Potential PCB Atmospheric Loading to the Green/Duwamish Basin

This exercise develops a tool that assesses the relative scale of atmospheric PCB mass relative to other PCB sources that are discharged from some landscape type. The exercise focuses on stormwater because the data is readily available; however, the analysis would be similar for other sources. The analysis assumes PCB concentrations in stormwater represent typical conditions over the calendar year; we consider PCB concentrations associated with annual discharge flow rates, annual rainfall depth, and typical atmospheric deposition rates. A conceptual model for a chemical of concern *c* is depicted in Figure 1.

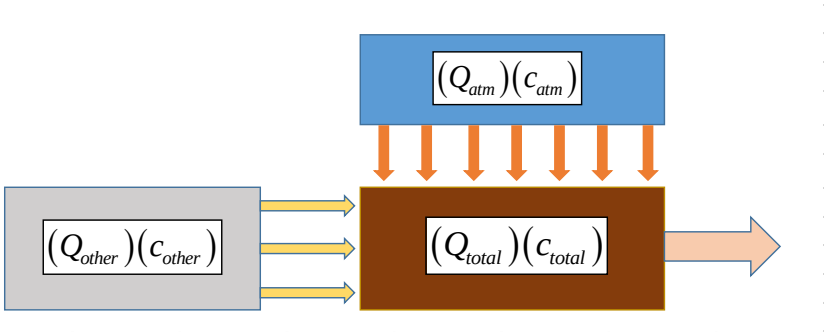

Figure 1. Conceptual mass balance model for total chemical concentration (c_{total}) that result from atmospheric deposition (c_{atm}) and other sources (c_{other}).

Methods

Storm water is assumed to be rainfall that falls on the impervious land and drains into a collection system. As the rainfall flows across the impervious surface, it washes off chemicals that have accumulated on the landscape over time; the chemicals come from different sources. For PCB's the washed off PCB mass comprises PCB's from other sources and atmospheric deposition equation (1.1).

$$PCB_{total} = PCB_{other} + PCB_{atm} \quad (1.1)$$

Where PCB_{total} is the total PCB concentration in the stormwater comprised of PCB from other sources (PCB_{other}) and atmospheric deposition (PCB_{atm}). If we assume all atmospheric PCB is washed off, the atmospheric PCB mass is given by equation (1.2).

$$PCB_{mass}^{atm} = R_{pcb}AT \quad (1.2)$$

Where PCB_{mass}^{atm} is the total PCB mass deposited in a year, R_{pcb} is the PCB atmospheric deposition rate, A is the basin area, and T is one-year of time in the correct units. The total PCB mass washed off the landscape is given by equation (1.3).

$$PCB_{mass}^{total} = PCB_{total}Ad_{rain} \quad (1.3)$$

Where PCB_{mass}^{total} is the total PCB mass discharged in a year and d_{rain} is the annual rainfall depth. The atmospheric PCB mass ratio in the stormwater is given by equation (1.4).

$$PCB_{mass}^{atm} \Big/ PCB_{mass}^{total} = R_{pcb} T \Big/ PCB_{total}\, d_{rain} \tag{1.4}$$

$$PCB_{mass}^{atm} \Big/ PCB_{mass}^{total} = \frac{\left(R_{pcb} / I_{rain}\right)}{PCB_{total}} \tag{1.5}$$

Where $I_{rain} = d_{rain} / T$. Because equation (1.5) accounts for all the atmospheric PCB mass deposited on the landscape, the ratio represents a conservative estimate in the contribution of atmospheric PCB mass relative to the total PCB mass measured from the basin stormwater.

Application to Duwamish Industrial Area

We are interested in estimating the relative contribution of atmospheric PCB mass in stormwater discharges from impervious areas within the Duwamish industrial area for two conditions:

1. PCB atmospheric deposition measured within the Duwamish industrial area. Defines atmospheric PCB mass ratio for current conditions.
2. PCB atmospheric deposition measured over the Puget Sound region. Defines atmospheric PCB mass ratio for atmospheric PCB fluxes reduced to regional values.

The analysis requires atmospheric PCB flux, stormwater PCB concentrations, and average annual rainfall rate.

Basin Data

The North Boeing Field (NBF), Plant 2, and Tully's/Brewery stormwater drainage areas were selected for the analysis because Seattle Public Utilities (2007) identified these as representative of PCBs in stormwater discharges into the Lower Duwamish Waterway (LDW). Locations of the drainage areas and atmospheric PCB flux monitoring stations are shown in Figure 2. Basin chemical characteristics are given in Table 1.

Table 1. Three basins used to assess atmospheric PCB mass ratios.

Basin	Total Suspended Solids (mg/L)	Suspended Solids PCB Concentration (ug/kg)	Estimated Total Water PCB Concentration (ng/L)
South Park	81	190	85
Plant 2	81	4,500	2022
North Boeing Field	82	8,400	3821
Tully's/Brewery	81	757,500	340331
Seattle Public Utilities, 2007.			

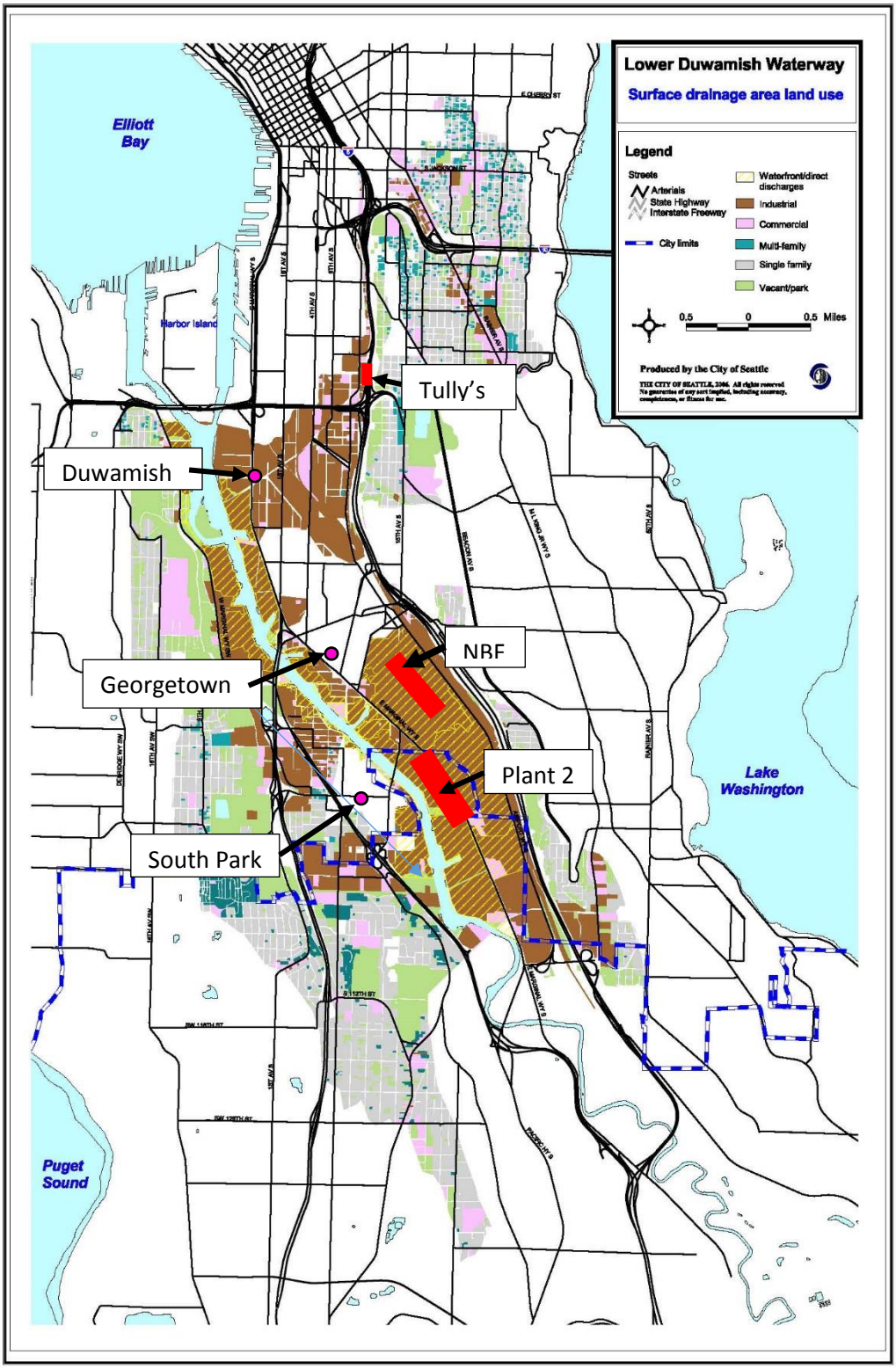

Figure 2. Surface land use drainage areas of the Lower Duwamish Waterway and approximate locations of the three atmospheric PCB flux sampling sites (Duwamish, Georgetown, and South Park) and the three stormwater basin drainage areas (Tully's, NBF, South Park; map reprinted from Seattle Public Utilities, 2007).

Atmospheric Data

Atmospheric deposition rates for PCB's were obtained from two reports that sampled over different areas of interest. Sample locations within the Duwamish industrial area are shown in Figure 2, and sample locations throughout the Puget Sound area are shown Figure 3. Atmospheric PCB fluxes for the three locations within the Duwamish industrial area and the seven regional locations are given in Table 2 and Table 3. In the Duwamish Industrial area the median deposition rates was 21 (ng/m^2-day), and in the rural areas the median deposition rate was 0.40 (ng/m^2-day). An average annual precipitation depth of 37.5 inches was used for the analysis (http://www.seattleweatherblog.com/rain-stats/).

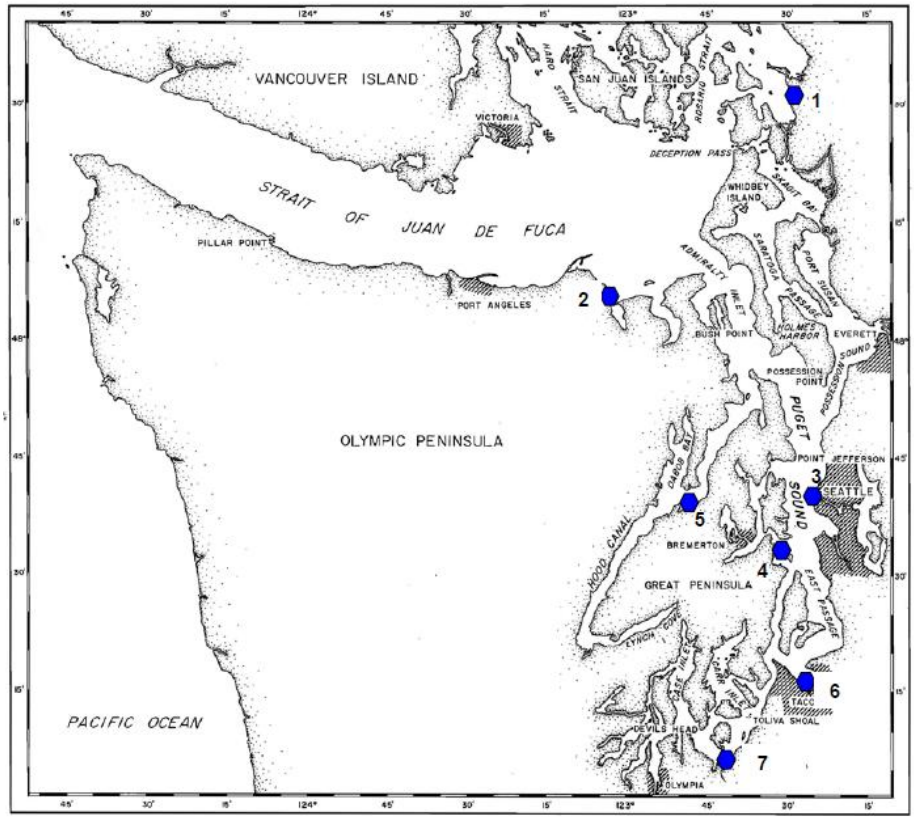

Figure 3. The seven sample site locations for the Puget Sound atmospheric deposition sites. From north to south: 1-Padilla Bay, 2-Sequim Bay, 3-West Point, 4-Manchester, 5-Hood Canal, 6-Tyee Marina, and 7-Nisqually River (Dept. of Ecology, 2010).

Statistical analyses on the Duwamish Industrial data set (King County, 2015) found PCB deposition rates were significantly influenced by air temperature and air concentrations of fine particles (<2.5 µm, PM 2.5). The largest significant correlation was between PCB flux and PM 2.5 (rho=0.56) with PCB flux and temperature being the second largest significant correlation (rho=0.48). Correlations between PCB flux and rain and wind where small and statistically insignificant. Between the Duwamish, Georgetown, and South Park sites, the relative overall PCB congener contributions appeared similar for the Georgetown and South Park sites, but the Duwamish PCB congener contributions appeared to be different (King County, 2015).

Table 2. PCB atmospheric deposition rates for three sites within the Duwamish Industrial area.

Site	Date	PCB Mass Flux (ng/m^2-day)
Duwamish	4/25/13	6.86
	5/9/13	56.1
	8/1/13	2.87
	10/31/13	17.2
	11/14/13	20.9
Georgetown	4/25/13	67.9
	5/9/13	204
	8/1/13	37.0
	10/31/13	81.0
	11/14/13	9.68
South Park	4/25/13	9.68
	5/9/13	11.6
	8/1/13	5.76
	10/31/13	28.0
	11/14/13	85.8
Average		43.0
Median		20.9
95th CI of Median		67.9
King County, 2015.		

Table 3. Regional PCB deposition rates for rural areas.

Location	PCB Mass Flux (ng/m^2-day)
Hood Canal	0.24
Nisqually R.	0.64
Padilla Bay	0.40
Port Orchard	0.39
Sequim Bay	0.32
Tyee Marina	0.45
West Point	0.57
Median	0.40
Department of Ecology, 2010.	

Results

Duwamish Industrial Area

The relative portion of PCB mass in stormwater from atmospheric deposition is small for all three stormwater basins. Relative atmospheric PCB mass portions range from 0.0024 % for the Tully's/Brewery basin to 0.40 % for the Plant 2 basin (Table 4). Calculating the atmospheric PCB mass portion at the 95th CI of the median atmospheric PCB flux increased the maximum range to 1.3%.

An effective annual atmospheric PCB loading concentration can be estimated from equation (1.4) by letting the ratio equal 1, which requires that the total PCB stormwater concentration results from atmospheric deposition alone. For atmospheric PCB deposition as the only source, the effective stormwater total PCB concentration would be 8 (ng/L) for current Duwamish industrial PCB flux and 0.15 (ng/L) for regional PCB flux (Table 5).

Table 4. Estimated atmospheric PCB mass ratios for an average annual rainfall depth of 37.5 inches.

Stormwater Basin	Estimated Total Water PCB Concentration (ng/L)	PCB mass ratio PCB_{atm}/PCB_{total} R_{pcb}=21 (ng/m^2-day) Median	PCB mass ratio PCB_{atm}/PCB_{total} R_{pcb}=68 (ng/m^2-day) 95th CI of Median
South Park	85	9 %	30%
Plant 2	2022	0.4%	1%
North Boeing Field	3821	0.2%	0.7%
Tully's/Brewery	340331	0.002%	0.008%

Table 5. Estimated annual atmospheric PCB loading concentration based on the Duwamish Industrial and Regional atmospheric PCB fluxes.

Atmospheric PCB Flux Type	R_{pcb} (ng/m^2-day)	Annual Average Atmospheric PCB Loading Concentration (ng/L)
Duwamish Industrial	21	8
Regional	0.4	0.2

Above Howard Hanson Dam

Annual average atmospheric PCB loading concentrations above Howard Hanson dam can be estimated using similar analyses and then compared to PCB concentrations in the Green River above the dam. PCB water concentrations were available for two sites above the Howard Hanson Dam with data provided in Table 6 (King County, 2018). Above the dam, the average annual rainfall depth is about 80 inches (Figure 4) and for a regional PCB deposition flux (0.4 ng/m^2-day) the estimated annual average atmospheric PCB loading concentration is 0.071 ng/L (Table 7). Because the atmospheric loading concentration characterizes an average of base and storm flow conditions, it is compared to the average of the base and storm river concentrations (33.4 pg/L). The atmospheric loading concentration (71 pg/L) is greater than the average river concentrations (33.4 pg/L). This result would be consistent with a conceptual model that some of the deposited PCB mass is absorbed to soils that are not washed into the river or seeped into the river through the groundwater.

Table 6. Total PCB water concentrations measured in the Green River above Howard Hanson Dam.

Field Site	Flow Condition	FOD	Min (pg/L)	Max (pg/L)	Average (pg/L)	Median (pg/L)
Upper Green-RM 85 (UG319)	Base	3/3	11.80 J	23.20 J	18.40 J	20.30 J
	Storm	3/3	18.20 J	99.70 J	53.90 J	43.90 J
Sunday Creek-RM 82 (SC319)	Base	3/3	13.20 J	33.70 J	22.20 J	19.60 J
	Storm	3/3	19.90 J	54.70 J	38.90 J	42.10 J
FOD is frequency of detection. J – Estimated value.						

Table 7. Estimated annual average atmospheric PCB loading concentration for the area above Howard Hanson Dam.

Atmospheric PCB Flux	R_{pcb} (ng/m^2-day)	Annual Average Rainfall Depth (in)	Annual Average Atmospheric PCB Loading Concentration (ng/L)
Regional	0.4	80	0.07

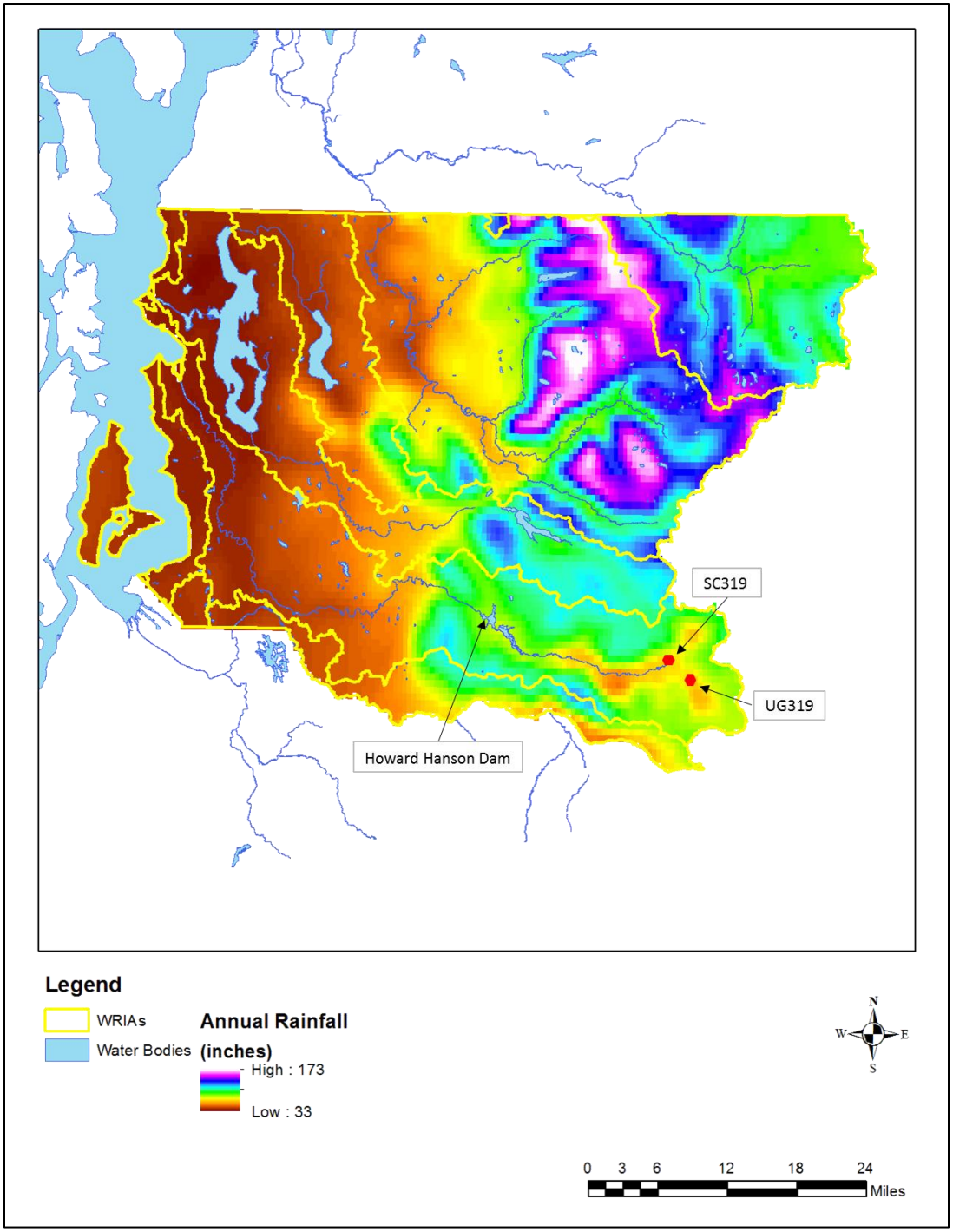

Figure 4. Annual average rainfall depth for areas within King County (Copyright © 2019, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu Map created 1/3/2019).

References:

King County, 2015. Lower Duwamish Waterway Source Control: Supplemental Bulk Atmospheric Deposition Study Final Data Report.

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Department of Ecology, 2010. Control of Toxic Chemicals in Puget Sound, Phase 3: Study of Atmospheric Deposition of Air Toxics to the Surface of Puget Sound. Publication No. 10-02-012.

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