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Stormwater Particulate Strengths by Particle Size and WinSLAMM Calculations

Contents

Summary

Currently, WinSLAMM routes many particle sizes from source areas, through stormwater controls, and along the drainage system to the outfall. However, only a lumped particulate strength value is used for the sum of all particle sizes to determine the stormwater concentrations and loads. As part of the current SERDP project, WinSLAMM is being expanded to incorporate particulate strength values for the particle sizes already being considered in the model, instead of using a single bulk value for all sizes for a specific contaminant.

This whitepaper summarizes available particulate strength data by different particle size ranges for several constituents, from past research by Pitt's research group at the University of Alabama, along with the first phase SERDP (2018) project data collected at Paleta Creek, in San Diego, and also includes summaries of the second phase SERDP (2022) project at San Diego, Puget Sound, WA, and Lubbock, TX. These data were normalized to obtain ratio factors for each particle size range that are to be multiplied with the calibrated lumped particle values to obtain particulate strengths for each range. This is in leu of using specific particle size range particulate strengths for each land use and source area in the model, as that detailed data are not available. These normalized factors are applied to the available lumped particulate strength values currently used in the model.

Particulate strength data presented here are used as an example of the factors to be used in the model. As with all stormwater characteristics, there are uncertainties associated with the parameters. For example, the coefficients of variation (COV, or the ratio of the standard deviation to the mean) range from about 0.6 to 1.3. These COV values can be optionally used by a model user in the Monte Carlo portion of the model to better represent the typical variability in stormwater characteristics. Also, locally collected data are preferred for a site rather than using these factors summarized here.

The data summarized in this whitepaper are associated with samples collected from sheetflows at source areas (mainly paved parking areas and roof runoff, plus mixed flows at stormdrain inlets), from sediment samples collected at sumps at stormdrain inlets (perhaps the most straight-forward way of collecting these data), from bulk stormwater outfall samples (most of the data), and from sediments from small urban creeks. The data are further separated into constituent categories: specific gravity and volatile solids; COD, TOC, and nutrients; heavy metals; PAHs; and chlordane and total PCBs. The particulate strength values from the research reports are presented, along with the resulting normalized factors.

There are some obvious trends in the values (and factors) when compared to particle size, with a few examples listed below:

- Specific gravity is high for small particles and decreases for large particles (and with increased organic material).

- Mixed residential and commercial area TOC values are high for small particles but decrease for large particles. In contrast, industrial area TOC values have the opposite trend, indicating the likely presence of oily debris as part of the large industrial particles.
- Many of the heavy metals behave similarly to the TOC trends, with high concentrations associated with the small particles, with lower values for large particles, except for industrial samples indicating higher values for larger sizes.
- Most of the PAHs have slightly higher values for small particles, then decrease for larger particles, except for the largest particles (including large organic material and oily debris) with very high PAH values.
- Total PCBs have high values for small particles and low values for the larger particles.

The factors for the constituents and particle size ranges can be organized as a matrix as a new parameter file, possibly linked to pollutant concentration parameter files. It may also be worthwhile to include a new solids and pollutant category for floatable material at this time, along with seasonal factors to reflect (at least) phosphorus particulate strength (and maybe even PSD) changes with time (in later model updates). An additional white paper addresses seasonal trends.

Introduction

Knowing the distribution of pollutants associated with different sized stormwater particles allows more accurate determinations of their sources, transport, and control. This summary will be used to modify WinSLAMM by expanding the particulate strength characteristics by particle size. WinSLAMM currently tracks particulates based on particle size distributions but only uses a single overall particulate strength value for all sizes. Stormwater controls usually preferentially remove the largest particles, resulting in changes in bulk particle strength values after treatment. Therefore, using particulate strength values for different particle sizes will result in more accurate calculations assisting stormwater management decisions and knowledge of the fates of these particulates.

This memo reviews stormwater pollutant strength data for different particle sizes to support these enhanced WinSLAMM calculations as part of the current SERDP project. Most of these data are from past master's theses and Ph.D. dissertations (Bathi 2008, Cai 2013, Eppakayala 2015, Goodson 2013, Khambhammettu 2005, and Morquecho 2005) from the University of Alabama, along with past reviews (Pitt, *et al*. 2005a and 2005b) and the first phase of this SERDP project (SERDP 2018). These data are supplemented by additional data obtained during the second SERDP project phase.

Pollutant strengths are the contaminant concentrations associated with the particulate matter in the stormwater. Particulate strengths are determined by calculating the pollutant concentration only associated with the particulates (measured as TSS or SSC, depending on how the sample was collected and analyzed) in the runoff water. Particulate strengths are calculated by the following equation:

$$\frac{(total\ conc. - filterable\ conc.)}{particulate\ solids\ conc.}$$

As an example, if the total copper concentration was 50 µg/L, the filterable ("dissolved") copper concentration was 10 µg/L, and the TSS concentration was 150 mg/L, the particulate strength for this sample would be:

$$\frac{\left(50\ \mu\frac{gCu}{L} - 10\mu\frac{gCu}{L}\right)}{150\ mg/L} = 0.26\ \mu\frac{gCu}{mg\ solids} = 260\ \mu g\ Cu/g\ solids =$$

260 mg Cu/kg solids (also = 260 ppm, the usual units for soil analyses)

This value is therefore the pollutant concentration associated with the particulate matter in the runoff sample. This calculation can be used based on stormwater samples divided into separate particle sizes.

It is also possible to calculate particulate strength data using particulate samples, such as sediment collected from stormwater inlets, creek sediments, sediments from sumps in stormwater controls, and even soil samples (including vacuumed particulates from different paved areas). The particulate samples are sieved before the chemical analyses to obtain data for different particle size ranges. It is more difficult to obtain data for very small particles as the smallest sieves available are about 20 µm. The membrane filters used for separating stormwater particulates are generally 0.45 µm (as used for most TSS vs. TDS analyses), while larger and smaller specialized membrane filters are also available. However, it is more difficult to obtain data for large particles from water samples due to their low abundance. The following summaries therefore combine data from water samples which emphasize small particles and from sediment data which emphasize large particles.

Pollutant Strengths for Urban Area Particulate Samples

Pitt, *et al.* (2005a and 2005b) summarized particulate strength data from a number of prior research studies. These studies collected dry soil samples from various urban surfaces for gravimetric, particle size, and quality analyses. In general, they were vacuumed from hard surfaces in very specific patterns in order to determine their accumulation rates and quality.

The data summarized in Tables 1 and 2 are average particulate strength values for different pollutants, land uses, and source areas. Generally, each sample comprised 12 to 40 subsamples for each collection. Collections were usually made several times a week for up to three years from 5 to 10 areas per project. Therefore, each project typically included data from hundreds to thousands of samples. Normally, each sample was separated into several particle sizes using standard sieves. Each sample fraction was retained, usually in small plastic bags. Seasonal composites were then made of all similar sized samples for each source area for the chemical analyses. The data shown in this section are averages of the chemical analyses for the smallest particle sizes (generally <125 µm) for all samples representing each land use for each project.

The smallest particle sizes are of the most interest here as they are the particles that are most mobile in stormwater drainage systems and affect receiving waters.

These data show the variations in chemical quality between particles from different land uses and source areas. Typically, the particulate strengths increase as the use of an area becomes more intensive, but the variations are slight for different locations. Seasonal variations may also be evident for nutrients that are affected by changes in leaf drop and accumulations in the drainage system.

Table 1. Summary of observed street dirt mean chemical quality for small particles (mg constituent/kg solids), collected by dry vacuuming (Pitt, *et al.* 2005a).

Constituent	Residential		Commercial		Industrial	
P	620	(4)				
	540	(6)			670	(4)
	1,100	(5)	400	(6)		
	710	(1)	1,500	(5)		
	810	(3)	910	(1)		
TKN	1,030	(4)				
	3,000	(6)			560	(4)
	290	(5)	1,100	(6)		
	2,630	(3)	340	(5)		
	3,000	(2)	4,300	(2)		
COD	100,000	(4)				
	150,000	(6)			65,000	(4)
	180,000	(5)	110,000	(6)		
	280,000	(1)	250,000	(5)		
	180,000	(3)	340,000	(1)		
	170,000	(2)	210,000	(2)		
Cu	162	(4)				
	110	(6)	130	(6)	360	(4)
	420	(2)	220	(2)		
Pb	1,010	(4)				
	1,800	(6)			900	(4)
	530	(5)	3,500	(6)		
	1,200	(1)	2,600	(5)		
	1,650	(3)	2,400	(1)		
	3,500	(2)	7,500	(2)		
Zn	460	(4)				
	260	(5)			500	(4)
	325	(3)	750	(5)		
	680	(2)	1,200	(2)		
Cd	<3	(5)	5	(5)		
	4	(2)	5	(2)		
Cr	42	(4)				
	31	(5)	65	(5)	70	(4)
	170	(2)	180	(2)		

References:

(1) Bannerman, et al. 1983 (Milwaukee, WI) <31μm

(2) Pitt 1979 (San Jose, CA) <45 μm

(3) Pitt 1985 (Bellevue, WA) <63 μm

(4) Pitt and McLean 1986 (Toronto, Ontario) <125 μm

(5) Pitt and Sutherland 1982 (Reno/Sparks, NV) <63 μm

(6) Terstriep, et al. 1982 (Champaign/Urbana, IL) <63 μm

Increasing concentrations of heavy metals with decreasing particle sizes was also evident, for those studies that included particle size information. However, phosphorus concentrations typically increased with increasing particle sizes associated with increased organic material with the large particles. Only the particulate quality of the smallest particle sizes are shown on these tables because they best represent the particles that are washed off during rains.

Table 2. Summary of observed particulate quality for other source areas (means for <125 µm particles) (mg constituent/kg solids), sheetflow samples during rains (Pitt and McLean 1986).

	P	TKN	COD	Cu	Pb	Zn	Cr
Residential/Commercial Land Uses							
Roofs	1,500	5,700	240,000	130	980	1,900	77
Paved parking	600	790	78,000	145	630	420	47
Unpaved driveways	400	850	50,000	45	160	170	20
Paved driveways	550	2,750	250,000	170	900	800	70
Dirt footpath	360	760	25,000	15	38	50	25
Paved sidewalk	1,100	3,620	146,000	44	1,200	430	32
Garden soil	1,300	1,950	70,000	30	50	120	35
Road shoulder	870	720	35,000	35	230	120	25
Industrial Land Uses							
Paved parking	770	1,060	130,000	1,110	650	930	98
Unpaved parking/storage	620	700	110,000	1,120	2,050	1,120	62
Paved footpath	890	1,900	120,000	280	460	1,300	63
Bare ground	700	1,700	70,000	91	135	270	38

Source: Pitt and McLean 1986 (Toronto, Ontario)

The above data are not separated by particle size but do indicate the overall range of pollutant strengths for different source areas (lead is high compared to current samples). The following sets of data show the particulate strengths by particle size which will be used for the normalizing calculations in this whitepaper.

Particulate Pollutant Strengths for Stormwater Source Area Sheetflow Samples

Morquecho (2005) collected a number of sheetflow samples from residential and commercial areas in Birmingham and Tuscaloosa, AL, for pollutant associations with particle size as part of her Ph.D. dissertation research at the University of Alabama. In contrast to most other researchers, she found that less than 50% of Zn, Cu, Cd, or Pb were associated with the particulate fraction of the stormwater, with most of these constituents associated with the filtered stormwater fraction. Table 3 summarizes particulate strengths by particle size for selected stormwater pollutants.

Table 3. Average pollutant strengths for different particle sizes for roof runoff samples (N=5) (Morquecho 2005)

	Total phosphorus		COD		Zinc		Copper		Lead		Cadmium	
	mg/kg SS	COV	mg/kg SS	COV	mg/kg SS	COV	mg/kg SS	COV	mg/kg SS	COV	mg/kg SS	COV
>250 µm	4,400	0.77	300,000	0.91	2,800	1.15	150	0.28	630	0.35	13	1.24
106-250 µm	1,400	na	510,000	0.95	580	1.38	6.2	na	53	0.83	1.9	na
45-106 µm	1,400	1.30	520,000	0.43	na	na	1,900	na	200	1.22	na	na
10-45 µm	3,000	0.56	840	1.18	5,589	1.41	310	na	150	1.40	4.6	na
2-10 µm	na	na	370,000	na	2,000	0.40	na	na	120	na	5.4	1.03
1-2 µm	5,200	na	630,000	0.50	na	na	na	na	390	na	22	0.68
0.45-1 µm	6,800	1.69	1,212	0.85	45,000	1.12	4,900	na	5,100	0.70	87	1.13

Note: na=too few detectable observations for calculation

Table 4 lists the average percentage of the heavy metals analyzed that occurred as either ionic or bound forms for the filtered samples. Most of the zinc, cadmium and lead were not present in free ionic forms, but were bound to colloids or organic matter whose bonds could be broken by exposure to UV light. Only copper occurred in mostly ionic forms. These results differ from previous results from this laboratory (Johnson, *et al.* 2003), in which only cadmium was mostly particulate bound (70%) and about 50% of copper was in ionic forms. The other metals were mostly found in their ionic forms. Results from these types of tests can be highly variable due to low metals concentrations in the filterable fractions.

Table 4. Average percentage of metals occurring as ionic or bound forms for last four samples (metals measured by ICP-MS) (Morquecho 2005)

	Average % ionic	Average % bound
Zinc	15	85
Copper	70	30
Cadmium	10	90
Lead	12	88

Particulate Pollutant Strengths for Sediment Samples Collected from Inlet Sumps

Table 5 lists average particulate strength results from sediment collected from stormwater inlets and catchbasins in Bellevue, WA (Pitt 1985). These values are comparable to recent data, with the expected exception for lead. Current lead sediment concentration values are about 1/10th of these older lead values, while the other particulate strengths shown on this table are similar to more current data.

Table 5. Chemical Quality of Bellevue, WA, Inlet Structure Sediment (mg constituent/kg total solids) (Pitt 1985)

Particle Size (µm)	COD	TKN	TP	Pb*	Zn
<63	160,000	2,900	880	1,200	400
61-125	130,000	2,100	690	870	320
125-250	92,000	1,500	630	620	200
250-500	100,000	1,600	610	560	200
500-1,000	140,000	1,600	550	540	200
1,000-2,000	250,000	2,600	930	540	230
2,000-6,350	270,000	2,500	1,100	480	190
>6,350	240,000	2,100	760	290	150

* these lead values are much higher than are found for current samples due to the decreased use of leaded gasoline since 1981 when these samples were collected.

Khambhammettu (2005) collected sediment samples from the UpFlo Filter sump that was located in the City Hall parking lot in Tuscaloosa, AL, as part of his MSCE thesis research at the University of Alabama. Table 6 is a summary of the particulate strengths by particle size. Except for lead, these particulate strengths are similar to those noted above for the Bellevue, WA (Pitt 1985) samples.

Table 6. Average Particulate Strengths of Sediment Collected from UpFlo Filter Sump (Khambhammettu 2005)

Sediment Size Range (µm)	COD (mg/kg)	P (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
<75	233,000	3,580	117	15,600	6,050	190	21.2	80.4	1,340
75-150	129,000	1,620	177	25,300	4,960	99.8	17.4	70.3	958
150-250	35,500	511	158	22,900	3,010	48.2	8.0	34.9	501
250-425	60,100	315	134	18,600	2,790	33.6	6.7	28.4	539
425-850	45,000	496	146	19,700	2,290	22.1	3.7	23.7	270
850-2,000	29,200	854	312	44,700	4,050	27.8	6.9	25.1	414
2,000-4,750	143,000	1,400	452	65,000	4,430	54.9	10.5	27.8	450
>4,750	251,000	1,700	134	8,390	7,000	48.7	9.3	59.6	564

Cai (2013) conducted performance monitoring of the UpFlo Filter in Tuscaloosa, AL, as part of his MSCE thesis research at the University of Alabama. The filter was installed in a small paved parking lot at a river-side park, with moderate parking activity (fishers and dog walkers), with some adjacent landscaping. At the end of the monitoring period, grab samples of sump sediment were collected, dried, and analyzed by particle size (nutrients and heavy metals along with solids characteristics and specific gravity). Table 7 shows the analysis results for nutrients, while Table 8 shows the analysis results for heavy metals. Total sulfite and total sulfide were analyzed to evaluate the potential for anaerobic conditions in the sediment and binding of heavy metals. These were both undetected for all samples. Total sulfate, total phosphorus, and all the heavy metal constituents tended to be higher on the organic leaves and on the very small particles.

Table 7. Nutrient Content of Sump Sediment Samples (Cai 2013)

	Total N (mg/kg)	Total P (mg/kg)	Total Sulfide (mg/kg)	Total Sulfate (mg/kg)	Total Sulfite (mg/kg)
Leaves	1790	127	BDL	1260	BDL
Sticks	2600	115	BDL	522	BDL
>2800	2740	131	BDL	540	BDL
1400 - 2800	2660	312	BDL	545	BDL
710-1400	1930	161	BDL	691	BDL
355-710	812	303	BDL	574	BDL
180-355	588	335	BDL	362	BDL
75-180	1900	350	BDL	949	BDL
45-75	1710	815	BDL	1780	BDL
<45 (Pan)	2740	670	BDL	2310	BDL

Table 8. Heavy Metal Content of Sump Sediment Samples

	Cadmium (mg/kg)	Chromium (mg/kg)	Lead (mg/kg)	Copper (mg/kg)	Zinc (mg/kg)
Leaves	2.1	24	4.3	9	28
Sticks	BDL	14	2.1	5	46
>2800	BDL	6	1.9	3	BDL
1400 - 2800	0.8	60	6.1	10	31
710-1400	0.8	160	15.1	18	56
355-710	0.7	97	15.6	15	71
180-355	BDL	85	14.7	25	71
75-180	11.0	81	35.5	29	76
45-75	2.0	135	60.2	41	198
<45 (Pan)	2.4	157	51.6	48	245

Table 9 shows the volatile solids and specific gravity values of these samples, separated by particle size.

Table 9. Solids Characteristics of Sump Sediment Samples (2)

Sieve size range (um)	Specific Gravity (g/cc)	Volatile Solids (%)
Decomposing leaves	2.28	93.2
Sticks	0.84	81.2
>2800	0.66	70.9
1400 - 2800	1.15	57.8
710-1400	1.43	42.7
355-710	2.56	26.1
180-355	2.76	19.4
75-180	2.97	20.6
45-75	3.30	25.7
<45 (Pan)	3.46	26.0

Except for the decomposing leaves, specific gravity decreases as the volatile solids content increases; larger particle sizes have lower specific gravity and greater volatile solids as they contain larger amounts of light-weight organic debris. Figure 1 is a scatterplot showing the close relationship of these two constituents supporting the likelihood that the low specific gravity values for the large particles are due to the increased amount of organic matter in those larger particle sizes. However, the decomposing leaves in the sediment have a very large volatile solids content, but also a high specific gravity. “Fresher” leaves would have a lower specific gravity and be associated with the floatable portion of the stormwater solids.

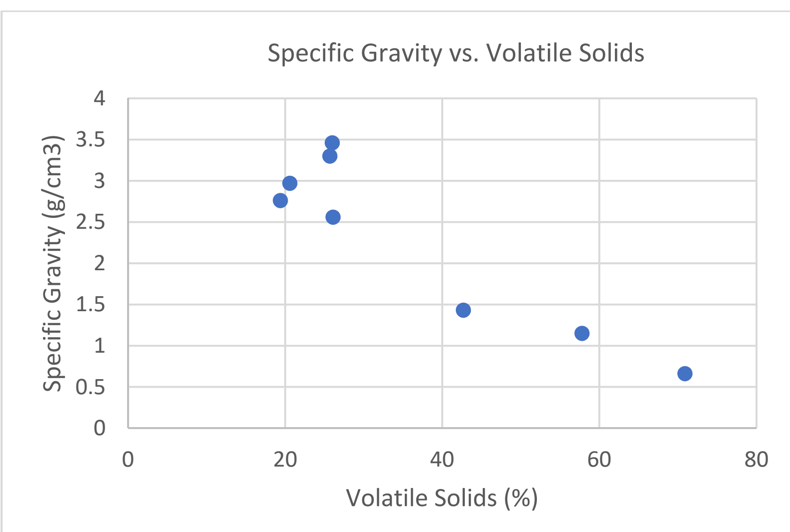


Figure 1. Specific gravity vs. volatile solids relationship.

Particulate Pollutant Strengths for Stormwater Outfall Samples

The first phase of this SERDP (2018) research included stormwater sampling in the Paleta Creek watershed, located in San Diego and National City, CA. The upper area of the watershed is comprised mainly of residential areas with some commercial activity. The creek then flows through Naval Base San Diego that has mostly industrial attributes. Tables 10 through 17 summarize the metal and organic pollutant strengths of particulates in four separate size ranges (0.45 to 5 µm, 5 to 20 µm, 20 to 63 µm, and >63 µm). These particle sizes represent potential near shore sedimentation effects (>63 µm) to long-range transport (0.45 to 5 µm) after discharge from the creek.

As expected, particulates from the NBSD (industrial) stormwater have greater pollutant strengths than the particulates from the residential/commercial area. In addition, the pollutant strengths increase dramatically with larger particles for the NBSD samples, likely due to relatively large particulates of metals and oily matter. The residential area particulate strengths are high for both the finest and the largest particles, with intermediate size particles having lower pollutant strengths.

Table 10. Particulate Strengths for Heavy Metals at Paleta Creek (SERDP 2018)

	Naval Base San Diego (Industrial Outfalls)							Paleta Creek (mixed urban mostly residential some commercial)				
	NBSD outfall at Paunack and Division Streets (1st event)	NBSD outfall at Paunack and Division Streets (2nd event)	NBSD outfall north of railroad crossing (1st event)	NBSD outfall #23 (1ST event)	NBSD outfall #33 (1st event)	NBSD outfall #33 (2nd event)	Industrial average (COV)	Paleta Creek at Main Street (1st event)	Paleta Creek at Main Street (2nd event)	Paleta Creek at Cummings Road 1st event)	Paleta Creek at Cummings Road (2nd event)	Residential/Commercial average (COV)
Mercury (µg/kg)												
Particulate (0.45 -5 µm)	1,606	310	na*	na	nd	75.7	664 (1.01)	nd	na	nd	46.6	47
Particulate (5-20 µm)	138	189	483	nd**	781	237	366 (0.65)	115	101	147	250	153 (0.44)
Particulate (20-63 µm)	4,804	1,859	na	31.0	nd	728	1,856 (0.98)	113	75.0	47.3	124	90 (0.39)
Particulate (> 63 µm)	10,048	1,795	2,800	91.7	22,143	384	6,210 (1.27)	933	42.1	433	115	381 (1.06)
Lead (mg/kg)												
Particulate (0.45 -5 µm)	396	nd	na*	na	0.1	4.1	133 (1.39)	485	na	24.7	42.4	184 (1.42)
Particulate (5-20 µm)	14.1	9.9	103	173	78.1	98.3	79 (0.70)	78.0	67.5	112	116	93 (0.26)
Particulate (20-63 µm)	nd**	nd	na	12.9	nd	401	207 (0.94)	44.1	15.2	20.3	98.6	45 (0.86)
Particulate (> 63 µm)	278	143	68.3	213	1262	577	424 (0.96)	563	37.4	192	47.5	210 (1.17)
Cadmium (mg/kg)												
Particulate (0.45 -5 µm)	nd**	nd	na*	na	nd	nd	all nd	nd	na	nd	nd	all nd
Particulate (5-20 µm)	nd	nd	0.2	0.1	1.4	nd	0.6 (1.04)	1.8	nd	nd	nd	1.8
Particulate (20-63 µm)	nd	nd	na	2.1	na*	nd	2.1	1.5	0.21	nd	2.3	1.3 (0.79)
Particulate (> 63 µm)	21.6	nd	29.1	3.2	165	nd	54.7 (1.18)	10.8	0.43	6.4	12.3	7.5 (0.71)
Zinc (mg/kg)												
Particulate (0.45 -5 µm)	2,667	2,995	na*	na	454	nd**	2,039 (0.55)	2,169	na	414	1,343	1,309 (0.67)
Particulate (5-20 µm)	146	nd	546	42.6	nd	173	227 (0.84)	543	595	265	502	476 (0.31)
Particulate (20-63 µm)	1,610	nd	na	1,098	2,039	nd	1,582 (0.24)	659	274.	161	523	404 (0.56)
Particulate (> 63 µm)	4,046	13,086	8,797	2,505	3,875	29,021	10,222 (0.89)	4,917	375	1,657	3,054	2,501 (0.78)
Nickel (mg/kg)												
Particulate (0.45 -5 µm)	34.8	nd	na*	na	nd	nd	35	175	na	95.3	0	90 (0.97)
Particulate (5-20 µm)	nd**	nd	nd	14.5	13.6	nd	14 (0.03)	22.1	33.4	nd	56.9	37 (0.47)
Particulate (20-63 µm)	356	nd	na	36.0	nd	nd	196 (0.82)	37.8	3.9	nd	nd	21 (1.15)
Particulate (> 63 µm)	526	nd	597	10.2	1,080	nd	553 (0.69)	195	14.4	78.4	nd	96 (0.95)
Copper (mg/kg)												
Particulate (0.45 -5 µm)	436	1,638	na	na	1.2	278	588 (1.06)	752	na	226	nd	489 (0.76)
Particulate (5-20 µm)	28.5	12.0	nd	55.7	76.0	94.3	53 (0.56)	116	122	nd	189	142 (0.28)
Particulate (20-63 µm)	608	714	na	128	nd	286	434 (0.55)	136	30.9	47.8	78.3	73 (0.63)
Particulate (> 63 µm)	505	nd	146	96.6	8,751	1,081	2,116 (1.58)	773	62.1	278	164	319 (0.99)
Silver (mg/kg)												
Particulate (0.45 -5 µm)		nd				nd	all nd		na*		nd	all nd
Particulate (5-20 µm)		nd				nd	all nd		0.4		1.4	0.9 (0.79)
Particulate (20-63 µm)		nd				nd	all nd		0.1		nd	0.1
Particulate (> 63 µm)		nd				nd	all nd		0.1		nd	0.1

Arsenic (mg/kg)												
Particulate (0.45 -5 µm)	nd		na*	na	nd		all nd	50.4	na	25.6		38 (0.46)
Particulate (5-20 µm)	5.2		1.3	6.2	16.9		7 (0.78)	16.9		nd		17
Particulate (20-63 µm)	134	nd	na	655	nd	nd	395 (0.66)	18.0	6.3	7.3	nd	11 (0.62)
Particulate (> 63 µm)	128	nd	1,418	nd	1,111	nd	886 (0.62)	544	4.3	559	22.4	282 (1.10)
TOC (%)												
Particulate (0.45 -5 µm)			na*	na	8.8	nd	8.8		na	40.5	nd	40.5
Particulate (5-20 µm)	2.4		6.7	15.7	2.7	2.0	5.9 (0.88)	2.0	nd	4.9	9.1	5.3 (0.67)
Particulate (20-63 µm)	nd		na	19.9	4.4	15.2	13.2 (0.49)	10.9	18.1	6.2	2.6	9.5 (0.71)
Particulate (> 63 µm)	47.2			23.6	10.0	21.6	25.6 (0.53)	19.8	2.2	21.3	16.2	14.9 (0.59)

* SSC was not detected; particulate strength could not be calculated and assumed to be zero

** not detected; particulate strength could not be calculated and assumed to be zero

Blanks are missing data

Table 11. Chlordane (ug/kg) All Flows Combined (SERDP 2018)

Size range	0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
	453	nd	nd	nd
	13.0	27.5	549	nd
	42.9	30.8	139	41.5
	nd	37.6	71.8	nd
	nd	3.58	19.7	81.0
	nd	21.0	nd	NA
	9.1	15.1	8.7	nd
	5.1	2.6	nd	nd
	26.8	2.8	286	nd
average	61.1	15.7	119	15.3
median	9.1	15.1	19.7	nd
COV	2.4	0.90	1.57	1.98
min	nd	nd	nd	nd
max	453	37.6	549	81.0
count	9	9	9	8

Table 12. Total PCBs (ug/kg) All Flows Combined (SERDP 2018)

Size range	0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
	nd	3.3	240	nd
	492	46.2	21.2	113
	23.0	nd	43.9	22.3
	3.2	273	nd	nd
	49.0	30.9	211	128
	1,270	72.5	nd	nd
	nd	20.0	39.0	nd
	418	2.7	126	nd
		258	268	nd
		4.3	174	nd
		22.3	519	nd
		30.2	nd	
		33.7	5.8	
		102	287	
		19.5	nd	
avg	282	61.2	129	23.9
median	36.0	30.2	43.9	0.0
COV	1.58	1.43	1.18	2.02
count	8	15	15	11
min	nd	nd	nd	nd
max	1,270	273	519	128

Table 13. Paleta Creek Stormwater PAH Pollutant Strengths (SERDP 2018)

		Naphthalene (ug/kg)					Fluorene (ug/kg)					Acenaphthene (ug/kg)			
		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
C2W event 1	resid	nd	98	nd	392		nd	36	nd	nd		nd	30	nd	nd
C2W event 2	resid	310	nd	86	15		nd	896	1,576	nd		nd	nd	9	82
O4W event 1	NBSD	25	nd	27	nd		20	nd	nd	nd		6	nd	99	nd
O3W event 1	NBSD	nd	nd	nd	16,756		nd	nd	37	137		nd	nd	254	628
O1W event 1	NBSD	nd	47	nd	529		nd	nd	20	474		nd	nd	57	1,255
O2W event 1	NBSD	nd	2	nd	117		nd	nd	nd	nd		nd	2	nd	7,204
O4W event2	NBSD	nd	61	274	nd		nd	3	nd	nd		nd	12	nd	672
O2W event2	NBSD	nd	10	nd	5,837		nd	30	nd	nd		nd	59	319	nd
C1W event 1	mixed flow	nd	16	4	182		nd	9	nd	30		149	10	nd	453
C1W event 2	mixed flow	nd	10	nd	192		nd	nd	nd	169		nd	nd	nd	450
A1W event 2	creek mouth	nd	17	68	145		nd	nd	nd	224		nd	12	nd	912
A2W event 1	creek mouth	nd	nd	nd	nd		nd	nd	nd	nd		65	nd	208	nd
A3W event 1	creek mouth	nd	nd	nd	4,388		573	nd	nd	1,400		3,420	nd	nd	996
A1W event 2	creek mouth	nd	5	nd	223		nd	21	nd	6		2	13	nd	297
A2W event 2	creek mouth	nd	8	451	nd		nd	nd	nd	nd		nd	10	nd	nd
count		2	10	6	11		2	6	3	7		5	8	6	10
min		25	2	4	15		20	3	20	6		2	2	9	82
max		310	98	451	16,756		573	896	1,576	1,400		3,420	59	319	7,204
average		167	27	152	2,616		296	166	544	348		728	18	158	1,295
median		167	13	77	223		296	26	37	169		65	12	153	650
stdev		202	31	175	5,093		391	358	893	489		1,506	18	121	2,105
COV		1.21	1.15	1.15	1.95		1.32	2.16	1.64	1.40		2.07	0.98	0.77	1.63

Table 14. Paleta Creek Stormwater PAH Pollutant Strengths (continued) (SERDP 2018)

		Phenanthrene (ug/kg)					**Anthracene (ug/kg)**					**Fluoranthene (ug/kg)**			
		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
C2W event 1	resid	nd	261	86	nd		nd	nd	212	nd		1,587	382	1,170	8,308
C2W event 2	resid	nd	nd	nd	541		nd	nd	nd	nd		nd	349	708	113
O4W event 1	NBSD	46	nd	121	nd		7	nd	nd	nd		nd	186	1,468	nd
O3W event 1	NBSD	nd	nd	109	19,198		nd	nd	493	18,310		nd	386	1,403	137,838
O1W event 1	NBSD	nd	360	296	2,126		nd	32	48	nd		nd	810	579	1,710
O2W event 1	NBSD	nd	14	7	10,098		nd	5	420	986		nd	95	nd	105,346
O4W event2	NBSD	nd	11	nd	997		nd	nd	nd	1,191		nd	23	nd	1,395
O2W event2	NBSD	nd	nd	nd	2,490		nd	nd	nd	135		nd	35	438	1,249
C1W event 1	mixed flow	nd	94	275	1,416		30	20	170	118		nd	645	3,646	nd
C1W event 2	mixed flow	nd	nd	357	443		nd	5	14	nd		715	134	709	nd
A1W event 2	creek mouth	nd	406	829	5,758		nd	48	79	1,141		nd	1,187	2,270	16,768
A2W event 1	creek mouth	nd	17	nd	nd		nd	4	nd	nd		95	171	3,444	nd
A3W event 1	creek mouth	nd	nd	nd	4,971		nd	36	185	nd		7,636	142	839	nd
A1W event 2	creek mouth	16	44	nd	3,070		42	nd	nd	nd		9	32	678	4,062
A2W event 2	creek mouth	nd	20	nd	nd		nd	18	nd	nd		nd	46	nd	nd
count		2	9	8	11		3	8	8	6		5	15	12	9
min		16	11	7	443		7	4	14	118		9	23	438	113
max		46	406	829	19,198		42	48	493	18,310		7,636	1,187	3,646	137,838
average		31	136	260	4,646		26	21	203	3,647		2,009	308	1,446	30,754
median		31	44	198	2,490		30	19	177	1,064		715	171	1,004	4,062
stdev		21	161	260	5,609		18	16	172	7,200		3,209	337	1,104	52,390
COV		0.69	1.18	1.00	1.21		0.68	0.78	0.85	1.97		1.60	1.09	0.76	1.70

Table 15. Paleta Creek Stormwater PAH Pollutant Strengths (continued) (SERDP 2018)

		Pyrene (ug/kg)					Chrysene (ug/kg)					Benzo[a]anthracene (ug/kg)			
		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
C2W event 1	resid	505	511	685	2,314		165	133	397	nd		90	95	401	294
C2W event 2	resid	nd	479	267	162		nd	183	105	48		nd	93	41	52
O4W event 1	NBSD	20	114	65	nd		9	34	329	nd		nd	22	193	nd
O3W event 1	NBSD	nd	230	nd	33,846		nd	91	230	6,838		nd	68	159	9,652
O1W event 1	NBSD	nd	433	163	687		nd	265	170	893		nd	266	175	1,468
O2W event 1	NBSD	nd	111	nd	67,884		nd	44	nd	20,094		50	32	nd	15,189
O4W event2	NBSD	nd	5	507	279		nd	nd	559	750		nd	nd	276	377
O2W event2	NBSD	nd	30	299	3,950		nd	18	124	2,926		nd	10	103	1,002
C1W event 1	mixed flow	129	372	1,163	2,043		152	172	343	1,176		69	126	465	246
C1W event 2	mixed flow	488	159	601	648		74	60	233	658		nd	39	167	431
A1W event 2	creek mouth	nd	934	307	19,374		nd	459	150	8,843		nd	490	nd	6,350
A2W event 1	creek mouth	115	145	320	nd		49	65	249	nd		37	44	22	nd
A3W event 1	creek mouth	3,336	58	217	nd		1,546	6	99	11		1,166	24	24	362
A1W event 2	creek mouth	nd	24	494	3,731		5	12	183	1,418		3	8	113	766
A2W event 2	creek mouth	nd	33	162	nd		nd	15	58	nd		nd	13	106	nd
count		6	15	13	11		7	14	14	11		6	14	13	12
min		20	5	65	162		5	6	58	11		3	8	22	52
max		3,336	934	1,163	67,884		1,546	459	559	20,094		1,166	490	465	15,189
average		765	243	404	12,265		286	111	231	3,969		236	95	173	3,016
median		308	145	307	2,314		74	63	207	1,176		59	42	159	599
stdev		1,276	259	292	21,247		559	127	137	6,076		457	133	136	4,856
COV		1.67	1.07	0.72	1.73		1.96	1.14	0.59	1.53		1.94	1.40	0.79	1.61

Table 16. Paleta Creek Stormwater PAH Pollutant Strengths (continued) (SERDP 2018)

		Benzo[b]fluoranthene (ug/kg)					**Benzo[k]fluoranthene (ug/kg)**					**Benzo[a]pyrene (ug/kg)**			
		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
C2W event 1	resid	300	183	997	2,945		83	68	344	nd		148	117	592	nd
C2W event 2	resid	nd	280	182	123		nd	76	54	24		nd	164	120	33
O4W event 1	NBSD	19	78	145	nd		2	21	21	nd		0.2	39.3	45.0	nd
O3W event 1	NBSD	nd	204	833	22,596		nd	86	229	5,641		nd	184	546	10,907
O1W event 1	NBSD	nd	492	508	2,514		nd	151	90	462		nd	330	261	1,687
O2W event 1	NBSD	nd	74	nd	30,990		nd	31	nd	13,632		nd	31	nd	14,676
O4W event2	NBSD	nd	nd	477	778		nd	nd	60	48		nd	nd	248	nd
O2W event2	NBSD	nd	58	584	1,663		nd	20	156	972		nd	20	220	1,287
C1W event 1	mixed flow	192	344	1,347	210		58	119	430	29		85	184	624	309
C1W event 2	mixed flow	242	125	624	39		46	41	214	54		190	72	398	110
A1W event 2	creek mouth	nd	1,105	nd	12,385		nd	412	594	2,032		nd	662	1,022	3,851
A2W event 1	creek mouth	161	147	nd	nd		51	51	nd	nd		72	69	nd	nd
A3W event 1	creek mouth	3,770	72	104	nd		1,333	25	25	nd		2,190	39	18	570
A1W event 2	creek mouth	3	19	312	1,554		1	5	106	496		3	8	198	969
A2W event 2	creek mouth	nd	31	357	nd		nd	9	109	nd		nd	14	153	nd
count		7	14	12	11		7	14	13	10		7	14	13	10
min		3	19	104	39		1	5	21	24		0.2	8	18	33
max		3,770	1,105	1,347	30,990		1,333	412	594	13,632		2,190	662	1,022	14,676
average		669	229	539	6,891		225	80	187	2,339		384	138	342	3,440
median		192	136	493	1,663		51	46	109	479		85	70	248	1,128
stdev		1,371	285	372	10,597		489	105	174	4,327		799	176	286	5,129
COV		2.05	1.24	0.69	1.54		2.18	1.31	0.93	1.85		2.08	1.28	0.84	1.49

Table 17. Paleta Creek Stormwater PAH Pollutant Strengths (continued) (SERDP 2018)

		Dibenzo[a,h]anthracene (ug/kg)					**Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene (ug/kg)**			
		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm		0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
C2W event 1	resid	34.0	52.7	137.7	nd		460	327	1,598	nd
C2W event 2	resid	nd	42.1	133.1	nd		nd	608	476	41
O4W event 1	NBSD	nd	11.7	52.6	nd		26	116	174	nd
O3W event 1	NBSD	nd	37.0	54.8	6018.2		nd	204	682	6,011
O1W event 1	NBSD	nd	119.7	nd	33.2		nd	779	383	1,644
O2W event 1	NBSD	2.8	6.4	nd	6254.6		4	19	nd	9,990
O4W event2	NBSD	nd	nd	nd	1585.4		nd	2	442	578
O2W event2	NBSD	nd	7.5	19.1	448.4		nd	33	402	1,638
C1W event 1	mixed flow	44.6	63.6	34.3	147.2		233	363	792	931
C1W event 2	mixed flow	45.6	19.3	74.1	31.2		293	193	1,098	183
A1W event 2	creek mouth	nd	193.8	53.5	1828.9		nd	1,081	1,297	6,901
A2W event 1	creek mouth	18.4	21.2	77.6	nd		132	107	nd	nd
A3W event 1	creek mouth	782.1	18.0	54.7	nd		3,569	45	nd	1,095
A1W event 2	creek mouth	4.5	2.5	166.3	nd		nd	16	750	2,512
A2W event 2	creek mouth	nd	5.4	nd	nd		nd	34	290	nd
count		7	14	11	8		7	15	12	11
min		2.8	3	19	31		3.8	2	174	41
max		782	194	166	6,255		3,569	1,081	1,598	9,990
average		133	43	78	2,043		674	262	699	2,866
median		34	20	55	1,017		233	116	579	1,638
stdev		287	54	47	2,619		1,286	323	435	3,276
COV		2.15	1.25	0.60	1.28		1.91	1.24	0.62	1.14

Morquecho (2005) also collected mixed stormwater flow samples for particulate strengths from flows entering inlets (Table 18) in addition to similar samples from roof runoff shown earlier.

Table 18. Summary table showing average pollutant associations for different particle sizes for storm drain outlet samples (N=10, rounded to two significant figures)

	Total phosphorus		COD		Zinc		Copper		Lead		Cadmium	
	mg/kg SS	COV	mg/kg SS	COV	mg/kg SS	COV	mg/kg SS	COV	mg/kg SS	COV	mg/kg SS	COV
>250 µm	5,900	1.00	1,100,000	1.49	800	0.55	120	0.55	140	0.57	9.4	0.35
106-250 µm	1,900	1.45	780,000	1.33	52	0.68	20	0.52	30	0.54	8.3	1.29
45-106 µm	2,300	0.77	540,000	1.57	na	na	21	0.90	200	1.24	na	na
10-45 µm	3,400	0.73	720,000	0.49	990	na	130	1.06	150	1.22	9.1	0.67
2-10 µm	2,800	0.69	340,000	na	1,700	0.71	150	0.69	75	1.10	500	1.41
1-2 µm	8,000	0.78	670,000	na	540	1.17	320	1.08	600	1.24	440	1.33
0.45-1 µm	8,200	0.88	1,400,000	na	1,600	1.05	430	0.91	430	0.71	110	0.80

Note: na=too few detectable observations for standard deviation and therefore COV calculations.

Particulate Pollutant Strengths for Sediment Samples Collected from Small Urban Creeks

Bathi (2008) collected and analyzed urban creek sediments in Tuscaloosa, AL, for PAHs as part of his Ph.D. dissertation research at the University of Alabama. Sediment samples were collected from three different creeks in and around Tuscaloosa and Northport, AL (Cribb's Mill Creek, Carroll's Creek, and Hunter Creek). The PAH concentrations were found to be strongly associated with particulate matter. The fugacity level I partitioning calculations were performed for the PAHs in a hypothetical environmental system. This modeling approach indicated that except for the low molecular weight PAHs (naphthalene, fluorene, phenanthrene, and anthracene), all the other studied PAHs were predominantly portioned with the sediment phase. The model predictions also indicated that the PAHs with Log (K_{OW}) or Log (K_{OC}) values greater than about 4.5 were mostly partitioned with the sediment phase, compared to other phases. The high molecular weight PAHs had a greater portion associated with the particulates than did the low molecular weight PAHs.

Tables 19 through 57 show the observed PAH particulate strength values for the different particles sizes for each sample collected at each creek location. Bathi (2008) found that overall, all characteristics studied showed similar trends, with the smaller and larger particles found to have relatively higher values compared to the intermediate sized particles. Cluster analyses of the PAH concentrations for the different particle sizes showed that for most cases examined, the large organic matter (LOM) fraction was found to be a statistically separate sample category (having much higher concentrations) from all other sizes.

Table 19. Observed Concentrations of Naphthalene at Cribbs Mill Creek

Size Range (µm)	**Concentration (µg/kg), Sample Number**					**Mean Concentration (µg/kg)**	**Standard Deviation**
	3/28	**8/18**	**9/9**	**9/26**	**10/9**		
< 45	189	92	1045	568	283	436	384
45 – 90	101	59	466	486	216	266	200
90 – 180	59	101	683	681	281	361	305
180 – 355	62	61	176	252	125	135	81
355 – 710	37	87	362	103	75	133	130
710 – 1400	156	113	8126	824	365	1917	3483
1400 – 2800	102	87	7973	1866	685	2143	3338
> 2800 (w/o LOM)	84	99	153	259	147	149	69
> 2800 (LOM)	1057	1895	4584	2015	1656	2241	1361

w/o LOM = with LOM removed LOM = Large organic matter

Table 20. Observed Concentrations of Fluorene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	56	89	26	685	256	223	273
45 - 90	67	35	54	212	111	96	71
90 - 180	25	81	567	329	307	262	217
180 - 355	59	52	15	521	199	169	209
355 - 710	48	41	541	105	231	193	209
710 - 1400	61	58	458	149	223	190	165
1400 - 2800	108	101	389	565	354	303	198
> 2800 (w/o LOM)	49	251	159	255	154	174	85
> 2800 (LOM)	1903	2057	3289	1204	2132	2117	751

w/o LOM = with LOM removed LOM = Large organic matter

Table 21. Observed Concentrations of Phenanthrene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/2 6	10/9		
< 45	256	98	27	189	105	135	89
45 – 90	206	40	86	78	68	96	64
90 – 180	167	ND	53	167	110	124	55
180 – 355	ND	52	12	111	58	58	41
355 – 710	ND	28	56	97	60	60	28
710 – 1400	392	42	41	166	83	145	147
1400 – 2800	941	15	276	247	179	332	355
> 2800 (w/o LOM)	124	611	18	98	242	219	234
> 2800 (LOM)	1980	2304	5821	953	3026	2817	1838

w/o LOM = with LOM removed LOM = Large organic matter

Table 22. Observed Concentrations of Anthracene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	223	125	178	593	298	283	184
45 - 90	193	65	309	402	259	246	126
90 - 180	53	20	105	442	189	162	169
180 - 355	ND	33	18	202	84	84	83
355 - 710	132	31	262	684	326	287	250
710 - 1400	603	73	832	525	477	502	276
1400 - 2800	2480	53	1035	632	573	955	921
> 2800 (w/o LOM)	321	126	69	429	208	231	146
> 2800 (LOM)	2540	4215	853	1621	2230	2292	1254

w/o LOM = with LOM removed LOM = Large organic matter

Table 23. Observed Concentrations of Fluoranthene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	332	290	44	302	222	238	116
45 – 90	441	399	67	325	302	307	145
90 – 180	245	243	43	208	177	183	83
180 – 355	141	159	43	127	114	117	44
355 – 710	138	160	133	139	143	143	10
710 – 1400	398	278	149	301	275	280	89
1400 – 2800	366	269	291	542	308	355	110
> 2800 (w/o LOM)	240	105	20	211	122	140	88
> 2800 (LOM)	2240	1092	3059	1092	2238	1944	847

w/o LOM = with LOM removed   LOM = Large organic matter

Table 24. Observed Concentrations of Pyrene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	313	363	66	562	330	327	177
45 - 90	405	226	116	369	237	271	117
90 - 180	178	95	71	543	236	225	190
180 - 355	117	60	99	215	125	123	57
355 - 710	98	69	40	289	133	126	98
710 - 1400	272	90	214	312	205	219	84
1400 - 2800	261	159	111	386	219	227	105
> 2800 (w/o LOM)	527	321	50	198	190	257	179
> 2800 (LOM)	2240	2654	922	2923	2166	2181	769

w/o LOM = with LOM removed   LOM = Large organic matter

Table 25. Observed Concentrations of Benzo(a)anthracene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	270	89	179	689	350	315	231
45 – 90	321	53	205	522	299	280	172
90 – 180	179	12	330	755	315	318	276
180 – 355	93	40	185	629	254	240	233
355 – 710	97	15	206	511	208	207	188
710 – 1400	185	22	419	173	127	185	146
1400 – 2800	171	25	933	393	196	344	355
> 2800 (w/o LOM)	350	72	29	218	1547	443	630
> 2800 (LOM)	4350	2537	1260	3202	3313	2932	1138

w/o LOM = with LOM removed   LOM = Large organic matter

Table 26. Observed Concentrations of Chrysene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	418	108	96	568	361	310	205
45 - 90	507	43	147	922	525	429	349
90 - 180	307	30	249	664	407	331	231
180 - 355	162	49	142	356	220	186	113
355 - 710	158	37	176	383	239	199	126
710 - 1400	350	42	424	142	305	253	157
1400 - 2800	313	56	833	136	427	353	305
> 2800 (w/o LOM)	310	134	15	142	156	151	105
> 2800 (LOM)	3010	2936	3016	1353	1788	2420	792

w/o LOM = with LOM removed   LOM = Large organic matter

Table 27. Observed Concentrations of Benzo(b)fluoranthene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	1010	686	216	496	574	597	289
45 – 90	105	119	205	562	291	257	187
90 – 180	593	62	252	268	371	309	194
180 – 355	2600	626	108	252	987	915	1002
355 – 710	320	103	167	322	270	236	98
710 – 1400	741	414	613	468	607	569	129
1400 – 2800	735	114	1323	236	765	635	483
> 2800 (w/o LOM)	532	455	36	163	1530	543	588
> 2800 (LOM)	4390	3522	1040	1633	1869	2491	1405

w/o LOM = with LOM removed   LOM = Large organic matter

Table 28. Observed Concentrations of Benzo(a)pyrene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	665	693	212	924	610	621	258
45 – 90	882	510	324	598	663	596	205
90 – 180	512	515	749	995	674	689	199
180 – 355	1970	289	233	570	943	801	711
355 – 710	159	664	242	430	445	388	197
710 – 1400	269	549	2086	435	1023	872	734
1400 – 2800	345	910	8132	294	3112	2559	3321
> 2800 (w/o LOM)	850	687	857	239	594	645	253
> 2800 (LOM)	4650	2109	3013	1099	2074	2589	1336

w/o LOM = with LOM removed   LOM = Large organic matter

Table 29. Observed Concentrations of Indeno(1,2,3-cd)pyrene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	732	562	420	854	668	647	165
45 – 90	281	393	992	470	581	543	273
90 – 180	374	312	1752	2406	1511	1271	908
180 - 355	131	130	588	427	382	332	199
355 - 710	219	356	786	360	455	435	213
710 - 1400	269	287	1308	376	651	578	436
1400 - 2800	261	550	3563	283	1369	1205	1393
> 2800 (w/o LOM)	534	144	98	211	610	320	235
> 2800 (LOM)	1520	956	3563	1956	2717	2142	1022

w/o LOM = with LOM removed LOM = Large organic matter

Table 30. Observed Concentrations of Dibenz(a,h)anthracene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	114	413	901	953	656	607	350
45 – 90	40	358	1266	562	623	570	451
90 – 180	50	412	1460	1051	854	765	550
180 – 355	23	257	623	623	423	390	256
355 – 710	32	301	715	699	482	446	287
710 – 1400	ND	227	1344	1398	1371	1085	572
1400 - 2800	559	448	4941	351	1950	1650	1952
> 2800 (w/o LOM)	720	148	68	492	427	371	265
> 2800 (LOM)	720	3022	1533	2533	1964	1954	891

w/o LOM = with LOM removed LOM = Large organic matter

Table 31. Observed Concentrations of Benzo(ghi)perylene at Cribbs Mill Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	3/28	8/18	9/9	9/26	10/9		
< 45	548	167	990	453	389	509	303
45 – 90	153	86	474	622	287	324	223
90 – 180	236	153	1346	269	219	444	506
180 – 355	84	129	151	182	132	136	36
355 – 710	135	69	ND	193	132	132	50
710 – 1400	190	62	386	1997	750	677	782
1400 – 2800	313	107	1027	683	368	499	360
> 2800 (w/o LOM)	588	147	562	365	500	433	181
> 2800 (LOM)	988	1238	798	3521	2658	1841	1190

Table 32. Observed Concentrations of Naphthalene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	11	178	192	74	195	130	83
45 – 90	27	98	186	109	59	96	60
90 - 180	21	172	87	4	68	70	66
180 - 355	15	281	57	9	26	78	115
355 - 710	27	63	254	94	44	97	92
710 - 1400	31	20	157	236	519	193	204
1400 - 2800	78	102	551	351	106	238	207
> 2800 (w/o LOM)	82	5	72	168	147	95	65
> 2800 (LOM)	1723	2150	5413	8667	2311	4053	2967

w/o LOM = with LOM removed LOM = Large organic matter

Table 33. Observed Concentrations of Fluorene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	107	542	93	198	1090	406	424
45 - 90	103	367	292	264	521	310	153
90 - 180	160	562	123	34	417	259	221
180 - 355	80	53	40	32	197	80	68
355 - 710	114	63	NA	14	245	109	99
710 - 1400	20	305	60	38	407	166	178
1400 - 2800	178	410	616	515	183	380	196
> 2800 (w/o LOM)	79	89	214	126	217	145	67
> 2800 (LOM)	2900	1435	986	297	1075	1339	965

w/o LOM = with LOM removed LOM = Large organic matter

Table 34. Observed Concentrations of Phenanthrene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	772	529	351	249	926	566	283
45 - 90	395	372	351	259	799	435	210
90 - 180	34	503	59	39	457	218	239
180 - 355	131	238	ND	9	241	155	110
355 - 710	248	162	55	27	260	150	107
710 - 1400	42	333	105	46	422	190	176
1400 - 2800	107	412	146	106	101	174	134
> 2800 (w/o LOM)	137	34	128	153	322	155	104
> 2800 (LOM)	2748	874	1400	925	479	1285	881

w/o LOM = with LOM removed LOM = Large organic matter

Table 35. Observed Concentrations of Anthracene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	58	708	125	320	1599	562	632
45 - 90	54	543	651	515	949	542	323
90 - 180	424	712	52	612	570	474	257
180 - 355	16	432	86	ND	456	248	229
355 - 710	55	342	19	136	306	172	146
710 - 1400	132	900	27	ND	637	424	414
1400 - 2800	83	309	214	152	566	265	188
> 2800 (w/o LOM)	103	200	313	178	613	281	200
> 2800 (LOM)	3502	2189	3141	2150	1594	2515	783

w/o LOM = with LOM removed LOM = Large organic matter

Table 36. Observed Concentrations of Fluranthene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	701	1256	1324	2935	2066	1656	864
45 – 90	1385	582	1521	2605	1352	1489	724
90 - 180	409	1122	846	323	1109	762	379
180 - 355	701	712	124	56	561	431	318
355 - 710	1294	633	201	79	506	543	476
710 - 1400	917	462	248	69	469	433	317
1400 - 2800	517	612	82	56	171	287	259
> 2800 (w/o LOM)	712	303	60	142	321	308	251
> 2800 (LOM)	1893	650	1543	620	638	1069	605

w/o LOM = with LOM removed LOM = Large organic matter

Table 37. Observed Concentrations of Pyrene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	1382	958	1324	1582	2495	1548	575
45 - 90	647	1022	1241	1770	1261	1188	408
90 - 180	2097	957	286	81	1154	915	798
180 - 355	340	563	58	25	522	302	252
355 - 710	1636	218	86	20	480	488	665
710 - 1400	330	271	124	33	612	274	222
1400 - 2800	216	328	119	31	403	220	151
> 2800 (w/o LOM)	270	74	161	41	129	135	89
> 2800 (LOM)	2987	1594	1875	748	1298	1700	832

Table 38. Observed Concentrations of Benzo(a)anthracene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	80	722	1622	1208	1826	1092	706
45 – 90	85	428	508	1411	1879	862	750
90 – 180	184	801	ND	11	677	418	380
180 – 355	263	390	39	22	291	201	163
355 – 710	862	287	27	175	460	362	321
710 – 1400	22	352	43	156	296	174	148
1400 – 2800	62	628	99	167	502	292	256
> 2800 (w/o LOM)	109	21	107	159	263	132	89
> 2800 (LOM)	2613	1180	2415	729	1526	1693	804

w/o LOM = with LOM removed LOM = Large organic matter

Table 39. Observed Concentrations of Chrysene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	210	1257	924	1591	2095	1215	709
45 - 90	186	1033	2354	1815	681	1214	871
90 - 180	518	1303	58	226	820	585	495
180 - 355	596	632	95	34	381	348	276
355 - 710	1037	589	51	190	505	475	384
710 - 1400	40	169	315	151	269	189	108
1400 - 2800	108	633	84	268	469	312	236
> 2800 (w/o LOM)	88	41	47	142	338	131	123
> 2800 (LOM)	1823	553	985	1462	1259	1217	480

w/o LOM = with LOM removed LOM = Large organic matter

Table 40. Observed Concentrations of Benzo(b)flourantrene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	109	1551	859	1307	1418	1049	586
45 – 90	69	875	1102	1626	1883	1111	708
90 – 180	77	1505	856	168	479	617	582
180 – 355	113	521	124	22	466	249	227
355 – 710	50	313	514	111	479	294	210
710 – 1400	204	285	413	62	671	327	231
1400 – 2800	152	154	241	64	835	289	311
> 2800 (w/o LOM)	204	81	77	244	637	249	229
> 2800 (LOM)	1524	870	745	940	4642	1744	1647

w/o LOM = with LOM removed LOM = Large organic matter

Table 41. Observed Concentrations of Benzo(a)pyrene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	675	2331	5421	7803	1514	3549	2979
45 - 90	401	782	2015	12311	2935	3689	4923
90 - 180	495	894	206	650	381	525	262
180 - 355	410	901	26	214	347	380	326
355 - 710	284	452	NA	45	524	326	213
710 - 1400	585	182	285	127	772	390	277
1400 - 2800	936	544	142	70	1055	550	448
> 2800 (w/o LOM)	431	279	144	100	544	300	188
> 2800 (LOM)	1023	1501	953	610	7556	2329	2939

w/o LOM = with LOM removed LOM = Large organic matter

Table 42. Observed Concentrations of Indeno(1,2,3-cd)pyrene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	420	255	1622	1935	493	945	773
45 – 90	276	125	1985	1570	627	917	820
90 – 180	234	972	125	256	109	339	359
180 – 355	184	322	ND	128	342	244	105
355 – 710	344	302	514	158	531	370	156
710 – 1400	492	80	100	216	3020	782	1262
1400 – 2800	626	403	317	209	1751	661	628
> 2800 (w/o LOM)	126	57	315	1723	624	569	682
> 2800 (LOM)	1203	588	542	2403	1505	1248	764

w/o LOM = with LOM removed LOM = Large organic matter

Table 43. Observed Concentrations of Dibenz(a,h)anthracene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	333	1962	4876	6448	433	2810	2739
45 – 90	217	918	2541	3630	925	1646	1399
90 – 180	183	1264	259	533	108	469	472
180 – 355	138	726	154	30	432	296	283
355 – 710	299	523	214	128	713	375	239
710 – 1400	412	431	512	206	939	500	270
1400 – 2800	488	625	112	220	1549	599	569
> 2800 (w/o LOM)	312	69	309	356	524	314	163
> 2800 (LOM)	1724	1385	679	802	864	1091	445

Table 44. Observed Concentrations of Benzo(ghi)perylene at Hunter Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	96	1390	2016	2247	894	1329	870
45 – 90	62	978	525	803	1683	810	598
90 – 180	59	1165	558	ND	176	490	498
180 – 355	43	782	57	ND	617	375	381
355 – 710	49	328	224	172	364	228	126
710 – 1400	67	734	219	173	1318	502	524
1400 – 2800	124	523	242	117	972	396	362
> 2800 (w/o LOM)	53	147	836	162	646	369	349
> 2800 (LOM)	1073	4222	1400	2092	7102	3178	2513

w/o LOM = with LOM removed LOM = Large organic matter

Table 45. Observed Concentrations of Naphthalene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	22	561	95	102	217	199	214
45 - 90	81	425	157	30	165	171	152
90 - 180	163	11	5	15	102	59	71
180 - 355	15	157	31	55	93	70	57
355 - 710	101	65	464	27	58	143	181
710 - 1400	99	31	782	16	379	261	326
1400 - 2800	107	759	102	215	286	294	271
> 2800 (w/o LOM)	27	183	36	169	231	129	92
> 2800 (LOM)	1702	672	1819	3029	863	1617	936

w/o LOM = with LOM removed LOM = Large organic matter

Table 46. Observed Concentrations of Fluorene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	27	175	228	169	121	144	76
45 - 90	184	113	147	266	102	163	66
90 - 180	252	ND	32	99	162	137	94
180 - 355	78	31	101	301	121	126	103
355 - 710	207	11	68	186	69	108	84
710 - 1400	313	ND	307	141	216	244	82
1400 - 2800	224	119	152	187	301	197	70
> 2800 (w/o LOM)	364	723	210	180	169	329	234
> 2800 (LOM)	1263	3621	687	2106	1623	1860	1113

w/o LOM = with LOM removed LOM = Large organic matter

Table 47. Observed Concentrations of Phenanthrene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	7	63	8	260	125	92	105
45 - 90	30	64	4	236	96	86	91
90 - 180	44	37	ND	69	81	58	21
180 - 355	17	45	3	241	38	69	98
355 - 710	82	23	178	216	54	111	83
710 - 1400	38	49	33	84	81	57	24
1400 - 2800	92	138	9	124	72	87	51
> 2800 (w/o LOM)	56	172	166	466	98	192	161
> 2800 (LOM)	1253	3802	627	1732	2183	1920	1200

w/o LOM = with LOM removed LOM = Large organic matter

Table 48. Observed Concentrations of Anthracene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	113	104	88	524	261	218	185
45 - 90	115	55	44	69	99	77	30
90 - 180	39	ND	ND	105	64	69	33
180 - 355	102	77	50	290	132	130	94
355 - 710	62	22	53	241	59	87	88
710 - 1400	67	ND	26	317	144	138	128
1400 - 2800	127	231	128	564	231	256	180
> 2800 (w/o LOM)	48	113	163	284	109	144	88
> 2800 (LOM)	1430	2987	627	1027	3724	1959	1332

w/o LOM = with LOM removed LOM = Large organic matter

Table 49. Observed Concentrations of Fluoranthene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	60	37	66	154	106	85	46
45 - 90	41	39	28	104	182	79	65
90 - 180	59	63	34	88	213	91	71
180 - 355	18	15	31	137	99	60	55
355 - 710	43	21	53	100	71	58	30
710 - 1400	29	27	61	50	162	66	56
1400 - 2800	93	48	43	99	63	69	26
> 2800 (w/o LOM)	103	69	61	285	121	128	91
> 2800 (LOM)	1026	624	2102	3281	712	1549	1133

w/o LOM = with LOM removed LOM = Large organic matter

Table 50. Observed Concentrations of Pyrene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	21	43	65	211	79	84	75
45 - 90	10	16	67	279	120	99	110
90 - 180	19	21	60	237	153	98	95
180 - 355	31	32	60	249	130	101	92
355 - 710	17	101	82	231	103	107	78
710 - 1400	31	87	49	184	301	130	112
1400 - 2800	51	73	51	202	278	131	104
> 2800 (w/o LOM)	41	71	121	207	182	125	71
> 2800 (LOM)	3120	872	3604	2892	927	2283	1289

w/o LOM = with LOM removed LOM = Large organic matter

Table 51. Observed Concentrations of Benzo(a)anthracene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	33	179	42	131	99	97	61
45 – 90	16	203	21	47	132	84	81
90 – 180	48	22	10	63	219	72	84
180 – 355	43	66	16	110	98	67	39
355 – 710	13	116	152	128	112	104	53
710 – 1400	65	41	99	124	382	142	138
1400 – 2800	99	234	23	223	312	178	115
> 2800 (w/o LOM)	194	452	224	323	110	261	132
> 2800 (LOM)	1782	2039	589	3026	1902	1868	868

w/o LOM = with LOM removed LOM = Large organic matter

Table 52. Observed Concentrations of Chrysene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	72	155	34	631	342	247	246
45 - 90	28	67	19	279	423	163	180
90 - 180	41	13	12	553	240	172	234
180 - 355	68	46	12	104	132	72	47
355 - 710	22	101	131	268	200	144	94
710 - 1400	89	ND	24	160	178	113	71
1400 - 2800	48	196	21	538	312	223	212
> 2800 (w/o LOM)	89	362	60	429	214	231	163
> 2800 (LOM)	1862	2973	894	969	2262	1792	881

w/o LOM = with LOM removed matter LOM = Large organic matter

Table 53. Observed Concentrations of Benzo(b)fluoranthene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	20	134	27	343	217	148	136
45 – 90	23	84	20	573	217	184	232
90 – 180	322	23	179	125	98	150	111
180 – 355	16	43	20	38	92	42	30
355 – 710	44	124	62	213	318	152	114
710 – 1400	21	25	18	61	129	51	47
1400 – 2800	162	206	6	314	313	200	127
> 2800 (w/o LOM)	179	178	90	315	216	196	81
> 2800 (LOM)	1027	2712	638	4023	3102	2301	1429

w/o LOM = with LOM removed LOM = Large organic matter

Table 54. Observed Concentrations of Benzo(a)pyrene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	473	180	93	231	289	253	142
45 - 90	431	82	72	536	313	287	207
90 - 180	1049	14	1951	228	612	771	769
180 - 355	303	39	104	31	123	120	110
355 - 710	481	ND	54	635	146	329	274
710 - 1400	340	ND	3	240	128	178	145
1400 - 2800	637	194	6	189	214	248	233
> 2800 (w/o LOM)	263	205	127	295	261	230	66
> 2800 (LOM)	1526	3027	3627	453	1729	2073	1262

w/o LOM = with LOM removed LOM = Large organic matter

Table 55. Observed Concentrations of Indeno(1,2,3-cd)pyrene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	245	216	1494	1302	587	769	596
45 – 90	159	ND	739	672	321	473	278
90 – 180	821	ND	2167	1555	587	1282	719
180 – 355	118	76	603	33	152	197	232
355 – 710	265	211	341	32	101	190	125
710 – 1400	114	ND	120	614	421	317	244
1400 – 2800	158	184	43	562	305	251	198
> 2800 (w/o LOM)	312	237	102	43	211	181	108
> 2800 (LOM)	1672	672	2134	3273	1903	1931	935

w/o LOM = with LOM removed LOM = Large organic matter

Table 56. Observed Concentrations of Dibenz(a,h)anthracene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	204	266	463	655	321	382	180
45 – 90	130	160	93	142	204	146	41
90 – 180	690	54	1838	856	512	790	658
180 – 355	91	110	97	115	291	141	84
355 – 710	214	191	402	114	301	245	111
710 – 1400	96	63	ND	1248	682	522	561
1400 – 2800	165	132	44	623	321	257	228
> 2800 (w/o LOM)	158	146	128	146	289	173	65
> 2800 (LOM)	1700	982	1110	673	2692	1432	797

w/o LOM = with LOM removed   LOM = Large organic matter

Table 57. Observed Concentrations of Benzo(ghi)perylene at Carroll's Creek

Size Range (µm)	Concentration (µg/kg), Sample Number					Mean Concentration (µg/kg)	Standard Deviation
	8/18	9/9	9/26	10/9	10/21		
< 45	56	172	522	371	261	277	180
45 – 90	132	ND	95	425	190	210	148
90 – 180	164	195	623	2578	528	818	1004
180 – 355	39	123	98	43	301	121	107
355 – 710	62	ND	365	50	112	147	148
710 – 1400	59	ND	263	1006	492	455	408
1400 – 2800	112	331	175	523	321	293	160
> 2800 (w/o LOM)	172	237	326	171	302	242	72
> 2800 (LOM)	1527	2386	3027	982	524	1689	1020

w/o LOM = with LOM removed   LOM = Large organic matter

Analyses of Particulate Pollutant Strengths by Particle Size

The following tables and figures summarize the normalized particulate pollutant strengths from the prior listed data. These are normalized values that can be used to modify the standard pollutant concentration files in WinSLAMM to represent particulate strength concentrations by particle size. The WinSLAMM pollutant files are divided into particulate strength and filtered concentrations. The particulate strength values represent the bulk value occurring rain events, which are generally less than about 200 µm in size. Therefore, the particulate strength values by particle size shown above were normalized by comparing each particle size range by the averages of the <200 µm values (varied between 180 to 250 µm). In some cases (SERDP 2018 2022 metals and PAHs), data were only available between 0.45 and 63 µm, so the normalizing ratios were calculated using that range.

Table 58 is an example calculation showing the normalization for volatile solids. The average volatile solids values for <200 µm (closest here is 180 µm) is 24.1%. Therefore, each of the individual values in each size range were divided by this value to obtain the ratio values shown on the table.

Table 58. Example Normalized Volatile Solids Values by Particle Size Ranges (Cai 2013)

Sieve size range (um)	Volatile Solids (%)	ratio with <200 µm
<45 (Pan)	26	1.08
45-75	25.7	1.07
75-180	20.6	0.85
180-355	19.4	0.80
355-710	26.1	1.08
710-1400	42.7	1.77
1400 - 2800	57.8	2.40
>2800	70.9	2.94
Sticks	81.2	3.37
Waterlogged decomposing leaves	93.2	3.87

Figure 2 shows these ratios for particle size ranges used in WinSLAMM. The values from Table 58 are placed in the size ranges closest to the observed values. A plot of these ratios is also shown on Figure 2 showing how the volatile solids increase for the larger particle sizes, and Figure 3 shows the close relationship between specific gravity and volatile solids (organic content).

WinSLAMM particle size range (um)	volatile solids (Cai 2013)
<1	
1 to 2	
2 to 5	
5 to 10	
10 to 20	
20 to 40	
40 to 50	1.08
50 to 60	1.07
60 to 80	1.07
80 to 100	0.85
100 to 150	0.85
150 to 200	0.85
200 to 300	0.80
300 to 500	1.08
500 to 800	1.08
800 to 1000	1.77
1000 to 2000	1.77
>2000	2.67
Sticks	3.37
Waterlogged decomposing leaves	3.87

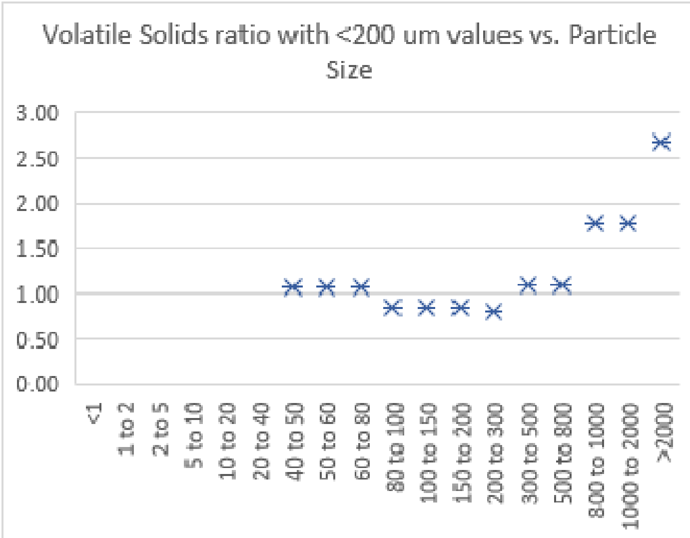


Figure 2. Volatile solids ratios for WinSLAMM particle size ranges.

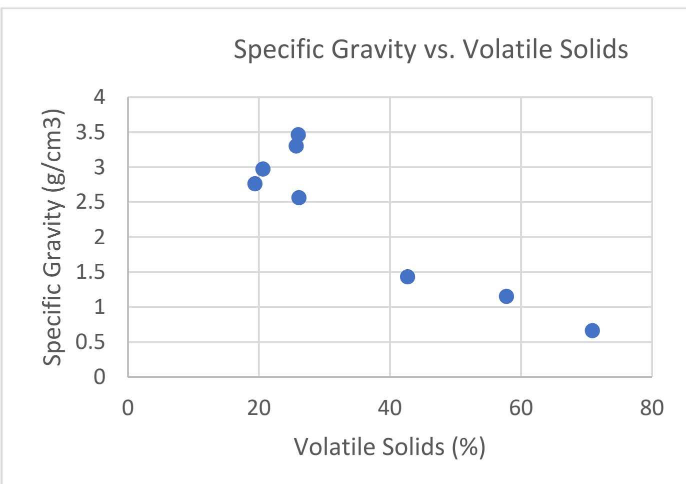


Figure 3. Specific gravity and volatile solids.

These ratios are then used in WinSLAMM to distribute the calibrated gross particulate strength values for the range of particle sizes. In many cases, coefficient of variation values (the ratio of standard deviation to mean) are also shown that illustrate the variability to be expected with these data. Typical COV values range from about 0.7 to 1.3. The particulate strength ratios shown here should be used as a starting point when modeling an area. Locally obtained particulate strength ratio values should always be used when available. Summary tables and associated plots for many constituents are shown in the following subsections.

Specific Gravity

The specific gravity values shown below are not ratios, but the actual values observed for the size ranges. Specific gravity is an important factor when calculating settling rates and therefore particulate removal performance of many stormwater controls.

WinSLAMM particle size range (um)	specific gravity (g/cm3) (Cai 2013)
<1	
1 to 2	
2 to 5	
5 to 10	
10 to 20	
20 to 40	
40 to 50	3.46
50 to 60	3.30
60 to 80	3.30
80 to 100	2.97
100 to 150	2.97
150 to 200	2.76
200 to 300	2.76
300 to 500	2.56
500 to 800	1.43
800 to 1000	1.43
1000 to 2000	1.15
>2000	0.66
Sticks	0.84
Waterlogged decomposing leaves	2.28 (much larger than for recently fallen leaves)

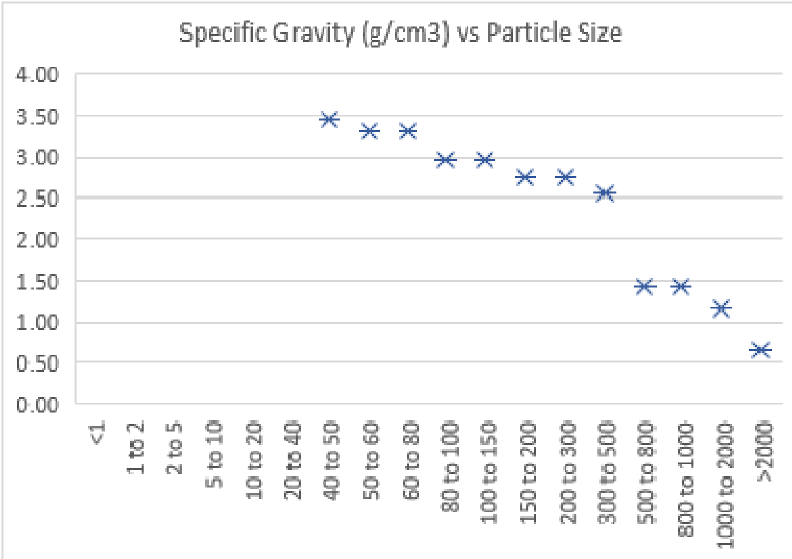


Figure 4. Specific gravity vs. particle sizes.

COD, TOC, and Nutrients

WinSLAMM particle size range (um)	roof and outlet ratio with <250 (Morquecho 2005)	inlet ratio with <250 um (Pitt 1985)	sump ratio with <250 (Khambhammettu 2005)	sump ratio with <180 (Cai 2013)	average COD ratio
<1	1.30				1.30
1 to 2	1.20				1.20
2 to 5	0.66				0.66
5 to 10	0.66				0.66
10 to 20	0.67				0.67
20 to 40	0.67				0.67
40 to 50	0.98			1.32	1.15
50 to 60	0.98	1.26		1.05	1.09
60 to 80	0.98	1.02	1.76	1.05	1.20
80 to 100	0.98	1.02	0.97	0.64	0.90
100 to 150	1.19	1.02	0.97	0.64	0.96
150 to 200		0.72	0.27	0.64	0.54
200 to 300		0.72	0.45	0.80	0.66
300 to 500		0.79	0.45	0.80	0.68
500 to 800		1.10	0.34	0.66	0.70
800 to 1000		1.10	0.22	1.26	0.86
1000 to 2000		1.96	0.22	1.25	1.15
>2000	1.19	2.00	1.49	1.04	1.43
				Sticks	1.28
				Leaves	3.35
				avg COV	0.97

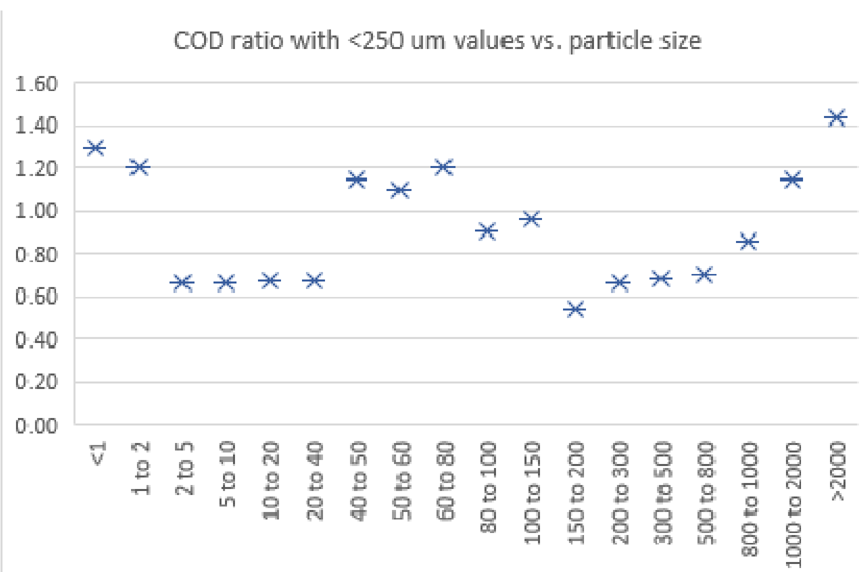


Figure 5. COD particulate strength ratios by size range.

WinSLAMM particle size range (um)	resid and commer avg TOC ratio with <63 (SERDP 2018)
<1	2.20
1 to 2	2.20
2 to 5	2.20
5 to 10	0.29
10 to 20	0.29
20 to 40	0.52
40 to 50	0.52
50 to 60	0.52
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	0.81
avg COV	0.66

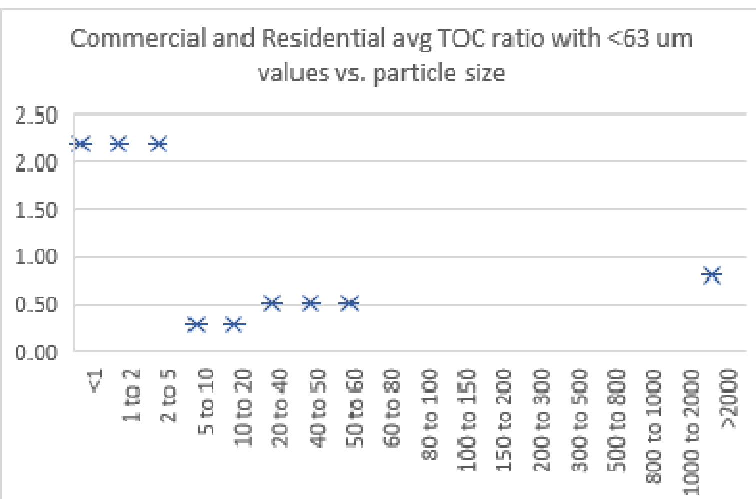


Figure 6. Residential and commercial area TOC particulate strength ratios by size range.

WinSLAMM particle size range (um)	indus avg TOC ratio with <63 (SERDP 2018)
<1	0.95
1 to 2	0.95
2 to 5	0.95
5 to 10	0.63
10 to 20	0.63
20 to 40	1.42
40 to 50	1.42
50 to 60	1.42
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	2.75
avg COV:	0.63

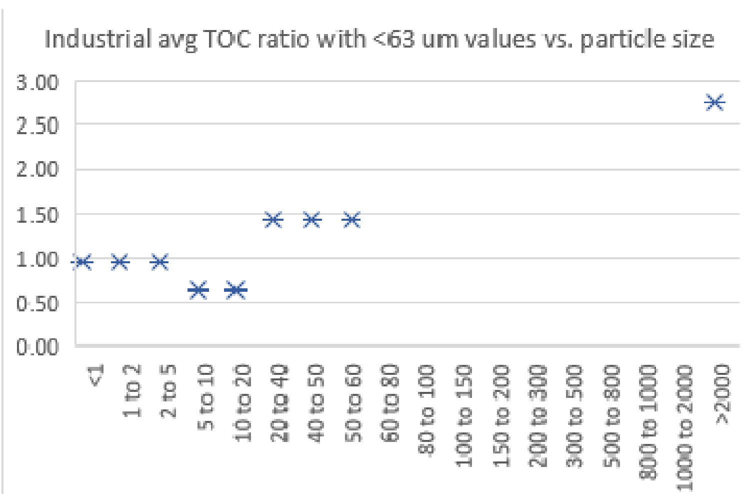


Figure 7. Industrial area TOC particulate strength ratios by size range.

WinSLAMM particle size range (um)	roof and inlet ratio with <250 (Morquecho 2005)	ratio with <250 um (Pitt 1985)	ratio with <250 (Khambhammettu 2005)	ratio with <180 (Cai 2013)	avg TP ratio with <250 um
<1	1.91				1.91
1 to 2	1.68				1.68
2 to 5	0.71				0.71
5 to 10	0.71				0.71
10 to 20	0.81				0.81
20 to 40	0.81				0.81
40 to 50	0.47			1.10	0.78
50 to 60	0.47	1.20		1.33	1.00
60 to 80	0.47	0.94	1.88	1.33	1.16
80 to 100	0.47	0.94	0.85	0.57	0.71
100 to 150	0.42	0.86	0.85	0.57	0.68
150 to 200	0.42	0.86	0.27	0.57	0.53
200 to 300	0.42	0.86	0.27	0.55	0.52
300 to 500	1.31	0.83	0.17	0.50	0.70
500 to 800	1.31	0.75	0.26	0.50	0.70
800 to 1000	1.31	0.75	0.45	0.26	0.69
1000 to 2000	1.31	1.27	0.45	0.51	0.88
>2000	1.31	1.27	0.81	0.21	0.90
				Sticks	0.19
				Leaves	0.21
				avg COV	0.97

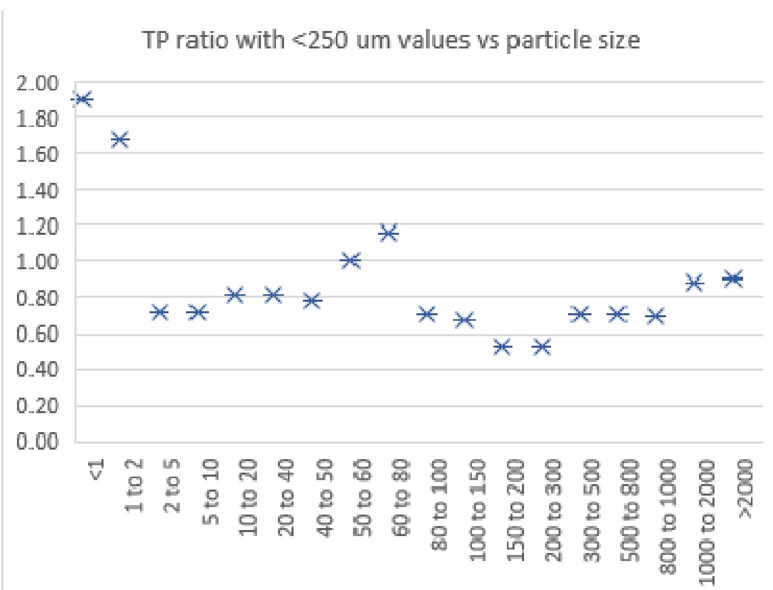


Figure 8. Total phosphorus particulate strength ratios by size range.

WinSLAMM particle size range (um)	ratio with <250 um (Pitt 1985)	ratio with <180 (Cai 2013)	TN ratio with <250 um
<1			
1 to 2			
2 to 5			
5 to 10			
10 to 20			
20 to 40			
40 to 50		1.29	1.29
50 to 60	1.34	0.81	1.07
60 to 80	0.97	0.81	0.89
80 to 100	0.97	0.90	0.93
100 to 150	0.97	0.90	0.93
150 to 200	0.69	0.90	0.79
200 to 300	0.69	0.28	0.49
300 to 500	0.74	0.38	0.56
500 to 800	0.74	0.38	0.56
800 to 1000	0.74	0.91	0.83
1000 to 2000	1.20	1.26	1.23
>2000	1.06	1.29	1.18
		Sticks	1.23
		Leaves	0.85

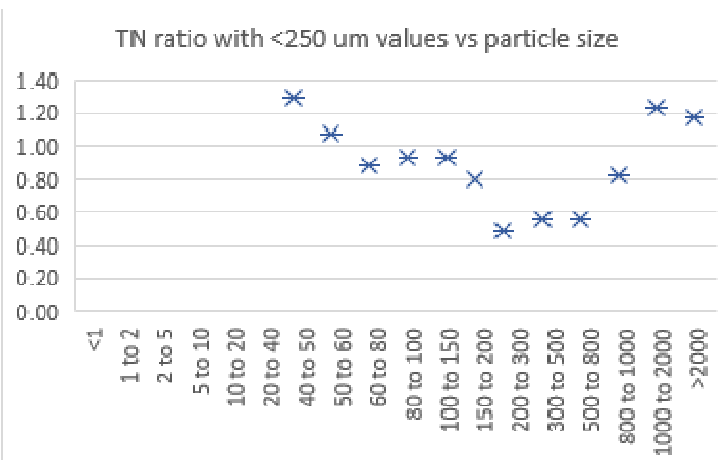


Figure 9. Total nitrogen particulate strength ratios by size range.

Heavy Metals

Cai (2013) also separated leaves and sticks and analyzed these separately from the >2800 um size fraction. These larger sizes are therefore shown separately in the summary tables but are not shown on the plots.

WinSLAMM particle size range (um)	roof and outlet Cd ratio with <250 (Morquecho 2005)	sump Cd ratio with <180 (Cai 2013)	res/com Cd ratio with <63 (SERDP 2018)	avg Cd ratio with <180
<1	0.83			0.83
1 to 2	1.94			1.94
2 to 5	2.12			2.12
5 to 10	2.12		1.16	1.64
10 to 20	0.06		1.16	0.61
20 to 40	0.06		0.84	0.45
40 to 50		0.47	0.84	0.65
50 to 60		0.39	0.84	0.61
60 to 80		0.39	4.84	2.61
80 to 100	0.04	2.14		1.09
100 to 150	0.04	2.14		1.09
150 to 200	0.04	2.14		1.09
200 to 300	0.04			0.04
300 to 500		0.14		0.14
500 to 800		0.16		0.16
800 to 1000		0.16		0.16
1000 to 2000		0.16		0.16
>2000	0.09			
			Leaves	0.41
			overall avg COV	0.87

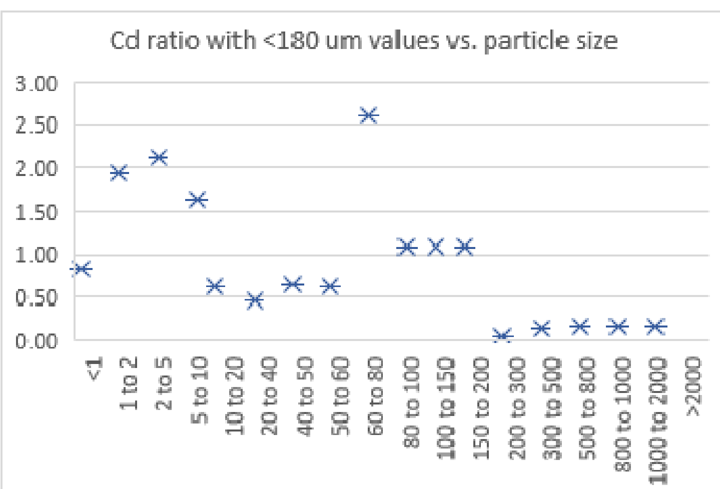


Figure 10. Cadmium particulate strength ratios by size range.

WinSLAMM particle size range (um)	indus Cd ratio with <63 (SERDP 2018)
<1	
1 to 2	
2 to 5	0.44
5 to 10	0.44
10 to 20	0.44
20 to 40	1.56
40 to 50	1.56
50 to 60	1.56
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	40.52
avg COV	1.11

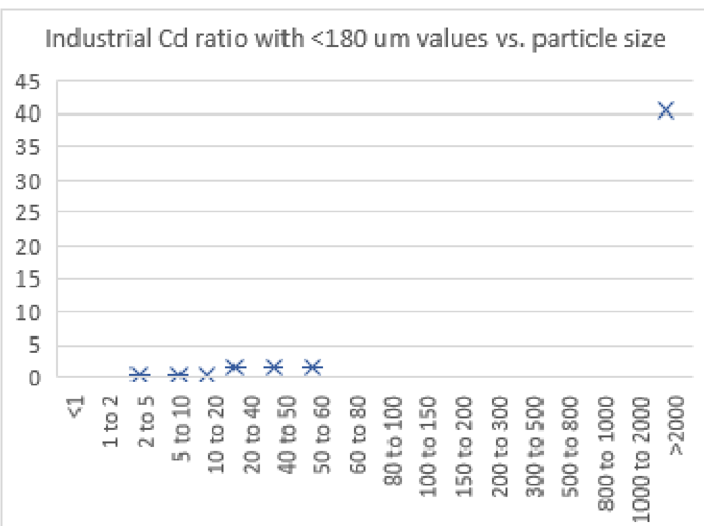


Figure 11. Industrial area cadmium particulate strength ratios by size range.

WinSLAMM particle size range (um)	roof and outlet Cu ratio with <250 (Morquecho 2005)	Sed Cu ratio with <250 (Khambhammettu 2005)	sump Cu ratio with <180 (Cai 2013)	res/com Cu ratio with <63 (SERDP 2018)	avg Cu ratio with <180
<1	3.70			2.08	2.89
1 to 2	0.44			2.08	1.26
2 to 5	0.21			2.08	1.15
5 to 10	0.21			0.61	0.41
10 to 20	0.31			0.61	0.46
20 to 40	0.31			0.31	0.31
40 to 50	0.31		1.22	0.31	0.61
50 to 60	1.33		1.04	0.31	0.90
60 to 80	1.33	1.69	1.04		1.35
80 to 100	1.33	0.89	0.74		0.99
100 to 150	0.02	0.89	0.74		0.55
150 to 200	0.02	0.43	0.74		0.39
200 to 300	0.02	0.43	0.64		0.36
300 to 500		0.30	0.38		0.34
500 to 800		0.20	0.38		0.29
800 to 1000		0.25	0.46		0.35
1000 to 2000		0.25	0.25		0.25
>2000	0.19	0.46	0.08	1.36	0.52
				Sticks	0.13
				Leaves	0.23
				overall avg COV	0.71

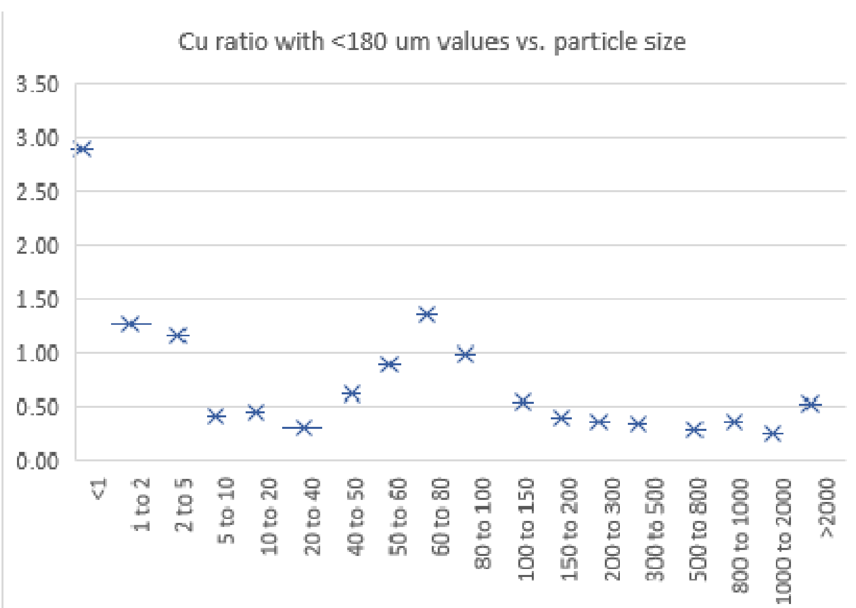


Figure 12. Copper particulate strength ratios by size range.

WinSLAMM particle size range (um)	indus Cu ratio with <63 (SERDP 2018)
<1	1.64
1 to 2	1.64
2 to 5	1.64
5 to 10	1.64
10 to 20	1.64
20 to 40	1.21
40 to 50	1.21
50 to 60	1.21
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	5.91
overall avg COV	0.94

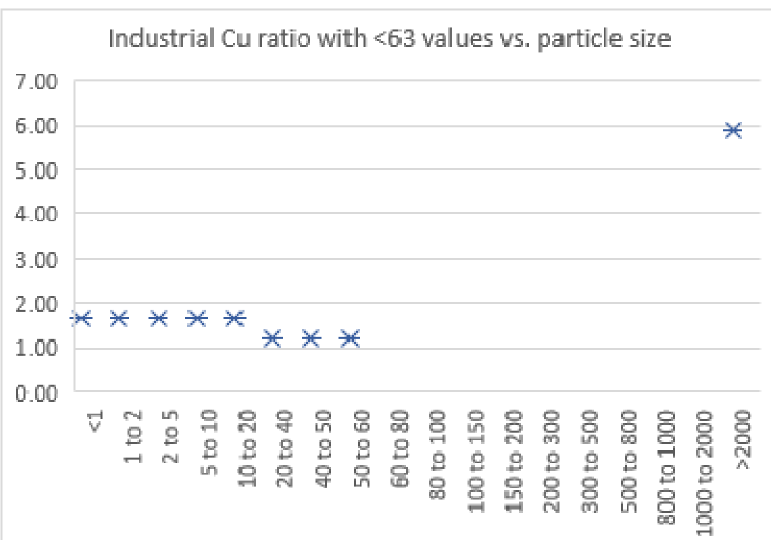


Figure 13. Industrial area copper particulate strength ratios by size range.

WinSLAMM particle size range (um)	roof and outlet Pb ratio with <250 (Morquecho 2005)	inlet Pb ratio with <250 (Pitt 1985)	sed Pb ratio with <250 (Khambhammettu 2005)	sump Pb ratio with <180 (Cai 2013)	res/com Pb ratio with <63 (SERDP 2018)	overall avg Pb ratio with <250
<1	4.42				1.71	3.07
1 to 2	0.79				1.71	1.25
2 to 5	0.16				0.87	0.51
5 to 10	0.16				0.87	0.51
10 to 20	0.24				0.87	0.55
20 to 40	0.24				0.42	0.33
40 to 50	0.32			1.05	0.42	0.60
50 to 60	0.32	1.34		1.23	0.42	0.83
60 to 80	0.32	0.97	1.30	1.23	0.42	0.85
80 to 100	0.32	0.97	1.14	0.72		0.79
100 to 150	0.07	0.69	1.14	0.72		0.65
150 to 200	0.07	0.69	0.56	0.72		0.51
200 to 300		0.69	0.46	0.30		0.48
300 to 500		0.62	0.38	0.32		0.44
500 to 800		0.60	0.38	0.32		0.43
800 to 1000		0.60	0.41	0.31		0.44
1000 to 2000		0.60	0.41	0.12		0.38
>2000	0.62	0.43	0.71	0.04	1.96	0.75
					Sticks	0.04
					Leaves	0.09
					avg COV	0.93

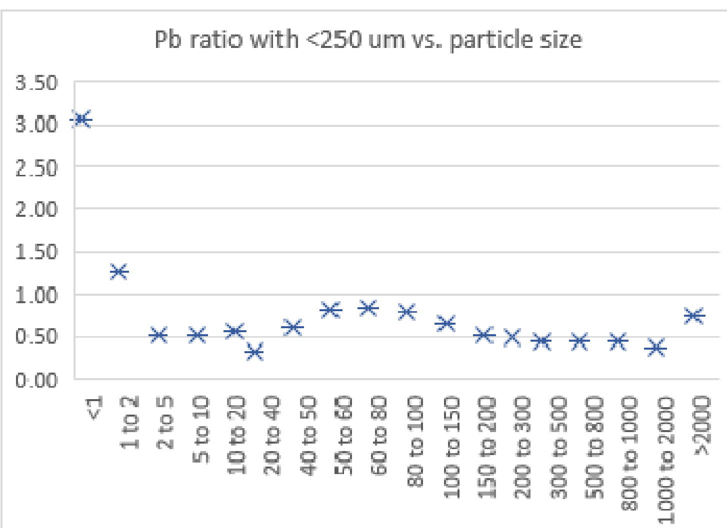


Figure 14. Lead particulate strength ratios by size range.

WinSLAMM particle size range (um)	indus Pb ratio with <63 (SERDP 2018)
<1	0.95
1 to 2	0.95
2 to 5	0.95
5 to 10	0.57
10 to 20	0.57
20 to 40	1.48
40 to 50	1.48
50 to 60	1.48
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	3.04
avg COV	1.00

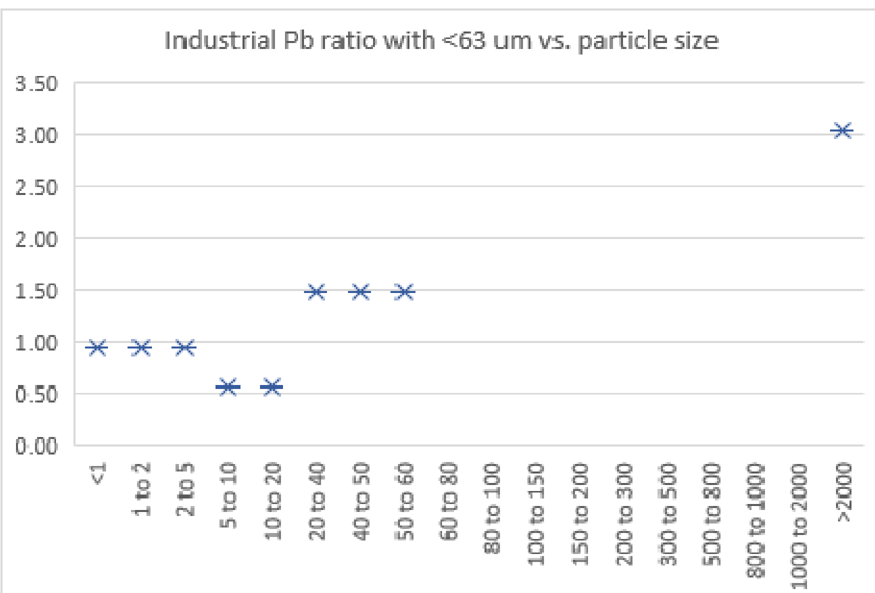


Figure 15. Industrial area lead particulate strength ratios by size range.

WinSLAMM particle size range (um)	roof and outlet Zn ratio with <250 (Morquecho 2005)	inlet Zn ratio with <250 (Pitt 1985)	sed Zn ratio with <250 (Khambhammettu 2005)	sump Zn ratio with <180 (Cai 2013)	res/com Zn ratio with <63 (SERDP 2018)	overall avg Zn ratio with <250
<1	3.98				1.79	2.89
1 to 2	0.09				1.79	0.94
2 to 5	0.32				1.79	1.05
5 to 10	0.32				0.65	0.48
10 to 20	0.56				0.65	0.61
20 to 40	0.56				0.55	0.56
40 to 50	0.56	1.30		1.42	0.55	0.96
50 to 60		1.04		1.14	0.55	0.91
60 to 80		1.04	1.44	1.14		1.21
80 to 100		1.04	1.03	0.44		0.84
100 to 150	0.05	1.04	1.03	0.44		0.64
150 to 200	0.05	0.65	0.54	0.44		0.42
200 to 300		0.65	0.54	0.41		0.53
300 to 500		0.65	0.58	0.41		0.55
500 to 800		0.65	0.29	0.41		0.45
800 to 1000		0.65	0.44	0.32		0.47
1000 to 2000		0.75	0.44	0.18		0.46
>2000	0.31	0.55	0.54		3.43	1.21
					Sticks	0.27
					Leaves	0.16
					avg COV	0.77

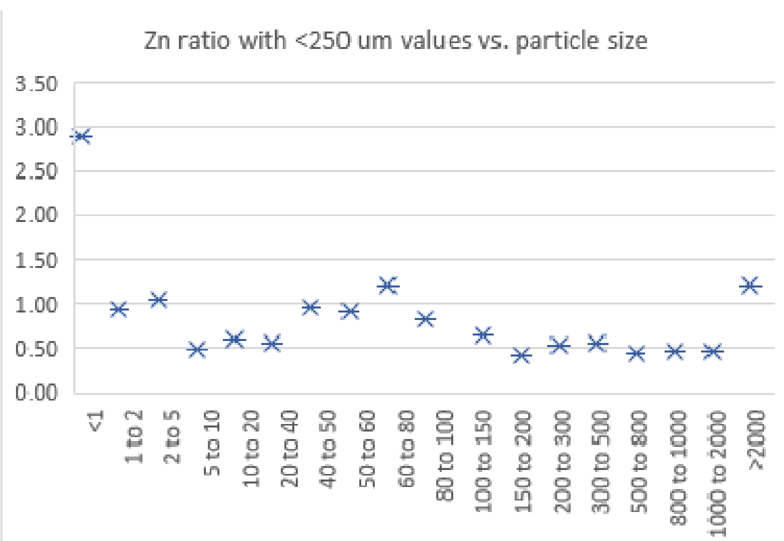


Figure 16. Zinc particulate strength ratios by size range.

WinSLAMM particle size range (um)	indus Zn ratio with <63 (SERDP 2018)
<1	1.59
1 to 2	1.59
2 to 5	1.59
5 to 10	1.23
10 to 20	1.23
20 to 40	1.23
40 to 50	1.23
50 to 60	1.23
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	7.97
avg COV	0.63

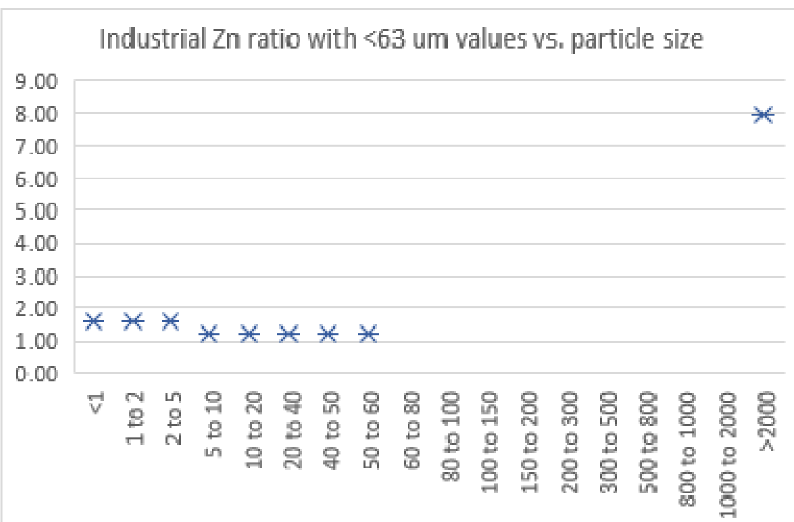


Figure 17. Industrial area zinc particulate strength ratios by size range.

WinSLAMM particle range (um)	Sed Cr ratio with <250 (Khambhammettu 2005)	sump Cr ratio with <180 (Cai 2013)	overall avg Cr ratio with <250
<1			
1 to 2			
2 to 5			
5 to 10			
10 to 20			
20 to 40			
40 to 50		1.26	1.26
50 to 60		1.09	1.09
60 to 80	1.36	1.09	1.23
80 to 100	1.12	0.65	0.89
100 to 150	1.12	0.65	0.89
150 to 200	0.52	0.65	0.58
200 to 300	0.43	0.68	0.56
300 to 500	0.24	0.78	0.51
500 to 800	0.24	0.78	0.51
800 to 1000	0.44	1.29	0.87
1000 to 2000	0.44	0.48	0.46
>2000	0.64	0.48	0.56
		Sticks	0.11
		Leaves	0.19

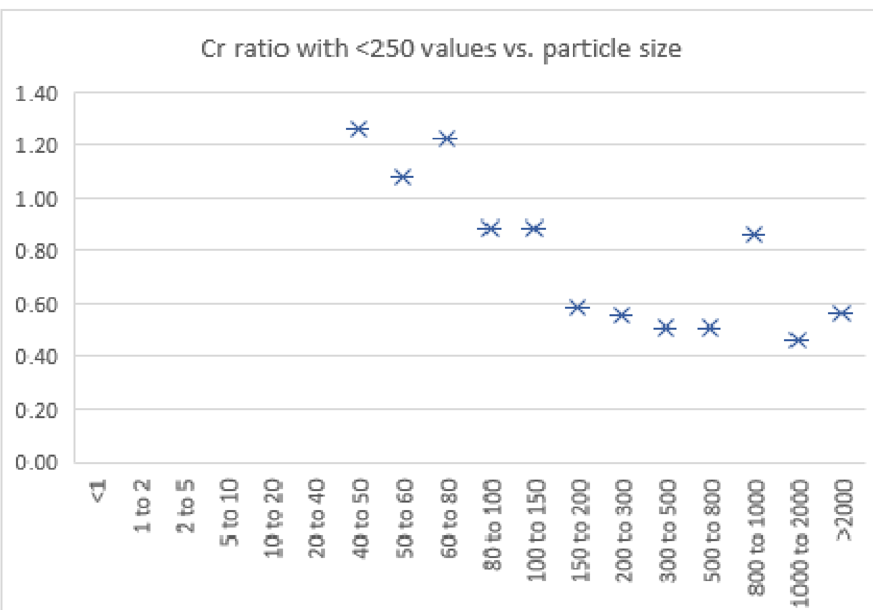


Figure 18. Chromium particulate strength ratios by size range.

WinSLAMM particle range (um)	Sed Fe ratio with <250 (Khambhammettu 2005)
<1	
1 to 2	
2 to 5	
5 to 10	
10 to 20	
20 to 40	
40 to 50	
50 to 60	
60 to 80	1.29
80 to 100	1.06
100 to 150	1.06
150 to 200	0.64
200 to 300	0.60
300 to 500	0.60
500 to 800	0.49
800 to 1000	0.87
1000 to 2000	0.87
>2000	1.22

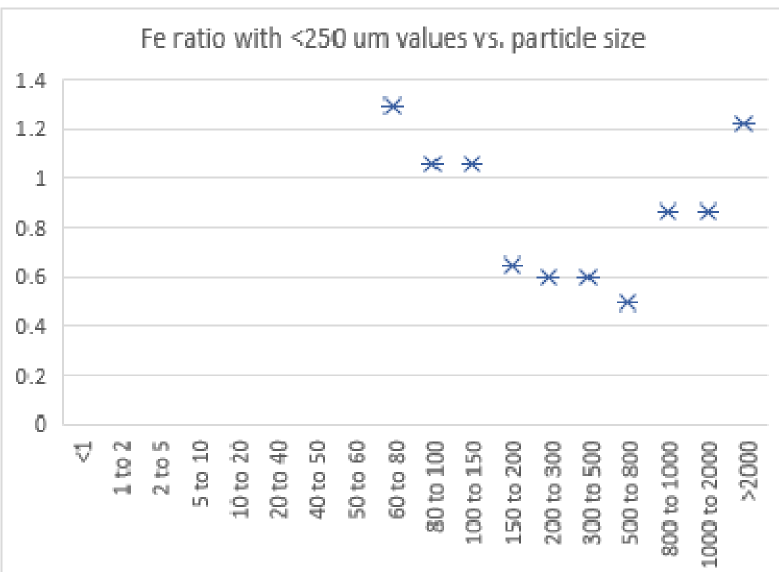


Figure 19. Iron particulate strength ratios by size range.

WinSLAMM particle range (um)	res/com Hg ratio with <63 (SERDP 2018)
<1	0.49
1 to 2	0.49
2 to 5	0.49
5 to 10	1.58
10 to 20	1.58
20 to 40	0.93
40 to 50	0.93
50 to 60	0.93
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	3.94
avg COV	0.63

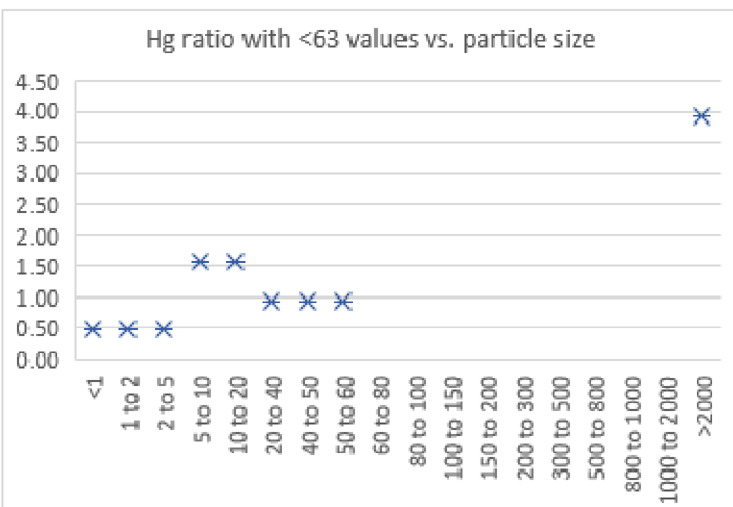


Figure 20. Mercury particulate strength ratios by size range.

WinSLAMM particle range (um)	indus Hg ratio with <63 (SERDP 2018)
<1	0.69
1 to 2	0.69
2 to 5	0.69
5 to 10	0.38
10 to 20	0.38
20 to 40	1.93
40 to 50	1.93
50 to 60	1.93
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	6.46
avg COV	0.98

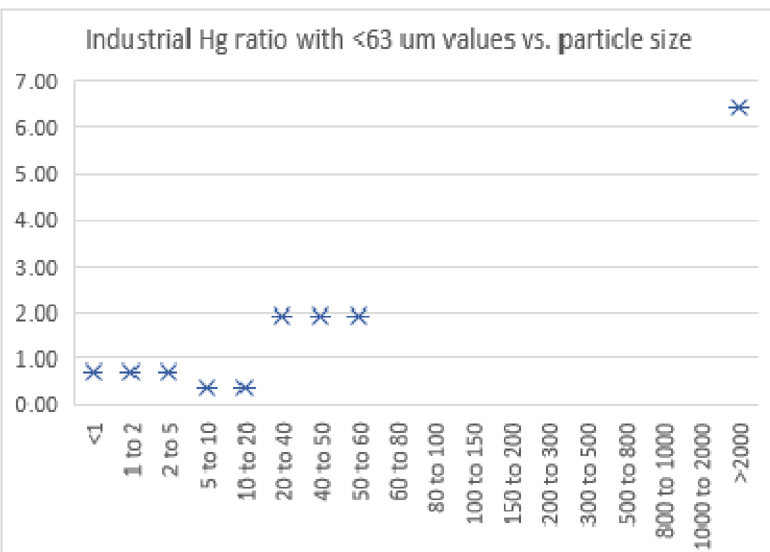


Figure 21. Industrial area mercury particulate strength ratios by size range.

WinSLAMM particle range (um)	res/com Ni ratio with <63 (SERDP 2018)
<1	1.82
1 to 2	1.82
2 to 5	1.82
5 to 10	0.75
10 to 20	0.75
20 to 40	0.43
40 to 50	0.43
50 to 60	0.43
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	1.95
avg COV	0.89

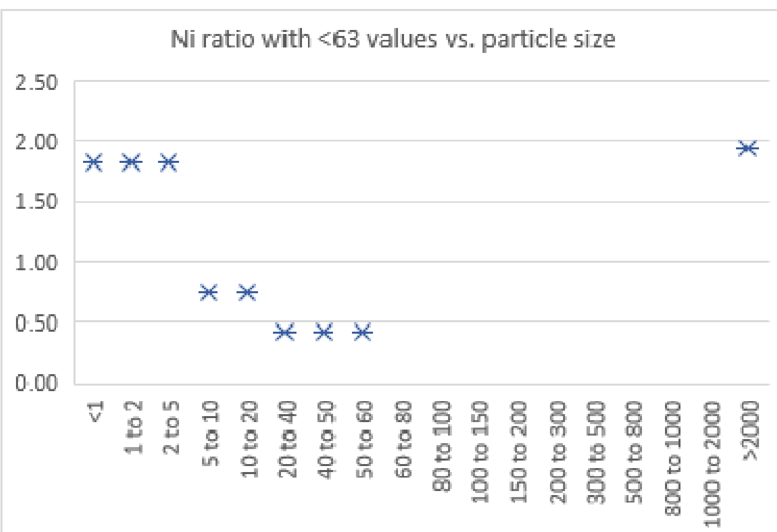


Figure 22. Nickel particulate strength ratios by size range.

WinSLAMM particle range (um)	indus Ni ratio with <63 (SERDP 2018)
<1	0.43
1 to 2	0.43
2 to 5	0.43
5 to 10	0.17
10 to 20	0.17
20 to 40	2.40
40 to 50	2.40
50 to 60	2.40
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	6.77
avg COV	0.51

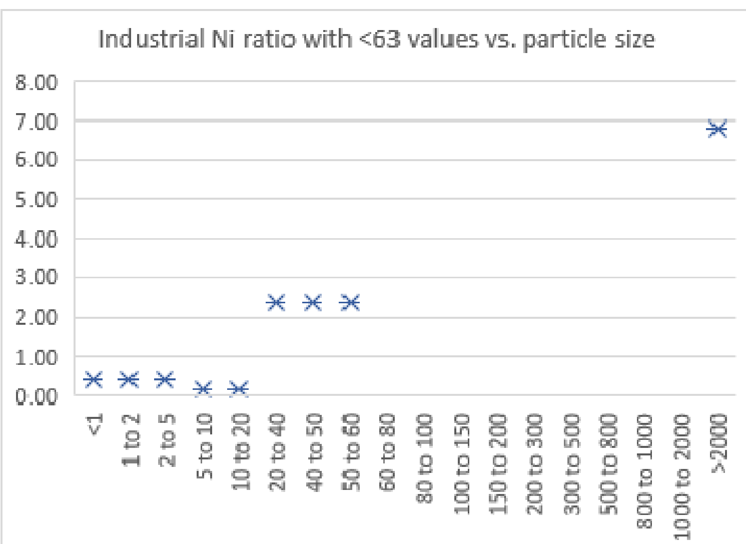


Figure 23. Industrial area nickel particulate strength ratios by size range.

WinSLAMM particle range (um)	res/com As ratio with <63 (SERDP 2018)
<1	1.73
1 to 2	1.73
2 to 5	1.73
5 to 10	0.77
10 to 20	0.77
20 to 40	0.50
40 to 50	0.50
50 to 60	0.50
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	12.82
avg COV	0.73

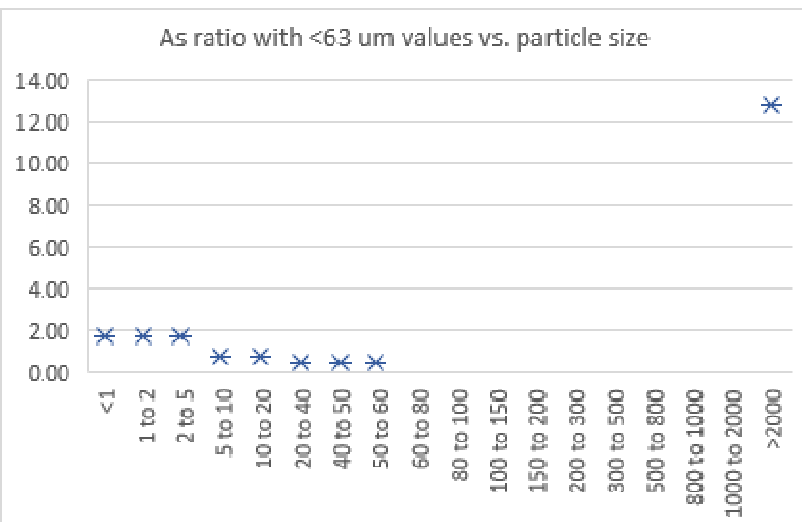


Figure 24. Arsenic particulate strength ratios by size range.

WinSLAMM particle range (um)	indus As ratio with <63 (SERDP 2018)
<1	
1 to 2	
2 to 5	0.03
5 to 10	0.03
10 to 20	0.03
20 to 40	1.97
40 to 50	1.97
50 to 60	1.97
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	4.41
avg COV	0.69

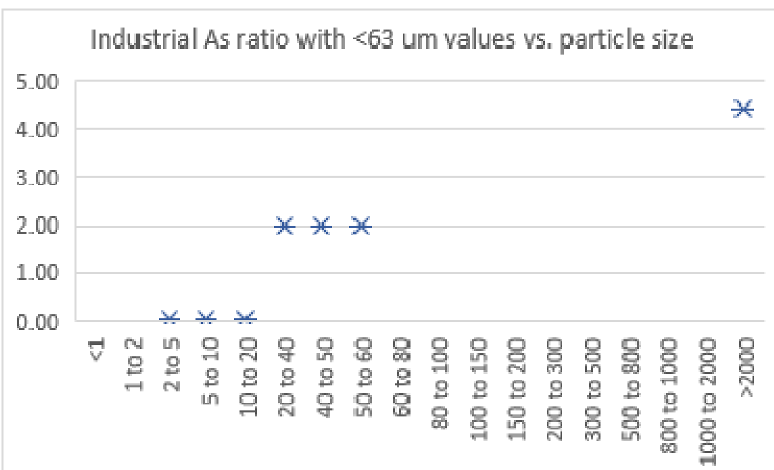


Figure 24. Industrial area nickel particulate strength ratios by size range.

PAHs

Bathi (2008) separated the large organic material (LOM) from the >2800 µm size fraction. These are shown separately on the tables but are not plotted on the graphs. Also, during the SERDP (2018 and 2022) analyses, the largest particle size analyzed separately was 63 µm, with all larger material grouped as >63 µm. The >63 µm are expected to represent the largest particles collected and not a broad distribution of sizes, based on the high particulate strength values and ratios. It is expected that these large particles are large organic material (LOM), such as leaf material or oily debris. The organic leaf material (expected in most urban areas) has a great attraction to PAHs, and the oily debris (expected in industrial areas) have high concentrations of the PAHs. These are therefore shown separately on the tables but are not included on the graphs. Limited PAH detections for the SERDP (2018) samples did not allow those samples to be separated by particle size, as was possible for the previously described heavy metal results.

WinSLAMM particle range (um)	Naphthalene ratio with <63 (SERDP 2018)	Naphthalene ratio with <200 (Bathi 2008)	avg Naphthalene ratio with <200
<1	1.45		1.45
1 to 2	1.45		1.45
2 to 5	0.23		0.23
5 to 10	0.23		0.23
10 to 20	0.23		0.23
20 to 40	1.32		1.32
40 to 50	1.32	1.28	1.30
50 to 60	1.32	0.89	1.11
60 to 80		0.89	0.89
80 to 100		0.89	0.89
100 to 150		0.82	0.82
150 to 200		0.82	0.82
200 to 300		0.47	0.47
300 to 500		0.63	0.63
500 to 800		0.63	0.63
800 to 1000		3.98	3.98
1000 to 2000		3.98	3.98
>2000		4.49	4.49
LOM and oily debris	22.68	13.27	17.98
		avg COV	1.28

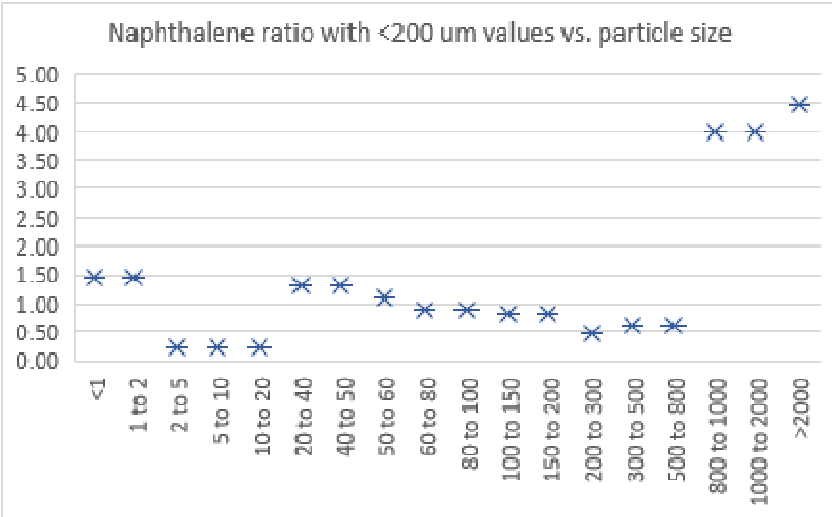


Figure 26. Naphthalene particulate strength ratios by size range.

WinSLAMM particle range (um)	Fluorene ratio with <63 (SERDP 2018)	Fluorene ratio with <200 (Bathi 2008)	avg Fluorene ratio with <200
<1	0.88		0.88
1 to 2	0.88		0.88
2 to 5	0.88		0.88
5 to 10	0.50		0.50
10 to 20	0.50		0.50
20 to 40	1.62		1.62
40 to 50	1.62	1.16	1.39
50 to 60	1.62	0.85	1.24
60 to 80		0.85	0.85
80 to 100		0.85	0.85
100 to 150		0.99	0.99
150 to 200		0.99	0.99
200 to 300		0.56	0.56
300 to 500		0.62	0.62
500 to 800		0.62	0.62
800 to 1000		0.90	0.90
1000 to 2000		0.90	0.90
>2000		1.15	1.15
LOM and oily debris	1.04	7.97	4.51
		avg COV	1.47

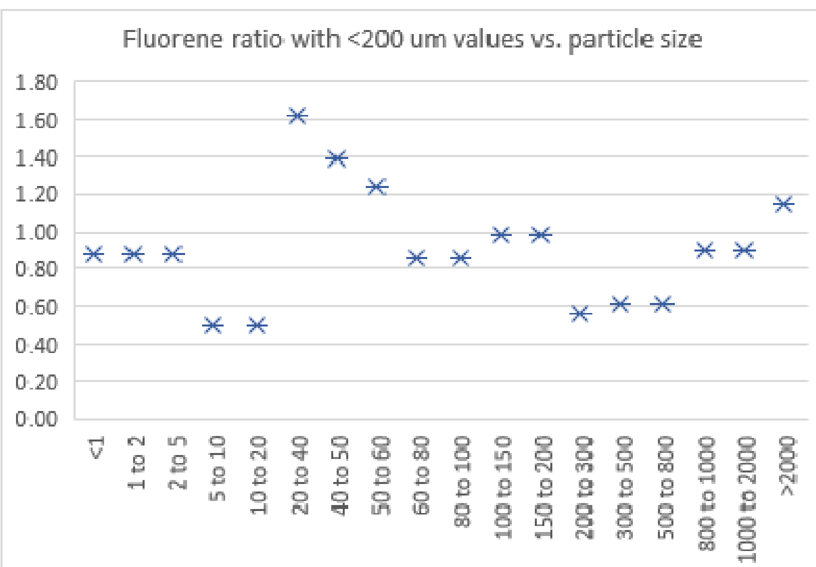


Figure 27. Fluorene particulate strength ratios by size range.

WinSLAMM particle range (um)	Acenaphthylene ratio with <63 (SERDP 2018)
<1	2.42
1 to 2	2.42
2 to 5	2.42
5 to 10	0.06
10 to 20	0.06
20 to 40	0.52
40 to 50	0.52
50 to 60	0.52
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	
LOM and oily debris	4.30

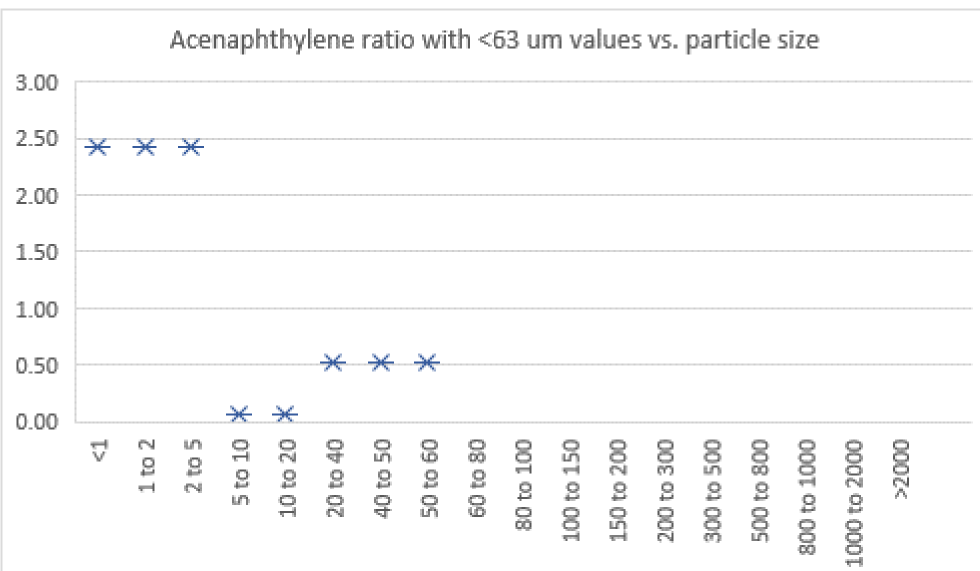


Figure 28. Acenaphthylene particulate strength ratios by size range.

WinSLAMM particle range (um)	Phenanthrene ratio with <63 (SERDP 2018)	Phenanthrene ratio with <200 (Bathi 2008)	avg Phenanthrene ratio with <200
<1	0.22		0.22
1 to 2	0.22		0.22
2 to 5	0.22		0.22
5 to 10	0.96		0.96
10 to 20	0.96		0.96
20 to 40	1.83		1.83
40 to 50	1.83	1.31	1.57
50 to 60	1.83	1.02	1.42
60 to 80		1.02	1.02
80 to 100		1.02	1.02
100 to 150		0.66	0.66
150 to 200		0.66	0.66
200 to 300		0.47	0.47
300 to 500		0.53	0.53
500 to 800		0.53	0.53
800 to 1000		0.65	0.65
1000 to 2000		0.65	0.65
>2000		0.96	0.96
LOM and oily debris	32.64	9.98	21.31
		avg COV	1.23

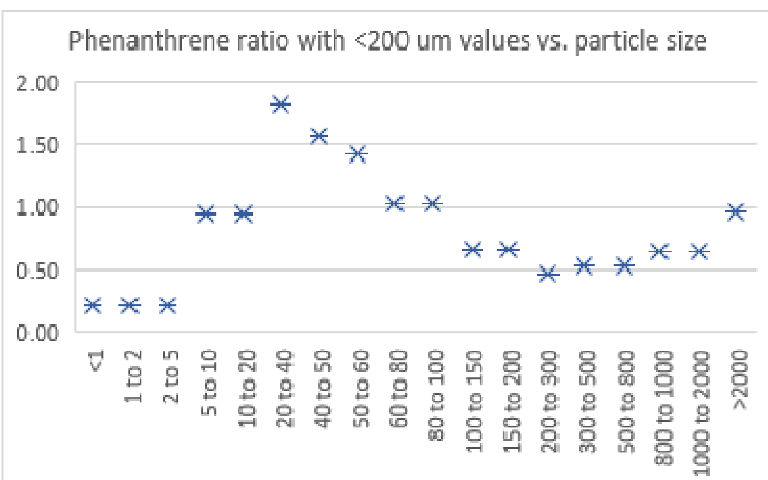


Figure 29. Phenanthrene particulate strength ratios by size range.

WinSLAMM particle range (um)	Anthracene ratio with <63 (SERDP 2018)	Anthracene ratio with <200 (Bathi 2008)	avg Anthracene ratio with <200
<1	0.31		0.31
1 to 2	0.31		0.31
2 to 5	0.31		0.31
5 to 10	0.25		0.25
10 to 20	0.25		0.25
20 to 40	2.44		2.44
40 to 50	2.44	1.21	1.82
50 to 60	2.44	0.99	1.71
60 to 80		0.99	0.99
80 to 100		0.99	0.99
100 to 150		0.80	0.80
150 to 200		0.80	0.80
200 to 300		0.53	0.53
300 to 500		0.62	0.62
500 to 800		0.62	0.62
800 to 1000		1.21	1.21
1000 to 2000		1.21	1.21
>2000		1.21	1.21
LOM and oily debris	43.76	7.71	7.71
		avg COV	1.28

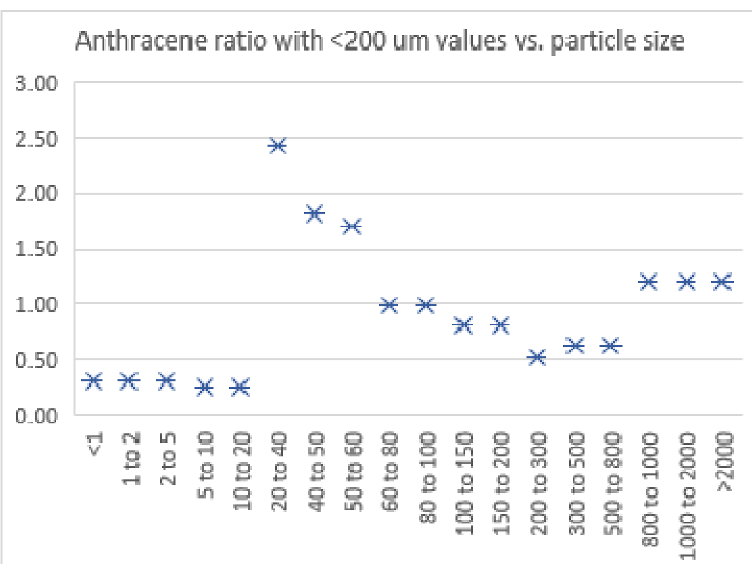


Figure 30. Anthracene particulate strength ratios by size range.

WinSLAMM particle range (um)	Fluoranthene ratio with <63 (SERDP 2018)	Fluoranthene ratio with <200 (Bathi 2008)	avg Fluoranthene ratio with <200
<1	1.60		1.60
1 to 2	1.60		1.60
2 to 5	1.60		1.60
5 to 10	0.25		0.25
10 to 20	0.25		0.25
20 to 40	1.15		1.15
40 to 50	1.15	1.21	1.18
50 to 60	1.15	1.15	1.15
60 to 80		1.15	1.15
80 to 100		1.15	1.15
100 to 150		0.64	0.64
150 to 200		0.64	0.64
200 to 300		0.37	0.37
300 to 500		0.46	0.46
500 to 800		0.46	0.46
800 to 1000		0.48	0.48
1000 to 2000		0.48	0.48
>2000		0.39	0.39
LOM and oily debris	24.52	2.80	13.66
		avg COV	1.78

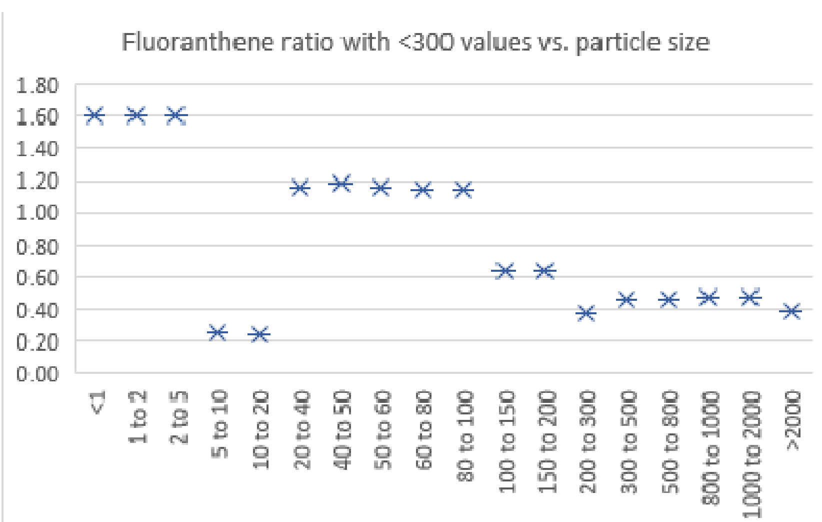


Figure 31. Fluoranthene particulate strength ratios by size range.

WinSLAMM particle range (um)	Pyrene ratio with <63 (SERDP 2018)	Pyrene ratio with <200 (Bathi 2008)	avg Pyrene ratio with <200
<1	1.63		1.63
1 to 2	1.63		1.63
2 to 5	1.63		1.63
5 to 10	0.52		0.52
10 to 20	0.52		0.52
20 to 40	0.86		0.86
40 to 50	0.86	1.24	1.05
50 to 60	0.86	0.98	0.92
60 to 80		0.98	0.98
80 to 100		0.78	0.78
100 to 150		0.78	0.78
150 to 200		0.78	0.78
200 to 300		0.33	0.33
300 to 500		0.45	0.45
500 to 800		0.45	0.45
800 to 1000		0.39	0.39
1000 to 2000		0.39	0.39
>2000		0.35	0.35
LOM and oily debris	26.06	3.89	14.97
		avg COV	1.18

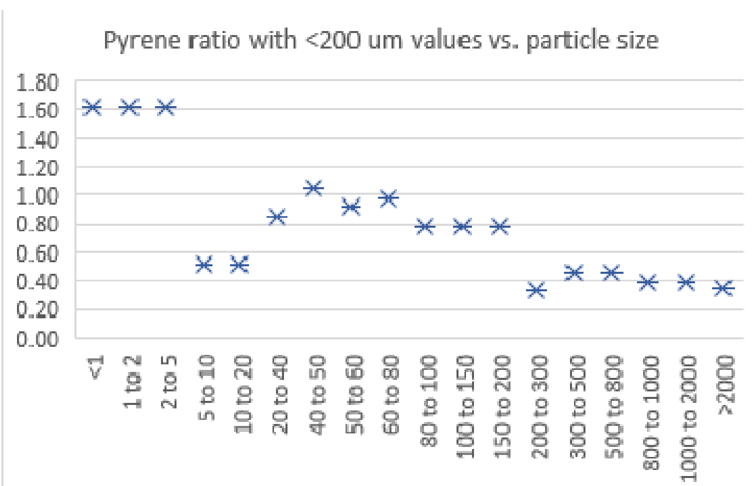


Figure 32. Pyrene particulate strength ratios by size range.

WinSLAMM particle range (um)	Chrysene ratio with <63 (SERDP 2018)	Chrysene ratio with <200 (Bathi 2008)	avg Chrysene ratio with <200
<1	1.37		1.37
1 to 2	1.37		1.37
2 to 5	1.37		1.37
5 to 10	0.53		0.53
10 to 20	0.53		0.53
20 to 40	1.10		1.10
40 to 50	1.10	1.14	1.12
50 to 60	1.10	1.16	1.13
60 to 80		1.16	1.16
80 to 100		0.70	0.70
100 to 150		0.70	0.70
150 to 200		0.70	0.70
200 to 300		0.39	0.39
300 to 500		0.53	0.53
500 to 800		0.53	0.53
800 to 1000		0.36	0.36
1000 to 2000		0.36	0.36
>2000		0.45	0.45
LOM and oily debris	18.96	3.49	11.23
		avg COV	1.12

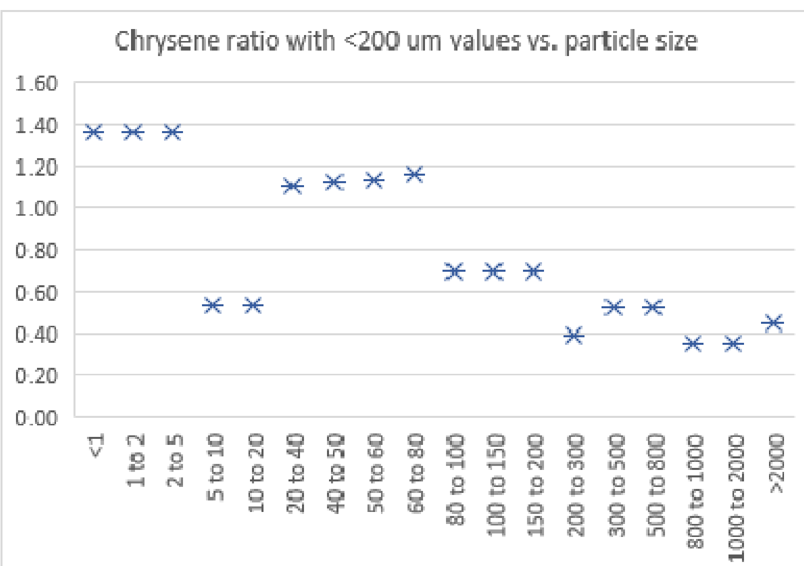


Figure 33. Chrysene particulate strength ratios by size range.

WinSLAMM particle range (um)	Benzo(a)anthracene ratio with <63 (SERDP 2018)	Benzo(a)anthracene ratio with <200 (Bathi 2008)	avg Benzo(a)anthracene ratio with <200
<1	1.40		1.40
1 to 2	1.40		1.40
2 to 5	1.40		1.40
5 to 10	0.57		0.57
10 to 20	0.57		0.57
20 to 40	1.03		1.03
40 to 50	1.03	1.28	1.15
50 to 60	1.03	1.04	1.03
60 to 80		1.04	1.04
80 to 100		1.04	1.04
100 to 150		0.69	0.69
150 to 200		0.69	0.69
200 to 300		0.43	0.43
300 to 500		0.57	0.57
500 to 800		0.57	0.57
800 to 1000		0.42	0.42
1000 to 2000		0.42	0.42
>2000		0.70	0.70
LOM and oily debris	17.95	5.51	11.73
		avg COV	1.42

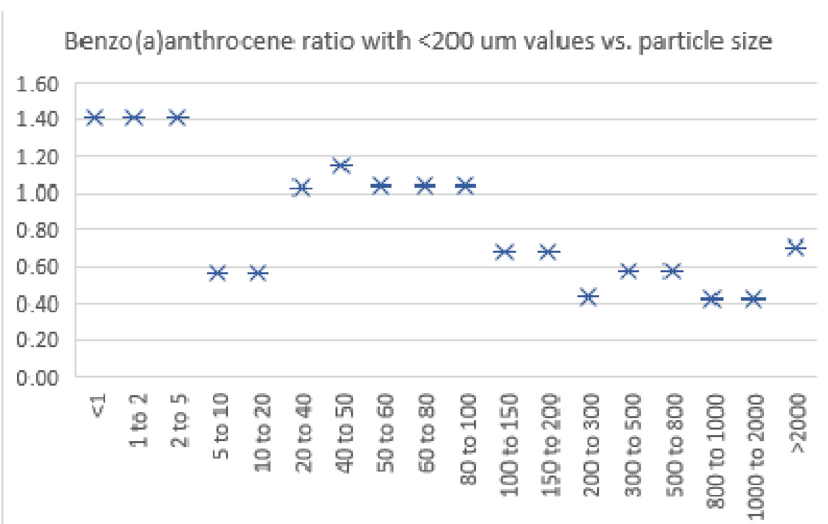


Figure 34. Benzo(a)anthracene particulate strength ratios by size range.

WinSLAMM particle range (um)	Benzo(b)fluoranthene ratio with <63 (SERDP 2018)	Benzo(b)fluoranthene ratio with <200 (Bathi 2008)	avg Benzo(b)fluoranthene ratio with <200
<1	1.40		1.40
1 to 2	1.40		1.40
2 to 5	1.40		1.40
5 to 10	0.48		0.48
10 to 20	0.48		0.48
20 to 40	1.13		1.13
40 to 50	1.13	1.22	1.17
50 to 60	1.13	1.05	1.09
60 to 80		1.05	1.05
80 to 100		1.05	1.05
100 to 150		0.73	0.73
150 to 200		0.73	0.73
200 to 300		0.82	0.82
300 to 500		0.46	0.46
500 to 800		0.46	0.46
800 to 1000		0.64	0.64
1000 to 2000		0.64	0.64
>2000		0.72	0.72
LOM and oily debris	14.39	4.43	9.41
		avg COV	1.45

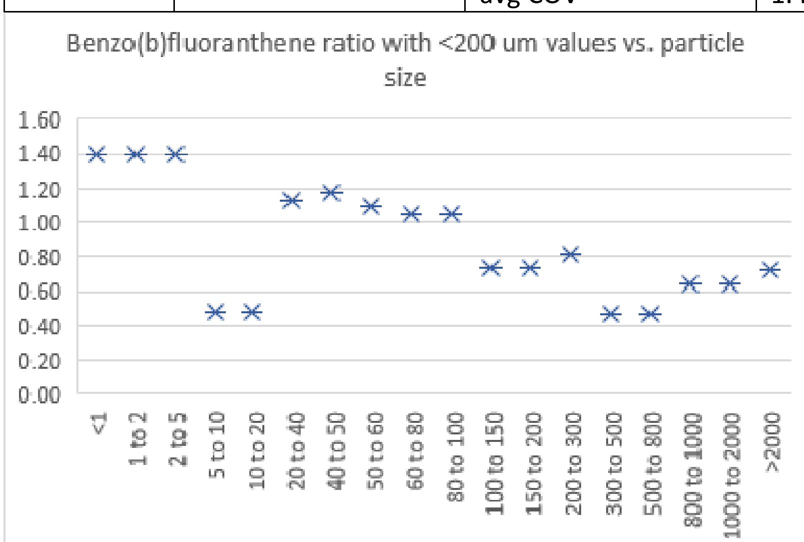


Figure 35. Benzo(b)fluoranthene particulate strength ratios by size range.

WinSLAMM particle range (um)	Benzo(k)fluoranthene ratio with <63 (SERDP 2018)
<1	1.37
1 to 2	1.37
2 to 5	1.37
5 to 10	0.49
10 to 20	0.49
20 to 40	1.14
40 to 50	1.14
50 to 60	1.14
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	
LOM and oily debris	14.26
avg COV	1.57

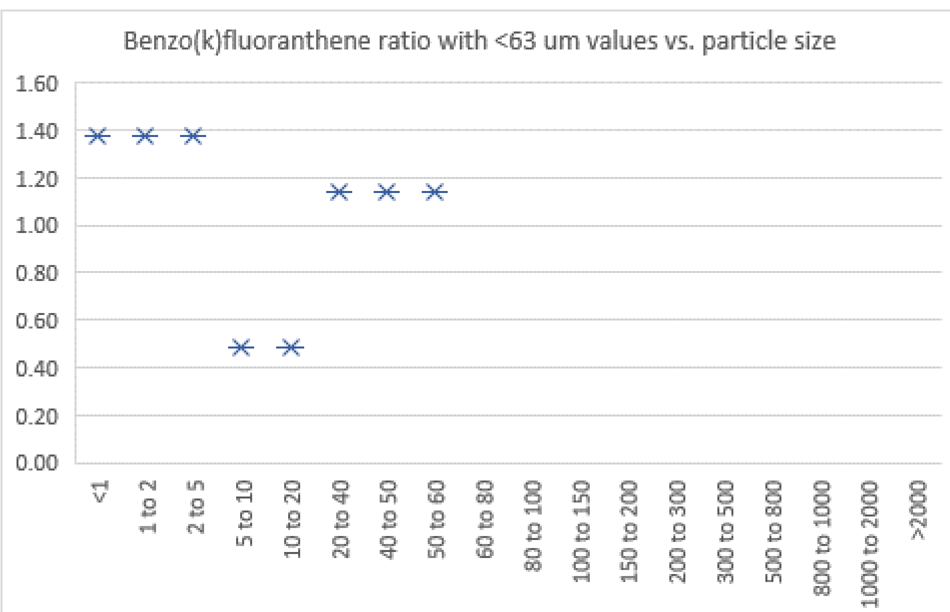


Figure 36. Benzo(k)fluoranthene particulate strength ratios by size range.

WinSLAMM particle range (um)	Benzo(a)pyrene ratio with <63 (SERDP 2018)	Benzo(a)pyrene ratio with <200 (Bathi 2008)	avg Benzo(a)pyrene ratio with <200
<1	1.33		1.33
1 to 2	1.33		1.33
2 to 5	1.33		1.33
5 to 10	0.48		0.48
10 to 20	0.48		0.48
20 to 40	1.19		1.19
40 to 50	1.19	1.21	1.20
50 to 60	1.19	1.25	1.22
60 to 80		1.25	1.25
80 to 100		1.25	1.25
100 to 150		0.54	0.54
150 to 200		0.54	0.54
200 to 300		0.36	0.36
300 to 500		0.28	0.28
500 to 800		0.28	0.28
800 to 1000		0.39	0.39
1000 to 2000		0.39	0.39
>2000		0.62	0.62
LOM and oily debris	11.94	1.91	6.93
		avg COV	1.52

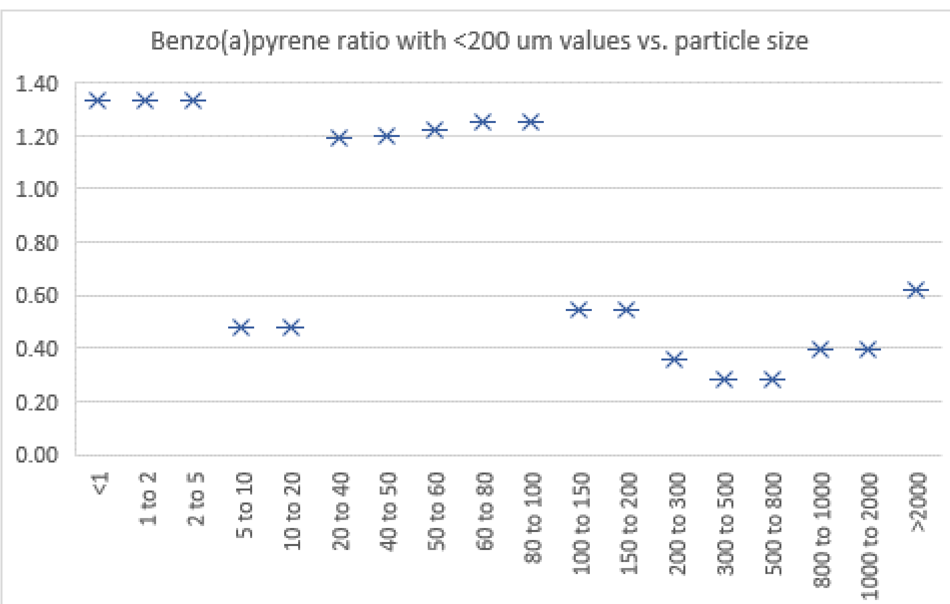


Figure 37. Benzo(a)pyrene particulate strength ratios by size range.

WinSLAMM particle range (um)	Dibenzo(a,h)anthracene ratio with <63 (SERDP 2018)	Dibenzo(a,h)anthracene ratio with <200 (Bathi 2008)	avg Dibenzo(a,h)anthracene ratio with <200
<1	0.94		0.94
1 to 2	0.94		0.94
2 to 5	0.94		0.94
5 to 10	0.55		0.55
10 to 20	0.55		0.55
20 to 40	1.51		1.51
40 to 50	1.51	1.39	1.45
50 to 60	1.51	0.87	1.19
60 to 80		0.87	0.87
80 to 100		0.87	0.87
100 to 150		0.74	0.74
150 to 200		0.74	0.74
200 to 300		0.30	0.30
300 to 500		0.39	0.39
500 to 800		0.39	0.39
800 to 1000		0.77	0.77
1000 to 2000		0.77	0.77
>2000		0.62	0.62
LOM and oily debris	27.99	1.64	14.82
		avg COV	1.48

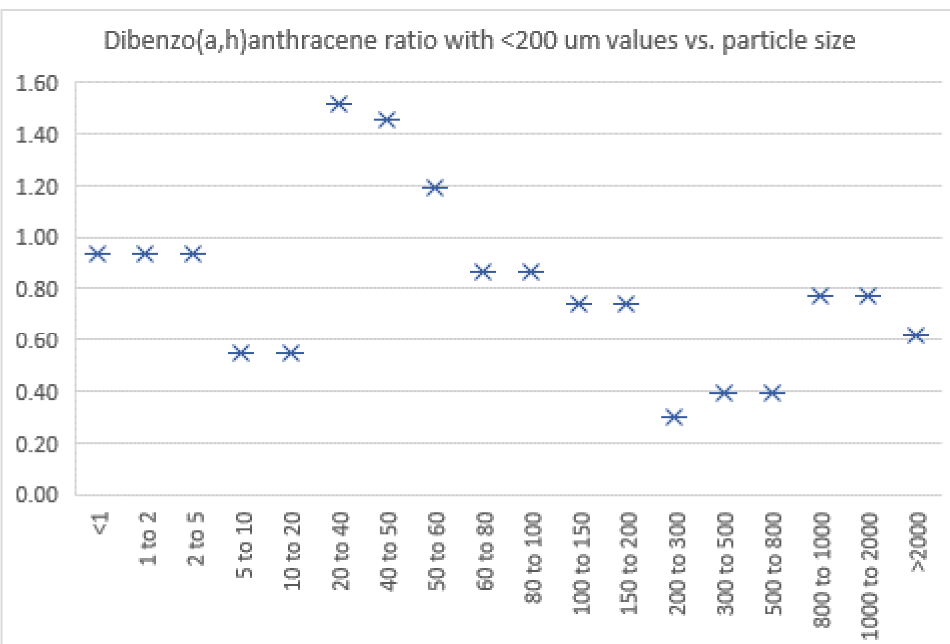


Figure 38. Dibenzo(a,h)anthracene particulate strength ratios by size range.

WinSLAMM particle range (um)	Benzo(ghi)perylene+Indeno(1,2,3-ed)pyrene ratio with <63 (SERDP 2018)	Benzo(ghi)perylene ratio with <200 (Bathi 2008)	avg Benzo(ghi)perylene ratio with <200
<1	1.24		1.24
1 to 2	1.24		1.24
2 to 5	1.24		1.24
5 to 10	0.48		0.48
10 to 20	0.48		0.48
20 to 40	1.28		1.28
40 to 50	1.28	1.22	1.25
50 to 60	1.28	0.77	1.03
60 to 80		0.77	0.77
80 to 100		0.77	0.77
100 to 150		1.01	1.01
150 to 200		1.01	1.01
200 to 300		0.36	0.36
300 to 500		0.29	0.29
500 to 800		0.29	0.29
800 to 1000		0.94	0.94
1000 to 2000		0.94	0.94
>2000		0.64	0.64
LOM and oily debris	5.26	3.86	4.56
		avg COV	1.38

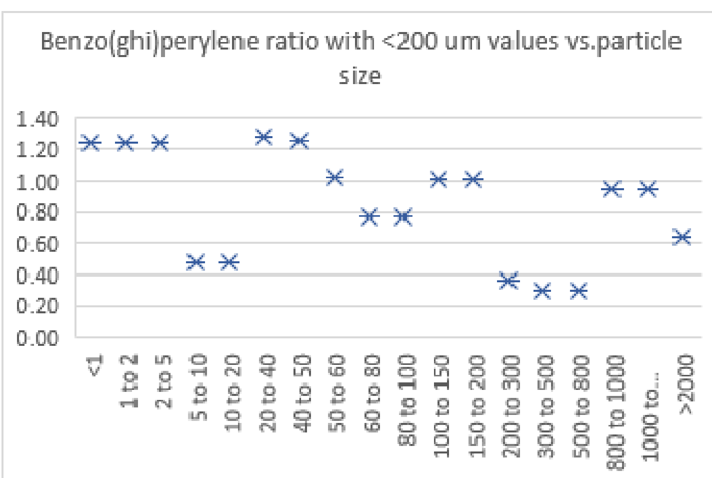


Figure 39. Benzo(ghi)perylene particulate strength ratios by size range.

Chordane and PCBs

Only the SERDP (2018) study included data for these two constituents. Limited detection did not allow these to be separated by land use.

WinSLAMM particle range (um)	Chlordane ratio with <63 um (SERDP 2018)
<1	0.96
1 to 2	0.96
2 to 5	0.96
5 to 10	0.25
10 to 20	0.25
20 to 40	1.88
40 to 50	1.88
50 to 60	1.88
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	0.24
avg COV	1.72

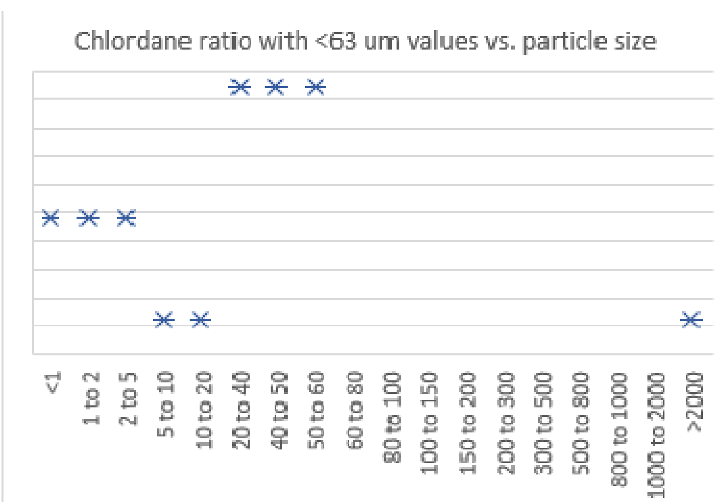


Figure 40. Chlordane particulate strength ratios by size range.

WinSLAMM particle range (um)	Total PCBs ratio with <63 um (SERDP 2018)
<1	1.79
1 to 2	1.79
2 to 5	1.79
5 to 10	0.39
10 to 20	0.39
20 to 40	0.82
40 to 50	0.82
50 to 60	0.82
60 to 80	
80 to 100	
100 to 150	
150 to 200	
200 to 300	
300 to 500	
500 to 800	
800 to 1000	
1000 to 2000	
>2000	0.15
avg COV	1.55

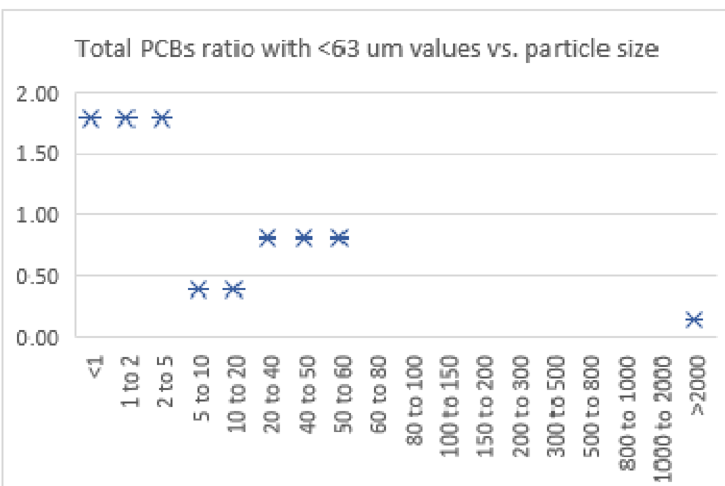


Figure 41. Total PCBs particulate strength ratios by size range.

Recent SERDP Monitoring of Particulate Strengths of Metals, PAHs, and PFAS Compounds

The recent SERDP (2022) project monitored stormwater and treatment systems at several locations in the US, at Lubbock, TX, San Diego, CA, and Bremerton, WA. These data were obtained during monitoring by the Texas Tech research group and local cooperators during the SERDP Project: *Development of Tools to Inform the Selection of Stormwater Controls at DoD Bases to Limit Potential Sediment Recontamination*. Prior reports presented the data with descriptions of the sites and monitoring programs and data evaluations for each location, and a compilation of the performance data in a separate report. This white paper includes of particulate strengths of heavy metals, PAHs and PFAS compounds and outlines how these data can be used to modify the WinSLAMM modeling outcomes to consider the varying particulate strengths by particle size. The sites monitored during this project were:

- The drainage area for the monitored Picnic Lake at the Reese Technology Center in Lubbock, TX, was about 255 acres. This location is a repurposed Air Force base, and the current land use is comprised of mixed industrial and commercial uses. Two events were monitored at inlets to the lake and within the lake.

- Two locations were monitored at Naval Base San Diego, the Commissary Bioinfiltration System and the Federal Credit Union Bioswale. These both had drainage areas of about 0.38 acres of paved parking areas for the adjacent commercial areas. Three events were monitored at each of these two locations.

- The Naval Base Point Loma (adjacent to the Naval Base San Diego) site included monitoring of a media bed stormwater control. The drainage area was about 0.8 acres of paved parking and small roofs surrounding a light industrial area. Three rains were monitored at this location.

- Three locations were monitored at the Puget Sound Naval Base, two events were sampled at the Pier B (3.1 acres of naval pier with storage areas and small sheds) media filter, three events were sampled at the Recycled Metal Transfer Station (RMTS) (2.6 acres mostly paved storage and staging areas, with some roofs), and four events at the Metals Yard (2.5 acres paved storage yard with sheds and containers).

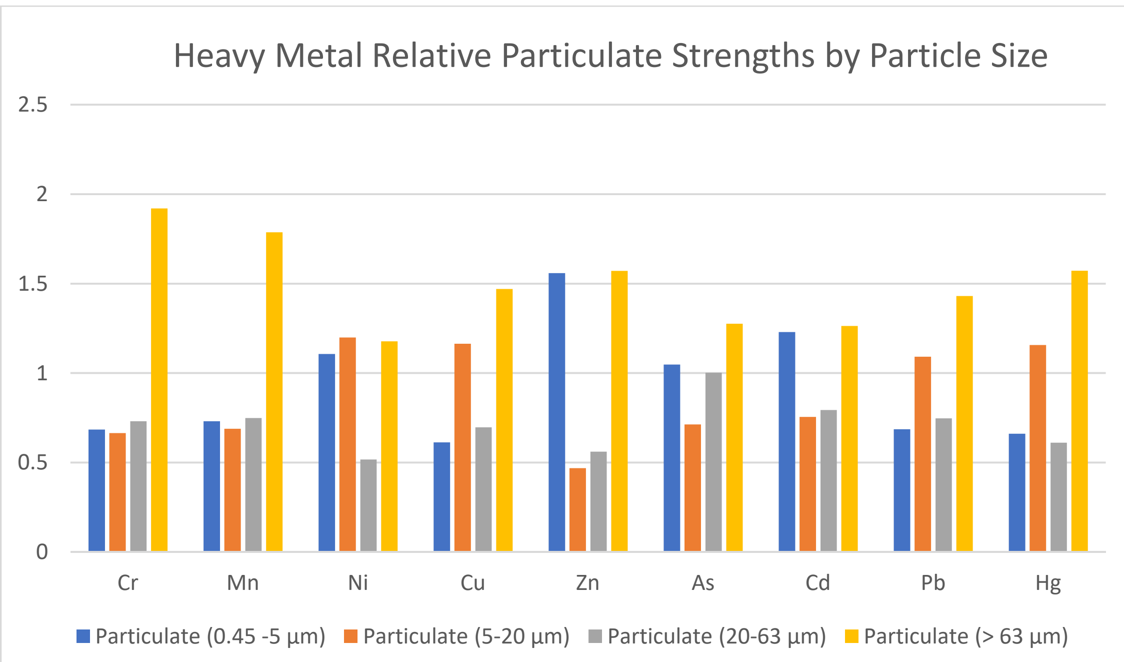
Particulate strengths were calculated for each sample and particle size using the previously described equation, based on the difference of the total and filtered concentrations (the particulate bound concentrations) and the total particulate solids (TSS in this case). Due to the few samples available, data from all the sites were combined to calculate the overall average particulate strengths by particle size. The treatment systems would not affect the particulate strengths by particle size, only the particle size distribution. Therefore, influent and effluent samples were also both combined for these calculations. The samples were collected at outfall locations of the drainage areas and do not represent separate source areas (except for the two NBSD small paved areas). Therefore, the factors describing the particulate strength by size can only be applied to the final calculated outfall conditions. Also, as reference, total particulate strength (mg/kg) for the influent total samples along with the filtered influent concentrations (µg/L for the metals and PAHs, and ng/L for the PFAS) were also calculated. The following sections summarize these data for heavy metals, PFAS congeners, and PAH compounds.

Heavy Metals

The following table shows the overall summary of the filtered water concentration and particulate strength for the total sample portions, as used in WinSLAMM.

Filtered inlet water concentrations (< 0.45 µm) µg/L									
	Cr	Mn	Ni	Cu	Zn	As	Cd	Pb	Hg
site count	7	7	7	7	7	7	6	7	4
minimum	0.29	1.05	1.17	3.5	1.15	0.44	0.06	0.26	0.001
maximum	2.88	138	9.76	265	313	3.58	1.17	2.37	0.004
average	1.44	32.7	5.20	70.5	161	1.96	0.47	1.12	0.003
median	1.23	12. 6	4.41	37.8	201	1.87	0.27	0.91	0.003
standard deviation	0.85	47.5	3.09	92.7	109	1.28	0.48	0.82	0.001
COV	0.59	1.45	0.59	1.31	0.68	0.66	1.02	0.74	0.50
Total Particulates (> 0.45 µm) mg/kg									
site count	7	7	7	7	7	7	7	7	4
minimum	29.3	182.3	18.0	29.9	149	3.0	0.6	28.6	0.049
maximum	308	1,587	442	4,310	15,500	86.1	80.6	115	0.542
average	129	785	145	1,640	5,40	34.6	17.6	65.0	0.236
median	63.7	845	61.4	1,130	1,260	14.1	2.7	64.3	0.176
standard deviation	110	496	159	1,530	6,080	34.0	29.6	27.8	0.225
COV	0.85	0.63	1.09	0.93	1.13	0.98	1.68	0.43	0.95

The following figure illustrates how the particulate strengths for the four particle sizes vary for the monitored heavy metals. All of the metals had higher relative particulate strengths for the largest sample fractions (>63 µm).



The following table lists the relative particulate strengths by the particle sizes used in WinSLAMM. The data for the four size ranges shown in the figure above were used to fill in this longer table.

WinSLAMM particle size range (µm)	Cr	Mn	Ni	Cu	Zn	As	Cd	Pb	Hg

1 to 1.9	0.68	0.73	1.11	0.61	1.56	1.05	1.23	0.69	0.66
2 to 2.9	0.68	0.73	1.11	0.61	1.56	1.05	1.23	0.69	0.66
3 to 3.9	0.68	0.73	1.11	0.61	1.56	1.05	1.23	0.69	0.66
4 to 4.9	0.68	0.73	1.11	0.61	1.56	1.05	1.23	0.69	0.66
5 to 5.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
6 to 6.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
7 to 7.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
8 to 8.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
9 to 9.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
10 to 10.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
11 to 11.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
12 to 12.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
13 to 13.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
14 to 14.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
15 to 19.9	0.66	0.69	1.20	1.16	0.47	0.71	0.75	1.09	1.16
20 to 24.9	0.73	0.75	0.52	0.70	0.56	1.00	0.79	0.75	0.61
25 to 29.9	0.73	0.75	0.52	0.70	0.56	1.00	0.79	0.75	0.61
30 to 34.9	0.73	0.75	0.52	0.70	0.56	1.00	0.79	0.75	0.61
35 to 39.9	0.73	0.75	0.52	0.70	0.56	1.00	0.79	0.75	0.61
40 to 49.9	0.73	0.75	0.52	0.70	0.56	1.00	0.79	0.75	0.61
50 to 59.9	0.73	0.75	0.52	0.70	0.56	1.00	0.79	0.75	0.61
60 to 79.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
80 to 99.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
100 to 149.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
150 to 199.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
200 to 299.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
300 to 499.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
500 to 799.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
800 to 999.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
1000 to 1999.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57
>1999.9	1.92	1.79	1.18	1.47	1.57	1.28	1.26	1.43	1.57

PAHs

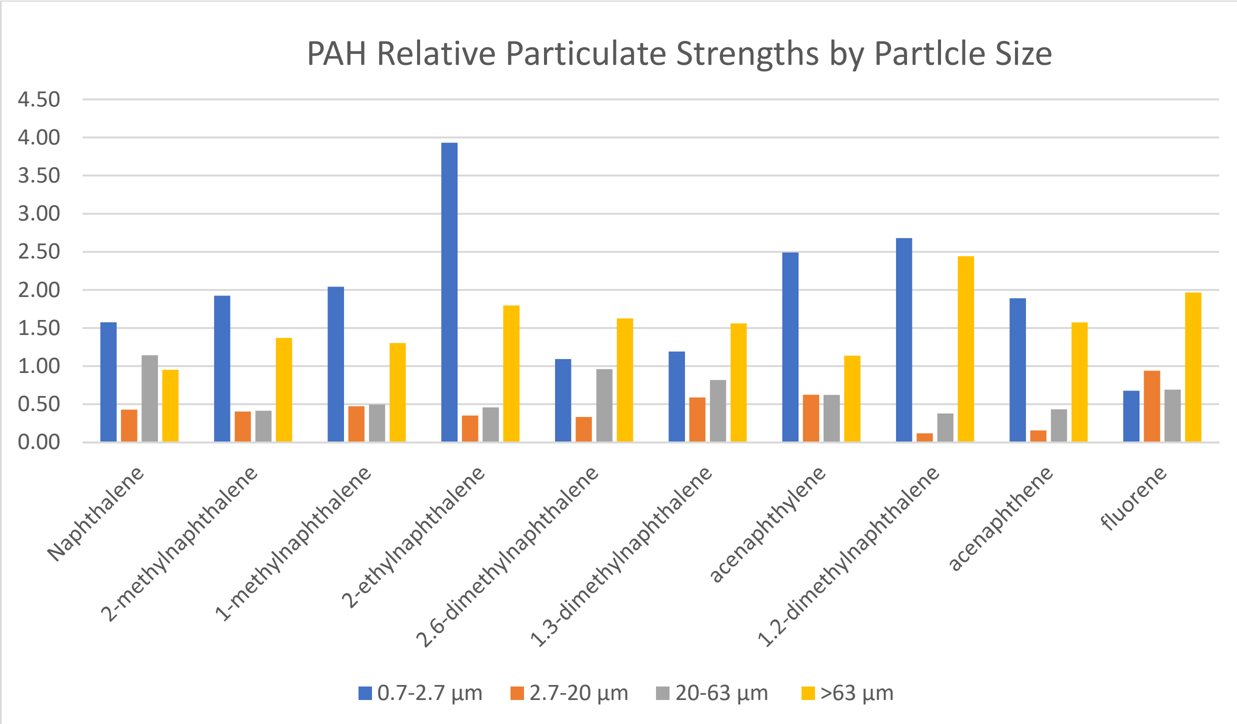
The tables and figures for PAHs are organized in a similar manner as for the heavy metals, except that the larger number of constituents required the tables and figures to be separated to fit the page width.

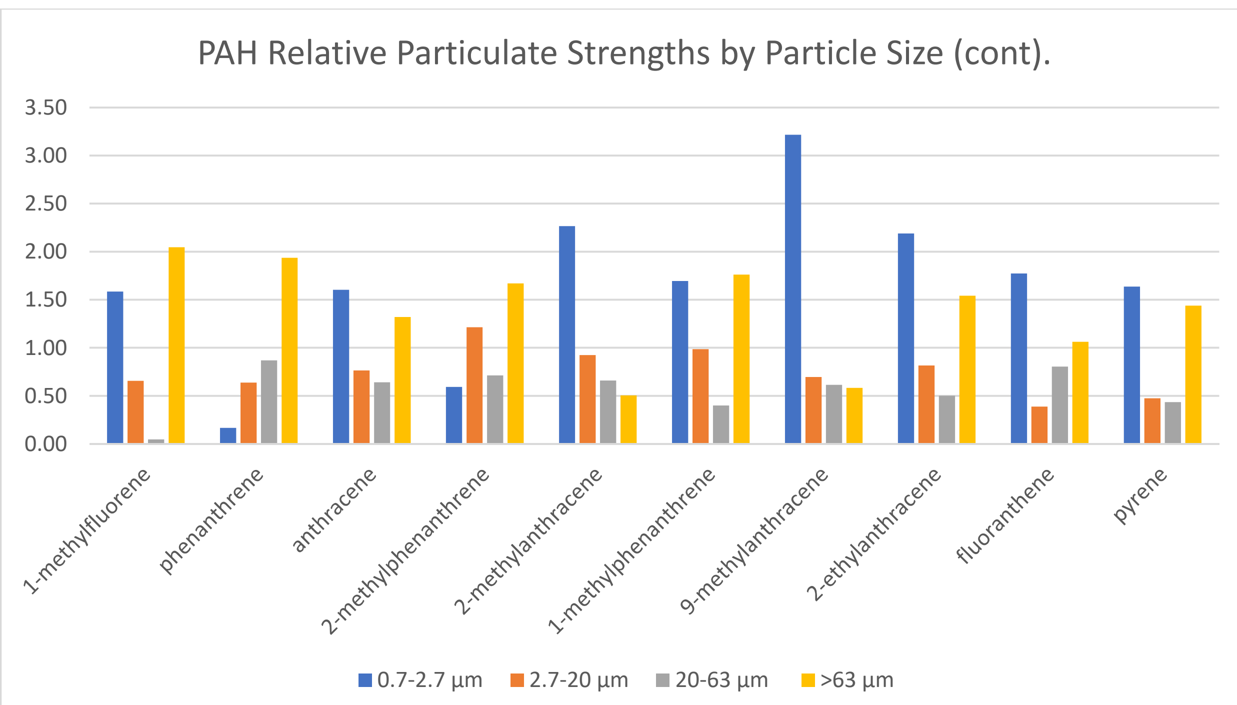
	Naphthalene	2-methylnaphthalene	1-methylnaphthalene	2-ethylnaphthalene	1-ethylnaphthalene	2.6-dimethylnaphthalene	1.3-dimethylnaphthalene	2-isopropylnaphthalene	acenaphthylene	1.2-dimethylnaphthalene
inlet filtered conc (µg/L)										
site count	6	6	5	4	3	5	5	2	5	3
minimum	1.86	1.30	0.555	0.340	0.087	0.423	0.456	0.036	0.065	0.127
maximum	8.98	6.43	3.26	0.881	0.147	2.07	1.65	0.055	1.48	0.456
average	5.55	3.92	2.02	0.664	0.126	1.22	1.09	0.046	0.644	0.289
median	5.62	4.12	2.25	0.717	0.142	1.30	1.13	0.046	0.161	0.283
standard deviation	2.59	2.25	1.29	0.259	0.033	0.679	0.486	0.013	0.713	0.165
COV	0.47	0.57	0.64	0.39	0.26	0.55	0.45	0.29	1.11	0.57
total part strength (mg/kg)										
site count	7	7	5	5	4	7	6	2	6	5
minimum	0.014	0.006	0.003	0.002	0.001	0.004	0.003	0.000	0.001	0.000
maximum	1.100	0.482	0.144	0.080	0.002	0.146	0.088	0.001	0.091	0.020
average	0.311	0.170	0.067	0.022	0.002	0.057	0.041	0.001	0.021	0.009
median	0.084	0.110	0.042	0.009	0.002	0.050	0.036	0.001	0.008	0.009
standard deviation	0.400	0.180	0.066	0.033	0.001	0.050	0.035	0.001	0.035	0.008
COV	1.29	1.06	0.99	1.54	0.32	0.87	0.85	1.41	1.69	0.92

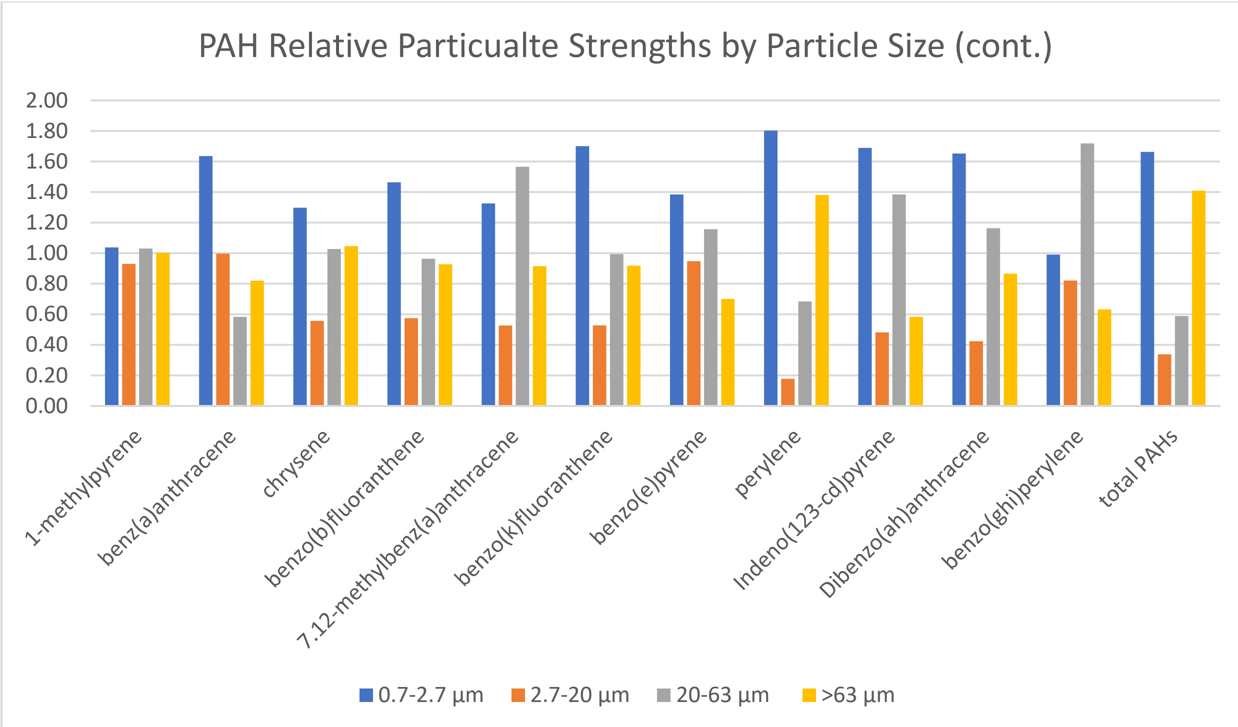
	1.8-dimethylnaphthalene	acenaphthene	2.3.5-trimethylnaphthalene	fluorene	1-methylfluorene	phenanthrene	anthracene	2-methylphenanthrene	2-methylanthracene	1-methylphenanthrene
inlet filtered conc (µg/L)										
site count	2	3	3	6	4	4	5	6	5	4
minimum	0.041	0.239	0.648	1.01	0.439	8.76	0.243	0.592	0.045	0.324
maximum	0.390	1.263	1.367	5.19	2.26	25.2	14.0	5.48	1.71	2.35
average	0.216	0.722	0.970	2.96	1.22	13.7	3.21	2.09	0.557	1.19
median	0.216	0.666	0.895	2.50	1.09	10.4	0.503	1.71	0.150	1.05
standard deviation	0.246	0.514	0.365	1.81	0.816	7.70	6.05	1.75	0.702	0.853
COV	1.14	0.71	0.38	0.61	0.67	0.56	1.89	0.84	1.26	0.71
total part strength (mg/kg)										
site count	3	5	4	7	5	5	6	7	6	5
minimum	0.000	0.000	0.001	0.013	0.004	0.336	0.015	0.041	0.005	0.027
maximum	0.006	0.070	0.026	0.221	0.031	0.817	0.910	0.154	0.131	0.080
average	0.003	0.022	0.014	0.081	0.014	0.485	0.176	0.102	0.043	0.049
median	0.002	0.015	0.014	0.066	0.013	0.449	0.031	0.085	0.008	0.037
standard deviation	0.003	0.027	0.013	0.070	0.011	0.192	0.360	0.042	0.056	0.024
COV	1.27	1.23	0.92	0.86	0.77	0.40	2.05	0.41	1.32	0.50

	9-methylanthracene	2-ethylanthracene	fluoranthene	pyrene	9.10-dimethylanthracene	2-terbutylanthracene	1-methylpyrene	benzo(a)anthracene	chrysene	benzo(b)fluoranthene
inlet filtered conc (µg/L)										
site count	3	4	6	6	3	3	4	6	6	6
minimum	0.026	0.085	1.563	1.18	0.117	0.040	0.006	0.046	0.382	0.058
maximum	0.064	1.14	12.9	26.9	2.74	0.189	0.214	0.419	2.81	1.07
average	0.044	0.595	5.25	9.10	0.995	0.103	0.118	0.226	1.36	0.427
median	0.042	0.573	3.58	3.41	0.128	0.079	0.125	0.207	1.40	0.271
standard deviation	0.019	0.438	4.39	10.8	1.51	0.077	0.109	0.155	0.870	0.382
COV	0.43	0.74	0.84	1.20	1.52	0.75	0.93	0.69	0.64	0.89
total part strength (mg/kg)										
site count	5	5	7	7	2	3	5	7	7	7
minimum	0.001	0.013	0.282	0.150	0.000	0.001	0.028	0.049	0.241	0.160
maximum	0.002	0.060	1.553	1.413	0.028	0.002	0.061	0.343	1.079	1.072
average	0.001	0.028	0.789	0.720	0.014	0.001	0.035	0.135	0.565	0.349
median	0.002	0.020	0.733	0.636	0.014	0.001	0.028	0.096	0.502	0.224
standard deviation	0.001	0.018	0.413	0.418	0.019	0.001	0.014	0.097	0.302	0.327
COV	0.46	0.66	0.52	0.58	1.37	0.49	0.41	0.72	0.53	0.94

	7.12-methylbenz(a)anthracene	benzo(k)fluoranthene	benzo(e)pyrene	benzo(a)pyrene	perylene	Indeno(123-cd)pyrene	Dibenzo(ah)anthracene	benzo(ghi)perylene	total PAHs
inlet filtered conc (µg/L)									
site count	4	5	5	3	4	5	4	5	6
minimum	0.000	0.034	0.008	0.103	0.085	0.119	0.043	0.053	12.6
maximum	0.063	0.664	0.207	0.633	0.148	0.540	0.388	0.408	93.3
average	0.042	0.312	0.131	0.412	0.110	0.256	0.200	0.182	52.8
median	0.053	0.192	0.162	0.499	0.102	0.205	0.184	0.147	54.9
standard deviation	0.030	0.262	0.079	0.276	0.027	0.164	0.145	0.147	28.0
COV	0.70	0.84	0.60	0.67	0.25	0.64	0.73	0.81	0.53
total part strength (mg/kg)									
site count	5	6	6	4	5	6	5	6	7
minimum	0.003	0.075	0.005	0.106	0.005	0.032	0.014	0.057	2.52
maximum	0.031	0.861	0.496	0.478	0.151	5.630	0.342	0.584	21.5
average	0.011	0.288	0.212	0.265	0.041	1.025	0.095	0.272	6.62
median	0.006	0.139	0.206	0.238	0.014	0.116	0.034	0.251	4.00
standard deviation	0.011	0.301	0.161	0.167	0.062	2.256	0.139	0.178	6.70
COV	1.04	1.04	0.76	0.63	1.52	2.20	1.47	0.66	1.01


PAH Relative Particulate Strengths by Partlcle Size
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Naphthalene
2-methylnaphthalene
1-methylnaphthalene
2-ethylnaphthalene
2.6-dimethylnaphthalene
1.3-dimethylnaphthalene
acenaphthylene
1.2-dimethylnaphthalene
acenaphthene
fluorene
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm


PAH Relative Particulate Strengths by Particle Size (cont).
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1-methylfluorene
phenanthrene
anthracene
2-methylphenanthrene
2-methylanthracene
1-methylphenanthrene
9-methylanthracene
2-ethylanthracene
fluoranthene
pyrene
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm


PAH Relative Particualte Strengths by Particle Size (cont.)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1-methylpyrene
benz(a)anthracene
chrysene
benzo(b)fluoranthene
7.12-methylbenz(a)anthracene
benzo(k)fluoranthene
benzo(e)pyrene
perylene
Indeno(123-cd)pyrene
Dibenzo(ah)anthracene
benzo(ghi)perylene
total PAHs
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm

WinSLAMM particle size range (um)	Naphthalene	2-methylnaphthalene	1-methylnaphthalene	2-ethylnaphthalene	2.6-dimethylnaphthalene	1.3-dimethylnaphthalene	acenaphthylene	1.2-dimethylnaphthalene	acenaphthene	fluorene
1 to 1.9	1.58	1.92	2.04	3.93	1.09	1.19	2.49	2.68	1.89	0.68
2 to 2.9	1.58	1.92	2.04	3.93	1.09	1.19	2.49	2.68	1.89	0.68
3 to 3.9	1.58	1.92	2.04	3.93	1.09	1.19	2.49	2.68	1.89	0.68
4 to 4.9	1.58	1.92	2.04	3.93	1.09	1.19	2.49	2.68	1.89	0.68
5 to 5.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
6 to 6.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
7 to 7.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
8 to 8.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
9 to 9.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
10 to 10.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
11 to 11.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
12 to 12.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
13 to 13.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
14 to 14.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
15 to 19.9	0.43	0.40	0.47	0.35	0.33	0.59	0.62	0.12	0.15	0.94
20 to 24.9	1.14	0.41	0.50	0.46	0.96	0.82	0.62	0.38	0.43	0.69
25 to 29.9	1.14	0.41	0.50	0.46	0.96	0.82	0.62	0.38	0.43	0.69
30 to 34.9	1.14	0.41	0.50	0.46	0.96	0.82	0.62	0.38	0.43	0.69
35 to 39.9	1.14	0.41	0.50	0.46	0.96	0.82	0.62	0.38	0.43	0.69
40 to 49.9	1.14	0.41	0.50	0.46	0.96	0.82	0.62	0.38	0.43	0.69
50 to 59.9	1.14	0.41	0.50	0.46	0.96	0.82	0.62	0.38	0.43	0.69
60 to 79.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
80 to 99.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
100 to 149.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
150 to 199.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
200 to 299.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
300 to 499.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
500 to 799.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
800 to 999.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
1000 to 1999.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97
>1999.9	0.95	1.37	1.30	1.80	1.63	1.56	1.14	2.44	1.57	1.97

WinSLAMM particle size range (um)	1-methylfluorene	phenanthrene	anthracene	2-methylphenanthrene	2-methylanthracene	1-methylphenanthrene	9-methylanthracene	2-ethylanthracene	fluoranthene	pyrene
1 to 1.9	1.58	0.17	1.60	0.59	2.27	1.70	3.22	2.19	1.77	1.64
2 to 2.9	1.58	0.17	1.60	0.59	2.27	1.70	3.22	2.19	1.77	1.64
3 to 3.9	1.58	0.17	1.60	0.59	2.27	1.70	3.22	2.19	1.77	1.64
4 to 4.9	1.58	0.17	1.60	0.59	2.27	1.70	3.22	2.19	1.77	1.64
5 to 5.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
6 to 6.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
7 to 7.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
8 to 8.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
9 to 9.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
10 to 10.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
11 to 11.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
12 to 12.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
13 to 13.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
14 to 14.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
15 to 19.9	0.66	0.64	0.76	1.21	0.92	0.99	0.70	0.82	0.39	0.48
20 to 24.9	0.05	0.87	0.64	0.71	0.66	0.40	0.61	0.50	0.80	0.43
25 to 29.9	0.05	0.87	0.64	0.71	0.66	0.40	0.61	0.50	0.80	0.43
30 to 34.9	0.05	0.87	0.64	0.71	0.66	0.40	0.61	0.50	0.80	0.43
35 to 39.9	0.05	0.87	0.64	0.71	0.66	0.40	0.61	0.50	0.80	0.43
40 to 49.9	0.05	0.87	0.64	0.71	0.66	0.40	0.61	0.50	0.80	0.43
50 to 59.9	0.05	0.87	0.64	0.71	0.66	0.40	0.61	0.50	0.80	0.43
60 to 79.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
80 to 99.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
100 to 149.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
150 to 199.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
200 to 299.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
300 to 499.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
500 to 799.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
800 to 999.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
1000 to 1999.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44
>1999.9	2.05	1.94	1.32	1.67	0.50	1.76	0.58	1.54	1.06	1.44

WinSLAMM particle size range (um)	1-methylpyrene	benz(a)anthracene	chrysene	benzo(b)fluoranthene	7.12-methylbenz(a)anthracene	benzo(k)fluoranthene	benzo(e)pyrene	perylene	Indeno(123-cd)pyrene	Dibenzo(ah)anthracene	benzo(ghi)perylene	total PAHs
1 to 1.9	1.04	1.64	1.30	1.46	1.33	1.70	1.38	1.80	1.69	1.65	0.99	1.66
2 to 2.9	1.04	1.64	1.30	1.46	1.33	1.70	1.38	1.80	1.69	1.65	0.99	1.66
3 to 3.9	1.04	1.64	1.30	1.46	1.33	1.70	1.38	1.80	1.69	1.65	0.99	1.66
4 to 4.9	1.04	1.64	1.30	1.46	1.33	1.70	1.38	1.80	1.69	1.65	0.99	1.66
5 to 5.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
6 to 6.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
7 to 7.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
8 to 8.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
9 to 9.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
10 to 10.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
11 to 11.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
12 to 12.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
13 to 13.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
14 to 14.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
15 to 19.9	0.93	1.00	0.56	0.57	0.53	0.53	0.95	0.18	0.48	0.42	0.82	0.34
20 to 24.9	1.03	0.58	1.03	0.96	1.57	0.99	1.16	0.68	1.38	1.16	1.72	0.59
25 to 29.9	1.03	0.58	1.03	0.96	1.57	0.99	1.16	0.68	1.38	1.16	1.72	0.59
30 to 34.9	1.03	0.58	1.03	0.96	1.57	0.99	1.16	0.68	1.38	1.16	1.72	0.59
35 to 39.9	1.03	0.58	1.03	0.96	1.57	0.99	1.16	0.68	1.38	1.16	1.72	0.59
40 to 49.9	1.03	0.58	1.03	0.96	1.57	0.99	1.16	0.68	1.38	1.16	1.72	0.59
50 to 59.9	1.03	0.58	1.03	0.96	1.57	0.99	1.16	0.68	1.38	1.16	1.72	0.59
60 to 79.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
80 to 99.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
100 to 149.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
150 to 199.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
200 to 299.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
300 to 499.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
500 to 799.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
800 to 999.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
1000 to 1999.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41
>1999.9	1.00	0.82	1.05	0.93	0.91	0.92	0.70	1.38	0.58	0.87	0.63	1.41

PFAS

No data for PFAS congeners were available for different particle sizes due to their very low concentrations. The following tables therefore only show the filtered concentrations and the total sample particulate strengths.

average inlet <0.7µm (filtered) ng/L									
	PFPeA	PFHxA	PFHpA	PFOA	PFDA	PFUdA	PFNA	PFOS	6:2 FTS
site count	3	5	3	5	3	2	4	5	3
minimum	0.7	2.2	0.2	2.0	0.8	0.1	0.2	3.9	1.7
maximum	11.8	53.6	4.8	29.0	2.5	0.9	2.5	85.8	28.8
average	5.3	15.3	2.1	13.4	1.3	0.5	1.0	29.4	18.2
median	3.3	7.1	1.2	16.5	0.8	0.5	0.6	24.1	24.1
standard deviation	5.8	21.7	2.4	11.4	1.0	0.6	1.1	33.0	14.5
COV	1.10	1.42	1.16	0.85	0.72	1.09	1.09	1.12	0.80
average PFAS particulate strengths (mg/kg)									
	PFPeA	PFHxA	PFHpA	PFOA	PFDA	PFUdA	PFNA	PFOS	6:2 FTS
site count	3	4	3	4	4	3	4	4	2
minimum	0.037	0.011	0.002	0.021	0.011	0.001	0.004	0.076	0.031
maximum	0.109	0.148	0.081	0.536	0.087	0.051	0.081	1.729	0.094
average	0.065	0.086	0.031	0.189	0.046	0.021	0.028	0.702	0.063
median	0.050	0.092	0.010	0.100	0.044	0.012	0.012	0.502	0.063
standard deviation	0.038	0.056	0.043	0.236	0.038	0.026	0.036	0.758	0.044
COV	0.59	0.66	1.39	1.24	0.81	1.23	1.32	1.08	0.71

Example WinSLAMM Calculations

The purpose of this white paper is to summarize data that can be used to calculate stormwater characterization and stormwater control performance as a function of particle size. WinSLAMM tracks particle sizes from source areas and through the drainage system and stormwater controls. However, it currently uses a single value for the particulate strengths corresponding to the whole sample fraction. The particle size particulate strength data can be used to adjust the effluent concentrations based on the particle size distributions, as illustrated in this section of the white paper.

The following table summarizes the particulate strength factors for the different particle sizes modeled in WinSLAMM for the “standard” pollutants listed in the model, along with examples for “other” pollutants that can be described and modeled.

The last two tables are examples of how the calculation adjustments can be accomplished in the model. Currently, a data output option can be selected that shows the fraction of particulates associated with the different particle sizes for each modeled rain and for different locations in the modeled system. The particulate strengths by particle sizes are mostly associated with outfall samples at mixed land use areas. Therefore, the correction factors should be applied to the flow-weighted particle size distribution information associated with the outfall location. These two examples show how the calculations can be used for an example for a location with stormwater treatment having very few larger particles. The second example is for an untreated stormwater having a wide range of stormwater particulates. In these examples, the correction factors and the resulting concentrations vary by about 5 to 20 percent compared to the original concentrations that are not corrected by these factors.

Particulate Strength Factors for Particle Sizes for Standard WinSLAMM Particulate Pollutants (and examples for “others’)

										example "others"					
bin#	% > size	range	Phosphorus	TKN	COD	Cr	Cu	Pb	Zn	Cd (1)	pyrene (2)	naphthalene (3)	fluorene (4)	phenanthrene (5)	anthracene (6)
1	0.45	0.45 to 1.9	1.68	1.00*	1.20	0.68	0.61	0.69	1.56	1.23	1.64	1.58	0.68	0.17	1.60
2	2	2 to 2.9	0.71	1.00	0.66	0.68	0.61	0.69	1.56	1.23	1.64	1.58	0.68	0.17	1.60
3	3	3 to 3.9	0.71	1.00	0.66	0.68	0.61	0.69	1.56	1.23	1.64	1.58	0.68	0.17	1.60
4	4	4 to 4.9	0.71	1.00	0.66	0.68	0.61	0.69	1.56	1.23	1.64	1.58	0.68	0.17	1.60
5	5	5 to 5.9	0.71	1.00	0.66	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
6	6	6 to 6.9	0.71	1.00	0.66	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
7	7	7 to 7.9	0.71	1.00	0.66	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
8	8	8 to 8.9	0.71	1.00	0.66	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
9	9	9 to 9.9	0.71	1.00	0.66	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
10	10	10 to 10.9	0.81	1.00	0.67	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
11	11	11 to 11.9	0.81	1.00	0.67	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
12	12	12 to 12.9	0.81	1.00	0.67	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
13	13	13 to 13.9	0.81	1.00	0.67	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
14	14	14 to 14.9	0.81	1.00	0.67	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
15	15	15 to 19.9	0.81	1.00	0.67	0.66	1.16	1.09	0.47	0.75	0.48	0.43	0.94	0.64	0.76
16	20	20 to 24.9	0.81	1.00	0.67	0.73	0.70	0.75	0.56	0.79	0.43	1.14	0.69	0.87	0.64
17	25	25 to 29.9	0.81	1.00	0.67	0.73	0.70	0.75	0.56	0.79	0.43	1.14	0.69	0.87	0.64
18	30	30 to 34.9	0.81	1.00	0.67	0.73	0.70	0.75	0.56	0.79	0.43	1.14	0.69	0.87	0.64
19	35	35 to 39.9	0.81	1.00	0.67	0.73	0.70	0.75	0.56	0.79	0.43	1.14	0.69	0.87	0.64
20	40	40 to 49.9	0.78	1.29	1.15	0.73	0.70	0.75	0.56	0.79	0.43	1.14	0.69	0.87	0.64
21	50	50 to 59.9	1.00	1.07	1.09	0.73	0.70	0.75	0.56	0.79	0.43	1.14	0.69	0.87	0.64
22	60	60 to 79.9	1.16	0.89	1.20	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
23	80	80 to 99.9	0.71	0.93	0.90	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
24	100	100 to 149.9	0.68	0.93	0.96	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
25	150	150 to 199.9	0.53	0.79	0.54	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
26	200	200 to 299.9	0.52	0.49	0.66	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
27	300	300 to 499.9	0.70	0.56	0.68	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
28	500	500 to 799.9	0.70	0.56	0.70	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
29	800	800 to 999.9	0.69	0.83	0.86	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
30	1000	1000 to 1999.9	0.88	1.23	1.15	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
31	2000	>1999.9	0.90	1.18	1.43	1.92	1.47	1.43	1.57	1.26	1.44	0.95	1.97	1.94	1.32
		source:	avg	avg	avg	SERDP 2022	SERDP 2022	SERDP 2022	SERDP 2022	SERDP 2022	SERDP 2022	SERDP 2022	SERDP 2022	SERDP 2022	SERDP 2022

*note: use 1.00 if unknown or missing

Calculation Example 1 (treated effluent with few large particles)

Part. Size No.	Particle Size (microns)	Inf. % > Particle Size	Eff. % > Particle Size (4)	size range	Outfall particulates % in size range (6)	P PSD fraction, from above Table (7)	weighted P conc fraction (8) = (6)x(7)/100	Cu PSD fraction	weighted Cu conc fraction	Zn PSD fraction	weighted Zn conc fraction	Pb PSD fraction	weighted Pb conc fraction	pyrene (2) PSD fraction	weighted pyrene conc fraction
0	0	100.000	100.000	0 to 1	14.075	1.68	0.236	0.61	0.086	1.56	0.220	0.686	0.097	1.64	0.230
1	1	85.925	85.925	1 to 1.9	25.335	1.68	0.426	0.61	0.155	1.56	0.395	0.686	0.174	1.64	0.414
2	2	60.590	60.590	2 to 2.9	11.260	0.71	0.080	0.61	0.069	1.56	0.175	0.686	0.077	1.64	0.184
3	3	49.330	49.330	3 to 3.9	5.630	0.71	0.040	0.61	0.035	1.56	0.088	0.686	0.039	1.64	0.092
4	4	43.700	43.700	4 to 4.9	5.630	0.71	0.040	0.61	0.035	1.56	0.088	0.686	0.039	1.64	0.092
5	5	38.070	38.070	5 to 5.9	5.630	0.71	0.040	1.16	0.066	0.47	0.026	1.092	0.061	0.48	0.027
6	6	32.440	32.440	6 to 6.9	5.630	0.71	0.040	1.16	0.066	0.47	0.026	1.092	0.061	0.48	0.027
7	7	26.810	26.810	7 to 7.9	2.815	0.71	0.020	1.16	0.033	0.47	0.013	1.092	0.031	0.48	0.013
8	8	23.995	23.995	8 to 8.9	5.630	0.71	0.040	1.16	0.066	0.47	0.026	1.092	0.061	0.48	0.027
9	9	18.366	18.366	9 to 9.9	2.815	0.71	0.020	1.16	0.033	0.47	0.013	1.092	0.031	0.48	0.013
10	10	15.551	15.551	10 to 10.9	2.815	0.81	0.023	1.16	0.033	0.47	0.013	1.092	0.031	0.48	0.013
11	11	12.736	12.736	11 to 11.9	2.815	0.81	0.023	1.16	0.033	0.47	0.013	1.092	0.031	0.48	0.013
12	12	9.921	9.921	12 to 12.9	2.815	0.81	0.023	1.16	0.033	0.47	0.013	1.092	0.031	0.48	0.013
13	13	7.106	7.106	13 to 13.9	2.815	0.81	0.023	1.16	0.033	0.47	0.013	1.092	0.031	0.48	0.013
14	14	4.291	4.291	14 to 14.9	2.815	0.81	0.023	1.16	0.033	0.47	0.013	1.092	0.031	0.48	0.013
15	15	1.476	1.476	15 to 19.9	1.476	0.81	0.012	1.16	0.017	0.47	0.007	1.092	0.016	0.48	0.007
16	20	0.000	0.000	20 to 24.9	0.000	0.81	0.000	0.70	0.000	0.56	0.000	0.747	0.000	0.43	0.000
17	25	0.000	0.000	25 to 29.9	0.000	0.81	0.000	0.70	0.000	0.56	0.000	0.747	0.000	0.43	0.000
18	30	0.000	0.000	30 to 34.9	0.000	0.81	0.000	0.70	0.000	0.56	0.000	0.747	0.000	0.43	0.000
19	35	0.000	0.000	35 to 39.9	0.000	0.81	0.000	0.70	0.000	0.56	0.000	0.747	0.000	0.43	0.000
20	40	0.000	0.000	40 to 49.9	0.000	0.78	0.000	0.70	0.000	0.56	0.000	0.747	0.000	0.43	0.000
21	50	0.000	0.000	50 to 59.9	0.000	1	0.000	0.70	0.000	0.56	0.000	0.747	0.000	0.43	0.000
22	60	0.000	0.000	60 to 79.9	0.000	1.16	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
23	80	0.000	0.000	80 to 99.9	0.000	0.71	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
24	100	0.000	0.000	100 to 149.9	0.000	0.68	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
25	150	0.000	0.000	150 to 199.9	0.000	0.53	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
26	200	0.000	0.000	200 to 299.9	0.000	0.52	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
27	300	0.000	0.000	300 to 499.9	0.000	0.7	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
28	500	0.000	0.000	500 to 799.9	0.000	0.7	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
29	800	0.000	0.000	800 to 999.9	0.000	0.69	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
30	1000	0.000	0.000	1000 to 1999.9	0.000	0.88	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
31	2000	0.000	0.000	>1999.9	0.000	0.9	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
(a) correction factor (sum of weighted concentration fractions)							1.108		0.823		1.144		0.840		1.194
(b) basic outfall particulate bound concentration, from model output							0.087		3.7		93.8		23.8		3.1
(c) corrected particulate bound concentration with factor (mg/L for P; ug/L for others) = (a)x(b)							0.096		3.0		107.3		20.0		3.7
(d) outfall filtered concentration (mg/L for P; ug/L for others), from model output							0.263		48.8		113.4		2.1		0.06
(e) Total corrected outfall concentration (mg/L for P; ug/L for others) = (c)+(d)							0.359		51.8		220.7		22.1		3.8

	original total concentration (mg/L for P; ug/L for others), for reference only from model ouput (b)+(d)	0.350		52.5		207.2		25.9		3.2

Calculation Example 2 (wide range of particles in untreated outfall)

Part. Size No.	Particle Size (microns)	Inf. % > Particle Size	Eff. % > Particle Size	size range	Outfall particulates % in size range	P PSD fraction	weighted P conc fraction	Cu PSD fraction	weighted Cu conc fraction	Zn PSD fraction	weighted Zn conc fraction	Pb PSD fraction	weighted Pb conc fraction	pyrene (2) PSD fraction	weighted pyrene conc fraction
0	0	100.000	100.000	0 to 1	11	1.68	0.185	0.61	0.067	1.56	0.172	0.686	0.075	1.64	0.180
1	1	85.925	85.925	1 to 1.9	2	1.68	0.034	0.61	0.012	1.56	0.031	0.686	0.014	1.64	0.033
2	2	60.590	60.590	2 to 2.9	4	0.71	0.028	0.61	0.025	1.56	0.062	0.686	0.027	1.64	0.065
3	3	49.330	49.330	3 to 3.9	4	0.71	0.028	0.61	0.025	1.56	0.062	0.686	0.027	1.64	0.065
4	4	43.700	43.700	4 to 4.9	7	0.71	0.050	0.61	0.043	1.56	0.109	0.686	0.048	1.64	0.115
5	5	38.070	38.070	5 to 5.9	3	0.71	0.021	1.16	0.035	0.47	0.014	1.092	0.033	0.48	0.014
6	6	32.440	32.440	6 to 6.9	4	0.71	0.028	1.16	0.047	0.47	0.019	1.092	0.044	0.48	0.019
7	7	26.810	26.810	7 to 7.9	4	0.71	0.028	1.16	0.047	0.47	0.019	1.092	0.044	0.48	0.019
8	8	23.995	23.995	8 to 8.9	3	0.71	0.021	1.16	0.035	0.47	0.014	1.092	0.033	0.48	0.014
9	9	18.366	18.366	9 to 9.9	1	0.71	0.007	1.16	0.012	0.47	0.005	1.092	0.011	0.48	0.005
10	10	15.551	15.551	10 to 10.9	1	0.81	0.008	1.16	0.012	0.47	0.005	1.092	0.011	0.48	0.005
11	11	12.736	12.736	11 to 11.9	1	0.81	0.008	1.16	0.012	0.47	0.005	1.092	0.011	0.48	0.005
12	12	9.921	9.921	12 to 12.9	1	0.81	0.008	1.16	0.012	0.47	0.005	1.092	0.011	0.48	0.005
13	13	7.106	7.106	13 to 13.9	2	0.81	0.016	1.16	0.023	0.47	0.009	1.092	0.022	0.48	0.010
14	14	4.291	4.291	14 to 14.9	2	0.81	0.016	1.16	0.023	0.47	0.009	1.092	0.022	0.48	0.010
15	15	1.476	1.476	15 to 19.9	13	0.81	0.105	1.16	0.151	0.47	0.061	1.092	0.142	0.48	0.062
16	20	0.000	0.000	20 to 24.9	2	0.81	0.016	0.70	0.014	0.56	0.011	0.747	0.015	0.43	0.009
17	25	0.000	0.000	25 to 29.9	5	0.81	0.041	0.70	0.035	0.56	0.028	0.747	0.037	0.43	0.022
18	30	0.000	0.000	30 to 34.9	2	0.81	0.016	0.70	0.014	0.56	0.011	0.747	0.015	0.43	0.009
19	35	0.000	0.000	35 to 39.9	3	0.81	0.024	0.70	0.021	0.56	0.017	0.747	0.022	0.43	0.013
20	40	0.000	0.000	40 to 49.9	3	0.78	0.023	0.70	0.021	0.56	0.017	0.747	0.022	0.43	0.013
21	50	0.000	0.000	50 to 59.9	2	1	0.020	0.70	0.014	0.56	0.011	0.747	0.015	0.43	0.009
22	60	0.000	0.000	60 to 79.9	2	1.16	0.023	1.47	0.029	1.57	0.031	1.430	0.029	1.44	0.029
23	80	0.000	0.000	80 to 99.9	3	0.71	0.021	1.47	0.044	1.57	0.047	1.430	0.043	1.44	0.043
24	100	0.000	0.000	100 to 149.9	3	0.68	0.020	1.47	0.044	1.57	0.047	1.430	0.043	1.44	0.043
25	150	0.000	0.000	150 to 199.9	2	0.53	0.011	1.47	0.029	1.57	0.031	1.430	0.029	1.44	0.029
26	200	0.000	0.000	200 to 299.9	2	0.52	0.010	1.47	0.029	1.57	0.031	1.430	0.029	1.44	0.029
27	300	0.000	0.000	300 to 499.9	2	0.7	0.014	1.47	0.029	1.57	0.031	1.430	0.029	1.44	0.029
28	500	0.000	0.000	500 to 799.9	1	0.7	0.007	1.47	0.015	1.57	0.016	1.430	0.014	1.44	0.014
29	800	0.000	0.000	800 to 999.9	3	0.69	0.021	1.47	0.044	1.57	0.047	1.430	0.043	1.44	0.043
30	1000	0.000	0.000	1000 to 1999.9	2	0.88	0.018	1.47	0.029	1.57	0.031	1.430	0.029	1.44	0.029
31	2000	0.000	0.000	>1999.9	0	0.9	0.000	1.47	0.000	1.57	0.000	1.430	0.000	1.44	0.000
correction factor (sum of weighted concentration fractions)							0.879		0.991		1.010		0.987		0.986
basic outfall particulate bound concentration							0.087		3.7		93.8		23.8		3.1
corrected particulate bound concentration with factor (mg/L for P; ug/L for others)							0.076		3.7		94.8		23.5		3.1
outfall filtered concentration (mg/L for P; ug/L for others)							0.263		48.8		113.4		2.1		0.06
Total corrected outfall concentration (mg/L for P; ug/L for others)							0.339		52.5		208.2		25.6		3.12

	original total concentration (mg/L for P; ug/L for others)	0.350		52.5		207.2		25.9		3.16

Conclusions

Knowing the distribution of pollutants associated with different sized stormwater particles allows more accurate determinations of their sources, transport, and control. This white paper data is being used to expand the WinSLAMM model by expanding the particulate strength characteristics by particle size. WinSLAMM currently tracks particulates based on particle size distributions but uses a single particulate strength value for all sizes. Stormwater controls usually preferentially remove the largest particles, resulting in increased bulk particle strength values after treatment. Therefore, using particulate strength values for different particle sizes will result in more accurate calculations assisting stormwater management decisions.

Pollutants in stormwater runoff can be separated into particulate-bound or filtered (filterable or "dissolved") forms, as reflected in the pollutant concentration parameter file. Pollutant strengths are the contaminant concentrations associated with the particulate matter in the stormwater and vary by particle size. The following are brief comments concerning these characteristics of stormwater particulates from the previously summarized data.

Specific Gravity and Volatile Solids

In most cases, stormwater particulates have specific gravities in the range of 1.5 to 2.5, depending on the mixture of organic and inert material in the particle. This corresponds to a relatively narrow range of settling rates for a specific particle size. Newton (laminar) and Stoke (turbulent) settling equations are used to calculate settling rates for these particulates. Specific gravity decreases as the organic content increases; larger particle sizes generally have lower specific gravity and greater organic material. With sedimentation treatment, preferential removal of higher specific gravity materials results in a shift to lower overall specific gravity of particulates in the effluent water for similar size classes. Scour of deposited sediment is dependent on the particle characteristics, including compaction of the material, compared to the shear stress (tractive force) of the flowing water.

COD and Nutrients

In residential and commercial areas, the smaller stormwater particles have the greatest concentrations of COD and nutrients (due to large surface areas per mass with pollutant sorption onto surfaces). Large particles have somewhat greater pollutant strengths for nutrients as they contain more organic material than other particle sizes. At industrial sites, larger particles may be of metallic (and/or oily) material instead of soil and organic material, with less of an increase in nutrients for the larger particles, but greater COD and TOC content if oily material.

At residential and commercial areas, removal of all particulates down to about 10 µm in the stormwater would remove almost all of the particulate associated phosphorus. However, the filterable phosphorus concentrations can still be high, requiring additional treatment targeting these filterable forms to reduce the phosphorus levels to typically acceptable levels. Similar results were found for industrial stormwater: removal of all particulates down to about 10 or 20 µm would remove almost all of the particulate bound COD. The filterable COD may still be substantial, indicating large amounts of dissolved organic material.

Heavy Metals
In almost all cases, the heavy metals are mostly associated with particulates in stormwater, except for Zn which can have large portions associated with the filterable fraction. Residential and commercial areas may have greater filterable fractions of metals in the stormwater than industrial sites that may have greater fractions associated with particulates. The normal trend is increases in pollutant strengths of metals with decreases in particle size. However, at industrial sites, large metallic portions may be associated with larger particles sizes due to the nature of the source material. At a monitored industrial area, the majority of the pollutant concentrations (and mass) were associated with the 10 to 100 µm particle size range.

Residential and commercial stormwater filterable heavy metals (zinc, cadmium, and lead) are mostly bound to organic complexes or as colloids that are difficult to remove by ion exchange but may be removed by sorption processes. Copper was mostly in ionic forms that can be readily removed by ion exchange (depending on the ionic strength).

Pre-treatment sedimentation controls removing only the largest particles (>100 µm for example) would only result in small reductions of the resulting effluent water concentrations. More effective treatment controls that can remove smaller particles would result in much better effluent quality (down to about 5 µm, beyond which little additional benefit is likely by sedimentation processes).

PAHs
Because of their low volatility (low Henry's Law constant), high octonal-water partition coefficients (K_{OW}) and high soil organic coefficients (K_{OC}), many of the stormwater PAHs are preferentially adsorbed to particulate matter, especially organics. The smaller and larger particles can have relatively higher PAH particulate strength values compared to the intermediate sized particles, depending on the organic content of the material. PAHs can be effectively controlled concurrent with high levels of stormwater particulate control.

Overall Particulate Strength Summary Tables
Table 59 are summary tables showing the particulate strength ratios for the constituents examined. There are some missing values. The closest values should be selected on the WinSLAMM factor tables for the particle size ranges.

Table 59. Overall Table of Particulate Strength Ratios

WinSLAMM particle range (um)	volatile solids (Cai 2013)	specific gravity (g/cm3) (Cai 2013)	average COD ratio	avg TP ratio with <250 um	TN ratio with <250 um	resid and commer avg TOC ratio with <63 (SERDP 2018)	indus avg TOC ratio with <63 (SERDP 2018)	Chlordane ratio with <63 um (SERDP 2018)	Total PCBs ratio with <63 um (SERDP 2018)
<1			1.30	1.91		2.20	0.95	0.96	1.79
1 to 2			1.20	1.68		2.20	0.95	0.96	1.79
2 to 5			0.66	0.71		2.20	0.95	0.96	1.79
5 to 10			0.66	0.71		0.29	0.63	0.25	0.39
10 to 20			0.67	0.81		0.29	0.63	0.25	0.39
20 to 40			0.67	0.81		0.52	1.42	1.88	0.82
40 to 50	1.08	3.46	1.15	0.78	1.29	0.52	1.42	1.88	0.82
50 to 60	1.07	3.30	1.09	1.00	1.07	0.52	1.42	1.88	0.82
60 to 80	1.07	3.30	1.20	1.16	0.89				
80 to 100	0.85	2.97	0.90	0.71	0.93				
100 to 150	0.85	2.97	0.96	0.68	0.93				
150 to 200	0.85	2.76	0.54	0.53	0.79				
200 to 300	0.80	2.76	0.66	0.52	0.49				
300 to 500	1.08	2.56	0.68	0.70	0.56				
500 to 800	1.08	1.43	0.70	0.70	0.56				
800 to 1000	1.77	1.43	0.86	0.69	0.83				
1000 to 2000	1.77	1.15	1.15	0.88	1.23				
>2000	2.67	0.66	1.43	0.90	1.18	0.81	2.75	0.24	0.15
Sticks	3.37	0.84	1.28	0.19	1.23				
Decomposing leaves	3.87	2.28	3.35	0.21	0.85				
overall avg COV			0.97	0.97		0.66	0.63	1.72	1.55

Table 59. Overall Table of Particulate Strength Ratios (continued)

WinSLAMM particle range (um)	avg Cd ratio with <180	avg Cu ratio with <180	overall avg Pb ratio with <250	overall avg Zn ratio with <250	overall avg Cr ratio with <250	Sed Fe ratio with <250 (Khambhammettu 2005)	res/com Hg ratio with <63 (SERDP 2018)	res/com Ni ratio with <63 (SERDP 2018)	res/com As ratio with <63 (SERDP 2018)
<1	0.83	2.89	3.07	2.89			0.49	1.82	1.73
1 to 2	1.94	1.26	1.25	0.94			0.49	1.82	1.73
2 to 5	2.12	1.15	0.51	1.05			0.49	1.82	1.73
5 to 10	1.64	0.41	0.51	0.48			1.58	0.75	0.77
10 to 20	0.61	0.46	0.55	0.61			1.58	0.75	0.77
20 to 40	0.45	0.31	0.33	0.56			0.93	0.43	0.50
40 to 50	0.65	0.61	0.60	0.96	1.26		0.93	0.43	0.50
50 to 60	0.61	0.90	0.83	0.91	1.09		0.93	0.43	0.50
60 to 80	2.61	1.35	0.85	1.21	1.23	1.29			
80 to 100	1.09	0.99	0.79	0.84	0.89	1.06			
100 to 150	1.09	0.55	0.65	0.64	0.89	1.06			
150 to 200	1.09	0.39	0.51	0.42	0.58	0.64			
200 to 300	0.04	0.36	0.48	0.53	0.56	0.60			
300 to 500	0.14	0.34	0.44	0.55	0.51	0.60			
500 to 800	0.16	0.29	0.43	0.45	0.51	0.49			
800 to 1000	0.16	0.35	0.44	0.47	0.87	0.87			
1000 to 2000	0.16	0.25	0.38	0.46	0.46	0.87			
>2000		0.52	0.75	1.21	0.56	1.22	3.94	1.95	12.82
Sticks		0.13	0.04	0.27	0.11				
Decomposing leaves	0.41	0.23	0.09	0.16	0.19				
overall avg COV	0.87	0.71	0.93	0.77			0.63	0.89	0.73

Table 59. Overall Table of Particulate Strength Ratios (continued)

WinSLAMM particle range (um)	indus Cd ratio with <63 (SERDP 20180	indus Cu ratio with <63 (SERDP 2018)	indus Pb ratio with <63 (SERDP 2018)	indus Zn ratio with <63 (SERDP 2018)	indus Hg ratio with <63 (SERDP 2018)	indus Ni ratio with <63 (SERDP 2018)	indus As ratio with <63 (SERDP 2018)
<1		1.64	0.95	1.59	0.69	0.43	
1 to 2		1.64	0.95	1.59	0.69	0.43	
2 to 5	0.44	1.64	0.95	1.59	0.69	0.43	0.03
5 to 10	0.44	1.64	0.57	1.23	0.38	0.17	0.03
10 to 20	0.44	1.64	0.57	1.23	0.38	0.17	0.03
20 to 40	1.56	1.21	1.48	1.23	1.93	2.40	1.97
40 to 50	1.56	1.21	1.48	1.23	1.93	2.40	1.97
50 to 60	1.56	1.21	1.48	1.23	1.93	2.40	1.97
60 to 80							
80 to 100							
100 to 150							
150 to 200							
200 to 300							
300 to 500							
500 to 800							
800 to 1000							
1000 to 2000							
>2000	40.52	5.91	3.04	7.97	6.46	6.77	4.41
Sticks							
Decomposing leaves							
overall avg COV	1.11	0.94	1.00	0.63	0.98	0.51	0.69

Table 59. Overall Table of Particulate Strength Ratios (continued)

WinSLAMM particle range (um)	avg Naphthalene ratio with <200	avg Fluorene ratio with <200	Acenaphthylene ratio with <63 (SERDP 2018)	avg Phenanthrene ratio with <200	avg Anthracene ratio with <200	avg Fluoranthene ratio with <200	avg Pyrene ratio with <200
<1	1.45	0.88	2.42	0.22	0.31	1.60	1.63
1 to 2	1.45	0.88	2.42	0.22	0.31	1.60	1.63
2 to 5	0.23	0.88	2.42	0.22	0.31	1.60	1.63
5 to 10	0.23	0.50	0.06	0.96	0.25	0.25	0.52
10 to 20	0.23	0.50	0.06	0.96	0.25	0.25	0.52
20 to 40	1.32	1.62	0.52	1.83	2.44	1.15	0.86
40 to 50	1.30	1.39	0.52	1.57	1.82	1.18	1.05
50 to 60	1.11	1.24	0.52	1.42	1.71	1.15	0.92
60 to 80	0.89	0.85		1.02	0.99	1.15	0.98
80 to 100	0.89	0.85		1.02	0.99	1.15	0.78
100 to 150	0.82	0.99		0.66	0.80	0.64	0.78
150 to 200	0.82	0.99		0.66	0.80	0.64	0.78
200 to 300	0.47	0.56		0.47	0.53	0.37	0.33
300 to 500	0.63	0.62		0.53	0.62	0.46	0.45
500 to 800	0.63	0.62		0.53	0.62	0.46	0.45
800 to 1000	3.98	0.90		0.65	1.21	0.48	0.39
1000 to 2000	3.98	0.90		0.65	1.21	0.48	0.39
>2000	4.49	1.15		0.96	1.21	0.39	0.35
LOM and or oily debris	17.98	4.51	4.30	21.31	7.71	13.66	14.97
avg COV	1.28	1.47	1.36	1.23	1.28	1.78	1.18

Table 59. Overall Table of Particulate Strength Ratios (continued)

WinSLAMM particle range (um)	avg Chrysene ratio with <200	avg Benzo(a)anthracene ratio with <200	avg Benzo(b)flourantene ratio with <200	Benzo(k)fluoranthene ratio with <63 (SERDP 2018)	avg Benzo(a)pyrene ratio with <200	avg Dibenzo(a,h)anthracene ratio with <200	avg Benzo(ghi)perylene ratio with <200
<1	1.37	1.40	1.40	1.37	1.33	0.94	1.24
1 to 2	1.37	1.40	1.40	1.37	1.33	0.94	1.24
2 to 5	1.37	1.40	1.40	1.37	1.33	0.94	1.24
5 to 10	0.53	0.57	0.48	0.49	0.48	0.55	0.48
10 to 20	0.53	0.57	0.48	0.49	0.48	0.55	0.48
20 to 40	1.10	1.03	1.13	1.14	1.19	1.51	1.28
40 to 50	1.12	1.15	1.17	1.14	1.20	1.45	1.25
50 to 60	1.13	1.03	1.09	1.14	1.22	1.19	1.03
60 to 80	1.16	1.04	1.05		1.25	0.87	0.77
80 to 100	0.70	1.04	1.05		1.25	0.87	0.77
100 to 150	0.70	0.69	0.73		0.54	0.74	1.01
150 to 200	0.70	0.69	0.73		0.54	0.74	1.01
200 to 300	0.39	0.43	0.82		0.36	0.30	0.36
300 to 500	0.53	0.57	0.46		0.28	0.39	0.29
500 to 800	0.53	0.57	0.46		0.28	0.39	0.29
800 to 1000	0.36	0.42	0.64		0.39	0.77	0.94
1000 to 2000	0.36	0.42	0.64		0.39	0.77	0.94
>2000	0.45	0.70	0.72		0.62	0.62	0.64
LOM and or oily debris	11.23	11.73	9.41	14.26	6.93	14.82	4.56
avg COV	1.12	1.42	1.45	1.57	1.52	1.48	1.38

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Appendix A: Characteristics of Stormwater PAHs and PPCPs Affecting their Portioning to Particulates

Bathi (2008) examined polycyclic aromatic hydrocarbons (PAHs) in urban runoff in both insoluble and particulate-associated forms. Because of their low volatility (low Henry's Law constant), high octonal-water partition coefficients (K_{OW}) and high soil organic coefficients (K_{OC}), many PAHs are preferentially adsorbed to particulate matter.

In contrast to what one would expect, high molecular weight (HMW) PAHs, which are assumed to be pyrogenic in origin, were found to be from original petroleum sources in these sediments. Of course, some of these primary petroleum materials have undergone combustion in transportation and industrial operations. Tracking the sources of PAHs based on the presence of low molecular weight (LWM) or HMW PAHs also becomes questionable as the PAHs are released into the environment and undergo chemical, physical and biological changes (Countway, *et al.* 2003). Physical changes (such as evaporation, or physical transport of by air or water from one location to other), chemical changes (such as photo transformation of PAHs to daughter products), and biological changes (such as biotransformation of the PAHs), changes their profile in the environment. Differentiating the sources of PAHs based on observed PAH molecular weights may be a useful tool if the samples analyzed for PAHs are assumed not to be affected by any of these modifications and are recently discharged. Aged sediment has a greater likelihood of undergoing these modifications compared to recently discharged materials, although many of these modifications can occur in the watershed (such as street dirt or other contaminated particulates) before the material is discharged.

The solid-water sorption coefficient (K_d) of a contaminant describes the distribution between the aqueous and solid phases of the system at equilibrium. According to Boethling, *et al.* (2000), the organic carbon normalized sorption coefficient (K_{oc}) approach is the most appropriate procedure for estimating the sorption coefficients, where:

$$K_{oc} = \frac{K_d}{oc}$$

The K_d is the solid-water sorption coefficient and OC is the organic fraction of the solid. There are many regression models available to estimate the Log K_{oc} of PAHs from Log K_{ow}, where K_{ow} is the octonal water partition coefficient, for example:

Log K_{oc} = 0.904 log K_{ow} – 0.006 (Chiou, *et al.* 1983)

Log K_{oc} = 1.000 log K_{ow} – 0.210 (Karichhoff, *et al.* 1979)

Regression equations relating the Log K_{oc} and Log S are also available in the literature, where S is the solubility of PAH in water, for example:

Log K_{oc} = log S + 0.44 (Karichhoff, *et al.* 1979)

In general, the relationship between the dissolved and sorbed chemical concentrations of PAHs is non-linear in nature which can be represented by the Freundlich isotherm:

$C_{sorb} = K_f \cdot (C_w)^n$;

The C_{sorb} is the concentration of the sorbed chemical, K_f is the Freundlich constant, C_w is the concentration of the dissolved chemical, and n reflects the nonlinearity, with n equal to one representing a linear partition relationship.

Under equilibrium conditions, the partition coefficients discussed above may be effective in predicting the PAH partition concentrations in the liquid and solid phases, but these predictions may not be accurate for real time systems which are not usually at equilibrium. Differences between predicted sorption coefficients and actual measured observations were seen by Hwang, *et al.* (2006) in their study of PAHs in stormwater samples along the lower Anacostia River in Washington, D.C. Though the report did not provide the details about how different the predicted and observed values were, they reported that the concentrations of particulate-bond PAHs were higher than the predicted concentrations, as one could expect based on analyses of the solid-water partition coefficient (K_d).

Factors that affect the PAH associations with the particulate matter in the aquatic environment include the physical and chemical properties of the specific PAH contaminant, the physical and chemical properties of the aquatic medium, and the physical and chemical properties of the particulate matter. For the purpose of understanding such effects, Zhou, *et al*. (1998) studied the relationships between the concentrations of fluoranthene and pyrene on suspended solids with salinity, suspended solids concentration and particulate organic carbon, in the Humber estuary, UK. The concentrations of selected PAHs on suspended solids showed no correlation with the salinity of the samples, while concentrations of suspended solids and particulate organic carbon showed a clear relationship with concentrations of PAHs on the suspended solids. Concentrations of suspended solids in the samples showed negative correlations with the concentrations of selected PAHs on suspended solids, whereas particulate organic content showed positive correlations with the concentrations of particulate-associated PAHs. Zhou, *et al.* (1998) also showed that higher concentrations of PAHs are likely associated with the finer particles (generally classified as clay material which have large surface areas per unit weight), compared to the coarser particles (generally classified as sand particles which have comparatively less organic matter which are needed for greater sorption of PAHs).

A similar pattern was observed by Aryal, *et al.* (2005) who monitored suspended solids and PAHs associated with fractionated suspended solids in highway runoff for four rain events (samples were only collected during the initial 3 mm of runoff) at an inlet point of treatment facilities for a highway drainage system in Winterthur, Switzerland. The measured concentrations of PAHs in fine fractions (<45µm) were higher than their concentrations in coarse fractions (>45µm).

Mahler, *et al.* (2005), of the U.S. Geological Survey, examined PAHs in washoff water runoff and particulates collected from four parking lot test plots. Results indicated that the coal-tar-sealed parking lots had higher concentrations of PAHs than those from any other examined type of surface. The reported average total PAH concentrations in particulates in the runoff from the parking lots were

3,500,000 µg/kg from coal-tar-sealed, 620,000 µg/kg from asphalt-sealed, and 54,000 µg/kg from unsealed parking lots.

Rushton (2006) studied the association of selected PAHs on gross solids while analyzing the performance of a hydrodynamic separator retrofit unit installed to control stormwater discharging to the Hillsborough River, south Florida. The gross solids, consisting of litter, leaves, trash and sediment, collected by the CDS unit was found to have a wide range of concentrations for the selected PAHs. They found high concentrations of PAHs on the gross solids that had high organic content.

Fugacity level 1 (Mackay, *et al.* 1992) calculations were used by Bathi (2008) to predict the partitioning of PAHs among the environmental phases (only applicable for equilibrium conditions). Prediction fate model calculations for selected PAHs were performed based on typical environmental conditions and with the assumption of system equilibrium. Based on this model, the partition percentages of selected PAHs into different phases were calculated. The equations involved in the model calculations are:

$$C = Z * f \quad \text{(or)} \quad f = \frac{M}{\sum (V_i * Z_i)}$$

Where, C = Concentration of contaminant, mol/m^3; Z = fugacity capacity constant, mol/m^3; f = fugacity, Pa; V_i = Volume of the corresponding phases; and Z_i = fugacity capacities of phases for air, water, sediment, suspended sediment, and fish for i =1, 2,3, 4, 5 respectively and are defined as follows.

$$Z_1 = \frac{1}{RT}$$

$$Z_2 = \frac{1}{H}$$

$$Z_3 = Z_2 * P_3 * \phi_3 * \frac{K_{OC}}{1000}$$

$$Z_4 = Z_2 * P_4 * \phi_4 * \frac{K_{OC}}{1000}$$

$$Z_5 = Z_2 * P_5 * L * \frac{K_{OW}}{1000}$$

Where R = gas constant (8.314 J/mol K), T = absolute temperature (K), H= Henry's law constant (Pa.m^3/mol), K_{OC} = Organic-water partition coefficient, K_{OW} = Octonal-water partition coefficient, P_3 = density of sediment (kg/m^3), P_4 = density of suspended sediment (kg/m^3), $Ø_3$= organic fraction of sediment, $Ø_4$= organic fraction of suspended sediment, P_5 = density of fish in the aquatic system (kg/m^3), L= Lipid content of fish.

During her UA dissertation research, Goodson (2013) investigated the sources and fates of PAHs and pharmaceutical and personal care products (PPCPs) at a Tuscaloosa, AL, wastewater treatment plant that also received substantial stormwater during wet weather.

PAHs are divided into two categories: low molecular weight (LMW) PAHs and high molecular weight (HMW) PAHs.

Table A-1. PAH Categories

Low Molecular Weight PAHs	High Molecular Weight PAHs
Naphthalene	Benzo(a)anthracene
Acenaphthene	Pyrene
Acenaphthylene	Benzo(a)pyrene
Fluorene	Chrysene
Phenanthrene	Benzo(b)fluoranthene
Anthracene	Fluoranthene

Table A-2. Summary of Characteristics and Treatability of Targeted Pollutants

Constituent	**Log Kow**	**Solubility (mg/L)**	**pka**	**Biodegradation half-life * **rate**	**Toxicity**
Pharmaceuticals					
Gemfibrozil	4.78	5.0	4.7	1.5 hours	EC 50 D. Magna 22.85 mg/L
Ibuprofen	3.5-4.0	41.5	4.9	2 hours	EC 50 Daphnia. 108 mg/L
Triclosan	4.8-5.4	2-4.6	7.8	125 hours	IC 50 P. subcapitata. 1.4 µg/L
Carbamazepine	2.25	17.7	13.9	10-20 hours	LC 50 D. magna >100 mg/L
Fluoxetine	4.05	38.4	9.5	24-72 hours	LC 50 P. subcapitata 24 µg/L
Sulfamethoxazole	0.9	600	5.7	10 hours	IC 50 P. subcapitata. 1.5 mg/L
Trimethoprim	0.79	400	6.8	8-10 hours	IC 50 P. subcapitata. 80.3 to 130 mg/L
Polycyclic Aromatic Hydrocarbons	**Log kow**	**Solubility**	**Volatility**	**Biodegradation rate**	**Toxicity**
Napthalene	3.37	31.7	4.6×10^{-4}	0.8-43 days	LC 50 Pimephales promelas 7.76 mg/L

Acenaphthene	4.02	1.93	7.91 x 10^{-5}	1-25 days	LC 50 Salmo gairdneri 1570 µg/L
Fluorene	4.12	1.68-1.98	1.0 x 10^{-4}	2-64 days	EC 50 V. fischeri 4.10 µg/mL
Fluoranthene	5.14	0.20-0.26	6.5 x $10-^{6}$	880 days	EC 50 S. capricornutum 54,400 µg/L
Acenaphthylene	3.89	3.93	1.5 x 10^{-3}	21-121 days	Did not find
Phenanthrene	4.48	1.20	2.56 x 10^{-5}	19 days ; 35-37 days;	Did not find
Anthracene	4.53	0.0076	1.77 x10^{-5}	108-139 days	EC 50 D.magna 211 µg/L;
Pyrene	5.12	0.0.077 (Dabestani and Ivanov 1999, 10-34)	4.3 x 10^{-4}	34 to 90 weeks	EC 50 D.magna 67000 µg/L
Benzo(a) anthracene and chrysene	5.61-5.71	0.0016-0.011	n/a	n/a	n/a
Benzo(b) fluoranthene, Benzo(k) fluoranthene, Benzo(a) pyrene, and indeno(1,2,3,cd) pryene			n/a	n/a	n/a
Benzo(a,h) anthracene and Benzo(g,h,i) perlene			n/a	n/a	n/a
Pesticides	Log kow	solubility	Reported most important treatment method	Biodegradation rate	Toxicity
Methoxychlor	4.68-5.08	0.1	Adsorption/biodegradation	7 to 29 days	D. magna EC 50=1800 µg/L
Aldrin	6.5	0.027	Adsorption/biodegradation	20-100 days	Salmo gairdneri LC 50 2.6 µg/L
Dieldrin	6.2	0.1	Adsorption/biodegradation	None found	Salmo gairdneri LC 50 1.2 µg/L
Chlordane	~5.54	insoluble*	Adsorption/biodegradation	60 days	Chironomus plummosus LC 50 10 µg/L
Arochlor Σ	5.6-6.8	insoluble*	Adsorption/biodegradation	Variable. Depends on chlorination of compound	P. subcapitata 182nmol/L
Lindane	3.8	17	Adsorption/biodegradation	69.41 hours	D. magna EC 50=1.64 mg/L
Heptachlor	6.10	0.056	Adsorption/biodegradation	6 months-3.5 years	S. capricornutum

					LC 50 26.7 µg/L
Heptachlor-epoxide	5.40	not found	Adsorption/biodegradation	None found; metabolite	None found
	4.68-5.08	0.1	Adsorption/biodegradation		

Naphthalene has a Henry's Law constant of 0.019 atm-m^3/mol, making it more volatile than the other PAHs and more likely to volatize during wastewater treatment. Acenaphthene, acenaphthylene, fluorene, phenanthrene and anthracene have Henry's Law constants of about 10^{-3}, and their solubilities range from 0.045 to 16.1 mg/L. Volatilization and oxidation were the primary means of reported treatment for PAHs having lower molecular weights. High molecular weight (HMW) PAH compounds (such as pyrene, fluoranthene, chrysene, and benzo(a)pyrene) had higher reduction percentages ranging from 83 to 91 percent. Adsorption is a primary removal factor for the HMW compounds. Influent concentrations for LMW PAHs ranged from 0.016 to 7.3 µg/L. Effluent concentrations for LMW PAHs had a range from 0.002 to 0.7 µg/L. Influent concentrations for the HMW PAHs ranged from 0.044 to 0.47 µg/L. Effluent concentrations for HMW PAHs ranged from 0.013 to 0.06 µg/L.