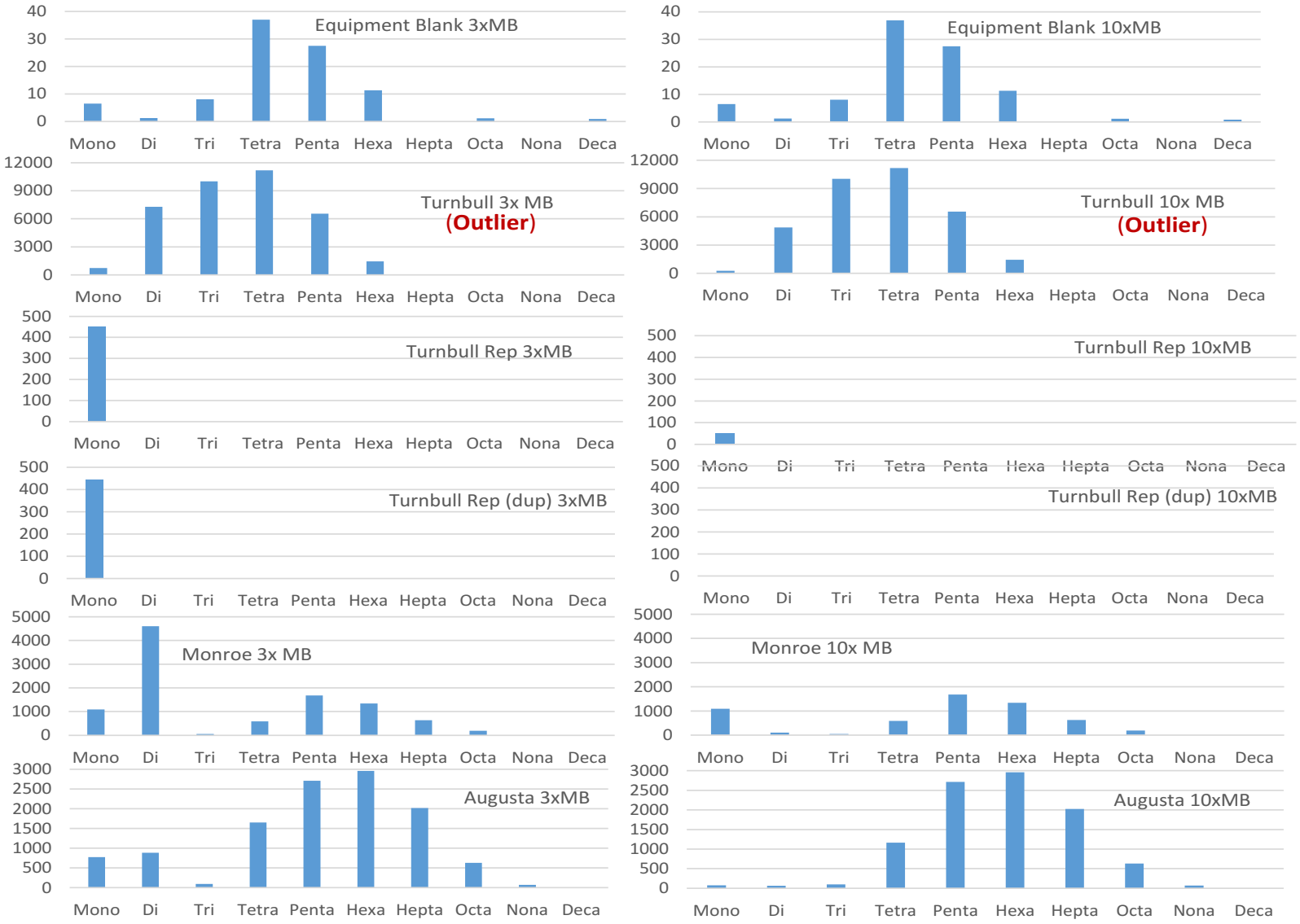


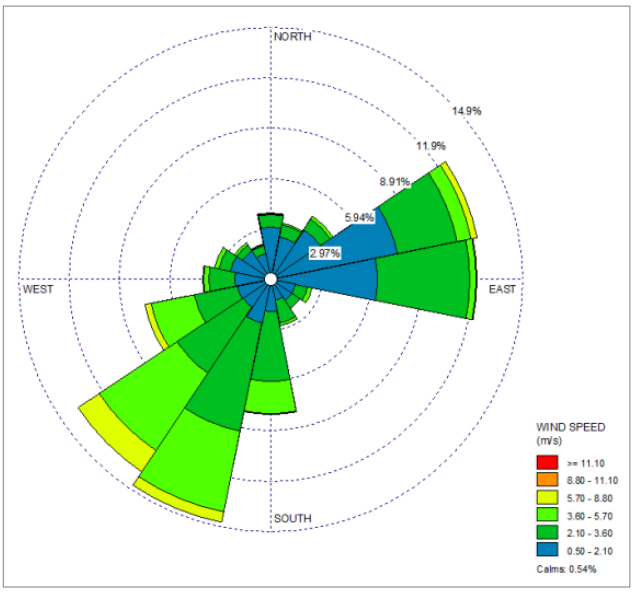
Figure B-4. Quarter 4 bulk deposition mass (pg) PCB homologues, censored at three and ten times the method blank (MB).

Appendix C. Wind Roses

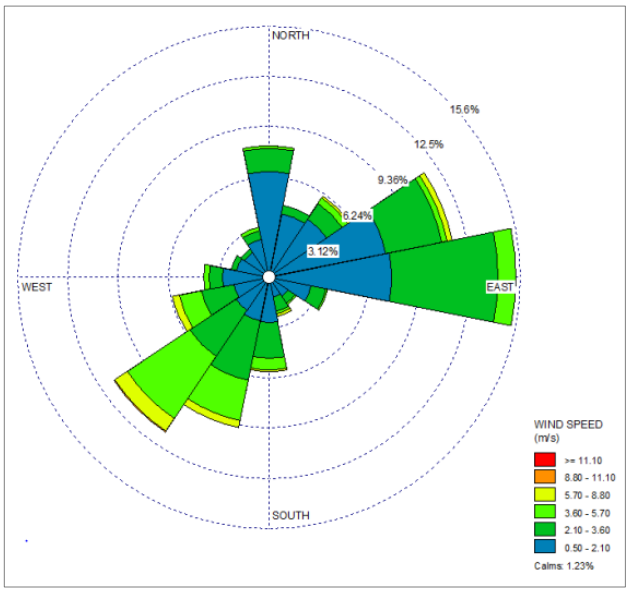
Wind roses were calculated for the bulk deposition sampling quarters at Augusta Avenue (Fig. C-1), the Spokane International Airport (Fig. C-2), and Felts Field Airport (Fig. C-3). Wind roses show how wind speed and wind direction are distributed at a particular location for a given period of time.

The wind roses in Figure C-1 were calculated using on-site data from the Augusta Avenue air quality monitoring station and best represent wind conditions at Augusta Avenue during the bulk deposition sampling. On-site wind data was not available for the Monroe Street and Turnbull NWR monitoring sites. However, wind roses from the Spokane International Airport (Fig. C-2) can be used for a general idea of wind conditions at the Turnbull NWR site, located 14 miles south of the airport, and for the Monroe Street site, located about 7 miles northeast of the airport. Wind roses from the Felts Field Airport (Fig. C-3) can also be used for an estimate of wind conditions at the Monroe Street site, located approximately 5 miles north-northwest of Felts Field.

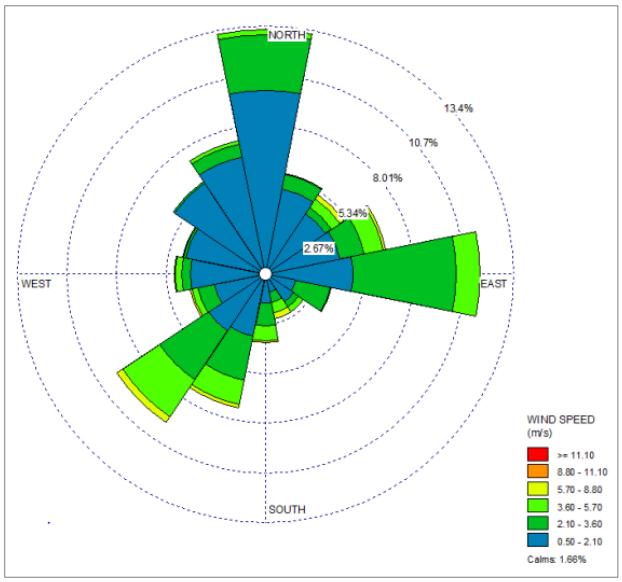
Quarter 1
5/11/16 – 8/11/16



Quarter 2
8/11/16 – 11/16/16



Quarter 3
11/16/16 – 2/16/16



Quarter 4
2/16/16 – 5/11/16

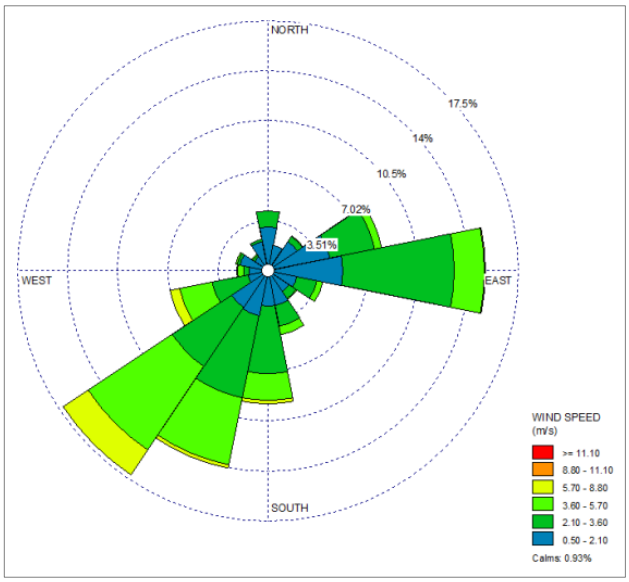


Figure C-1. Quarterly wind roses for the Augusta Avenue monitoring site. *Calculated with AERMET wind rose products using on-site data.*

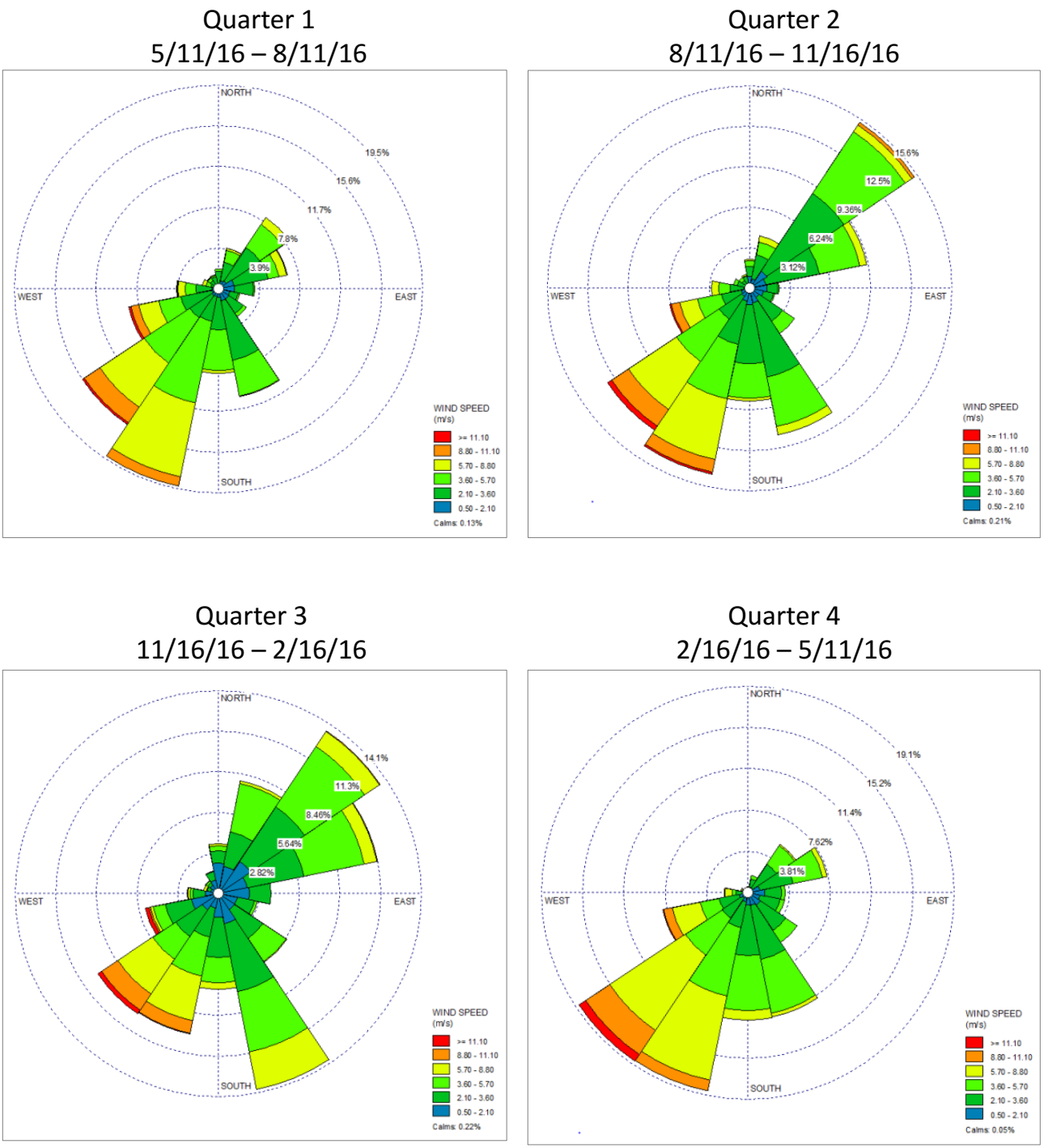


Figure C-2. Quarterly wind roses for the Spokane International Airport. *Calculated with AERMET wind rose products using ASOS 1-minute data*.

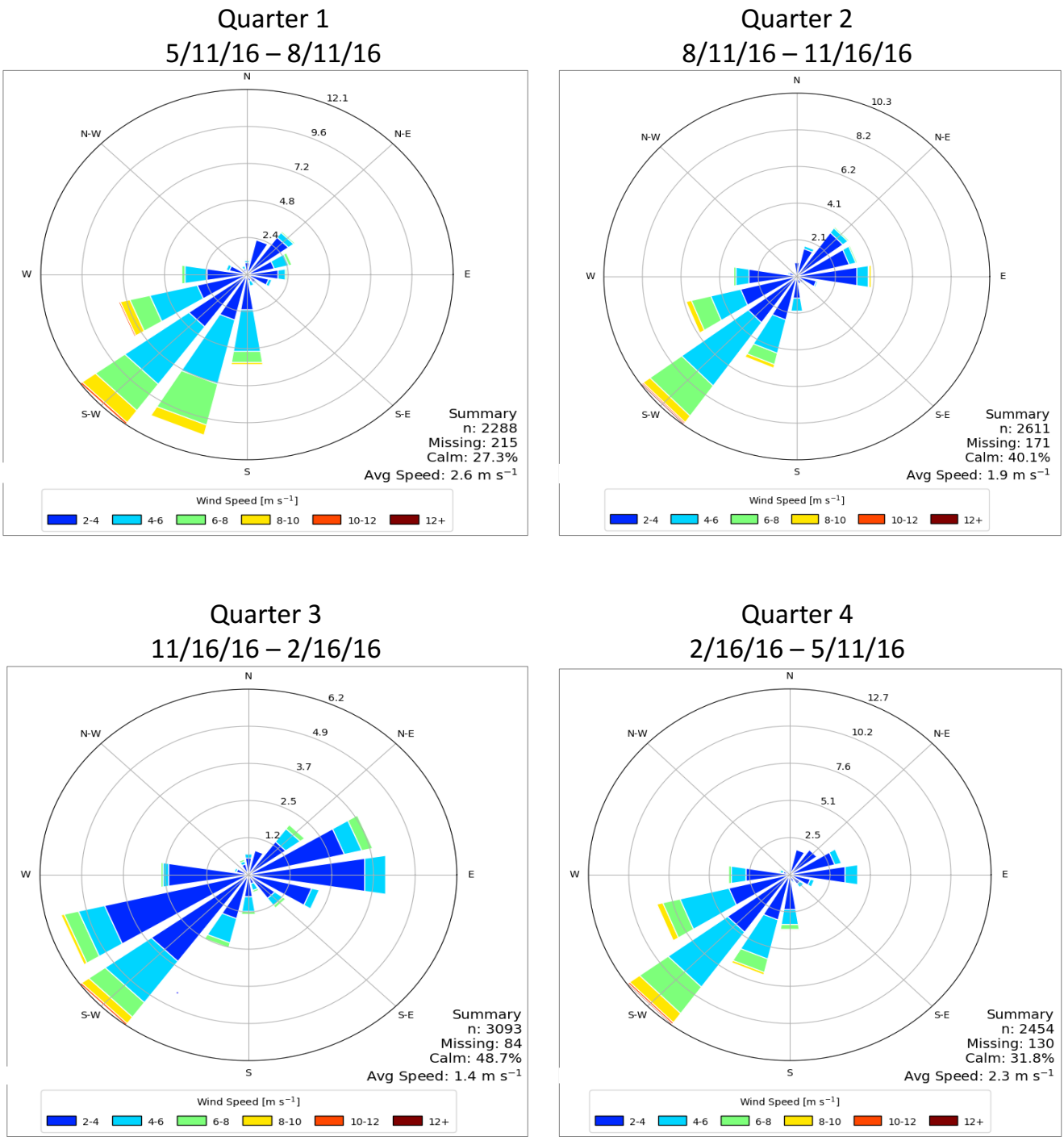


Figure C-3. Quarterly wind roses for the Felts Field Airport. *Calculated with Iowa State University online products using ASOS hourly data.*

Appendix D. Waste to Energy Plume Dispersion Modeling

Spokane Waste to Energy Facility Plume Dispersion Modeling and Analysis

Tes Ghidey
Air Quality Program, Department of Ecology
Olympia, Washington

March 9, 2018

1. Introduction

This plume dispersion modeling and analysis report is prepared for the City of Spokane Regional Solid Waste System – Waste to Energy (WTE) Facility. The Environmental Assessment Program, Washington State Department of Ecology (Ecology), performed bulk deposition measurements downwind of the facility to investigate pollutant deposition. Adjacent to the Spokane International Airport, the facility is located about 5 miles (8 km) southwest of downtown Spokane (Fig. D1). There are also significant geographical structures around the facility. These include the Spokane River, located approximately 2.8 miles northeast; Latah Creek, approximately 2.7 miles northeast; and Silver Lake, approximately 7.4 miles southwest of the facility.

The Spokane WTE facility incinerates 800 tons per day of municipal solid wastes from Spokane and its surrounding areas to generate 24 to 26 megawatts of electricity per hour. There are two combustion units that incinerate the wastes at 400 tons per day each and release emissions through a common 52.1-m (171-foot) stack. The facility is assumed to operate 24 hours per day, 7 days per week, and 49 weeks per year. In the process, airborne trace metals, trace organic compounds, and other air pollutants totaling 77 chemicals of potential concern are released into the atmosphere. It is important to note that ash is controlled in an enclosed system and removed properly, minimizing fugitive dust (1991 and 2001 modeling reports).

Ecology's Air Quality Program used the American Meteorological Society/U.S. Environmental Protection Agency Regulatory Model (AERMOD v16216r [EPA, 2016]) to simulate the transport, dispersion, and deposition of polychlorinated biphenyls (PCBs) released from the facility. While the modeling results are relevant to most pollutants, the goal of this report is to examine measurements of PCB deposition downwind of the facility from May 11, 2016, to May 11, 2017. Further, we assessed the representativeness of this one-year period by running AERMOD for 5 years using meteorological data from 2011 through 2015.

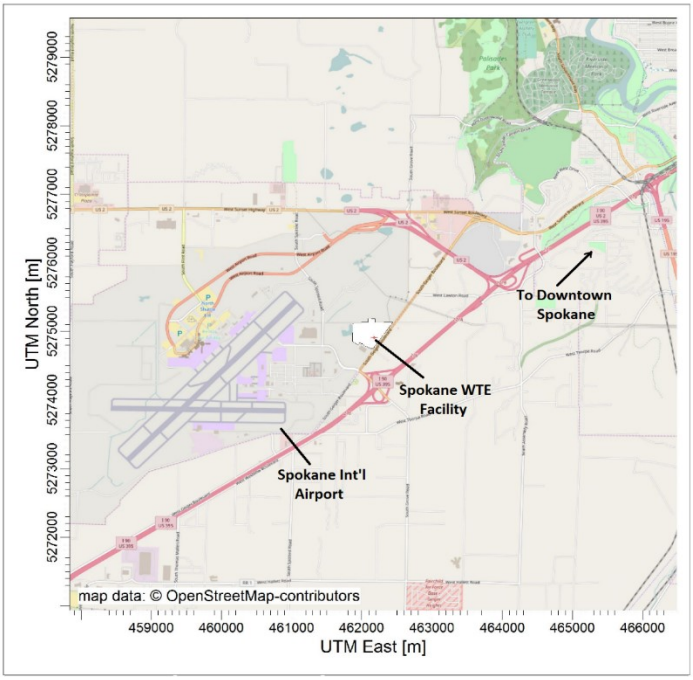


Figure D1. Schematic of the Spokane Waste to Energy Facility adjacent to the Spokane International Airport. Downtown Spokane is about 5 miles northeast of the facility.

A brief description of modeling methodology and data type and acquisition is detailed in section 2. Section 3 discusses modeling results and analysis for both the one-year field study and 5-year representative period, with a short concluding summary given in section 4.

2. Methodology

The revised AERMOD version 16216r, along with its latest pre-processor release of AERMET (v16216), was used in this plume dispersion modeling simulation. Annual (highest), monthly (highest), and 24-hour (eighth-highest) averaging times were used to estimate the PCB concentration, as well as dry, wet, and total (bulk) deposition within 15 km (9.3 miles) from the center of emissions release in all directions. In the modeling process, the two WTE facility flues were combined to form one stack with a height of 52.1 m (171 feet). Multiple simulations were run by utilizing two emission rate inputs: (1) a unit emission rate (i.e., 1 g/s), so that concentration and deposition results are normalized, and (2) actual emission rates measured. In order to estimate the actual modeling results from outputs that used a unit emission rate as input, normalized model output is multiplied by the actual emission rate of any chemical compound released from the facility.

AERMOD is complemented by pre-processors that account for meteorology, terrain structure, surface characteristics (i.e., albedo, Bowen ratio, and surface roughness), and building downwash due to wake effects, as detailed in Figure D2. The diagram shows the input data each program requires to run and their output types, along with their place in the modeling system.

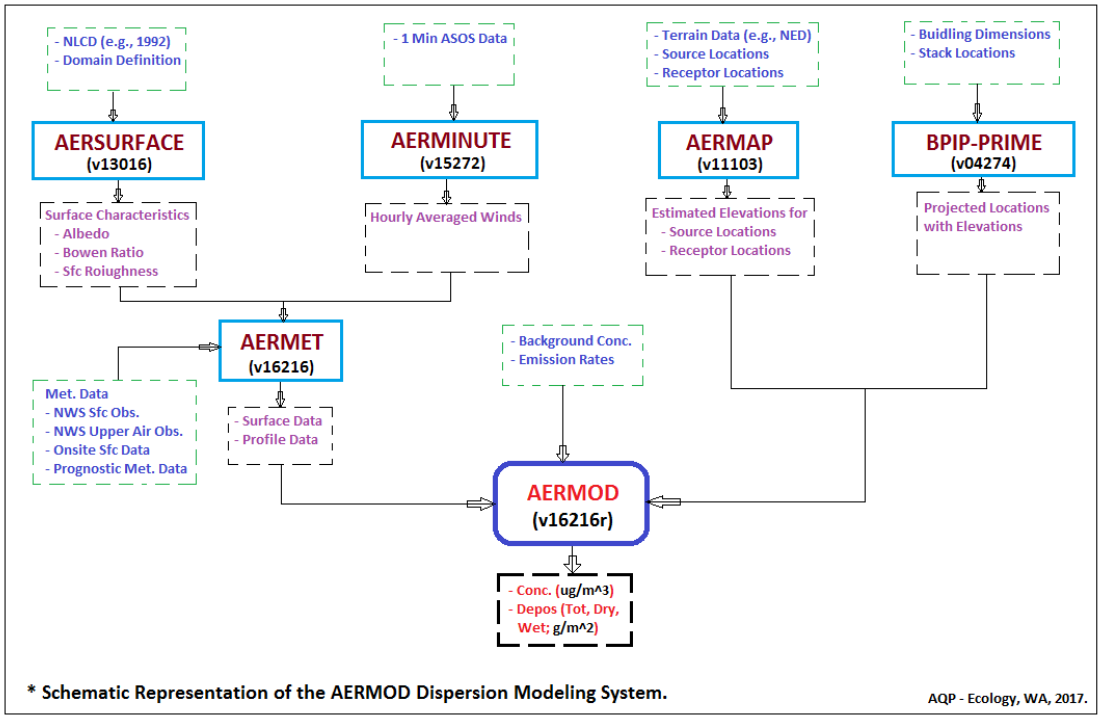


Figure D2. The AERMOD dispersion modeling system (with program versions) is depicted schematically, with the required input data for each program and their expected outputs.

2.1. Meteorological and Terrain Data Processing

The Spokane WTE Facility is surrounded by small hills, valley floors, and rivers in the Spokane Airport industrial region. Representative on-site surface data was acquired from the Spokane Augusta site. The surface hourly and 1-minute Automated Surface Observing System (ASOS), as well as upper air meteorological data, were acquired from the National Weather Service (NWS) Spokane International Airport site. Table D2.1 shows the meteorological stations, type (level) of data, station codes, and geographical locations. The location of the Spokane WTE Facility is also included.

Table D2.1. Meteorological stations used for AERMET pre-processor programs.

Station Name	Level	**Code** (USAF;WBAN)	Lat. (°)	Long. (°)	Elev. (m)
Spokane Int'l Airport	Upper-Air	KGEG;727850; 04176	47.622N	117.528W	717.2
Spokane Int'l Airport	Surface	KGEG;720322; 04129	47.622N	117.528W	717.2
Spokane Int'l Airport	Surface; ASOS	KGEG; –; 24157	47.622N	117.528W	717.2
Augusta Avenue on-site data	Surface on-site	–; –; 4129	47.672482N	117.364885W	582.0
Spokane WTE	–	–	~47.626543N	~117.503419W	709.3

ASOS: automated surface observing system; USAF: United States Air Force; WBAN: Weather Bureau Army Navy; KGEG: Spokane Inernational Airport code.

Two meteorological periods were used to run AERMET (v16216), namely, January 01, 2016, to June 15, 2017, and January 01, 2011, to January 01, 2016. The NWS surface and upper air data and the on-site meteorological data sets were acquired for the stations listed in Table D2.1. We used these data to prepare the surface and profile input data for AERMOD. To reduce the missing data and calm gaps, the NWS Spokane Airport hourly surface data was processed using the 1-minute ASOS data via AERMINUTE (v15272). The Augusta Avenue on-site data was used as primary dataset in AERMET. The utilization of the airport hourly and 1-minute ASOS data onto the on-site data brought down the calms wind speed percentage values to 1.3% and 2.3% for January 01, 2016, to June 15, 2017, and the 5-year representative period of January 2011 to January 2016, respectively (Fig. D3).

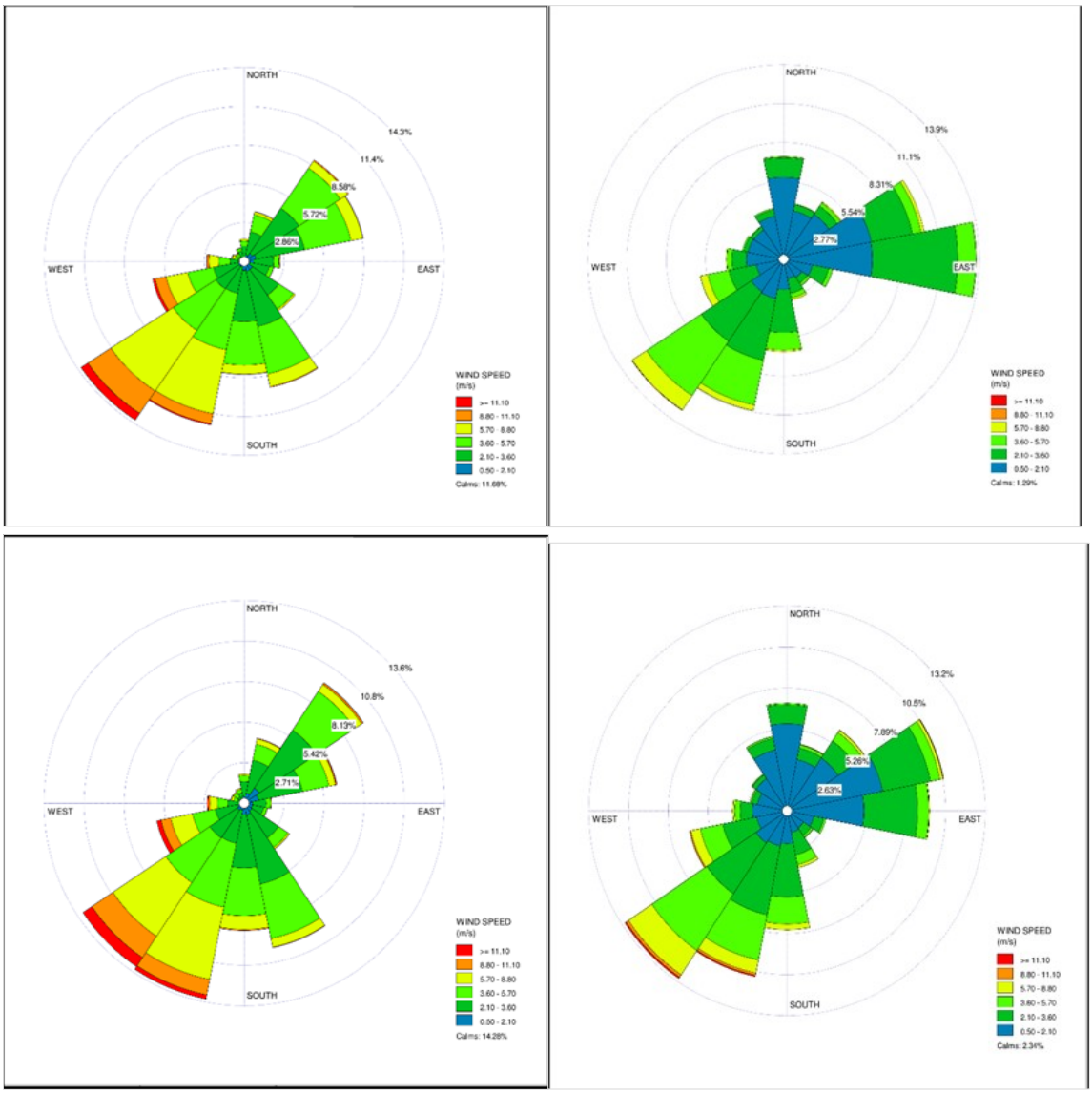


Figure D3. Wind rose plot of raw data (left panel) and pre-processed with 1-minute ASOS data (right panel) for January 2016 to June 2017 (upper) and January 2011 to January 2016 (lower), for the Spokane International Airport National Weather Service meteorological station.

In addition to the meteorological data prepared to run AERMET, AERSURFACE (v13016) processed the national land cover dataset that was downloaded from the Multi-Resolution Land Characteristics Consortium website (https://www.mrlc.gov/data) to calculate surface characteristics for the facility. We also obtained from this site the National Elevation Dataset for input into AERMAP (v11103) for topographic (elevation) information required to run AERMOD.

2.2. Sources

There are two flues from the two mass-burn incinerators that release emissions to the atmosphere through a common stack at a height of 52.1 m (171 feet). Since the flues have similar physical parameters, the plume dispersion modeling was simulated using a combined "one-source" emission rate. Therefore, parameters are either multiplied by two or an equivalent value is estimated, where appropriate. To calculate the emission rates of the different test runs from 2011 to 2017, the air flow rates and emission factors are taken from each year's measurement report (see Tables D2.2.1 and D2.2.2).

Table D2.2.1. Spokane WTE Facility air flow data for test runs from 2011 through 2017, taken from Table 2-1(b) of the test run reports of 2011 to 2017. **Bold text** rows indicate units from which PCB stack measurements were taken (measurements were from alternate units each year).

Year	Source ID	Flue gas avg. temp. (°F)	Air flow (acfm)	Air flow (dscfm)	Air flow (dscfm) @ 7% O_2
2017	Unit-1	249.3	120,900	65,200	43,480
	Unit-2	**258.3**	**127,700**	**67,700**	**45,496**
2016	**Unit-1**	**254.4**	**129,800**	**70,000**	**45,000**
	Unit-2	260.2	129,500	68,400	44,700
2015	Unit-1	260.7	120,000	63,900	43,860
	Unit-2	**257.1**	**113,900**	**61,400**	**42,979**
2014	**Unit-1**	**255.4**	**119,200**	**62,900**	**42,425**
	Unit-2	252.7	130,200	68,200	46,307
2013	Unit-1	262.1	125,200	66,600	46,969
	Unit-2	**261.9**	**122,700**	**65,400**	**45,602**
2012	**Unit-1**	**266.0**	**121,500**	**63,600**	**44,870**
	Unit-2	256.4	118,400	62,900	44,438
2011	Unit-1	250.9	133,000	73,900	48,989
	Unit-2	**255.7**	**120,500**	**65,900**	**44,784**

The average air flow rate at 7% oxygen is equal to 44,252.5 dscfm (for both units this rate is 88,505 dscfm).

Using the emission flow rates and factors in Table D2.2.1 and Table D2.2.2 (see below), emission rates were estimated by assuming the facility operates at full capacity throughout the year. The concentrations of PCBs in the exhaust flue given in units of mass per dry standard cubic meter of exhaust gas normalized to 7% oxygen (ng/dscm @ 7% O_2) were taken, after unit adjustment was performed. The concentrations were then multiplied by a flow rate in dry standard cubic feet per minute at 7% oxygen (dscfm @ 7% O_2) to develop an emission rate in

mass per unit of time, using equation 1. Note that before multiplying by the flow rate, unit conversions or adjustments need to be performed.

$$Q\ [\frac{\mu g}{s}] = (1000) * \left(\frac{E_{fac}}{35.3147}\right) * \left(\frac{U_{air}}{60}\right) \qquad \text{(equation 1)}$$

For equation 1, Q is the estimated emission rate in units of micrograms per second (µg/s), E_{fac} is the emission factor in units of mass per dry standard cubic meter (ng/dscm), and U_{air} is the flow rate in dry standard cubic feet per minute (dscfm), with both qualities measured at 7% oxygen intake level. In Table D2.2.2, estimated emission rates are given for 2011 to 2017. The factor of 1000 changes the scale of E_{fac} from units of nanograms to micrograms, while the factor of (1/60) converts the time units for U_{air} from a minute to a second. Note that PCBs measurements were taken alternately for only one flue each year, as highlighted in bold in Table D2.2.1.

Table D2.2.2. Emission rates estimations for two point sources at 7% oxygen (Unit-1 & Unit-2).

Year	Pollutant	Emission rates – Unit-1	Emission rates – Unit-2	Avg. run time (min.)
2017	Total PCBs		567.0 ng 179.5 ng/dscm 3.854E-06 g/s 3.059E-05 lb/hr	263.7
2016	Total PCBs	77.1 ng 25.5 ng/dscm 5.416E-07 g/s 4.298E-06 lb/hr		259.0
2015	Total PCBs		157.2 ng 55.4 ng/dscm 1.124E-06 g/s 8.92E-06 lb/hr	250.0
2014	Total PCBs	1115.4 ng 394.0 ng/dscm 7.889E-06 g/s 6.261E-05 lb/hr		269.3
2013	Total PCBs		361.3 ng 124.2 ng/dscm 2.673E-06 g/s 2.121E-05 lb/hr	262.0
2012	Total PCBs	120.8 ng 41.8 ng/dscm 8.852E-07 g/s 7.025E-06 lb/hr		263.0
2011	Total PCBs		365.5 ng 112.1 ng/dscm 2.369E-06 g/s 1.880E-5 lb/hr	259.3

Measurement runs performed on the flues during the last seven years (2011 – 2017) showed that PCBs values significantly vary depending on the type of solid wastes burned (Fig. D4). The type of solid wastes burned at the facility were generally categorized as corporate and noncorporate municipality materials. The PCBs emission rate estimates ranged from a maximum of 7.889 µg/s emitted in 2014 to 0.542 µg/s in 2016, with an average amount calculated to be 2.76226 µg/s from each flue.

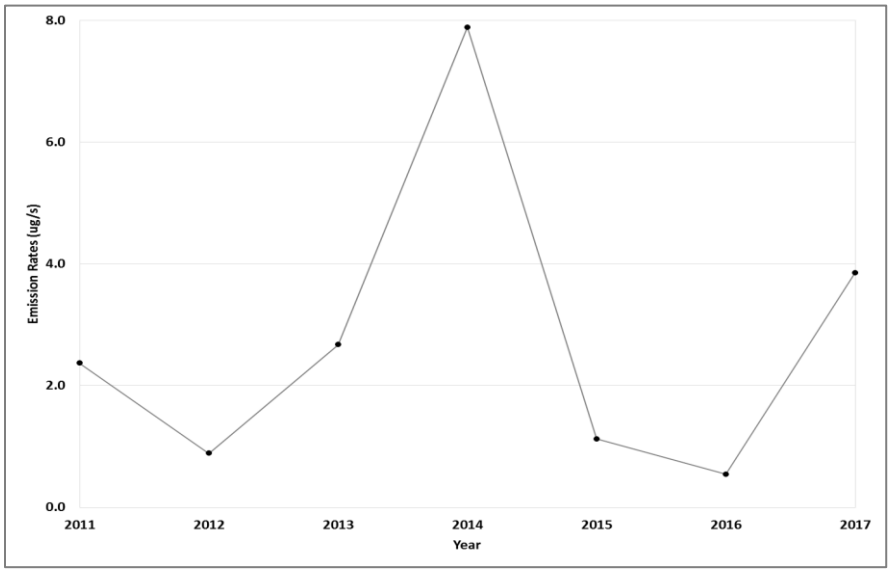


Figure D4. Spokane WTE Facility single-unit PCBs emission rates, estimated from measurement runs for 2011 through 2017 using equation 1.

Table D2.2.3 shows the average stack parameters with emission rates averaged from measurement runs performed from 2011 to 2017. Note also that the emission rates and actual flow rate need to be added when combining the two unit sources as a single stack for modeling purposes, as long as they are under similar other physical parameters and conditions, as shown in Table D2.2.3. The averaged and combined values were used as input into AERMOD to compute the concentration and total (bulk) deposition.

Table D2.2.3. Averaged stack parameters and PCBs emission rates for each unit and the combined units.

Source ID	PCB emission rate (µg/s)	Stack height (ft)	Temperature (°F)	Flow rate (acfm)	Exit velocity (ft/s)	Stack diameter (ft)
Unit 1	2.76226	171.0	257.2	124,228.6	87.148	5.5
Unit 2	2.76226	171.0	257.2	123,271.4	86.476	5.5
Combined	5.52452	171.0	257.2	247,500.0	86.771	7.78

Note: Combined stack diameter is estimated by using $\sqrt{2}$ × single flue diameter.

Other physical parameters that are needed as input in AERMOD include the PCB particle density, the representative particle diameter, and the particle phase mass fraction. PCB particle density ranges from 1.182 – 1.566 g/cm^3 (WikiVisually, n.d.). In most of our computations, an average density of 1.374 g/cm^3 was taken as input into AERMOD. The particle size distribution (diameter and mass fraction) data was taken from Table 2-2 of the 2001 health assessment report (Pioneer Technologies Corporation, 2001). The researchers underlined that the particle size distribution specified in Table D2.2.4 below was estimated based on emission source tests conducted at the WTE facility in September 1999. Note that only the particle phase mass fraction was used in AERMOD simulation.

Table D2.2.4. Particle size distribution used as input into the AERMOD modeling system.

Particle size class	Representativediameter (μm)	Particle phase mass fraction	Particle bound mass fraction
1	22.280	0.0382	0.0014
2	13.154	0.0822	0.0051
3	9.173	0.1074	0.0096
4	3.734	0.0928	0.0204
5	2.038	0.0648	0.0261
6	1.256	0.0542	0.0355
7	0.924	0.0482	0.0429
8	0.728	0.1444	0.1630
9	0.565	0.1246	0.1811
10	0.479	0.1632	0.2798
11	0.280	0.0802	0.2350

2.3. Building Data

The stack of Spokane WTE Facility is centered approximately at UTM coordinates of 462,177.02 Easting and 5,274,914.75 Northing. The coordinates are in units of meters. The Building Profile Input Program – Plume Rise Model with Enhancements (BPIP-PRIME v04274) was used to estimate the building downwash through wake effects on the plumes from the stack. The base elevation of the building was set at 716.4 m. Table D2.3.1 shows the heights of the southwest corners of the three-building complex with multiple tiers, and their lateral x-axis and y-axis dimensions.

Table D2.3.1. Multiple-tier building complex coordinates and dimensions.

Tier – height (ft)	UTM Easting (m)	UTM Northing (m)	x-dimension (m)	y-dimension (m)
Building 1				
Tier 1 – 59.38	462119.14	5274877.61	24.0	21.0
Tier 2 – 59.38	462146.21	5274868.11	54.0	11.0
Tier 3 – 69.88	462022.07	5274865.69	73.0	79.0
Tier 4 – 69.88	Polygon with multiple UTM dimensions (x, y): (462079.95, 5274865.69); (462079.95, 5274842.75); (462032.74, 5274842.75); (462022.07, 5274852.72); (462022.07, 5274865.69)			
Tier 5 – 95.14	462137.47	5274898.73	37.0	30.0
Tier 6 – 108.92	462095.63	5274877.61	23.0	79.0
Tier 7 – 136.15	462119.14	5274898.73	18.0	31.0
Building 2				
Tier 8 – 45.28	462122.43	5275003.74	29.0	19.0
Tier 9 – 61.68	462122.43	5274977.74	29.0	26.0
Building 3				
Tier 10 – 16.08 (60° rotation angle)	462240.94	5274958.19	16.0	29.0

2.4. Receptor Grids

A total of 7,148 receptors were used to compute concentration distribution and total (bulk) deposition in a horizontal dimension. These included a multiple-tier grid (7,121) Cartesian plant boundary, with grid distance of 100 m (24) and selected discrete Cartesian (3) grids. The receptors are defined within a 30 km domain, where the facility emission source is at the center. Table D2.4.1 shows the receptor spacing compared to the receptors' closeness to the facility stack.

Table D2.4.1. Receptor grid spacing definitions.

Distance from building stack (m)	Grid spacing (m)
0–3000	100
3000–6000	300
6000–15000	600

2.5. Monitoring Stations and Data

The three discrete Cartesian grids correspond to the location of the bulk deposition monitoring sites described in Table D2.5.1. This table contains the site coordinates in the UTM system. These receptors were used to extract the concentration distribution and total deposition values from AERMOD to compare against their corresponding bulk deposition monitoring stations in the Spokane area. In general, the Augusta Avenue station is categorized as urban-commercial, the Monroe Street station is urban-residential, and the Turnbull National Wildlife Refuge station is a regional background site. Table D2.5.2 shows the bulk deposition values from the three

deposition monitoring sites in a quarterly timeframe for May 11, 2016, to May 11, 2017. These data were provided by Ecology's Environmental Assessment Program.

Table D2.5.1. Three Washington State Department of Ecology deposition monitoring sites that collected bulk deposition data downwind of the facility from May 11, 2016, to May 11, 2017.

Monitoring site	X-UTM (m)	Y-UTM (m)
Augusta Avenue	472609.2	5279965.0
Monroe Street	468040.5	5283051.0
Turnbull National Wildlife Refuge	460035.7	5251575.98

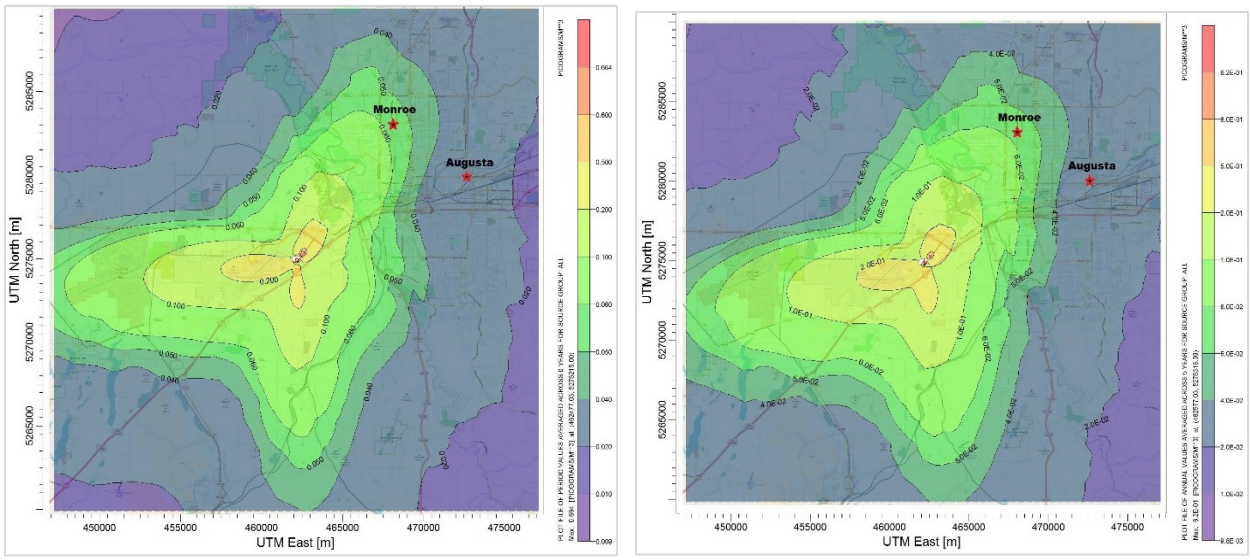
Table D2.5.2. Bulk (total) deposition data from EAP monitoring sites averaged per day for three stations for the field measurement run period of four quarters of May 11, 2016, to May 11, 2017.

Monitoring site	Site type	Quarter	Start date	End date	Flux (ng/m^2-day)
Turnbull	regional background	1	5/11/16	8/10/16	0.37
		2	8/11/16	11/16/16	0.85
		3	11/17/16	2/15/17	2.94
		4	2/16/17	5/11/17	0.06
Monroe	urban-residential	1	5/11/16	8/10/16	1.24
		2	8/11/16	11/16/16	1.74
		3	11/17/16	2/15/17	3.66
		4	2/16/17	5/11/17	1.38
Augusta	urban-commerical	1	5/11/16	8/10/16	2.61
		2	8/11/16	11/16/16	10.92
		3	11/17/16	2/15/17	3.71
		4	2/16/17	5/11/17	1.67

*BC = Blank corrected using equipment blank results.

3. Results

The 1-year field study (Fig. D5a) and 5-year study (Fig. D5b) annual concentration distributions show that highest PCB values were located over the northeastern, south, and west-southwestern region in about a 2-mile radius from the emission source. This distribution is in agreement with the annual wind flow of the region, as depicted in the Figures 3a and 3b wind rose plots. In the figures, the two urban air quality monitoring sites of Augusta and Monroe are outside of the areas of highest concentration. In general, the 5-year modeling case shows concentrations over a larger area than the 1-year field study case, while the overall concentration distribution trend is similar. Quantitatively, the 5-year modeling results are about 16% higher in concentration and 20% higher in bulk deposition than the 1-year field study modeling results (Table D3.1). These analyses highlight the importance of using a longer period of meteorological data to avoid basing decisions on less representative conditions.



(a) (b)

Figure D5. Modeled average annual concentration distribution from the Spokane WTE stack. (a) For May 11, 2016, to May 11, 2017, field measurement case study. (b) Regulatory 5-year modeling study period of January 2011 to December 2015. Coordinates are in UTM (m) and concentration is in picograms per cubic meter (pg/m^3).

Table D3.1. AERMOD results of concentration and deposition for the 24-hour averaging period for PCBs at the WTE facility.*

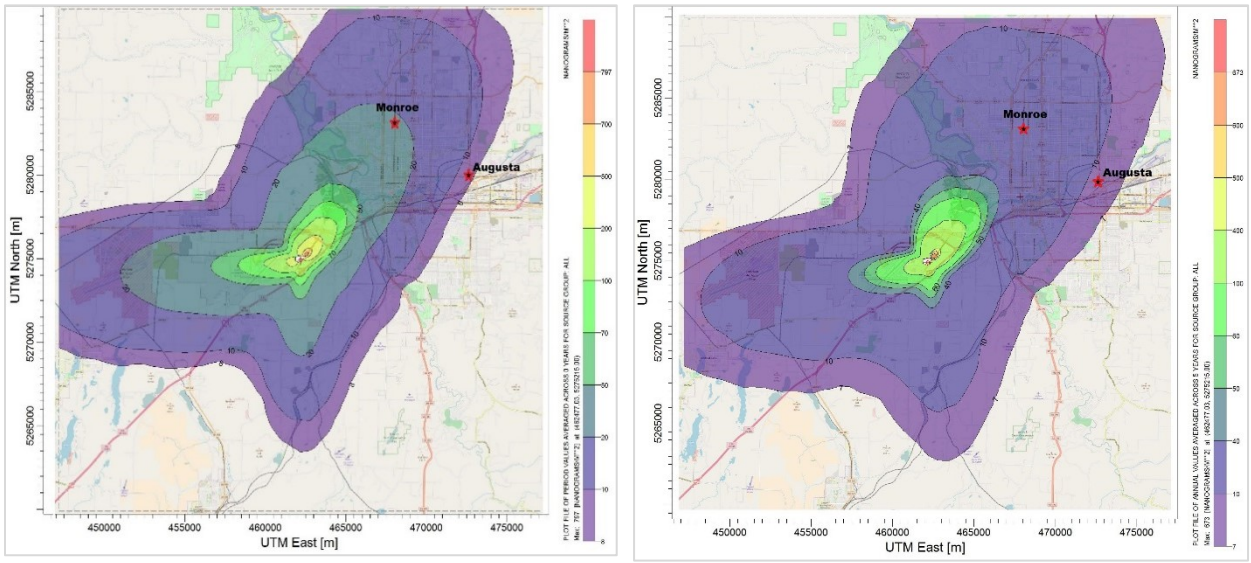
Modeling time	Concentration (pg/m^3)	Total deposition (ng/m^2)	Dry deposition (ng/m^2)	Wet deposition (ng/m^2)
1 year	2.431	11.056	10.987	6.204
5 years	2.826	13.277	13.273	11.389

*Average particle density and average emission rates used in calculations.

The qualitative plots of both the 1-year and the 5-year study periods show that total (bulk) deposition across the domain has a similar distribution as the concentration, but circumscribed within a smaller area (Figs. D6a & b). The modeled deposition over the Spokane urban sites of Augusta and Monroe are very low compared to the observation data at the monitoring sites. From Figure D6a, the Augusta site is situated within 8 – 10 ng/m^2-year (0.02 – 0.03 ng/m^2-day) of modeled deposition values, while Monroe is within 20 – 50 ng/m^2-year (0.05 – 0.14 ng/m^2-day) deposition.

On the other hand, observed bulk deposition values at these two sites vary from 1.2 – 10.9 ng/m^2/day (see Table D3.2). Figure 7 also shows that the logarithmic plot of the modeled PCBs values are less than 2% of the monitored values in four quarters of the study period. In other words, the monitored deposition values are about two orders of magnitude higher than the modeled values. This quantitative and qualitative comparisons show that the PCBs contribution from the Spokane WTE Facility is significantly low. Past AERMOD sensitivity analysis suggested that the model generally overestimates observations, especially during calm and/or low wind speeds (e.g., Perry et al., 2005; Duoxing et al., 2007). Therefore the modeling results

shown here are likely upper bounds of what the Spokane WTE Facility could contribute to the observed deposition, implying that there must be other contributing PCBs sources in the region.



(a) (b)

Figure D6. Modeled average annual total (bulk) deposition distribution from the Spokane WTE stack. (a) For May 11, 2016, to May 11, 2017, field measurement case study. (b) Regulatory 5-year modeling study period of January 2011 to December 2015. Coordinates are in UTM (m) and deposition is in nanograms per square meter (ng/m^2).

Table D3.2. AERMOD modeled and monitored quarterly total (bulk) deposition data for three monitoring sites for the Spokane WTE study period of May 11, 2016, to May 11, 2017.

Site	Site type	Data type	Q1 5/11/16 – 8/10/16 (ng/m^2)	Q2 8/11/16 – 11/16/16 (ng/m^2)	Q3 11/17/16 – 2/15/17 (ng/m^2)	Q4 2/16/17 – 5/11/17 (ng/m^2)
Augusta	urban-commercial	modeled	0.025	0.023	0.015	0.030
		observed	2.610	10.920	3.710	1.670
Monroe	urban-residential	modeled	0.062	0.060	0.041	0.074
		observed	1.240	1.740	3.660	1.380
Turnbull	regional background	modeled	0.004	0.007	0.011	0.004
		observed	0.370	0.850	2.940	0.060

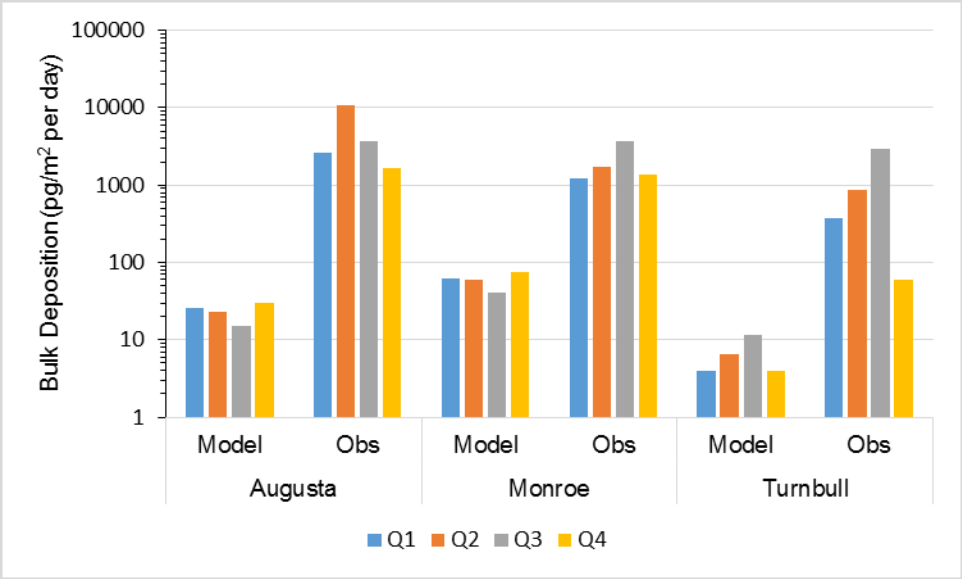


Figure D7. Logarithmic plot comparing quarterly bulk deposition of modeled (Model) versus monitored (Obs) data for three sites in pg/m^2-day. (Q1 = 5/11/2017 – 8/10/2016; Q2 = 8/11/2016 – 11/16/2017; Q3 = 11/17/2016 – 2/15/2017; Q4 = 2/16/2017 – 5/11/2017).

4. Summary

The Spokane Waste to Energy Facility plume dispersion modeling simulation was run for May 11, 2016, to May 11, 2017, and for the 5-year period of 2011 to 2015. Emission data were collected from reports of the source sampling run tests performed from 2011 to 2017. Other important pollutant and building information were taken from 1991 and 2001 dispersion modeling done for health risk assessment studies. Meteorological data were obtained from the on-site Augusta Avenue station, as well as the Spokane International Airport. These meteorological data were most representative for the facility.

AERMOD-simulated concentrations and deposition (total, dry, and wet) estimates covered a 900 km^2 domain, centered on the emission source. Model outputs averaged over 24-hour, monthly, and whole (May 2016 to May 2017) time periods were compared against the 1-year field study period for three monitoring sites.

In general, the highest concentration distribution and deposition rates occur within a radius of about 2 miles (3 km) from the center of the emission source. The main areas susceptible to pollutants from the emission source are the northeastern, south, and southwestern regions. The 5-year modeling results are 16% higher in magnitude and cover a larger area of concentration distribution when compared to the 1-year field study period. However, the overall concentration distribution trend and orientation are similar. These results highlight the importance of using a longer representative modeling period to better inform decisionmaking.

Bulk deposition data from three monitoring sites (Augusta Avenue, Monroe Street, and Turnbull National Wildlife Refuge) were also compared against their corresponding model results for the study period. The WTE facility's PCB emissions account for about 2% of the measured deposition at these sites. As AERMOD modeling tends to overestimate observed values, this study suggests the presence of other contributing PCB sources to these sites.

5. References

Agency for Toxic Substances and Disease Registry, 2016. Polychlorinated Biphenyls (PCBs) Toxicity: What Standards and Regulations Exist for PCB Exposure? Updated Aug. 9, 2016. https://www.atsdr.cdc.gov/csem/csem.asp?csem=30&po=8.

DEECO Inc., n.d. Stationary Source Sampling Report, Spokane Waste to Energy, Spokane, Washington, 2011–2017. DEECO Inc., 3404 Lake Woodard Rd., Raleigh, North Carolina 27604. www.stacksampling.com.

Duoxing, Yang, C. Gangcai, and Y. Yunjiang, 2007. Inter-comparison of AERMOD and ISC3 modeling results to the Alaska tracer field experiment. Chinese Journal of Geochemistry 26: 182–185.

EPA [United States Environmental Protection Agency], 2016. AERMOD Modeling System, Version Date 16216. Air Quality Dispersion Modeling - Preferred and Recommended Models. Support Center for Regulatory Atmospheric Modeling (SCRAM). https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod.

ETI [Environmental Toxicology International, Inc.], 1991. Spokane Regional Solid Waste Disposal Project Dispersion Modeling Analysis. 21907 64th Ave., W Suite 230, Mountlake Terrace, Washington 98043.

Perry, Steven G., A.J. Cimorelli, R.J. Paine, R.W. Brode, J.C. Weil, A.Venkatram, R.B. Wilson, R.F. Lee, and W.D. Peters, 2005. AERMOD: A dispersion model for industrial source applications. Part II: Model performance against 17 field study databases. Journal of Applied Meteorology 44: 694–708.

Pioneer Technologies Corporation, 2001. Spokane Waste-To-Energy Facility Human Health Risk Assessment. 2612 Yelm Hwy SE, Suite B, Olympia, Washington 98501-4826. www.uspioneer.com.

WikiVisually, 2018. Polychlorinated Biphenyl (PCB). Accessed November 6, 2018. https://wikivisually.com/wiki/Polychlorinated_biphenyl.

Appendix E. Glossary, Acronyms, and Abbreviations

Glossary

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality–limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

Airshed: A geographical area within which the air frequently is confined or channeled, with all parts of the area thus being subject to similar conditions of air pollution.

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.

Flux: An amount of a substance deposited in a given area per a period of time. An example unit of measure for atmospheric deposition flux is ng/m^2-day.

PCB congener: Any single, unique, well-defined chemical compound in the PCB group. They are identified by the number and position of chlorine atoms around the biphenyl rings. There are theoretically 209 possible congeners.

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

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from not meeting water quality standards. A TMDL is equal to the sum of all of the following: (1) the individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution from natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

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.

Wind rose: A diagram showing how wind speed and wind direction are distributed at a particular location for given period of time.

Acronyms and Abbreviations

ACFM	Actual cubic feet per minute
AERMAP	Terrain pre-processor for AERMOD
AERMET	Meteorological pre-processor for AERMOD
AERMINUTE	1-minute ASOS wind data averaging processor for AERMET/AERMOD
AERMOD	American Meteorological Society/U.S. Environmental Protection Agency Regulatory Model
AERSURFACE	Surface characteristics pre-processor for AERMOD
AQP	Ecology's Air Quality Program
ASOS	Automated Surface Observing System
BPIP-PRIME	Building Profile Input Program – Plume Rise Model with Enhancements
DSCFM	Dry standard cubic feet per minute
DSCM	Dry standard cubic meter
Ecology	Washington State Department of Ecology
EAP	Environmental Assessment Program
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory
NWS	National Weather Service
QA	Quality assurance
QC	Quality control
PCA	Principal Component Analysis
PCBs	Polychlorinated biphenyls
PM2.5	Particulate matter size 2.5 microns and smaller
PM10	Particulate matter size 10 microns and smaller
PUF	Polyurethane foam – a type of sorption media
RPD	Relative percent difference
SOP	Standard operating procedure
SRCAA	Spokane Regional Clean Air Agency
SRRTTF	Spokane River Regional Toxics Taskforce
TMDL	Total Maximum Daily Load (see Glossary)
tPCB	Total PCB
WTE	Waste to Energy
XAD-2	A type of sorption media made of small polymer resin beads

Units of Measurement

°C	degrees centigrade
cm	centimeter
dscfm	dry standard cubic feet per minute
dscm	dry standard cubic meter
°F	degrees Fahrenheit
in.	inches
km	kilometer, a unit of length equal to 1,000 meters
km^2	square kilometer
L	liter
m	meters
m^3	meters cubed
m^3/min.	meters cubed per minute
mL	milliliters
ng	nanograms (10^{-9} grams, or one billionth of a gram)
ng/L	nanograms per liter (parts per trillion)
ng/m^2-day	nanogram per meter squared per day
pg	picogram (10^{-12} grams, or one trillionth of a gram)
pg/m^3	picogram per meter cubed
pg/L	picograms per liter (parts per quadrillion)
µg/m^3	microgram per meter cubed