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Development of Tools to Inform the Selection of Stormwater Controls at DoD Bases to Limit Potential Sediment Recontamination (ER18-1371)

Reese Technology Center, Lubbock, Texas, Development Characteristics, Monitoring Data Summary, and Stormwater Modeling

Contents

Summary

The objective of this report is to describe various aspects of stormwater quality and its current treatment at the Reese Technology as part of the SERDP project titled *Development of Tools to Inform the Selection of Stormwater Controls at DoD Bases to Limit Potential Sediment Recontamination*. Additional reports are being submitted describing the stormwater conditions at monitored locations at San Diego and Puget Sound facilities.

This report describes the development characteristics of the Reese Technology Center, monitored stormwater and Picnic Lake water quality, and modeled pollutant sources and lake sedimentation performance. Four main areas drain into Picnic Lake, three through discharge points and one as sheetflow. The total drainage area is about 255 acres and the lake is about 4 acres (1.6% of the drainage area). About half of the total area is comprised of directly connected paved areas (mainly parking areas and the old airfield apron, plus streets, roofs, and walkways).

Stormwater and Picnic Lake water quality were monitored by researchers at Texas Tech University located near the site. This report focusses on the data most relevant to supporting modeling of the area and the treatment provided by the lake. Of the two events monitored, one had about a 25mm rainfall and was widespread over the Lubbock area, while the other event was very small and localized (with no rainfall recorded by the National Weather Service). Therefore, the analyses in this report focused on the 25mm rain conditions. Additional water quality analyses have been provided by the Texas Tech researchers.

Outfall concentrations were much greater than the in-pond concentrations. The similarities within the two sample groups (stormwater discharges vs. in-pond locations) are much closer than between the sample groups. The concentrations generally increase for larger particle sizes (see the later cumulative mass plots also). This is common for industrial locations associated with more contaminated large debris, and may also be associated with channel scour in the drainage channels. This is especially evident for the particulate solid's stormwater concentrations, where the >63 µm concentrations are much greater than for the smaller increments. The highest particulate solids concentrations for the in-pond samples are for the 5 to 20 µm size range, indicating that the large particles are substantially removed by sedimentation in the lake.

Many of the size-related PAH concentrations were not detected, especially for the in-lake samples. The stormwater PAH concentration trends with size were not as obvious as for the metals and particulates, but the outfall PAH concentrations were much greater than the in-lake PAH concentrations.

Pollutant particulate strengths associated with different particle sizes were also evaluated. The particulate strengths were similar for the stormwater and lake samples for each size range as they originate from the same source. The lake has fewer larger suspended particles compared to the stormwater, and the overall concentrations are much lower. This resulted in many non-detected concentration observations for the lake water. Ratios of pollutant strengths for the different particle sizes were compared to the total bulk particulate strength, as a primary tool in the future modifications to the WinSLAMM stormwater model that will be made during the next project phase.

Analyses were also made examining the cumulative pollutant masses by particle size. This indicates the importance of which size ranges are associated with most of the pollutant discharges, as a tool in determining appropriate levels of stormwater control. These analyses also illustrate the performance of Picnic Lake as a sedimentation treatment facility. Total particulate solids size distributions from the stormwater samples are distinctly different from the in-lake samples. The median size for the stormwater samples was about 100 µm, while it was only about 10 µm for the in-lake samples. There were very few in-lake particles greater than 64 µm, while about 75% of the stormwater samples were greater than 64 µm, substantiating the preferential removal of the larger particles through sedimentation.

Additional analyses were also made to illustrate the performance of Picnic Lake. The discharge particulate solids average concentration was about 730 mg/L (high for most stormwater, but possible affected by erosion in the unlined stormwater channel conveyances). The average in-lake particulate solids concentration was about 50 mg/L, indicating a 93% reduction. The COV values for both data sets were relatively low, but there were few data available. The concentration reductions for the heavy metals ranged from about 60 to 90%, with arsenic showing a possible increase (likely faulty), but no statistical comparison tests were used due to the limited data. Most of the PAHs indicate large reductions in concentrations between the stormwater and in-lake samples. Most of the unfiltered PAH concentration reductions are very high >90%), with the filtered concentration reductions being less, but still high (80 and 90% reductions).

WinSLAMM modeling, using the calibrated and verified files developed previously for use on US naval facilities in San Diego, Puget Sound, and Norfolk, was used to examine the main sources of flows and pollutants for different rain categories and to calculate the expected treatment of Picnic Lake for comparison to the monitored data. For the smallest rains, most of the flows are expected to originate from the paved parking and old airport apron areas. For the 25mm rain depth associated with data described in this report, flat roofs and streets are also important with some runoff originating from the large turf areas. For the largest rains. The paved parking areas contribute about 27%, the old airport apron contributes about 22%, large turf areas contribute about 17%, and the flat roofs contribute about 13% of the total runoff.

Particulate solids sources were quite different, especially for the large rains. For the smallest rains, paved parking and the old airfield apron areas were the major sources, with streets being important for small rains up to about 13 mm. For the 25mm rain, these two areas still comprised the majority of the particulate solids discharges, while for the largest rains, the large turf areas were the major source, with the two large paved areas also important. Roofs areas were never significant sources (due to low concentrations.

A 25 mm rain is expected to cause a 6 cm rise is the water surface elevation of Picnic Lake. The pond outlet is a pair of 36-inch culverts that results in relatively large outflow discharges at low stages, compared to triangular outlets for example. However, the large capacity outlets are necessary to reduce flooding risks in the surrounding area, especially over-topping the adjacent road. The maximum 6-cm increase is associated with 9 µm particles, which would be associated with about an 80% reduction in particulate solids. This is the minimum value associated with peak inflow rates and would be greater for most of the rain event. This calculated worst-case removal compares to the observed average performance of about 93% for the complete event.

The next phase of the project will involve modifying WinSLAMM to calculate the sources and treatment benefits for discrete particle size ranges instead of the current use of bulk characteristics. This will result in more accurate predictions of pollutant discharges and their fates in receiving water.

Reese Technology Center Site Characteristics

Figure 1 is an aerial image show the Reese Technology Center near Lubbock, Texas. The site is a decommissioned US Air Force base that is being converted to multiple uses.

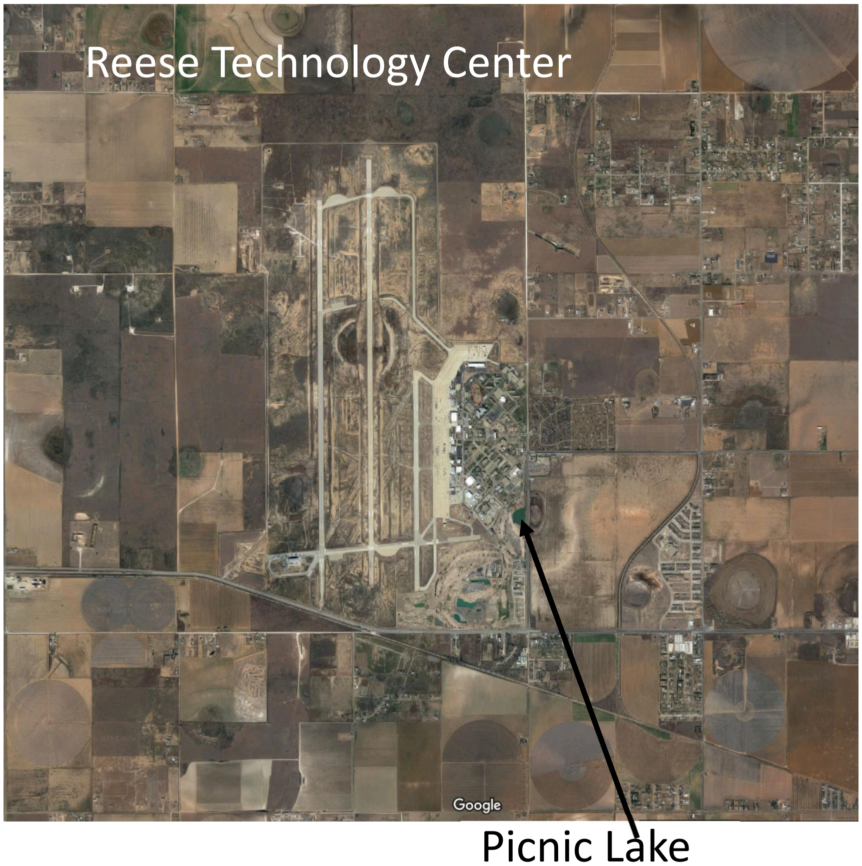


Figure 1. Reese Technology Center (Google Map image supplied by TT)

Figure 2 is an aerial image showing Picnic Lake and the stormwater discharge locations to the lake. The lake is a wet detention pond serving much of the developed Reese Technology Center area. Appendix A includes photographs of Picnic Lake and the sampling locations.

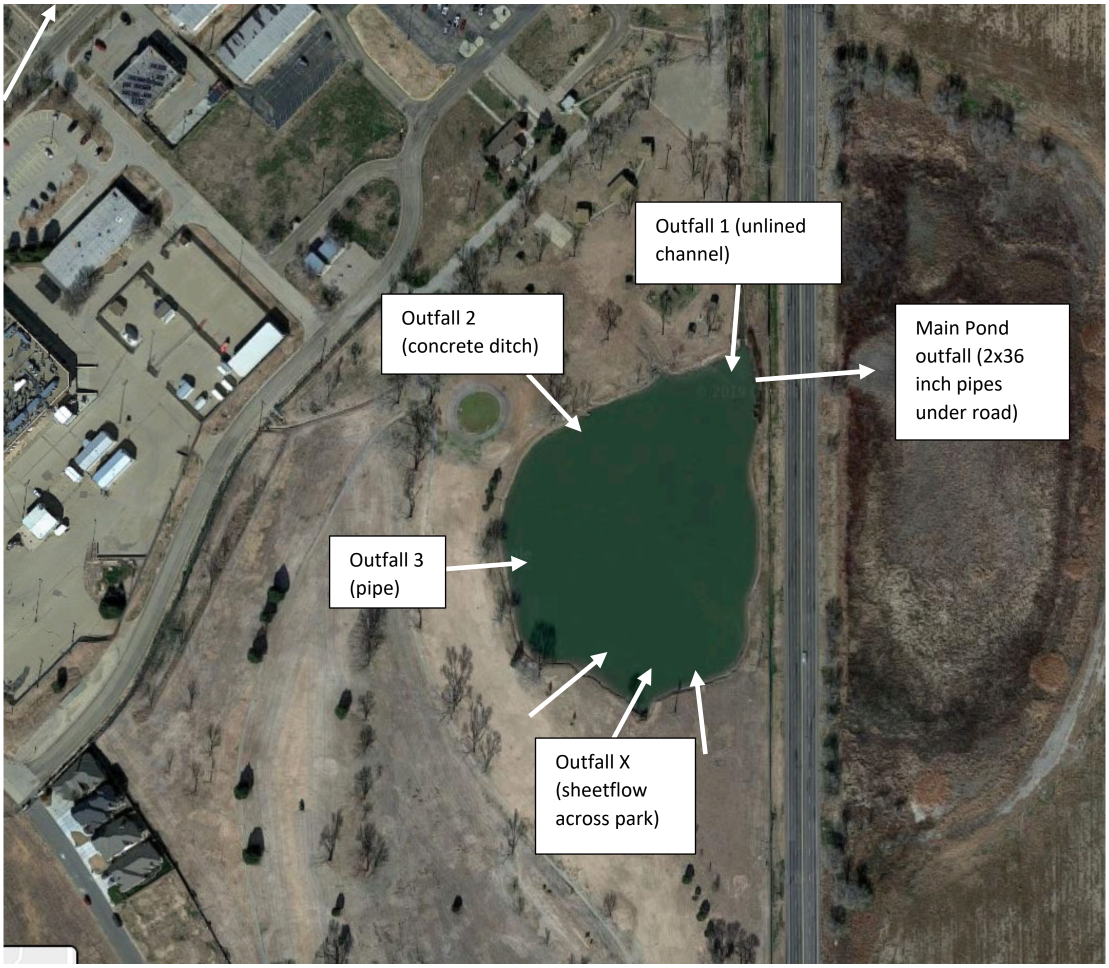


Figure 2. Picnic Lake and outfalls (Google Map image supplied by TT)

Figure 3 is a composite of several Google Earth images showing the four drainage areas to Picnic Lake. These drainages are shown as area 1, 2, 3, and X. Drainage from the X watershed area enters the pond mostly as sheetflow across the park area around the pond. Site survey locations are also shown on this map numbered 1 through 16. The drainage areas and the site surveys are described on Tables 1 through 8.

Tables 1 through 4 show the surface area characteristics of the drainage areas. These were directly measured from the full-size composite aerial image as shown on Figure 3, supplemented with the site surveys. These source areas are divided by the major land uses on the site (institutional and light to medium industry, plus park areas). The source areas those that are used in the stormwater quality modeling using WinSLAMM. These areas include the old airfield apron, storage and parking areas, roofs, streets, walkways, and large turf areas. The roofs are subdivided into flat and pitched roofs. The large flat roofs mostly are directly connected to the stormwater drainage system while the smaller pitched roof areas mostly drain to adjacent landscaped areas. The streets are divided into two width categories. Table 5 shows these source areas summed (255 acres) for the total Picnic Lake drainage area. Table 6 shows these areas divided by the two main land uses. The park area has almost 90% turf areas, and the institutional/light to medium industry area has about 40% turf areas, while the remaining area is comprised of various impervious areas. Table 7 shows the breakdown of directly connected impervious, disconnected impervious, and pervious areas for the four drainage areas and land uses.

The drainage areas shown on Figure 3 were determined using detailed stormwater drainage maps and topography maps from Reese Technology Center, supplemented by site surveys of the perimeters to verify drainage divides.

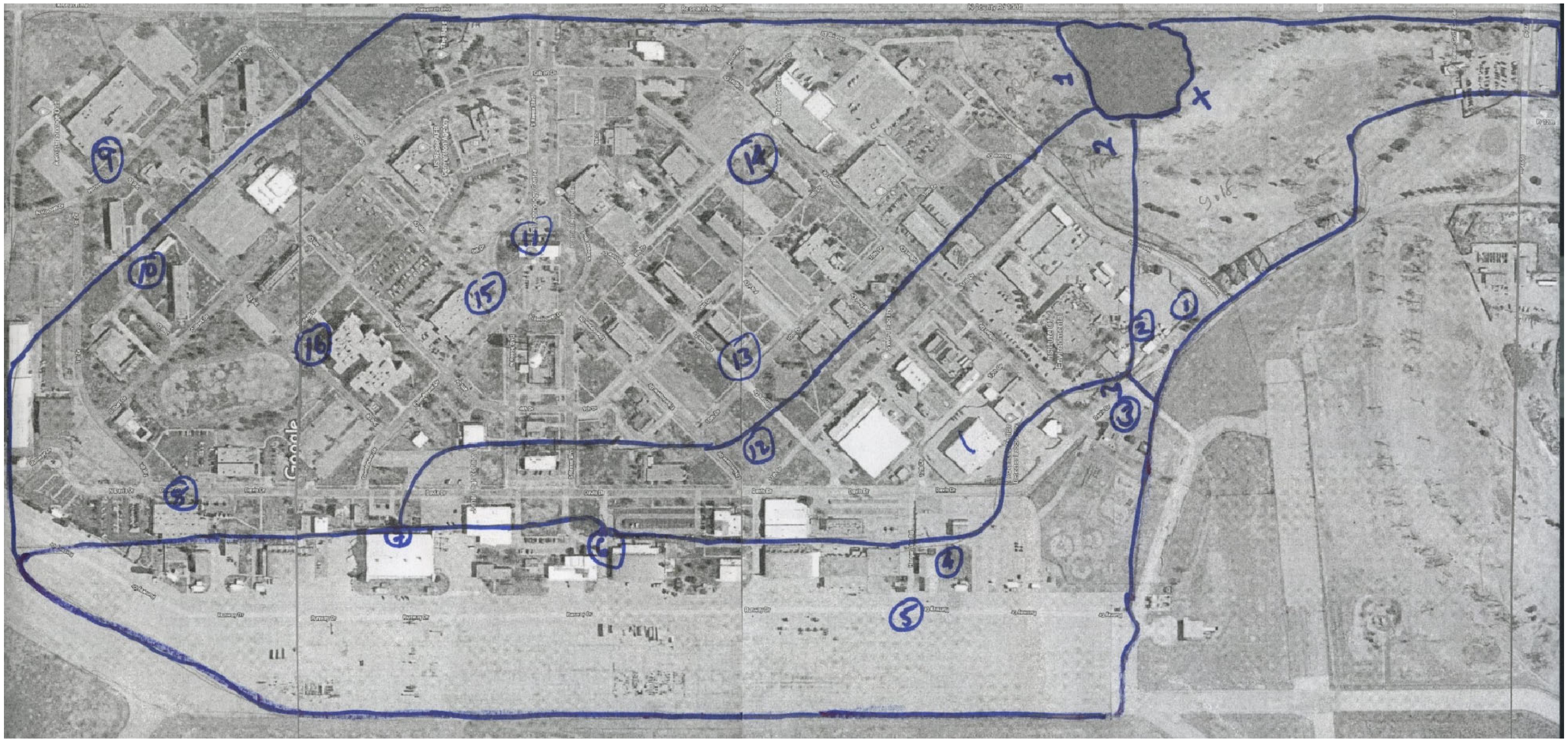


Figure 3. Reese Technology Center drainage areas to Picnic Lake and locations of site surveys

Table 1. Outfall 1 Surface Area Characteristics

		large pvd (old airfield apron) - concrete, directly connected	pvd storage/parking areas. Directly connected	roofs - flat dir connected	roofs - pitched disconnected	streets, narrow (26 ft wide)	streets, wide (36 ft wide)	walkways, disconnected	large turf areas, silty soils, normal compaction	total area	% of total area to pond
institutional/light to medium industrial	acres	0.0	19.77	11.98	0.0	1.88	15.60	1.71	51.04	101.98	39.92
	notes					3157 ft length	18871 ft length				
	% of total land use	0.0	19.4	11.7	0.0	1.8	15.3	1.7	50.0	100.0	
park	acres								3.89	3.89	1.52
	% of total land use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	
total outfall 1 area	acres	0.0	19.77	11.98	0.00	1.88	15.60	1.71	54.93	105.87	41.45
	% of total land use	0.0	18.7	11.3	0.0	1.8	14.7	1.6	51.9	100.0	

Table 2. Outfall 2 Surface Area Characteristics

		large pvd (old runway) - concrete, directly connected	pvd storage/parking areas. Directly connected	roofs - flat dir connected	roofs - pitched disconnected	streets, narrow (26 ft wide)	streets, wide (36 ft wide)	walkways, disconnected	large turf areas, silty soils, normal compaction	total area	% of total area to pond
institutional/light to medium industrial	acres	0.0	8.35	4.25	0.0	0.0	7.17	0.5	20.09	40.36	15.80
	notes						8439 ft length				
	% of total land use	0.0	20.7	10.5	0.0	0.0	17.8	1.2	49.8	100.00	
park	acres	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.33	2.33	0.91
	% of total land use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.00	
total outfall 2 area	acres	0.0	8.35	4.25	0.0	0.0	7.17	0.5	22.42	42.69	16.71
	% of total land use	0.0	19.6	10.0	0.0	0.0	16.8	1.2	52.5	100.00	

Table 3. Outfall 3 Surface Area Characteristics

		large pvd (old runway) - concrete, directly connected	pvd storage/parking areas. Directly connected	roofs - flat dir connected	roofs - pitched disconnected	streets, narrow (26 ft wide)	streets, wide (36 ft wide)	walkways, disconnected	large turf areas, silty soils, normal compaction	total area	% of total area to pond
institutional/light to medium industrial	acres	34.85	13.71	4.25	0.0	0.0	4.45	0.0	21.04	78.30	30.65
	notes						6025 ft length				
	% of total land use	44.5	17.5	5.4	0.0	0.0	5.7	0.0	26.9	100.00	

Table 4. Outfall X (Sheetflow to Picnic Pond) Surface Area Characteristics

		large pvd (old runway) - concrete, directly connected	pvd storage/parking areas. Directly connected	roofs - flat dir connected	roofs - pitched disconnected	streets, narrow (26 ft wide)	streets, wide (36 ft wide)	walkways, disconnected	large turf areas, silty soils, normal compaction	total area	% of total area to pond
institutional/light to medium industrial	acres		0.073	0.09			1.32		2.92	4.40	1.72
	notes						1644 ft length				
	% of total land use	0.0	1.7	2.0	0.0	0.0	30.0	0.0	66.3	100.00	
park/golf	acres		1.03	0.07	0.07		2.20		20.79	24.17	9.46
	notes						2743 ft length				
	% of total land use	0.0	4.3	0.3	0.3	0.0	9.1	0.0	86.0	100.00	
total outfall X area	acres	0.00	1.10	0.16	0.07	0.00	3.52	0.00	23.71	28.57	11.18
	% of total land use	0.0	3.9	0.6	0.3	0.0	12.3	0.0	83.0	100.00	

Table 5. Total Drainage Area to Picnic Pond Characteristics

	large pvd (old runway) - concrete, directly connected	pvd storage/parking areas. Directly connected	roofs - flat dir connected	roofs - pitched disconnected	streets, narrow (26 ft wide)	streets, wide (36 ft wide)	walkways, disconnected	large turf areas, silty soils, normal compaction	total area
acres	34.85	42.93	20.64	0.07	1.88	30.74	2.21	122.10	255.43
% of total area to pond	13.6	16.8	8.1	0.0	0.7	12.0	0.9	47.8	100.00

Table 6. Land Use Summary to Picnic Pond

		large pvd (old runway) - concrete, directly connected	pvd storage/parking areas. Directly connected	roofs - flat dir connected	roofs - pitched disconnected	streets, narrow (26 ft wide)	streets, wide (36 ft wide)	walkways, disconnected	large turf areas, silty soils, normal compaction	total area	% of total area to pond
institutional/light to medium industrial	acres	34.85	41.90	20.57	0.00	1.88	28.54	2.21	95.09	225.04	88.10
	% of total land use	15.5	18.6	9.1	0.0	0.8	12.7	1.0	42.3		
park/golf course	acres	0.00	1.03	0.07	0.07	0.00	2.20	0.00	27.01	30.39	11.90
	% of total land use	0.0	3.4	0.2	0.2	0.0	7.2	0.0	88.9		

Table 7. Impervious and Pervious Areas by Land Use Draining to Picnic Pond

		directly connected impervious area	disconnected impervious area	total impervious area	total pervious area
Outfall 1					
institutional/light to medium industrial	acres	49.2	1.7	50.9	51.0
	% of total land use	48.3	1.7	50.0	50.0
park	acres	0.0	0.0	0.0	3.8
	% of total land use	0.0	0.0	0.0	100.0
total outfall 1 area	acres	49.2	1.7	50.9	54.9
	% of total land use	46.5	1.6	48.1	51.9
Outfall 2					
institutional/light to medium industrial	acres	19.7	0.5	20.2	20.0
	% of total land use	49.0	1.2	50.2	49.8
park	acres	0.0	0.0	0.0	2.3
	% of total land use	0.0	0.0	0.0	100.0
total outfall 2 area	acres	19.7	0.5	20.2	22.4
	% of total land use	46.3	1.2	47.5	52.5
Outfall 3					
institutional/light to medium industrial	acres	57.2	0.0	57.2	21.0
	% of total land use	73.1	0.0	73.1	26.9
Outfall X					
institutional/light to medium industrial	acres	1.4	0.0	1.4	2.9
	% of total land use	33.7	0.0	33.7	66.3
park/golf	acres	3.3	0.07	3.3	20.7
	% of total land use	13.7	0.3	14.0	86.0
total outfall X area	acres	4.7	0.07	4.8	23.7
	% of total land use	16.8	0.3	17.0	83.0
Total area to Picnic Pond	acres	131.0	2.2	133.3	122.1
	% of total area to pond	51.3	0.9	52.2	47.8
institutional/light to medium industrial	acres	127.7	2.2	129.9	95.0
	% of total land use	56.8	1.0	57.7	42.3
park/golf course	acres	3.30	0.07	3.3	27.0
	% of total land use	10.9	0.2	11.1	88.9

A site survey was conducted at the Reese Technology Center in October 2019. Table 8 is a summary from the survey. Appendix B includes Google Earth images of the site survey locations and Appendix C shows photographs of the locations. These surveys were also conducted to support the WinSLAMM stormwater quality modeling. This table shows the site number (corresponding to the numbers shown on the Figure 3 composite image) along with the drainage areas for the locations. Major information shown includes land use, building characteristics, presence of treated wood nearby, landscaping characteristics, slopes, road characteristics (including parked cars and vehicle speed, pavement type and condition), and other paved area characteristics.

Table 8. Reese Technology Center Site Survey

site #	Picnic Pond Drainage	Date	Time	Location	Description	land use	Building Maintenance	heights of buildings	roof types
1	X	10/22/2019	12:50	Davis Dr and Hoover (7th st)	vacant roadside, buildings across road	roadside, golf nearby	no buildings	n/a	n/a
2	X	10/22/2019	12:55	Gilbert and 12th	toxicology bldg. With outfall 3 sampler in yard	medium industrial	excellent	2	flat
3	3	10/22/2019	2:10	Davis and Gilbert Dr	bldg. 790	light industrial	excellent	1 and 2	flat
4	3	10/22/2019	2:10	Gate 50	at old airfield	medium industrial	poor	1 and 2	flat
5	3	10/22/2019	2:20	Near Gate 50	on old airfield apron	airport apron	poor	2 and 3	flat
6	3	10/22/2019	2:30	Davis and Eisenhower	between Zachry Industries and bldg. 61	medium indus	moderate	2 and 3	flat
7	3	10/22/2019	2:45	Davis and Eisenhower (north side)	Zachry Industries	medium indus	moderate	2 and 3	flat
8	1	10/22/2019	2:50	102 Davis Dr.	South Plains College	school	excellent	1	flat
9	near 1	10/22/2019	3:00	1st St.	at Zachry Industry Bldg.	medium indus	moderate to excellent	2 and 3	flat
10	1	10/22/2019	3:10	1145 Bldg. off Hoover	abandoned base housing	multi-family resid	excellent	2	flat
11	1	10/23/2019	11:15	So. Reese Blvd. and Circle Rd.	Reese Admin. Bldg.	administration	excellent	3	flat
12	2	10/23/2019	11:30	Gilbert and Hoover	across from Reese conference center	parking lot	no buildings	n/a	n/a
13	1	10/23/2019	11:40	4th and Garfield	between apartments and administration bldgs.	institutional and resid	excellent	2	flat
14	1	10/23/2019	11:45	3rd and Eisenhower	vacant parking lot for institutional area	parking for instit - vacant	excellent	3	flat
15	1	10/23/2019	12:00	9th and Eisenhower	administration bldg.	administration	excellent	2	flat
16	1	10/23/2019	12:15	Gilbert and 10th	apartments	multi-family resid	excellent	3	flat

Table 8 (cont.). Reese Technology Center Site Survey (continued)

site #	nearby sediment sources	treated wood near drainage	landscaping near road	topography - street slope	topography - land slope	traffic speed	traffic density	parking density	street width - # parking lanes	street width - # street lanes	street condition	street pavement texture	street pavement material
1	no	tele poles	unmaintained	<2%	<2%	25 - 40 mph	light	none	0	2	good	very rough	asphalt
2	no	no	much lawn	<2%	<2%	<25	light	20 to 50%	0	2	good	intermediate	asphalt
3	no	no	some lawn	<2%	<2%	25 - 40 mph	light	none	0	2	good	very rough	asphalt
4	no	tele poles	none	<2%	<2%	<25	light	none	0	2	fair	intermediate	concrete
5	no	no	none	<2%	<2%	<25	light	none	0	2	fair	smooth	concrete
6	rocky debris on street edge	tele poles	some lawn	<2%	<2%	<25	light	none	0	2	fair to good	intermediate	asphalt
7	rocky debris on street edge	tele poles	some lawn	<2%	<2%	<25	light	none	0	2	fair to good	intermediate	asphalt
8	no	tele poles	some lawn	<2%	<2%	<25	light	none	0	2	good	intermediate	asphalt
9	rocky debris on street edge	no	none	<2%	<2%	<25	light	none	0	2	good	rough to very rough	asphalt
10	no	no	some lawn	<2%	<2%	25 - 40 mph	light	none	0	2	good	intermediate	asphalt
11	rocky debris on street edge	no	some lawn and trees	<2%	<2%	<25	light	none	0	divided 2	good	very rough	asphalt
12	no	no	some lawn	<2%	<2%	25 - 40 mph	moderate	none	0	2	good	very rough	asphalt
13	rocky debris on street edge	tele poles	much lawn	<2%	<2%	<25	light	none	0	2	good	very rough	asphalt
14	no	tele poles	some lawn and trees	<2%	<2%	<25	light	none	0	2	good	very rough	asphalt
15	rocky debris on street edge	tele poles	some lawn and trees	<2%	<2%	<25	light	none	0	2	good	very rough	asphalt
16	no	tele poles	some lawn and trees	<2%	<2%	<25	light	none	0	2	good	very rough	asphalt

Table 8 (cont.). Reese Technology Center Site Survey (continued)

site #	driveways condition	driveways texture	gutter material	gutter condition	gutter interface	litter loadings near street	parking/storage condition	parking/storage texture	other paved areas condition	other paved areas texture	notes and comments
1			concrete			clean					
2						clean	good	intermediate			short swale drains roofs and pvd areas
3							good	intermediate			directly connected
4	pvd fair to poor	smooth				clean	good	smooth concrete			parking lot and dead-end road
5									good	smooth	directly connected
6	pvd good	smooth	concrete	good		no litter but dirt	fair	intermediate			transformers stored on concrete apron
7	pvd good	smooth	concrete	good	smooth	heavy dirt	fair to good	intermediate			directly connected
8	pvd good	smooth	concrete	good	smooth	heavy dirt	good	rough			directly connected
9	pvd good	intermediate to rough	concrete	good	smooth	heavy dirt	good	rough			
10			concrete	good	smooth	clean	good	intermediate			directly connected
11			concrete	good	smooth	heavy dirt	good	rough			
12			concrete	good	smooth	heavy dirt	good	intermediate			directly connected
13	pvd good	very rough	concrete	good	smooth	heavy dirt					
14	pvd good	very rough	concrete	good	smooth	fair litter and dirty	good	intermediate			directly connected
15	pvd fair	rough	concrete	good	smooth	heavy dirt	good	rough, oil and screens			directly connected
16	pvd good	rough	concrete	good	smooth	heavy dirt	fair	inter to rough			directly connected

Stormwater and Picnic Lake Stormwater Characterization Monitoring

The *Sampling and Analysis Plan* (April 13, 2019) described the sampling and analyses protocols used, while the *Candidate Sites and Points of Contact* (August 6, 2019) listed the potential sites to be monitored during the project.

The stormwater quality analyses presented in this reported are to support the WinSLAMM modeling analyses. The previously presented site areas and descriptions were also used for the modeling effort. Additional analyses are provided by the Texas Tech University research group (such as the February 8, 2021, *Assessment of Data for Representativeness and Quality* report by Reible, Rao, Gomez-Avila, Shou, Hussain, and Sackey).

This report therefore focuses on the stormwater and Picnic Lake quality for the 2.5 cm (0.97-inch) rain (per National Weather Service for Reese Technology Center) of September 12 and 13, 2019. The December 26 and 28, 2019 rain event was not evaluated in this report as it was a likely a small and localized event and the stormwater samples had mostly non-detected analytical results. The particulate solids, heavy metals, PFAS, and PAH data evaluated in this report were received from Texas Tech researchers in June 2021. These data for this event included stormwater from outfalls 1 and 2, along with two pond locations (a southern and northern location). It was not possible to install a monitoring installation at the pond effluent culverts, so these in-pond locations are used to represent the effects of pond treatment.

Several subsections follow, dividing the analyses into discussions of:

- Concentrations of particulate solids, heavy metals, and PAHs by particle size
- Pollutant strengths by particle size (and comparisons to bulk pollutant strengths)
- Cumulative particulate solids, heavy metals, and PAHs mass by particle size

Particle Size Concentrations of Stormwater and Pond Water Particulate Solids, Metals, and PAHs

Figure 4 contains summary tables and plots showing the concentrations of the particulate solids and heavy metals into four size intervals (0.45 to 5, 5 to 20, 20 to 63, and >63 µm). Figure 5 shows similar data and plots for the PAHs. Some of the PAHs do not include plots for those compounds missing most of the information due to non-detectable concentrations. The data are shown for the two stormwater outfall discharges to the pond (outfalls 1 and 2), and for four in-pond conditions (pre- and post-event concentrations for the northern and the southern lake sampling location). In these analyses, too few data are available for traditional statistical comparison analyses, but the visual representation of the data clearly indicate possible trends:

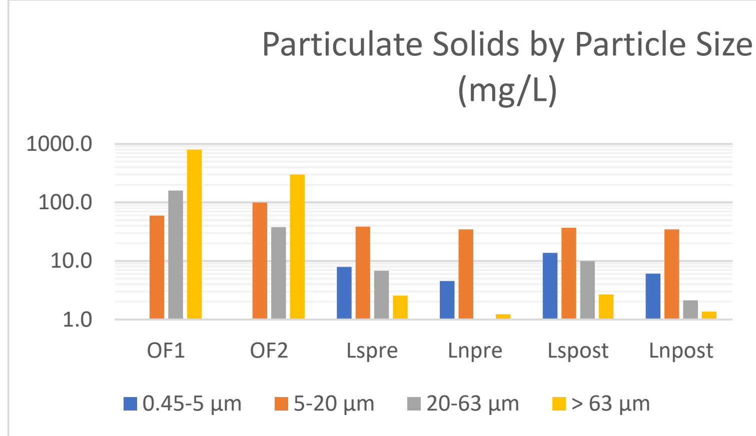
- Outfall concentrations are much greater than the in-pond concentrations. The similarities within the two sample groups (stormwater discharges vs. in-pond locations) are much closer than between the sample groups.

- The concentrations generally increase for larger particle sizes (see the later cumulative mass plots also). This is especially evident for the particulate solid's stormwater concentrations, where the >63 µm concentrations are much greater than for the smaller increments. This may be due to erosion of bed material in the unlined channel of outfall 1 (the highest concentration). The highest particulate solids concentrations for the in-pond samples are for the 5 to 20 µm size range, indicating that the large particles are substantially removed by sedimentation in the lake.

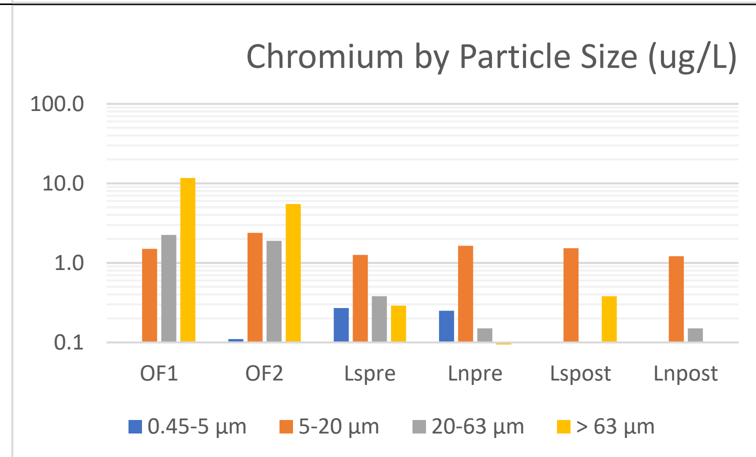
- The stormwater concentration trends for the metals are similar as the particulate solids, but generally not as strong, except for manganese (a primary component of soils).

- Many of the size-related PAH concentrations were not detected, especially for the in-lake samples. The stormwater PAH concentration trends with size are not as obvious as for the metals and particulates, but the outfall PAH concentrations are much greater than the in-lake PAH concentrations.

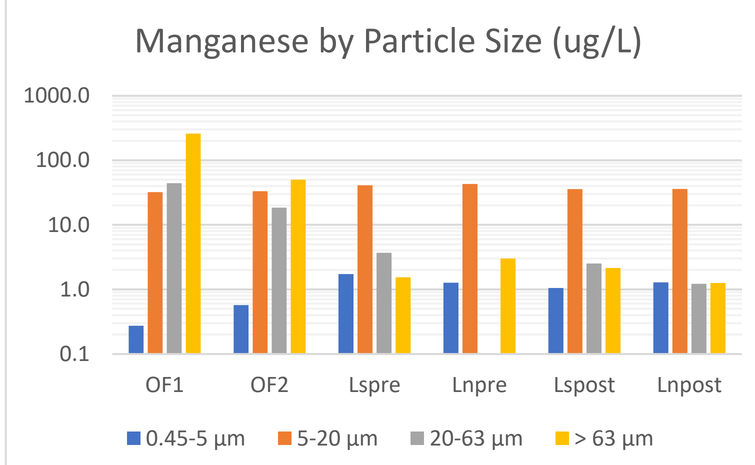
Size Interval	Particulate Solids (mg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm	0.0	0.0	7.9	4.5	13.8	6.1
5-20 µm	59.4	99.9	38.6	34.7	37.0	34.6
20-63 µm	159.7	37.7	6.8	1.0	9.9	2.1
> 63 µm	801.3	299.5	2.6	1.2	2.7	1.4



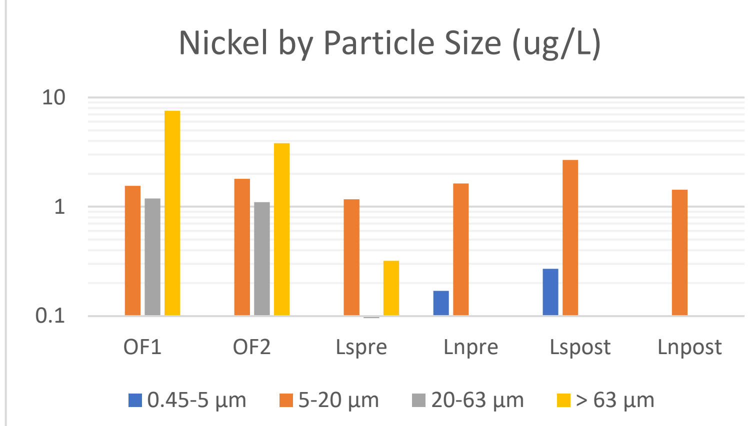
Size Interval	Chromium (µg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm	0.1	0.1	0.3	0.3		
5-20 µm	1.5	2.4	1.3	1.6	1.5	1.2
20-63 µm	2.3	1.9	0.4	0.2		0.2
> 63 µm	11.7	5.5	0.3	0.1	0.4	



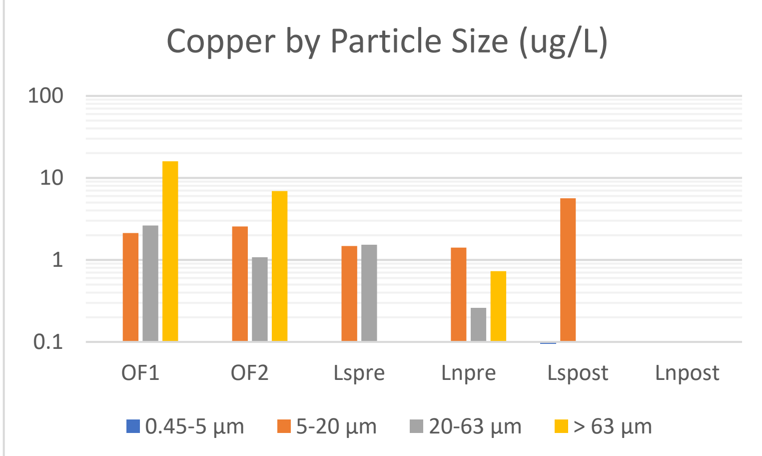
Size Interval	Manganese (µg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm	0.3	0.6	1.7	1.3	1.1	1.3
5-20 µm	32.1	33.2	41.1	43.0	35.7	36.0
20-63 µm	44.2	18.5	3.7		2.5	1.2
> 63 µm	260.0	50.2	1.5	3.0	2.1	1.3



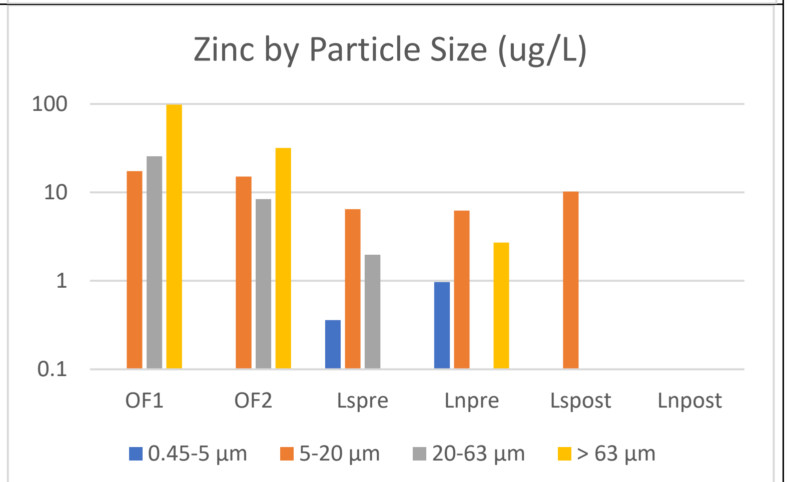
Size Interval	Nickel (µg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm				0.2	0.3	
5-20 µm	1.6	1.8	1.2	1.6	2.7	1.4
20-63 µm	1.2	1.1	0.1			0.1
> 63 µm	7.6	3.8	0.3			



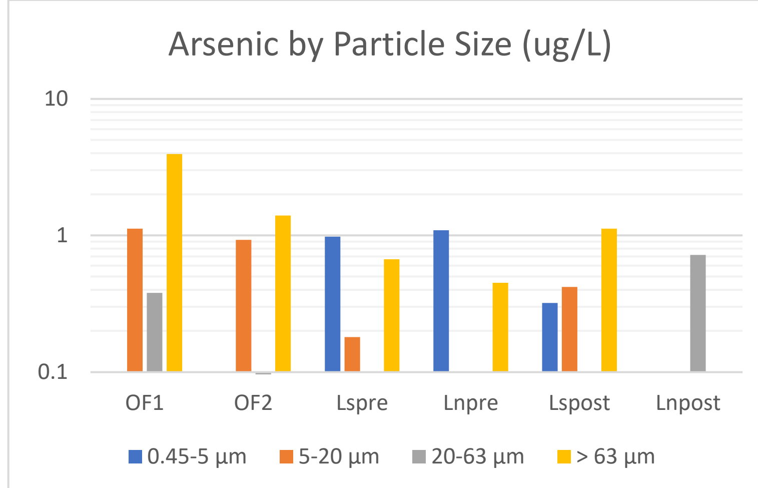
Size Interval	Copper (µg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm					0.1	
5-20 µm	2.1	2.6	1.5	1.4	5.6	
20-63 µm	2.6	1.1	1.5	0.3		
> 63 µm	15.9	6.9		0.7		



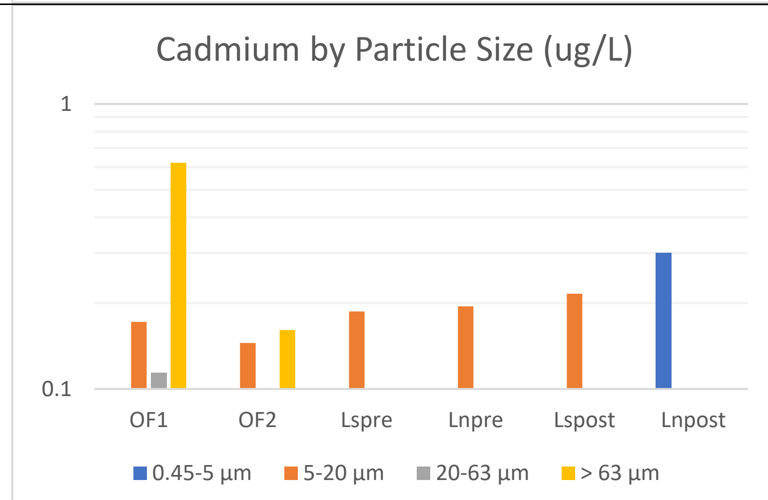
Size Interval	Zinc (µg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm			0.4	1.0		
5-20 µm	17.4	15.1	6.5	6.2	10.2	
20-63 µm	25.6	8.4	2.0			
> 63 µm	98.1	31.8		2.7		



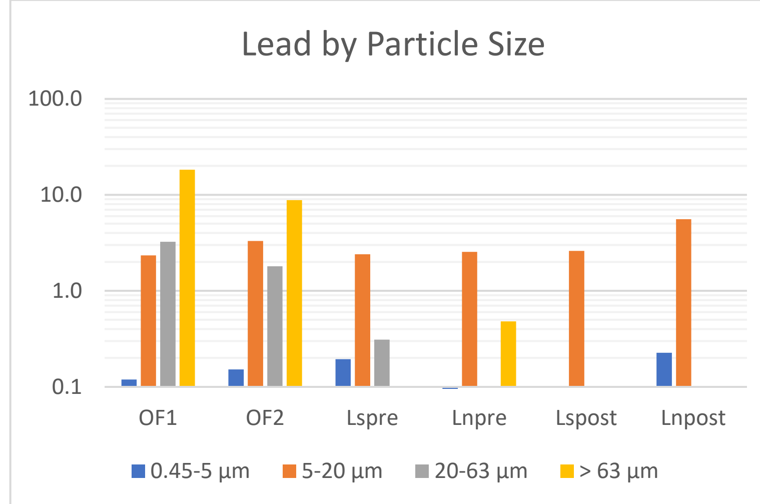
Size Interval	Arsenic (µg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm			1.0	1.1	0.3	
5-20 µm	1.1	0.9	0.2		0.4	
20-63 µm	0.4	0.1				0.7
> 63 µm	4.0	1.4	0.7	0.5	1.1	



Size Interval	Cadmium (µg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm						0.3
5-20 µm	0.2	0.1	0.2	0.2	0.2	
20-63 µm	0.1					
> 63 µm	0.6	0.2				



Size Interval	Lead (µg/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm	0.1	0.2	0.2	0.1		0.2
5-20 µm	2.3	3.3	2.4	2.5	2.6	5.6
20-63 µm	3.2	1.8	0.3			
> 63 µm	18.3	8.8		0.5		



Size Interval	Total mercury (ng/L) OF1	OF2	Lspre	Lnpre	Lspost	Lnpost
0.45-5 µm	0.27	0.57	1.73	1.27	1.05	1.28
5-20 µm	32.08	33.20	41.10	42.99	35.70	36.01
20-63 µm	44.16	18.51	3.69	0.01	2.51	1.22
> 63 µm	260.02	50.18	1.54	3.00	2.15	1.26

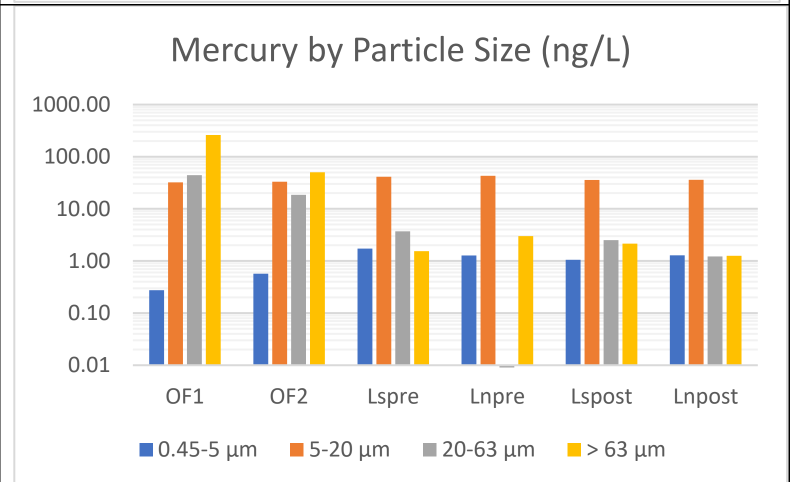


Figure 4. Particulate solids and heavy metal concentrations by particle size and location.

Naphthalene (ug/L)	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost	Too few data to plot
0.7-2.7 µm							
2.7-20 µm		1.0					
20-63 µm		0.8			0.3		
>63 µm		22.5					

2-methylnaphthalene (ug/L)	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost	Too few data to plot
0.7-2.7 µm							
2.7-20 µm		0.4					
20-63 µm		0.3					
>63 µm		7.1					

1-methylnaphthalene (ug/L)	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost	Too few data to plot
0.7-2.7 µm							
2.7-20 µm		0.5					
20-63 µm		0.9					
>63 µm		6.3					

2-ethylnaphthalene (ug/L)	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost	Too few data to plot
0.7-2.7 µm							
2.7-20 µm		0.1					
20-63 µm		0.4					
>63 µm		2.0					

1-ethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost	Too few data to plot
0.7-2.7 µm							
2.7-20 µm							
20-63 µm		0.1			0.1		
>63 µm		0.4			0.1		

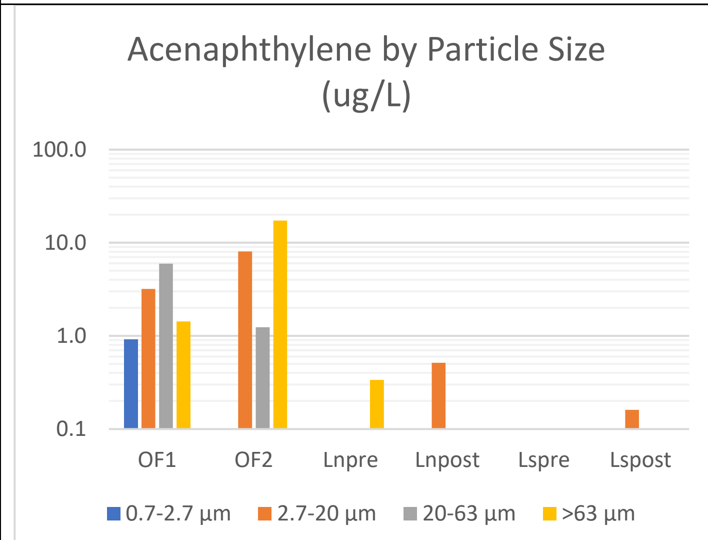
2.6-dimethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost	Too few data to plot
0.7-2.7 µm							

2.7-20 µm						
20-63 µm		0.6				
>63 µm		3.5				

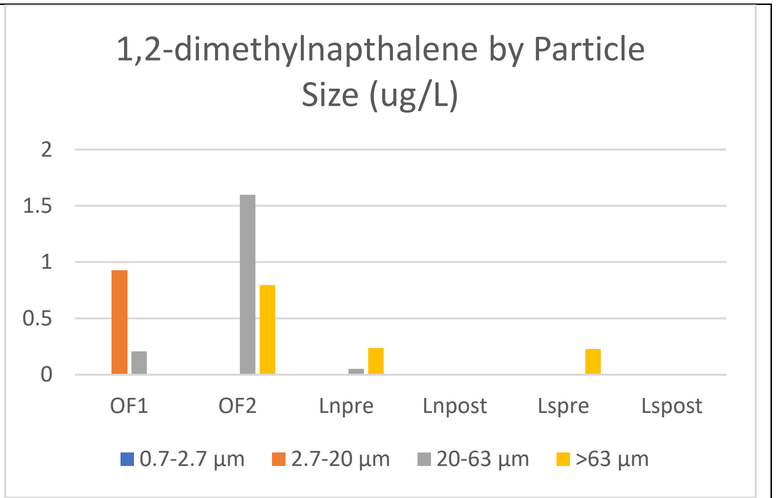
1.3-dimethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						
2.7-20 µm		0.5				
20-63 µm		1.2				
>63 µm		4.5				

Too few data to plot

acenaphthylene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm	0.9					
2.7-20 µm	3.2	8.1		0.5		0.2
20-63 µm	6.0	1.2				
>63 µm	1.4	17.3	0.3			



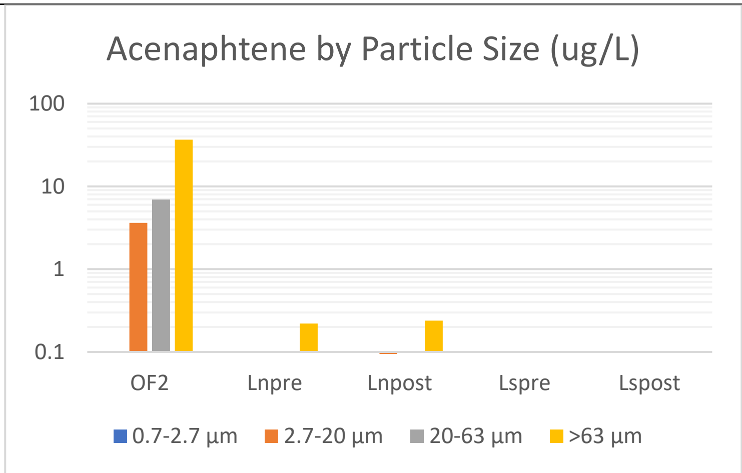
1.2-dimethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						
2.7-20 µm	0.9					
20-63 µm	0.2	1.6	0.1			
>63 µm		0.8	0.2		0.2	



1.8-dimethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm		0.1				
2.7-20 µm	0.8	1.1				
20-63 µm	0.3					
>63 µm	0.1					

Too few data to plot

acenaphthene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						
2.7-20 µm		3.6		0.1		
20-63 µm		6.9				
>63 µm		36.6	0.2	0.2		



2.3.5-trimethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost

Too few data to plot

	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm		0.4				0.1
2.7-20 µm					0.1	
20-63 µm		0.3				
>63 µm		1.8				

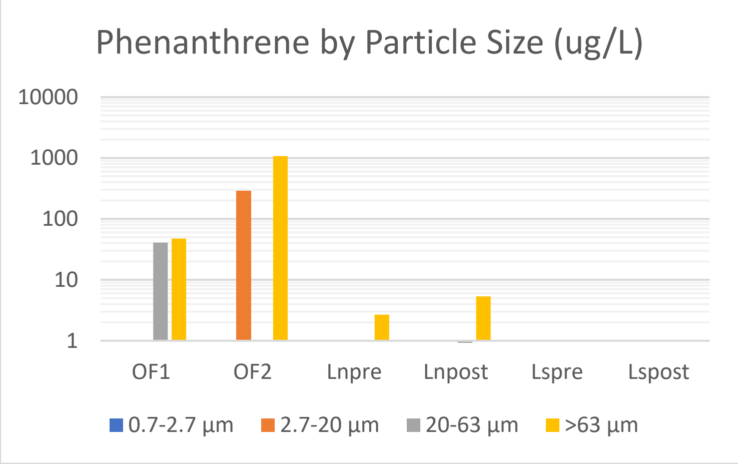
fluorene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						
2.7-20 µm		3.8				
20-63 µm		1.1				
>63 µm		30.8			0.3	

Too few data to plot

1-methylfluorene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						0.1
2.7-20 µm		1.1				
20-63 µm					0.1	
>63 µm		5.0			0.1	

Too few data to plot

phenanthrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						
2.7-20 µm		290.7				
20-63 µm	40.9			0.8		
>63 µm	47.4	1073.2	2.7	5.3		



anthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 μm						0.2
2.7-20 μm		25.4				0.1
20-63 μm			0.2			
>63 μm		117.5				

Too few data to plot

2-methylphenanthrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 μm						
2.7-20 μm		36.9				
20-63 μm	9.4					
>63 μm	7.7	137.2	0.9	0.5		

Too few data to plot

2-methylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 μm						
2.7-20 μm	0.1	5.7				
20-63 μm	0.8					
>63 μm	0.8	29.7				

Too few data to plot

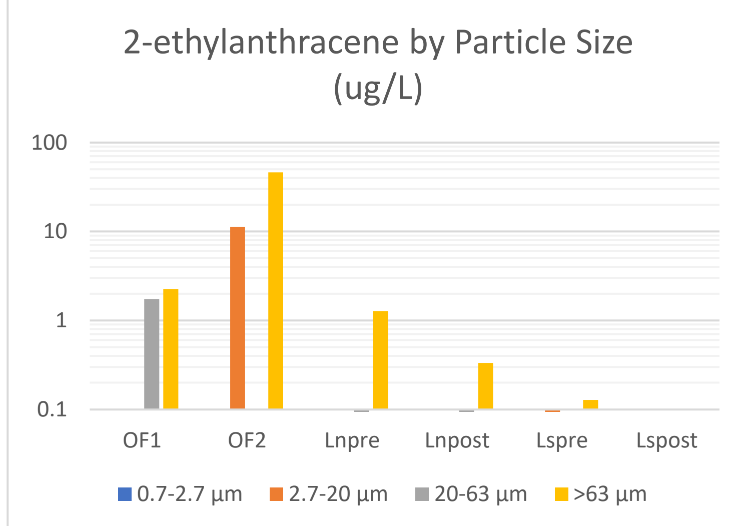
1-methylphenanthrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 μm						
2.7-20 μm		24.1				
20-63 μm	7.1					
>63 μm	4.8	109.0	0.5	0.2	0.1	

Too few data to plot

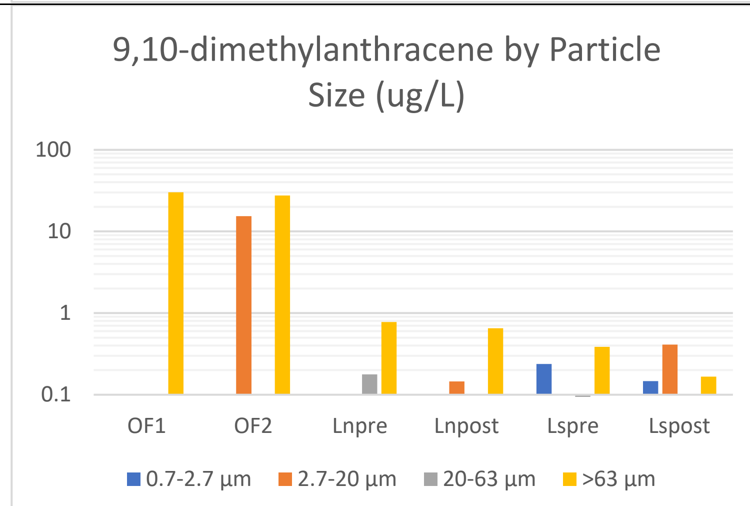
9-methylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 μm						
2.7-20 μm		0.2				
20-63 μm						
>63 μm		1.7				

Too few data to plot

2-ethylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						
2.7-20 µm		11.2			0.1	
20-63 µm	1.7		0.1	0.1		
>63 µm	2.2	46.2	1.3	0.3	0.1	



9.10-dimethylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm					0.2	0.1
2.7-20 µm		15.4		0.1		0.4
20-63 µm			0.2		0.1	
>63 µm	30.2	27.6	0.8	0.7	0.4	0.2



2-tertbutylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm	0.3					
2.7-20 µm		0.1				
20-63 µm	0.2	0.1				

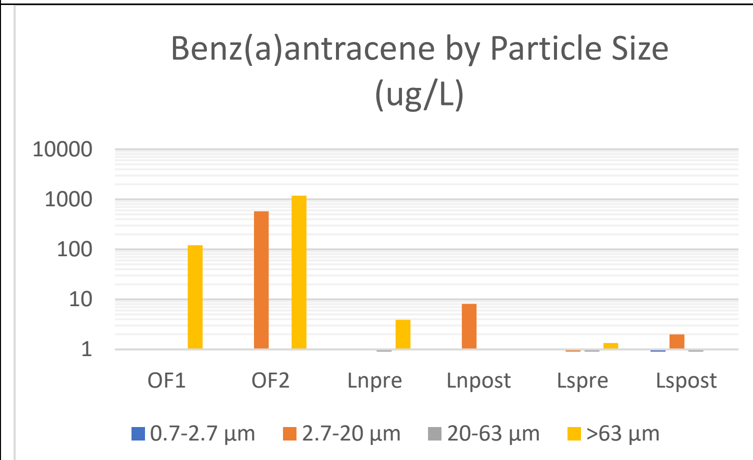
Too few data to plot

	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
>63 µm	0.8	3.0	0.1		0.1	

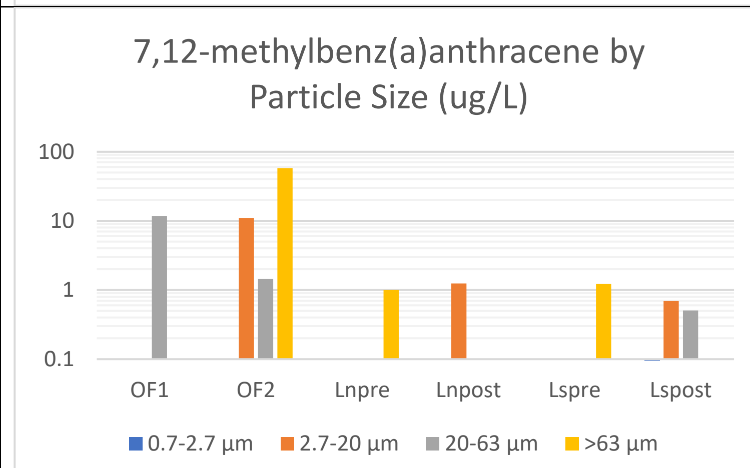
1-methylpyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						0.1
2.7-20 µm		29.9		0.6		0.1
20-63 µm	8.8					0.1
>63 µm	5.3	70.4	0.4			

Too few data to plot

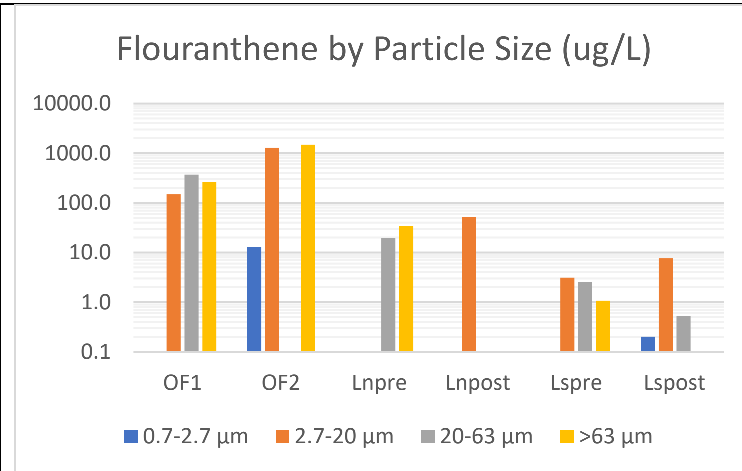
benz(a)anthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						0.4
2.7-20 µm		576.7		8.1	0.3	2.0
20-63 µm			0.8		0.4	0.1
>63 µm	121.0	1179.3	3.9		1.3	



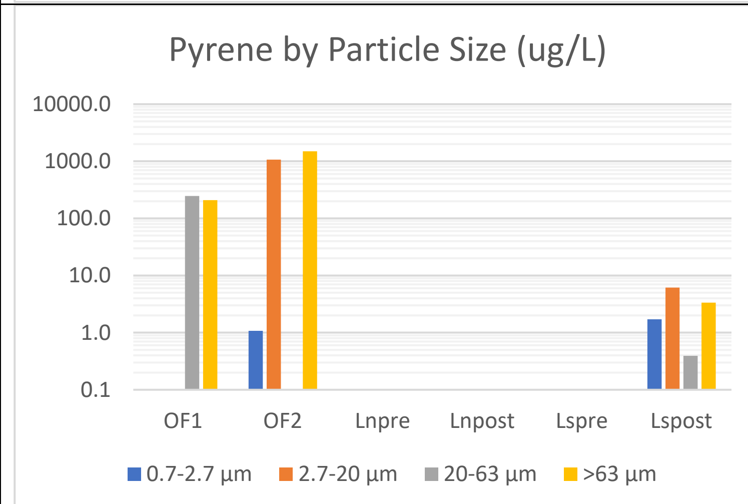
7.12-methylbenz(a)anthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						0.1
2.7-20 µm		11.0		1.2		0.7
20-63 µm	11.7	1.4				0.5
>63 µm		57.5	1.0		1.2	



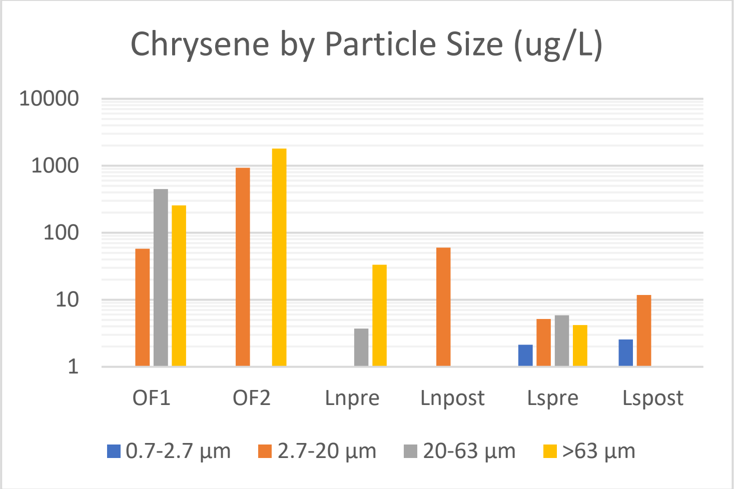
fluoranthene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm		12.9				0.2
2.7-20 µm	148.6	1288.0		52.3	3.1	7.7
20-63 µm	370.7		19.5		2.6	0.5
>63 µm	261.1	1483.8	34.2		1.1	



pyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm		1.1				1.7
2.7-20 µm		1069.8				6.1
20-63 µm	247.0					0.4
>63 µm	209.2	1499.2				3.4

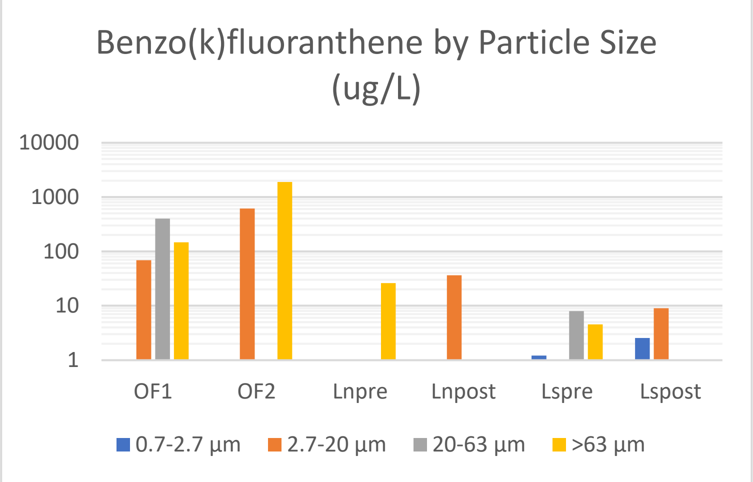


chrysene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm					2.1	2.6
2.7-20 µm	57.8	929.6		59.8	5.2	11.8
20-63 µm	448.1		3.7		5.9	
>63 µm	256.4	1804.7	33.4		4.2	

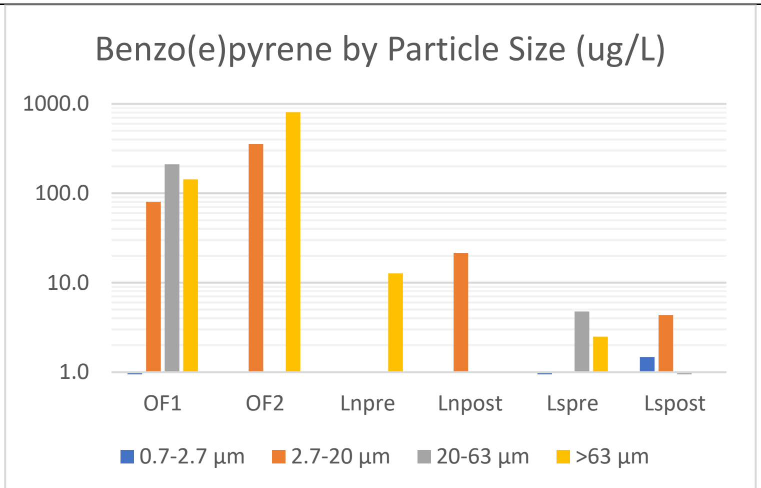


benzo(b)fluoranthene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm					1.8	3.1
2.7-20 µm	112.7	679.1		51.2		11.3
20-63 µm	478.0				10.0	
>63 µm	181.7	2184.3	36.0		5.9	

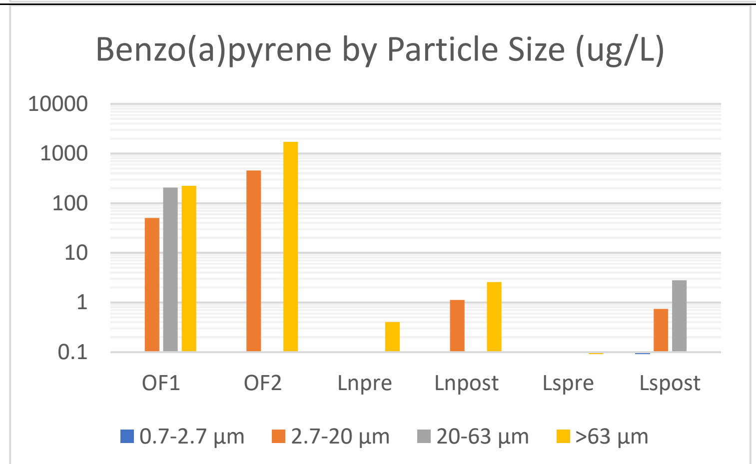
benzo(k)fluoranthene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm					1.2	2.5
2.7-20 µm	68.9	612.4		36.4		9.0
20-63 µm	401.3				7.9	
>63 µm	147.1	1884.4	26.0		4.5	



benzo(e)pyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm	0.4				0.8	1.5
2.7-20 µm	80.1	354.6		21.5		4.3
20-63 µm	210.5				4.8	0.3
>63 µm	143.1	805.3	12.7		2.5	

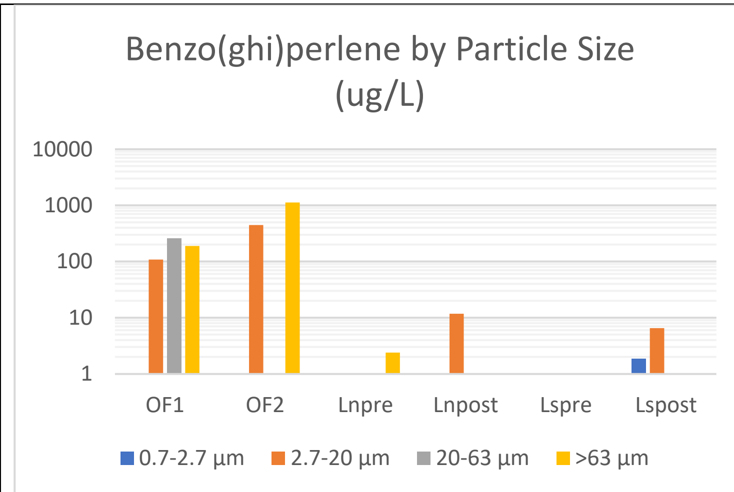


benzo(a)pyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						0.1
2.7-20 µm	50.3	455.5		1.1		0.7
20-63 µm	207.1					2.8
>63 µm	224.5	1724.5	0.4	2.6	0.1	

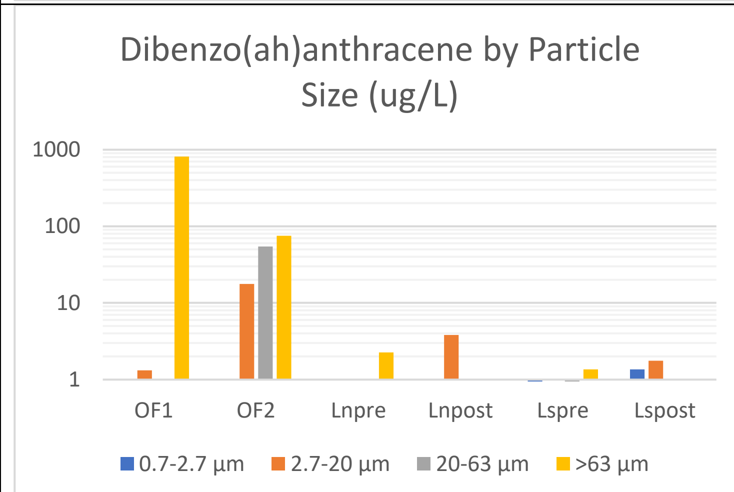


perylene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm	0.1				0.1	
2.7-20 µm	0.1			0.1		
20-63 µm						
>63 µm	75.2	531.7				

benzo(ghi)perylene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm						1.9
2.7-20 µm	108.7	447.0		11.8		6.5
20-63 µm	256.5					
>63 µm	189.6	1121.4	2.4			



Dibenzo(ah)anthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm					0.3	1.4
2.7-20 µm	1.3	17.7		3.8		1.8
20-63 µm		54.3			0.3	
>63 µm	811	75.2	2.3		1.4	



Indeno(123-cd)pyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost
0.7-2.7 µm					3.7	14.8
2.7-20 µm	1282.8	332.7		103.5		53.4
20-63 µm		1511.1			0.6	
>63 µm	10993.8	1306.5	45.7		41.3	

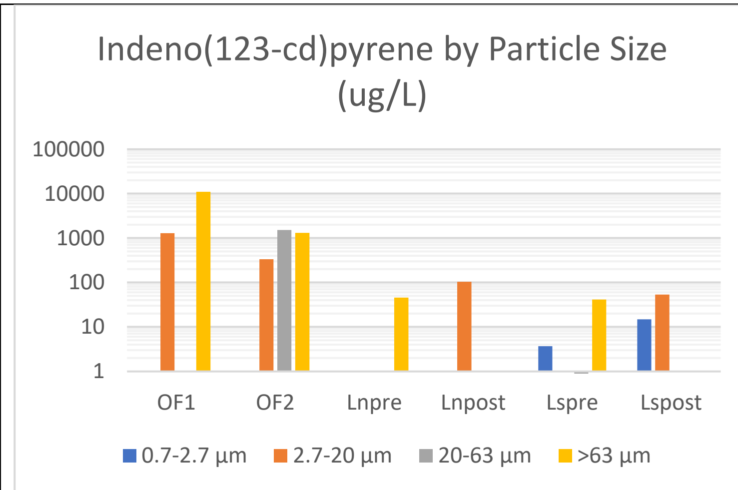


Figure 5. PAH concentrations by particle size and location.

Pollutant Particulate Strengths by Particle Size

Particulate pollutant strengths refer to the associations of pollutants to particulate solids. These vary by particle size, as shown in this discussion. Particulate pollutant strengths are determined by calculating the pollutant concentrations only associated with the particulates in the stormwater:

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

As an example, if the total copper concentration was 50 µg/L, the filtered copper concentration was 10 µg/L, and the particulate solids concentration was 150 mg/L, the pollutant 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)

Table 9 lists the calculated pollutant strengths for the heavy metals by the four particle sizes monitored during this project for the outfall and in-lake samples, while Table 10 shows similar data for the PAHs. Bar charts of these values are also shown in Figures 6 and 7. If the particulates have similar sources (such as stormwater in this case), the particulate pollutant strengths should be the same for all samples for the same particle size. With the sedimentation treatment in Picnic Lake, larger particles settle, leaving a larger percentage of the smaller particles. However, the pollutant characteristics of the particles do not change for most heavy metals and PAHs, although some biodegradation of some PAHs may occur with time in an aquatic environment. Some metals may disassociate from the particulates and may form complexes such as organometallic compounds. However, these changes have not been shown to be rapid or large. Therefore, these analyses examine the pollutant particulate strengths by size for the stormwater discharges and for the in-lake samples to identify any obvious differences. Again, too few data are available to statistically test for differences.

These tables show the calculated pollutant particulate strengths (mg/kg for most metals, µg/kg for mercury and PAHs) for each sample and particle size range, along with their overall average for all samples for each size range, and the corresponding coefficient of variation (COV, the ratio of the standard deviation to the average value). Relatively small COV values indicate small variations for the sample groups.

- In general, the COV values for the metals are low to moderate, indicating relatively narrow data ranges, with greater COV values as the particle sizes increase.

- The bar graphs for the metal particulate strength values (in log scales for concentrations) also indicate similar pollutant strengths within each size range.
- As noted previously, many of the PAH concentration values are missing due to being non-detected. More data are available for the outfall stormwater samples.
- The COV values for the PAH particulate strengths are greater than for the metals, indicating greater variabilities in the same size ranges. There are no apparent trends of COV with particle size range.
- The bar graphs for the PAH particulate strengths also show greater variabilities compared to the metal values.

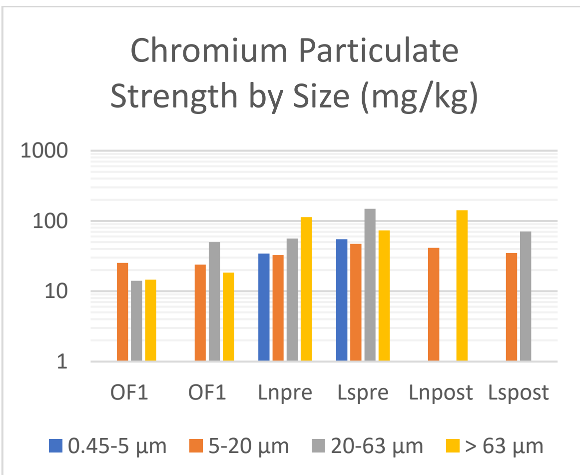
Tables 11 and 12 shows the ratios of the individual size range particulate strength values to the total sample bulk pollutant particulate strength for the metals and PAHs. These ratios are important in the modeling of pollutant by particle size range. Currently, WinSLAMM uses a single bulk pollutant particulate strength value, but does calculate particle size distributions from source areas, along the stormwater flow paths, and through stormwater control measures. The next project phase will include modifying WinSLAMM to consider the size fraction pollutant particulate strength values needed to calculate the performance of stormwater controls and the characteristics of the discharges more accurately.

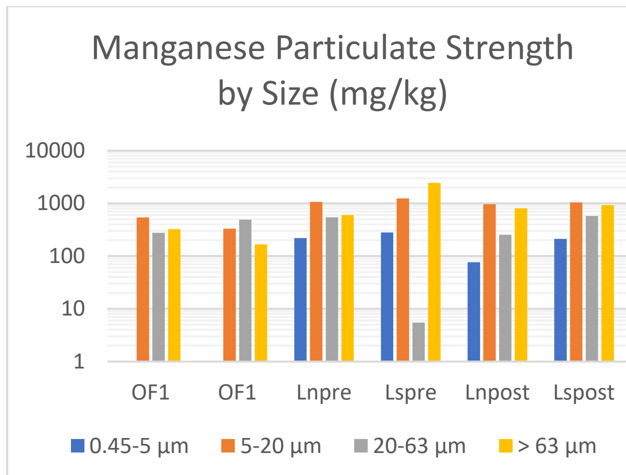
Table 9. Heavy Metal Pollutant Particulate Strengths for Different Particle Sizes for Stormwater and Picnic Lake Water

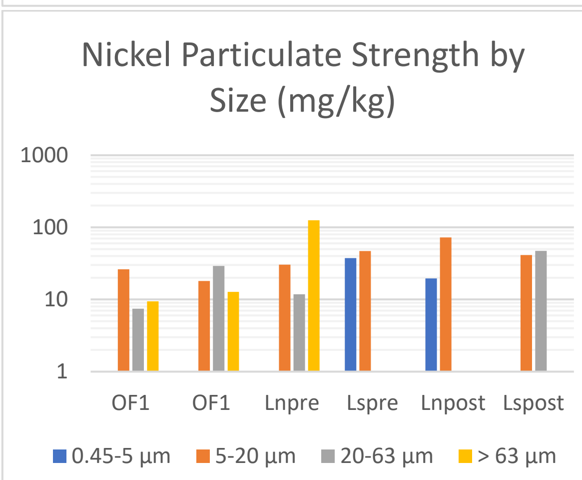
Chromium mg/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost	avg	COV
0.45-5 µm			34.2	55.0			44.6	0.33
5-20 µm	25.3	23.8	32.7	47.3	41.4	35.0	34.2	0.27
20-63 µm	14.1	50.1	56.0	148.6		70.7	67.9	0.73
> 63 µm	14.6	18.4	113.3	73.3	142.1		72.3	0.78
Manganese mg/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost		
0.45-5 µm			218.9	280.2	76.5	212.0	196.9	0.44
5-20 µm	540.5	332.2	1065.7	1240.4	964.8	1041.4	864.2	0.40
20-63 µm	276.6	490.4	544.3	5.5	254.6	575.9	357.9	0.61
> 63 µm	324.5	167.6	601.3	2445.3	803.7	923.2	877.6	0.93
Nickel mg/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost		
0.45-5 µm				37.4	19.6		28.5	0.44
5-20 µm	26.2	18.0	30.3	47.0	72.4	41.4	39.2	0.49
20-63 µm	7.5	29.1	11.8			47.1	23.9	0.76

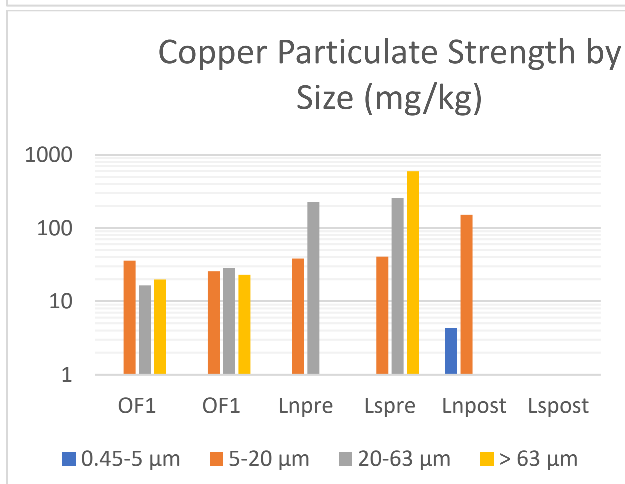
> 63 µm	9.4	12.7	125.1				49.1	1.34
Copper mg/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost		
0.45-5 µm					4.4		4.4	
5-20 µm	35.9	25.6	38.4	40.7	152.4		58.6	0.90
20-63 µm	16.5	28.6	225.6	257.6			132.1	0.96
> 63 µm	19.9	23.1		594.6			212.5	1.56
Zinc mg/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost		
0.45-5 µm			45.6	213.6			129.6	0.92
5-20 µm	293.6	151.1	167.5	179.4	275.7		213.5	0.31
20-63 µm	160.4	222.6	290.5				224.5	0.29
> 63 µm	122.4	106.2		2207.5	7.5		610.9	1.74
Arsenic mg/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost		
0.45-5 µm			124.2	240.0	23.3		129.2	0.84
5-20 µm	18.9	9.3	4.7		11.4		11.0	0.54
20-63 µm	2.4	1.9				339.3	114.5	1.70
> 63 µm	4.9	4.7	261.8	366.6	418.8		211.4	0.93
Cadmium mg/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost		
0.45-5 µm						49.5	49.5	
5-20 µm	2.9	1.5	4.8	5.6	5.8		4.1	0.46
20-63 µm	0.7	1.2		5.9			2.6	1.10
> 63 µm	0.8	0.5	1.2	20.4	12.0		7.0	1.28
Lead mg/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost		
0.45-5 µm			24.6	15.6		37.3	25.8	0.42
5-20 µm	39.4	33.1	62.4	73.4	70.5	161.5	73.4	0.63
20-63 µm	20.3	47.7	45.7				37.9	0.40
> 63 µm	22.8	29.4		391.0	52.4		123.9	1.44

Total mercury ug/kg								
Size Interval	OF1	OF1	Lnpre	Lspre	Lnpost	Lspost		
0.45-5 µm			218.9	280.2	76.5	212.0	196.9	0.44
5-20 µm	540.5	332.2	1065.7	1240.4	964.8	1041.4	864.2	0.40
20-63 µm	276.6	490.4	544.3	5.5	254.6	575.9	357.9	0.61
> 63 µm	324.5	167.6	601.3	2445.3	803.7	923.2	877.6	0.93









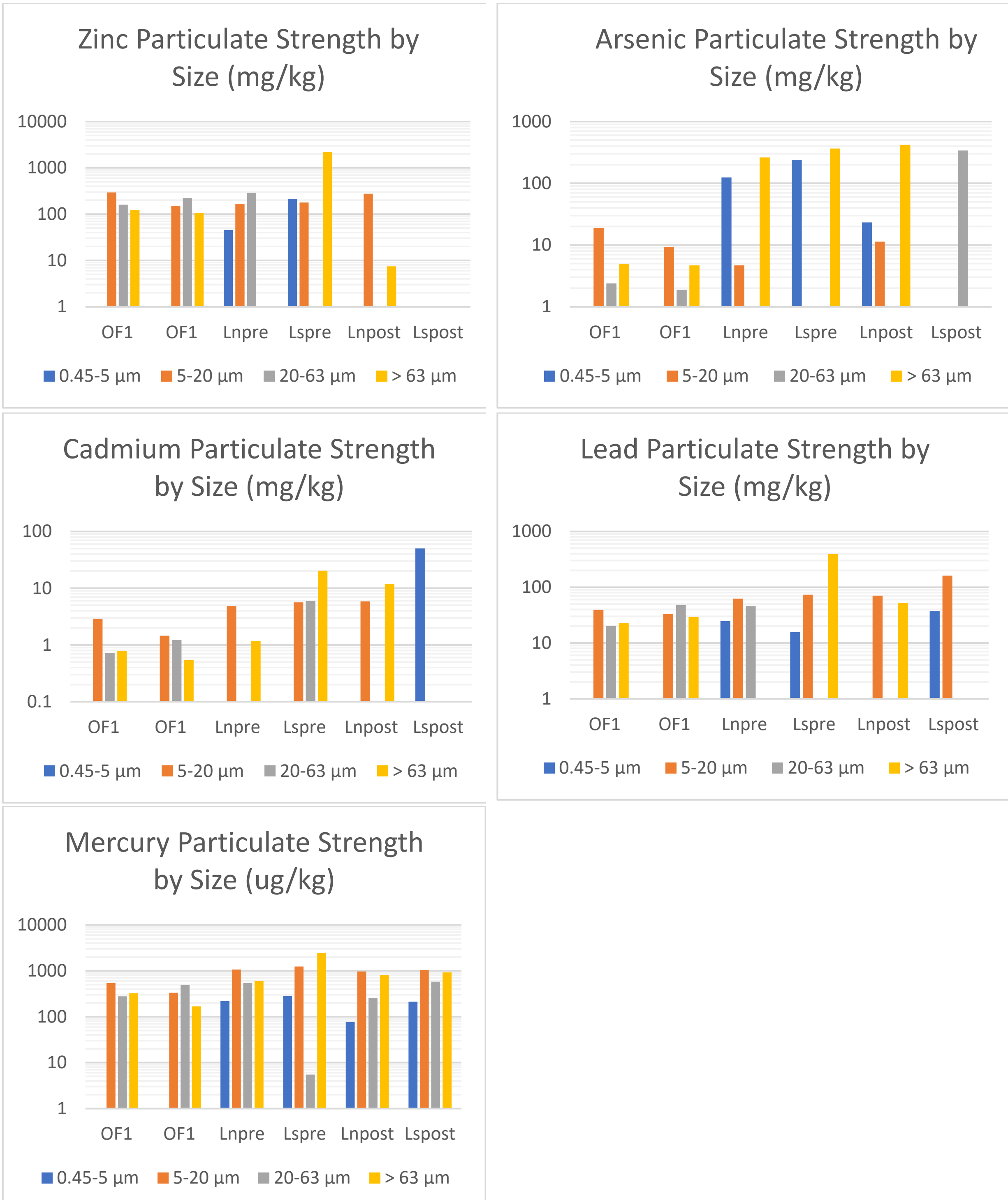


Figure 6. Metal pollutant strength comparisons by size and location.

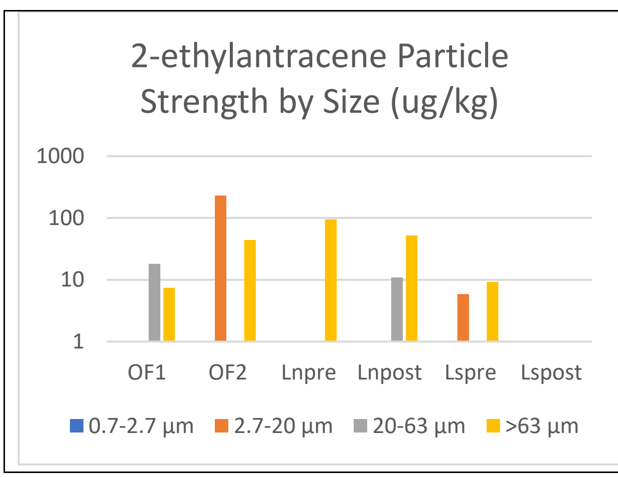
Table 10. PAH Particulate Strengths by Particle Size (all ug/kg)

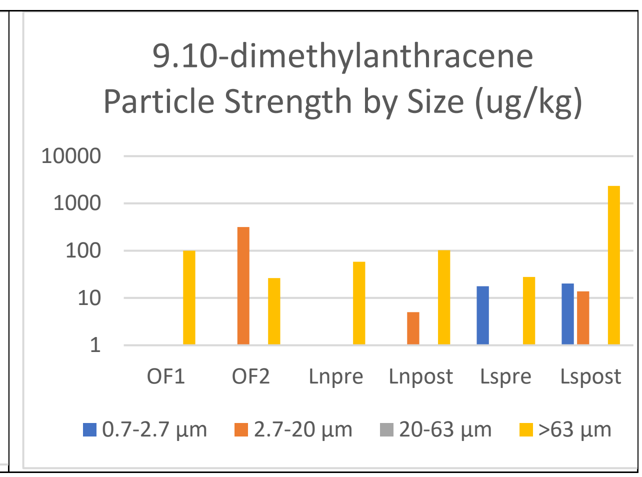
Naphthalene (ug/kg)	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost	count	average	COV
0.7-2.7 µm							0		
2.7-20 µm		20.4					1	20.4	
20-63 µm		6.8					1	6.8	
>63 µm		21.5					1	21.5	
2-methylnaphthalene (ug/kg)	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		8.0					1	8.0	
20-63 µm		2.3					1	2.3	
>63 µm		6.7					1	6.7	
1-methylnaphthalene (ug/kg)	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		9.8					1	9.8	
20-63 µm	2.4	7.9					2	5.2	0.76
>63 µm		6.0					1	6.0	
2-ethylnaphthalene (ug/kg)	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		2.0					1	2.0	
20-63 µm		3.1					1	3.1	
>63 µm		2.0					1	2.0	
1-ethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm	1.6				1.0		2	1.3	0.29
2.7-20 µm		0.2					1	0.2	
20-63 µm	0.1	0.9					2	0.5	1.18
>63 µm		0.4			4.4		2	2.4	1.20
2.6-dimethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm							0		
20-63 µm		5.8					1	5.8	
>63 µm		3.4					1	3.4	
1.3-dimethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		10.9					1	10.9	
20-63 µm		10.6					1	10.6	
>63 µm		4.3			0.2		2	2.2	1.29
acenaphthylene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm	35.1						1	35.1	
2.7-20 µm	55.2	165.8		17.7		5.4	4	61.0	1.20
20-63 µm	62.1	11.0					2	36.6	0.99
>63 µm	4.7	16.5	25.1				3	15.4	0.66
2.3.5-trimethylnaphthalene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm						7.9	1	7.9	
2.7-20 µm					5.0		1	5.0	
20-63 µm		3.0					1	3.0	

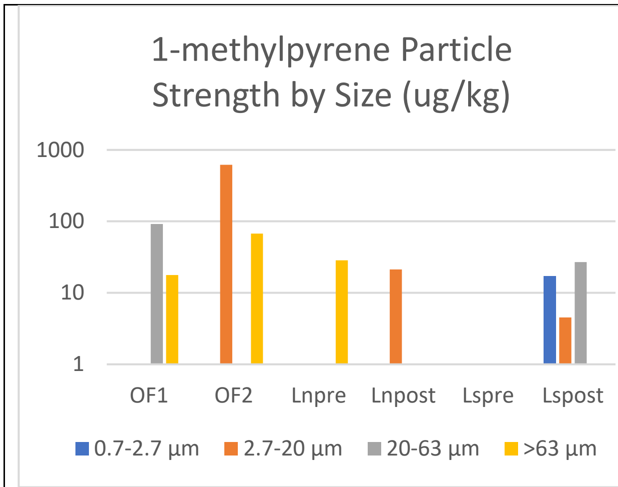
>63 µm		1.7			0.9		2	1.3	0.44
fluorene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm					2.9		1	2.9	
2.7-20 µm		77.8					1	77.8	
20-63 µm		10.2					1	10.2	
>63 µm		29.4	0.9		19.7		3	16.6	0.87
1-methylfluorene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm					0.4	15.5	2	8.0	1.33
2.7-20 µm		21.8					1	21.8	
20-63 µm							0		
>63 µm		4.8			6.5		2	5.6	0.22
phenanthrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		5985.5					1	5985.5	
20-63 µm	426.1			106.9			2	266.5	0.85
>63 µm	157.0	1024.5	200.1	833.6			4	553.8	0.80
anthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm						28.6	1	28.6	
2.7-20 µm		523.8				1.8	2	262.8	1.40
20-63 µm							0		
>63 µm		112.2	3.6				2	57.9	1.33
2-methylphenanthrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		759.7					1	759.7	
20-63 µm	98.3						1	98.3	
>63 µm	25.3	131.0	64.2	78.8	0.2		5	59.9	0.84
2-methylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm						3.2	1	3.2	
2.7-20 µm	1.9	118.2				0.7	3	40.3	1.68
20-63 µm	8.8						1	8.8	
>63 µm	2.6	28.4	2.3				3	11.1	1.35
1-methylphenanthrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		496.1					1	496.1	
20-63 µm	74.1						1	74.1	
>63 µm	15.9	104.1	40.4	35.9	10.8		5	41.4	0.90
9-methylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		3.8					1	3.8	
20-63 µm							0		
>63 µm		1.6					1	1.6	
2-ethylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm							0		
2.7-20 µm		231.1			5.9		2	118.5	1.34
20-63 µm	18.1			10.9			2	14.5	0.35
>63 µm	7.4	44.1	95.0	52.2	9.2		5	41.6	0.87
9.10-dimethylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm					17.7	20.1	2	18.9	0.09
2.7-20 µm		317.2		5.0		13.8	3	112.0	1.59
20-63 µm							0		
>63 µm	99.8	26.3	58.0	101.8	27.8	2335.3	6	441.5	2.10

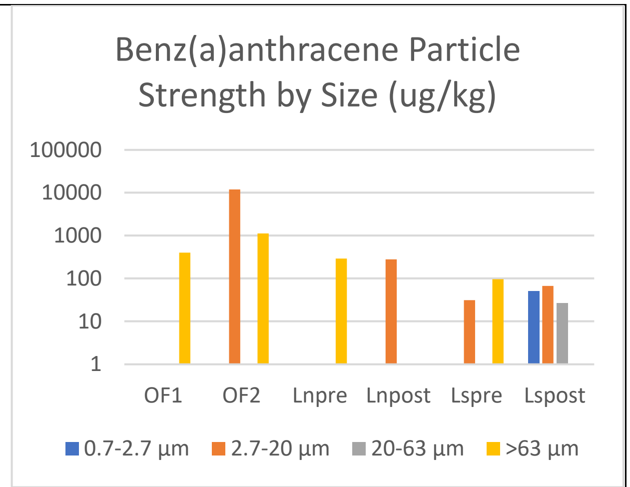
2-tertbutylanthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm	10.6				0.7	0.7	3	4.0	1.43
2.7-20 µm	0.2	2.1					2	1.2	1.15
20-63 µm	2.2	1.3					2	1.7	0.36
>63 µm	2.6	2.8	6.0		3.8	3.8	5	3.8	0.36
1-methylpyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm						17.1	1	17.1	
2.7-20 µm		616.0		21.2		4.5	3	213.9	1.63
20-63 µm	91.5					26.8	2	59.2	0.77
>63 µm	17.7	67.2	28.5	1.0			4	28.6	0.98
benz(a)anthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm						50.6	1	50.6	
2.7-20 µm		11873.7		279.3	31.0	66.7	4	3062.7	1.92
20-63 µm						26.7	1	26.7	
>63 µm	400.7	1125.7	291.4		96.2		4	478.5	0.94
7.12-methylbenz(a)anthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm	13.2					13.2	2	13.2	0.00
2.7-20 µm	23.2	226.0		42.8		23.2	4	78.8	1.25
20-63 µm	137.5	12.9				137.5	3	96.0	0.75
>63 µm		54.9	74.5		88.2		3	72.5	0.23
fluoranthene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm						27.8	1	27.8	
2.7-20 µm	2578.2	2578.2		1800.6	288.2	257.9	5	1500.6	0.78
20-63 µm	3865.0	3865.0				144.2	3	2624.7	0.82
>63 µm	864.5	864.5	2554.1		76.9		4	1090.0	0.96
pyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm						235.0	1	235.0	
2.7-20 µm		22026.0				206.3	2	11116.2	1.39
20-63 µm	2575.5					106.5	2	1341.0	1.30
>63 µm	692.7	1431.1				47249.5	3	16457.8	1.62
chrysene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm					158.5	351.2	2	254.8	0.53
2.7-20 µm	1003.1	19138.2		2059.1	479.0	395.0	5	4614.9	1.77
20-63 µm	4672.4						1	4672.4	
>63 µm	849.0	1722.8	2491.3		301.8		4	1341.2	0.72
benzo(b)fluoranthene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm					135.1	422.3	2	278.7	0.73
2.7-20 µm	1955.6	13982.4		1761.3		378.1	4	4519.3	1.40
20-63 µm	4984.5						1	4984.5	
>63 µm	601.6	2085.2	2689.6		428.0		4	1451.1	0.77
benzo(k)fluoranthene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm					90.1	349.5	2	219.8	0.83
2.7-20 µm	1195.9	12608.3		1253.0		302.5	4	3839.9	1.53
20-63 µm	4184.4						1	4184.4	
>63 µm	486.9	1798.9	1945.2		326.2		4	1139.3	0.75
benzo(e)pyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm	14.6				61.5	202.6	3	92.9	1.05
2.7-20 µm	1390.3	7300.4		739.8		145.9	4	2394.1	1.38
20-63 µm	2195.4					86.8	2	1141.1	1.31
>63 µm	473.8	768.7	948.6		179.1		4	592.5	0.57

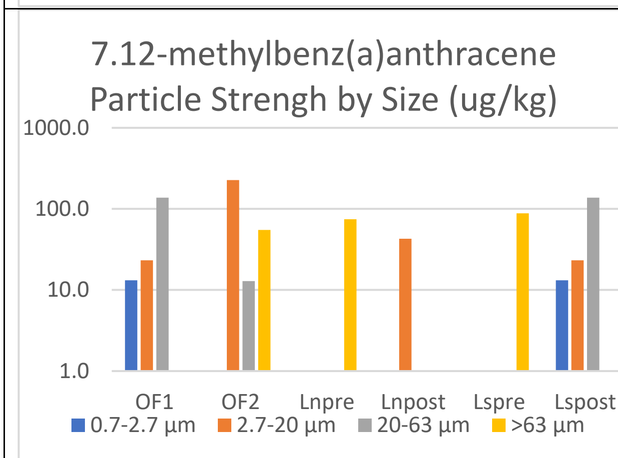
benzo(a)pyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm					3.3	12.0	2	7.7	0.80
2.7-20 µm	873.2	9377.7		38.7		24.9	4	2578.6	1.76
20-63 µm	2160.0					756.1	2	1458.1	0.68
>63 µm	743.2	1646.2	30.2	401.6	4.9		5	565.2	1.20
perylene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm	3.4				11.1		2	7.2	0.74
2.7-20 µm	2.4			2.5			2	2.5	0.01
20-63 µm				4.9			1	4.9	
>63 µm	248.8	507.6			1.2		3	252.5	1.00
benzo(ghi)perylene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm						255.4	1	255.4	
2.7-20 µm	1885.3	9202.7		405.0		218.5	4	2927.9	1.45
20-63 µm	2674.1						1	2674.1	
>63 µm	628.0	1070.4	179.1				3	625.9	0.71
Dibenzo(ah)anthracene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost			
0.7-2.7 µm					25.3	186.4	2	105.8	1.08
2.7-20 µm	22.9	364.0		130.9		59.1	4	144.2	1.06
20-63 µm		483.3					1	483.3	
>63 µm	2684.5	71.8	168.9		97.7		4	755.7	1.70
Indeno(123-cd)pyrene	OF1	OF2	Lnpre	Lnpost	Lspre	Lspost	0		
0.7-2.7 µm					274.6	2035.7	2	1155.1	1.08
2.7-20 µm	22257.8	6850.7		3563.0		1794.2	4	8616.4	1.08
20-63 µm		13441.3					1	13441.3	
>63 µm	36403.3	1247.2	3413.2		2973.5		4	11009.3	1.54

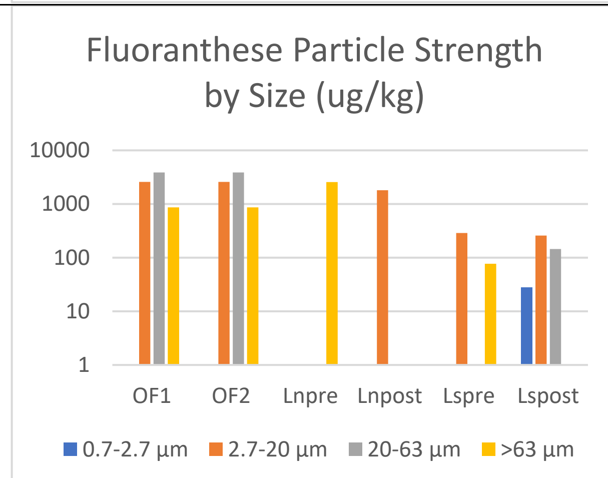


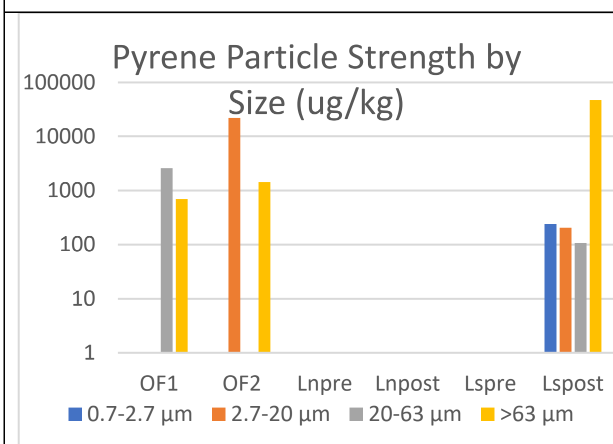



1-methylpyrene Particle Strength by Size (ug/kg)
1000
100
10
1
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm


Benz(a)anthracene Particle Strength by Size (ug/kg)
100000
10000
1000
100
10
1
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm


7.12-methylbenz(a)anthracene Particle Strengh by Size (ug/kg)
1000.0
100.0
10.0
1.0
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm


Fluoranthese Particle Strength by Size (ug/kg)
10000
1000
100
10
1
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm


Pyrene Particle Strength by Size (ug/kg)
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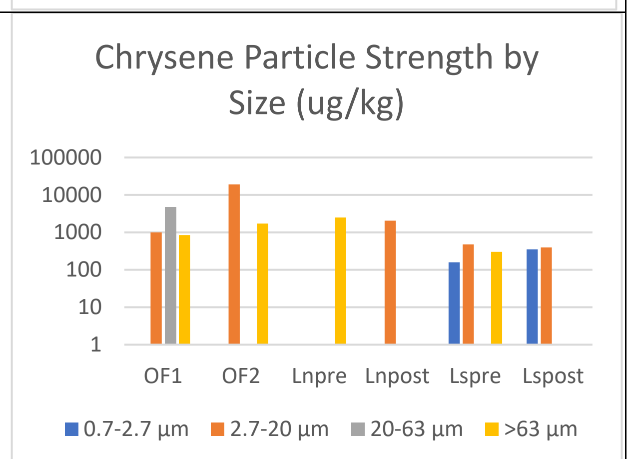
10000
1000
100
10
1
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm


Chrysene Particle Strength by Size (ug/kg)
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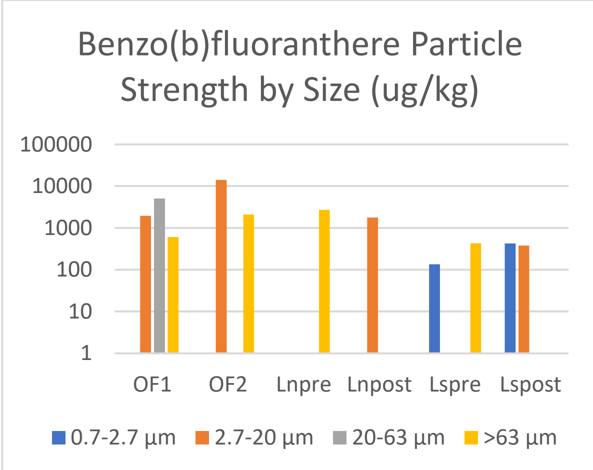
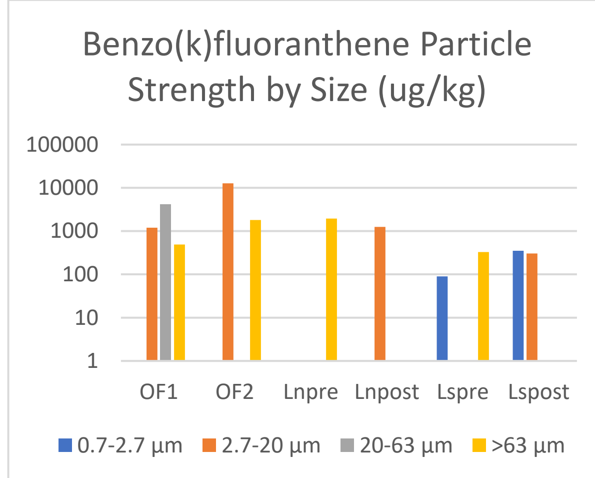
10000
1000
100
10
1
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost
0.7-2.7 µm
2.7-20 µm
20-63 µm
>63 µm


Benzo(b)fluoranthere Particle Strength by Size (ug/kg)
100000
10000
1000
100
10
1
OF1 OF2 Lnpre Lnpost Lspre Lspost
0.7-2.7 µm 2.7-20 µm 20-63 µm >63 µm


Benzo(k)fluoranthene Particle Strength by Size (ug/kg)
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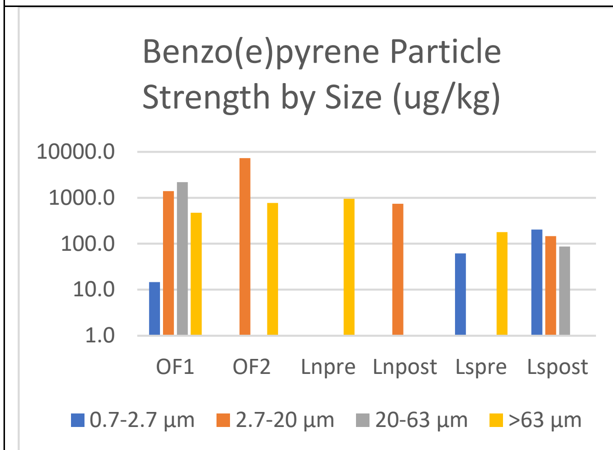
10000
1000
100
10
1
OF1 OF2 Lnpre Lnpost Lspre Lspost
0.7-2.7 µm 2.7-20 µm 20-63 µm >63 µm


Benzo(e)pyrene Particle Strength by Size (ug/kg)
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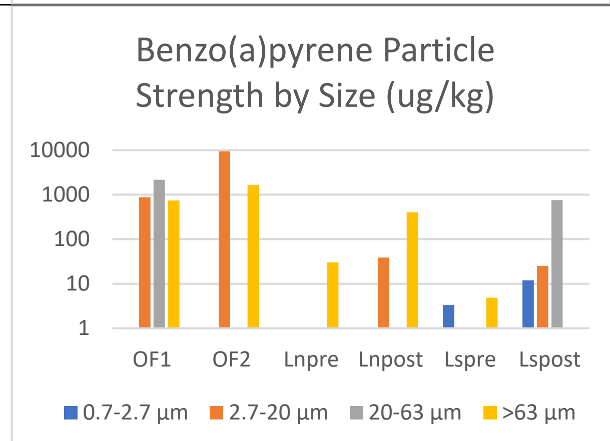
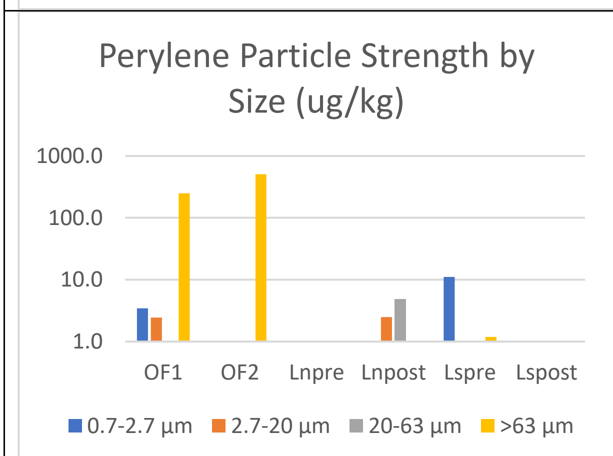
1000.0
100.0
10.0
1.0
OF1 OF2 Lnpre Lnpost Lspre Lspost
0.7-2.7 µm 2.7-20 µm 20-63 µm >63 µm


Benzo(a)pyrene Particle Strength by Size (ug/kg)
10000
1000
100
10
1
OF1 OF2 Lnpre Lnpost Lspre Lspost
0.7-2.7 µm 2.7-20 µm 20-63 µm >63 µm


Perylene Particle Strength by Size (ug/kg)
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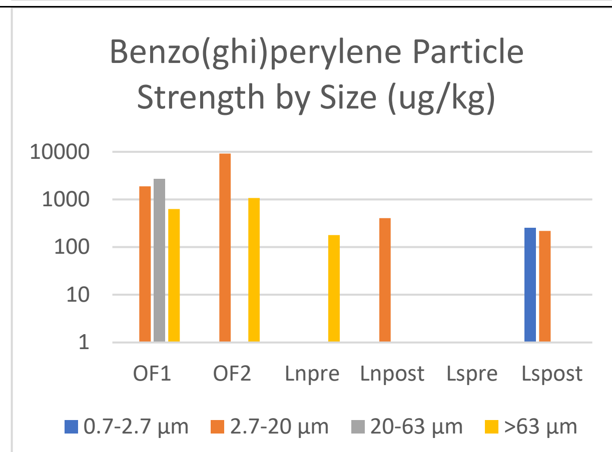
100.0
10.0
1.0
OF1 OF2 Lnpre Lnpost Lspre Lspost
0.7-2.7 µm 2.7-20 µm 20-63 µm >63 µm


Benzo(ghi)perylene Particle Strength by Size (ug/kg)
10000
1000
100
10
1
OF1 OF2 Lnpre Lnpost Lspre Lspost
0.7-2.7 µm 2.7-20 µm 20-63 µm >63 µm

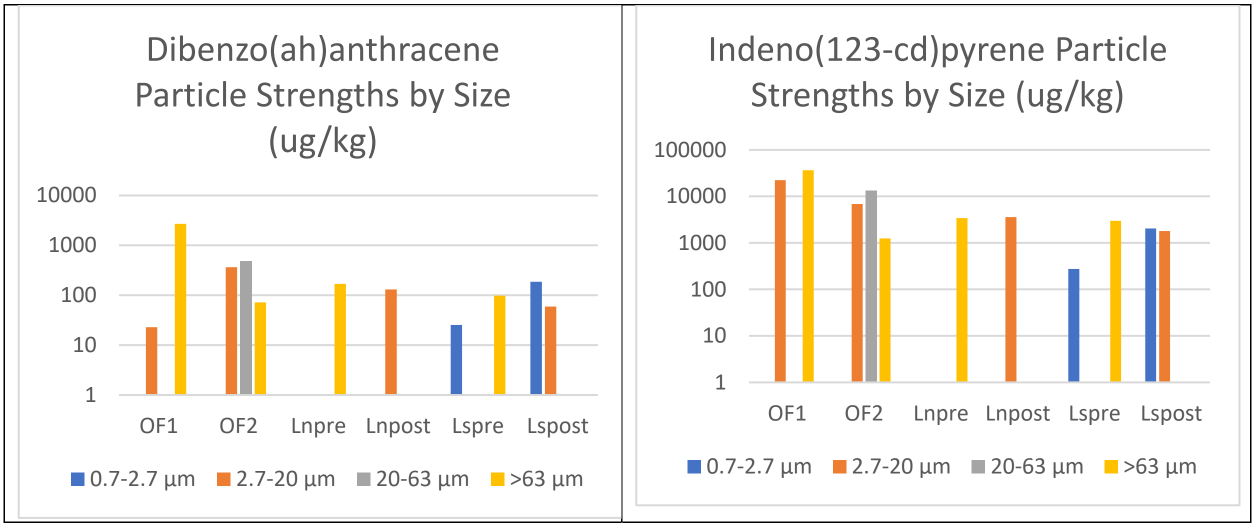


Figure 7. PAH pollutant strengths by particle size.

Table 11. Ratios of Heavy Metal Particulate Strengths for each Size Fraction Compared to Total Runoff Particulate Strength

Chromium mg/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	29.3	0.47	
0.45-5 µm	44.6	0.33	1.53
5-20 µm	34.2	0.27	1.17
20-63 µm	67.9	0.73	2.32
> 63 µm	72.3	0.78	2.47
Manganese mg/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	687.3	0.51	
0.45-5 µm	196.9	0.44	0.29
5-20 µm	864.2	0.40	1.26
20-63 µm	357.9	0.61	0.52
> 63 µm	877.6	0.93	1.28
Nickel mg/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	18.0	0.50	
0.45-5 µm	28.5	0.44	1.59
5-20 µm	39.2	0.49	2.18
20-63 µm	23.9	0.76	1.33
> 63 µm	49.1	1.34	2.73
Copper mg/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	29.9	0.45	
0.45-5 µm	4.4		0.15

5-20 µm	58.6	0.90	1.96
20-63 µm	132.1	0.96	4.42
> 63 µm	212.5	1.56	7.11
Zinc mg/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	149.0	0.18	
0.45-5 µm	129.6	0.92	0.87
5-20 µm	213.5	0.31	1.43
20-63 µm	224.5	0.29	1.51
> 63 µm	610.9	1.74	4.10
Arsenic mg/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	12.5	0.55	
0.45-5 µm	129.2	0.84	10.33
5-20 µm	11.0	0.54	0.88
20-63 µm	114.5	1.70	9.16
> 63 µm	211.4	0.93	16.90
Cadmium mg/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	2.7	0.70	
0.45-5 µm	49.5		18.05
5-20 µm	4.1	0.46	1.51
20-63 µm	2.6	1.10	0.96
> 63 µm	7.0	1.28	2.54
Lead mg/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	44.4	0.39	
0.45-5 µm	25.8	0.42	0.58
5-20 µm	73.4	0.63	1.65
20-63 µm	37.9	0.40	0.85
> 63 µm	123.9	1.44	2.79
Total mercury ug/kg			
Size Interval	avg	COV	ratio avg total PS to size fraction PS
Total Particulate (> 0.45 µm)	542.0	0.77	
0.45-5 µm	196.9	0.44	0.36
5-20 µm	864.2	0.40	1.59
20-63 µm	357.9	0.61	0.66
> 63 µm	877.6	0.93	1.62

Table 12. Ratios of PAH Particulate Strengths for each Size Fraction Compared to Total Runoff Particulate Strength

Naphthalene (ug/kg)	average	COV	ratio avg total PS to size fraction PS
total part (>0.7 um)	14.2	0.65	
0.7-2.7 µm			
2.7-20 µm	20.4	0.67	1.44
20-63 µm	6.8	0.60	0.48
>63 µm	21.5	0.67	1.51
2-methylnaphthalene (ug/kg)			
total part (>0.7 um)	6.4		
0.7-2.7 µm			
2.7-20 µm	8.0		1.25
20-63 µm	2.3		0.37
>63 µm	6.7		1.06
1-methylnaphthalene (ug/kg)			
total part (>0.7 um)	3.4	1.22	
0.7-2.7 µm			
2.7-20 µm	9.8		2.86
20-63 µm	5.2	0.76	1.51
>63 µm	6.0		1.75
2-ethylnaphthalene (ug/kg)			
total part (>0.7 um)	2.1		
0.7-2.7 µm			
2.7-20 µm	2.0		0.96
20-63 µm	3.1		1.49
>63 µm	2.0		0.93
1-ethylnaphthalene			
total part (>0.7 um)	1.3	1.38	
0.7-2.7 µm	1.3	0.29	1.01
2.7-20 µm	0.2		0.13
20-63 µm	0.5	1.18	0.36
>63 µm	2.4	1.20	1.83
2.6-dimethylnaphthalene			
total part (>0.7 um)	3.7		
0.7-2.7 µm			
2.7-20 µm			
20-63 µm	5.8		1.56
>63 µm	3.4		0.91
1.3-dimethylnaphthalene			
total part (>0.7 um)	2.6	1.38	
0.7-2.7 µm			
2.7-20 µm	10.9		4.17
20-63 µm	10.6		4.05
>63 µm	2.2	1.29	0.86
acenaphthylene			
total part (>0.7 um)	13.2	0.70	
0.7-2.7 µm	35.1		2.67
2.7-20 µm	61.0	1.20	4.64
20-63 µm	36.6	0.99	2.78

>63 µm	15.4	0.66	1.17
2.3.5-trimethylnaphthalene			
total part (>0.7 um)	1.4	0.63	
0.7-2.7 µm	7.9		5.83
2.7-20 µm	5.0		3.70
20-63 µm	3.0		2.18
>63 µm	1.3	0.44	0.95
fluorene			
total part (>0.7 um)	12.7	1.20	
0.7-2.7 µm	2.9		0.23
2.7-20 µm	77.8		6.15
20-63 µm	10.2		0.80
>63 µm	16.6	0.87	1.31
1-methylfluorene			
total part (>0.7 um)	4.0	0.28	
0.7-2.7 µm	8.0	1.33	2.00
2.7-20 µm	21.8		5.46
20-63 µm			
>63 µm	5.6	0.22	1.41
phenanthrene			
total part (>0.7 um)	369.5	1.38	
0.7-2.7 µm			
2.7-20 µm			
20-63 µm	267	0.85	0.72
>63 µm	554	0.80	1.50
anthracene			
total part (>0.7 um)	43.4	1.49	
0.7-2.7 µm	28.6		0.66
2.7-20 µm	262.8	1.40	6.06
20-63 µm			
>63 µm	57.9	1.33	1.33
2-methylphenanthrene			
total part (>0.7 um)	41.0	1.44	
0.7-2.7 µm			
2.7-20 µm	759.7		18.51
20-63 µm	98.3		2.39
>63 µm	59.9	0.84	1.46
2-methylanthracene			
total part (>0.7 um)	8.6	1.60	
0.7-2.7 µm	3.2		0.37
2.7-20 µm	40.3	1.68	4.66
20-63 µm	8.8		1.02
>63 µm	11.1	1.35	1.28
1-methylphenanthrene			
total part (>0.7 um)	30.7	1.48	
0.7-2.7 µm			
2.7-20 µm	496.1		16.18
20-63 µm	74.1		2.42
>63 µm	41.4	0.90	1.35
9-methylanthracene			

total part (>0.7 um)	1.6		
0.7-2.7 µm			
2.7-20 µm	3.8		2.39
20-63 µm			
>63 µm	1.6		1.04
2-ethylanthracene			
total part (>0.7 um)	18.8	0.95	
0.7-2.7 µm			
2.7-20 µm	118.5	1.34	6.31
20-63 µm	14.5	0.35	0.77
>63 µm	41.6	0.87	2.21
9.10-dimethylanthracene			
total part (>0.7 um)	27.7	0.67	
0.7-2.7 µm	18.9	0.09	0.68
2.7-20 µm	112.0	1.59	4.04
20-63 µm			
>63 µm	441.5	2.10	15.91
2-tertbutylanthracene			
total part (>0.7 um)	1.8	0.53	
0.7-2.7 µm	4.0	1.43	2.26
2.7-20 µm	1.2	1.15	0.65
20-63 µm	1.7	0.36	0.97
>63 µm	3.8	0.36	2.15
1-methylpyrene			
total part (>0.7 um)	28.0	1.14	
0.7-2.7 µm	17.1		0.61
2.7-20 µm	213.9	1.63	7.64
20-63 µm	59.2	0.77	2.11
>63 µm	28.6	0.98	1.02
benz(a)anthracene			
total part (>0.7 um)	343.3	1.60	
0.7-2.7 µm	50.6		0.15
2.7-20 µm	3062.7	1.92	8.92
20-63 µm	26.7		0.08
>63 µm	478.5	0.94	1.39
7.12-methylbenz(a)anthracene			
total part (>0.7 um)	31.4	0.45	
0.7-2.7 µm	13.2	0.00	0.42
2.7-20 µm	78.8	1.25	2.51
20-63 µm	96.0	0.75	3.06
>63 µm	72.5	0.23	2.31
fluoranthene			
total part (>0.7 um)	1049.6	0.78	
0.7-2.7 µm	28		0.03
2.7-20 µm	1501	0.78	1.43
20-63 µm	2625	0.82	2.50
>63 µm	1090	0.96	1.04
pyrene			
total part (>0.7 um)	1119.4	0.83	
0.7-2.7 µm	235		0.21

2.7-20 µm	11116	1.39	9.93
20-63 µm	1341	1.30	1.20
>63 µm	16458	1.62	14.70
chrysene			
total part (>0.7 um)	1079.1	0.68	
0.7-2.7 µm	255	0.53	0.24
2.7-20 µm	4615	1.77	4.28
20-63 µm	4672		4.33
>63 µm	1341	0.72	1.24
benzo(b)fluoranthene			
total part (>0.7 um)	1071.5	0.73	
0.7-2.7 µm	279	0.73	0.26
2.7-20 µm	4519	1.40	4.22
20-63 µm	4985		4.65
>63 µm	1451	0.77	1.35
benzo(k)fluoranthene			
total part (>0.7 um)	860.8	0.80	
0.7-2.7 µm	220	0.83	0.26
2.7-20 µm	3840	1.53	4.46
20-63 µm	4184		4.86
>63 µm	1139	0.75	1.32
benzo(e)pyrene			
total part (>0.7 um)	477.8	0.76	
0.7-2.7 µm	93	1.05	0.19
2.7-20 µm	2394	1.38	5.01
20-63 µm	1141	1.31	2.39
>63 µm	593	0.57	1.24
benzo(a)pyrene			
total part (>0.7 um)	495.6	1.51	
0.7-2.7 µm	7.7	0.80	0.02
2.7-20 µm	2579	1.76	5.20
20-63 µm	1458	0.68	2.94
>63 µm	565	1.20	1.14
perylene			
total part (>0.7 um)	150.7	1.37	
0.7-2.7 µm	7.2	0.74	0.05
2.7-20 µm	2.5	0.01	0.02
20-63 µm	4.9		0.03
>63 µm	253	1.00	1.68
benzo(ghi)perylene			
total part (>0.7 um)	584.4	1.01	
0.7-2.7 µm	255		0.44
2.7-20 µm	2928	1.45	5.01
20-63 µm	2674		4.58
>63 µm	626	0.71	1.07
Dibenzo(ah)anthracene			
total part (>0.7 um)	341.9	1.93	
0.7-2.7 µm	106	1.08	0.31
2.7-20 µm	144	1.06	0.42
20-63 µm	483		1.41

>63 µm	756	1.70	2.21
Indeno(123-cd)pyrene			
total part (>0.7 um)	5629.9	1.73	
0.7-2.7 µm	1155	1.08	0.21
2.7-20 µm	8616	1.08	1.53
20-63 µm	13441		2.39
>63 µm	11009	1.54	1.96

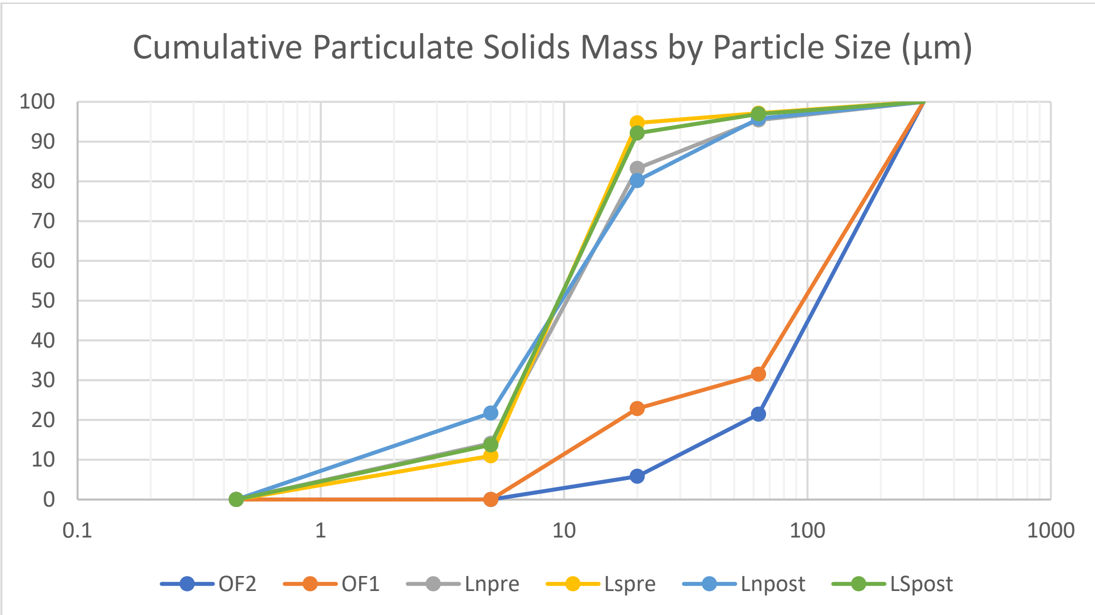
Cumulative Pollutant Mass by Particle Size

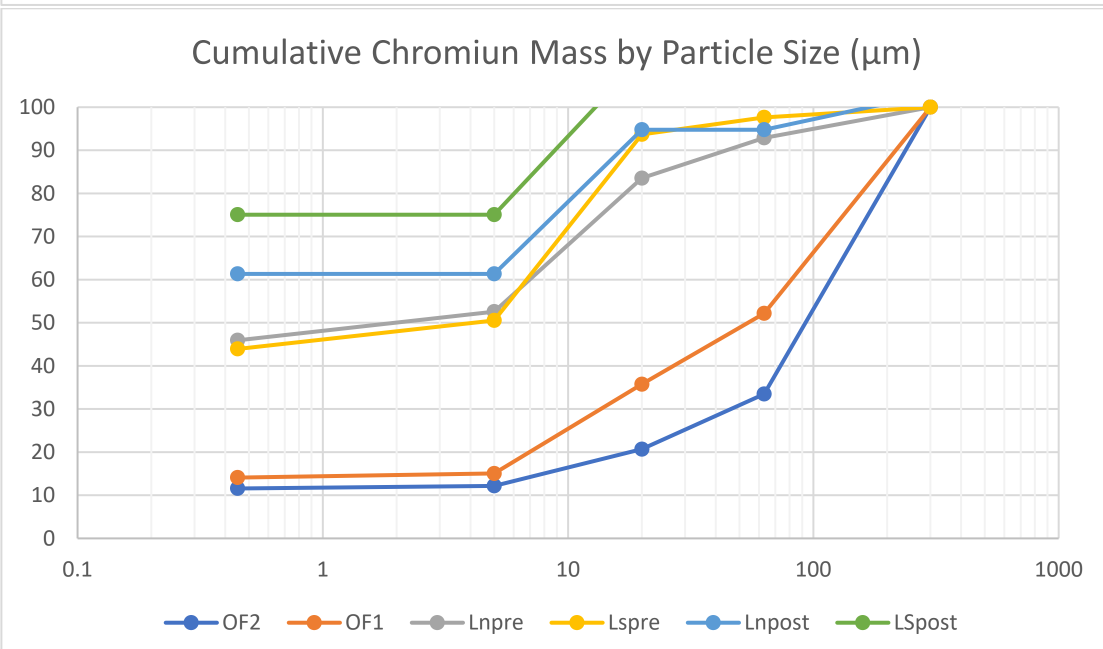
Figures 9 and 10 include plots of pollutant cumulative mass by particle size, for the particulate solids, metals, and PAHs. These graphically show the particle size ranges responsible for the mass of the pollutants. The upper limit of the size ranges monitored was 64 µm, with the difference between those values and the bulk values are therefore associated with sizes greater than 64 µm. Total suspended solids (TSS) analyses usually have an upper size limit of about 75 µm, while suspended sediment concentration (SSC) include larger sizes, up to several hundred µm, depending on collection and analytical methods (see Pitt, R., Clark, S., Eppakayala, V., Sileshi, R. "Don't Throw the Baby Out with the Bathwater—Sample Collection and Processing Issues Associated with Particulate Solids in Stormwater." *Journal of Water Management Modeling*, CHI JWMM 2017; C416: https://www.chijournal.org/C416). For these analyses, a typical upper limit of 300 µm was assumed, with some particles larger than that size limit possible.

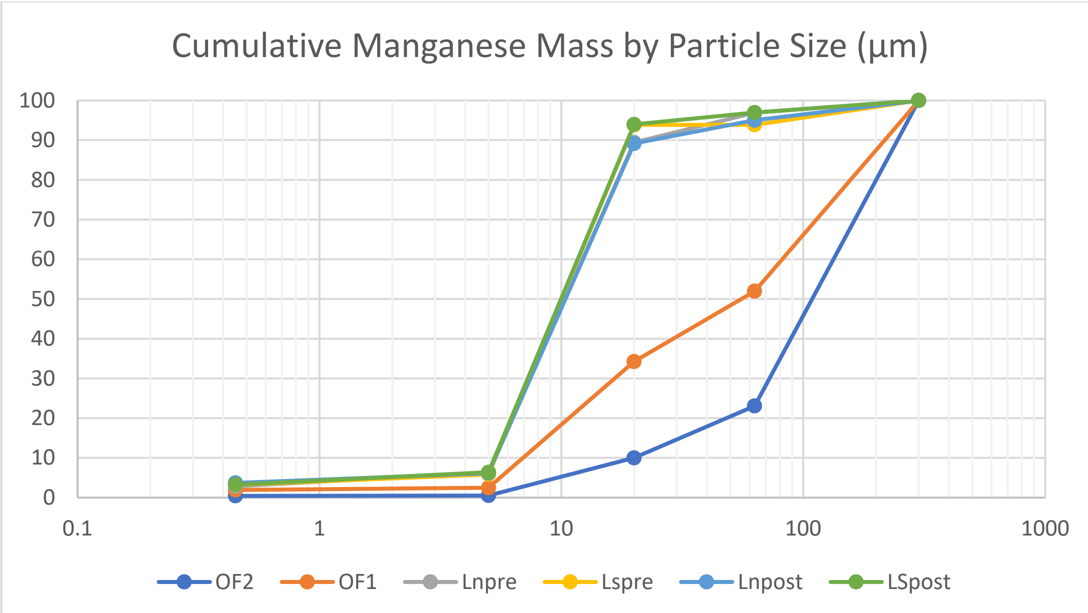
The following comments are from visual observations of these plots:

- Total particulate solids size distribution from the stormwater samples are distinctly different from the in-lake samples. The median size for the stormwater samples was about 100 µm, while it was only about 10 µm for the in-lake samples. There were very few in-lake particles greater than 64 µm, while about 75% of the stormwater samples were greater than 64 µm, substantiating the preferential removal of the larger particles through sedimentation.
- The pre- and post-event in-lake sample concentration distributions were similar, indicating relatively constant concentrations in the lake.
- Most of the heavy metals also had similar pollutant distributions with particle size.
- Some of the in-lake metal concentrations had much greater filterable (<0.45 um) percentage portions (especially chromium, nickel, copper, and arsenic) than the stormwater samples. This may be associated with the lower in-lake concentrations and the preferential removal of the particulate bound forms.
- The cadmium data had greater variations than for the other metals, with less distinct differences in the pollutant mass distributions by size.
- Most of the PAH pollutant size distributions also had distinctly different pollutant distributions for the stormwater and in-lake samples, with the in-lake sample PAH masses being associated with smaller particles than the corresponding stormwater samples. The differences for most of the PAHs were not as large as for the metals.
- The in-lake PAH samples had greater portions of filterable (<0.45 µm) concentrations than the stormwater samples. Again, this is due to the lower in-lake PAH concentrations along with the preferential removal of the particulate forms of the PAHs.

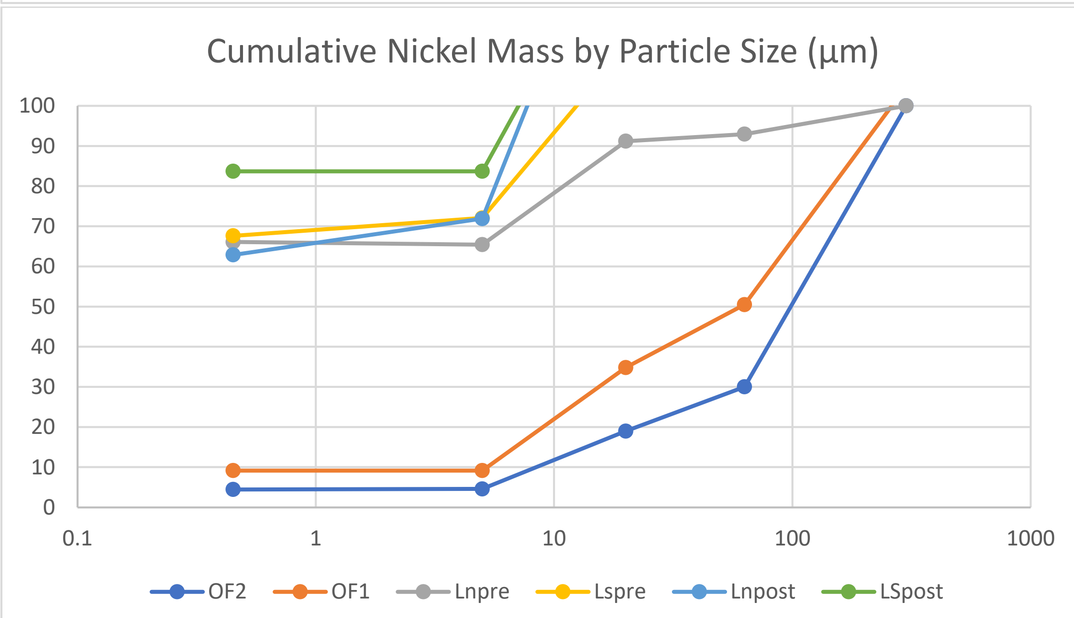
- Many of the PAHs had missing data due to non-detected concentrations, especially for the divided particulate fraction subsamples, resulting in greater uncertainty in the PAH particle size associations. The lake north pre-event samples had many missing observations and are therefore only shown for a few of the PAHs.



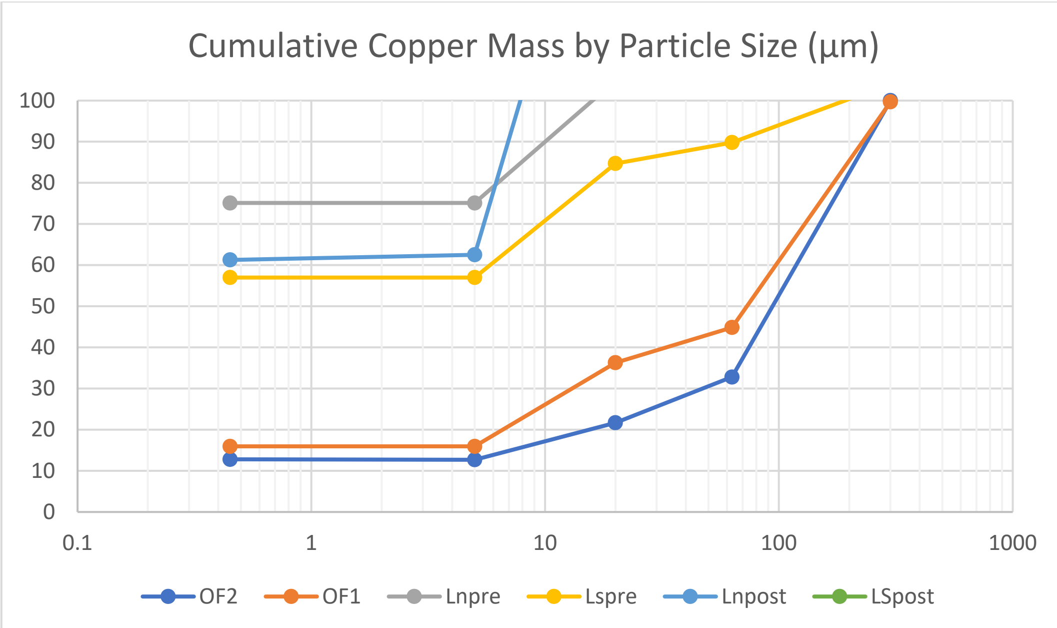


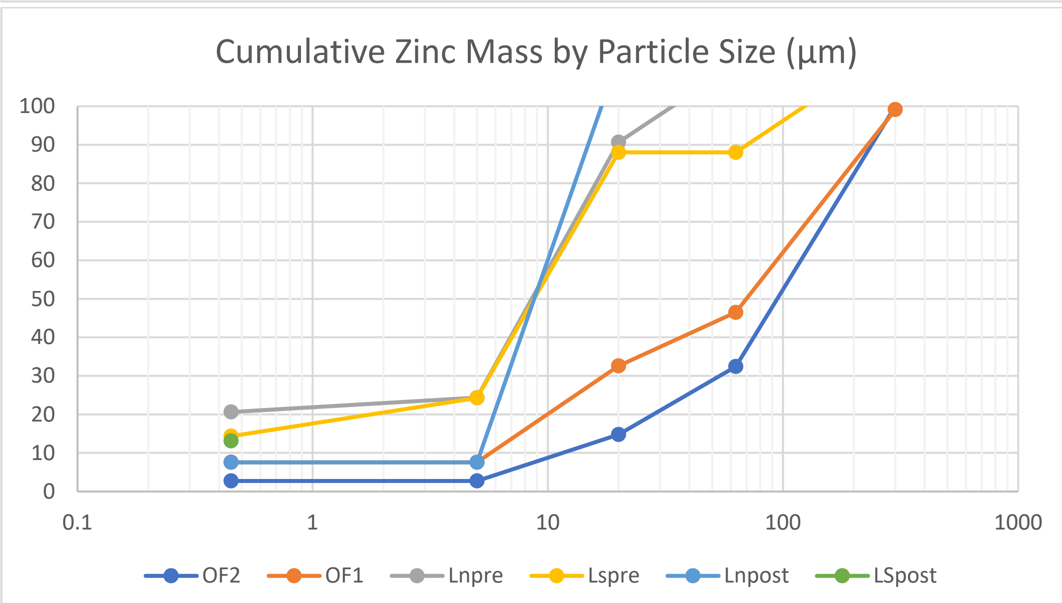


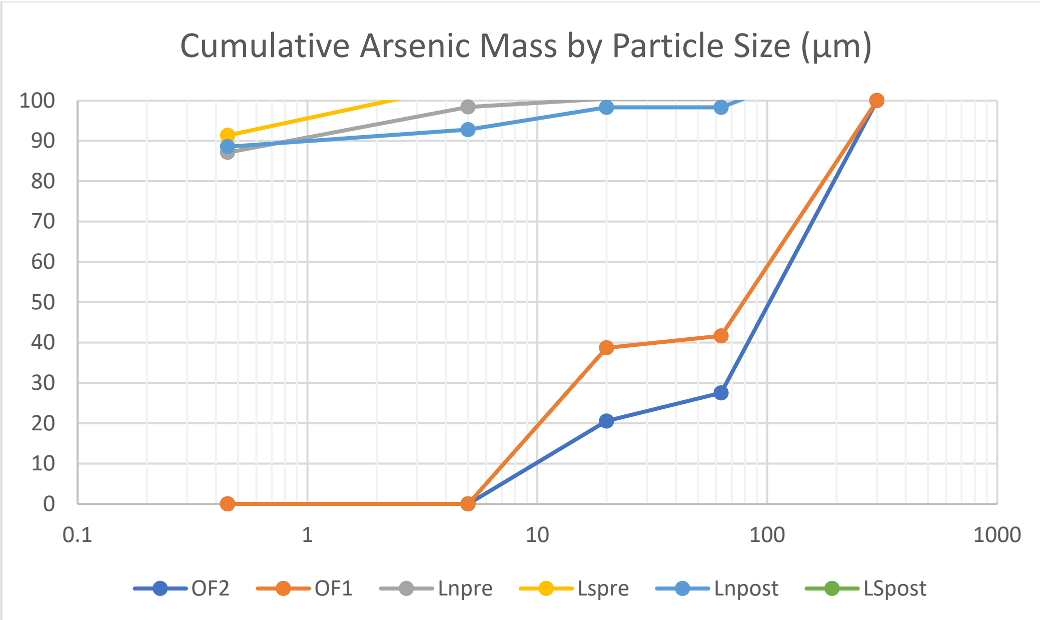
Cumulative Manganese Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF2
OF1
Lnpre
Lspre
Lnpost
LSpost

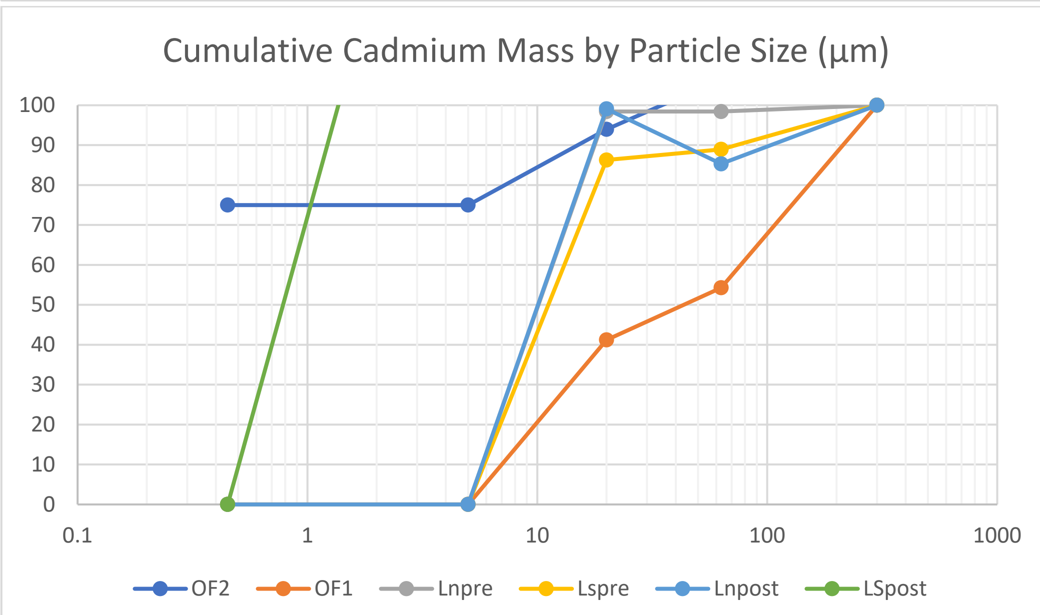


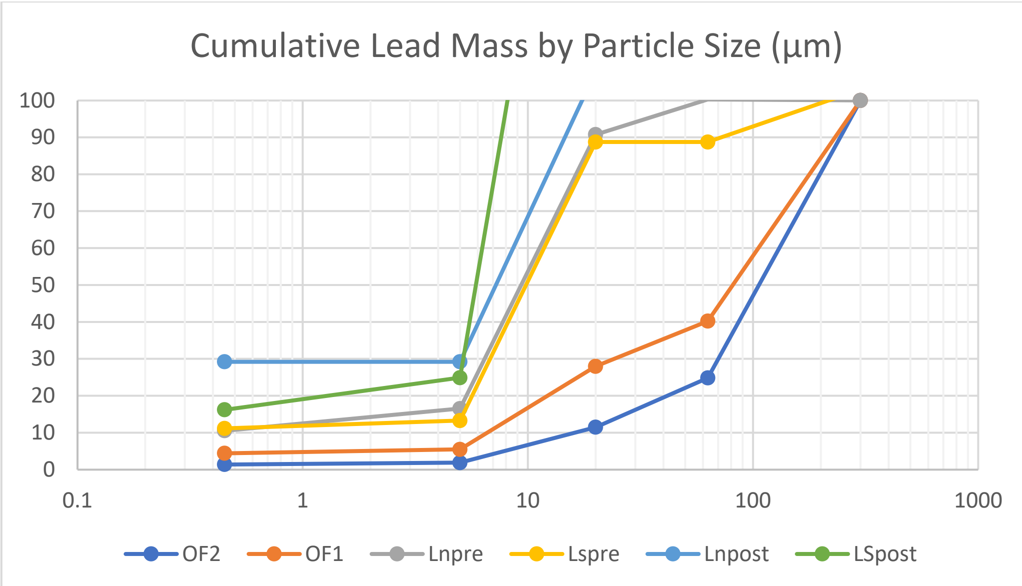
Cumulative Nickel Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF2
OF1
Lnpre
Lspre
Lnpost
LSpost


Cumulative Copper Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF2
OF1
Lnpre
Lspre
Lnpost
LSpost


Cumulative Zinc Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF2
OF1
Lnpre
Lspre
Lnpost
LSpost


Cumulative Arsenic Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF2
OF1
Lnpre
Lspre
Lnpost
LSpost


Cumulative Cadmium Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF2
OF1
Lnpre
Lspre
Lnpost
LSpost



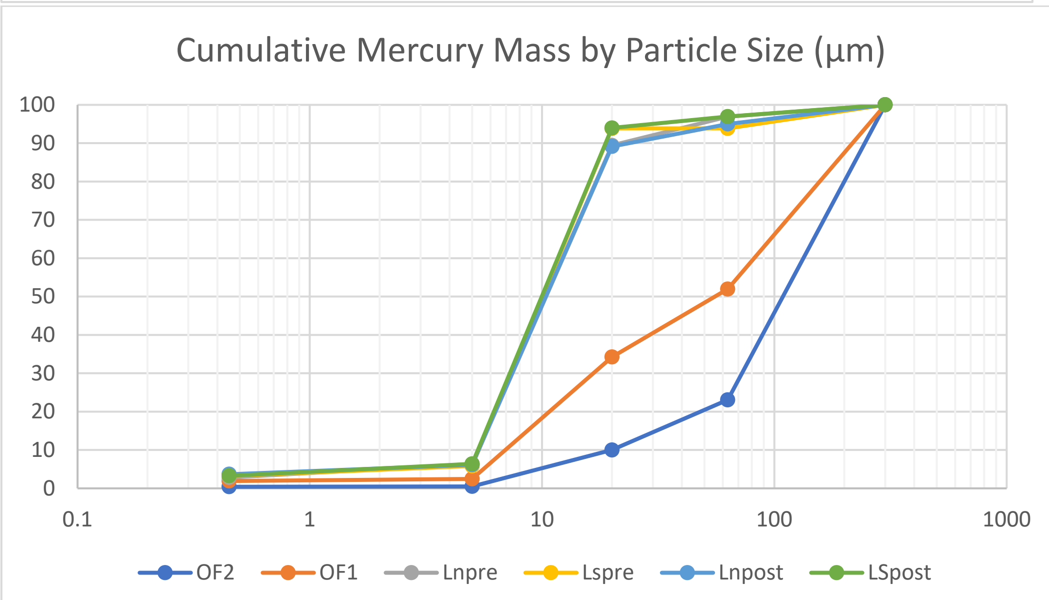
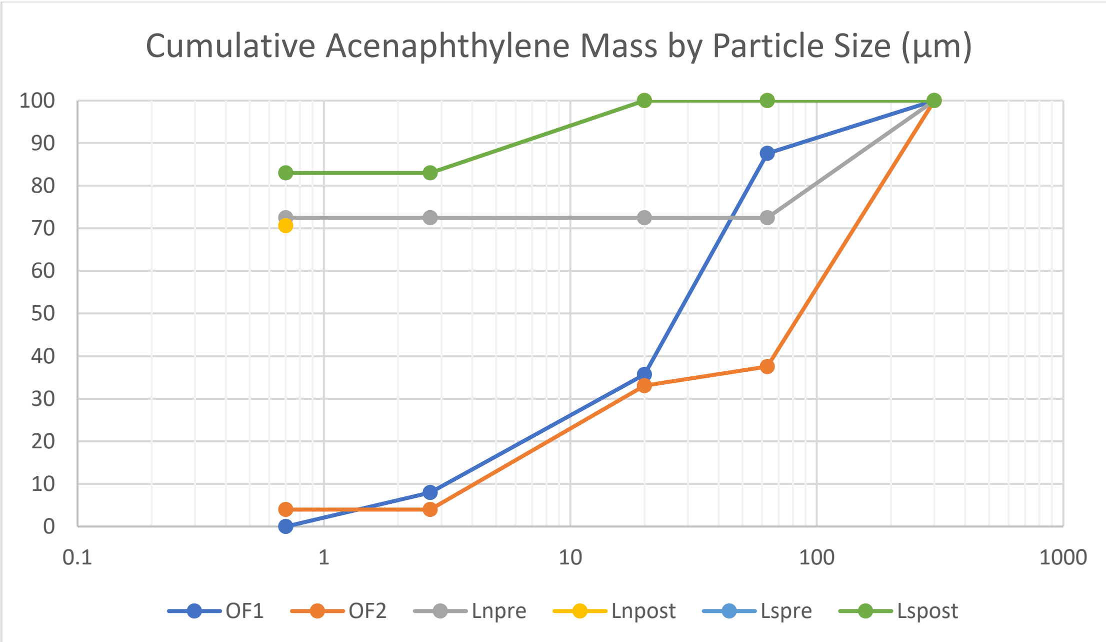
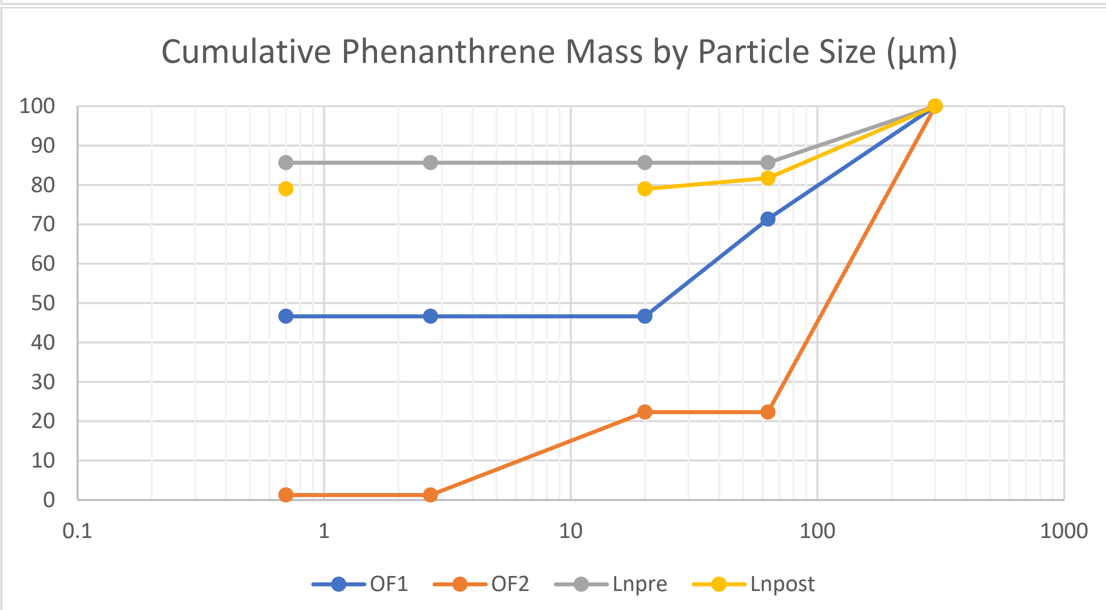
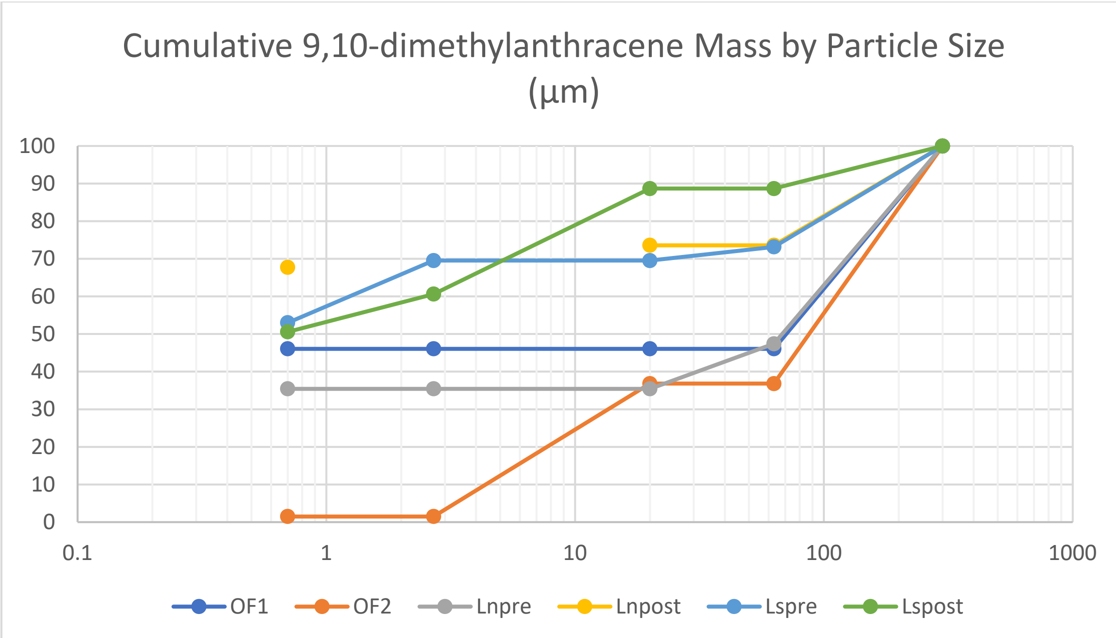


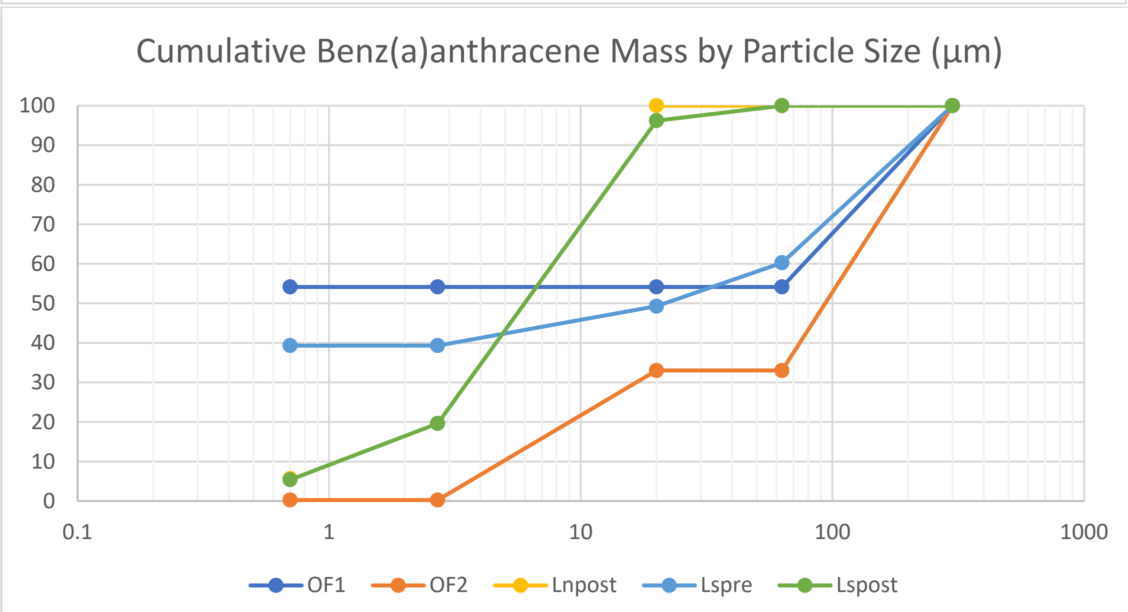
Figure 8. Cumulative heavy metal masses by particle size in stormwater and in pond.


Cumulative Acenaphthylene Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost

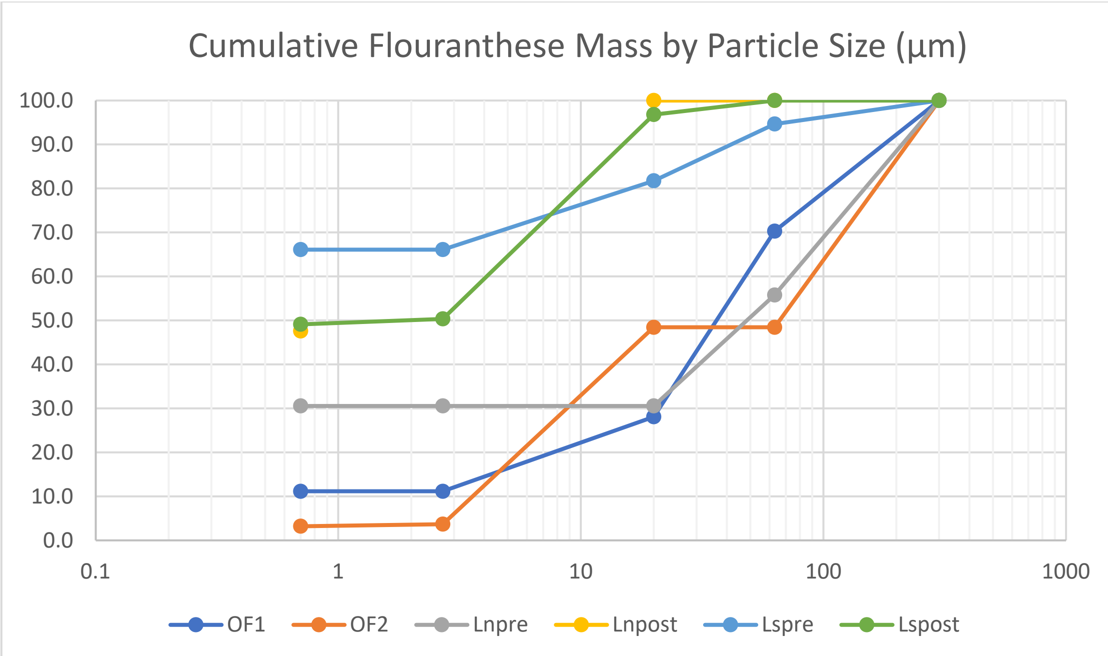

Cumulative Phenanthrene Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpre
Lnpost

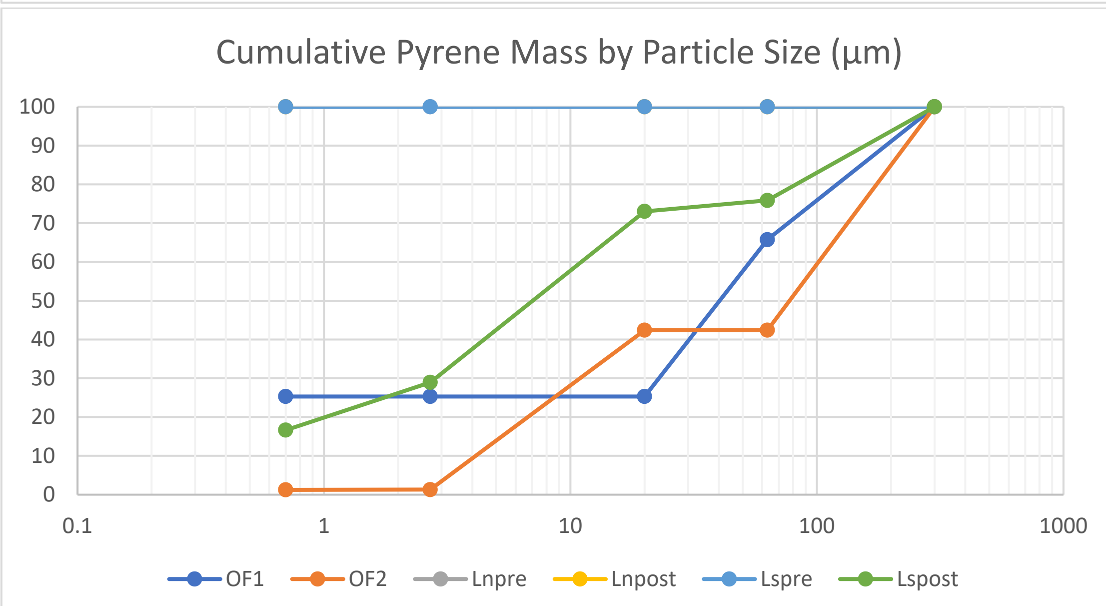


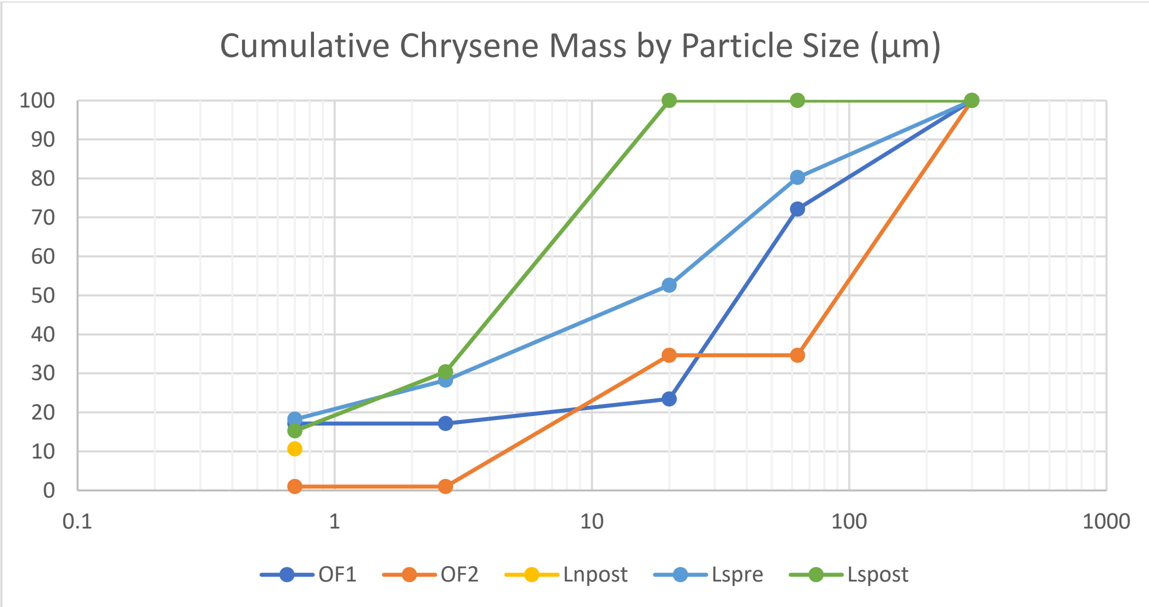
Cumulative 9,10-dimethylanthracene Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost

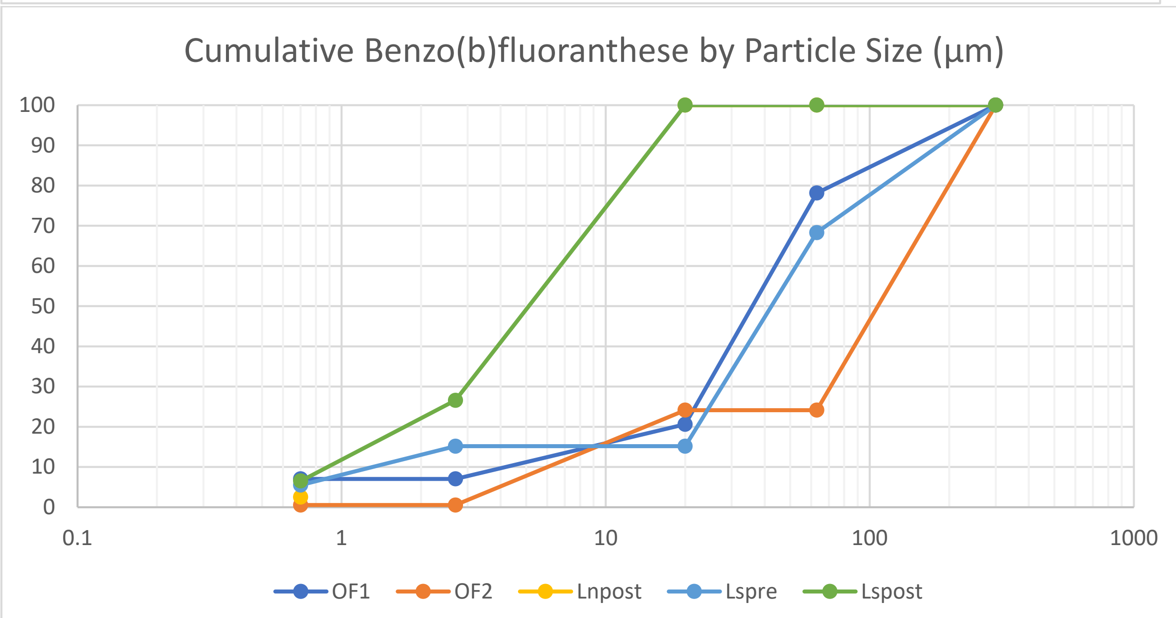


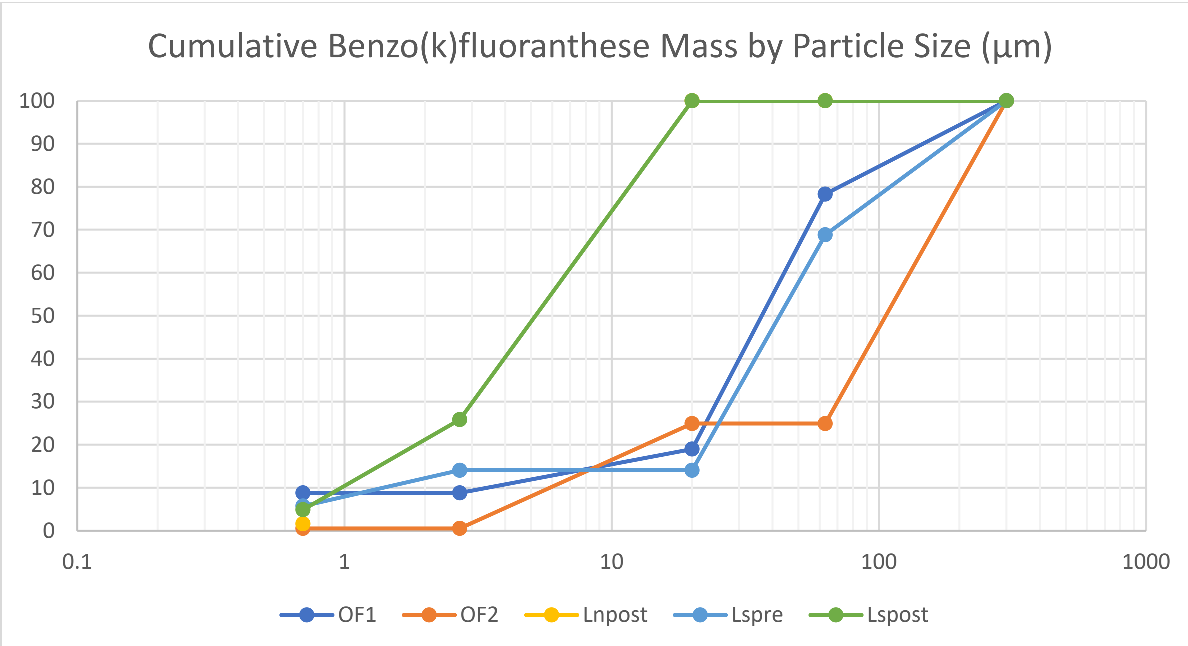
Cumulative Benz(a)anthracene Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpost
Lspre
Lspost


Cumulative Flouranthese Mass by Particle Size (µm)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.1
1
10
100
1000
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost

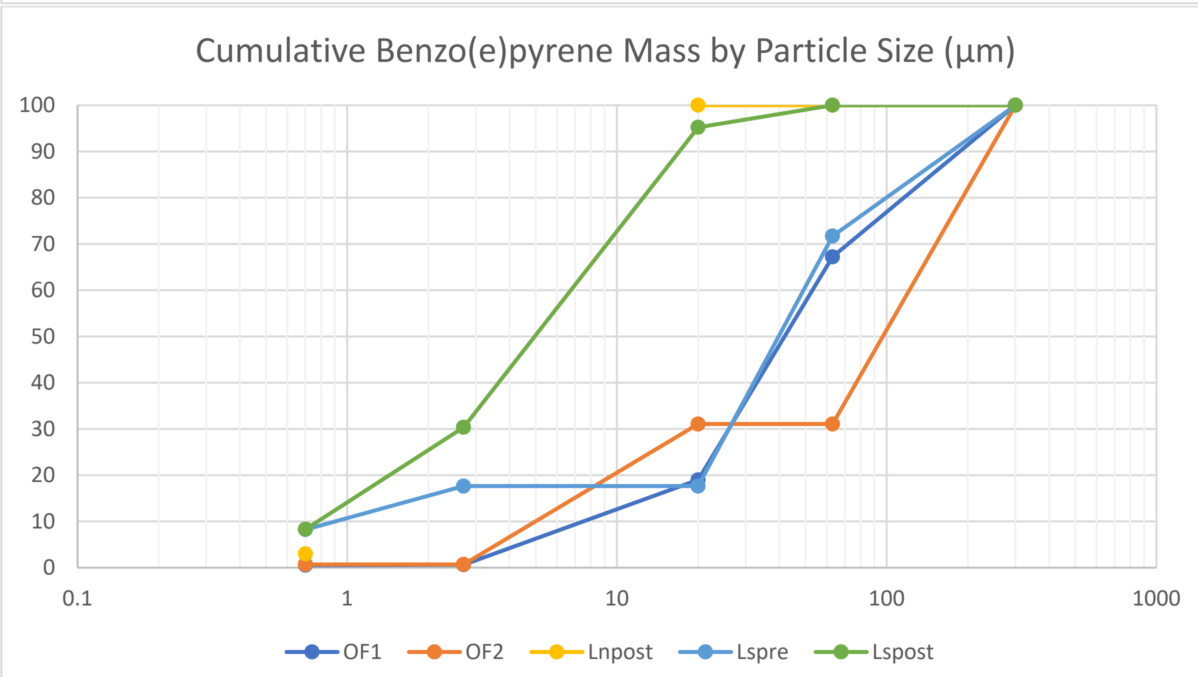

Cumulative Pyrene Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpre
Lnpost
Lspre
Lspost


Cumulative Chrysene Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpost
Lspre
Lspost

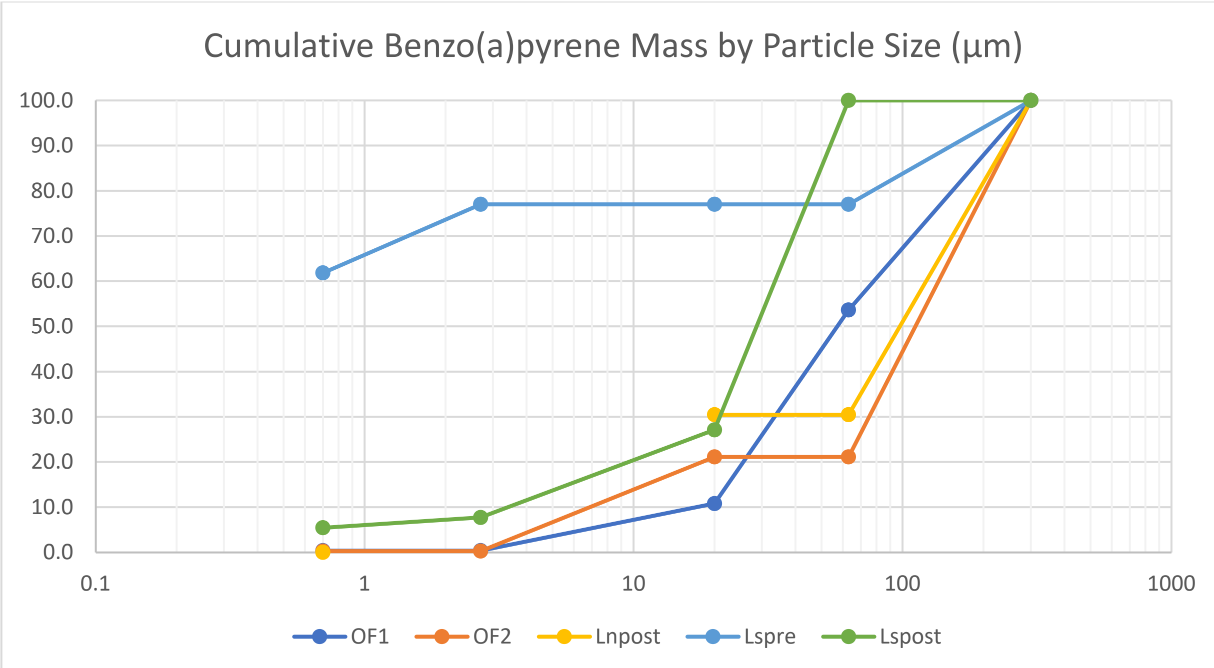

Cumulative Benzo(b)fluoranthese by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpost
Lspre
Lspost



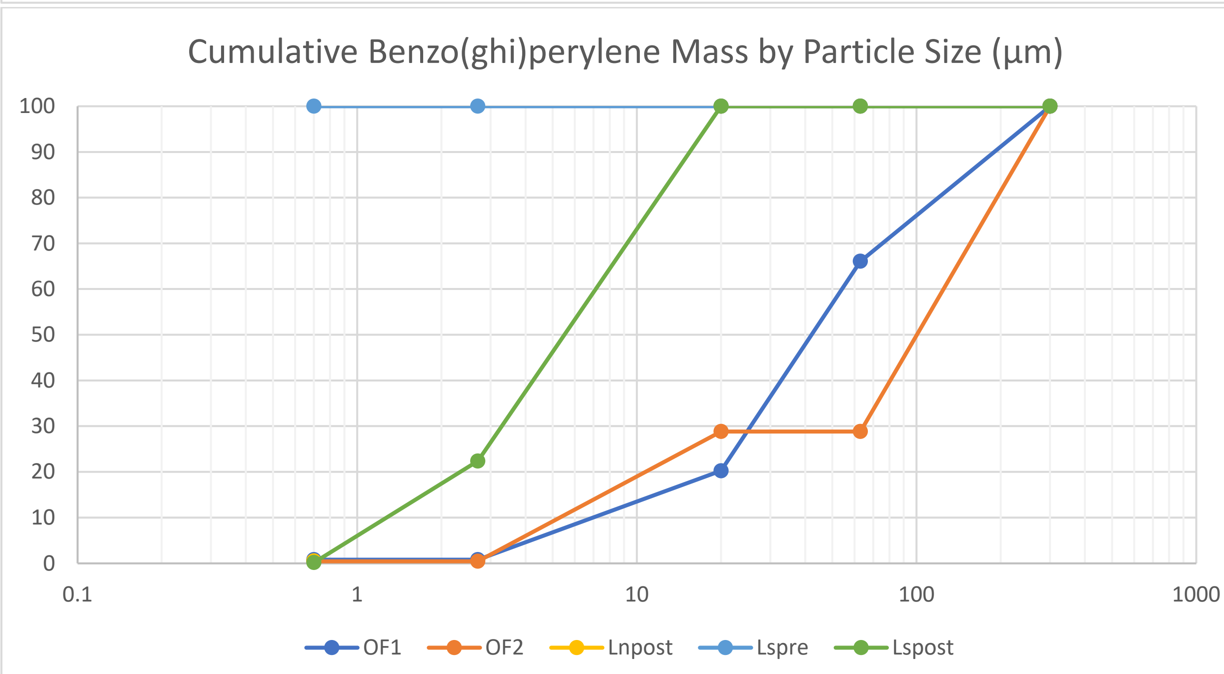
Cumulative Benzo(k)fluoranthese Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpost
Lspre
Lspost



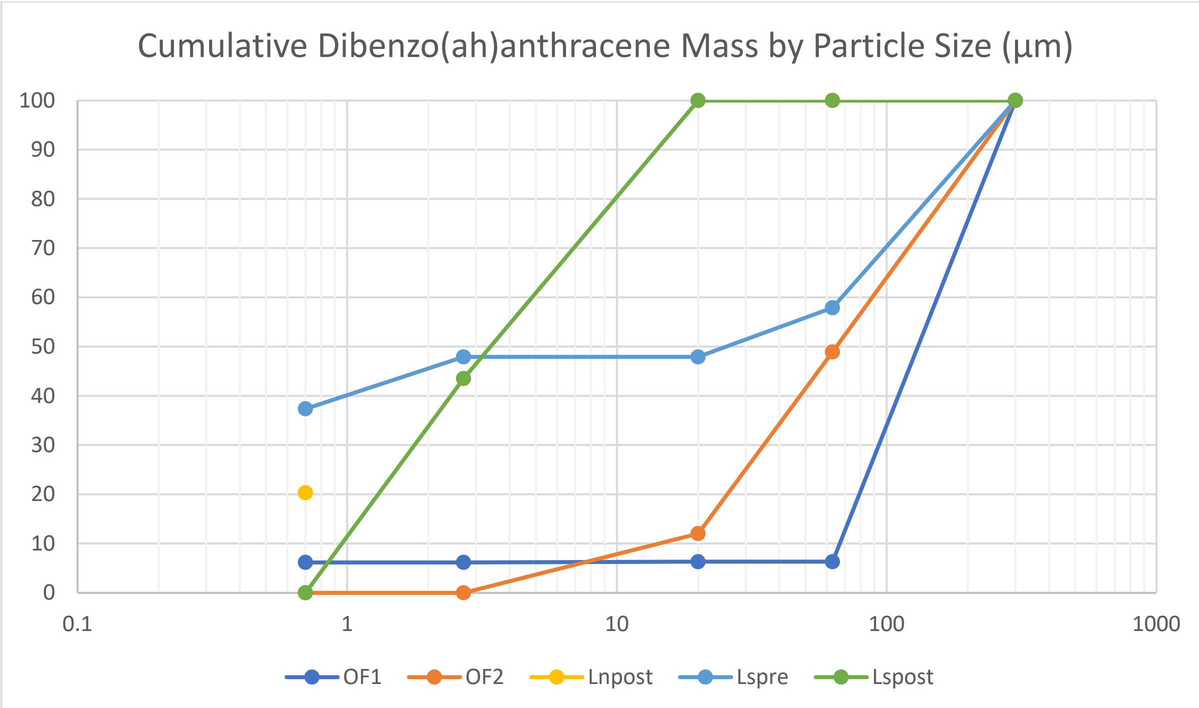
Cumulative Benzo(e)pyrene Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpost
Lspre
Lspost



Cumulative Benzo(a)pyrene Mass by Particle Size (µm)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.1
1
10
100
1000
OF1
OF2
Lnpost
Lspre
Lspost



Cumulative Benzo(ghi)perylene Mass by Particle Size (µm)
100
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
OF1
OF2
Lnpost
Lspre
Lspost



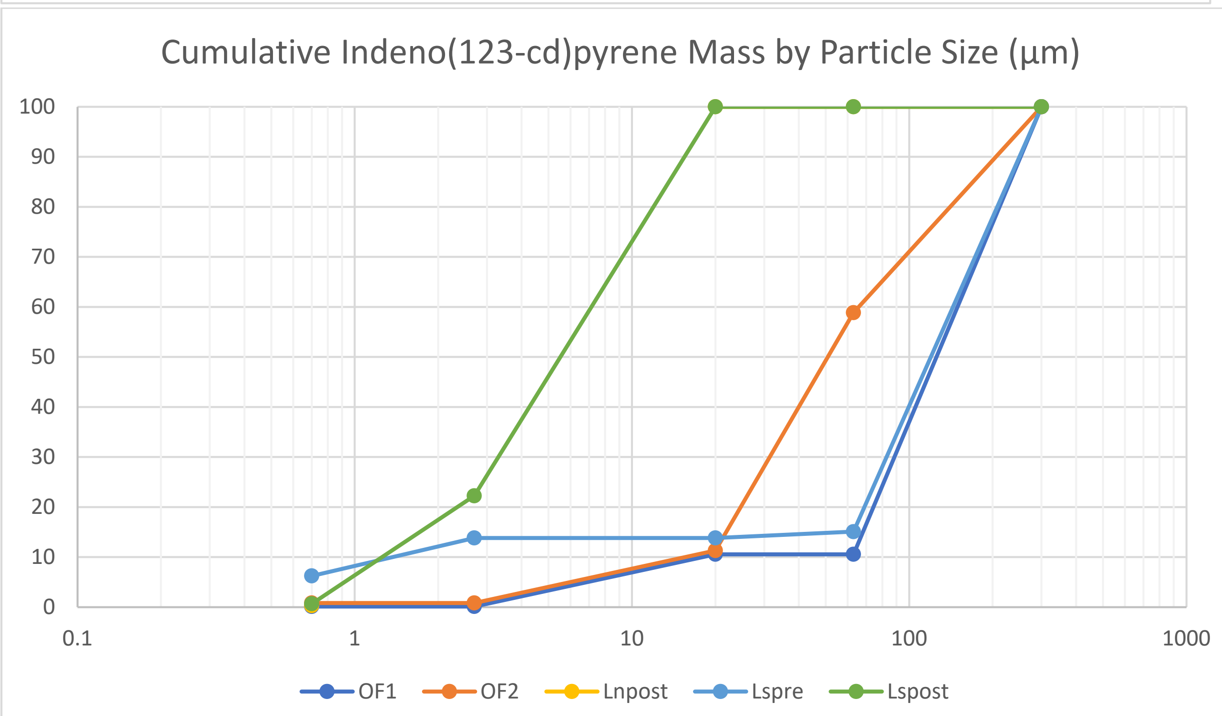


Figure 9. Cumulative PAH masses by particle size in stormwater and in pond.

Performance Monitoring of Picnic Lake

This report section compares the discharge stormwater quality data to the in-lake water quality data, specifically focusing on characteristics that affect treatability. Tables 13 and 14 summarize the discharge and pond total and filtered concentrations for the locations, along with the percentage removal associated with the lake sedimentation processes.

- The discharge particulate solids average concentration was about 730 mg/L (high for most stormwater, but likely affected by erosion in the unlined stormwater channel conveyances). The average in-lake particulate solids concentration was about 50 mg/L, with a 93% reduction. The COV values for both data sets were relatively low, but there were few data available.
- The concentration reductions for the heavy metals ranged from about 60 to 90%, with arsenic showing a possible increase (likely faulty), but no statistical comparison tests were used due to the limited data.
- The filtered metal concentration changes varied greatly, with no consistent pattern. It is not likely that any reductions were real. Sedimentation processes have no effect on filtered pollutants, although biochemical processes may affect the relationships of some of the metals to particulates.

Tables 15 and 16 summarize the filtered and particulate bound fractions of the metals in the discharge stormwater and lake samples.

- The stormwater metals had <15% associated with their filtered fractions, with the exception of cadmium that had about 40% associated with its filtered fraction.
- In contrast, the in-lake samples had much greater portions of some of the metals associated with the filtered fractions (Cr, Ni, Cu, and As at 50 to 98% filtered, while Mn, Zn, Hg, and Cd had <15% associated with the filtered fractions).

Figure 10 and 11 contains probability plots of the stormwater and in-lake particulate solids and metal concentrations, for the unfiltered (total) and filtered samples). These plots show log-normal concentrations along with the 95% confidence intervals for the concentrations. Little overlap signifies significant differences in the concentrations between the two sampling locations, while overlapping confidence bands indicate that the concentration groups are not distinct. Also shown on these plots are the Anderson-Darling (AD) test statistics and associated probabilities of how the data fit the log-normal distributions. If the probability of the AD test statistic is small (<0.05), the distribution is significantly different from the log-normal distribution. Also, the slopes of the probability distributions indicate the variability in the concentrations. If the distributions are parallel, the variations are similar.

These plots mostly show distinct separations of the stormwater vs. in-lake concentrations for the total unfiltered samples, while the filtered concentrations show much overlap in the 95% confidence bands of the concentrations.

- Most distributions fit the log-normal probability distributions.
- In many cases, the slope of the distributions for the in-lake unfiltered sample concentrations are steeper than for the stormwater distribution slopes, indicating narrower ranges in the in-lake sample concentrations. This is typical behavior for treated stormwater where the large concentrations receive preferential reductions, while the smaller concentrations are not reduced as much (approaching “irreducible” concentrations).

Tables 17, 18, and 19 along with Figure 11 are similar data summaries indicating the treatability of PAHs.

- Most of the PAHs indicate large reductions in concentrations between the stormwater and in-lake samples. Most of the unfiltered PAH concentration reductions are very high >90%), with the filtered concentration reductions being less, but still high (80 and 90% reductions). Filtered acenaphthylene indicates an increase.
- The particulate bound fractions of the stormwater PAHs are mostly high (>90%), with some as low as about 50%.
- The particulate bound fractions of the in-lake PAHs are lower than for the stormwater, with some as low as about 20%, but some are much higher. These fractions are generally related to their molecular weights and affinity to particulates.
- The probability plots of unfiltered PAHs indicate more overlapping than for the metals, but many are clearly separated. Filtered perylene and benzo(a)pyrene distributions of stormwater vs. in-lake samples are the most distinct for the filtered samples.

Table 13. Unfiltered Metal Concentrations in Stormwater Discharges and in Picnic Lake, and Removal

unfiltered	Particulate solids (mg/L)		Chromium (µg/L)		Manganese(µg/L)		Nickel (µg/L)		Copper (µg/L)	
	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	2	4	2	4
average	728.7	51.2	14.6	3.9	221.2	45.6	8.9	3.4	18.2	4.6
COV	0.57	0.20	0.30	0.13	0.75	0.09	0.30	0.30	0.43	0.19
% removal (avg)		93.0		72.9		79.4		61.9		74.9

Table 13. Unfiltered Metal Concentrations in Stormwater Discharges and in Picnic Lake, and Removal (continued)

unfiltered	Zinc (µg/L)		Lead (µg/L)		Total mercury (ng/L)		Arsenic (µg/L)		Cadmium (µg/L)	
	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	2	4	2	4
average	102.7	9.2	19.5	3.1	221.2	45.6	3.9	7.5	0.6	0.2
COV	0.58	0.13	0.35	0.11	0.75	0.09	0.55	0.21	0.62	0.21
% removal (avg)		91.1		83.9		79.4		-91.8		69.4

Table 14. Filtered Metal Concentrations in Stormwater Discharges and in Picnic Lake, and Removal

filtered	Particulate solids (mg/L)		Chromium (µg/L)		Manganese(µg/L)		Nickel (µg/L)		Copper (µg/L)	
	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	not applicable		2	4	2	4	2	4	2	4
average			1.8	2.2	1.7	1.5	0.6	2.3	2.5	3.4
COV			0.16	0.24	0.23	0.09	0.20	0.24	0.29	0.14
% removal (avg)				-20.9		14.4		-315.3		-33.5

Table 14. Filtered Metal Concentrations in Stormwater Discharges and in Picnic Lake, and Removal (continued)

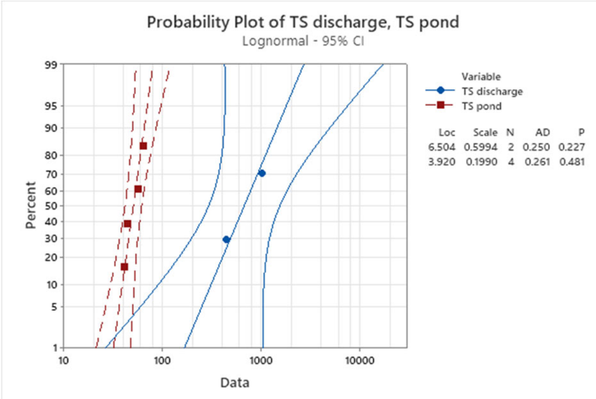
filtered	Zinc (µg/L)		Lead (µg/L)		Total mercury (ng/L)		Arsenic (µg/L)		Cadmium (µg/L)	
	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	mostly undetected		mostly undetected	
average	4.3	1.3	0.5	0.5	1.7	1.5				
COV	0.10	0.44	0.46	0.56	0.23	0.09				
% removal (avg)		70.1		-6.9		14.4				

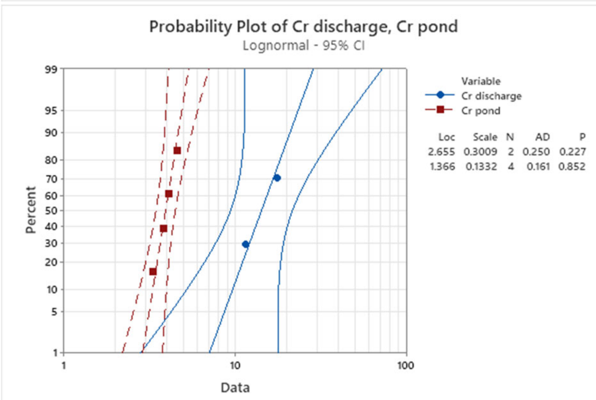
Table 15. Filtered and Particulate Bound Fractions of Stormwater Heavy Metals Entering Picnic Lake

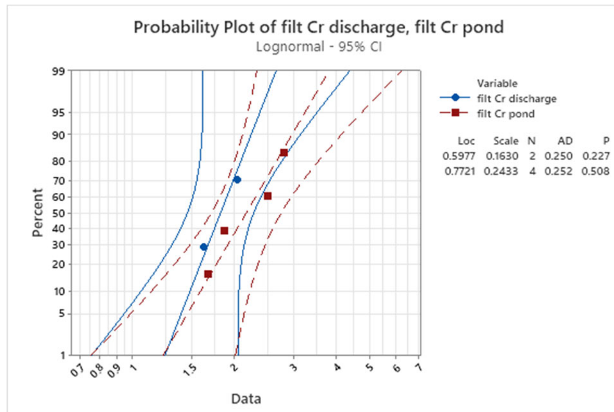
	Size Interval	Particulate Solids (mg/L)	Chromium (µg/L)	Manganese (µg/L)	Nickel (µg/L)	Copper (µg/L)	Zinc (µg/L)	Lead (µg/L)	Total mercury (ng/L)	Arsenic (µg/L)	Cadmium (µg/L)
OF1	Bulk	437.1	11.5	104.5	7.0	12.6	60.4	14.7	104.46	2.4	0.4
OF1	<0.45 µm	NA	1.6	2.0	0.6	2.0	4.6	0.7	2.00	0.0	0.0
OF1	% filt	n/a	14.1	1.9	9.2	16.0	7.6	4.4	1.9	0.0	0.0
OF1	% part	100.0	85.9	98.1	90.8	84.0	92.4	95.6	98.1	100.0	100.0
OF2	Bulk	1020.3	17.6	338.0	10.8	23.7	145.0	24.3	337.97	5.5	0.9
OF2	<0.45 µm	NA	2.0	1.4	0.5	3.0	4.0	0.3	1.44	0.0	0.7
OF2	% filt	n/a	11.6	0.4	4.4	12.8	2.7	1.4	0.4	0.0	75.0
OF2	% part	100.0	88.4	99.6	95.6	87.2	97.3	98.6	99.6	100.0	25.0
	avg % filt	n/a	12.8	1.2	6.8	14.4	5.2	2.9	1.2	0.0	37.5
	avg % part	100.0	87.2	98.8	93.2	85.6	94.8	97.1	98.8	100.0	62.5

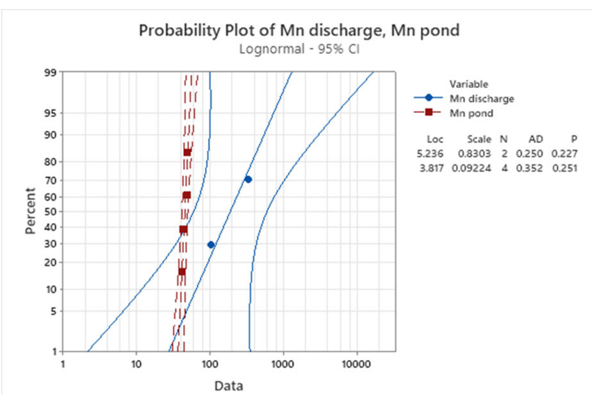
Table 16. Filtered and Particulate Bound Fractions of Stormwater Heavy Metals within Picnic Lake

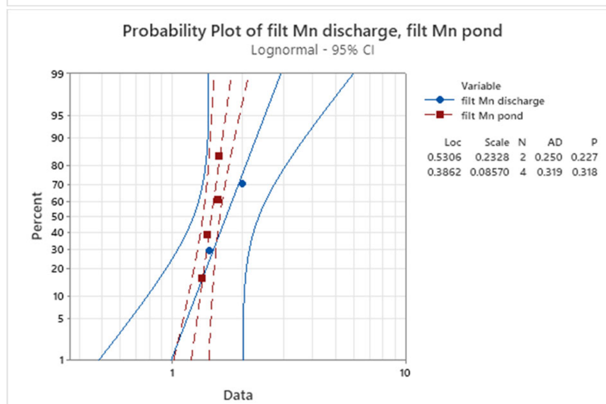
	Size Interval	Particulate Solids (mg/L)	Chromium (µg/L)	Manganese (µg/L)	Nickel (µg/L)	Copper (µg/L)	Zinc (µg/L)	Lead (µg/L)	Total mercury (ng/L)	Arsenic (µg/L)	Cadmium (µg/L)
Lnpre	Bulk	55.8	4.1	49.5	4.5	5.0	9.7	3.2	49.47	8.7	0.2
Lnpre	<0.45 µm	NA	1.9	1.4	3.0	3.7	2.0	0.3	1.41	7.6	0.0
Lnpre	% filt	n/a	45.9	2.8	66.1	75.1	20.6	10.5	2.8	87.1	0.0
Lnpre	% part	100.0	54.1	97.2	33.9	24.9	79.4	89.5	97.2	12.9	100.0
Lspre	Bulk	41.4	3.8	48.8	3.8	5.1	9.8	3.4	48.85	8.6	0.2
Lspre	<0.45 µm	NA	1.7	1.6	2.6	2.9	1.4	0.4	1.57	7.8	0.0
Lspre	% filt	n/a	43.9	3.2	67.6	57.0	14.3	11.2	3.2	91.4	0.0
Lspre	% part	100.0	56.1	96.8	32.4	43.0	85.7	88.8	96.8	8.6	100.0
Lnpost	Bulk	63.3	4.6	43.0	3.0	4.9	9.7	3.3	43.01	7.6	0.2
Lnpost	<0.45 µm	NA	2.8	1.6	1.9	3.0	0.7	1.0	1.59	6.7	0.0
Lnpost	% filt	n/a	61.4	3.7	62.9	61.3	7.5	29.2	3.7	88.6	0.0
Lnpost	% part	100.0	38.6	96.3	37.1	38.7	92.5	70.8	96.3	11.4	100.0
Lspost	Bulk	44.1	3.3	41.1	2.2	3.3	7.4	2.6	41.10	5.3	0.1
Lspost	<0.45 µm	NA	2.5	1.3	1.9	3.8	1.0	0.4	1.33	6.5	0.0
Lspost	% filt	n/a	75.1	3.2	83.7	117.5	13.1	16.2	3.2	123.0	0.0
Lspost	% part	100.0	24.9	96.8	16.3	-17.5	86.9	83.8	96.8	-23.0	100.0
	avg % filt	n/a	56.6	3.3	70.1	77.7	13.9	16.8	3.3	97.5	0.0
	avg % part	100.0	43.4	96.7	29.9	22.3	86.1	83.2	96.7	2.5	100.0

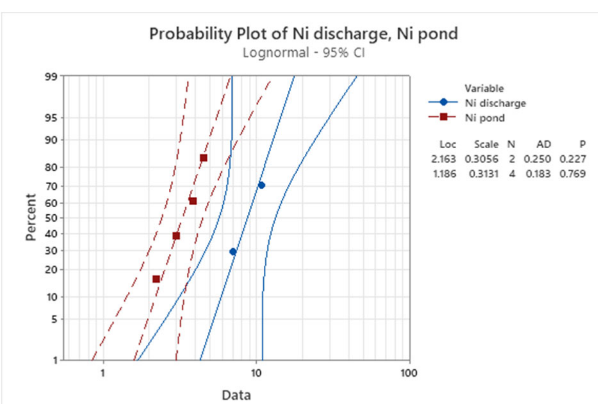

Probability Plot of TS discharge, TS pond
Lognormal - 95% CI
Variable
TS discharge
TS pond
Loc Scale N AD P
6.504 0.5994 2 0.250 0.227
3.920 0.1990 4 0.261 0.481
Percent
Data

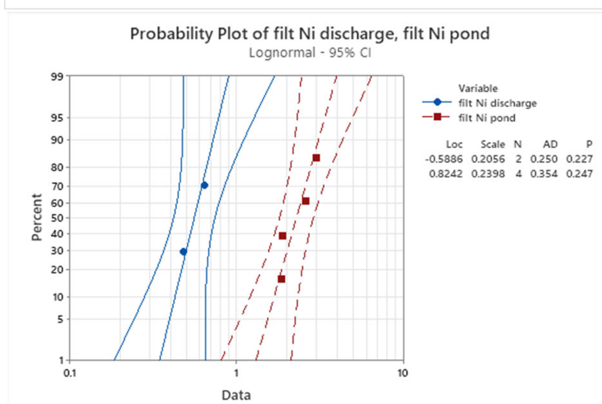

Probability Plot of Cr discharge, Cr pond
Lognormal - 95% CI
Variable
Cr discharge
Cr pond
Loc Scale N AD P
2.655 0.3009 2 0.250 0.227
1.366 0.1332 4 0.161 0.852
Percent
Data


Probability Plot of filt Cr discharge, filt Cr pond
Lognormal - 95% CI
Variable
filt Cr discharge
filt Cr pond
Loc Scale N AD P
0.5977 0.1630 2 0.250 0.227
0.7721 0.2433 4 0.252 0.508
Percent
Data


Probability Plot of Mn discharge, Mn pond
Lognormal - 95% CI
Variable
Mn discharge
Mn pond
Loc Scale N AD P
5.236 0.8303 2 0.250 0.227
3.817 0.09224 4 0.352 0.251
Percent
Data


Probability Plot of filt Mn discharge, filt Mn pond
Lognormal - 95% CI
Variable
filt Mn discharge
filt Mn pond
Loc Scale N AD P
0.5306 0.2328 2 0.250 0.227
0.3862 0.08570 4 0.319 0.318
Percent
Data


Probability Plot of Ni discharge, Ni pond
Lognormal - 95% CI
Variable
Ni discharge
Ni pond
Loc Scale N AD P
2.163 0.3056 2 0.250 0.227
1.186 0.3131 4 0.183 0.769
Percent
Data


Probability Plot of filt Ni discharge, filt Ni pond
Lognormal - 95% CI
Variable
filt Ni discharge
filt Ni pond
Loc Scale N AD P
-0.5886 0.2056 2 0.250 0.227
0.8242 0.2398 4 0.354 0.247
Percent
Data

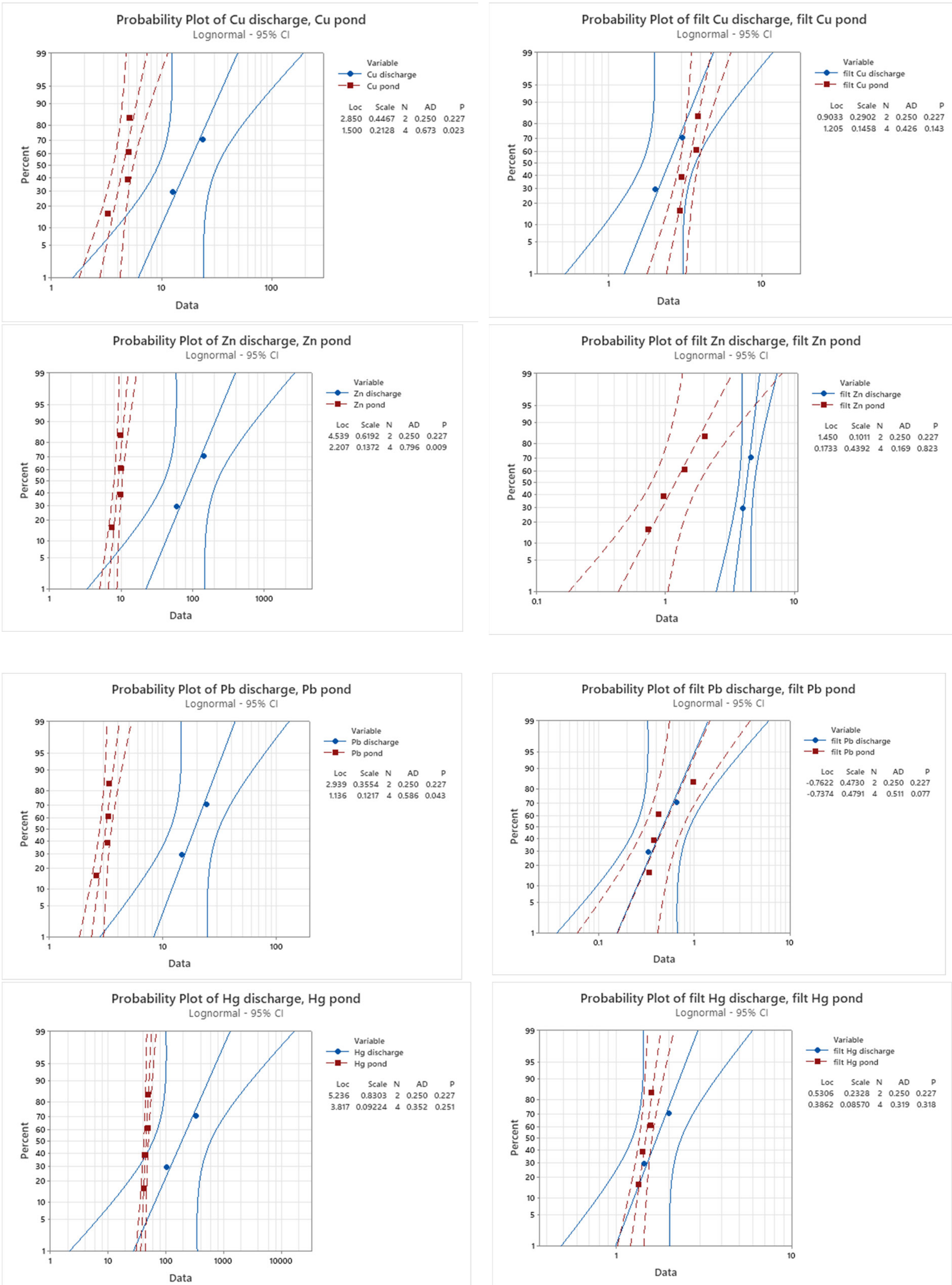


Figure 10. Probability plots of stormwater discharge and in-lake heavy metal total and filtered concentrations.

Table 17. Filtered and Unfiltered Stormwater and Pond PAH Concentrations, and Percentage Removals

all ng/L	acenaphthylene		fluorene		phenanthrene		anthracene		2-methylphenanthrene		1-methylphenanthrene	
unfiltered	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	2	4	2	4	2	4
Average (ng/L)	19.6	2.3	26.4	1.6	773.3	16.1	106.7	1.0	99.4	1.8	75.6	1.3
COV	0.59	0.87	0.57	0.16	1.11	0.64	0.50	0.64	1.10	0.76	1.12	0.64
% removal (avg)		88.3		93.9		97.9		99.0		98.2		98.3

all ng/L	acenaphthylene		fluorene		phenanthrene		anthracene		2-methylphenanthrene		1-methylphenanthrene	
filtered	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	2	4	2	4	2	4
Average (ng/L)	0.6	2.0	8.5	1.5	47.2	13.9	35.2	0.9	3.7	1.5	3.1	1.1
COV	1.41	1.06	1.21	0.22	0.90	0.54	1.37	0.89	0.49	0.72	0.29	0.66
% removal (avg)		-268.2		82.0		70.6		97.5		60.2		64.8

Table 17. Filtered and Unfiltered Stormwater and Pond PAH Concentrations, and Percentage Removals (continued)

all ng/L	9.10-dimethylanthracene		benz(a)anthracene		fluoranthene		pyrene		chrysene		benzo(b)fluoranthene	
unfiltered	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	2	4	2	4	2	4
Average (ng/L)	49.8	1.7	1012.2	4.8	1878.0	53.4	1606.5	31.7	1840.8	35.6	1855.1	30.7
COV	0.17	0.29	1.05	0.55	0.75	0.78	0.88	0.61	0.71	0.64	0.78	0.56
% removal (avg)		96.6		99.5		97.2		98.0		98.1		98.3

all ng/L	9.10-dimethylanthracene		benz(a)anthracene		fluoranthene		pyrene		chrysene		benzo(b)fluoranthene	
filtered	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	2	4	2	4	2	4
Average (ng/L)	13.2	0.9	73.7	0.5	95.5	23.1	93.4	28.8	92.5	3.4	37.1	0.9
COV	1.34	0.55	1.33	1.18	0.04	0.76	0.92	0.81	1.00	0.84	0.82	0.60
% removal (avg)		93.0		99.3		75.8		69.2		96.3		97.7

Table 17. Filtered and Unfiltered Stormwater and Pond PAH Concentrations, and Percentage Removals (continued)

	benzo(k)fluoranthene		benzo(e)pyrene		benzo(a)pyrene		perylene		benzo(ghi)perylene		Dibenzo(ah)anthracene		Indeno(123-cd)pyrene	
unfiltered	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	2	4	2	4	2	4	2	4
Average (ng/L)	1593.0	22.4	802.3	12.6	1334.8	2.1	305.1	0.3	1067.4	6.1	506.3	3.3	7734.6	66.7
COV	0.81	0.51	0.64	0.54	0.90	0.96	1.06	0.18	0.67	0.79	1.00	0.31	0.83	0.40
% removal (avg)		98.6		98.4		99.8		99.9		99.4		99.3		99.1

	benzo(k)fluoranthene		benzo(e)pyrene		benzo(a)pyrene		perylene		benzo(ghi)perylene		Dibenzo(ah)anthracene		Indeno(123-cd)pyrene	
filtered	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond	discharge	pond
count	2	4	2	4	2	4	2	4	2	4	2	4	2	4
Average (ng/L)	36.0	0.5	5.3	0.5	3.9	0.1	1.5	0.2	5.8	0.5	26.7	0.5	21.1	1.0
COV	0.92	0.63	0.79	0.68	0.71	1.16	0.21	0.19	0.32	1.89	1.41	1.17	0.36	1.47
% removal (avg)		98.6		90.9		97.5		86.4		91.8		98.0		95.5

Table 18. Filtered and Particulate Bound Fractions of Stormwater PAHs Entering Picnic Lake

	All µg/L	acenaphthylene	fluorene	phenanthrene	anthracene	2-methylphenanthrene	1-methylphenanthrene	9.10-dimethylanthracene	benz(a)anthracene	fluoranthene	pyrene
OF1	Filtered (<0.7µm)	0.0	15.8	77.2	69.3	5.0	3.7	25.7	142.9	98.0	154.5
OF1	Bulk	11.5	15.8	165.5	69.3	22.1	15.6	55.9	263.9	878.4	610.6
	% filt	0.0	100.0	46.6	100.0	22.8	23.8	46.1	54.1	11.2	25.3
	% part	100.0	0.0	53.4	0.0	77.2	76.2	53.9	45.9	88.8	74.7
OF2	Filtered (<0.7µm)	1.1	1.3	17.2	1.2	2.5	2.4	0.7	4.6	92.9	32.3
OF2	Bulk	27.7	37.0	1381.2	144.1	176.6	135.6	43.6	1760.6	2877.6	2602.4
	% filt	4.0	3.4	1.2	0.8	1.4	1.8	1.5	0.3	3.2	1.2
	% part	96.0	96.6	98.8	99.2	98.6	98.2	98.5	99.7	96.8	98.8
	avg % filt	2.0	51.7	23.9	50.4	12.1	12.8	23.8	27.2	7.2	13.3
	avg % part	98.0	48.3	76.1	49.6	87.9	87.2	76.2	72.8	92.8	86.7

Table 18. Filtered and Particulate Bound Fractions of Stormwater PAHs Entering Picnic Lake (continued)

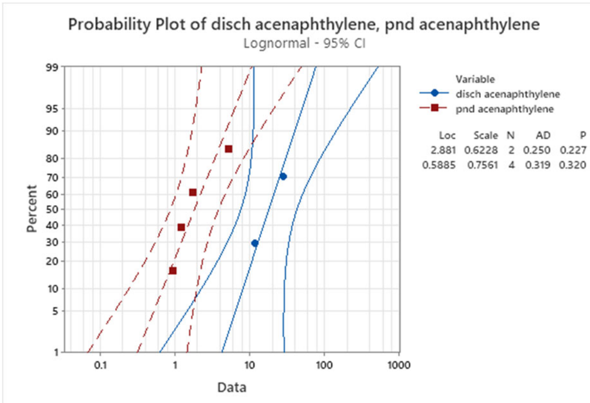
	All µg/L	chrysene	benzo(b)fluoranthene	benzo(k)fluoranthene	benzo(e)pyrene	benzo(a)pyrene	perylene	benzo(ghi)perylene	Dibenzo(ah)anthracene	Indeno(123-cd)pyrene
OF1	Dissolved (<0.7µm)	157.8	58.6	59.4	2.4	1.9	1.3	4.5	53.3	15.7
OF1	Bulk	920.1	831.0	676.6	436.5	483.9	76.7	559.3	865.4	12292.3
	% filt	17.2	7.1	8.8	0.5	0.4	1.7	0.8	6.2	0.1
	% part	82.8	92.9	91.2	99.5	99.6	98.3	99.2	93.8	99.9
OF2	Dissolved (<0.7µm)	27.2	15.6	12.6	8.3	5.8	1.7	7.2	0.0	26.4
OF2	Bulk	2761.5	2879.1	2509.4	1168.1	2185.8	533.5	1575.5	147.2	3176.8
	% filt	1.0	0.5	0.5	0.7	0.3	0.3	0.5	0.0	0.8
	% part	99.0	99.5	99.5	99.3	99.7	99.7	99.5	100.0	99.2
	avg % filt	9.1	3.8	4.6	0.6	0.3	1.0	0.6	3.1	0.5
	avg % part	90.9	96.2	95.4	99.4	99.7	99.0	99.4	96.9	99.5

Table 19. Filtered and Particulate Bound Fractions of Stormwater PAHs within Picnic Lake

	All µg/L	acenaphthylene	fluorene	phenanthrene	anthracene	2-methylphenanthrene	1-methylphenanthrene	9.10-dimethylanthracene	benz(a)anthracene	fluoranthene	pyrene
Lnpre	Filtered (<0.7µm)	0.9	1.6	16.0	0.5	1.7	1.2	0.5	0.0	23.6	37.7
Lnpre	Bulk	1.2	1.6	18.7	0.8	2.6	1.7	1.5	4.8	77.3	37.7
	% filt	72.5	99.3	85.7	62.4	66.7	69.0	35.4	0.7	30.6	100.0
	% part	27.5	0.7	14.3	37.6	33.3	31.0	64.6	99.3	69.4	0.0
LNpost	Filtered (<0.7µm)	1.2	2.0	23.1	1.9	2.9	2.1	1.7	0.5	47.5	56.2
LNpost	Bulk	1.7	2.0	29.2	1.9	3.4	2.3	2.5	8.6	99.8	56.2
	% filt	70.6	100.0	79.0	100.0	85.2	90.0	67.7	5.7	47.6	100.0
	% part	29.4	0.0	21.0	0.0	14.8	10.0	32.3	94.3	52.4	0.0
Lspre	Filterred (<0.7µm)	5.2	1.2	10.9	1.0	0.8	0.6	0.8	1.3	13.1	18.9
Lspre	Bulk	5.2	1.5	10.9	1.0	0.8	0.7	1.4	3.4	19.9	18.9
	% filt	100.0	78.9	100.0	100.0	99.6	79.7	53.0	39.3	66.1	100.0
	% part	0.0	21.1	0.0	0.0	0.4	20.3	47.0	60.7	33.9	0.0
Lspost	Filtered (<0.7µm)	0.8	1.4	5.4	0.1	0.6	0.5	0.7	0.1	8.1	2.3
Lspost	Bulk	0.9	1.4	5.4	0.4	0.6	0.5	1.5	2.6	16.5	13.9
	% filt	83.0	100.0	100.0	27.5	100.0	100.0	50.6	5.4	49.1	16.7
	% part	17.0	0.0	0.0	72.5	0.0	0.0	49.4	94.6	50.9	83.3
	avg % filt	81.5	94.6	91.2	72.5	87.9	84.7	51.7	12.8	48.3	79.2
	avg % part	18.5	5.4	8.8	27.5	12.1	15.3	48.3	87.2	51.7	20.8

Table 19. Filtered and Particulate Bound Fractions of Stormwater PAHs within Picnic Lake (continued)

	All µg/L	chrysene	benzo(b)fluoranthene	benzo(k)fluoranthene	benzo(e)pyrene	benzo(a)pyrene	perylene	benzo(ghi)perylene	Dibenzo(ah)anthracene	Indeno(123-cd)pyrene
Lnpre	Filtered (<0.7µm)	0.2	0.1	0.1	0.0	0.0	0.3	0.0	0.0	0.0
Lnpre	Bulk	37.2	36.1	26.1	12.7	0.4	0.3	2.4	2.3	45.7
	% filt	0.4	0.3	0.2	0.0	0.0	100.0	0.0	0.0	0.0
	% part	99.6	99.7	99.8	100.0	100.0	0.0	100.0	100.0	100.0
LNpost	Filtered (<0.7µm)	7.1	1.3	0.6	0.7	0.0	0.2	0.1	1.0	0.3
LNpost	Bulk	67.0	52.5	37.0	22.2	3.7	0.3	11.8	4.8	103.9
	% filt	10.6	2.5	1.6	3.0	0.0	60.5	0.5	20.3	0.3
	% part	89.4	97.5	98.4	97.0	100.0	39.5	99.5	79.7	99.7
Lspre	Filtered (<0.7µm)	3.9	1.0	0.8	0.7	0.2	0.2	1.8	1.2	3.0
Lspre	Bulk	21.2	18.7	14.5	8.8	0.3	0.3	1.8	3.2	48.6
	% filt	18.2	5.5	5.7	8.2	61.8	52.6	100.0	37.4	6.3
	% part	81.8	94.5	94.3	91.8	38.2	47.4	0.0	62.6	93.7
Lspost	Filtered (<0.7µm)	2.6	1.0	0.6	0.6	0.2	0.2	0.0	0.0	0.5
Lspost	Bulk	16.9	15.3	12.1	6.7	3.8	0.2	8.4	3.1	68.7
	% filt	15.3	6.5	4.9	8.3	5.4	99.4	0.2	0.0	0.7
	% part	84.7	93.5	95.1	91.7	94.6	0.6	99.8	100.0	99.3
	avg % filt	11.2	3.7	3.1	4.9	16.8	78.1	25.2	14.4	1.8
	avg % part	88.8	96.3	96.9	95.1	83.2	21.9	74.8	85.6	98.2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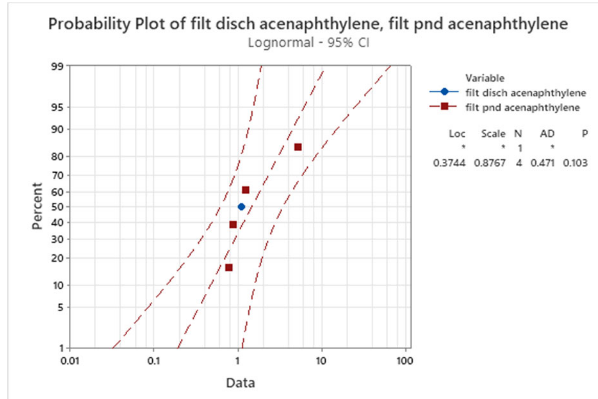
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Loc Scale N AD P
* * 1 *
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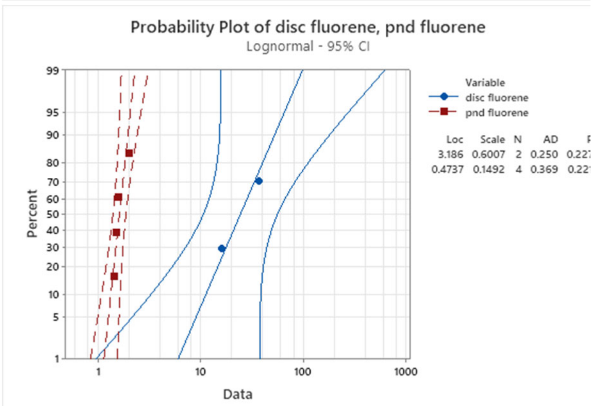
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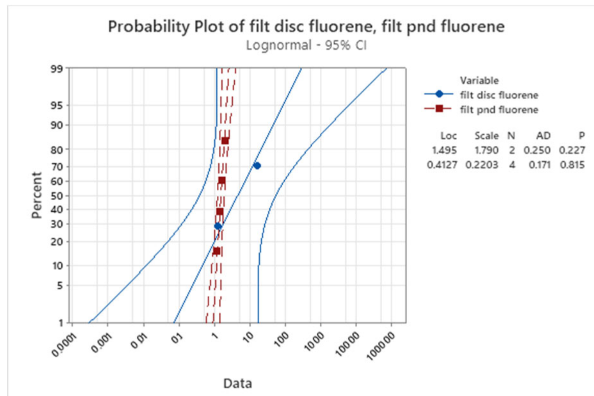
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Lognormal - 95% CI
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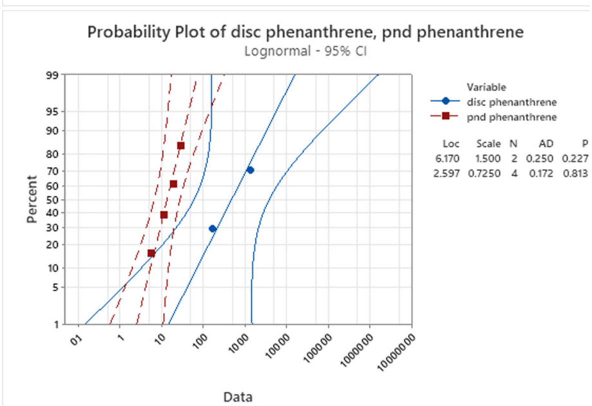
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Percent
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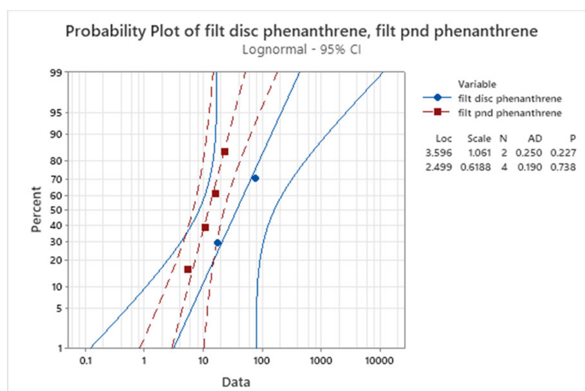
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Loc Scale N AD P
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Percent
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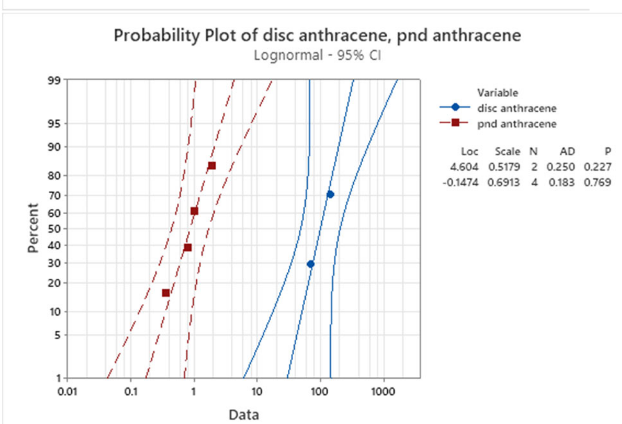
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Lognormal - 95% CI
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pnd anthracene
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Percent
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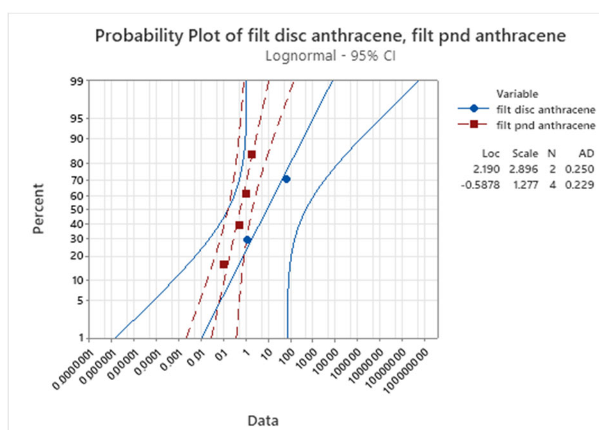
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Lognormal - 95% CI
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Loc Scale N AD
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Percent
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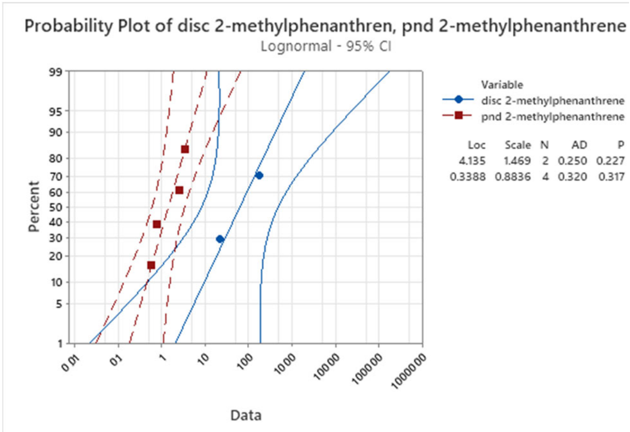
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Percent
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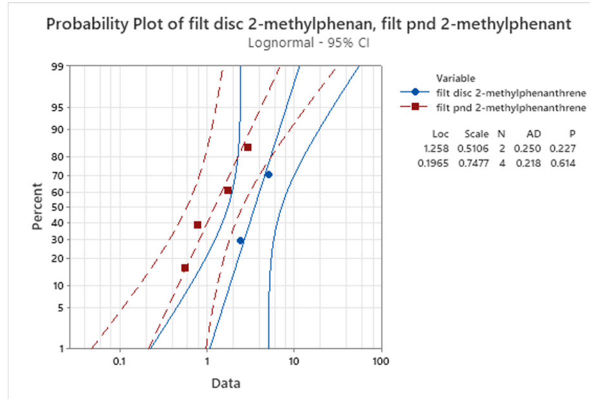
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Percent
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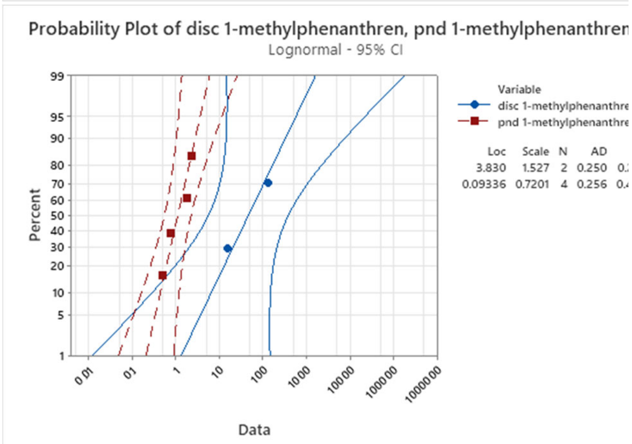
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Lognormal - 95% CI
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Loc Scale N AD
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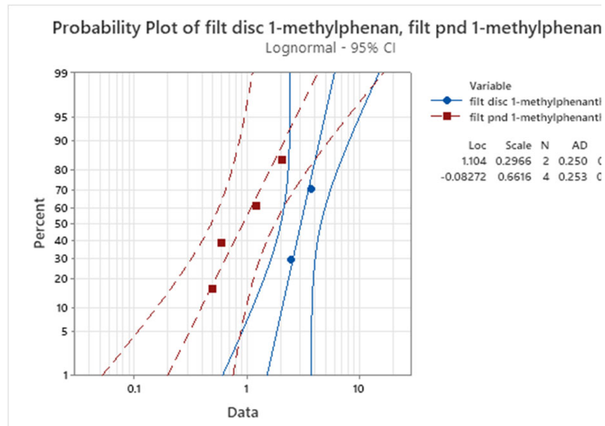
Percent
Data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Lognormal - 95% CI
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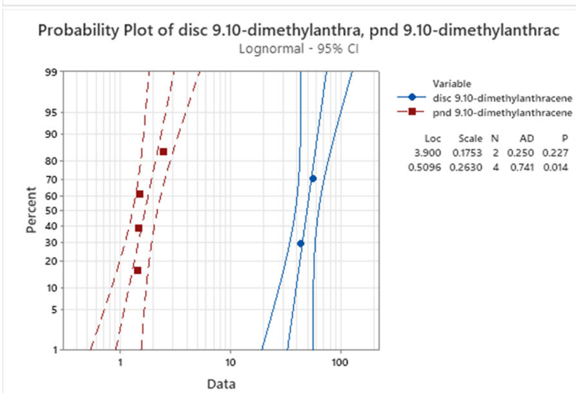
Percent
Data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Percent
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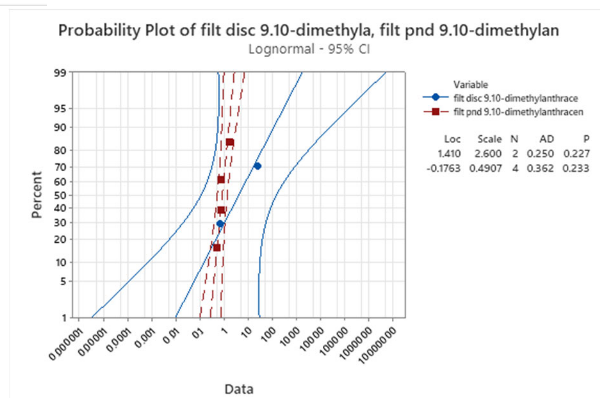
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Loc Scale N AD P
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Percent
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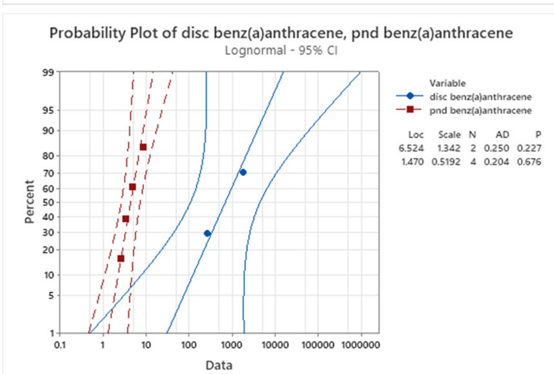
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Lognormal - 95% CI
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Loc Scale N AD P
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Percent
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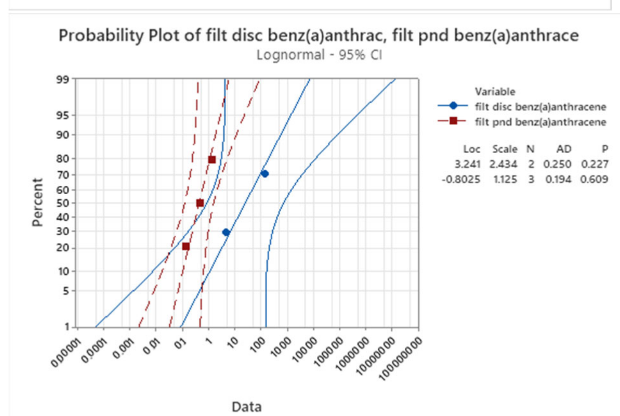
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Lognormal - 95% CI
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filt pnd benz(a)anthracene
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Percent
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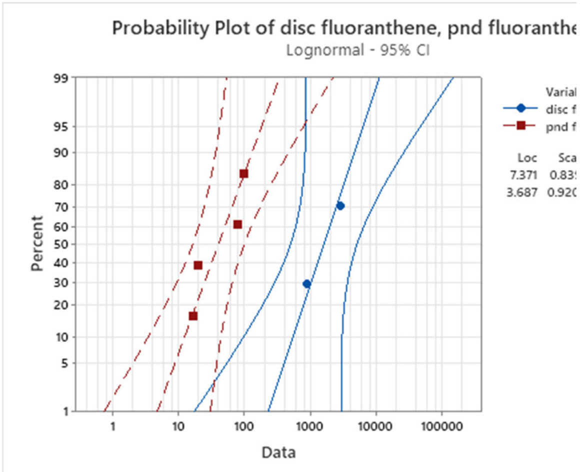
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Lognormal - 95% CI
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Loc Sca
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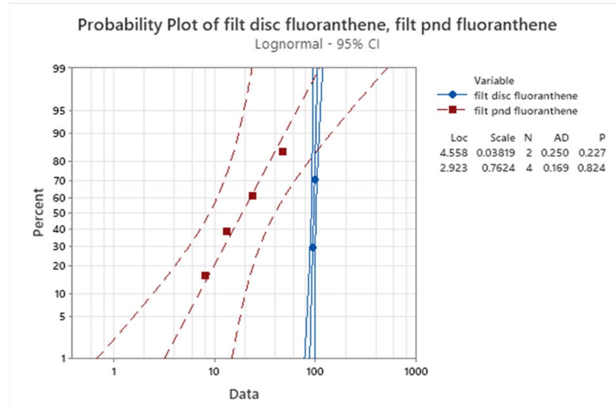
Percent
Data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Percent
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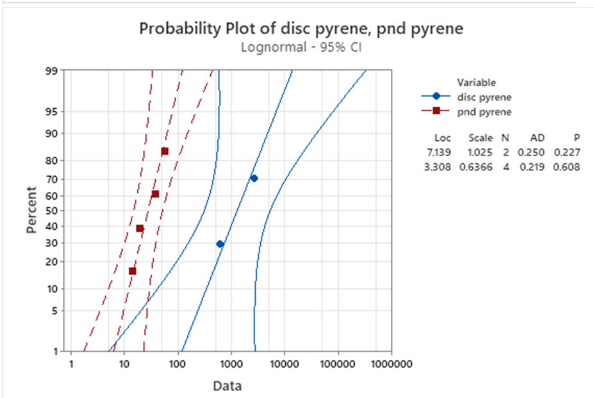
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Lognormal - 95% CI
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pnd pyrene
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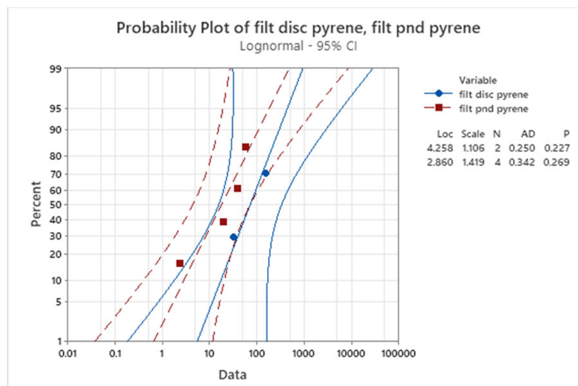
Percent
Data


Probability Plot of filt disc pyrene, filt pnd pyrene
Lognormal - 95% CI
Variable
filt disc pyrene
filt pnd pyrene
Loc Scale N AD P
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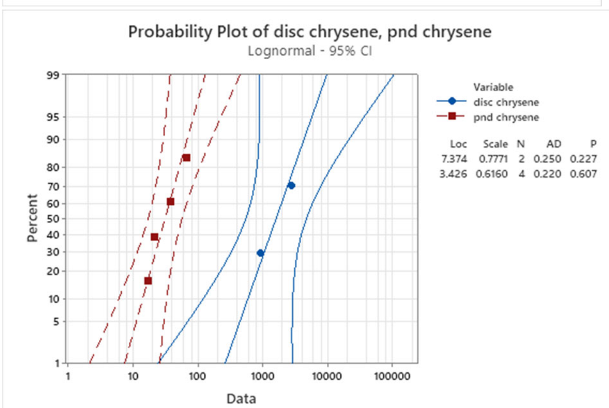
2.860 1.419 4 0.342 0.269
Percent
Data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Lognormal - 95% CI
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pnd chrysene
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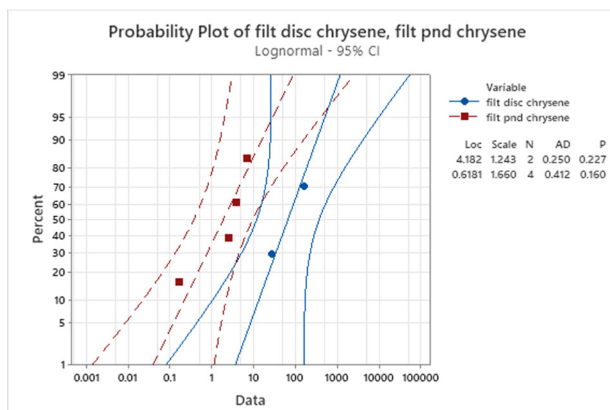
3.426 0.6160 4 0.220 0.607
Percent
Data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Lognormal - 95% CI
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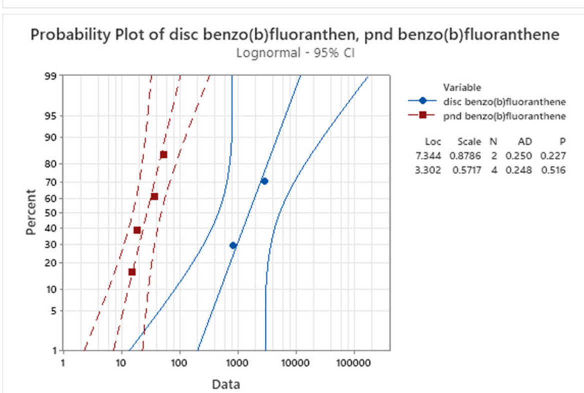
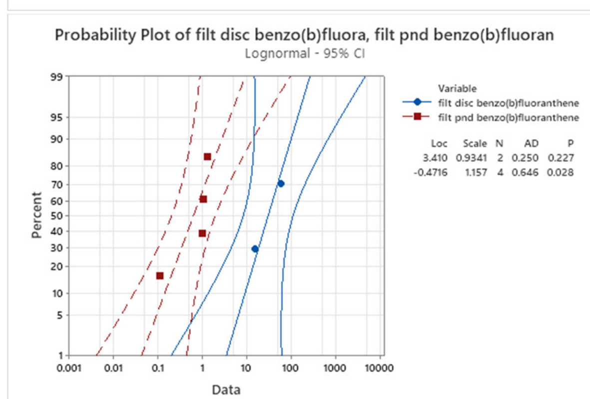
0.6181 1.660 4 0.412 0.160
Percent
Data


Probability Plot of disc benzo(b)fluoranthen, pnd benzo(b)fluoranthene
Lognormal - 95% CI
Variable
disc benzo(b)fluoranthene
pnd benzo(b)fluoranthene
Loc Scale N AD P
7.344 0.8786 2 0.250 0.227
3.302 0.5717 4 0.248 0.516
Percent
Data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Lognormal - 95% CI
Variable
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filt pnd benzo(b)fluoranthene
Loc Scale N AD P
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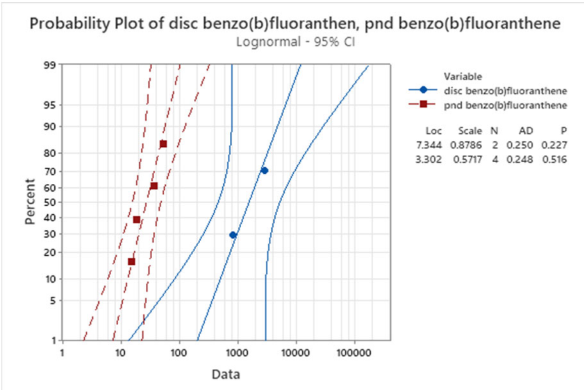
-0.4716 1.157 4 0.646 0.028
Percent
Data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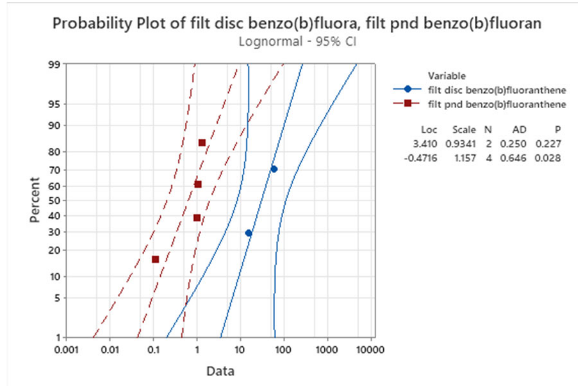
Lognormal - 95% CI
Percent
Data
Variable
disc benzo(b)fluoranthene
pnd benzo(b)fluoranthene
Loc Scale N AD P
7.344 0.8786 2 0.250 0.227
3.302 0.5717 4 0.248 0.516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Lognormal - 95% CI
Percent
Data
Variable
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filt pnd benzo(b)fluoranthene
Loc Scale N AD P
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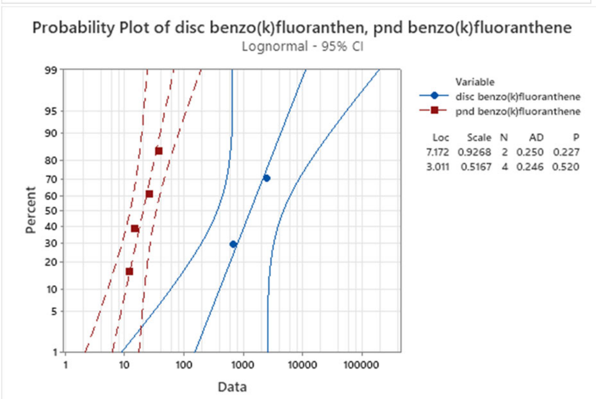
-0.4716 1.157 4 0.646 0.028


Probability Plot of disc benzo(k)fluoranthen, pnd benzo(k)fluoranthene
Lognormal - 95% CI
Percent
Data
Variable
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pnd benzo(k)fluoranthene
Loc Scale N AD P
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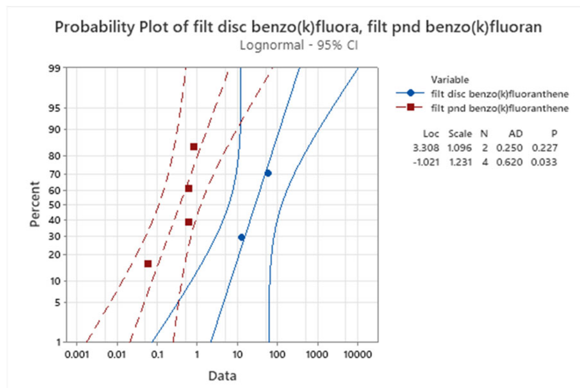
3.011 0.5167 4 0.246 0.520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Lognormal - 95% CI
Percent
Data
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filt pnd benzo(k)fluoranthene
Loc Scale N AD P
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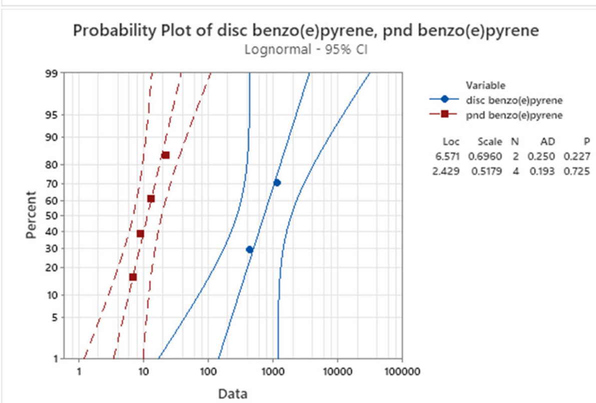
-1.021 1.231 4 0.620 0.033


Probability Plot of disc benzo(e)pyrene, pnd benzo(e)pyrene
Lognormal - 95% CI
Percent
Data
Variable
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pnd benzo(e)pyrene
Loc Scale N AD P
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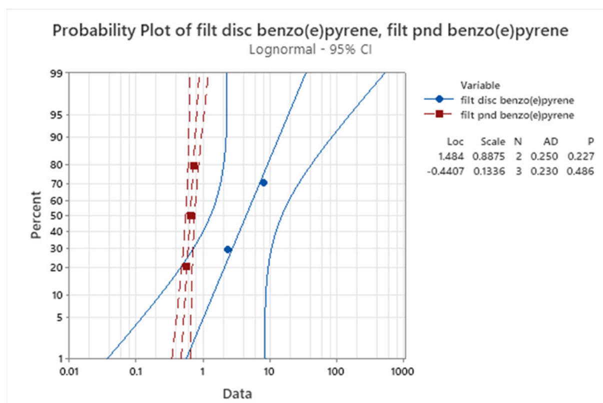
2.429 0.5179 4 0.193 0.725


Probability Plot of filt disc benzo(e)pyrene, filt pnd benzo(e)pyrene
Lognormal - 95% CI
Percent
Data
Variable
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filt pnd benzo(e)pyrene
Loc Scale N AD P
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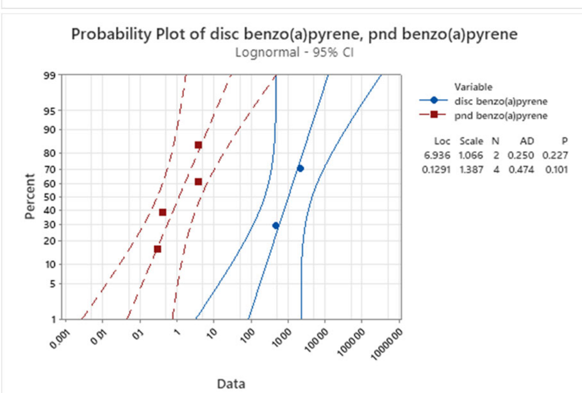
-0.4407 0.1336 3 0.230 0.486


Probability Plot of disc benzo(a)pyrene, pnd benzo(a)pyrene
Lognormal - 95% CI
Percent
Data
Variable
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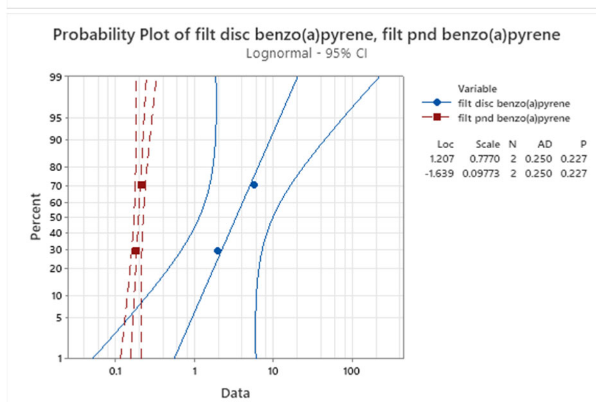
pnd benzo(a)pyrene
Loc Scale N AD P
6.936 1.066 2 0.250 0.227
0.1291 1.387 4 0.474 0.101


Probability Plot of filt disc benzo(a)pyrene, filt pnd benzo(a)pyrene
Lognormal - 95% CI
Percent
Data
Variable
filt disc benzo(a)pyrene
filt pnd benzo(a)pyrene
Loc Scale N AD P
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-1.639 0.09773 2 0.250 0.227

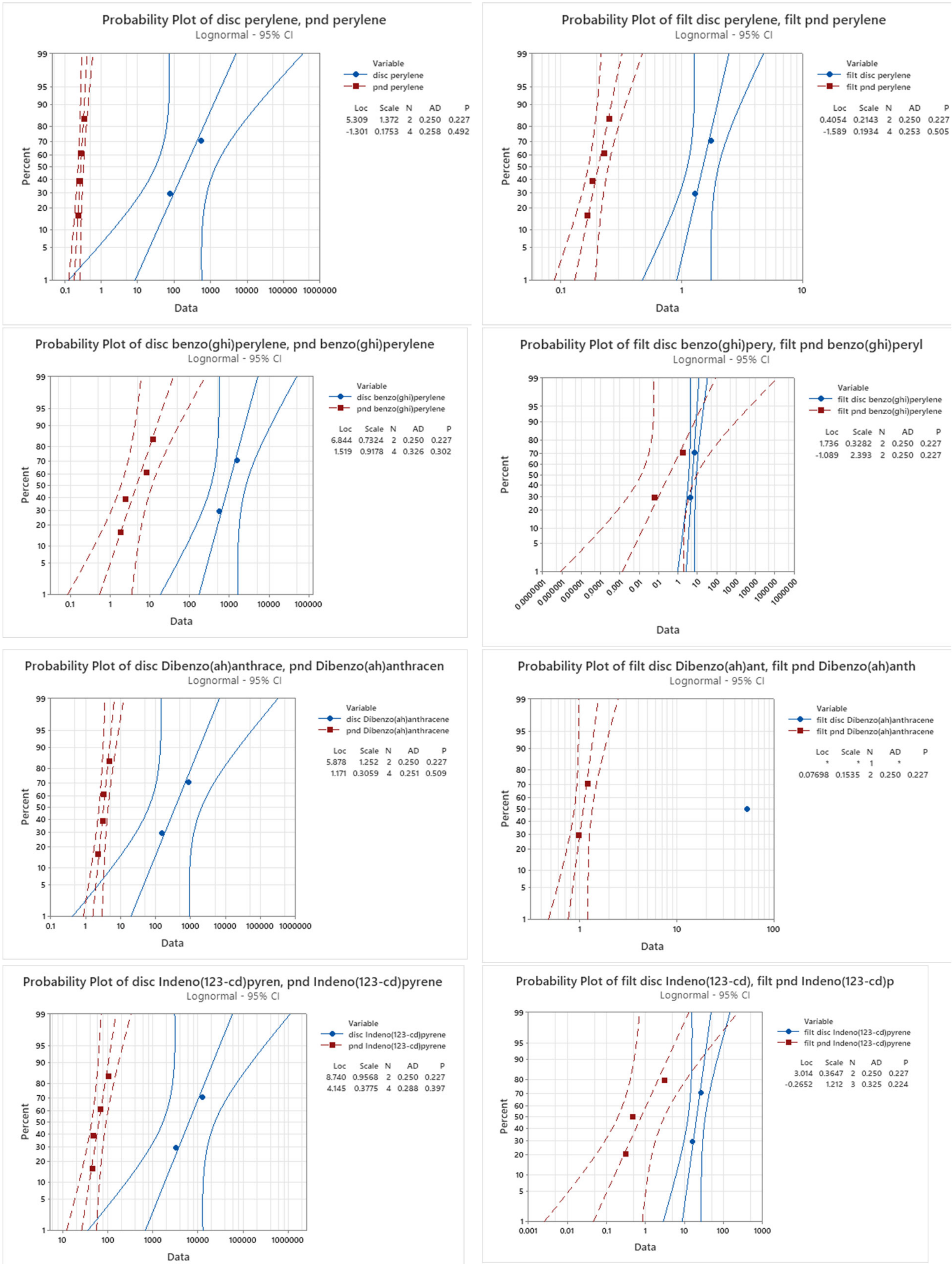


Figure 11. Probability plots of stormwater discharge and in-lake PAH total and filtered concentrations.

PFAS Monitoring at Picnic Lake

As noted previously, Picnic Lake and outfalls to the lake were monitored during two events (2.5 cm (0.97-inch) rain on September 12 and 13, 2019 and samples obtained during December 26 and 28, 2019 (which had no recorded rainfall and was therefore localized and small). The samples are from outfalls 1 and 2 and two locations in the lake. Figures 12, 13, and 14 are bar plots showing the detected concentrations, grouped by concentration ranges. Figure 12 shows the PFAS congeners having the highest concentrations (up to about 1,000 ng/L), while Figure 13 are for medium concentration PFAS congeners (up to about 100 ng/L), and Figure 14 are for the low concentration PFAS congeners (up to about 10 ng/L). Table 20 lists the actual observed concentrations. These are for filtered samples. It was not possible to analyze particulate bound PFAS congeners by particle size due to the low concentrations. It is also noted that the lake water sample PFAS congener concentrations were greater than for the stormwater samples. The few stormwater samples were likely not representative of all of the flows affecting the lake. It is also possible that the lake water may have been affected by infiltration of contaminated groundwater.

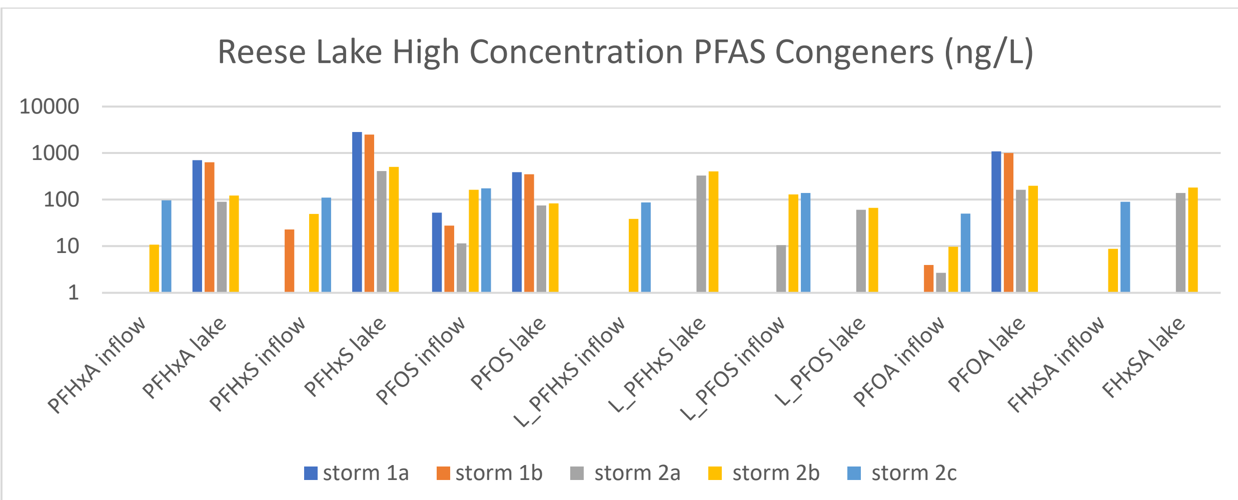


Figure 12. Bar plots of stormwater and Picnic Lake high PFAS congener concentrations.

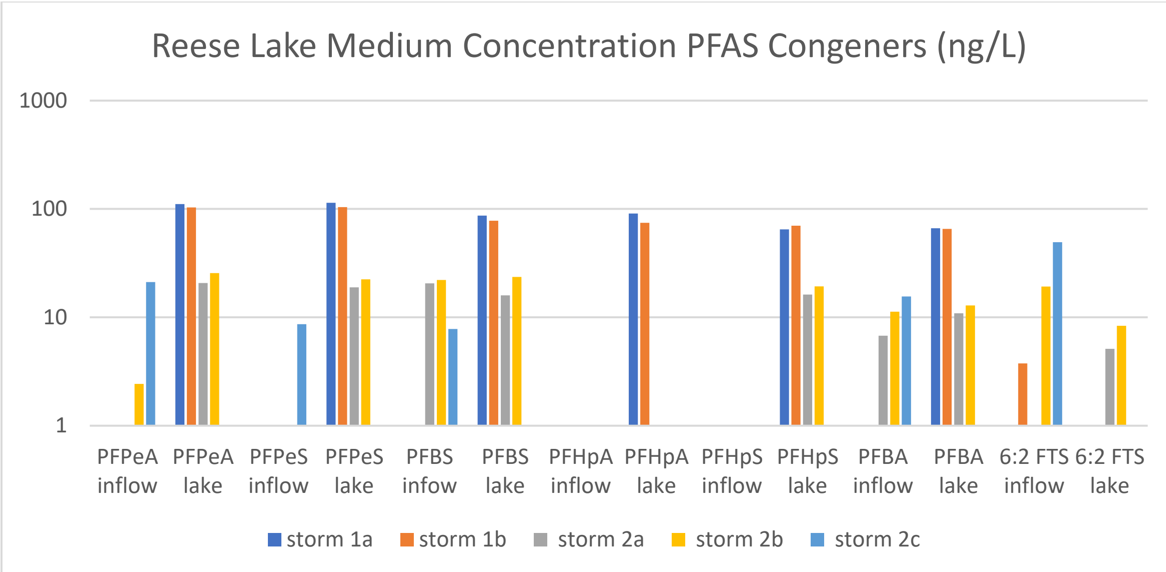


Figure 13. Bar plots of stormwater and Picnic Lake medium PFAS congener concentrations.

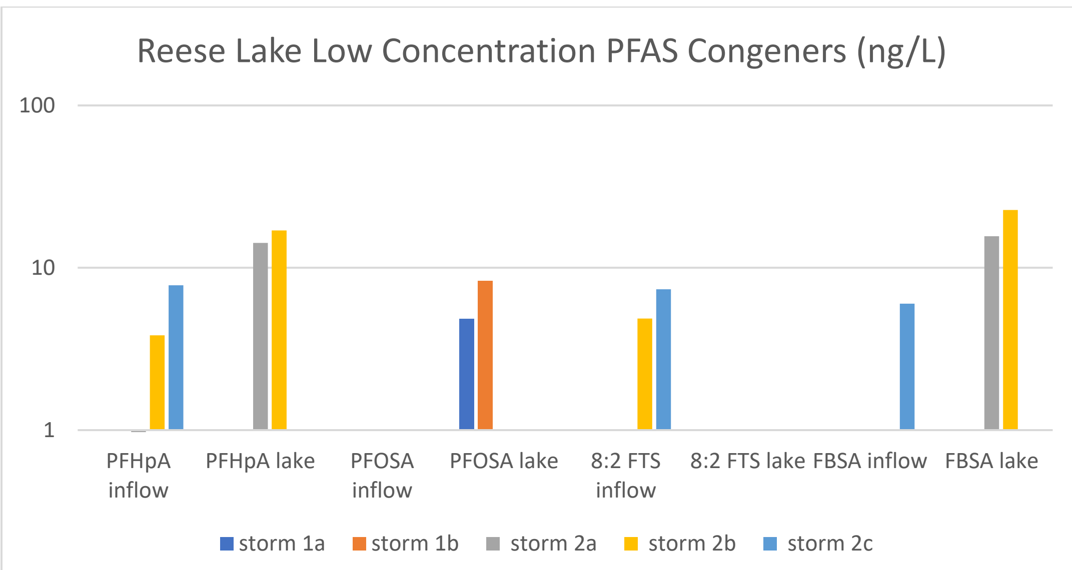


Figure 14. Bar plots of stormwater and Picnic Lake low PFAS congener concentrations.

Table 20. Detected PFAS Congeners in Stormwater and in Picnic Lake

filtered, ng/L	PFBA inflow	PFBA lake	PFBS infow	PFBS lake	PFPeA inflow	PFPeA lake	PFHxA inflow	PFHxA lake	PFPeS inflow	PFPeS lake	PFHpA inflow	PFHpA lake	PFHxS inflow	PFHxS lake	PFHpA inflow	PFHpA lake	PFOA inflow	PFOA lake
storm 1a		66.3		86.6		110.8		703.5		113.9		90.8		2829.8				1084.6
storm 1b		65.4		77.8		103.2		635.7		103.7		74.5	22.8	2493.6			3.9	1005.0
storm 2a	6.8	10.9	20.6	15.9		20.7		89.9		18.9				411.0	0.7	14.2	2.7	162.7
storm 2b	11.3	12.9	22.1	23.6	2.4	25.6	10.8	122.6		22.4			49.0	502.7	3.8	17.0	9.7	197.8
storm 2c	15.5		7.8		21.2		96.5		8.6				110.6		7.8		49.8	
average influent	11.2		16.8		11.8		53.6		8.6				60.8		4.1		16.5	
average pond		38.8		51.0		65.0		387.9		64.7		82.6		1559.3		15.6		612.5

Table 20. Detected PFAS Congeners in Stormwater and in Picnic Lake (cont.)

filtered, ng/L	6:2 FTS inflow	6:2 FTS lake	PFHpS inflow	PFHpS lake	PFOSA inflow	PFOSA lake	PFOS inflow	PFOS lake	L_PFHxS inflow	L_PFHxS lake	L_PFOS inflow	L_PFOS lake	8:2 FTS inflow	8:2 FTS lake	FBSA inflow	FBSA lake	FHxSA inflow	FHxSA lake
storm 1a				64.7		4.8	52.5	388.5										
storm 1b	3.8			70.0		8.3	27.6	349.8										
storm 2a		5.1		16.2			11.5	75.0		328.6	10.5	60.5				15.6		139.1
storm 2b	19.2	8.4		19.3			163.1	82.7	38.5	403.1	129.7	66.5	4.9			22.7	8.8	181.6
storm 2c	49.3						174.0		87.0		138.3		7.4		6.0		90.0	
Average influent	24.1						85.8		62.7		92.9		6.1		6.0		49.4	
Average pond		6.7		42.5		6.6		224.0		365.9		63.5				19.2		160.4

WinSLAMM Modeling to Identify Sources of Stormwater Runoff and Pollutants

A previously calibrated version of the Source Loading and Management Model (WinSLAMM, version 10.5) was used to identify sources of stormwater flows and pollutants, and the performance of Picnic Lake as a sedimentation treatment process at the Reese Technology Center. WinSLAMM used previously calibrated parameter files developed for the US Navy at facilities in Southern California, Puget Sound, Washington, and Norfolk, Virginia. One of the numerous project reports that described the model calibration and use at naval facilities is: Pitt, R. 2014. *The Use of WinSLAMM at Naval Bases to Predict Stormwater Pollutant Sources and to Identify Treatment Options* (http://unix.eng.ua.edu/~rpitt/Publications/8_Stormwater_Management_and_Modeling/WinSLAMM_modeling_examples/Site_Descriptions_Calibration_and_Sources_Feb_17_2014.pdf). The following discussion summarizes the calibration and verification processes, and enhancements to the model made during those previous navy projects.

Calibration and Verification of WinSLAMM for US Naval Operations

The calibration method used a detailed characterization of land uses/infrastructure and site materials at a number of Naval base drainages to generate model predictions of storm water volume, particulate solids, copper, and zinc masses and concentrations and comparing them to actual stormwater monitoring data. The standard model pollutant source loading data were then modified in iterative fashion (storm by storm, outfall by outfall, and region by region) to generate predictions that best fit the observed storm water contaminant data.

The model calibration was generated by conducting detailed site characterizations at 19 drainages on 11 Navy Bases in the Southwest, Mid-Atlantic, and Northwest regions of the US. The sites evaluated, shown on Table 20, ranged from 1 to 1400 acres in size and represented the wide range of land use diversity found at Navy bases around the country. The characterizations utilized aerial photos, geographic information system (GIS) and facility maps, and site visits to quantify/validate categories and sizes of land uses, materials, and infrastructure within each drainage. The characterizations, along with local rainfall data and standard model input parameter files, were used to compare the model output against a historical storm water contaminant dataset collected for each drainage. This dataset was mostly composed of concentrations of total solids, copper, and zinc.

Comparisons were done iteratively storm by storm for each drainage site by modifying the pollutant source loading data associated with each land use to produce a best fit between model result and storm data. Once a best fit was found for a single drainage area, the iterative process was repeated at each successive drainage until completed for the entire region. After each regional pollutant source loading file was generated, additional model-observation comparisons of land use, wash-off rates, and mass loading adjustments were made to obtain results with the least error (sum of squares of the residuals). Overall, the calibration process evaluated over 300 storm event datasets from the 19 Navy sites. During these earlier US Navy WinSLAMM modeling projects, the model was modified to allow additional important source areas (mainly different lay down areas used for site storage, airfield operations, and piers) to be tracked independently, as shown on Tables 21 and 22. The outcome of the calibration and validation process was the development of a pollutant source loading file specific to regional Navy land uses/materials that provided the best overall predictions to the observed stormwater data.

Table 20. Regions, bases, and outfall drainage areas used in calibrating the WinSLAMM stormwater quality model for Navy use.

Region	Base	Outfall	Drainage Area (acres)	Comment
Southwest	Naval Base San Diego	1	1.4	Pier
		13	3.2	Pier
		14	50	
		51	19	
		70	78	
		72	45	
		73	17	
	Naval Base Coronado	9	5	
		26	73	
	Naval Base Point Loma	26	6.4	Pier
Northwest	Naval Base Kitsap Bangor	2	1442	
		3A	9	Pier
	Naval Station Everett	A	15	Pier
		B	12	
	Naval Air Station Whidbey Island	3D	13	
	Naval Base Kitsap Bremerton	15	104	
	Naval Magazine Indian Island	120	3	
Mid Atlantic	St. Julien's Creek Annex	40/41	26	
	Joint Expeditionary Base Little Creek-Fort Story	7	3	

Table 21. Basic Source Area Categories

Roofs - directly connected
Roofs - disconnected sandy soils
Roofs - disconnected silty or clayey soils
Paved parking/storage - directly connected
Paved parking/storage - disconnected sandy soils
Paved parking/storage - disconnected silty or clayey soils
unpaved parking/storage - directly connected
unpaved parking/storage - disconnected sandy soils
unpaved parking/storage - disconnected silty or clayey soils
driveways - directly connected
driveways - disconnected sandy soils
driveways - disconnected silty or clayey soils
sidewalks/walks - directly connected
sidewalks/walks - disconnected sandy soils
sidewalks/walks - disconnected silty or clayey soils
street/high traffic urban areas - smooth pavement
street/high traffic urban areas - intermediate pavement
street/high traffic urban areas - rough pavement
large landscaping areas - sandy soils
large landscaping areas - silty soils

large landscaping areas - clayey soils
undeveloped areas - sandy soils
undeveloped areas - silty soils
undeveloped areas - clayey soils
small landscaped areas - sandy soils
small landscaped areas - silty soils
small landscaped areas - clayey soils
other pervious areas - sandy soils
other pervious areas - silty soils
other pervious areas - clayey soils
other directly connected impervious areas
other partially connected impervious areas - sandy soils
other partially connected impervious areas - silty or clayey soils
highway paved lane and shoulder areas
highway large turf areas - sandy soils
highway large turf areas - silty soils
highway large turf areas - clayey soils

Table 22. Additional Source Areas for US Navy Facilities

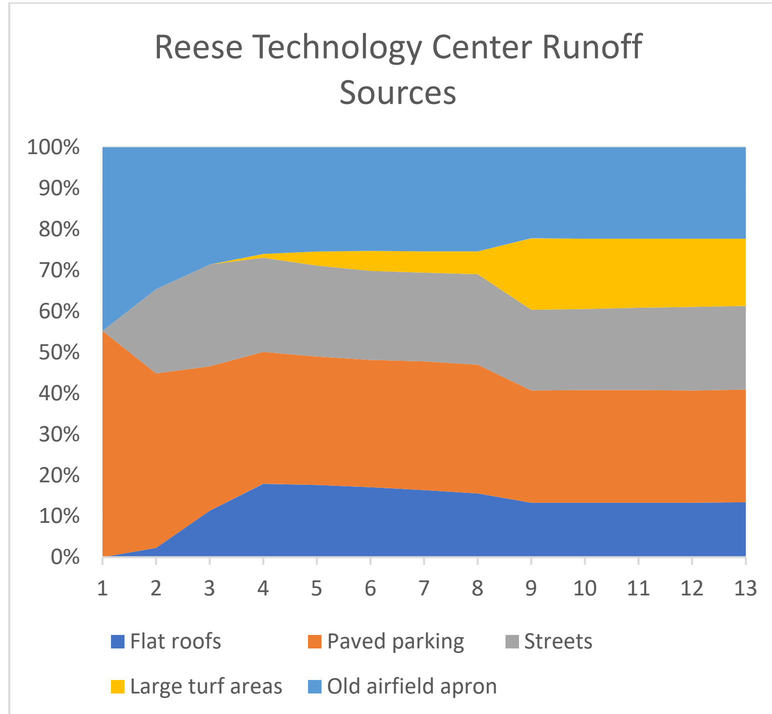
OIA1 - airfield apron/runway paved areas - directly connected
OIA1 - airfield apron/runway paved areas- disconnected sandy
OIA1 - airfield apron/runway paved areas - disconnected silty or clayey
OIA2 - other airfield paved areas- directly connected
OIA2 - other airfield paved areas- disconnected sandy soils
OIA2 - other airfield paved areas- - disconnected silty or clayey soils
OIA3 - light pier/laydown/storage/loading dock concrete areas- directly connected
OIA3 - light pier/laydown/storage/loading dock concrete areas - disconnected sandy soils
OIA3 - light pier/laydown/storage/loading dock concrete areas - disconnected silty or clayey soils
OIA4 - moderate pier/laydown/storage/loading dock concrete areas - directly connected
OIA4 - moderate pier/laydown/storage/loading dock concrete areas - disconnected sandy soils
OIA4 - moderate pier/laydown/storage/loading dock concrete areas - disconnected silty or clayey soils
OIA5 - heavy pier/laydown/storage/loading dock and scrapyard concrete areas- directly connected
OIA5 - heavy pier/laydown/storage/loading dock and scrapyard concrete areas - disconnected sandy soils
OIA5 - heavy pier/laydown/storage/loading dock and scrapyard concrete areas- disconnected silty or clayey soils
OIA6 - light pier/laydown/storage/loading dock asphalt areas - directly connected
OIA6 - light pier/laydown/storage/loading dock asphalt areas- disconnected sandy soils
OIA6 - light pier/laydown/storage/loading dock asphalt areas- disconnected silty or clayey soils
OIA7 - moderate pier/laydown/storage/loading dock asphalt areas- directly connected
OIA7 - moderate pier/laydown/storage/loading dock asphalt areas- disconnected sandy soils
OIA7 - moderate pier/laydown/storage/loading dock asphalt areas- disconnected silty or clayey soils
OIA8 - heavy pier/laydown/storage/loading dock and scrapyard asphalt areas - directly connected
OIA8 - heavy pier/laydown/storage/loading dock and scrapyard asphalt areas - disconnected sandy soils
OIA8 - heavy pier/laydown/storage/loading dock and scrapyard asphalt areas - disconnected silty or clayey soils
OIA9 - galvanized metal roofs, directly connected- directly connected
OIA9 - galvanized metal roofs - disconnected sandy soils
OIA9 - galvanized metal roofs- disconnected silty or clayey soils
OIA10 - other impervious areas with galvanized materials- directly connected
OIA10 - other impervious areas with galvanized materials - disconnected sandy soils
OIA10 - other impervious areas with galvanized materials - disconnected silty or clayey soils

WinSLAMM Calculations of Stormwater Runoff and Pollutant Sources at Reese Technology Center

The calibrated WinSLAMM model was used to calculate the sources of runoff volume, particulate solids, phosphorus, copper, and zinc (the constituents currently available in the calibrated files) at the Reese Technology Center. Figures 12 through 16 show summary tables and area graphs summarizing these calculations. A series of rains from 0.25 to 200 mm (0.01 to 8 inches) were individually used to show how these sources as the rain depth changes. The major sources for these parameters include flat roofs, paved parking areas, streets, large turf areas, and the old airfield apron. These tables and figures show where the runoff and other constituents are expected to originate for the different rains, as a percentage of the total discharges into Picnic Lake. The runoff volume, and especially the particulate sources, are the most important and drive the discharges for the pollutants of interest.

- For the smallest rains, most of the flows originate from the paved parking and old airport apron areas. At the rain depth associated with data described in this report (0.97-inch rain, close to 25mm, or rain #7 on the plots), flat roofs and streets were also important with some runoff originating from the large turf areas. For the largest rains. The paved parking areas contributed about 27%, the old airport apron contributed about 22%, large turf areas contributed about 17%, and the flat roofs contribute about 13% of the total.
- Particulate solids sources were quite different, especially for the large rains. For the smallest rains, paved parking and the old airfield apron were the major sources, with streets being important for small rains up to about 13 mm. For the 25 mm rain, these two areas still comprised the majority of the particulate solids discharges, while for the largest rains, the large turf areas were the major source, with the two large paved areas also important. Roofs were never significant sources (due to low concentrations.
- Phosphorus sources during the small rains were dominated by the streets and the large paved areas, while the large turf areas become major sources for rains greater than about 25mm.
- Copper and zinc sources were similar, with paved parking areas being most important, along with streets for all rains. Roofs, landscaped areas, and the old airfield apron each contributed about 10% of the zinc sources, and much smaller fractions of the copper sources.

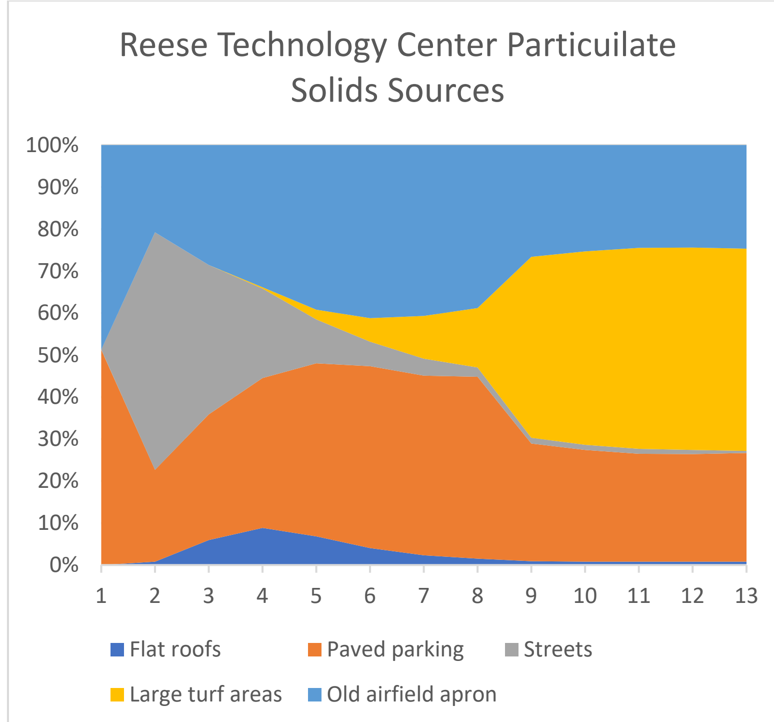
Event #	Rain depth (in.)	Rain depth (mm)	Flat roofs	Paved parking	Streets	Large turf areas	Old airfield apron
1	0.01	0.25	0%	53.7%	0%	0%	43.6%
2	0.05	1.3	2.2	41.7	20.1	0	33.9
3	0.1	2.5	11.1	34.6	24.4	0	28.1
4	0.25	6.4	17.6	31.6	22.6	0.9	25.6
5	0.5	13	17.3	30.8	21.8	3.4	25
6	0.75	19	16.8	30.6	21.4	4.8	24.9
7	1	25	16.1	30.9	21.3	5.1	25
8	1.5	38	15.3	30.9	21.7	5.5	25
9	2	51	13.1	27	19.4	17.2	21.9
10	2.5	64	13.1	27.1	19.5	16.9	22
11	3	76	13.1	27.1	19.8	16.6	22
12	4	102	13.1	27	20.1	16.4	22
13	8	203	13.2	27.1	20.1	16.2	22



Numbers on x-axis refer to event #, not rain depth

Figure 12. Source Area Percentage Contribution of Stormwater Runoff Volume

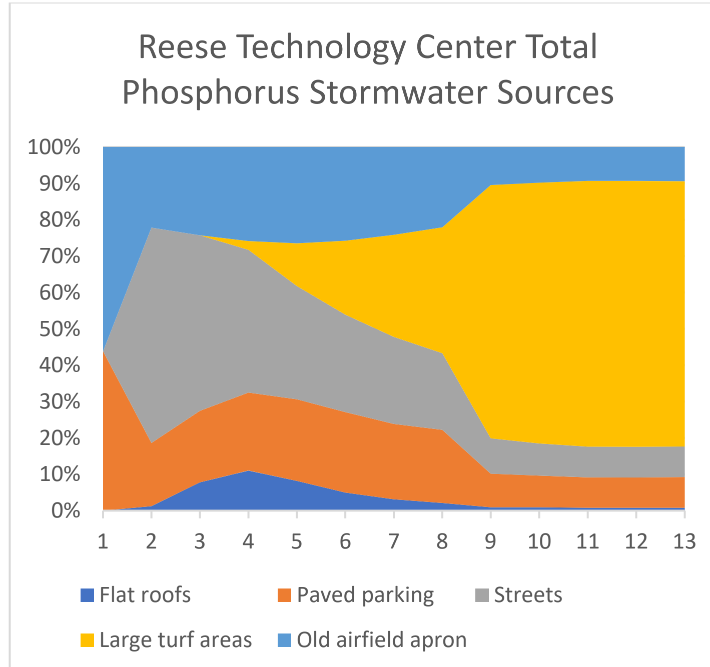
Event #	Rain depth (in.)	Rain depth (mm)	Flat roofs	Paved parking	Streets	Large turf areas	Old airfield apron
1	0.01	0.25	0%	50.9%	0%	0%	48.3%
2	0.05	1.3	0.8	21.8	56.4	0	20.7
3	0.1	2.5	5.9	29.8	35.4	0	28.4
4	0.25	6.4	8.8	35.5	21.2	0.3	33.7
5	0.5	13	6.8	41	10.4	2.3	39
6	0.75	19	4	43.1	5.8	5.6	41
7	1	25	2.3	42.5	4	10.1	40.4
8	1.5	38	1.5	43.1	2.2	14.1	38.6
9	2	51	0.9	27.9	1.4	42.9	26.5
10	2.5	64	0.8	26.5	1.2	45.9	25.2
11	3	76	0.8	25.6	1.2	47.7	24.4
12	4	102	0.8	25.5	1	48	24.3
13	8	203	0.8	25.8	0.5	48	24.6



Numbers on x-axis refer to event #, not rain depth

Figure 13. Source Area Percentage Contribution of Stormwater Particulate Solids Yield

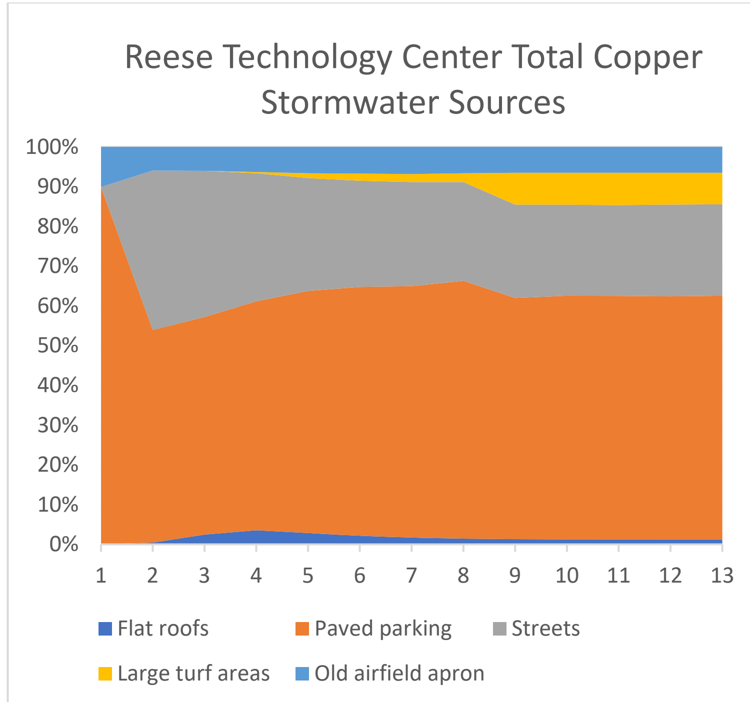
Event #	Rain depth (in.)	Rain depth (mm)	Flat roofs	Paved parking	Streets	Large turf areas	Old airfield apron
1	0.01	0.25	0	42.5	0	0	54.5
2	0.05	1.3	1.2	17.2	58.5	0	21.9
3	0.1	2.5	7.7	19.4	47.7	0	24
4	0.25	6.4	10.9	21.2	38.8	2.4	25.6
5	0.5	13	8.1	22.2	30.8	11.6	26.2
6	0.75	19	4.9	21.9	26.5	20.1	25.5
7	1	25	3.1	20.5	23.7	27.8	23.9
8	1.5	38	2.1	19.9	20.9	34.3	21.9
9	2	51	0.9	9.2	9.7	69.3	10.4
10	2.5	64	0.9	8.7	8.8	71.5	9.8
11	3	76	0.8	8.3	8.4	72.7	9.3
12	4	102	0.8	8.3	8.4	72.8	9.3
13	8	203	0.8	8.4	8.4	72.7	9.4



Numbers on x-axis refer to event #, not rain depth

Figure 14. Source Area Percentage Contributions of Stormwater Total Phosphorus

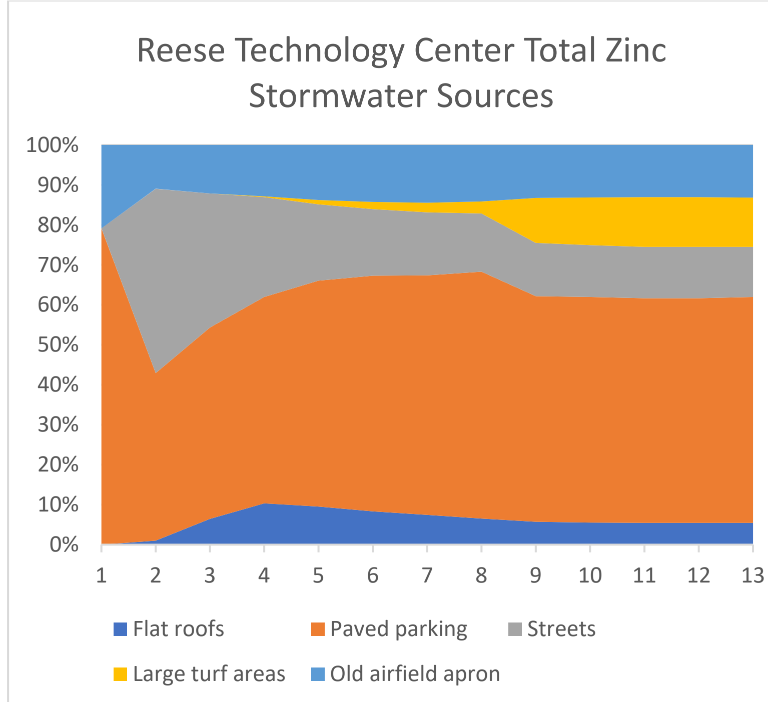
Event #	Rain depth (in.)	Rain depth (mm)	Flat roofs	Paved parking	Streets	Large turf areas	Old airfield apron
1	0.01	0.25	0	89.2	0	0	10
2	0.05	1.3	0.4	53.2	39.9	0	5.9
3	0.1	2.5	2.4	54.5	36.6	0	6
4	0.25	6.4	3.5	57.4	32.1	0.3	6.3
5	0.5	13	2.8	60.7	28.3	1.2	6.6
6	0.75	19	2.1	62.4	26.6	1.8	6.7
7	1	25	1.7	63	26.1	2	6.8
8	1.5	38	1.4	64.6	24.8	2.2	6.6
9	2	51	1.3	60.5	23.4	8	6.5
10	2.5	64	1.2	61.1	22.8	8	6.5
11	3	76	1.2	61.1	22.8	8.1	6.5
12	4	102	1.2	61	23	8	6.5
13	8	203	1.2	61.1	22.9	7.9	6.5



Numbers on x-axis refer to event #, not rain depth

Figure 15. Source Area Percentage Contributions of Stormwater Total Copper

Event #	Rain depth (in.)	Rain depth (mm)	Flat roofs	Paved parking	Streets	Large turf areas	Old airfield apron
1	0.01	0.25	0	78.7	0	0	20.7
2	0.05	1.3	1	41.8	46	0	10.9
3	0.1	2.5	6.4	47.7	33.4	0	12.1
4	0.25	6.4	10.3	51.4	24.9	0.2	12.8
5	0.5	13	9.5	56.3	19	1.1	13.7
6	0.75	19	8.3	58.8	16.6	1.8	14.2
7	1	25	7.4	59.7	15.7	2.4	14.4
8	1.5	38	6.5	61.6	14.5	3	14.1
9	2	51	5.7	56.2	13.3	11.2	13.2
10	2.5	64	5.5	56.3	12.9	11.9	13.1
11	3	76	5.4	56	12.8	12.4	13
12	4	102	5.4	56	12.8	12.4	13
13	8	203	5.4	56.3	12.5	12.3	13.1



Numbers on x-axis refer to event #, not rain depth

Figure 16. Source Area Percentage Contributions of Stormwater Total Zinc

WinSLAMM Modeling of Picnic Lake Particulate Solids Retention

WinSLAMM was also used to calculate the expected stormwater pollutant retention in Picnic Lake. The lake has a surface area of about 4 acres and drains through two 36-inch culverts under the adjoining roadway. The lake can also be discharged through a pump to the golf course lakes if the lake elevation threatens the surround area. The total drainage area to Picnic Lake is 255 acres, with the lake water surface footprint therefore being about 1.6% of the drainage area. This is in the range of a wet pond with a goal of at least 80% particulate solids control, although it is a bit on the small size considering the fraction of directly connected paved areas in the watershed. A rough sizing goal for a wet detention pond would be 3% of the directly connected paved areas plus 1.5% of the remaining areas. Having approximately 50% paved areas, an increased pond size of 2.3% of the drainage area (about 6 acres) would be more robust. However, slightly undersized ponds can still be quite effective.

In an ideal system, particles that do not settle below the bottom of the detention pond outlet will pass through the sedimentation pond, while particles that do settle below/before the outlet will be retained. The path of any particle is the vector sum of the water velocity (V) passing through the pond and the particle settling velocity (v). Therefore, if the water velocity is slow, slowly falling particles can be retained. If the water velocity is fast, then only the heaviest (fastest falling) particles are likely to be retained. The critical ratio of water velocity to particle settling velocity must therefore be equal to the ratio of the sedimentation pond length (L) to depth to the bottom of the outlet (D):

$$\frac{V}{v} = \frac{L}{D}$$

as shown on Figure 17.

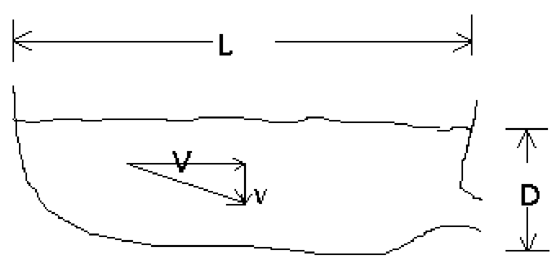


Figure 17. Critical Velocity and Pond Dimensions

The water velocity is equal to the water volume rate (Q, such as measured by cubic feet per second) divided by the pond cross-sectional area (a, or depth times width: DW):

$$V = \frac{Q}{a}$$

or

$$V = \frac{Q}{DW}$$

The pond outflow rate equals the pond inflow rate under steady state conditions. The critical time period for steady state conditions is the time of travel from the inlet to the outlet. During critical portions of a storm, the inflow rate (Q_{in}) will be greater than the outflow rate (Q_{out}) due to freeboard storage. Therefore, the outflow rate controls the water velocity through the pond. By substituting this definition of water velocity into the critical ratio:

$$\frac{Q_{out}}{WDv} = \frac{L}{D}$$

The water depth to the outlet bottom (D) cancels out, leaving:

$$\frac{Q_{out}}{Wv} = L$$

Or

$$\frac{Q_{out}}{v} = LW$$

However, pond length (L) times pond width (W) equals pond surface area (A). Substituting leaves:

$$\frac{Q_{out}}{v} = A$$

and the definition of upflow velocity:

$$v = \frac{Q_{out}}{A}$$

where Q_{out} = pond outflow rate (cubic feet per second),
A = pond surface area (square feet: pond length times pond width), and
v = upflow velocity, or critical particle settling velocity (feet per second).

Therefore, for an ideal sedimentation pond, particles having settling velocities less than this upflow velocity will be retained. Only increasing the surface area, or decreasing the pond outflow rate, will increase pond settling efficiency. Increasing the pond depth does lessen the possibility of bottom scour, decreases the amount of attached aquatic plants, and decreases the chance of winter kill of fish. A 3 ft minimum depth is recommended to reduce scour of previously captured sediment in the pond. Deeper ponds may also be needed to provide sacrificial storage volumes for sediment between dredging operations. Short-circuiting (such as having a short flow between the outfall into the pond and the outlet from the pond) will result in reduced performance through the release of larger particles than predicted. However, for well sized ponds, this effect is relatively small.

Pond performance curves can be easily prepared relating upflow velocity (and therefore critical particle control) for all stages at a pond site. Figure 18 is a plot of the water surface elevation increase above the outfall invert for different rain depths (for the assumed rain durations and double triangular hydrographs). A 2.5 cm rain (similar to the monitored rain discussed earlier) is expected to result is a 6 cm rise is the water surface elevation. The pond outlet is a pair of 36-inch culverts that results in relatively large outflow discharges at low stages, compared to triangular outlets for example. However, the large capacity outlets are necessary to reduce flooding risks in the surrounding area, especially over-topping the adjacent road.

rain depth (cm)	rain duration (hrs)	stage above invert (cm)
0.64	10	<1
1.27	12	1.8
1.9	14	3.4
2.5	14	6.0
3.8	14	13
5.1	14	26
6.4	14	37
7.6	14	48
10	14	71
20	14	135

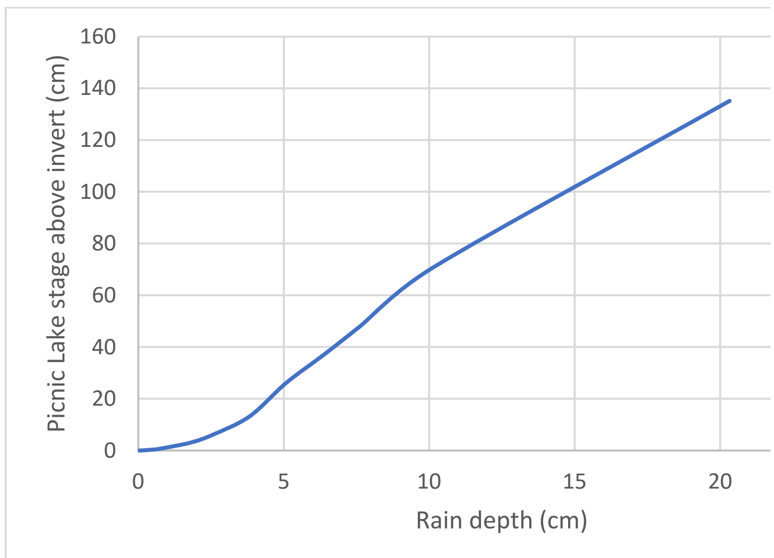


Figure 18. Picnic Lake maximum stage above invert (cm) vs. rain depth (cm)

Figure 19 shows the drainage time for the expected maximum pond water surface elevation. Even at the maximum water depth of 135 cm above the inverts, the pond is expected to completely drain to the outlet inverts within 10 hrs, well within the typical 24-hr drainage time specified in some's state guidance manuals. A 6 cm water depth should rain within one hour.

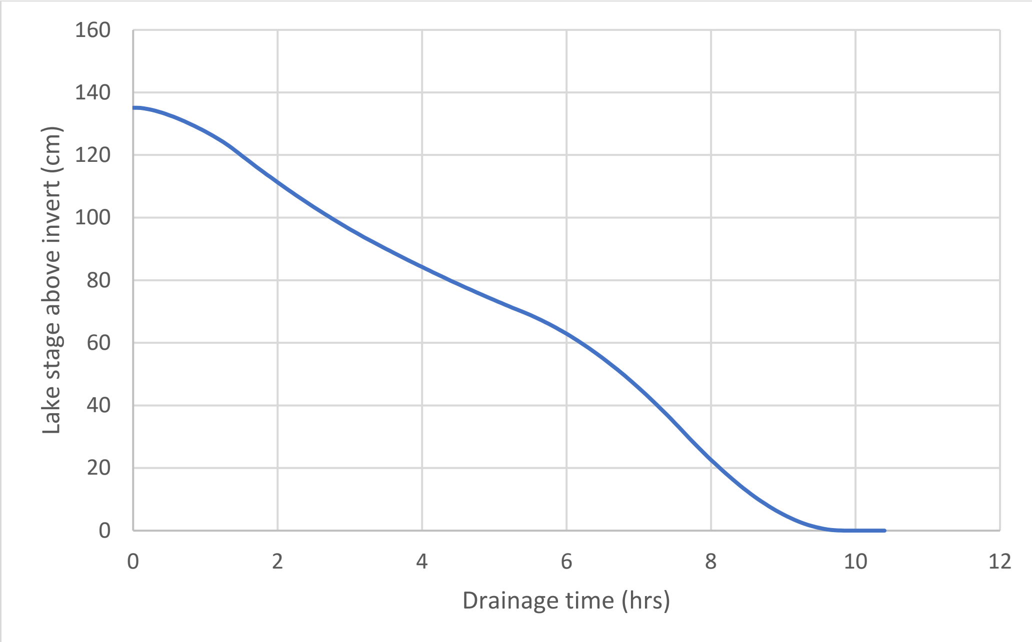


Figure 19. Picnic Lake stage above invert (cm) vs. drainage time (hrs)

Figure 20 is a plot of the upflow velocity associated with the critical particle sizes that would be trapped in the pond for different Picnic Lake water elevations above the outlet invert. The 6-cm stage increase is associated with an upflow velocity of about 13 cm/sec. Lower stages associated other times of the rising or falling hydrograph would have smaller upflow velocities (and increased particle trapping). The 6-cm stage increase is a maximum value associated with the peak of the hydrograph entering the lake.

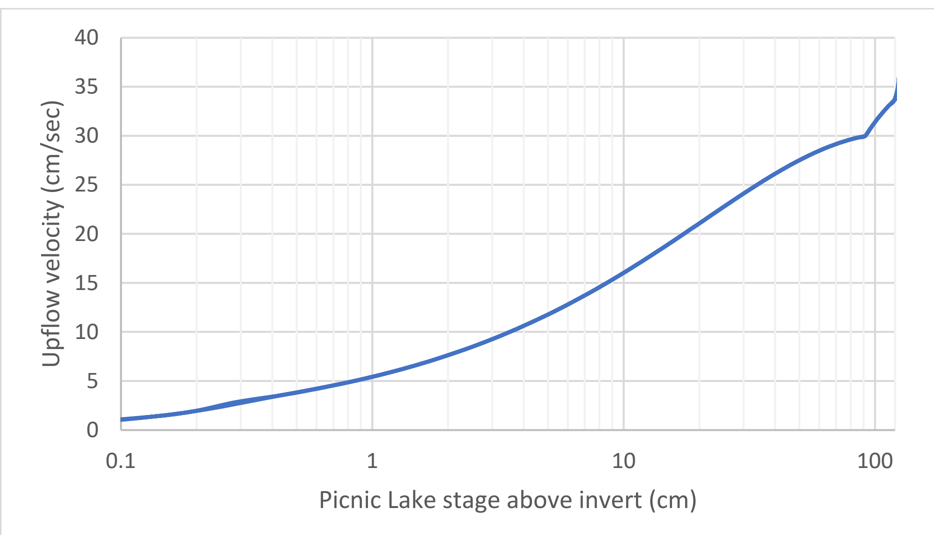


Figure 20. Upflow velocity (cm/hr) vs. Picnic Lake stage above invert (cm)

Figure 21 is a plot of the critical particle size retained in Picnic Lake for different water surface elevations above the outlet invert. The maximum 6-cm increase is associated with 9 µm particles, and Figure 22 indicates that this stage would be associated with about an 80% reduction in particulate solids. Again, this is the maximum value associated with peak inflow rates and would be greater for most of the rain event. This calculated worst-case removal compares to the observed average performance of about 93% for the complete event.

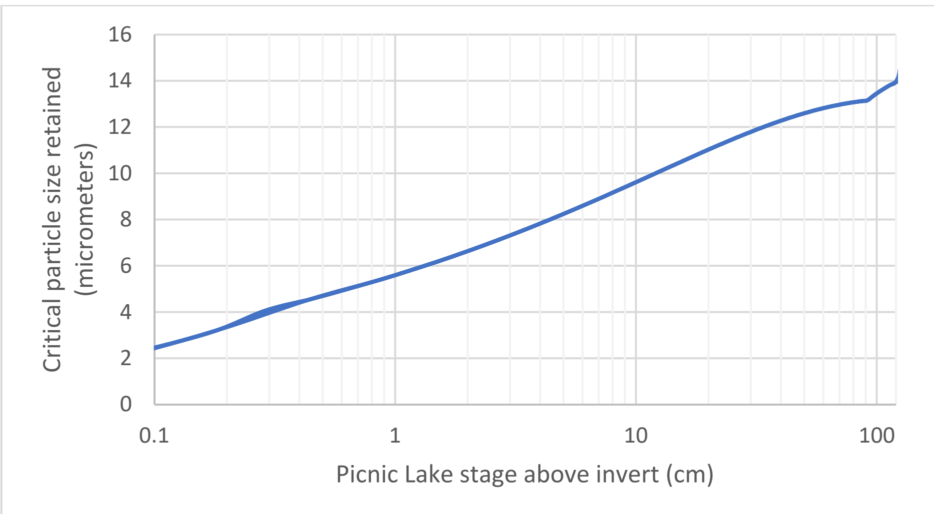


Figure 21. Critical particle size (µm) vs. Picnic Lake stage above invert (cm)

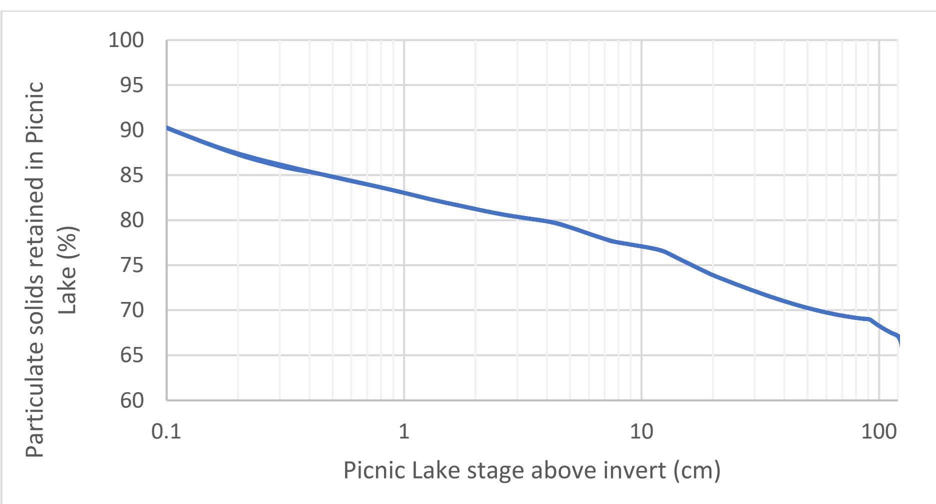
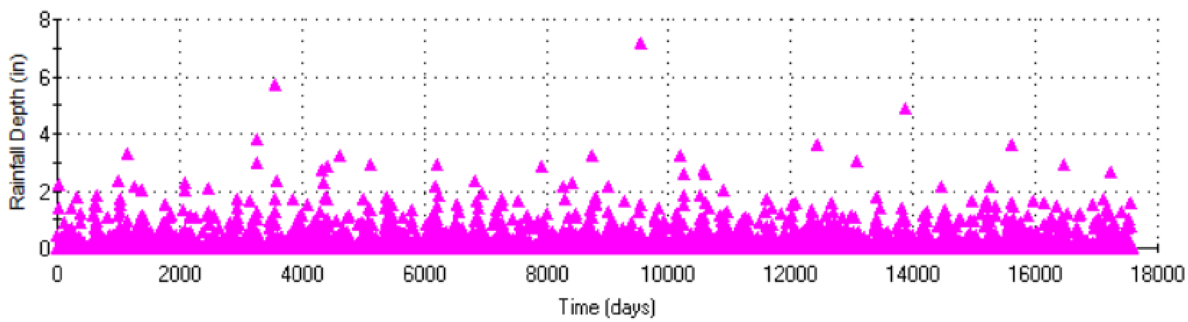


Figure 22. Percent particulate solids controlled vs. Picnic Lake stage above invert (cm)

Production Functions of Picnic Lake Performance

The following presents several production functions for particulate (TSS) control in the Picnic Lake wet detention pond at the Reese Technology Center. About 15 years of continuous rain data were used to calculate the lake performance. The following plot shows the rainfall distribution the longer period from 1957 through 2005. Three events were larger than 4 inches, while the long-term annual average rainfall was about 18.4 inches.

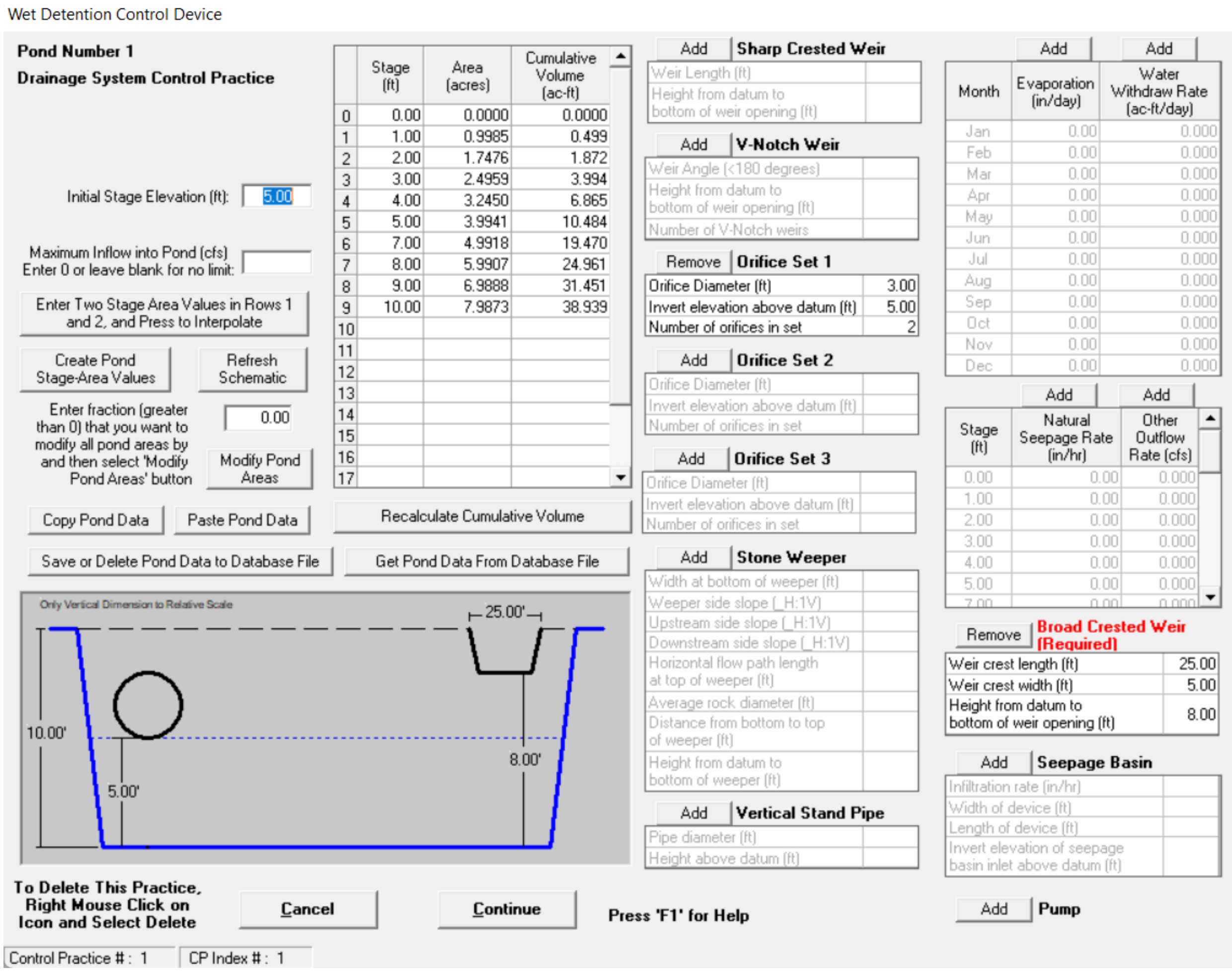


The following shows the long-term average rainfall (inches) per month:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.46	0.66	0.97	1.17	2.28	3.04	2.14	2.10	2.40	1.75	0.81	0.63

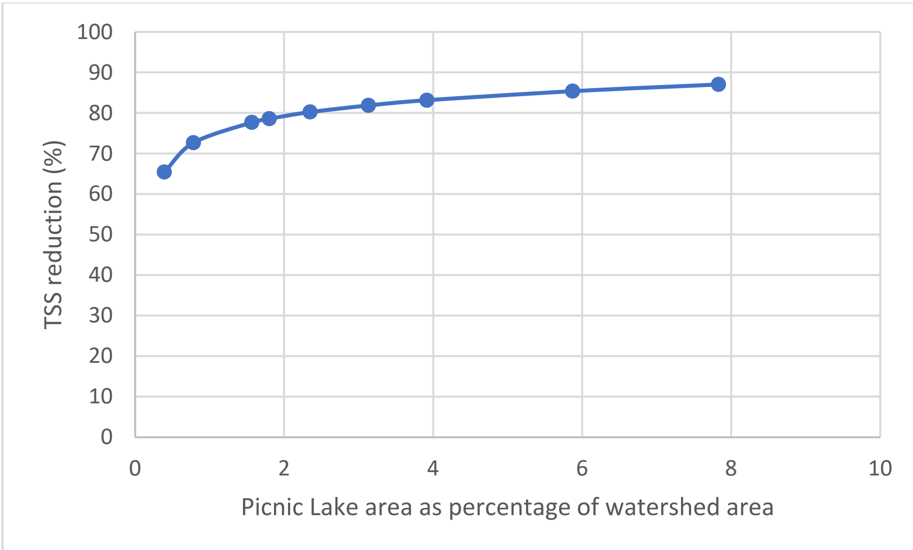
Most of the annual rainfall occurs in the six months from May through October, with much less rainfall during the late fall to early spring months.

The following is the data entry form for the Picnic Lake wet detention pond. The pond surface is about 4 acres, at the 5 ft elevation, where the lowest outfalls are located. The production functions were created by changing the pond areas from as small as 1 ac up to 20 ac. These calculations allow the performance of the pond to be plotted as a function of the area of the pond. The following plots were normalized with the pond area as a percentage of the watershed area. Obviously Picnic Lake is not likely to be enlarged (or reduced in area), but these plots indicate the sensitivity of pond area for similar drainage area characteristics.

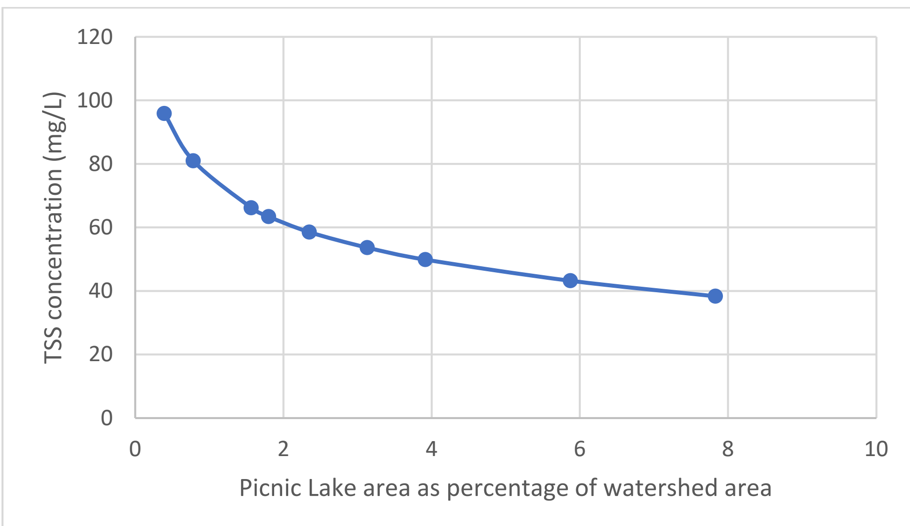


An initial estimate of an effective pond area can be calculated as 3% of the paved drainage area plus 0.5% of the nonpaved drainage area, estimated to result in about an 80% reduction in TSS discharges. This results in a pond area of about 4.6 acres (1.8% of the drainage area) for the Picnic Lake drainage area, slightly larger than the current 4 ac (1.6 % of the drainage area) pond size. The plot below indicates that for the Lubbock area rains and the drainage area characteristics, an 80% TSS reduction would require a pond about 2.2% of the drainage area (about 5.6 acres), about an acre larger than the initial calculated area. As expected, these plots show decreasing incremental benefits as the size of the pond increases.

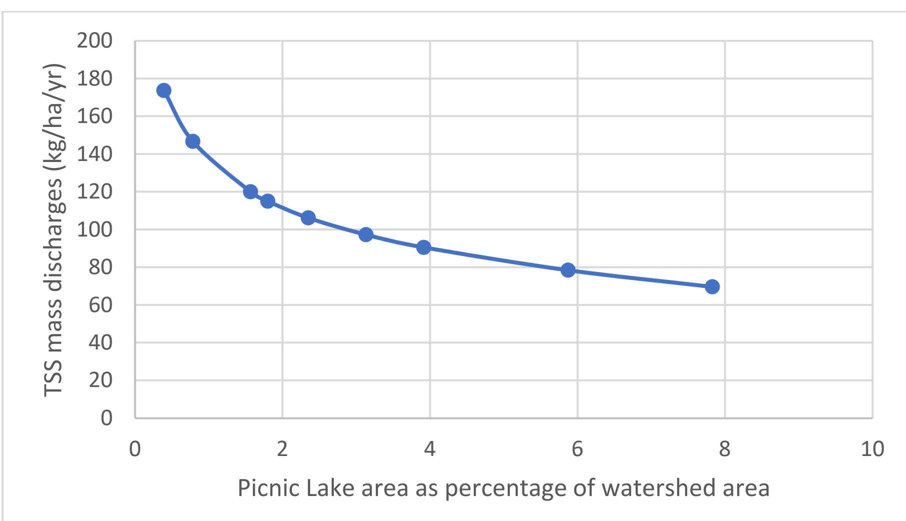
Similar plots can be created using WinSLAMM for different drainage area and rainfall characteristics for other locations. The most suitable size wet pond can then be determined, with other design guidance attributes used for the final pond design.



TSS reduction (%)
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Picnic Lake area as percentage of watershed area



TSS concentration (mg/L)
120
100
80
60
40
20
0
0
2
4
6
8
10
Picnic Lake area as percentage of watershed area



TSS mass discharges (kg/ha/yr)
200
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
Picnic Lake area as percentage of watershed area

Appendix A: Picnic Lake and Sampling Sites Photographs


ISCO




Appendix B: Site Survey Google Earth Images of Site Survey Locations

Sites 1, 2, and 3 (Google Earth image taken Feb 5, 2021)

Sites 4 and 5 (Google Earth image taken Feb 5, 2021)

Sites 6 and 7 (Google Earth image taken Feb 5, 2021)

Site 8 (Google Earth image taken Feb 5, 2021)

Sites 9 and 10 (Google Earth image taken Feb 5, 2021)

Sites 11 and 15 (Google Earth image taken Feb 5, 2021)

Sites 12 and 13 (Google Earth image taken Feb 5, 2021)

Site 14 (Google Earth image taken Feb 5, 2021)

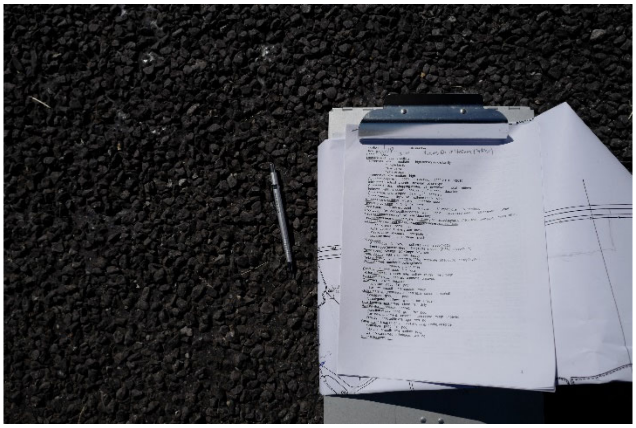
Site 16 (Google Earth image taken Feb 5, 2021)

Infiltration area near sites 9 and 10 (Google Earth image taken Feb 5, 2021); not monitored and therefore not modeled.

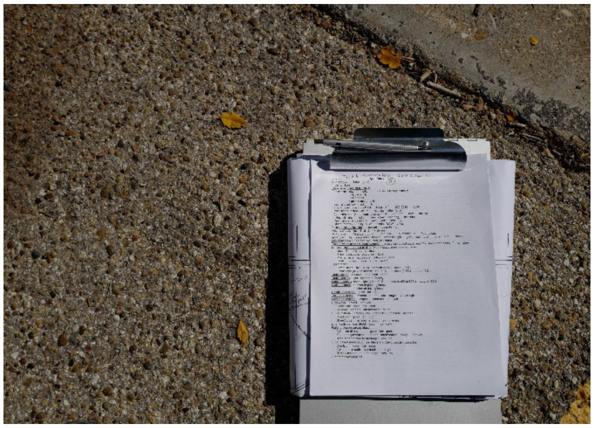
Picnic Lake (Google Earth image taken Feb 5, 2021); Main receiving water for drainage areas 1, 2, 3, and X. Monitored and modeled.

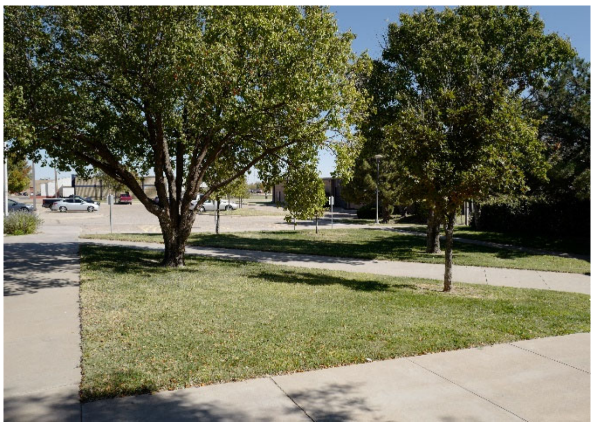
Appendix C: Site Survey Photographs

Site 1. Davis Dr. and Hoover (7th St), vacant area along road

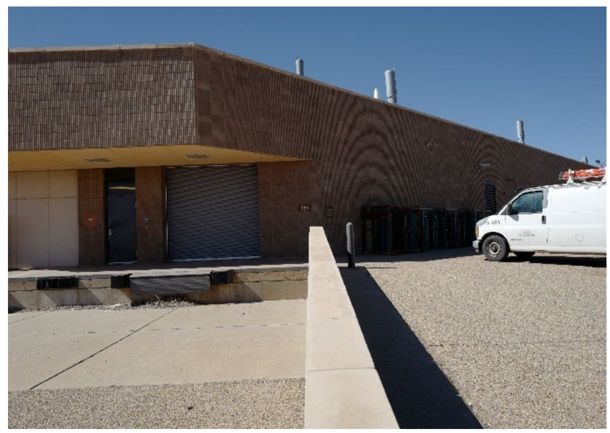


Site 2. Gilbert and 12th, toxicology bldg.

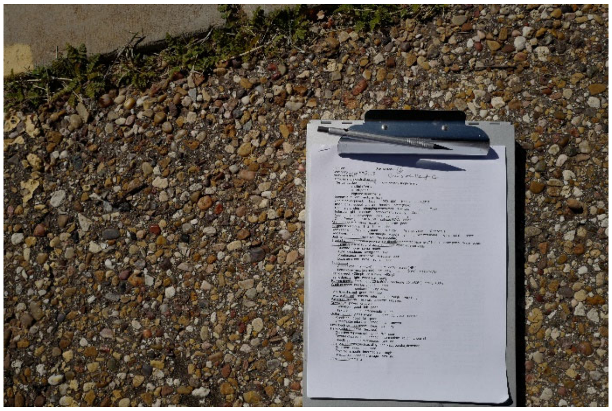




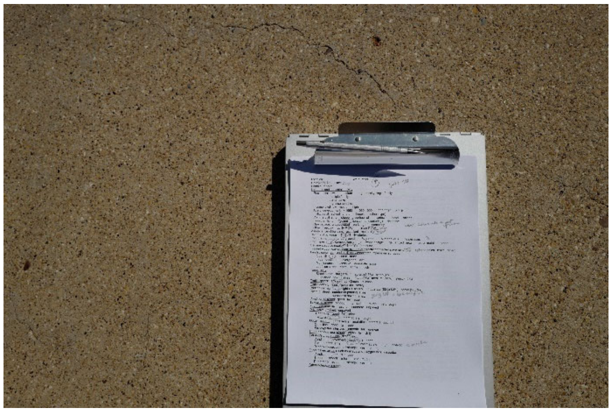

Site 2. (continued) Rear Storage and Parking Area and Outfall 3 Sampler Location



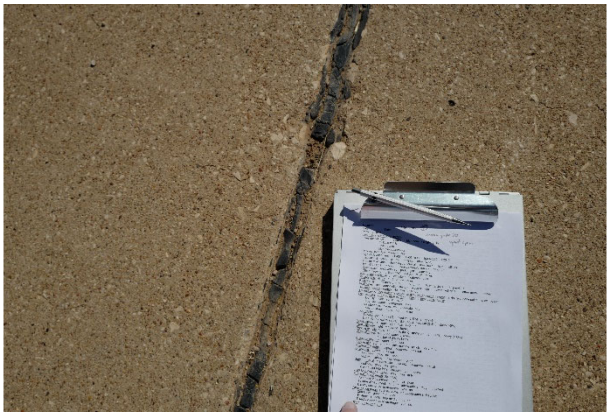
Site 3. Davis and Gilbert Dr, bldg. 790



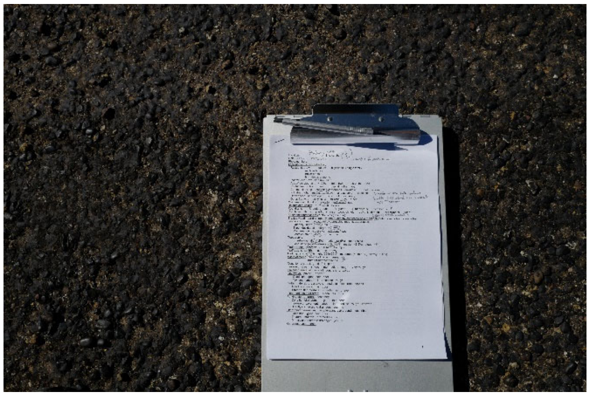
Site 4. Gate 50 at old airfield



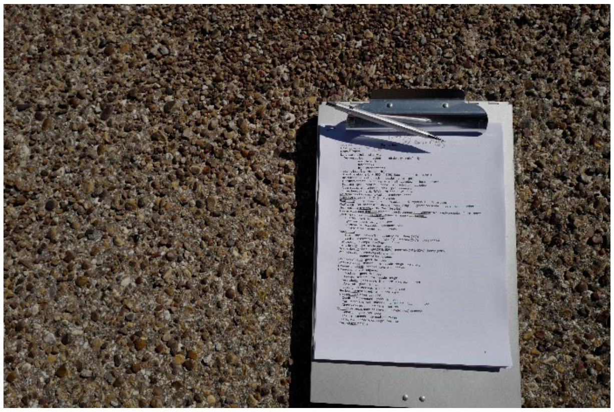
Site 5. Near Gate 50 on old airfield apron



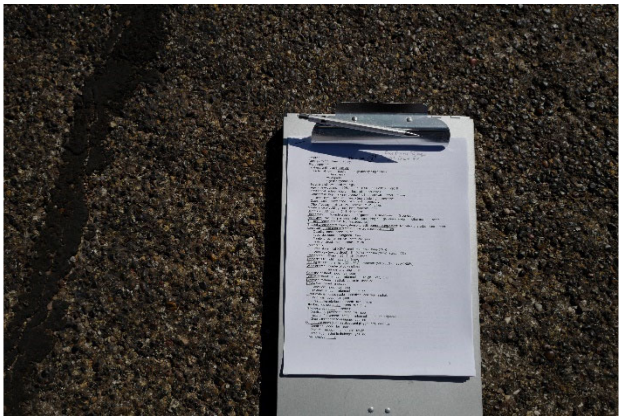
Site 6. Davis and Eisenhower, between Zachry Industries and bldg. 61

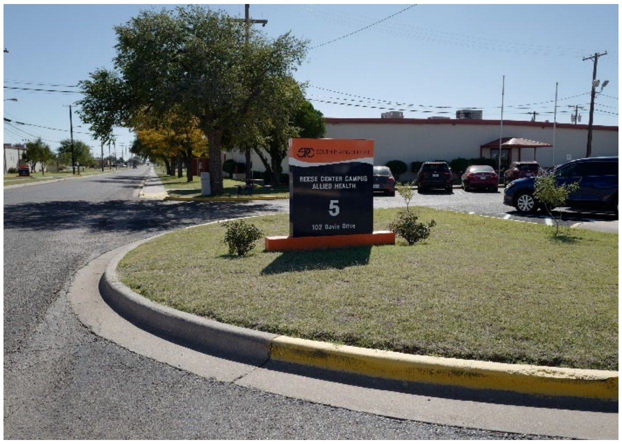


Site 7. Davis and Eisenhower (north side), Zachry Industries

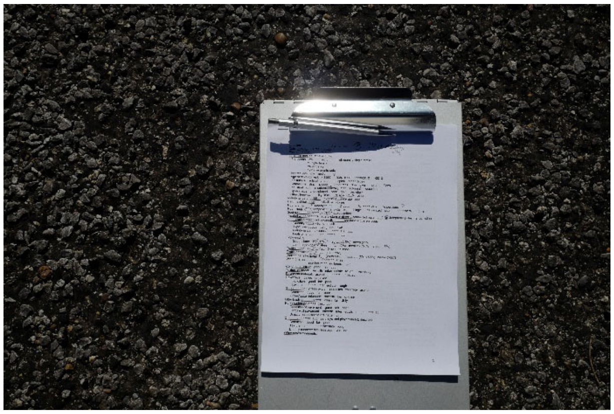


Site 8. 102 Davis Dr., South Plains College




REESE CENTER CAMPUS
ALLIED HEALTH
5
102 Davis Drive

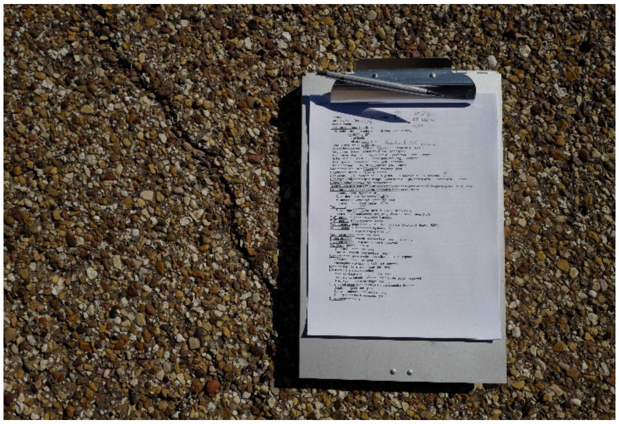

Site 9. 1st St. at Zachry Industry Bldg.



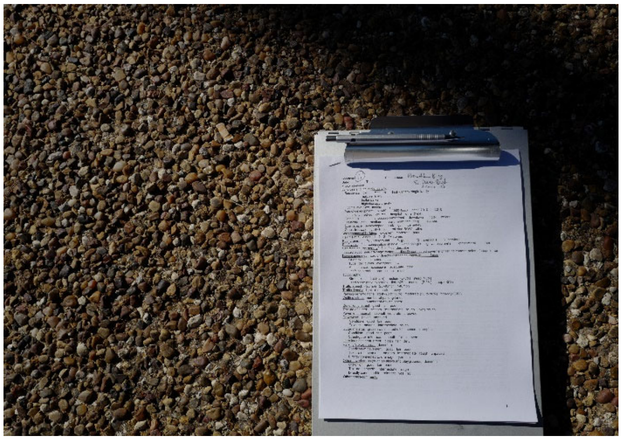
Site 9 (continued)

Infiltration pond near Sites 9 and 10 (outside of drainage area, not monitored and not modeled)

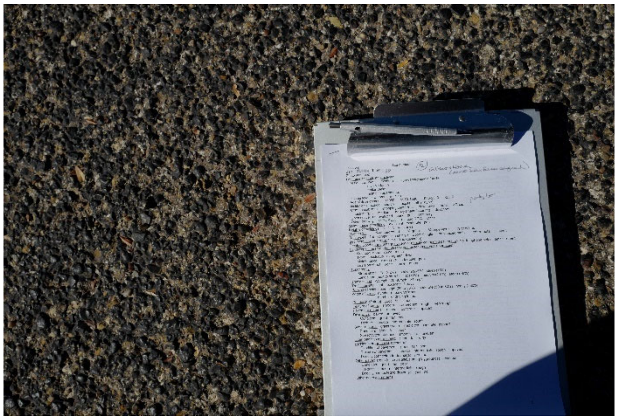
Site 10. 1145 Bldg. off Hoover, abandoned base housing

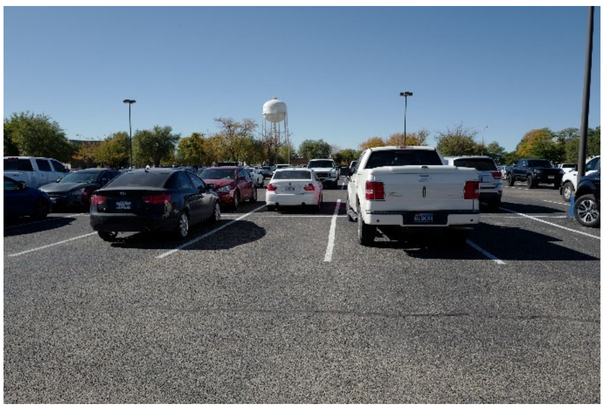


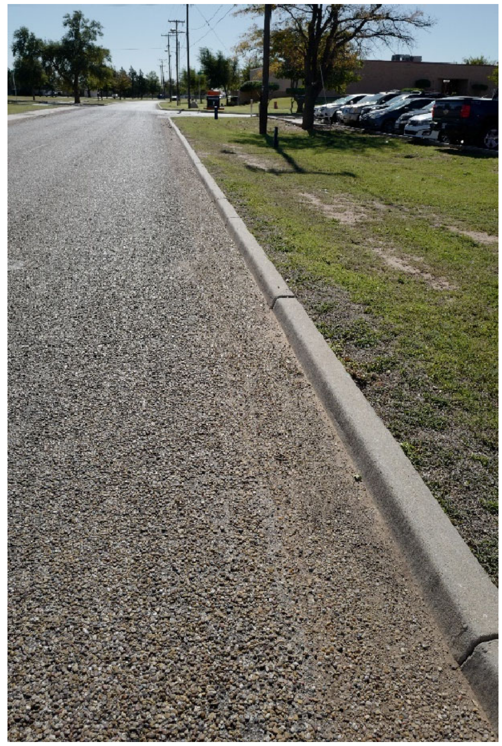
Site 11. So. Reese Blvd. and Circle Rd., Reese Admin. Bldg.



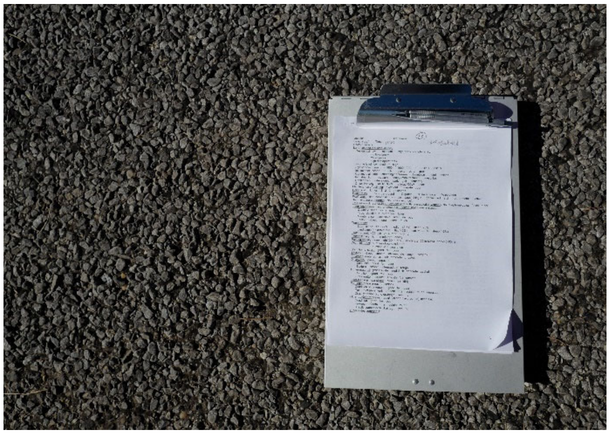
Site 12. Gilbert and Hoover, across from Reese conference center



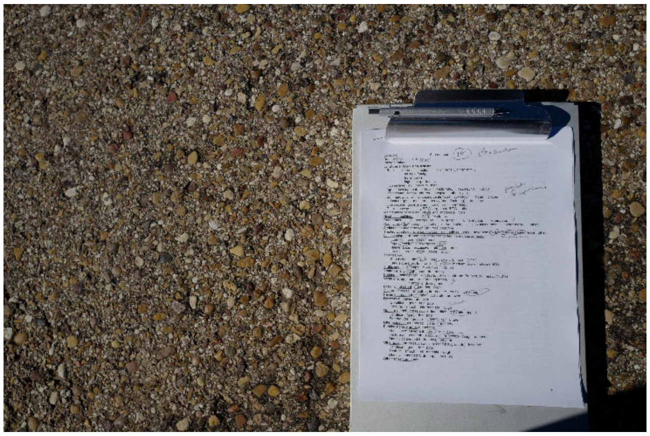


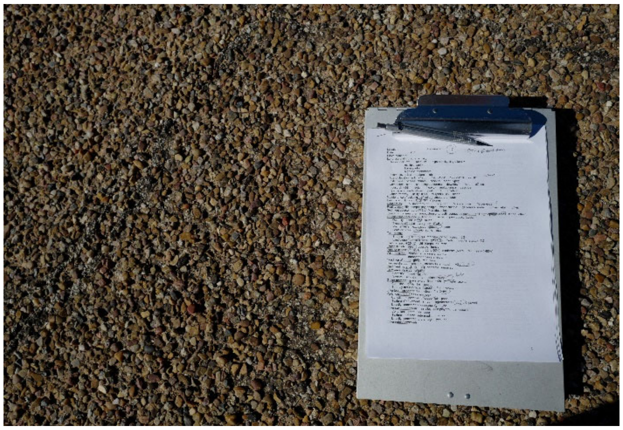
Site 13. 4th and Garfield, institutional and residential between apartments and administration bldgs.

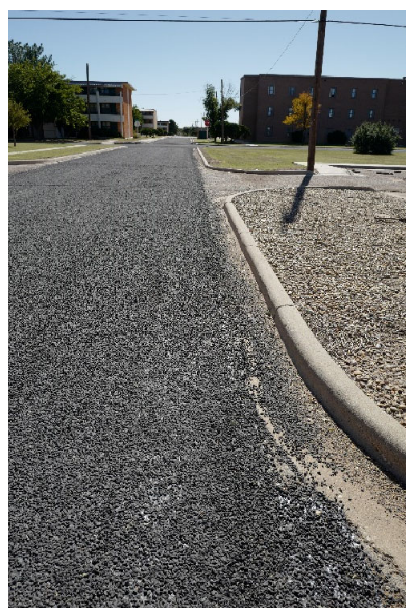


Site 14. 3rd and Eisenhower, vacant parking lot for institutional area



Site 15. 9th and Eisenhower, administration bldg.





Site 16. Gilbert and 10th, apartments